Chapter 4

Helicopter Components, Sections, and Systems

Introduction

This chapter discusses the components, sections, and systems found on most modern helicopters. Helicopters come in a variety of sizes and shapes, but most share the same major components. The chapter introduces the major components/sections of the helicopter and the systems that correlate with each. Knowing how the components and systems work on the helicopter enables the pilot to more easily recognize malfunctions and possible emergency situations. Understanding the relationship of these systems allows the pilot to make an informed decision and take the appropriate corrective action should a problem arise.

Airframe

The airframe, or fundamental structure, of a helicopter can be made of either metal, wood, or composite materials, or some combination of the two. Typically, a composite component consists of many layers of fiber-impregnated resins, bonded to form a smooth panel. Tubular and sheet metal substructures are usually made of aluminum, though stainless steel or titanium are sometimes used in areas subject to higher stress or heat. Airframe design encompasses engineering, aerodynamics, materials technology, and manufacturing methods to achieve favorable balances of performance, reliability, and cost. *[Figure 4-1]*

Fuselage

The fuselage, the outer core of the airframe, is an aircraft's main body section that houses the cabin that holds the crew, passengers, and cargo. Helicopter cabins have a variety of seating arrangements. Most have the pilot seated on the right side, although there are some with the pilot seated on the left side or center. The fuselage also houses the engine, the transmission, avionics, flight controls, and the powerplant. *[Figure 4-1]*

Main Rotor System

The rotor system is the rotating part of a helicopter which generates lift. The rotor consists of a mast, hub, and rotor blades. The mast is a hollow cylindrical metal shaft which extends upwards from and is driven and sometimes supported by the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub by any number of different methods. Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: semirigid, rigid, or fully articulated. Some modern rotor systems, such as the bearingless rotor system, use an engineered combination of these types.

Semirigid Rotor System

A semirigid rotor system is usually composed of two blades that are rigidly mounted to the main rotor hub. The main rotor hub is free to tilt with respect to the main rotor shaft on what is known as a teetering or flapping hinge. This allows the blades to flap together as a unit. As one blade flaps up, the other flaps down. Since there is no vertical drag hinge, lead/lag forces are absorbed and mitigated by blade bending. The semirigid rotor is also capable of feathering, which means that the pitch angle of the blade changes. This is made possible by the feathering hinge. *[Figure 4-2]*

If the semirigid rotor system is an underslung rotor, the center of gravity (CG) is below where it is attached to the mast. This underslung mounting is designed to align the blade's center of mass with a common flapping hinge so that both blades' centers of mass vary equally in distance from the center of rotation during flapping. The rotational speed of the system tends to change, but this is restrained by the inertia of the engine and flexibility of the drive system. Only a moderate amount of stiffening at the blade root is necessary to handle this restriction. Simply put, underslinging effectively eliminates geometric imbalance. *[Figure 4-3]*

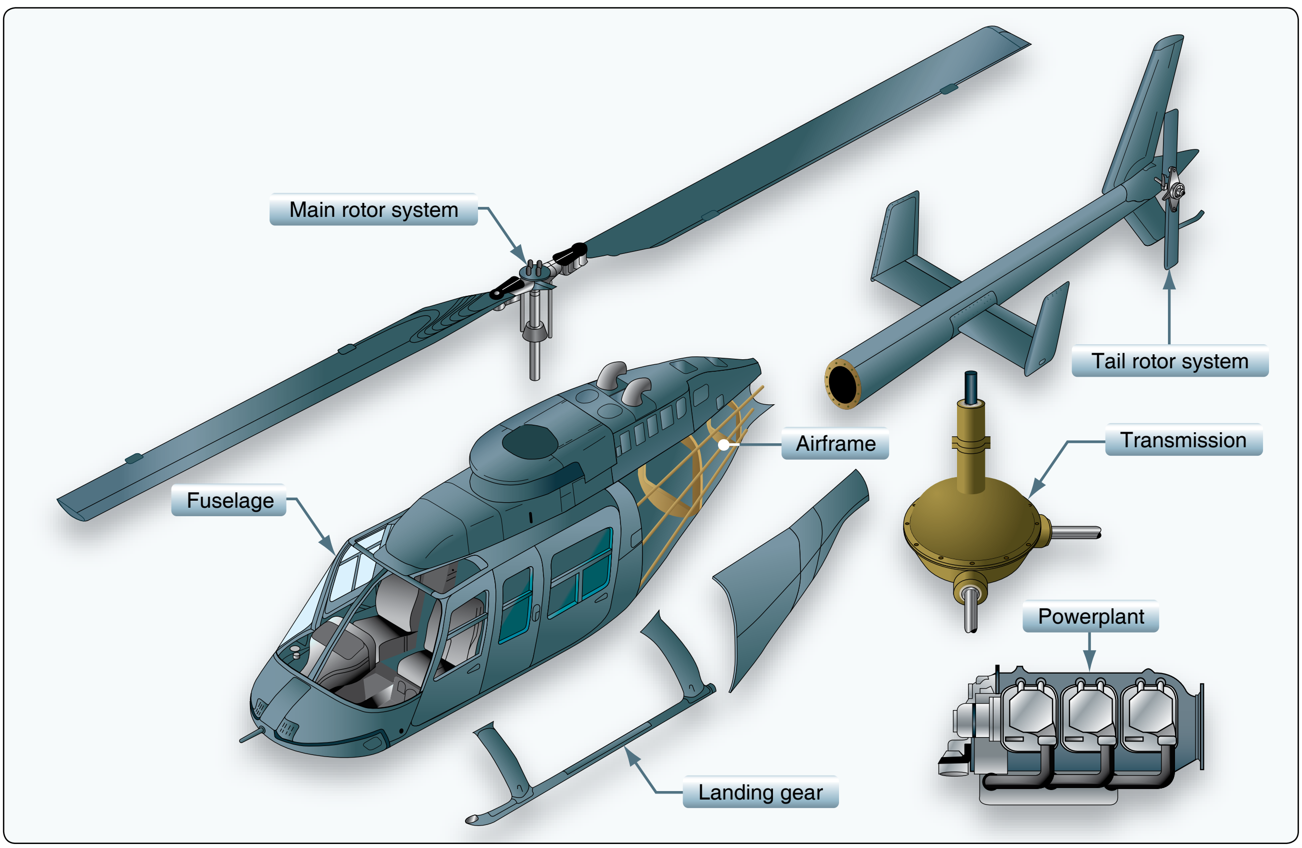

Figure 4-1. *The major components of a helicopter are the airframe, fuselage, landing gear, powerplant, transmission, main rotor system,and tail rotor system.*

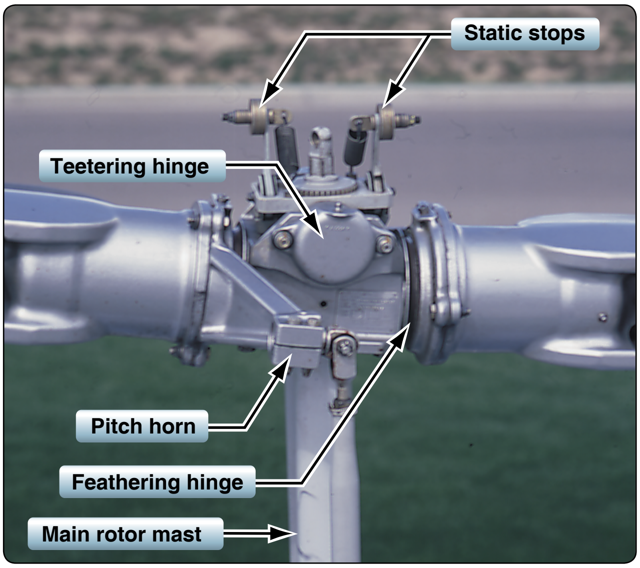

Figure 4-2. *The teetering hinge allows the main rotor hub to tilt, and the feathering hinge enables the pitch angle of the blades to change.*

The underslung rotor system mitigates the lead/lag forces by mounting the blades slightly lower than the usual plane of rotation, so the lead/lag forces are minimized. As the blades cone upward, the center of pressures of the blades are almost in the same plane as the hub. Whatever stresses are remaining bend the blades for compliance.

Helicopters with semirigid rotors are vulnerable to a condition known as mast bumping which can cause the rotor flap stops to shear the mast. The mechanical design of the semirigid rotor system dictates downward flapping of the blades must have some physical limit. Mast bumping is the result of excessive rotor flapping. Each rotor system design has a maximum flapping angle. If flapping exceeds the design value, the static stop will contact the mast. The static stop is a component of the main rotor providing limited movement of strap fittings and a contoured surface between the mast and hub. It is the violent contact between the static stop and the mast during flight that causes mast damage or separation. This contact must be avoided at all costs.

Mast bumping is directly related to how much the blade system flaps. In straight and level flight, blade flapping is minimal, perhaps 2° under usual flight conditions. Flapping angles increase slightly with high forward speeds, at low rotor rpm, at high-density altitudes, at high gross weights, and when encountering turbulence. Maneuvering the aircraft in a sideslip or during low-speed flight at extreme CG positions can induce larger flapping angles.

Rigid Rotor System

The rigid rotor system shown in *Figure 4-4* is mechanically simple, but structurally complex because operating loads must be absorbed in bending rather than through hinges. In this system, the blade roots are rigidly attached to the rotor hub. Rigid rotor systems tend to behave like fully articulated systems through aerodynamics, but lack flapping or lead/lag hinges. Instead, the blades accommodate these motions by bending. They cannot flap or lead/lag, but they can be feathered. As advancements in helicopter aerodynamics

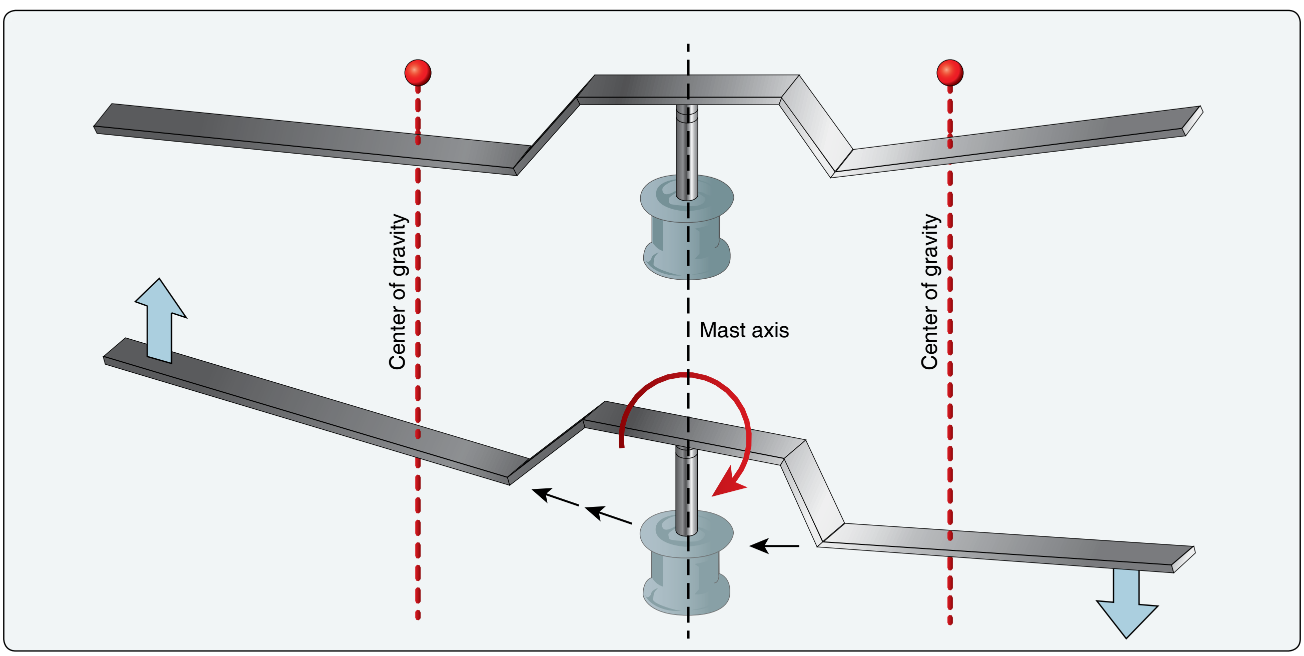

Figure 4-3. *With an underslung rotor, the center of gravity (CG) remains in the same approximate location relative to the mast before and after rotor tilt.*

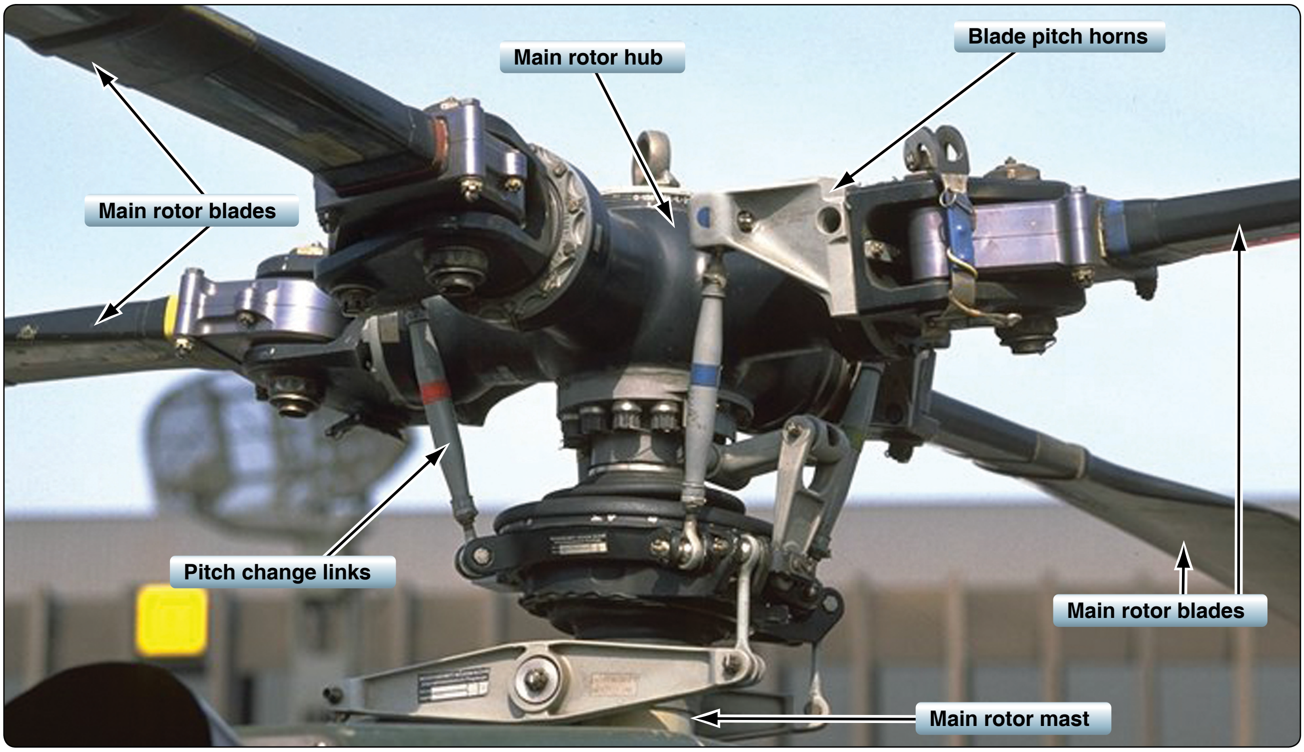

Figure 4-4. *Four-blade hingeless (rigid) main rotor. Rotor blades are comprised of glass fiber reinforced material. The hub is a single piece of forged rigid titanium.*

and materials continue to improve, rigid rotor systems may become more common because the system is fundamentally easier to design and offers the best properties of both semirigid and fully articulated systems.

The rigid rotor system is very responsive and is usually not susceptible to mast bumping like the semirigid systems because the rotor hubs are mounted solid to the main rotor mast. This allows the rotor and fuselage to move together as one entity and eliminates much of the oscillation usually present in the other rotor systems. Other advantages of the rigid rotor include a reduction in the weight and drag of the rotor hub and a larger flapping arm, which significantly reduces control inputs. Without the complex hinges, the rotor system becomes much more reliable and easier to maintain than the other rotor configurations. A disadvantage of this system is the quality of ride in turbulent or gusty air. Because there are no hinges to help absorb the larger loads, vibrations are felt in the cabin much more than with other rotor head designs.

There are several variations of the basic three rotor head designs. The bearingless rotor system is closely related to the articulated rotor system but has no bearings or hinges. This design relies on the structure of blades and hub to absorb stresses. The main difference between the rigid rotor system and the bearingless system is that the bearingless system has no feathering bearing—the material inside the cuff is twisted by the action of the pitch change arm. Nearly all bearingless rotor hubs are made of fiber-composite materials. The differences in handling between the types of rotor system are summarized in *Figure 4-5*.

Fully Articulated Rotor System

Fully articulated rotor systems allow each blade to lead/lag (move back and forth in plane), flap (move up and down about an inboard mounted hinge) independent of the other blades, and feather (rotate about the pitch axis to change lift). *[Figures 4-6* and *4-7]* Each of these blade motions is related

System Type	Advantages	Disadvantages
Articulated	Good control response	High aerodynamic drag. *More complex, greater cost.*
Semirigid (Teetering, Underslung, or See-Saw)	Simple, easy to hangar due to two blades	Reaction to control input not as quick as articulated head. Vibration can be higher than *multi-bladed articulated* systems.
Rigid	Simple design, crisp response	Higher vibration than articulated rotor.

Figure 4-5. *Differences in handling between the types of rotor systems.*

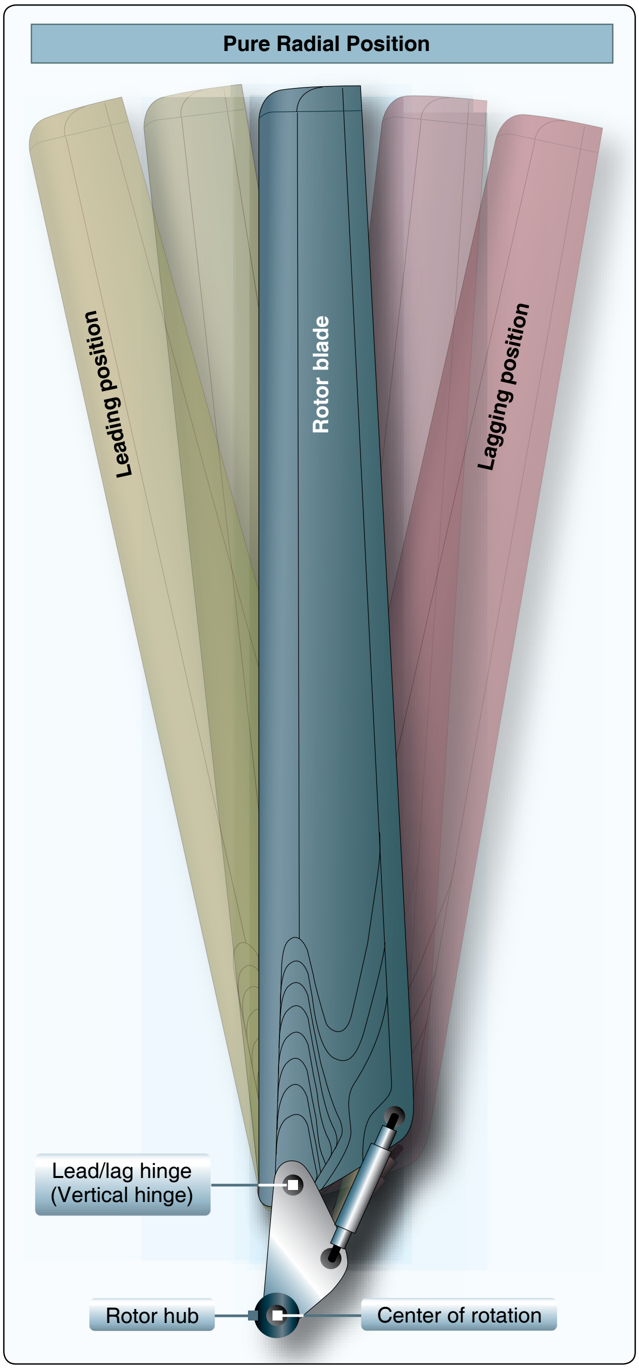

Figure 4-6. *Lead/lag hinge allows the rotor blade to move back and forth in plane.*

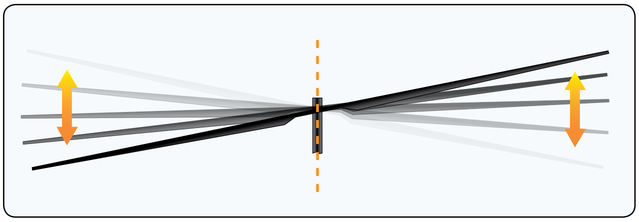

Figure 4-7. *Fully articulated flapping hub.*

to the others. Fully articulated rotor systems are found on helicopters with more than two main rotor blades.

As the rotor spins, each blade responds to inputs from the control system to enable aircraft control. The center of lift on the whole rotor system moves in response to these inputs to effect pitch, roll, and upward motion. The magnitude of this lift force is based on the collective input, which changes pitch on all blades in the same direction at the same time. The location of this lift force is based on the pitch and roll inputs from the pilot. Therefore, the feathering angle of each blade (proportional to its own lifting force) changes as it rotates with the rotor, hence the name "cyclic control."

As the lift on a given blade increases, it tends to flap upwards. The flapping hinge for the blade permits this motion and is balanced by the centrifugal force of the weight of the blade, which tries to keep it in the horizontal plane. *[Figure 4-8]*

Either way, some motion must be accommodated. The centrifugal force is nominally constant; however, the flapping force is affected by the severity of the maneuver (rate of climb, forward speed, aircraft gross weight). As the blade flaps, its CG changes. This changes the local moment of inertia of the blade with respect to the rotor system and it speeds up or slows down with respect to the rest of the blades and the whole rotor system. This is accommodated by the lead/lag or drag hinge, shown in *Figure 4-9,* and is easier to visualize with the classical 'ice skater doing a spin' image. As the skater moves her arms in, she spins faster because her inertia changes but her total energy remains constant (neglect friction for purposes of this explanation). Conversely, as her arms extend, her spin slows. This is also known as the conservation of angular momentum. An in-plane damper typically moderates lead/lag motion.

Following a single blade through a single rotation beginning at some neutral position, as load increases from increased feathering, it flaps up and leads forward. As it continues

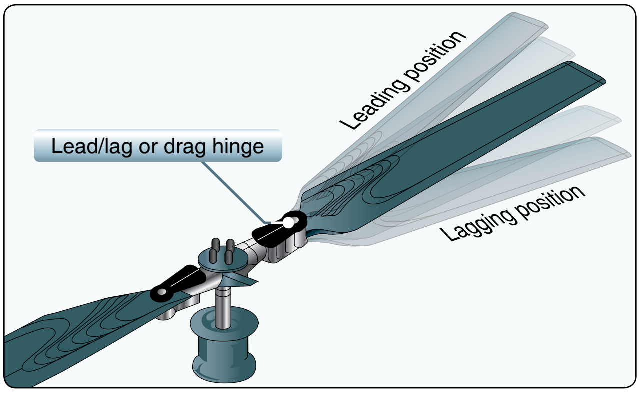

Figure 4-8. *Fully articulated rotor blade with flapping hinge.*

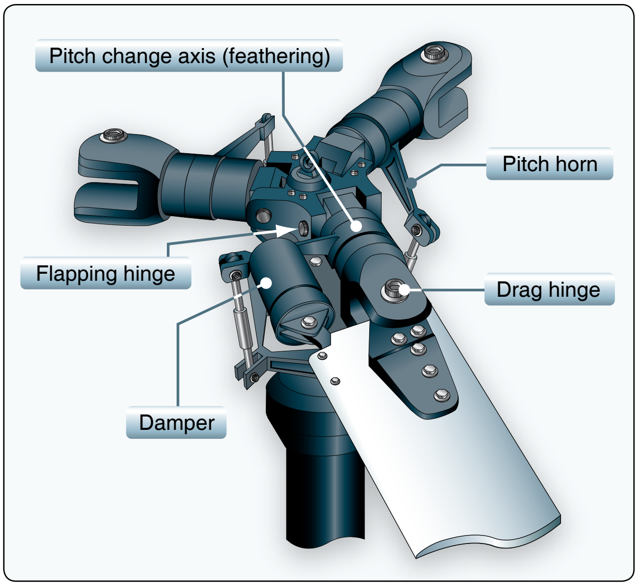

Figure 4-9. *Drag hinge.*

around, it flaps down and lags backward. At the lowest point of load, it is at its lowest flap angle and also at its most 'rearward' lag position. Because the rotor is a large, rotating mass, it behaves somewhat like a gyroscope. The effect of this is that a control input is usually realized on the attached body at a position 90° prior to the control input displacement in the axis of rotation. This is accounted for by the designers through placement of the control input to the rotor system so that a forward input of the cyclic control stick results in a nominally forward motion of the aircraft. The effect is made transparent to the pilot.

Older hinge designs relied on conventional metal bearings. By basic geometry, this precludes a coincident flapping and lead/lag hinge and is cause for recurring maintenance. Newer rotor systems use elastomeric bearings, arrangements of rubber and steel that can permit motion in two axes. Besides solving some of the above-mentioned kinematic issues, these bearings are usually in compression, can be readily inspected, and eliminate the maintenance associated with metallic bearings.

Elastomeric bearings are naturally fail-safe, and their wear is gradual and visible. The metal-to-metal contact of older bearings and the need for lubrication is eliminated in this design.

Tandem Rotor

Tandem rotor (sometimes referred to as dual rotor) helicopters have two large horizontal rotor assemblies; a twin rotor system, instead of one main assembly, and a smaller tail rotor. *[Figure 4-10]* Single rotor helicopters need an anti-torque system to neutralize the twisting momentum produced by the single large rotor. Tandem rotor helicopters, however, use counter-rotating rotors, with each canceling

Figure 4-10. *Tandem rotor heads.*

out the other's torque. Counter-rotating rotor blades will not collide with and destroy each other if they flex into the other rotor's pathway. This configuration also has the advantage of being able to hold more weight with shorter blades, since there are two sets. Also, all of the power from the engines can be used for lift, whereas a single rotor helicopter uses power to counter the torque.

Coaxial Rotors

A coaxial rotor system is a pair of rotors mounted on the same shaft but turning in opposite directions. This design eliminates the need for a tail rotor or other antitorque mechanisms, and since the blades turn in opposite directions, the effects of dissymmetry of lift are avoided. The main disadvantage of coaxial rotors is the increased mechanical complexity of the rotor system. Numerous Russian helicopters, such as the Kaman Ka-31 and Ka-50, along with the Sikorsky experimental X2 use a coaxial rotor design.

Intermeshing Rotors

An intermeshing rotor system is a set of two rotors turning in the opposite directions with each rotor mast mounted on the helicopter with a slight angle, so the blades intermesh without colliding. This design also eliminates the need for an antitorque system, which provides more engine power for lift. However, neither rotor lifts directly vertical which reduces each rotor's efficiency. The Kaman HH-43, which was used by the USAF in a firefighting role and the Kaman K-MAX are examples of an intermeshing rotor systems.

Swash Plate Assembly

The purpose of the swash plate is to convert stationary control inputs from the pilot into rotating inputs which can be connected to the rotor blades or control surfaces. It consists of two main parts: stationary swash plate and rotating swash plate. *[Figure 4-11]*

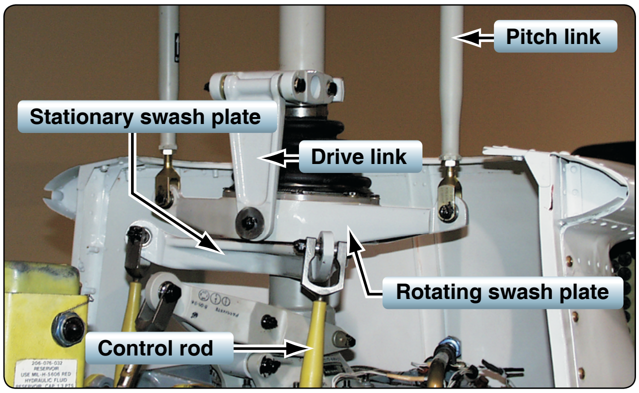

Figure 4-11. *Stationary and rotating swash plate.*

The stationary swash plate is mounted around the main rotor mast and connected to the cyclic and collective controls by a series of pushrods. It is restrained from rotating by an anti-drive link but can tilt in all directions and move vertically. The rotating swash plate is mounted to the stationary swash plate by means of a uniball sleeve. It is connected to the mast by drive links and must rotate in constant relationship with the main rotor mast. Both swash plates tilt and slide up and down as one unit. The rotating swash plate is connected to the pitch horns by the pitch links.

Freewheeling Unit

Since lift in a helicopter is provided by rotating airfoils, these airfoils must be free to rotate if the engine fails. The freewheeling unit automatically disengages the engine from the main rotor when engine revolutions per minute (rpm) is less than main rotor rpm. *[Figure 4-12]* This allows the main rotor and tail rotor to continue turning at normal in-flight speeds. The most common freewheeling unit assembly consists of a one-way sprag clutch located between the engine and main rotor transmission. This is usually in the upper pulley in a piston helicopter or mounted on the accessory gearbox in a turbine helicopter. When the engine is driving the rotor, inclined surfaces in the sprag clutch force rollers against an outer drum. This prevents the engine from exceeding transmission rpm. If the engine fails, the rollers move inward, allowing the outer drum to exceed the speed of the inner portion. The transmission can then exceed the speed of the engine. In this condition, engine speed is less than that of the drive system, and the helicopter is in an autorotative state.

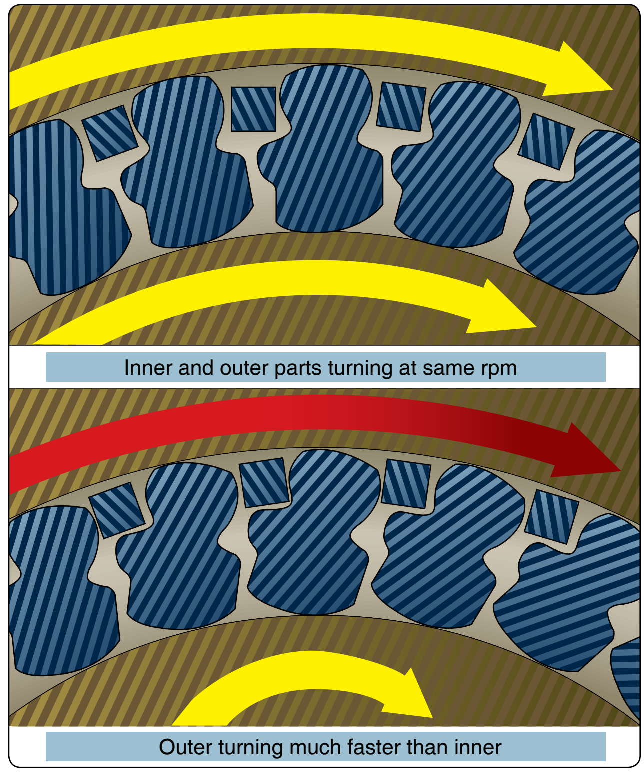

Figure 4-12. *Freewheeling unit in normal drive position and freewheeling position. Note that in the top example, the engine output shaft (inner part) drives the rotor shaft (outer part) at the same speed (normal flight). In the bottom example, the rotor shaft (outer part) breaks free under autorotation, as it turns faster than the driver shaft (inner part).*

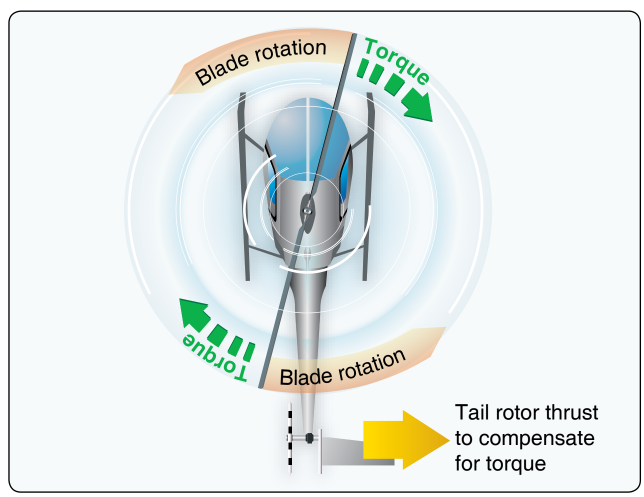

Figure 4-13. *Antitorque rotor produces thrust to oppose torque.*

Antitorque System

Helicopters with a single, main rotor system require a separate antitorque system. This is most often accomplished through a variable pitch, antitorque rotor or tail rotor. *[Figure 4-13]* Pilots vary the thrust of the antitorque system to maintain directional control whenever the main rotor torque changes, or to make heading changes while hovering. Most helicopters drive the tail rotor shaft from the transmission to ensure tail rotor rotation (and hence control) in the event that the engine quits. Usually, negative antitorque thrust is needed in autorotations to overcome transmission friction.

Fenestron

Another form of antitorque system is the Fenestron or "fan-in-tail" design. This system uses a series of rotating blades shrouded within a vertical tail. Because the blades are located within a circular duct, they are less likely to come into contact with people or objects. *[Figure 4-14]*

NOTAR®

Using the natural characteristics of helicopter aerodynamics, the NOTAR® antitorque system provides safe, quiet, responsive, foreign object damage (FOD) resistant directional control. The enclosed variable-pitch composite blade fan produces a low pressure, high volume of ambient air to pressurize the composite tailboom. The air is expelled through two slots which run the length of the tailboom on the right side, causing a boundary-layer control called the Coanda effect. The result is that the tailboom becomes a "wing," flying in the downwash of the rotor system, producing up to 60 percent of the antitorque required in a hover. The balance of the directional control is accomplished by a rotating direct jet thruster. In forward flight, the vertical stabilizers provide the majority of the antitorque; however, directional control remains a function of the direct jet thruster. The NOTAR® antitorque system eliminates some of the mechanical disadvantages of a tail rotor, including long drive shafts, hanger bearings, intermediate gearboxes and 90° gearboxes. *[Figure 4-15]*

Antitorque Drive Systems

The antitorque drive system consists of an antitorque drive shaft and a antitorque gearbox mounted at the end of the tail boom. The drive shaft may consist of one long shaft or a series of shorter shafts connected at both ends with flexible couplings. This allows the drive shaft to flex with the tail boom. The tail rotor gearbox provides a right-angle drive for the tail rotor and may also include gearing to adjust the output to optimum tail rotor rpm. *[Figure 4-16]* Tail rotors may also have an intermediate gearbox to turn the power up a pylon or vertical fin.

Figure 4-14. *Fenestron or "fan-in-tail" antitorque system. This design provides an improved margin of safety during ground operations.*

Engines

Reciprocating Engines

Reciprocating engines, also called piston engines, are generally used in smaller helicopters. Most training helicopters use reciprocating engines because they are relatively simple and inexpensive to operate. Refer to the Pilot's Handbook of Aeronautical Knowledge for a detailed explanation and illustrations of the piston engine.

Turbine Engines

Turbine engines are more powerful and are used in a wide variety of helicopters. They produce a tremendous amount of power for their size but are generally more expensive to operate. The turbine engine used in helicopters operates differently from those used in airplane applications. In most applications, the exhaust outlets simply release expended gases and do not contribute to the forward motion of the helicopter. Approximately 75 percent of the incoming airflow is used to cool the engine.

The gas turbine engine mounted on most helicopters is made up of a compressor, combustion chamber, turbine, and accessory gearbox assembly. The compressor draws filtered air into the plenum chamber and compresses it. Common type filters are centrifugal swirl tubes where debris is ejected outward and blown overboard prior to entering the compressor, or engine barrier filters (EBF), similar to the K&N filter element used in automotive applications.

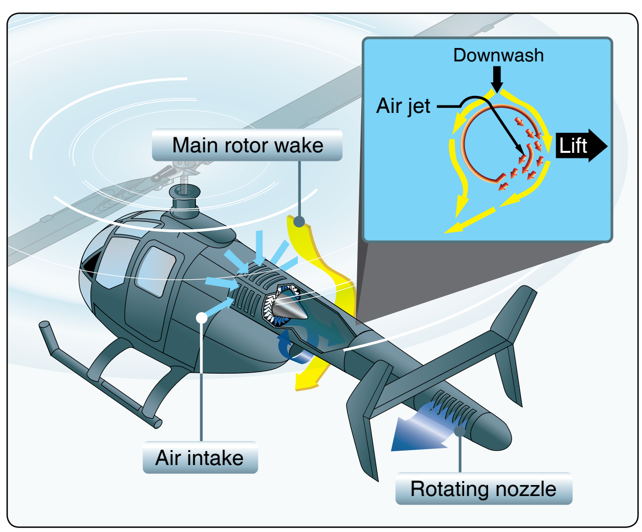

Figure 4-15. *While in a hover, Coanda effect supplies approximately two-thirds of the lift necessary to maintain directional control. The rest is created by directing the thrust from the controllable rotating nozzle.*

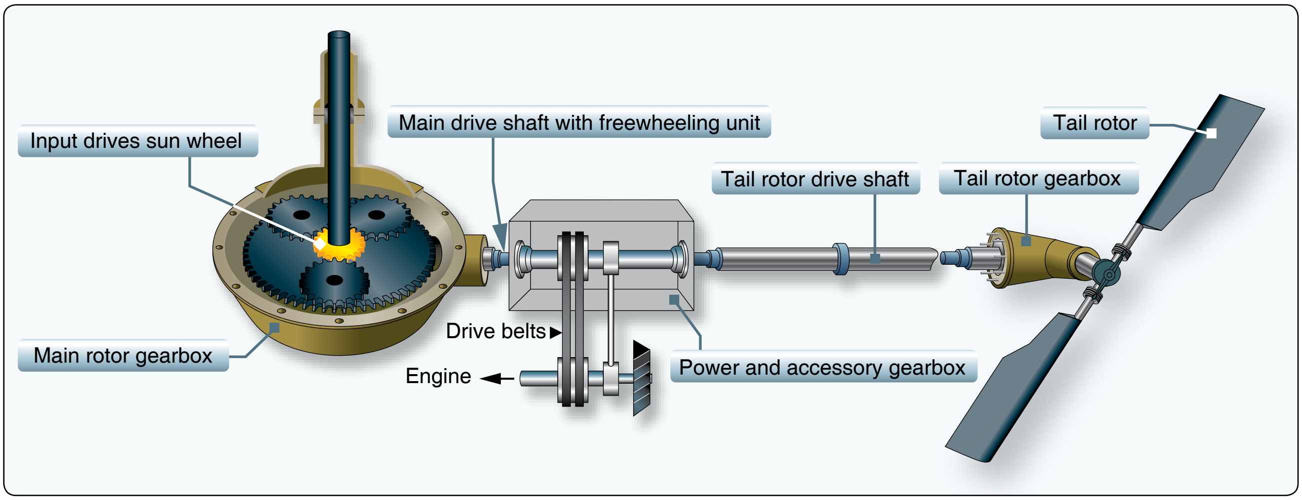

Figure 4-16. *The tail rotor driveshaft is connected to both the main transmission and the tail rotor transmission.*

Although this design significantly reduces the ingestion of foreign objects into the engine, it is important for pilots to be aware of how much debris is actually being filtered. Operating in the sand, dust, or even in grassy type materials can choke an engine in just minutes. The compressed air is directed to the combustion section through discharge tubes where atomized fuel is injected into it. The fuel/air mixture is ignited and allowed to expand. This combustion gas is then forced through a series of turbine wheels causing them to turn. These turbine wheels provide power to both the engine compressor and the accessory gearbox. Depending on model and manufacturer, the rpm can vary from 20,000 to 51,600.

Power is provided to the main rotor and tail rotor systems through the freewheeling unit which is attached to the accessory gearbox power output gear shaft. The combustion gas is finally expelled through an exhaust outlet. The temperature of gas is measured at different locations and is referenced differently by each manufacturer. Some common terms are inter-turbine temperature (ITT), exhaust gas temperature (EGT), measured gas temperature (MGT), or turbine outlet temperature (TOT). TOT is used throughout this discussion for simplicity. *[Figure 4-17]*

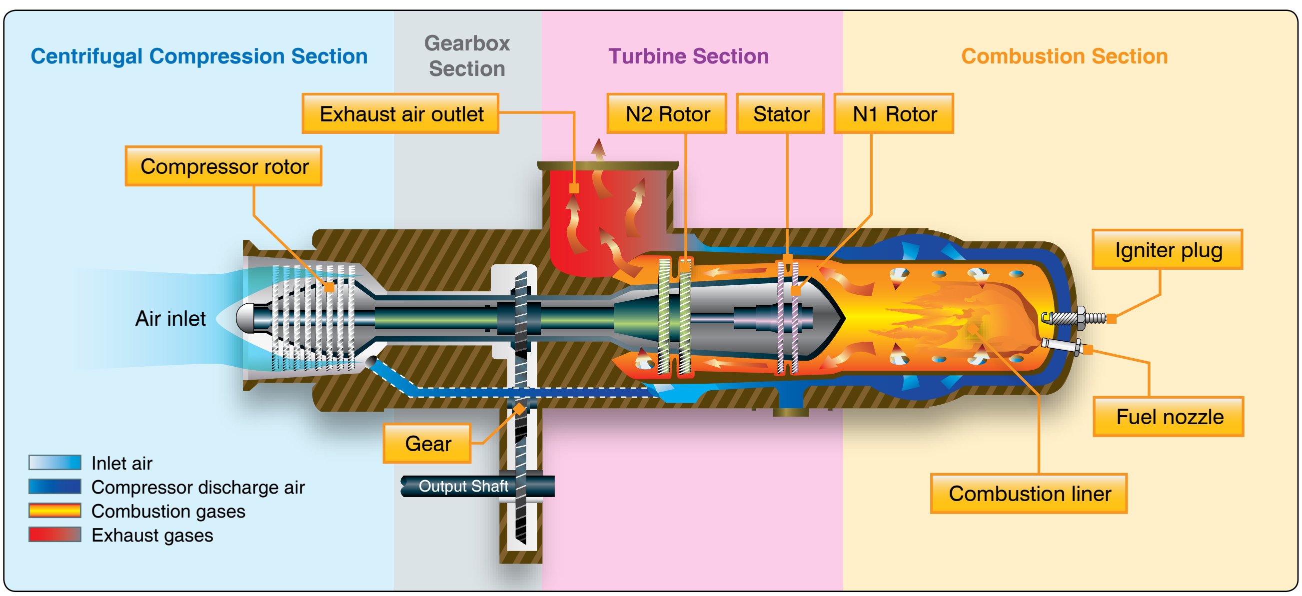

Figure 4-17. *Many helicopters use a turboshaft engine as shown above to drive the main transmission and rotor systems. The main difference between a turboshaft and a turbojet engine is that most of the energy produced by the expanding gases is used to drive a turbine rather than producing thrust through the expulsion of exhaust gases.*

Compressor

The compressor may consist of an axial compressor, a centrifugal compressor, or combination of the two.

An axial compressor consists of two main elements: the rotor and the stator. The rotor consists of a number of blades fixed on a rotating spindle and resembles a fan. As the rotor turns, air is drawn inward. Stator vanes are arranged in fixed rows between the rotor blades and act as a diffuser at each stage to decrease air velocity and increase air pressure. There may be a number of rows of rotor blades and stator vanes. Each row constitutes a pressure stage, and the number of stages depends on the amount of air and pressure rise required for the particular engine.

A centrifugal compressor consists of an impeller, diffuser, and a manifold. The impeller, which is a forged disc with integral blades, rotates at a high speed to draw air in and expel it at an accelerated rate. The air then passes through the diffuser, which slows the air down. When the velocity of the air is slowed, static pressure increases, resulting in compressed, high pressure air. The high-pressure air then passes through the compressor manifold where it is distributed to the combustion chamber via discharge tubes.

If the airflow through the compressor is disturbed, a condition called surge, or compressor stall, may take effect. This phenomenon is a periodic stalling of the compressor blades. When this occurs, the pressure at the compressor is reduced and the combustion pressure may cause reverse flow into the compressor output. As the airflow through the compressor is reduced, the air pressure then increases temporarily correcting the condition until it occurs again. This is felt throughout the airframe as vibrations and is accompanied by power loss and an increase in TOT as the fuel control adds fuel in an attempt to maintain power. This condition may be corrected by activating the bleed air system which vents excess pressure to the atmosphere and allows a larger volume of air to enter the compressor to unstall the compressor blades.

Combustion Chamber

Unlike a piston engine, the combustion in a turbine engine is continuous. An igniter plug serves only to ignite the fuel/air mixture when starting the engine. Once the fuel/air mixture is ignited, it continues to burn as long as the fuel/air mixture continues to be present. If there is an interruption of fuel, air, or both, combustion ceases. This is known as a "flameout," and the engine must be restarted or re-lit. Some helicopters are equipped with auto-relight, which automatically activates the igniters to start combustion if the engine flames out.

Turbine

The two-stage turbine section consists of a series of turbine wheels that are used to drive the compressor section and other components attached to the accessory gearbox. Both stages may consist of one or more turbine wheels. The first stage is usually referred to as the gas producer (N1 or NG) while the second stage is commonly called the power turbine (N2 or NP). (The letter N is used to denote rotational speed.)

If the first and second stage turbines are mechanically coupled to each other, the system is said to be a fixed turbine (turboshaft). These engines share a common shaft, which means the first and second stage turbines, and thus the compressor and output shaft, are connected.

On most turbine assemblies used in helicopters, the first stage and second stage turbines are not mechanically connected to each other. Rather, they are mounted on independent shafts, one inside the other, and can turn freely with respect to each other. This is referred to as a "free turbine." When a free turbine engine is running, the combustion gases pass through the first stage turbine (N1) to drive the compressor and other components, and then past the independent second stage turbine (N2), which turns the power and accessory gearbox to drive the output shaft, as well as other miscellaneous components.

Accessory Gearbox

The accessory gearbox of the engine houses all of the necessary gears to drive the numerous components of the helicopter. Power is provided to the accessory gearbox through the independent shafts connected to the N1 and N2 turbine wheels. The N1 stage drives the components necessary to complete the turbine cycle, making the engine self-sustaining. Common components driven by the N1 stage are the compressor, oil pump, fuel pump, and starter/generator. The N2 stage is dedicated to driving the main rotor and tail rotor drive systems and other accessories such as generators, alternators, and air conditioning.

Transmission System

The transmission system transfers power from the engine to the main rotor, tail rotor, and other accessories during normal flight conditions. The main components of the transmission system are the main rotor transmission, tail rotor drive system, clutch, and freewheeling unit. The freewheeling unit or autorotative clutch allows the main rotor transmission to drive the tail rotor drive shaft during autorotation. In some helicopter designs, such as the Bell BH-206, the freewheeling unit is located in the accessory gearbox. Because it is part of the transmission system, the transmission lubricates it to ensure free rotation. Helicopter transmissions are normally lubricated and cooled with their own oil supply. A sight gauge is provided to check the oil level. Some transmissions have chip detectors located in the sump, to detect loose pieces of metal. These detectors are wired to warning lights located on the pilot's instrument panel that illuminate in the event of an internal problem. Some chip detectors on modern helicopters have a "burn off" capability and attempt to correct the situation without pilot action. If the problem cannot be corrected on its own, the pilot must refer to the emergency procedures for that particular helicopter.

Main Rotor Transmission

The primary purpose of the main rotor transmission is to reduce engine output rpm to optimum rotor rpm. This reduction is different for the various helicopters. As an example, suppose the engine rpm of a specific helicopter is 2,700. A rotor speed of 450 rpm would require a 6:1 reduction. A 9:1 reduction would mean the rotor would turn at 300 rpm.

Dual Tachometers

Most helicopters use a dual-needle tachometer or a vertical scale instrument to show both engine and rotor rpm or a percentage of engine and rotor rpm. The rotor rpm indicator is used during clutch engagement to monitor rotor acceleration, and in autorotation to maintain rpm within prescribed limits. It is vital to understand that rotor rpm is paramount, and that engine rpm is secondary. If the rotor tachometer fails, rotor rpm can still be determined indirectly by the engine rpm during powered flight, because the engine drives the rotor at a fixed, one-to-one ratio (by virtue of the sprag clutch). There have been many accidents where the pilot responded to the rotor rpm tachometer failure and entered into autorotation while the engine was still operating.

Look closer at the markings on the gauges in *Figure 4-18.* All gauges shown are dual tachometer gauges. The two on the left have two needles each, one marked with the letter 'T' (turbine) the other marked with the letter 'R' (rotor). The lower left gauge shows two arced areas within the same needle location. In this case, both needles should be nearly together or superimposed during normal operation. Note the top left gauge shows two numerical arcs. The outer arc, with larger numbers, applies one set of values to engine rpm. The inner arc, or smaller numbers, represents a separate set of values for rotor rpm. Normal operating limits are shown when the needles are married or appear superimposed. The top right gauge shows independent needles, focused toward the middle of the gauge, with colored limitation areas respective to the needle head. The left side represents engine operational parameters; the right, rotor operational parameters.

In normal conditions when the rotor is coupled to the engine, both needles move together in the same direction. However, with a sudden loss in engine power the needles "split" showing that the engine and rotor are no longer coupled as the clutch has disconnected. *[Figure 4-19]*

Many newer aircraft have what is referred to as a glass cockpit, meaning the instrumentation is digital and displayed

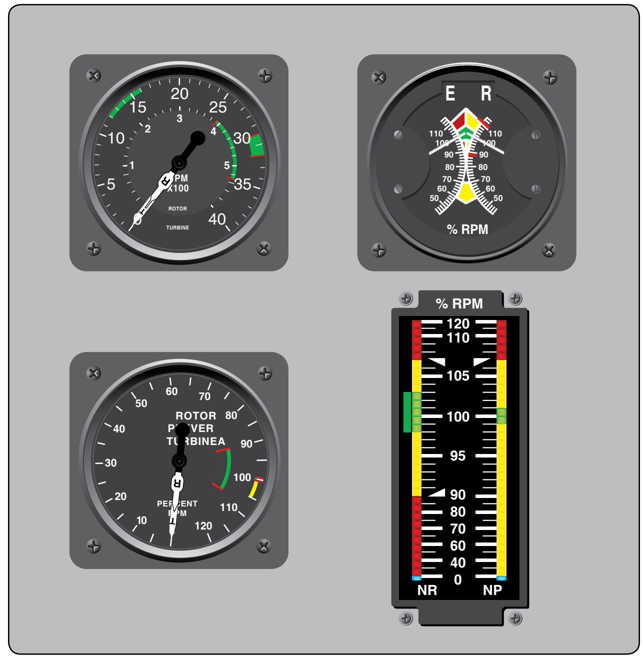

Figure 4-18. *Various types of dual-needle tachometers.*

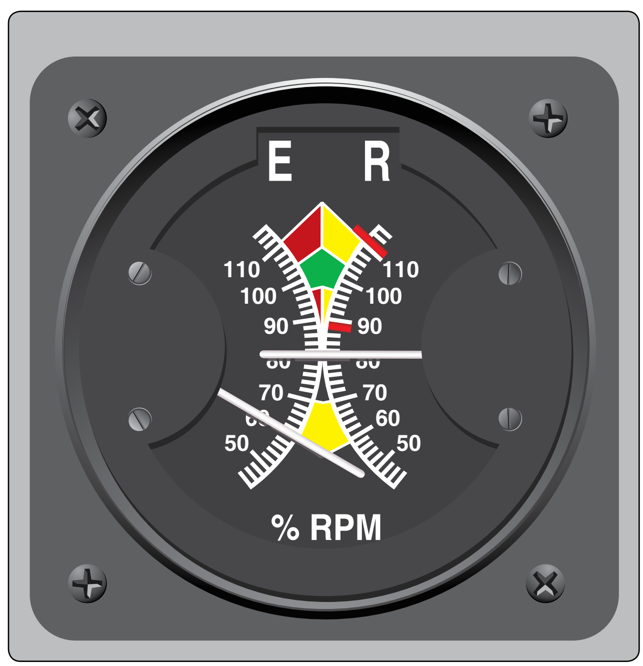

Figure 4-19. *A "split" or divided needle condition is a result of a sudden loss of engine power.*

to the pilot on digital screens and vertical scale instruments. The bottom right gauge in *Figure 4-18* replicates a vertical scale instrument. The dual tachometer shown displays rotor rpm (NR) on the left and engine rpm (NP) on the right side of the vertical scale. Corresponding color limits are present for each component parameter.

Structural Design

In helicopters with horizontally mounted engines, another purpose of the main rotor transmission is to change the axis of rotation from the horizontal axis of the engine to the vertical axis of the rotor shaft. *[Figure 4-20]* This differs from airplanes, which have their propellers mounted directly to the crankshaft or to a shaft that is geared to the crankshaft.

Maintaining main rotor rpm is essential for adequate lift. RPM within normal limits produces adequate lift for normal maneuvering. Therefore, it is imperative not only to know the location of the tachometers, but also to understand the information they provide. If rotor rpm is allowed to go below normal limits, the outcome could be catastrophic.

Clutch

In a conventional airplane, the engine and propeller are permanently connected. However, in a helicopter they are not. Because of the greater weight of a rotor in relation to the power of the engine, as compared to the weight of a propeller and the power in an airplane, the rotor must be disconnected from the engine when the starter is engaged. A clutch allows the engine to be started and then gradually pick up the load of the rotor.

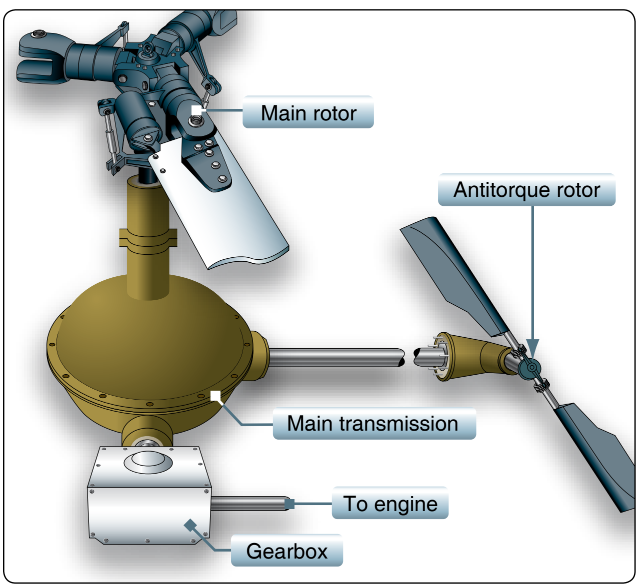

Figure 4-20. *The main rotor transmission reduces engine output rpm to optimum rotor rpm.*

Freewheeling turbine engines do not require a separate clutch since the air coupling between the gas producer turbine and the power (takeoff) turbine functions as an air clutch for starting purposes. When the engine is started, there is little resistance from the power turbine. This enables the gas-producer turbine to accelerate to normal idle speed without the load of the transmission and rotor system dragging it down. As the gas pressure increases through the power turbine, the rotor blades begin to turn, slowly at first and then gradually accelerate to normal operating rpm.

On reciprocating and fixed turbine engines, a clutch is required to enable engine start. Air, or windmilling starts, are not possible. The two main types of clutches are the centrifugal clutch and the idler or manual clutch.

How the clutch engages the main rotor system during engine start differs between helicopter design. Piston-powered helicopters have a means of engaging the clutch manually just as a manual clutch in an automobile. This may be by means of an electric motor that positions a pulley when the engine is at the proper operating condition (oil temperature and pressure in the appropriate range), but which is controlled by a cockpit mounted switch.

Belt Drive Clutch

Some helicopters utilize a belt drive to transmit power from the engine to the transmission. A belt drive consists of a lower pulley attached to the engine, an upper pulley attached to the transmission input shaft, a belt or a set of V-belts, and some means of applying tension to the belts. The belts fit loosely over the upper and lower pulley when there is no tension on the belts. *[Figure 4-21]*

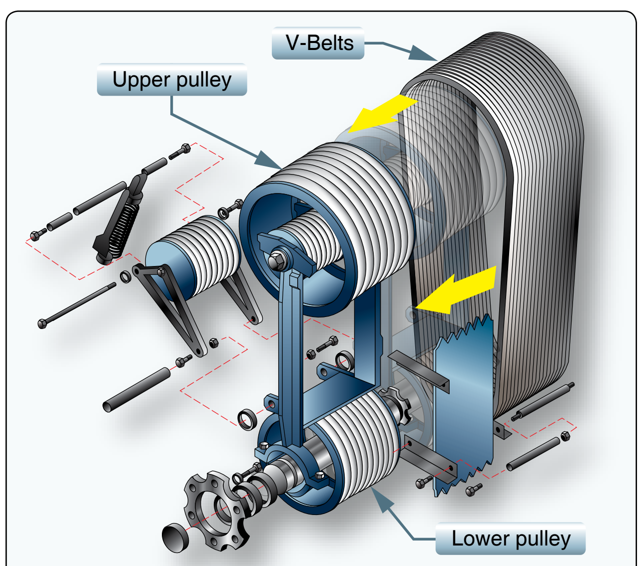

Figure 4-21. *Idler or manual clutch.*

Some aircraft utilize a clutch for starting. This allows the engine to be started without requiring power to turn the transmission. One advantage this concept has is that without a load on the engine starting may be accomplished with minimal throttle application. However, caution should also be used during starting, since rapid or large throttle inputs may cause overspeeds.

Once the engine is running, tension on the belts is gradually increased. When the rotor and engine tachometer needles are superimposed, the rotor and the engine are synchronized, and the clutch is then fully engaged. Advantages of this system include vibration isolation, simple maintenance. When the clutch is not engaged, engines are very easy to overspeed, resulting in costly inspections and maintenance. Power, or throttle control, is very important in this phase of engine operation.

Centrifugal Clutch

A centrifugal clutch is made up of an inner assembly and an outer drum. The inner assembly, which is connected to the engine driveshaft, consists of shoes lined with material similar to automotive brake linings. At low engine speeds, springs hold the shoes in, so there is no contact with the outer drum, which is attached to the transmission input shaft. As engine speed increases, centrifugal force causes the clutch shoes to move outward and begin sliding against the outer drum. The transmission input shaft begins to rotate, causing the rotor to turn slowly at first, but increasing as the friction increases between the clutch shoes and transmission drum.

As rotor speed increases, the rotor tachometer needle shows an increase by moving toward the engine tachometer needle. When the two needles are superimposed (in the case of a coaxial-type gage), the engine and the rotor are synchronized, indicating the clutch is fully engaged and there is no further slippage of the clutch shoes.

The turbine engine engages the clutch through centrifugal force, as stated above. Unless a rotor brake is used to separate the automatic engagement of the main driveshaft and subsequently the main rotor, the drive shaft turns at the same time as the engine and the inner drum of the freewheeling unit engages gradually to turn the main rotor system.

Fuel Systems

The fuel system in a helicopter is made up of two components: supply and control.

Fuel Supply System

The supply system consists of a fuel tank or tanks, fuel quantity gauges, a shut-off valve, fuel filter, a fuel line to the engine, and possibly a primer and fuel pumps. *[Figure 4-22]* The fuel tanks are usually mounted to the airframe as close as possible to the CG. This way, as fuel is burned off, there is a negligible effect on the CG. A drain valve located on the bottom of the fuel tank allows the pilot to drain water and sediment that may have collected in the tank. A fuel vent prevents the formation of a vacuum in the tank, and an overflow drain allows fuel to expand without rupturing the tank.

The fuel travels from the fuel tank through a shut-off valve, which provides a means to completely stop fuel flow to the engine in the event of an emergency or fire. The shut-off valve remains in the open position for all normal operations.

Most non-gravity feed fuel systems contain both an electric pump and a mechanical engine-driven pump. The electrical pump is used to maintain positive fuel pressure to the engine pump and may also serve as a backup in the event of mechanical pump failure. The electrical pump is controlled by a switch in the cockpit. The engine driven pump is the primary pump that supplies fuel to the engine and operates any time the engine is running. A fuel filter removes moisture and other sediment from the fuel before it reaches the engine. These contaminants are usually heavier than fuel and settle to the bottom of the fuel filter sump where they can be drained out by the pilot.

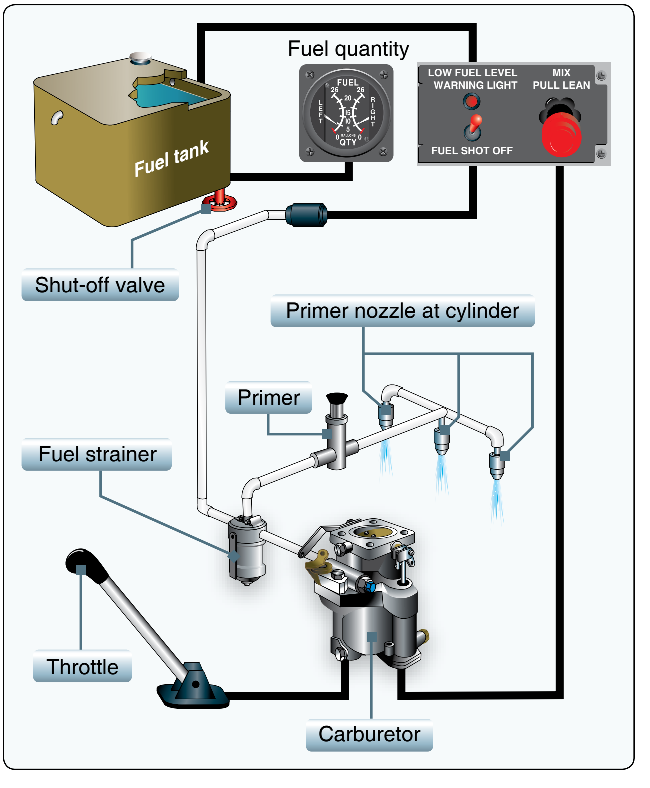

Figure 4-22. *A typical gravity feed fuel system, in a helicopter with a reciprocating engine, contains the components shown here.*

Some fuel systems contain a small hand-operated pump called a primer. A primer allows fuel to be pumped directly into the intake port of the cylinders prior to engine start. The primer is useful in cold weather when fuel in the carburetor is difficult to vaporize.

A fuel quantity gauge located on the pilot's instrument panel shows the amount of fuel measured by a sensing unit inside the tank. Most fuel gauges will indicate in gallons or pounds and must be accurate only when empty.

It is worth noting that in accordance with Title 14 of the Code of Federal Regulations (14 CFR) section 27.1337(b)(1), fuel quantity indicators "must be calibrated to read 'zero' during level flight when the quantity of fuel remaining in the tank is equal to the unusable fuel supply." Therefore, it is of the utmost importance that the pilot or operator determine an accurate means of verifying partial or full fuel loads. It is always a good habit, if possible, to visually verify the fuel on board prior to flight and determine if adequate fuel is present for the duration of the flight.

Additionally, 14 CFR section 27.1305(l)(1) requires newer helicopters to have warning systems "provide a warning to the flight crew when approximately 10 minutes of usable fuel remains in the tank." Caution should be used to eliminate unnecessary or erratic maneuvering that could cause interruption of fuel flow to the engine. Although these systems must be calibrated, never assume the entire amount is available. Many pilots have not reached their destinations due to poor fuel planning or faulty fuel indications.

Engine Fuel Control System

Regardless of the device, the reciprocating engine and the turbine engine both use the ignition and combustion of the fuel/air mix to provide the source of their power. Engine fuel control systems utilize several components to meter the proper amount of fuel necessary to produce the required amount of power. The fuel control system, in concert with the air induction components, combines the proper amount of fuel and air to be ignited in the combustion chamber. Refer to the Pilot's Handbook of Aeronautical Knowledge for a detailed explanation and illustration.

Carburetor Ice

The effect of fuel vaporization and/or a decrease of air pressure in the venturi causes a rapid decrease in air temperature in the carburetor. If the air is moist, the water vapor in the air may condense causing ice to form in the carburetor. If ice is allowed to form inside the carburetor, engine failure is a very real possibility and the ability to restart the engine is greatly reduced. Carburetor icing can occur during any phase of flight but is particularly dangerous when you are using reduced power, such as during a descent. You may not notice it during the descent until you try to add power. Indications of carburetor icing are a decrease in engine rpm or manifold pressure, the carburetor air temperature gauge indicating a temperature outside the safe operating range, and engine roughness. A reciprocating engine with a governor may mask the formation of carburetor ice since it will maintain a constant manifold pressure and rpm.

Since changes in rpm or manifold pressure can occur for a number of reasons, closely check the carburetor air temperature gauge when in possible carburetor icing conditions. Carburetor air temperature gauges are marked with a yellow caution arc or green operating arcs. In most cases, it is best to keep the needle out of the yellow arc or in the green arc. This is accomplished by using a carburetor heat system, which eliminates the ice by routing air across

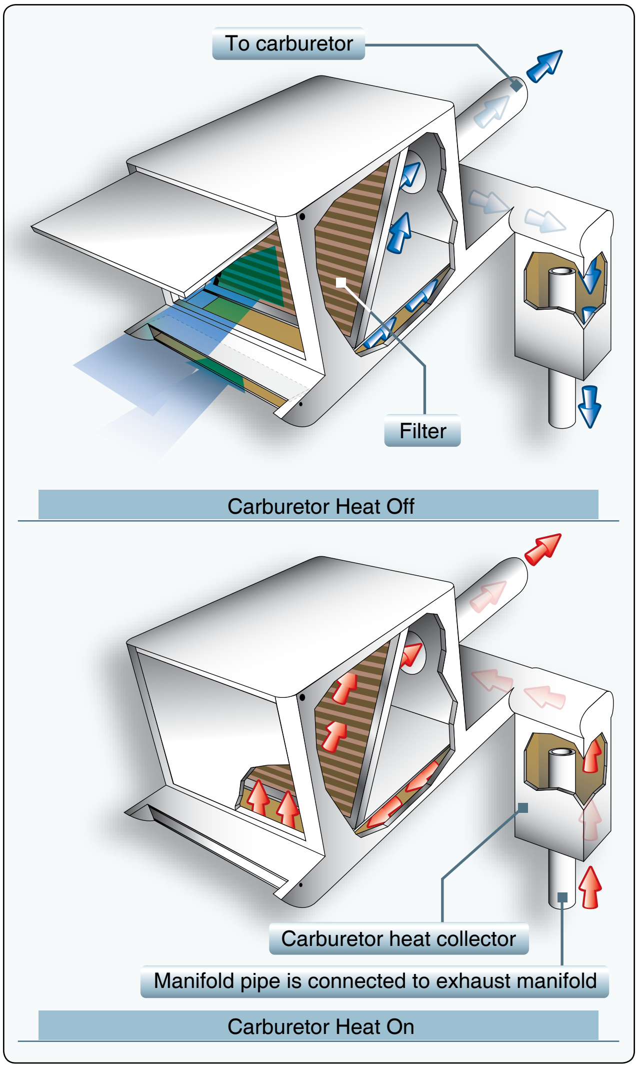

Figure 4-23. *When the carburetor heat is turned ON, normal air flow is blocked, and heated air from an alternate source flows through the filter to the carburetor.*

a heat source, such as an exhaust manifold, before it enters the carburetor. [*Figure 4-23*] Refer to the RFM (see Chapter 5, Rotorcraft Flight Manual) for the specific procedure as to when and how to apply carburetor heat.

Fuel Injection

In a fuel injection system, fuel and air are metered at the fuel control unit but are not mixed. The fuel is injected directly into the intake port of the cylinder where it is mixed with

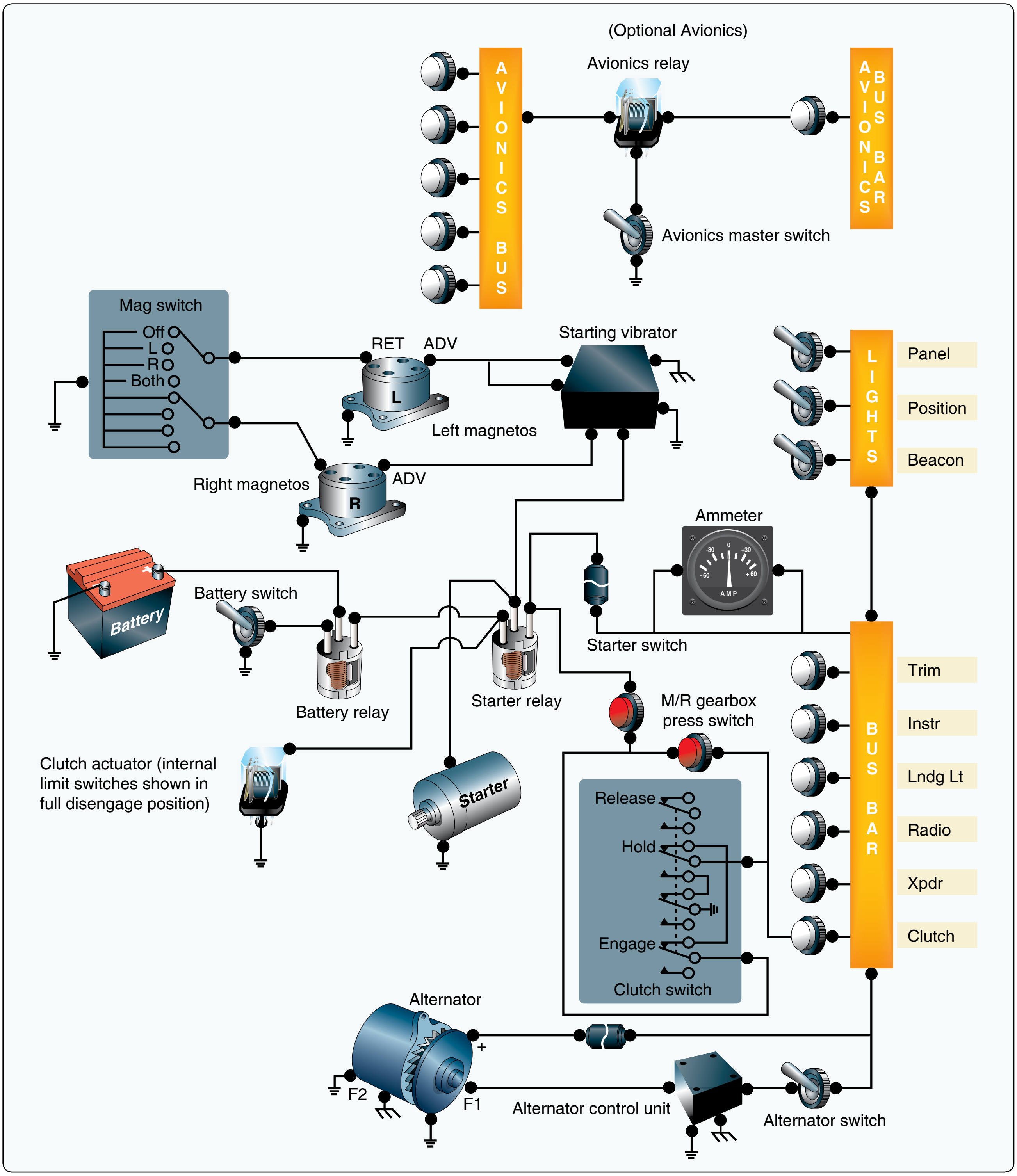

Figure 4-24. *An electrical system schematic like this sample is included in most POHs. Notice that the various bus bar accessories are protected by circuit breakers. However, ensure that all electrical equipment is turned off before starting the engine. This protects sensitive components, particularly the radios, from damage that may be caused by random voltages generated during the starting process.*

the air just before entering the cylinder. This system ensures a more even fuel distribution between cylinders and better vaporization, which in turn promotes more efficient use of fuel. Also, the fuel injection system eliminates the problem of carburetor icing and the need for a carburetor heat system.

Electrical Systems

The electrical systems, in most helicopters, reflect the increased use of sophisticated avionics and other electrical accessories. *[Figure 4-24]* More and more operations in today's flight environment are dependent on the aircraft's electrical system; however, all helicopters can be safely flown without any electrical power in the event of an electrical malfunction or emergency.

Helicopters have either a 14- or 28-volt, direct-current electrical system. On small, piston powered helicopters, electrical energy is supplied by an engine-driven alternator by means of a belt and pulley system similar to that of an automobile. These alternators have advantages over older-style generators as they are lighter in weight, require lower maintenance, and maintain a uniform electrical output even at low engine rpm. (As a reminder, think of volts or voltage as the measure of electrical pressure in the system, analogous to pounds per square inch in water systems. Amperes is the measure of electrical quantity in the system or available. For example, a 100-amp alternator would be analogous to a 100 gallon per hour water pump.)

Turbine-powered helicopters use a starter/generator system. The starter/generator is permanently coupled to the accessory gearbox. When starting the engine, electrical power from the battery is supplied to the starter/generator, which turns the engine over. Once the engine is running, the starter/generator is driven by the engine and then functions as a generator.

Current from the alternator or generator is delivered through a voltage regulator to a bus bar. The voltage regulator maintains the constant voltage required by the electrical system, by regulating the output of the alternator or generator. An over-voltage control may be incorporated to prevent excessive voltage, which may damage the electrical components. The bus bar serves to distribute the current to the various electrical components of the helicopter.

A battery is used mainly for starting the engine. In addition, it permits limited operation of electrical components, such as radios and lights, without the engine running. The battery is also a valuable source of standby or emergency electrical power in the event of alternator or generator failure.

An ammeter (or load meter) is used to monitor the electrical current within the system. The ammeter reflects current flowing to and from the battery. A charging ammeter indicates that the battery is being charged. This is normal after an engine start since the battery power used in starting is being replaced. After the battery is charged, the ammeter should stabilize near zero since the alternator or generator is supplying the electrical needs of the system.

An ammeter showing a discharge means the electrical load is exceeding the output of the alternator or generator, and the battery is helping to supply electrical power. This may mean the alternator or generator is malfunctioning, or the electrical load is excessive. An ammeter displays the load placed on the alternator or generator by the electrical equipment. The RFM (see page 5-1) for a particular helicopter shows the normal load to expect. Loss of the alternator or generator causes the load meter to indicate zero.

Electrical switches are used to select electrical components. Power may be supplied directly to the component or to a relay, which in turn provides power to the component. Relays are used when high current and/or heavy electrical cables are required for a particular component, which may exceed the capacity of the switch.

Circuit breakers or fuses are used to protect various electrical components from overload. A circuit breaker pops out when its respective component is overloaded. The circuit breaker may be reset by pushing it back in, unless a short or the overload still exists. In this case, the circuit breaker continues to pop, indicating an electrical malfunction. A fuse simply burns out when it is overloaded and needs to be replaced. Manufacturers usually provide a holder for spare fuses in the event one has to be replaced in flight. Caution lights on the instrument panel may be installed to show the malfunction of an electrical component.

Hydraulics

Most helicopters, other than smaller piston-powered helicopters, incorporate the use of hydraulic actuators to overcome high control forces. *[Figure 4-25]* A typical hydraulic system consists of actuators, also called servos, on each flight control, a pump which is usually driven by the main rotor transmission and a reservoir to store the hydraulic fluid. Some helicopters have accumulators located on the pressure side of the hydraulic system. This allows for a continuous fluid pressure into the system. A switch in the cockpit can turn the system off, although it is left on under normal conditions. When the pilot places the hydraulic switch/circuit breaker into the on position, the electrical power is being removed from the solenoid valve allowing

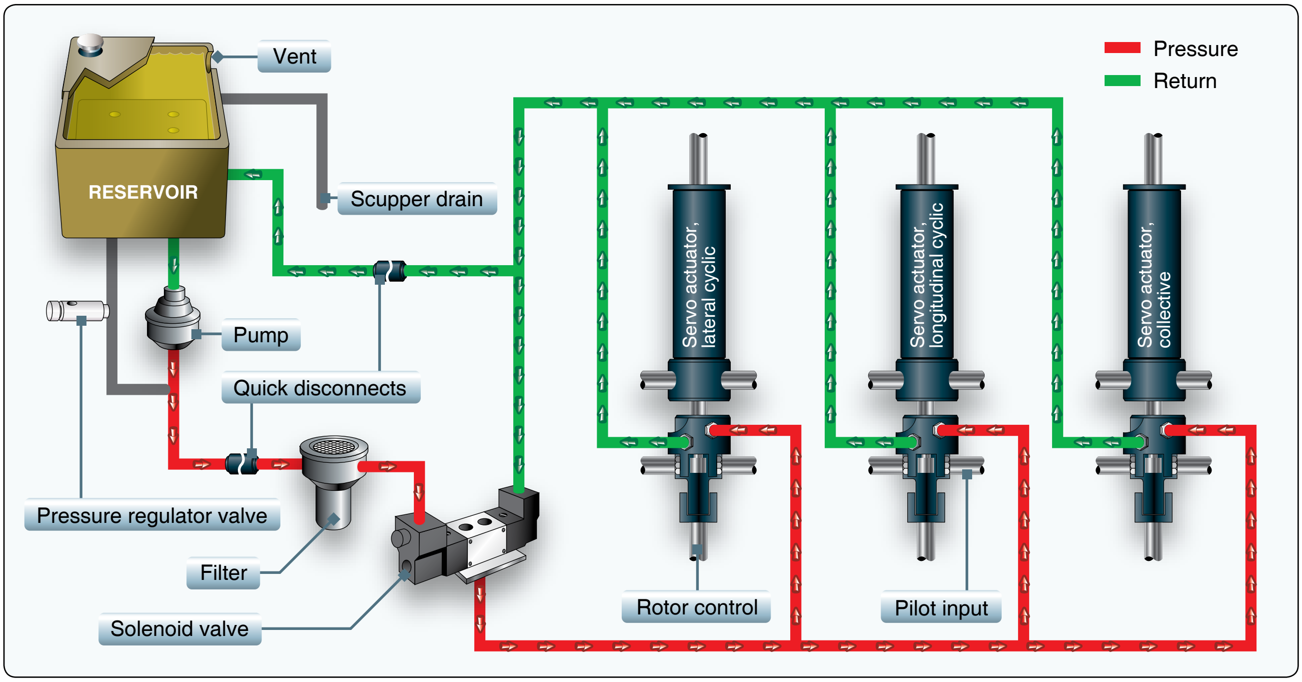

Figure 4-25. *A typical hydraulic system for helicopters in the light to medium range.*

hydraulic fluid to enter the system. When the switch/circuit breaker is put in the off position, the solenoid valve is now de-energized and closes, which then allows the pilot to maintain control of the helicopter with the hydraulic fluid in the actuators. This is known as a failsafe system. If helicopter electrical power is lost in flight, the pilot is still able to maintain control of the hydraulic system. A pressure indicator in the cockpit may also be installed to monitor the system.

When making a control input, the servo is activated and provides an assisting force to move the respective flight control, thus reducing the force the pilot must provide. These boosted flight controls ease pilot workload and fatigue. In the event of hydraulic system failure, a pilot is still able to control the helicopter, but the control forces are very heavy.

In those helicopters in which the control forces are so high that they cannot be moved without hydraulic assistance, two or more independent hydraulic systems may be installed. Some helicopters are designed to use their hydraulic accumulators to store hydraulic pressure for an emergency, allowing for uninterrupted use of the controls for a short period of time following a hydraulic pump failure. This gives you enough time to land the helicopter with normal control.

Stability Augmentations Systems

Some helicopters incorporate a stability augmentation system (SAS) to help stabilize the helicopter in flight and in a hover. The original purpose and design allowed decreased pilot workload and lessened fatigue. It allowed pilots to place an aircraft at a set attitude to accomplish other tasks or simply stabilize the aircraft for long cross-country flights.

Force Trim

Force trim was a passive system that simply held the cyclic in a position that gave a control force to transitioning airplane pilots who had become accustomed to such control forces. The system uses a magnetic clutch and springs to hold the cyclic control in the position where it was released. The system does not use sensor-based data to make corrections, but rather is used by the pilot to "hold" the cyclic in a desired position. The most basic versions only apply to the cyclic requiring the pilot to continue power and tail rotor inputs. With the force trim on or in use, the pilot can override the system by disengaging the system through the use of a force trim release button or, with greater resistance, can physically manipulate the controls. Some recent basic systems are referred to as attitude retention systems.

Active Augmentation Systems

So-called actual augmentation systems use electric actuators that provide input to the hydraulic servos. These servos receive control commands from a computer that senses external environmental inputs, such as wind and turbulence. SAS complexity varies by manufacturer but can be as sophisticated as providing three-axis stability. That is, computer-based inputs adjust attitude, power and aircraft trim for a more stabilized flight.

Once engaged by the pilot, these actual systems use a multitude of sensors, from stabilized gyros to electromechanical actuators, which provide instantaneous inputs to all flight controls without pilot assistance. As with all SASs, they may be overridden or disconnected by the pilot at any time. Helicopters with complex Automatic Flight Control Systems (AFCS) and autopilots normally have a trim switch referred to as "beeper trim." This switch is used when minor changes to the trim setting are desired.

Stability augmentation systems reduce pilot workload by improving basic aircraft control harmony and decreasing disturbances. These systems are very useful when the pilot is required to perform other duties, such as sling loading and search-and-rescue operations. Other inputs such as heading, speed, altitude, and navigation information may be supplied to the computer to form a complete autopilot system.

Autopilot

Helicopter autopilot systems are similar to stability augmentation systems, but they have additional features. An autopilot can actually fly the helicopter and perform certain functions selected by the pilot. These functions depend on the type of autopilot and systems installed in the helicopter.

The most common functions are altitude and heading hold. Some more advanced systems include a vertical speed or indicated airspeed (IAS) hold mode, where a constant rate of climb/descent or IAS is maintained by the autopilot. Some autopilots have navigation capabilities, such as very high frequency (VHF) OmniRange Navigation System (VOR), Instrument Landing System (ILS), and global positioning system (GPS) intercept and tracking, which is especially useful in instrument flight rules (IFR) conditions. This is referred to as a coupled system. An additional component, called a flight director (FD), may also be installed. The FD provides visual guidance cues to the pilot to fly selected lateral and vertical modes of operation. The most advanced autopilots can fly an instrument approach to a hover without any additional pilot input once the initial functions have been selected.

The autopilot system consists of electric actuators or servos connected to the flight controls. The number and location of these servos depends on the type of system installed. A two-axis autopilot controls the helicopter in pitch and roll; one servo controls fore and aft cyclic, and another controls left and right cyclic. A three-axis autopilot has an additional servo connected to the antitorque pedals and controls the helicopter in yaw. A four-axis system uses a fourth servo which controls the collective. These servos move the respective flight controls when they receive control commands from a central computer. This computer receives data input from the flight instruments for attitude reference and from the navigation equipment for navigation and tracking reference. An autopilot has a control panel in the cockpit that allows the pilot to select the desired functions, as well as engage the autopilot.

For safety purposes, an automatic disengagement feature is usually included which automatically disconnects the autopilot in heavy turbulence or when extreme flight attitudes are reached. Even though all autopilots can be overridden by the pilot, there is also an autopilot disengagement button located on the cyclic or collective which allows pilots to completely disengage the autopilot without removing their hands from the controls. Because autopilot systems and installations differ from one helicopter to another, it is very important to refer to the autopilot operating procedures located in the RFM.

Environmental Systems

Heating and cooling the helicopter cabin can be accomplished in different ways. The simplest form of cooling is by ram air. Air ducts in the front or sides of the helicopter are opened or closed by the pilot to let ram air into the cabin. This system is limited as it requires forward airspeed to provide airflow and also depends on the temperature of the outside air. Air conditioning provides better cooling, but it is more complex and weighs more than a ram air system.

One of the simplest methods of cooling a helicopter is to remove the doors allowing air to flow through the cockpit and engine compartments. Care must be taken to store the doors properly, whether in a designed door-holding rack in a hangar, or if it is necessary to carry them on the flight, in the helicopter. When storing the doors, care must be taken to not scratch the windows. Special attention should be paid to ensuring that all seat belt cushions and any other loose items are stored away to prevent ingestion into the main or tail rotor. When reattaching the doors, proper care must be taken to ensure that they are fully secured and closed.

Air conditioners or heat exchanges can be fitted to the helicopter as well. They operate by drawing bleed air from the compressor, passing it through the heart exchanger and then releasing it into the cabin. As the compressed air is released, the expansion absorbs heat and cools the cabin. The disadvantage of this type of system is that power is required to compress the air or gas for the cooling function, thus robbing the engine of some of its capability. Some systems are restricted from use during takeoff and landings.

Piston-powered helicopters use a heat exchanger shroud around the exhaust manifold to provide cabin heat. Outside air is piped to the shroud and the hot exhaust manifold heats the air, which is then blown into the cockpit. This warm air is heated by the exhaust manifold but is not exhaust gas. Turbine helicopters use a bleed air system for heat. Bleed air is hot, compressed, discharge air from the engine compressor. Hot air is ducted from the compressor to the bleed air heater assembly where it is combined with ambient air through and induction port mounted to the fuselage. The amount of heat delivered to the helicopter cabin is regulated by a pilot-controlled bleed air mixing valve.

Anti-Icing Systems

Anti-icing is the process of protecting against the formation of frozen contaminant, snow, ice, or slush on a surface.

Engine Anti-Ice

The anti-icing system found on most turbine-powered helicopters uses engine bleed air. Bleed air in turbine engines is compressed air taken from within the engine, after the compressor stage(s) and before the fuel is injected in the burners. The bleed air flows through the inlet guide vanes and to the inlet itself to prevent ice formation on the hollow vanes. A pilot-controlled, electrically operated valve on the compressor controls the air flow. Engine anti-ice systems should be on prior to entry into icing conditions and remain on until exiting those conditions. Use of the engine anti-ice system should always be in accordance with the proper RFM.

Airframe Anti-Ice

Airframe and rotor anti-icing may be found on some larger helicopters, but it is not common due to the complexity, expense, and weight of such systems. The leading edges of rotors may be heated with bleed air or electrical elements to prevent ice formation. Balance and control problems might arise if ice is allowed to form unevenly on the blades. Research is being done on lightweight ice-phobic (anti-icing) materials or coatings. These materials placed in strategic areas could significantly reduce ice formation and improve performance.

The pitot tube on a helicopter is very susceptible to ice and moisture buildup as well. To prevent this, they are usually equipped with a heating system that uses an electrical element to heat the tube.

Deicing

Deicing is the process of removing frozen contaminant, snow, ice, and/or slush from a surface. Deicing of the helicopter fuselage and rotor blades is critical prior to starting. Helicopters that are unsheltered by hangars are subject to frost, snow, freezing drizzle, and freezing rain that can cause icing of rotor blades and fuselages, rendering them unflyable until cleaned. Asymmetrical shedding of ice from the blades can lead to component failure, and shedding ice can be dangerous as it may hit any structures or people that are around the helicopter. The tail rotor is very vulnerable to shedding ice damage. Thorough preflight checks should be made before starting the rotor blades. If any ice was removed prior to starting, ensure that the flight controls move freely. While in flight, for those helicopters that have them, deicing systems should be activated immediately after entry into an icing condition.

Chapter Summary

This chapter discussed all of the common components, sections, and systems of the helicopter. The chapter also explained how each of them work with one another to make flight possible.