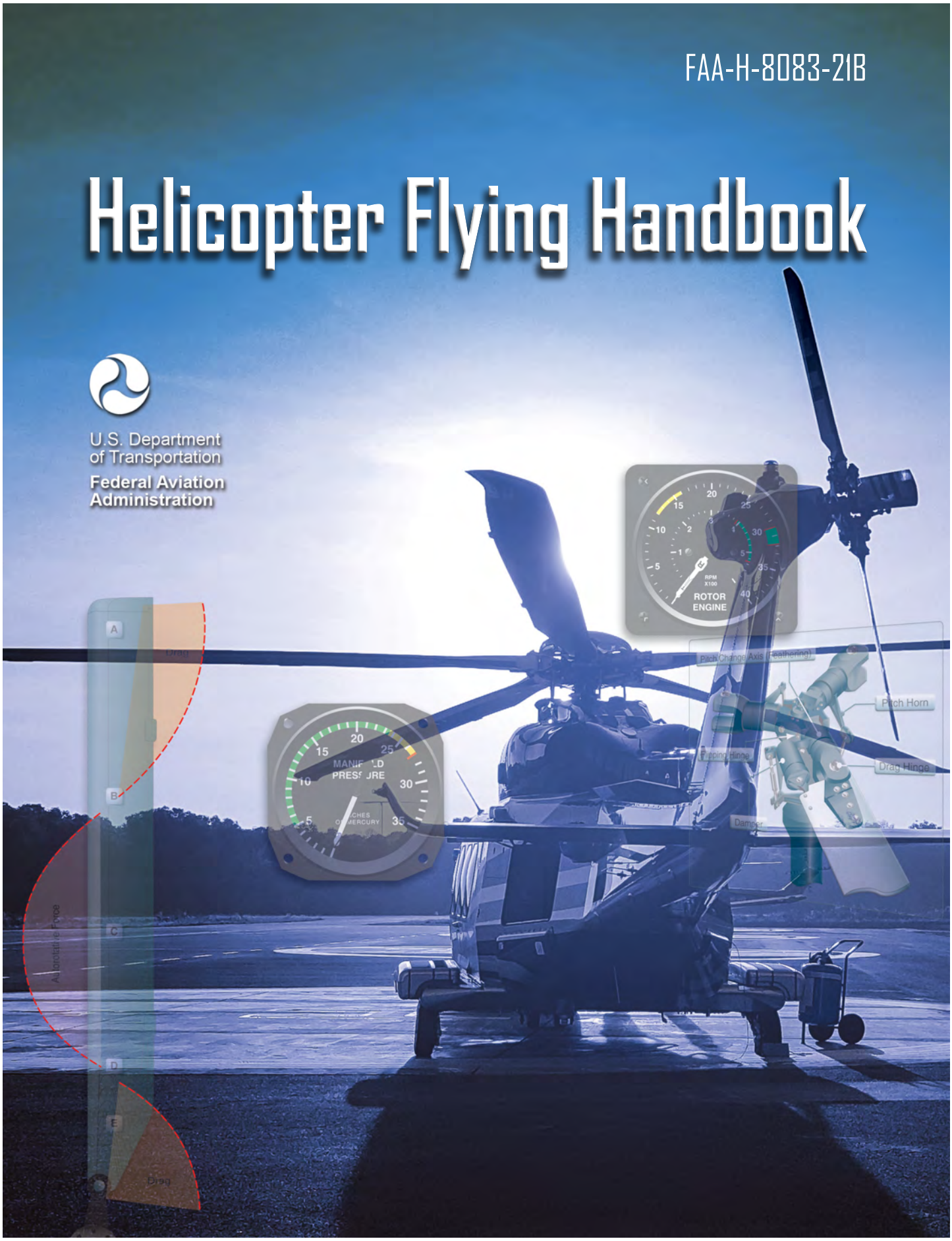
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Helicopter Flying Handbook



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Helicopter Flying Handbook

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FEDERAL AVIATION ADMINISTRATION
Flight Standards Service

Preface

The Helicopter Flying Handbook is designed as a technical manual for applicants who are preparing for their private, commercial, or flight instructor pilot certificates with a helicopter class rating. Certificated flight instructors may find this handbook a valuable training aid, since detailed coverage of aerodynamics, flight controls, systems, performance, flight maneuvers, emergencies, and aeronautical decision-making is included. Topics such as weather, navigation, radio navigation and communications, use of flight information publications, and regulations are available in other Federal Aviation Administration (FAA) publications.

This handbook conforms to pilot training and certification concepts established by the FAA. There are different ways of teaching, as well as performing, flight procedures and maneuvers, and many variations in the explanations of aerodynamic theories and principles. This handbook adopts a selective method and concept to flying helicopters. The discussion and explanations reflect the most commonly used practices and principles. Occasionally the word “must” or similar language is used where the desired action is deemed critical. The use of such language is not intended to add to, interpret, or relieve a duty imposed by Title 14 of the Code of Federal Regulations (14 CFR). Persons working towards a helicopter rating are advised to review the references from the applicable practical test standards (FAA-S-8081-3 for recreational applicants, FAA-S-8081-15 for private applicants, and FAA-S-8081-16 for commercial applicants). Resources for study include FAA-H-8083-25, Pilot’s Handbook of Aeronautical Knowledge, and FAA-H-8083-1, Weight and Balance Handbook, as these documents contain basic material not duplicated herein. All beginning applicants should refer to FAA-H-8083-25, Pilot’s Handbook of Aeronautical Knowledge, for study and basic library reference.

It is essential for persons using this handbook to become familiar with and apply the pertinent parts of 14 CFR and the Aeronautical Information Manual (AIM). The AIM is available online at www.faa.gov. The current Flight Standards Service airman training and testing material and learning statements for all airman certificates and ratings can be obtained from www.faa.gov.

This handbook supersedes FAA-H-8083-21A, Helicopter Flying Handbook, dated 2012. Gyroplane information can be found in the FAA-H-8083-20, Gyroplane Flying Handbook.

This handbook is available for download, in PDF format, from www.faa.gov.

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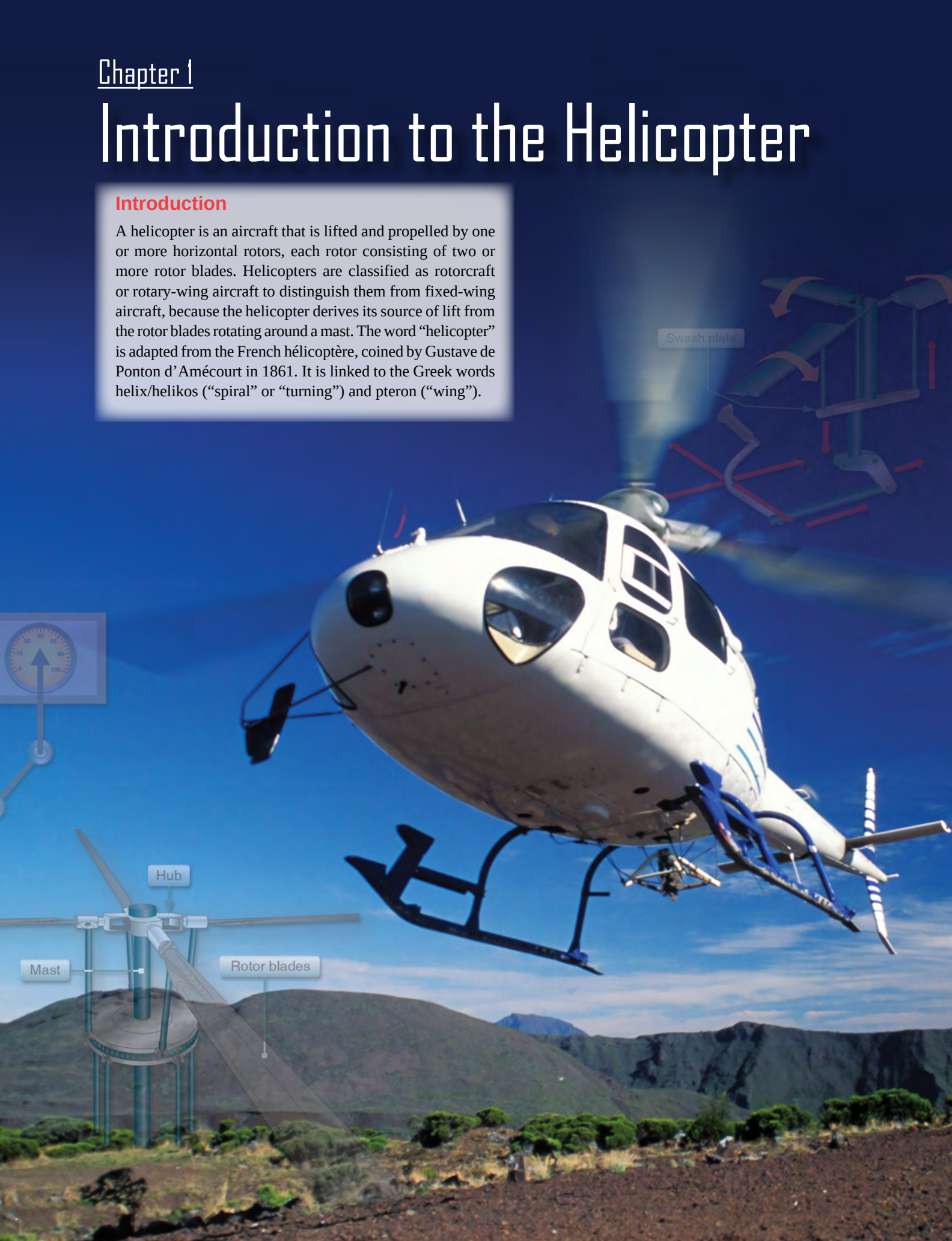
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Chapter 1

Introduction to the Helicopter

Introduction

A helicopter is an aircraft that is lifted and propelled by one or more horizontal rotors, each rotor consisting of two or more rotor blades. Helicopters are classified as rotorcraft or rotary-wing aircraft to distinguish them from fixed-wing aircraft, because the helicopter derives its source of lift from the rotor blades rotating around a mast. The word "helicopter" is adapted from the French hélicoptère, coined by Gustave de Ponton d'Amécourt in 1861. It is linked to the Greek words helix/helikos ("spiral" or "turning") and pteron ("wing").



As an aircraft, the primary advantages of the helicopter are due to the rotor blades that revolve through the air, providing lift without requiring the aircraft to move forward. This lift allows the helicopter to hover in one area and to take off and land vertically without the need for runways. For this reason, helicopters are often used in congested or isolated areas where fixed-wing aircraft are not able to take off or land. *[Figures 1-1* and *1-2]*

Piloting a helicopter requires adequate, focused and safety-orientated training. It also requires continuous attention to the machine and the operating environment. The pilot must work in three dimensions and use both arms and both legs constantly to keep the helicopter in a desired state. Coordination, timing and control touch are all used simultaneously when flying a helicopter.

Although helicopters were developed and built during the first half-century of flight, some even reaching limited production; it was not until 1942 that a helicopter designed by Igor Sikorsky reached full-scale production, with 131 aircraft built. Even though most previous designs used more than one main rotor, it was the single main rotor with an antitorque tail rotor configuration that would come to be recognized worldwide as the helicopter.



Figure 1-1. *Search and rescue helicopter conducting a pinnacle approach.*



Figure 1-2. *Search and rescue helicopter landing in a confined area.*

Turbine Age

In 1951, at the urging of his contacts at the Department of the Navy, Charles H. Kaman modified his K-225 helicopter with a new kind of engine, the turbo-shaft engine. This adaptation of the turbine engine provided a large amount of horsepower to the helicopter with a lower weight penalty than piston engines, heavy engine blocks, and auxiliary components. On December 11, 1951, the K-225 became the first turbine-powered helicopter in the world. Two years later, on March 26, 1954, a modified Navy HTK-1, another Kaman helicopter, became the first twin-turbine helicopter to fly. However, it was the Sud Aviation Alouette II that would become the first helicopter to be produced with a turbine engine.

Reliable helicopters capable of stable hover flight were developed decades after fixed-wing aircraft. This is largely due to higher engine power density requirements than fixed-wing aircraft. Improvements in fuels and engines during the first half of the 20th century were critical factors in helicopter development. The availability of lightweight turbo-shaft engines in the second half of the 20th century led to the development of larger, faster, and higher-performance helicopters. While smaller and less expensive helicopters still use piston engines, turboshaft engines are the preferred powerplant for helicopters today.

The turbine engine has the following advantages over a reciprocating engine:

- Less vibration
- Increased aircraft performance
- Reliability
- Ease of operation

Uses

Due to the unique operating characteristics of the helicopter—its ability to take off and land vertically, to hover for extended periods of time, and the aircraft's handling properties under low airspeed conditions—it has been chosen to conduct tasks that were previously not possible with other aircraft or were too time- or work-intensive to accomplish on the ground. Today, helicopters are used for transportation, construction, firefighting, search and rescue, and a variety of other jobs that require its special capabilities. *[Figure 1-3]*



Figure 1-3. *The many uses for a helicopter include search and rescue (top), firefighting (middle), and construction (bottom).*

Rotor System

The helicopter rotor system is the rotating part of a helicopter that generates lift. A rotor system may be mounted horizontally, as main rotors are, providing lift vertically; and it may be mounted vertically, such as a tail rotor, to provide lift horizontally as thrust to counteract torque effect. In the case of tilt rotors, the rotor is mounted on a nacelle that rotates at the edge of the wing to transition the rotor from a horizontal mounted position, providing lift horizontally as thrust, to a vertical mounted position providing lift exactly as a helicopter.

The rotor consists of a mast, hub, and rotor blades. *[Figure 1-4]* The mast is a hollow cylindrical metal shaft which extends upwards from and is driven 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 several 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, although some modern rotor systems use an engineered combination of these types. All three rotor systems are discussed with greater detail in Chapter 4, Helicopter Components, Sections, and Systems.

With a single main rotor helicopter, a torque effect is created as the engine turns the rotor. This torque causes the body of the helicopter to turn in the opposite direction of the rotor (Newton's Third Law: Every action has an equal and opposite reaction, as explained in Chapter 2, Aerodynamics of Flight). To eliminate this effect, some sort of antitorque control must be used with a sufficient margin of power available to allow the helicopter to maintain its heading and prevent the aircraft from moving unsteadily. The three most common controls used today are the traditional tail rotor, Fenestron (also called a fantail), and the NOTAR®. All three antitorque designs will be discussed in Chapter 4, Helicopter Components, Sections, and Systems.

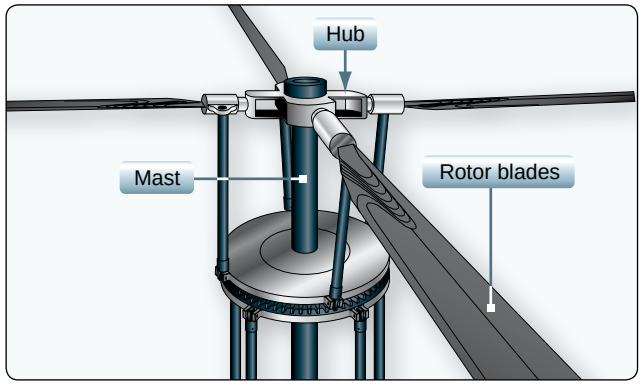


Figure 1-4. *Basic components of the rotor system.*

Rotor Configurations

Most helicopters have a single, main rotor but require a separate rotor to overcome torque which is a turning or twisting force. This is accomplished through a variable pitch, antitorque rotor or tail rotor. This is the design that Igor Sikorsky settled on for his VS-300 helicopter shown in *Figure 1-5.* It has become the recognized convention for helicopter design, although designs do vary. Helicopter main rotor designs from different manufacturers rotate in one of two different directions (clockwise or counter-clockwise when viewed from above). This can make it confusing when discussing aerodynamic effects on the main rotor between different designs, since the effects may manifest on opposite sides of each aircraft. For clarity, throughout this handbook, all examples use a counter-clockwise rotating main rotor system when viewed from above.

For clarity, throughout this handbook, all examples use a counter-clockwise rotating main rotor system when viewed from above.

Tandem Rotor

Tandem rotor (sometimes referred to as dual rotor) helicopters have two large horizontal rotor assemblies, instead of one main assembly and a smaller tail rotor. *[Figure 1-6]* Single rotor helicopters need a tail rotor to neutralize the twisting momentum produced by the single large rotor. Tandem rotor helicopters, however, use counter-rotating rotors, each canceling 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 has the advantage of being able to hold more weight with shorter blades, since there are two blade sets. Also, all the power from the engines can be used for lift, whereas a single rotor helicopter must use some power to counter main rotor torque. Because of this, tandem helicopters make up some of the most powerful and fastest rotor system aircraft.



Figure 1-5. *Igor Sikorsky designed the VS-300 helicopter incorporating the tail rotor into the design.*



Figure 1-6. *Tandem rotor helicopters.*

Coaxial Rotors

Coaxial rotors are a pair of rotors turning in opposite directions, but mounted on a mast, with the same axis of rotation, one above the other. This configuration is a noted feature of helicopters produced by the Russian Kamov helicopter design bureau. *[Figure 1-7]*

Intermeshing Rotors

Intermeshing rotors on a helicopter are a set of two rotors turning in opposite directions, with each rotor mast mounted on the helicopter with a slight angle to the other so that the blades intermesh without colliding. *[Figure 1-8]* This arrangement allows the helicopter to function without the need for a tail rotor. It has high stability and powerful lifting capability. This configuration is sometimes referred to as a synchropter. The arrangement was developed in Germany



Figure 1-7. *Coaxial rotors.*



Figure 1-8. *HH-43 Huskie with intermeshing rotors.*

for a small anti-submarine warfare helicopter, the Flettner Fl 282 Kolibri. During the Cold War the American Kaman Aircraft company produced the HH-43 Huskie, for USAF firefighting purposes. The latest Kaman K-MAX model is a dedicated sky crane design used for construction work.

Tail Rotor

The tail rotor is a smaller rotor mounted vertically or near-vertically on the tail of a traditional single-rotor helicopter. The tail rotor either pushes or pulls against the tail to counter the torque. The tail rotor drive system consists of a drive shaft powered from the main transmission and a gearbox mounted at the end of the tail boom. *[Figure 1-9]* The drive shaft may consist of one long shaft or a series of shorter shafts connected at both ends with flexible couplings. The flexible couplings allow the drive shaft to flex with the tail boom.

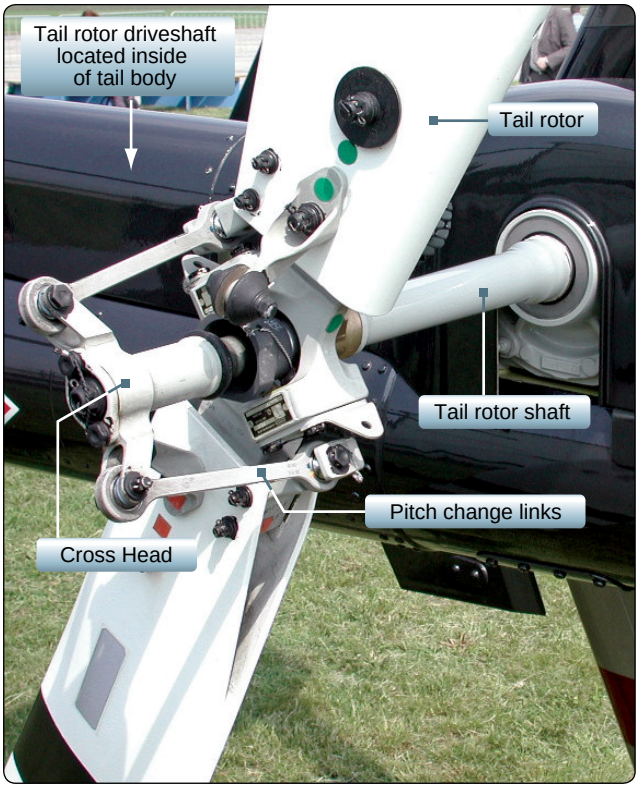


Figure 1-9. *Basic tail rotor components.*

The gearbox at the end of the tail boom provides an angled drive for the tail rotor and may also include gearing to adjust the output to the optimum rotational speed typically measured in revolutions per minute (rpm) for the tail rotor. On some larger helicopters, intermediate gearboxes are used to angle the tail rotor drive shaft from along the tail boom or tailcone to the top of the tail rotor pylon, which also serves as a vertical stabilizing airfoil to alleviate the power requirement for the tail rotor in forward flight. The pylon (or vertical fin) may also provide limited antitorque within certain airspeed ranges if the tail rotor or the tail rotor flight controls fail.

Controlling Flight

A helicopter has four primary flight controls:

- Cyclic
- Collective
- Antitorque pedals
- Throttle

Cyclic

The cyclic control is usually located between the pilot's legs and is commonly called the "cyclic stick" or simply "cyclic." On most helicopters, the cyclic is similar to a joystick; however, Robinson helicopters have unique T-bar cyclic control systems. A few helicopters have cyclic controls that descend into the cockpit from overhead while others use side cyclic controls.

The control is called the cyclic because it can vary the pitch of the rotor blades throughout each revolution of the main rotor system (i.e., through each cycle of rotation) to develop unequal lift (thrust). The result is to tilt the rotor disk in a particular direction, resulting in the helicopter moving in that direction. If the pilot pushes the cyclic forward, the rotor disk tilts forward, and the rotor produces a thrust in the forward direction. If the pilot pushes the cyclic to the side, the rotor disk tilts to that side and produces thrust in that direction, causing the helicopter to hover sideways. *[Figure 1-10]*

Collective

The collective pitch control, or collective, is located on the left side of the pilot's seat with a pilot-selected variable friction control to prevent inadvertent movement. The collective changes the pitch angle of all the main rotor blades

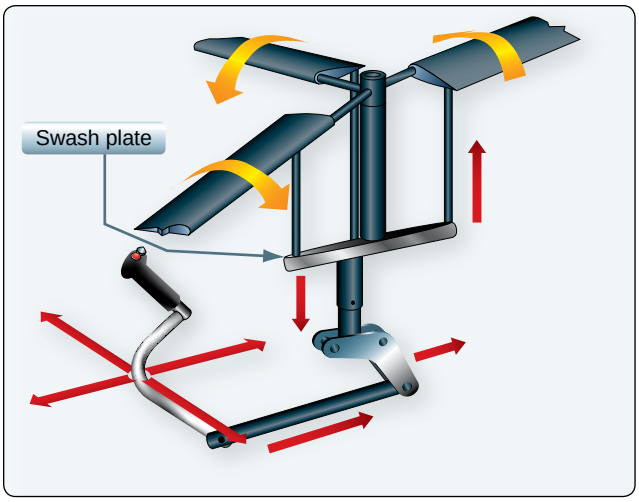


Figure 1-10. *Cyclic controls changing the pitch of the rotor blades.*

collectively (i.e., all at the same time) and independently of their positions. Therefore, if a collective input is made, all the blades change equally, increasing or decreasing total lift or thrust, with the result of the helicopter increasing or decreasing in altitude or airspeed.

Antitorque Pedals

The antitorque pedals are located in the same position as the rudder pedals in a fixed-wing aircraft and serve a similar purpose, namely to control the direction in which the nose of the aircraft is pointed. Application of the pedal in a given direction changes the pitch of the tail rotor blades, increasing or reducing the thrust produced by the tail rotor, causing the nose to yaw in the direction of the applied pedal. The pedals mechanically change the pitch of the tail rotor, altering the amount of thrust produced.

Throttle

Helicopter rotors are designed to operate at a specific rpm.

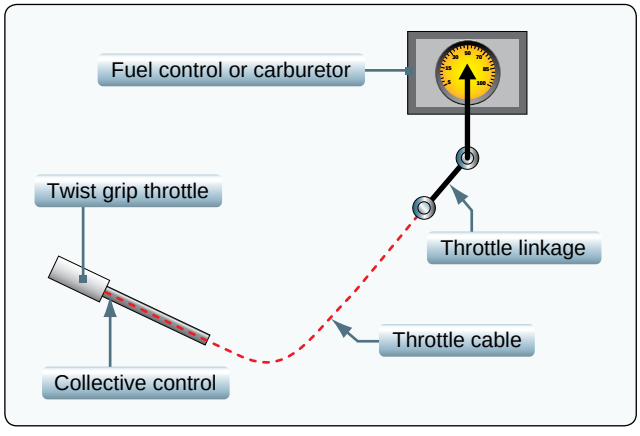


Figure 1-11. *The throttle control mounted at the end of the collective control.*

The throttle controls the power produced by the engine, which is connected to the rotor by a transmission. The purpose of the throttle is to maintain enough engine power to keep the rotor rpm within allowable limits to produce enough lift for flight. In single-engine helicopters, if so equipped, the throttle control is typically a twist grip mounted on the collective control, but it can also be a lever mechanism in fully governed systems. Multi-engine helicopters generally have a power lever or mode switch for each engine. *[Figure 1-11]* Helicopter flight controls are discussed in greater detail throughout Chapter 4, Helicopter Components, Sections and Systems.

Flight Conditions

There are two basic flight conditions for a helicopter: hover and forward flight. Hovering is the most challenging part of flying a helicopter. This is because a helicopter generates its own gusty air while in a hover, which acts against the fuselage and flight control surfaces. The end result is the need for constant control inputs and corrections by the pilot to keep the helicopter where it is required to be. Despite the complexity of the task, the control inputs in a hover are simple. The cyclic is used to eliminate drift in the horizontal direction that is to control forward and back, right and left. The collective is used to maintain altitude. The pedals are used to control nose direction or heading. It is the interaction of these controls that makes hovering so difficult, since an adjustment in any one control requires an adjustment of the other two, creating a cycle of constant correction.

Displacing the cyclic forward initially causes the nose to pitch down, with a resultant increase in airspeed and loss of altitude. Aft cyclic initially causes the nose to pitch up, slowing the helicopter and causing it to climb; however, as the helicopter reaches a state of equilibrium, the horizontal stabilizer helps level the helicopter to minimize drag, unlike



Figure 1-12. *The horizontal stabilizer helps level the helicopter to minimize drag during flight.*

an airplane. *[Figure 1-12]* Therefore, the helicopter has very little pitch deflection up or down when the helicopter is stable in a flight mode. The variation from absolutely level depends on the particular helicopter and the horizontal stabilizer function.
Increasing collective (power) while maintaining a constant airspeed induces a climb while decreasing collective causes a descent. Coordinating these two inputs, down collective plus aft cyclic or up collective plus forward cyclic, results in airspeed changes while maintaining a constant altitude.

The pedals serve the same function in both a helicopter and a fixed-wing aircraft, to maintain balanced flight. This is done by applying pedal input in whichever direction is necessary to center the ball in the turn and bank indicator. Flight maneuvers are discussed in greater detail throughout Chapter 9, Basic Flight Maneuvers.

Chapter Summary

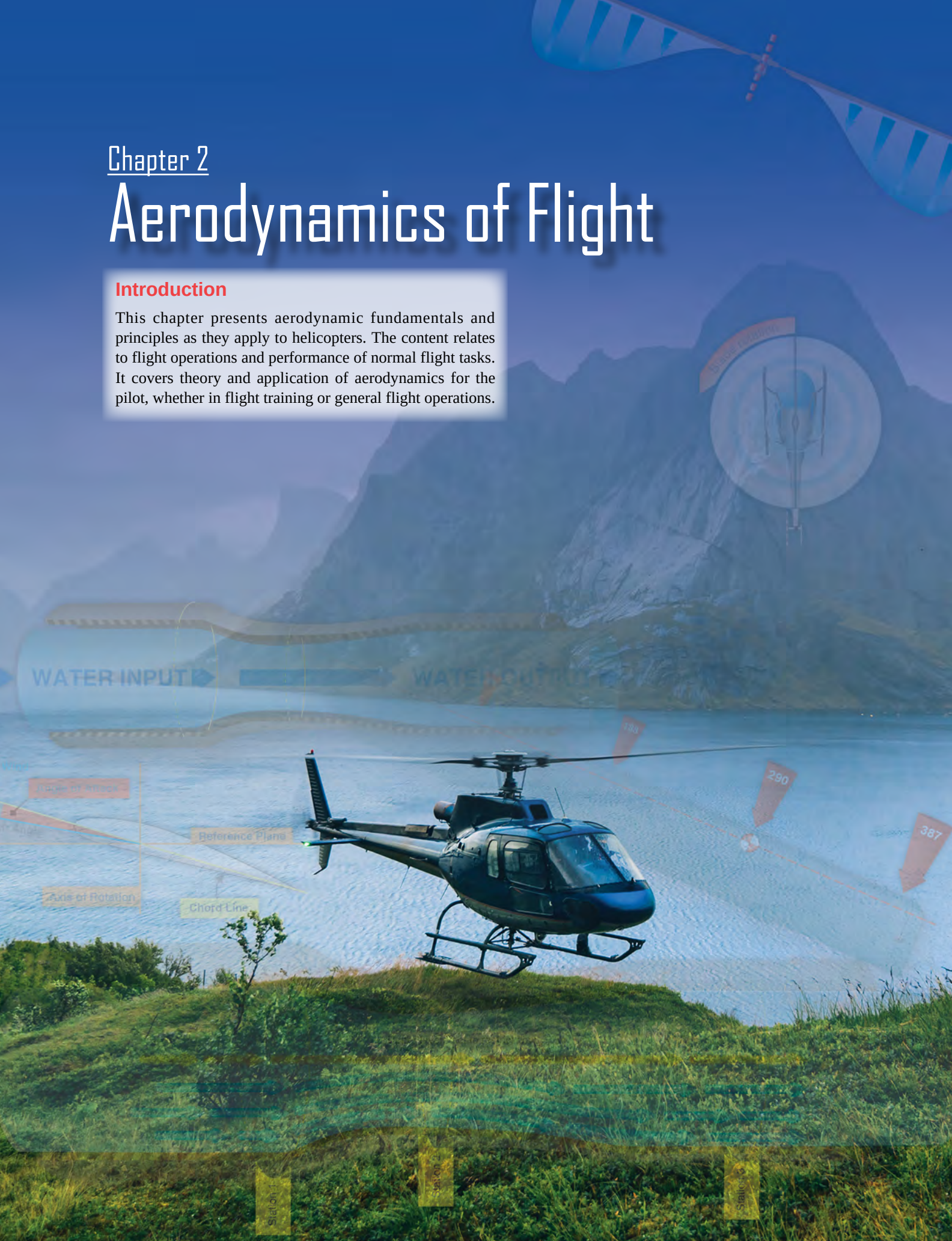
This chapter gives the reader an overview of the history of the helicopter, its many uses, and how it has developed throughout the years. The chapter also introduces basic terms and explanations of the helicopter components, sections, and the theory behind how the helicopter flies.

Chapter 2

Aerodynamics of Flight

Introduction

This chapter presents aerodynamic fundamentals and principles as they apply to helicopters. The content relates to flight operations and performance of normal flight tasks. It covers theory and application of aerodynamics for the pilot, whether in flight training or general flight operations.



Gravity acting on the mass (the amount of matter) of an object creates a force called weight. The rotor blade below weighs 100 lbs. It is 20 feet long (span) and is 1 foot wide (chord). Accordingly, its surface area is 20 square feet. *[Figure 2-1]*

The blade is perfectly balanced on a pinpoint stand, as you can see in *Figure 2-2* from looking at it from the end (the airfoil view). The goal is for the blade to defy gravity and stay exactly where it is when we remove the stand. If we do nothing before removing the stand, the blade will simply fall to the ground. Can we exert a force (a push or pull) opposite gravity that equals the 100 lb. weight of the blade? Yes, for example, electromagnetic force could be used. In helicopters, however, we use aerodynamic force to oppose weight and to maneuver.

Every object in the atmosphere is surrounded by a gas that exerts a static force of 2,116 lb per square foot (a force times a unit area, called pressure) at sea level. However, that pressure is exerted equally all over the blade (top and bottom) and therefore does not create any useful force on the blade. We need only create a difference of a single pound of static pressure differential per square foot of blade surface to have a force equal to the blade's weight (100 lb of upward pressure opposite 100 lb downward weight).

Total pressure consists of static pressure and, if the air is moving, dynamic pressure (a pressure in the direction of the air movement). As shown in *Figure 2-3*, if dynamic pressure is increased the static pressure will decrease. Due to the design of the airfoil, the velocity of the air passing over the upper surface will be greater than that of the lower surface, leading to higher dynamic pressure on the upper surface than on the lower surface. The higher dynamic pressure on the upper surface lowers the static pressure on the upper surface. The static pressure on the bottom will now be greater than the static pressure on the top. The blade will experience an upward force. With just the right amount of air passing over the blade the upward force will equal one pound per square foot. This upward force is equal to, and acts opposite the blade's weight of 100 lb. So, if we now remove the stand, the blade will defy gravity and remain in its position (ignoring rearward drag for the moment).

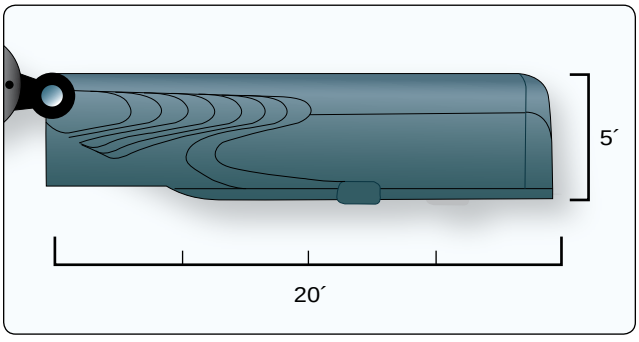


Figure 2-1. *Area of a blade.*

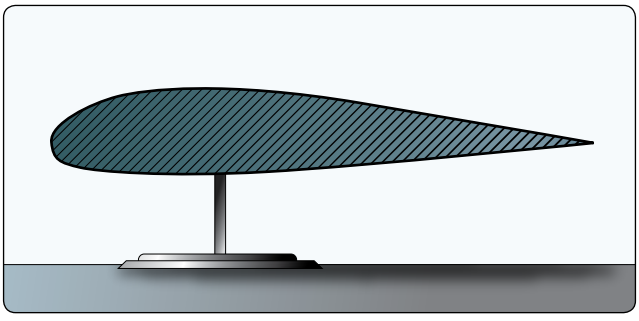


Figure 2-2. *Profile of an airfoil.*

The force created by air moving over an object (or moving an object through the air) is called aerodynamic force. Aero means air. Dynamic means moving or motion. Accordingly, by moving the air over an airfoil we can change the static pressures on the top and bottom thereby generating a useful force (an aerodynamic force). The portion of the aerodynamic force that is usually measured perpendicular to the air flowing around the airfoil is called lift and is used to oppose weight. Drag is the portion of aerodynamic force that is measured as the resistance created by an object passing through the air (or having the air passed over it). Drag acts in a streamwise direction with the wind passing over the airfoil and retards forward movement.

Forces Acting on the Aircraft

Once a helicopter leaves the ground, it is acted upon by four aerodynamic forces; thrust, drag, lift, and weight. Understanding how these forces work and knowing how to control them with the use of power and flight controls are essential to flight. *[Figure 2-3]* They are defined as follows:

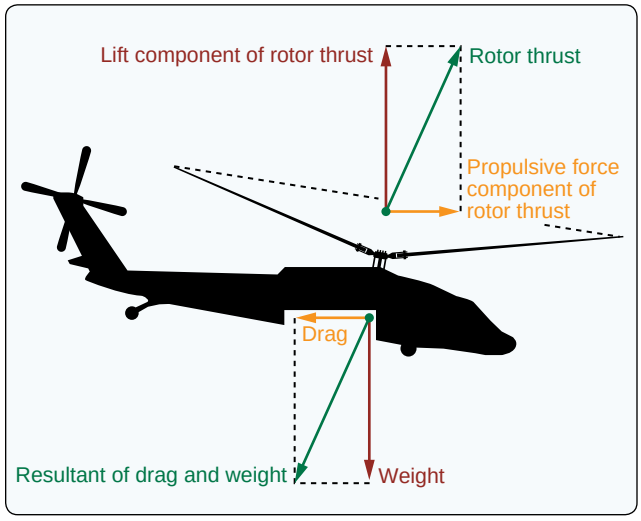


Figure 2-3. *Four forces acting on a helicopter in forward flight.*

- Lift—opposes the downward force of weight, is produced by the dynamic effect of the air acting on the airfoil and acts perpendicular to the flightpath through the center of lift.
- Weight—the combined load of the aircraft itself, the crew, the fuel, and the cargo or baggage. Weight pulls the aircraft downward because of the force of gravity. It opposes lift and acts vertically downward through the aircraft's center of gravity (CG).
- Thrust—the force produced by the power plant/propeller or rotor. It opposes or overcomes the force of drag. As a general rule, it acts parallel to the longitudinal axis. However, this is not always the case, as explained later.
- Drag—a rearward, retarding force caused by disruption of airflow by the wing, rotor, fuselage, and other protruding objects. Drag opposes thrust and acts rearward parallel to the relative wind.

For a more in-depth explanation of general aerodynamics, refer to the Pilot's Handbook of Aeronautical Knowledge.

Lift

Lift is generated when an object changes the direction of flow of a fluid or when the fluid is forced to move by the object passing through it. When the object and fluid move relative to each other and the object turns the fluid flow in a direction perpendicular to that flow, the force required to do this work creates an equal and opposite force that is lift. The object may be moving through a stationary fluid, or the fluid may be flowing past a stationary object—these two are effectively identical as, in principle, it is only the frame of reference of the viewer which differs. The lift generated by an airfoil depends on such factors as:

- Speed of the airflow
- Density of the air
- Total area of the segment or airfoil
- Angle of attack (AOA) between the air and the airfoil

The AOA is the angle at which the airfoil meets the oncoming airflow (or vice versa). In the case of a helicopter, the object is the rotor blade (airfoil) and the fluid is the air. Lift is produced when a mass of air is deflected, and it always acts perpendicular to the resultant relative wind. A symmetric airfoil must have a positive AOA to generate positive lift. At a zero AOA, no lift is generated. At a negative AOA, negative lift is generated. A cambered or nonsymmetrical airfoil may produce positive lift at zero, or even small negative AOA.

The basic concept of lift is simple. However, the details of how the relative movement of air and airfoil interact to produce the turning action that generates lift are complex. In any case causing lift, an angled flat plate, revolving cylinder, airfoil, etc., the flow meeting the leading edge of the object is forced to split over and under the object. The sudden change in direction over the object causes an area of low pressure to form behind the leading edge on the upper surface of the object. In turn, due to this pressure gradient and the viscosity of the fluid, the flow over the object is accelerated down along the upper surface of the object. At the same time, the flow forced under the object is rapidly slowed or stagnated causing an area of high pressure. This also causes the flow to accelerate along the upper surface of the object. The two sections of the fluid each leave the trailing edge of the object with a downward component of momentum, producing lift. *[Figure 2-4]*

Bernoulli's Principle

Bernoulli's principle describes the relationship between internal fluid pressure and fluid velocity. It is a statement of the law of conservation of energy and helps explain why an airfoil develops an aerodynamic force. The concept of conservation of energy states energy cannot be created or destroyed and the amount of energy entering a system must also exit. Specifically, in this case the "energy" referred to is the dynamic pressure (the kinetic energy of the air—more velocity, more kinetic energy) and static air pressure (potential energy). These will change among themselves, but the total pressure energy remains constant inside the tube.

A simple tube with a constricted portion near the center of its length illustrates this principle. An example is running water through a garden hose. The mass of flow per unit area (cross-sectional area of tube) is the mass flow rate. In *Figure 2-5*, the flow into the tube is constant, neither accelerating nor decelerating; thus, the mass flow rate through the tube must be the same at stations 1, 2, and 3. If the cross-sectional area at any one of these stations—or any given point—in the tube is reduced, the fluid velocity must increase to maintain a constant mass flow rate to move the same amount of fluid through a smaller area. The continuity of mass flow causes the air to move faster through the venturi. In other words, fluid speeds up in direct proportion to the reduction in area.

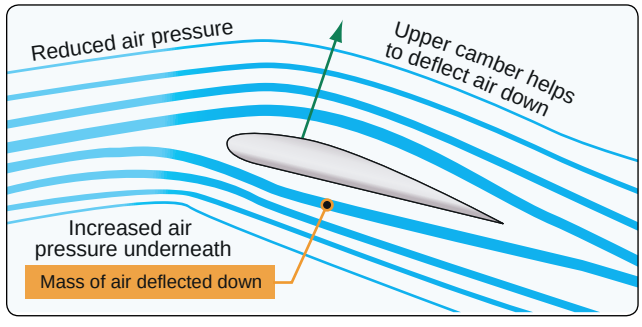


Figure 2-4. *Production of lift.*

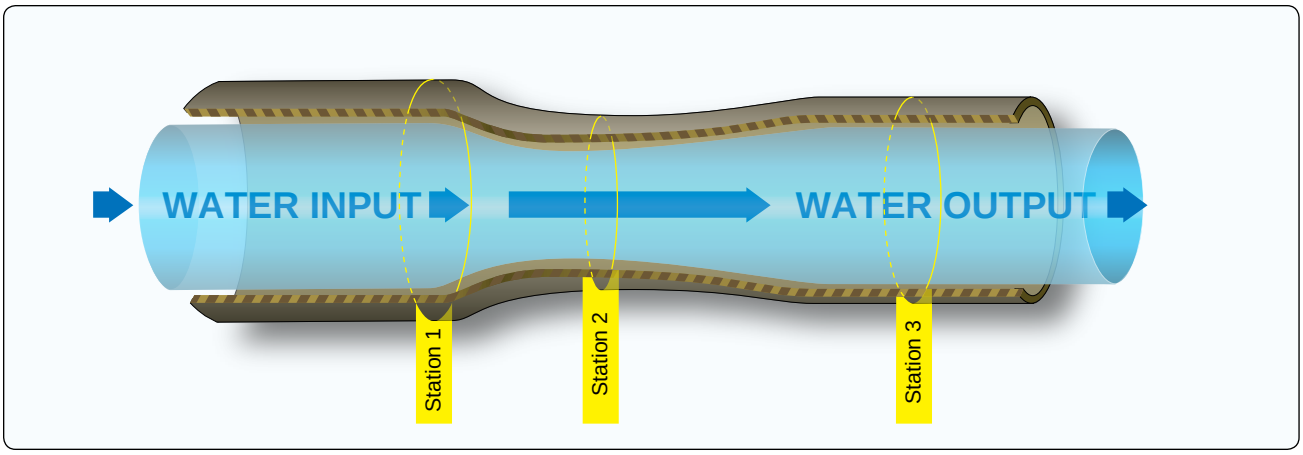


Figure 2-5. *Water flow through a tube.*

Bernoulli ($P_{total} = P_{dynamic} + P_{static}$) states that the increase in velocity will increase the streamwise dynamic pressure. Since the total pressure in the tube must remain constant, the static pressure on the sides of the venturi will decrease. Venturi effect is the term used to describe this phenomenon.

Figure 2-6 illustrates plates of one square foot in the dynamic flow and on the sides of the tube indicating static pressure, with corresponding pressure. At point 2, it is easier to visualize the static pressure reduction on the top of the airfoil as compared to the bottom of the airfoil, which is depicted as outside of the tube and therefore at ambient static pressure. Keep in mind with actual blades it is not a simple as this example because the bottom static pressure is influenced by blade design and blade angle, among other things. However, the basic idea is that it is the static pressure differential between the top and bottom multiplied by the surface area of the blade that generates the aerodynamic force.

Venturi Flow

While the amount of total energy within a closed system (the tube) does not change, the form of the energy may be altered. Pressure of flowing air may be compared to energy in that the total pressure of flowing air always remains constant unless energy is added or removed. Fluid flow pressure has two components—static and dynamic pressure. Static pressure is the pressure component measured in the flow but not moving with the flow as pressure is measured. Static pressure is also known as the force per unit area acting on a surface. Dynamic pressure of flow is that component existing as a result of movement of the air. The sum of these two pressures is total pressure. As air flows through the constriction, static pressure decreases as velocity increases. This increases dynamic pressure. *Figure 2-7* depicts the bottom half of the constricted area of the tube, which resembles the top half of an airfoil. Even with the top half of the tube removed, the air

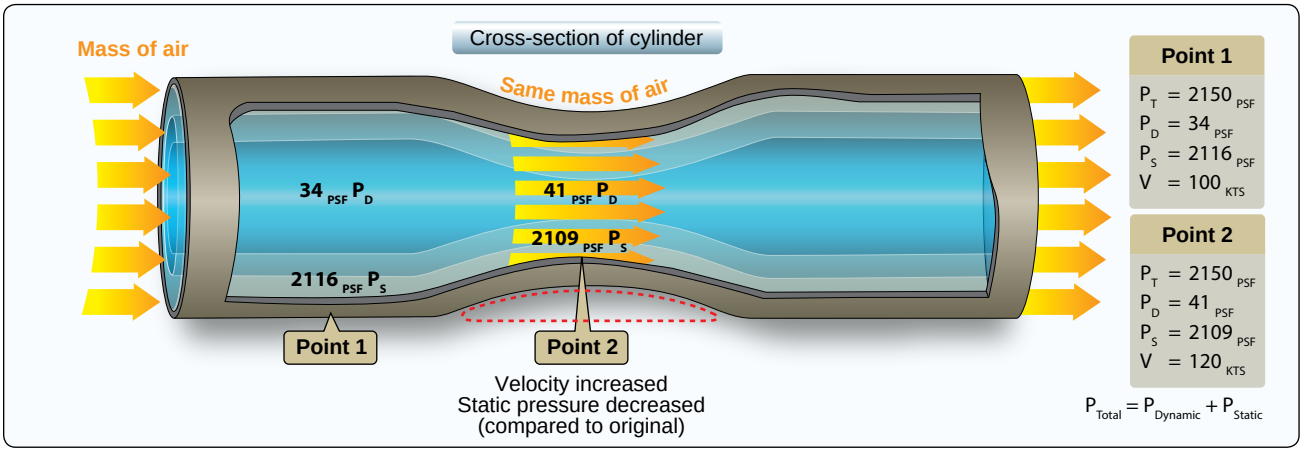


Figure 2-6. *Venturi effect.*

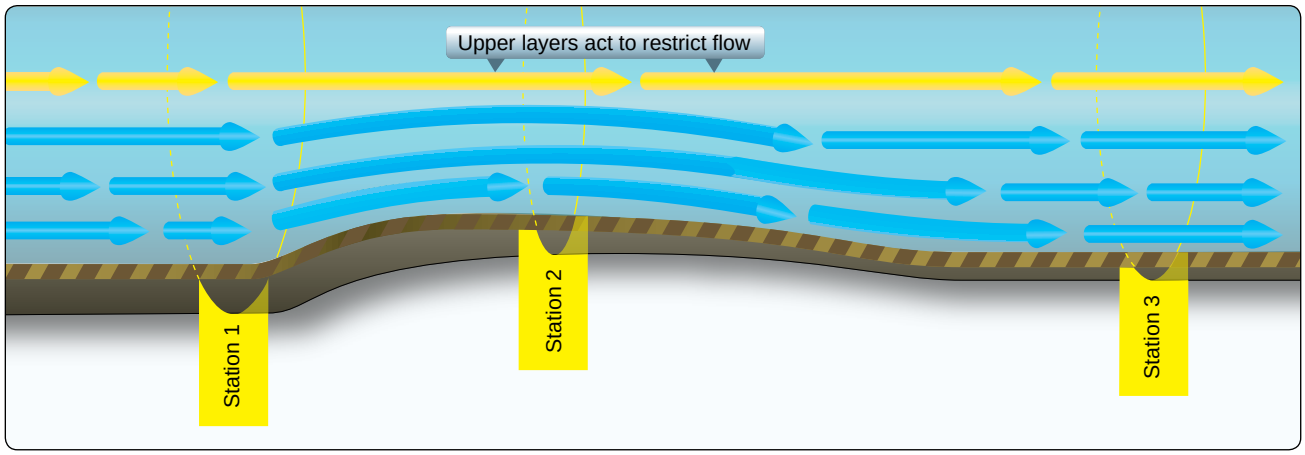


Figure 2-7. *Venturi flow.*

still accelerates over the curved area because the upper air layers restrict the flow—just as the top half of the constricted tube did. This acceleration causes decreased static pressure above the curved portion and creates a pressure differential caused by the variation of static and dynamic pressures.

Newton's Third Law of Motion

Additional lift is provided by the rotor blade's lower surface as air striking the underside is deflected downward. According to Newton's Third Law of Motion, "for every action there is an equal and opposite reaction," the air that is deflected downward also produces an upward (lifting) reaction.

Since air is much like water, the explanation for this source of lift may be compared to the planing effect of skis on water. The lift that supports the water skis (and the skier) is the force caused by the impact pressure and the deflection of water from the lower surfaces of the skis.

Under most flying conditions, the impact pressure and the deflection of air from the lower surface of the rotor blade provides a comparatively small percentage of the total lift. The majority of lift is the result of decreased pressure above the blade, rather than the increased pressure below it.

Weight

Normally, weight is thought of as being a known, fixed value, such as the weight of the helicopter, fuel, and occupants. To lift the helicopter off the ground vertically, the rotor disk must generate enough lift to overcome or offset the total weight of the helicopter and its occupants. Newton's First Law states: "Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it." In this case, the object is the helicopter whether at a hover or on the ground and the external force applied to it is lift, which is accomplished by increasing the pitch angle of the main rotor blades. This action forces the helicopter into a state of motion, without it the helicopter would either remain on the ground or at a hover.

The weight of the helicopter can also be influenced by aerodynamic loads. When you bank a helicopter while maintaining a constant altitude, the "G" load or load factor increases. The load factor is the actual load on the rotor blades at any time, divided by the normal load or gross weight (weight of the helicopter and its contents). Any time a helicopter flies in a constant altitude curved flightpath, the load supported by the rotor blades is greater than the total weight of the helicopter. The tighter the curved flightpath is, the steeper the bank is; the more rapid the flare or pullout from a dive is, the greater the load supported by the rotor. Therefore, the greater the load factor must be. *[Figure 2-8]*

To overcome this additional load factor, the helicopter must be able to produce more lift. If excess engine power is not available, the helicopter either descends or has to decelerate in order to maintain the same altitude. The load factor and, hence,

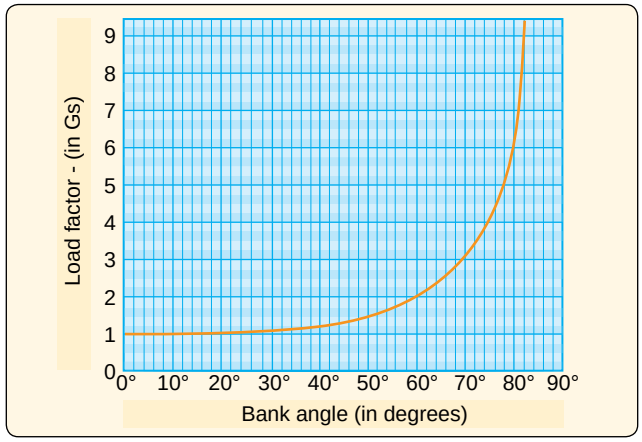


Figure 2-8. *The load factor diagram allows a pilot to calculate the amount of "G" loading exerted with various angles of bank.*

apparent gross weight increase is relatively small in banks up to 30°. Even so, under the right set of adverse circumstances, such as high-density altitude, turbulent air, high gross weight, and poor pilot technique, sufficient or excess power may not be available to maintain altitude and airspeed. Pilots must take all of these factors into consideration throughout the entire flight from the point of ascending to a hover to landing. Above 30° of bank, the apparent increase in gross weight soars. At 30° of bank, or pitch, the apparent increase is only 16 percent, but at 60°, it is twice the load on the wings and rotor disk. For example, if the weight of the helicopter is 1,600 pounds, the weight supported by the rotor disk in a 30° bank at a constant altitude would be 1,856 pounds (1,600 + 16 percent (or 256)). In a 60° bank, it would be 3,200 pounds; in an 80° bank, it would be almost six times as much, or 8,000 pounds. It is important to note that each rotor blade must support a percentage of the gross weight. In a two-bladed system, each blade of the 1,600-pound helicopter as stated above would have to lift 50 percent or 800 pounds. If this same helicopter had three rotor blades, each blade would have to lift only 33 percent, or 533 pounds. One additional cause of large load factors is rough or turbulent air. The severe vertical gusts produced by turbulence can cause a sudden increase in AOA, resulting in increased rotor blade loads that are resisted by the inertia of the helicopter.

Each type of helicopter has its own limitations that are based on the aircraft structure, size, and capabilities. Regardless of how much weight one can carry or the engine power that it may have, they are all susceptible to aerodynamic overloading. Unfortunately, if the pilot attempts to push the performance envelope the consequence can be fatal. Aerodynamic forces effect every movement in a helicopter, whether it is increasing the collective or a steep bank angle. Anticipating results from a particular maneuver or adjustment of a flight control is not good piloting technique. Instead pilots need to truly understand the capabilities of the helicopter under any and all circumstances and plan never to exceed the flight envelope for any situation.

Thrust

Thrust, like lift, is generated by the rotation of the main rotor disk. In a helicopter, thrust can be forward, rearward, sideward, or vertical. The resultant lift and thrust determines the direction of movement of the helicopter.

The solidity ratio is the ratio of the total rotor blade area, which is the combined area of all the main rotor blades, to the total rotor disk area. This ratio provides a means to measure the potential for a rotor disk to provide thrust and lift. The mathematical calculations needed to calculate the solidity ratio for each helicopter may not be of importance to most pilots but what should be are the capabilities of the rotor disk to produce and maintain lift. Many helicopter accidents are caused from the rotor disk being overloaded. Simply put, pilots attempt maneuvers that require more lift than the rotor disk can produce or more power than the helicopter's powerplant can provide. Trying to land with a nose high attitude along with any other unfavorable condition (i.e., high gross weight or wind gusts) is most likely to end in disaster.

The tail rotor also produces thrust. The amount of thrust is variable through the use of the antitorque pedals and is used to control the helicopter's yaw.

Drag

The force that resists the movement of a helicopter through the air and is produced when lift is developed is called drag. Drag must be overcome by the engine to turn the rotor. Drag always acts parallel to the relative wind. Total drag is composed of three types of drag: profile, induced, and parasite.

Profile Drag

Profile drag develops from the frictional resistance of the blades passing through the air. It does not change significantly with the airfoil's AOA but increases moderately when airspeed increases. Profile drag is composed of form drag and skin friction. Form drag results from the turbulent wake caused by the separation of airflow from the surface of a structure. The amount of drag is related to both the size and shape of the structure that protrudes into the relative wind. *[Figure 2-9]*

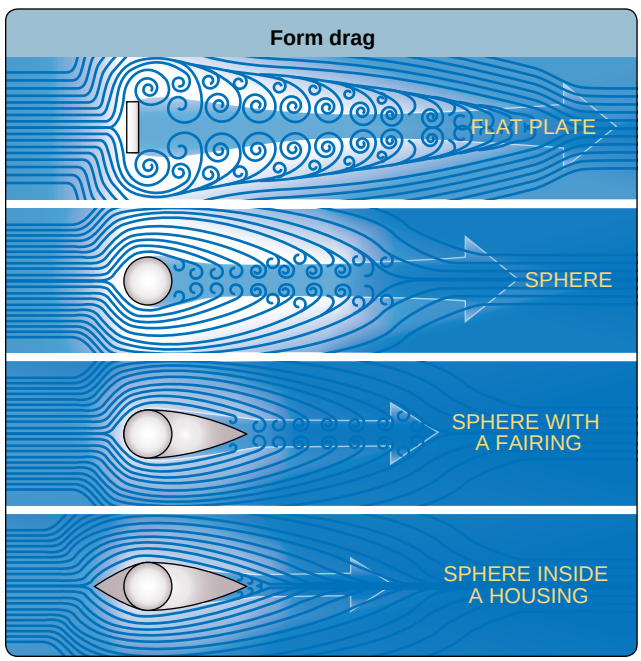


Figure 2-9. *It is easy to visualize the creation of form drag by examining the airflow around a flat plate. Streamlining decreases form drag by reducing the airflow separation.*

Skin friction is caused by surface roughness. Even though the surface appears smooth, it may be quite rough when viewed under a microscope. A thin layer of air clings to the rough surface and creates small eddies that contribute to drag.

Induced Drag

Induced drag is generated by the airflow circulation around the rotor blade as it creates lift. The high-pressure area beneath the blade joins the low-pressure area above the blade at the trailing edge and at the rotor tips. This causes a spiral, or vortex, which trails behind each blade whenever lift is being produced. These vortices deflect the airstream downward in the vicinity of the blade, creating an increase in downwash. Therefore, the blade operates in an average relative wind that is inclined downward and rearward near the blade. Because the lift produced by the blade is perpendicular to the relative wind, the lift is inclined aft by the same amount. The component of lift that is acting in a rearward direction is induced drag. *[Figure 2-10]*

As the air pressure differential increases with an increase in AOA, stronger vortices form, and induced drag increases. Since the blade's AOA is usually lower at higher airspeeds, and higher at low speeds, induced drag decreases as airspeed increases and increases as airspeed decreases. Induced drag is the major cause of drag at lower airspeeds.

Parasite Drag

Parasite drag is present any time the helicopter is moving through the air. This type of drag increases with airspeed. Non-lifting components of the helicopter, such as the cabin, rotor mast, tail, and landing gear, contribute to parasite drag. Any loss of momentum by the airstream, due to such things as openings for engine cooling, creates additional parasite drag. Because of its rapid increase with increasing airspeed, parasite drag is the major cause of drag at higher airspeeds. Parasite drag varies with the square of the velocity; therefore, doubling the airspeed increases the parasite drag four times.

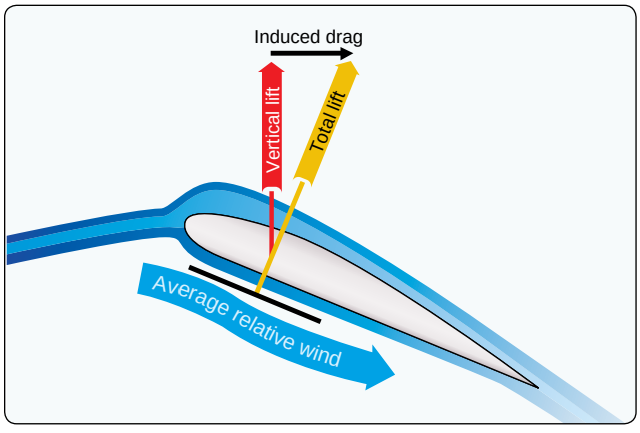


Figure 2-10. *The formation of induced drag is associated with the downward deflection of the airstream near the rotor blade.*

Total Drag

Total drag for a helicopter is the sum of all three drag forces. *[Figure 2-11]* As airspeed increases, parasite drag increases, while induced drag decreases. Profile drag remains relatively constant throughout the speed range with some increase at higher airspeeds. Combining all drag forces results in a total drag curve. The low point on the total drag curve shows the airspeed at which drag is minimized. This is the point where the lift-to-drag ratio is greatest and is referred to as L/D_{MAX}. At this speed, the total lift capacity of the helicopter, when compared to the total drag of the helicopter, is most favorable. This is an important factor in helicopter performance.

Airfoil

Helicopters are able to fly due to aerodynamic forces produced when air passes around the airfoil. An airfoil is any surface producing more lift than drag when passing through the air at a suitable angle. Airfoils are most often associated with production of lift. Airfoils are also used for stability (fin), control (elevator), and thrust or propulsion (propeller or rotor). Certain airfoils, such as rotor blades, combine some of these functions. The main and tail rotor blades of the helicopter are airfoils, and air is forced to pass around the blades by mechanically powered rotation. In some conditions, parts of the fuselage, such as the vertical and horizontal stabilizers, can become airfoils. Airfoils are carefully structured to accommodate a specific set of flight characteristics.

Airfoil Terminology and Definitions

- Blade span—the length of the rotor blade from center of rotation to tip of the blade.

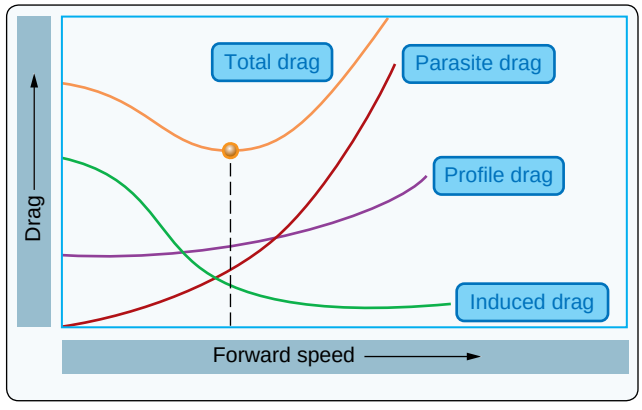


Figure 2-11. *The total drag curve represents the combined forces of parasite, profile, and induced drag and is plotted against airspeed.*

- Chord line—a straight line intersecting leading and trailing edges of the airfoil. *[Figure 2-12]*
- Chord—the length of the chord line from leading edge to trailing edge; it is the characteristic longitudinal dimension of the airfoil section.
- Mean camber line—a line drawn halfway between the upper and lower surfaces of the airfoil. *[Figure 2-12]*

  The chord line connects the ends of the mean camber line. Camber refers to curvature of the airfoil and may be considered as curvature of the mean camber line. The shape of the mean camber is important for determining aerodynamic characteristics of an airfoil section. Maximum camber (displacement of the mean camber line from the chord line) and its location help to define the shape of the mean camber line. The location of maximum camber and its displacement from the chord line are expressed as fractions or percentages of the basic chord length. By varying the point of maximum camber, the manufacturer can tailor an airfoil for a specific purpose. The profile thickness and thickness distribution are important properties of an airfoil section.
- Leading edge—the front edge of an airfoil. *[Figure 2-12]*
- Flightpath velocity—the speed and direction of the airfoil passing through the air. For airfoils on an airplane, the flightpath velocity is equal to true airspeed (TAS). For helicopter rotor blades, flightpath velocity is equal to rotational velocity, plus or minus a component of directional airspeed. The rotational velocity of the rotor blade is lowest closer to the hub and increases outward towards the tip of the blade during rotation.
- Relative wind—defined as the airflow relative to an airfoil and is created by movement of an airfoil through the air. This is rotational relative wind for rotary-wing aircraft and is covered in detail later. As an induced airflow may modify flightpath velocity, relative wind experienced by the airfoil may not be exactly opposite its direction of travel.
- Trailing edge—the rearmost edge of an airfoil.
- Induced flow—the downward flow of air through the rotor disk.
- Resultant relative wind—relative wind modified by induced flow.
- AOA—the angle measured between the resultant relative wind and chord line.
- Angle of incidence (AOI)—the angle between the chord line of a blade and rotor hub. It is usually referred to as blade pitch angle. For fixed airfoils, such as vertical fins or elevators, angle of incidence is the angle between the chord line of the airfoil and a selected reference plane of the helicopter.
- Center of pressure—the point along the chord line of an airfoil through which all aerodynamic forces are considered to act. Since pressures vary on the surface of an airfoil, an average location of pressure variation is needed. As the AOA changes, these pressures change, and the center of pressure moves along the chord line.

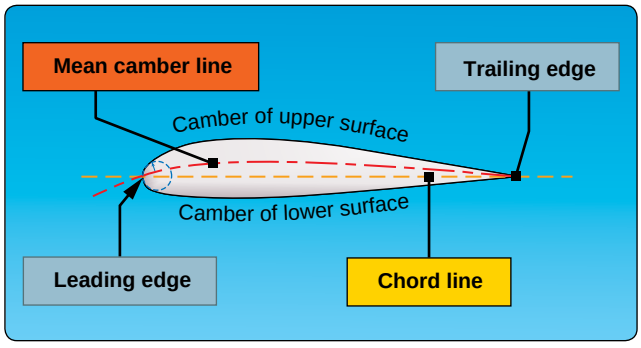


Figure 2-12. *Aerodynamic terms of an airfoil.*

Airfoil Types

Symmetrical Airfoil

The symmetrical airfoil is distinguished by having identical upper and lower surfaces. *[Figure 2-13]* The mean camber line and chord line are the same on a symmetrical airfoil, and it produces no lift at zero AOA. Most light helicopters incorporate symmetrical airfoils in the main rotor blades.

Nonsymmetrical Airfoil (Cambered)

The nonsymmetrical airfoil has different upper and lower surfaces, with a greater curvature of the airfoil above the chord line than below. *[Figure 2-13]* The mean camber line and chord line are different. The nonsymmetrical airfoil design can produce useful lift at zero AOA. A nonsymmetrical design

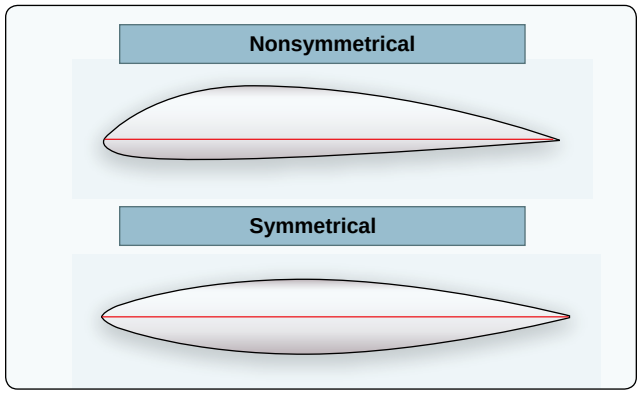


Figure 2-13. *The upper and lower curvatures are the same on a symmetrical airfoil and vary on a nonsymmetrical airfoil.*

has advantages and disadvantages. The advantages are more lift production at a given AOA than a symmetrical design, an improved lift-to-drag ratio, and better stall characteristics. The disadvantages are center of pressure travel of up to 20 percent of the chord line (creating undesirable torque on the airfoil structure) and greater production costs.

Blade Twist

Because of lift differential due to differing rotational relative wind values along the blade, the blade should be designed with a twist to alleviate internal blade stress and distribute the lifting force more evenly along the blade. Blade twist provides higher pitch angles at the root where velocity is low and lower pitch angles nearer the tip where velocity is higher. This increases the induced air velocity and blade loading near the inboard section of the blade. *[Figure 2-14]*

Rotor Blade and Hub Definitions

- Hub—on the mast, the attaching point for the root of the blade, and the axis about which the blades rotate. *[See Figure 1-7]*
- Tip—the farthest outboard section of the rotor blade
- Root—the inner end of the blade and is the point that attaches to the hub
- Twist—the change in blade incidence from the root to the outer blade

The angular position of the main rotor blades (as viewed from above, as they rotate about the vertical axis of the mast) is measured from the helicopter's longitudinal axis, and usually from its nose. The radial position of a segment of the blade is the distance from the hub as a fraction of the total distance.

Airflow and Reactions in the Rotor Disk

Relative Wind

Knowledge of relative wind is essential for an understanding of aerodynamics and its practical flight application for the pilot. Relative wind is airflow relative to an airfoil. Movement of an airfoil through the air creates relative wind. Relative wind moves in a direction parallel to but opposite of the movement of the airfoil. *[Figure 2-15]*

There are two parts to wind passing a rotor blade:

- Horizontal part—caused by the blades turning plus movement of the helicopter through the air *[Figure 2-16]*
- Vertical part—caused by the air being forced down through the rotor blades plus any movement of the air relative to the blades caused by the helicopter climbing or descending *[Figures 2-17* and *2-18]*

Rotational Relative Wind (Tip-Path Plane)

The rotation of rotor blades as they turn about the mast produces rotational relative wind (tip-path plane). The term rotational refers to the method of producing relative wind. Rotational relative wind flows opposite the physical flightpath of the airfoil, striking the blade at 90° to the leading edge and parallel to the plane of rotation; and it is constantly changing in direction during rotation. Rotational relative wind velocity is highest at blade tips, decreasing uniformly to zero at the axis of rotation (center of the mast). *[Figure 2-19]*

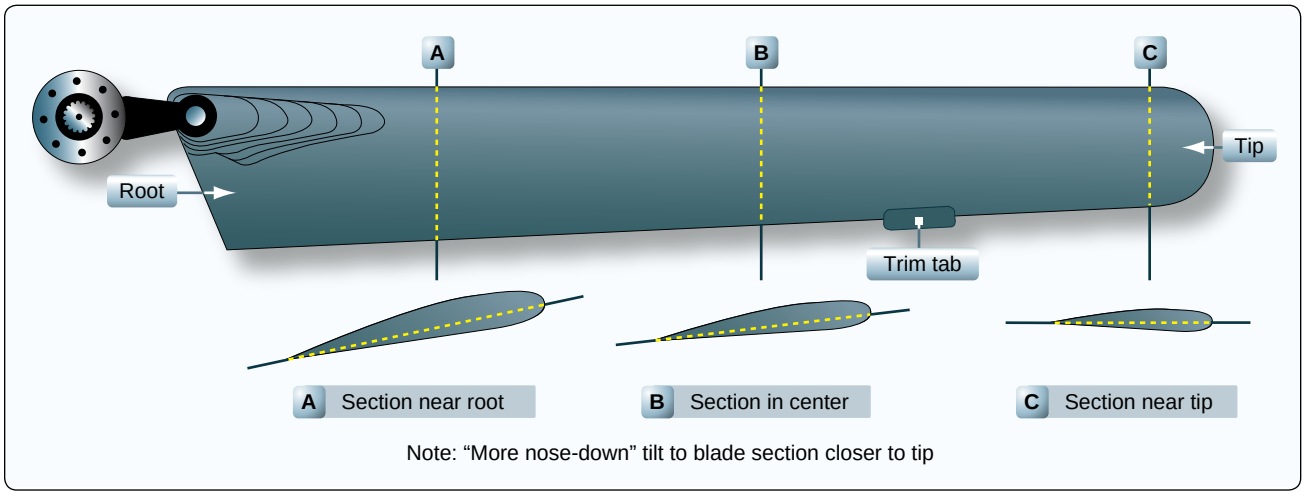


Figure 2-14. *Blade twist.*

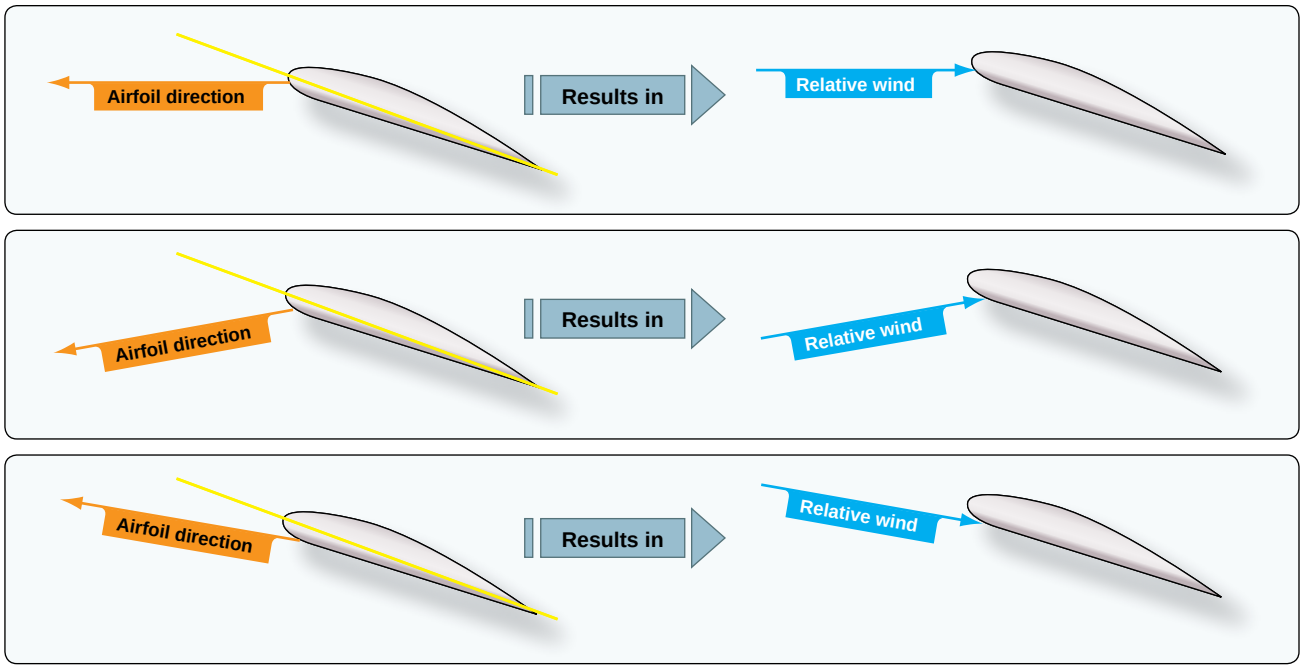


Figure 2-15. *Relative wind.*

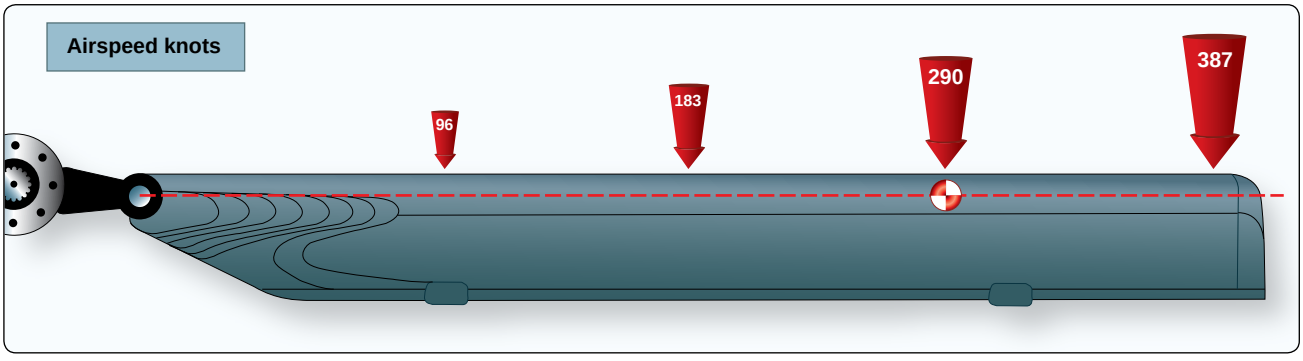


Figure 2-16. *Horizontal component of relative wind.*

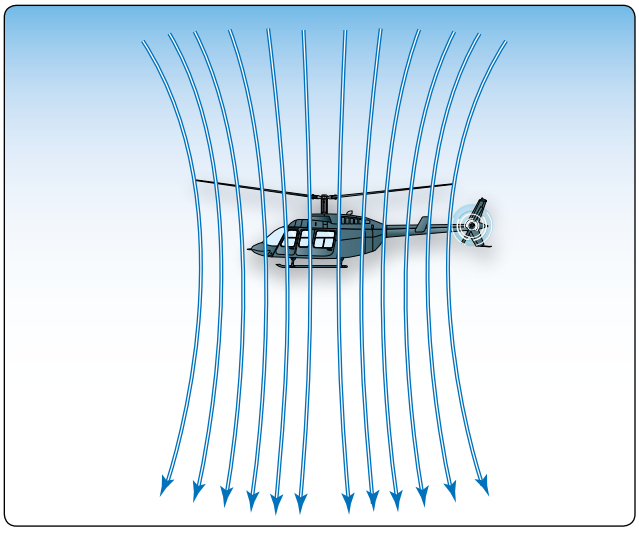


Figure 2-17. *Induced flow.*

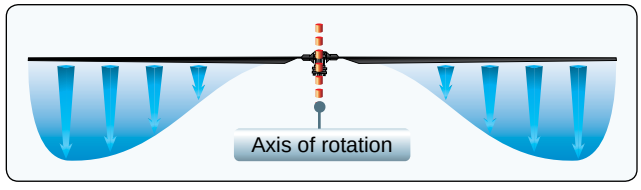


Figure 2-18. *Normal induced flow velocities along the blade span during hovering flight. Downward velocity is highest at the blade tip where blade speed is highest. As blade speed decreases nearer the center of the disk, downward velocity is less.*

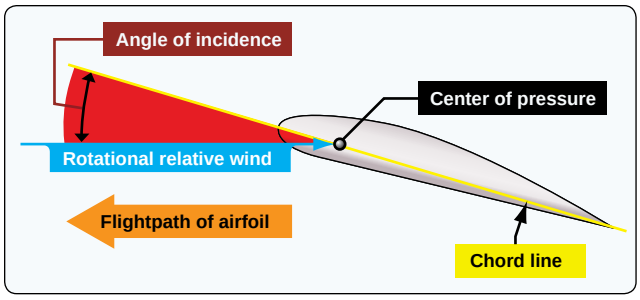


Figure 2-19. *Rotational relative wind.*

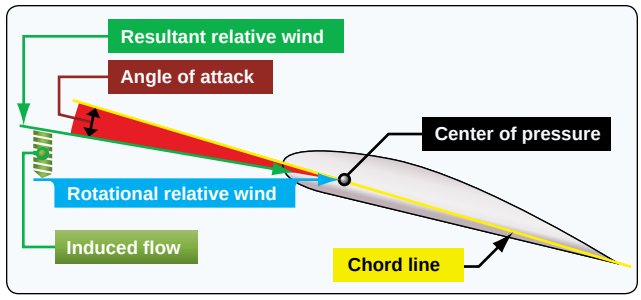


Figure 2-20. *Resultant relative wind.*

Resultant Relative Wind

The resultant relative wind at a hover is rotational relative wind modified by induced flow. This is inclined downward at some angle and opposite the effective flightpath of the airfoil, rather than the physical flightpath (rotational relative wind). The resultant relative wind also serves as the reference plane for development of lift, drag, and total aerodynamic force (TAF) vectors on the airfoil. *[Figure 2-20]* When the helicopter has horizontal motion, airspeed further modifies the resultant relative wind. The airspeed component of relative wind results from the helicopter moving through the air. This airspeed component is added to, or subtracted from, the rotational relative wind depending on whether the blade is advancing or retreating in relation to helicopter movement. Introduction of airspeed relative wind also modifies induced flow. Generally, the downward velocity of induced flow is reduced. The pattern of air circulation through the disk changes when the aircraft has horizontal motion. As the helicopter gains airspeed, the addition of forward velocity results in decreased induced flow velocity. This change results in an improved efficiency (additional lift) being produced from a given blade pitch setting.

Induced Flow (Downwash)

At flat pitch, air leaves the trailing edge of the rotor blade in the same direction it moved across the leading edge; no lift or induced flow is being produced. As blade pitch angle is increased, the rotor disk induces a downward flow of air through the rotor blades creating a downward component of air that is added to the rotational relative wind. Because the blades are moving horizontally, some of the air is displaced downward. The blades travel along the same path and pass a given point in rapid succession. Rotor blade action changes the still air to a column of descending air. Therefore, each blade has a decreased AOA due to the downwash. This downward flow of air is called induced flow (downwash). It is most pronounced at a hover under no-wind conditions. *[Figure 2-21]*

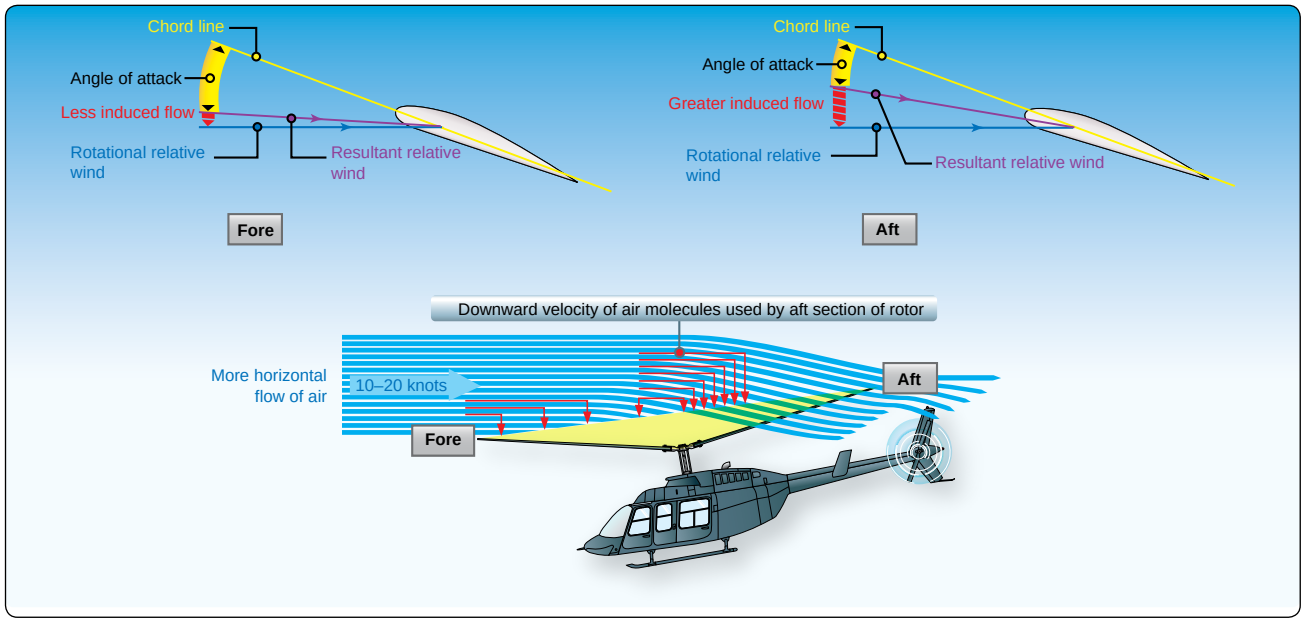


Figure 2-21. *A helicopter in forward flight, or hovering with a headwind or crosswind, has more molecules of air entering the aft portion of the rotor disk. Therefore, at the rear of the rotor disk, the angle of attack is less and the induced flow is greater.*

In Ground Effect (IGE)

Ground effect is the increased efficiency of the rotor disk caused by interference of the airflow when near the ground. The air pressure or density is increased, which acts to decrease the downward velocity of air. Ground effect permits relative wind to be more horizontal, lift vector to be more vertical, and induced drag to be reduced. These conditions allow the rotor disk to be more efficient. Maximum ground effect is achieved when hovering over smooth hard surfaces. When hovering over surfaces as tall grass, trees, bushes, rough terrain, and water, maximum ground effect is reduced. Rotor efficiency is increased by ground effect to a height of about one rotor diameter (measured from the ground to the rotor disk) for most helicopters. Since the induced flow velocities are decreased, the AOA is increased, which requires a reduced blade pitch angle and a reduction in induced drag. This reduces the power required to hover IGE. *[Figure 2-22]*

Out of Ground Effect (OGE)

The benefit of placing the helicopter near the ground is lost above IGE altitude. Above this altitude, the power required to hover remains nearly constant, given similar conditions (such as wind). Induced flow velocity is increased, resulting in a decrease in AOA and a decrease in lift. Under the correct circumstances, this downward flow can become so localized that the helicopter and locally disturbed air will sink at alarming rates. This effect is called vortex ring state (formerly referenced as settling-with-power) and is discussed at length in Chapter 11, Helicopter Emergencies and Hazards. A higher blade pitch angle is required to maintain the same AOA as in IGE hover. The increased pitch angle also creates more drag. This increased pitch angle and drag requires more power to hover OGE than IGE. *[Figure 2-23]*

Rotor Blade Angles

There are two angles that enable a rotor disk to produce the lift required for a helicopter to fly: angle of incidence and angle of attack.

Angle of Incidence

Angle of incidence is the angle between the chord line of a main or tail rotor blade and its rotor disk. It is a mechanical angle rather than an aerodynamic angle and is sometimes referred to as blade pitch angle. *[Figure 2-24]* In the absence of induced flow, AOA and angle of incidence are the same. Whenever induced flow, up flow (inflow), or airspeed modifies the relative wind, the AOA is different from the angle of incidence. Collective input and cyclic feathering (see page 2-12) change the angle of incidence. A change in the angle of incidence changes the AOA, which changes the coefficient of lift, thereby changing the lift produced by the airfoil.

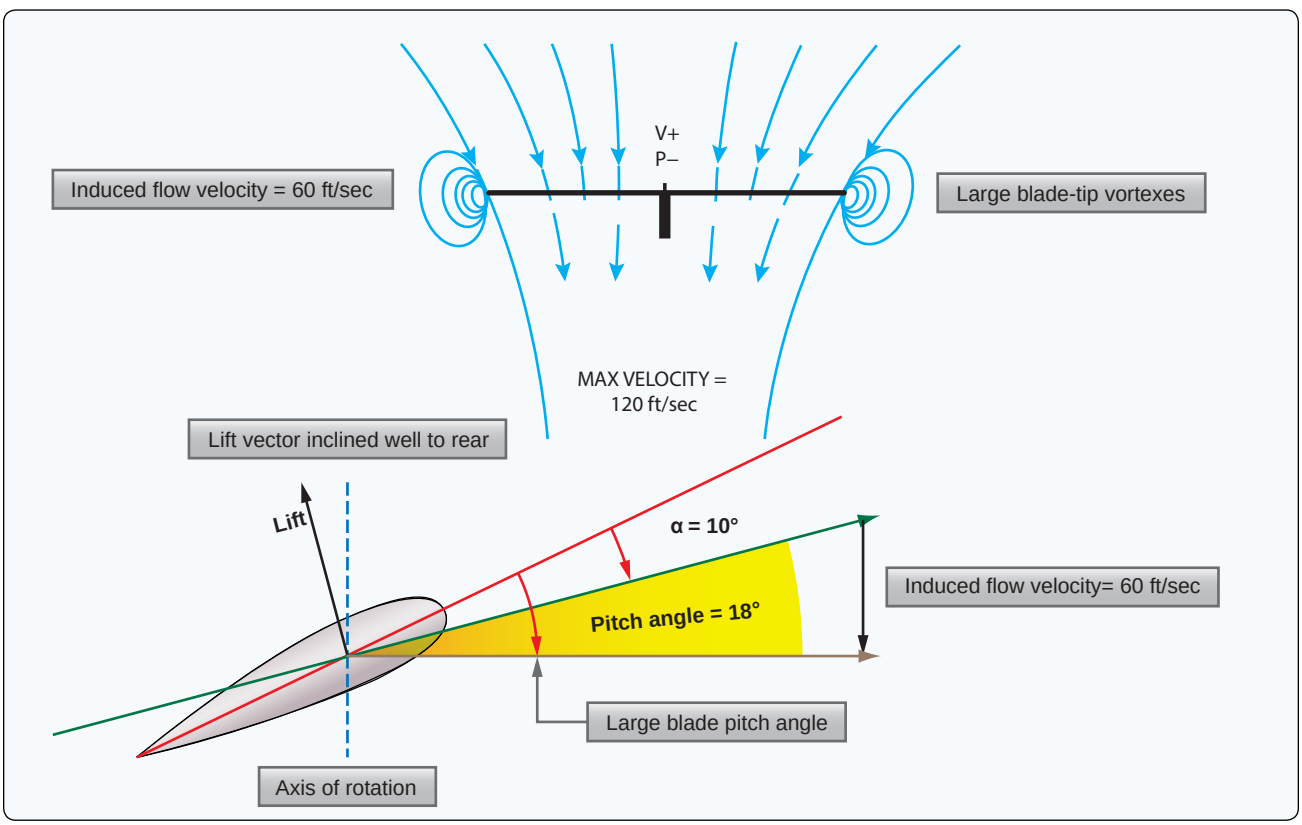


Figure 2-22. *In ground effect (IGE).*

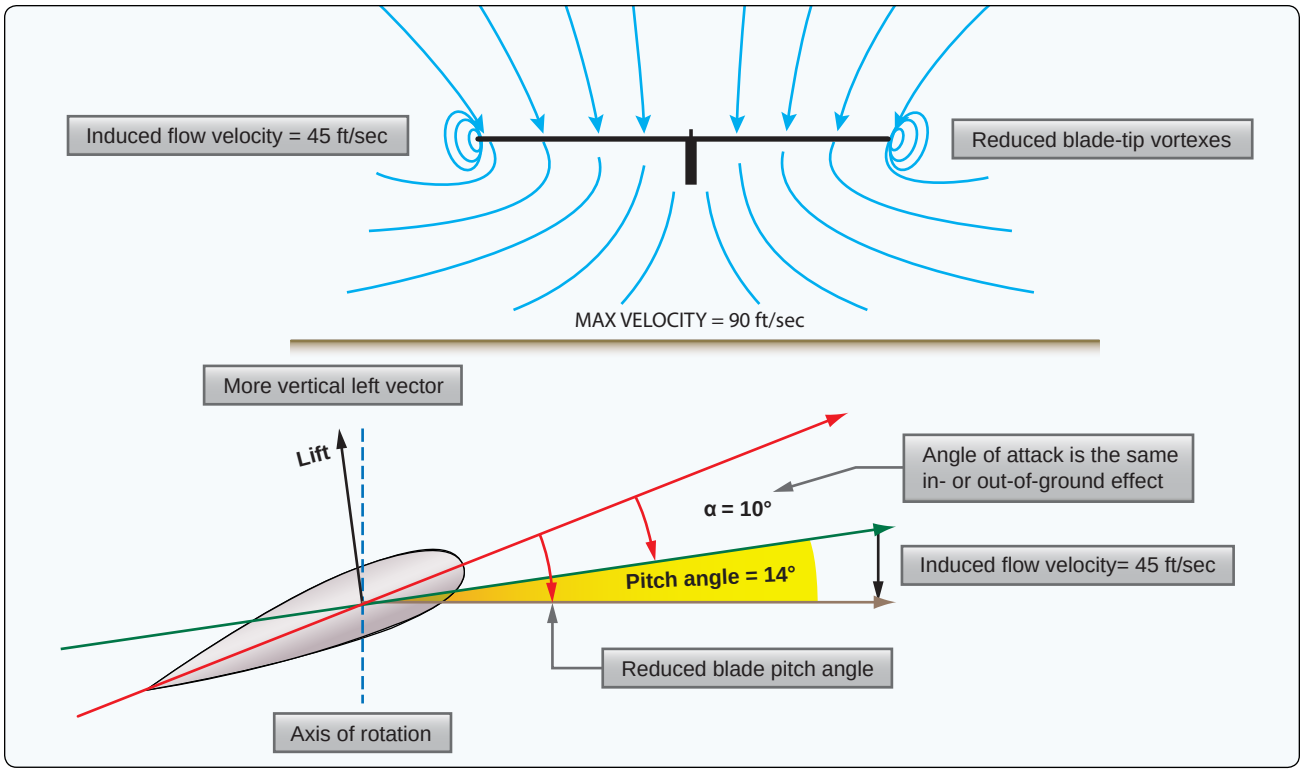


Figure 2-23. *Out of ground effect (OGE).*

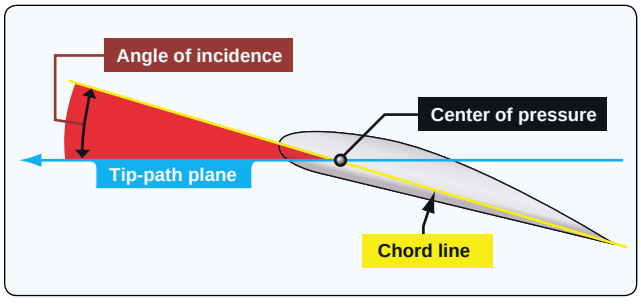


Figure 2-24. *Angle of incidence.*

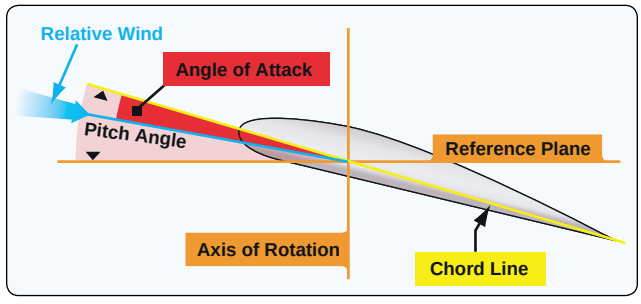


Figure 2-25. *The AOA is the angle between the airfoil chord line and resultant relative wind.*

Angle of Attack

AOA is the angle between the airfoil chord line and resultant relative wind. *[Figure 2-25]* It is an aerodynamic angle and not easy to measure. It can change with no change in the blade pitch angle (angle of incidence, discussed earlier).

When the AOA is increased, air flowing over the airfoil is diverted over a greater distance, resulting in an increase of air velocity and more lift. As the AOA is increased further, it becomes more difficult for air to flow smoothly across the top of the airfoil. At this point, the airflow begins to separate from the airfoil and enters a burbling or turbulent pattern. The turbulence results in a large increase in drag and loss of lift in the area where it is taking place. Increasing the AOA increases lift until the critical angle of attack is reached. Any increase in the AOA beyond this point produces a stall and a rapid decrease in lift (refer to the Low Rotor RPM and Rotor Stall section of Chapter 11, Helicopter Emergencies and Hazards).

Several factors may change the rotor blade AOA. The pilot has little direct control over AOA except indirectly through the flight control input. Collective and cyclic feathering help to make these changes. Feathering is the rotation of the blade about its longitudinal axis by collective/cyclic inputs causing changes in blade pitch angle. Collective feathering changes angle of incidence equally and in the same direction on all rotor blades simultaneously. This action changes AOA, which changes coefficient of lift (CL), and affects overall lift of the rotor disk.

Cyclic feathering changes the blade's AOA differentially around the rotor disk and creates a differential lift. Aviators use cyclic feathering to control attitude of the rotor disk. It is the means to control rearward tilt of the rotor (blowback) caused by flapping action and (along with blade flapping) counteract dissymmetry of lift (discussed in chapter 3). Cyclic feathering causes attitude of the rotor disk to change but does not change the amount of net lift the rotor disk is producing.

Most of the changes in AOA come from change in airspeed and rate of climb or descent; others such as flapping occur automatically due to the rotor system design. Flapping is the up and down movement of rotor blades about a hinge on a fully articulated rotor system. A semi-rigid system does not have a hinge but flap as a unit. A rigid rotor system has no vertical or horizontal hinges, so the blades cannot flap or drag, but they can flex. By flexing, the blades themselves compensate for the forces which previously required rugged hinges. It occurs in response to changes in lift due to changing velocity or cyclic feathering. No flapping occurs when the tip-path plane is perpendicular to the mast. The flapping action alone, or along with cyclic feathering, controls dissymmetry of lift. Flapping is the primary means of compensating for dissymmetry of lift.

Pilots adjust AOA through normal control manipulation of the pitch angle of the blades. If the pitch angle is increased, the AOA increases; if the pitch angle is reduced, the AOA is reduced.

Powered Flight

In powered flight (hovering, vertical, forward, sideward, or rearward), the total lift and thrust forces of a rotor are perpendicular to the rotor disk.

Hovering Flight

Hovering is the most challenging part of flying a helicopter. This is because a helicopter generates its own gusty air while in a hover, which acts against the fuselage and flight control surfaces. The end result is constant control inputs and corrections by the pilot to keep the helicopter where it is required to be. Despite the complexity of the task, the control inputs in a hover are simple. The cyclic is used to eliminate drift in the horizontal plane, controlling forward, backward, right and left movement or travel. The throttle, if not governor controlled, is used to control revolutions per minute (rpm). The collective is used to maintain altitude. The pedals are used to control nose direction or heading. It is the interaction of these controls that makes hovering difficult, since an adjustment in any one control requires an adjustment of the other two, creating a cycle of constant correction. During hovering flight, a helicopter maintains a constant position over a selected point, usually a few feet above the ground. The ability of the helicopter to hover comes from the both the lift component, which is the force developed by the main rotor(s) to overcome gravity and aircraft weight, and the thrust component, which acts horizontally to accelerate or decelerate the helicopter in the desired direction. Pilots direct the thrust of the rotor disk by using the cyclic to rotate the rotor disk plane relative to the horizon. They do this in order to induce travel or compensate for the wind and hold a position. At a hover in a no-wind condition, all opposing forces (lift, thrust, drag, and weight) are in balance; they are equal and opposite. Therefore, lift and weight are equal, resulting in the helicopter remaining at a stationary hover. *[Figure 2-26]*

While hovering, the amount of main rotor thrust can be adjusted to maintain the desired hovering height. This is done by changing the angle of incidence (by moving the collective) of the rotor blades, and hence their AOA. Changing the AOA changes the drag on the rotor blades, and the power delivered by the engine must change as well to keep the rotor speed constant.

The weight that must be supported is the total weight of the helicopter and its occupants. If the amount of lift is greater than the actual weight, the helicopter accelerates upwards until the lift force equals the weight of the helicopter; if lift is less than weight, the helicopter accelerates downward.

The drag of a hovering helicopter is mainly induced drag incurred while the blades are producing lift. There is, however, some profile drag on the blades as they rotate through the air and a small amount of parasite drag from the non-lift-producing surfaces of the helicopter, such as the rotor hub, cowlings, and

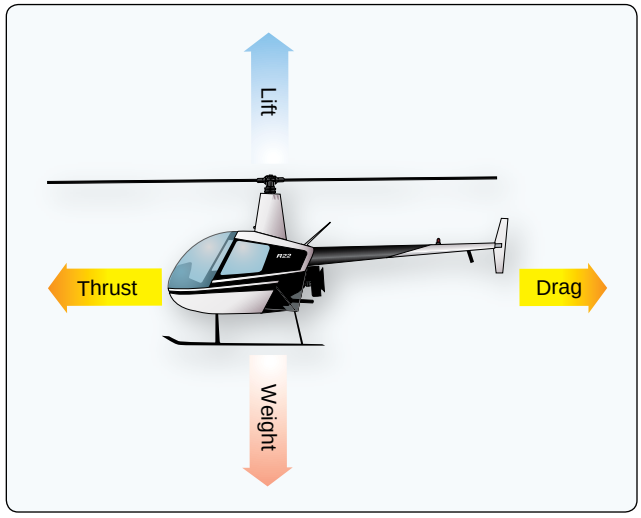


Figure 2-26. *To maintain a hover at a constant altitude, the lift must equal the weight of the helicopter. Thrust must equal any wind and tail rotor thrust to maintain position. The power must be sufficient to turn the rotors and overcome the various drags and frictions involved.*

landing gear. Throughout the rest of this discussion, the term "drag" includes induced, profile and parasite drag.

An important consequence of producing thrust is torque. As discussed earlier, Newton's Third Law states: for every action there is an equal and opposite reaction. Therefore, as the engine turns the main rotor disk in a counterclockwise direction, the helicopter fuselage wants to turn clockwise. The amount of torque is directly related to the amount of engine power being used to turn the main rotor disk. As power changes, torque changes.

To counteract this torque-induced turning tendency, an antitorque rotor or tail rotor is incorporated into most helicopter designs. A pilot can vary the amount of thrust produced by the tail rotor in relation to the amount of torque produced by the engine. As the engine supplies more power to the main rotor, the tail rotor must produce more thrust to overcome the increased torque effect. This control change is accomplished through the use of antitorque pedals (See page 3-4).

Translating Tendency (Drift)

During hovering flight, a single main rotor helicopter tends to move in the direction of tail rotor thrust. This lateral (or sideward) movement is called translating tendency. *[Figure 2-27]*

To counteract this tendency, one or more of the following features may be used. All examples are for a counterclockwise rotating main rotor disk.

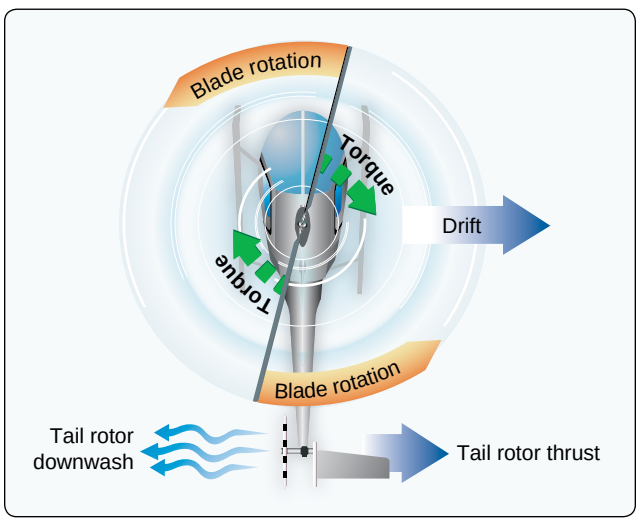


Figure 2-27. *A tail rotor is designed to produce thrust in a direction opposite torque. The thrust produced by the tail rotor is sufficient to move the helicopter laterally.*

- The main transmission is mounted at a slight angle to the left (when viewed from behind) so that the rotor mast has a built-in tilt to oppose the tail rotor thrust.
- Flight controls can be rigged so that the rotor disk is tilted to the left slightly when the cyclic is centered. Whichever method is used, the tip-path plane is tilted slightly to the left in the hover.
- The transmission is mounted so the rotor shaft is vertical with respect to the fuselage, the helicopter "hangs" left skid low in the hover. (The opposite is true for rotor disks turning clockwise when viewed from above.)
- The helicopter fuselage will also be tilted when the tail rotor is below the main rotor disk and supplying antitorque thrust. The fuselage tilt is caused by the imperfect balance of the tail rotor thrust against the main rotor torque in the same plane. The helicopter tilts due to two separate forces, the main rotor disk tilt to neutralize the translating tendency and the lower tail rotor thrust below the plane of the torque action.
- In forward flight, the tail rotor continues to push to the right, and the helicopter makes a small angle with the wind when the rotors are level and the slip ball is in the middle (See page 12-2). This is called inherent sideslip. For some larger helicopters, the vertical fin or stabilizer is often designed with the tail rotor mounted on them to correct this side slip and to eliminate some of the tilting at a hover. (By mounting the tail rotor on top of the vertical fin or pylon, the antitorque is more in line with or closer to the horizontal plane of torque, resulting in less airframe (or body) lean from the tail rotor.) Also, having the tail rotor higher off the ground reduces the risk of objects coming in contact with the blades, but at the cost of increased weight and complexity.

Pendular Action

Since the fuselage of the helicopter, with a single main rotor, is suspended from a single point and has considerable mass, it is free to oscillate either longitudinally or laterally in the same way as a pendulum. This pendular action can be exaggerated by overcontrolling; therefore, control movements should be smooth and not exaggerated. *[Figure 2-28]*

The horizontal stabilizer helps to level the helicopter in forward flight. However, in rearward flight, the horizontal stabilizer can press the tail downward, resulting in a tail strike if the helicopter is moved rearward into the wind. Normally, with the helicopter mostly into the wind, the horizontal stabilizer experiences less headwind component as the helicopter begins rearward travel (downwind). When

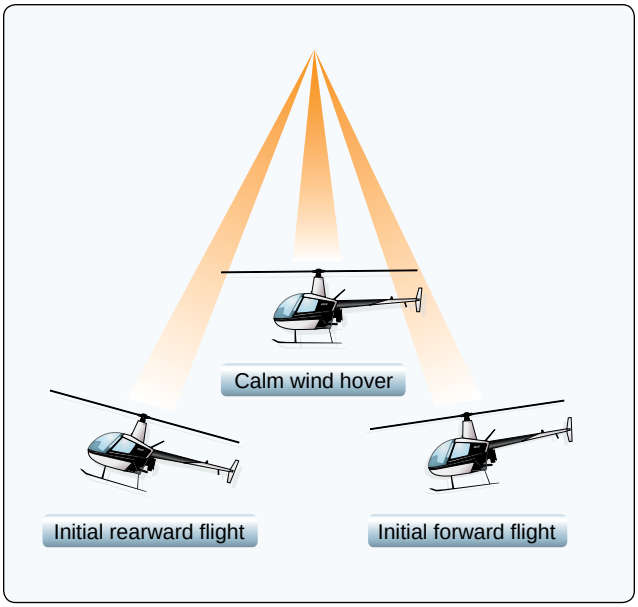


Figure 2-28. *Because the helicopter's body has mass and is suspended from a single point (the rotor mast head), it tends to act much like a pendulum.*

rearward flight groundspeed equals the windspeed, then the helicopter is merely hovering in a no-wind condition. However, rearward hovering into the wind requires considerable care and caution to prevent tail strikes.

It is important to note that there is a difference in the amount of pendular action between a semirigid system and a fully articulated system. Because of the hard connection (offset) of the latter, the centrifugal force pulling out on the blades is transferred to the fuselage, and the fuselage tends to follow the rotor attitude. The semirigid system is a true pendulum, with thrust required to create a moment around the fuselage CG to allow for control of the fuselage. This comes into play later when mast bumping is discussed.

Coning

In order for a helicopter to generate lift, the rotor blades must be turning. Rotor disk rotation drives the blades into the air, creating a relative wind component without having to move the airframe through the air as with an airplane or glider. Depending on the motion of the blades and helicopter airframe, many factors cause the relative wind direction to vary. The rotation of the rotor disk creates centrifugal force (inertia), which tends to pull the blades straight outward from the main rotor hub: the faster the rotation, the greater the centrifugal force, the slower the rotation, the smaller the centrifugal force. This force gives the rotor blades their rigidity and, in turn, the strength to support the weight of the helicopter. The maximum centrifugal force generated is determined by the maximum operating rotor revolutions per minute (rpm).

As lift on the blades is increased (in a takeoff, for example), two major forces are acting at the same time—centrifugal force acting outward, and lift acting upward. The result of these two forces is that the blades assume a conical path instead of remaining in the plane perpendicular to the mast. This can be seen in any helicopter when it takes off; the rotor disk changes from flat to a slight cone shape. *[Figure 2-29]*

If the rotor rpm is allowed to go too low (below the minimum power-on rotor rpm, for example), the centrifugal force becomes smaller and the coning angle becomes much larger. In other words, should the rpm decrease too much, at some point the rotor blades fold up with no chance of recovery.

Coriolis Effect (Law of Conservation of Angular Momentum)

The Coriolis Effect is also referred to as the law of conservation of angular momentum. It states that the value of angular momentum of a rotating body does not change unless an external force is applied. In other words, a rotating body continues to rotate with the same rotational velocity until some external force is applied to change the speed of rotation. Angular momentum is the moment of inertia (mass times distance from the center of rotation squared) multiplied by the speed of rotation.

Changes in angular velocity, known as angular acceleration and deceleration, take place as the mass of a rotating body is moved closer to or farther away from the axis of rotation. The speed of the rotating mass varies proportionately with the square of the radius.

An excellent example of this principle in action is a figure skater performing a spin on ice skates. The skater begins rotation on one foot, with the other leg and both arms extended. The rotation of the skater's body is relatively slow. When a skater draws both arms and one leg inward, the moment of inertia (mass times radius squared) becomes

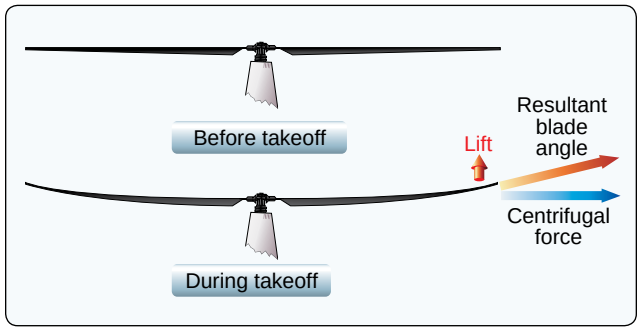


Figure 2-29. *During takeoff, the combination of centrifugal force and lift cause the rotor disk to cone upward.*

much smaller and the body is rotating almost faster than the eye can follow. Because the angular momentum must, by law of nature, remain the same (no external force applied), the angular velocity must increase.

The rotor blade rotating about the rotor hub possesses angular momentum. As the rotor begins to cone due to G-loading maneuvers, the diameter of the rotor disk shrinks. Due to conservation of angular momentum, the blades increase speed even though the blade tips have a shorter distance to travel due to reduced disk diameter. The action results in an increase in rotor rpm which causes a slight increase in lift. Most pilots arrest this increase of rpm with an increase in collective pitch. This increase in blade rpm lift is somewhat negated by the slightly smaller disk area as the blades cone upward.

Gyroscopic Precession

The spinning main rotor of a helicopter acts like a gyroscope. As such, it has the properties of gyroscopic action, one of which is precession. Gyroscopic precession is the resultant action or deflection of a spinning object when a force is applied to this object. This action occurs approximately 90° in the direction of rotation from the point where the force is applied (or 90° later in the rotation cycle). *[Figure 2-30]*

Examine a two-bladed rotor disk to see how gyroscopic precession affects the movement of the tip-path plane. Moving the cyclic pitch control increases the angle of incidence of one rotor blade with the result of a greater lifting force being applied at that point in the plane of rotation. This same control movement simultaneously decreases the angle of incidence of the other blade the same amount, thus decreasing the lifting force applied at that point in the plane of rotation. The blade with the increased angle of incidence tends to flap up; the blade with the decreased angle of incidence tends to flap down. Because the rotor disk acts like a gyro, the blades reach maximum deflection at a point approximately 90° later in the plane of rotation. *Figure 2-31* illustrates the result of a forward cyclic input. The retreating blade angle of incidence is increased, and the advancing blade angle of incidence is decreased resulting in a tipping forward of the tip-path plane, since maximum deflection takes place 90° later when the blades are at the rear and front, respectively. In a rotor disk using three or more blades, the movement of the cyclic pitch control changes the angle of incidence of each blade an appropriate amount so that the end result is the same.

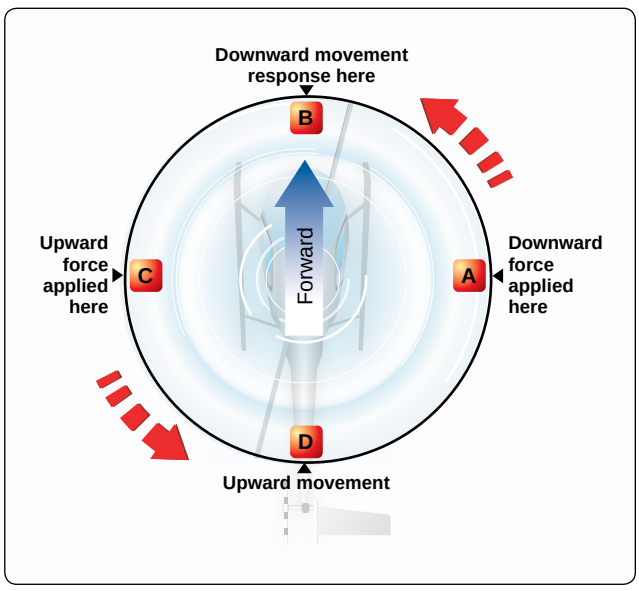


Figure 2-30. *Gyroscopic precession.*

Vertical Flight

Hovering is actually an element of vertical flight. Increasing the angle of incidence of the rotor blades (pitch) while keeping their rotation speed constant generates additional lift and the helicopter ascends. Decreasing the pitch causes the helicopter to descend. In a no-wind condition in which lift and thrust are less than weight and drag, the helicopter descends vertically. If lift and thrust are greater than weight and drag, the helicopter ascends vertically. *[Figure 2-32]*

Forward Flight

In steady forward flight, with no change in airspeed or vertical speed, the four forces of lift, thrust, drag, and weight must be in balance. Once the tip-path plane is tilted forward, the total lift-thrust force is also tilted forward. This resultant lift-thrust force can be resolved into two components—lift acting vertically upward and thrust acting horizontally in the direction of flight. In addition to lift and thrust, there is weight (the downward acting force) and drag (the force opposing the motion of an airfoil through the air). *[Figure 2-33]*

In straight-and-level, unaccelerated forward flight (straight-and-level flight is flight with a constant heading and at a constant altitude), lift equals weight and thrust equals drag. If lift exceeds weight, the helicopter accelerates vertically until the forces are in balance; if thrust is less than drag, the helicopter slows down until the forces are in balance. As a helicopter initiates a move forward, it begins to lose altitude because lift is lost as thrust is diverted forward. However, as the helicopter begins to accelerate from a hover, the rotor disk becomes more efficient due to translational lift (see translational lift on page 2-19). The result is excess power over that which is required to hover. Continued acceleration causes an even larger increase in airflow through the rotor disk (up to a maximum determined by drag and the engine's limit of power), and more efficient flight. In order to maintain unaccelerated flight, the pilot must understand that with

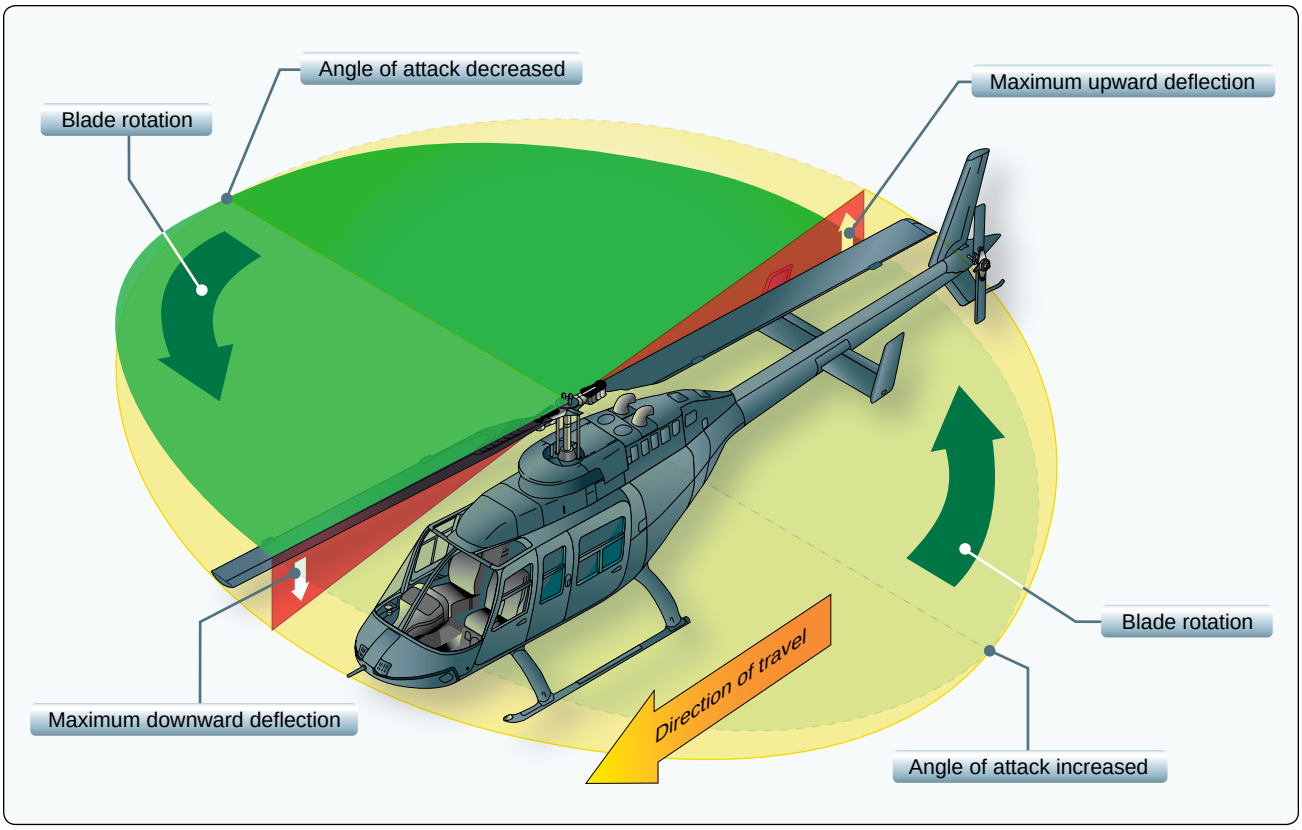


Figure 2-31. *As each blade passes the 90° position on the left in a counterclockwise main rotor blade rotation, the maximum increase in angle of incidence occurs. As each blade passes the 90° position to the right, the maximum decrease in angle of incidence occurs. Maximum deflection takes place 90° later—maximum upward deflection at the rear and maximum downward deflection at the front—and the tip-path plane tips forward.*

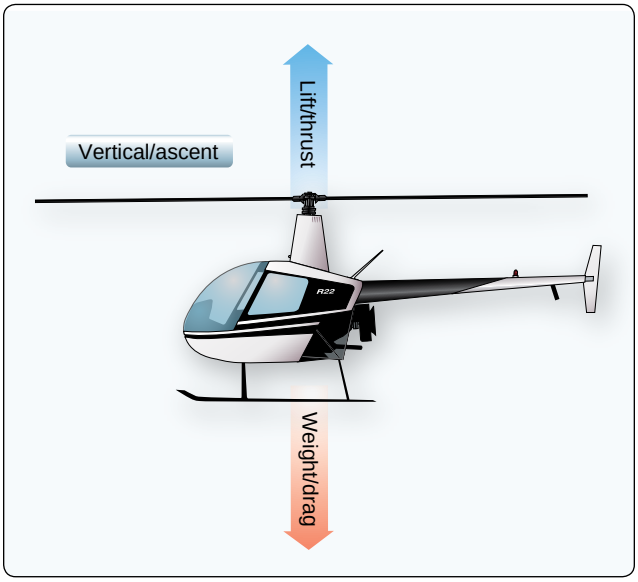


Figure 2-32. *Balanced forces: hovering in a no-wind condition.*

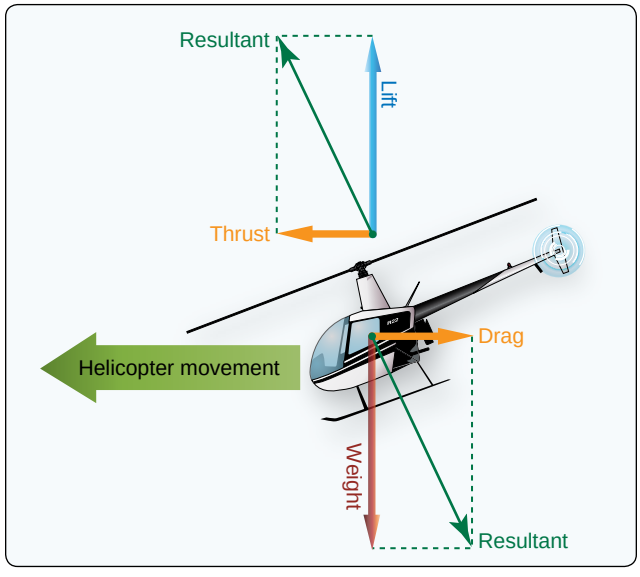


Figure 2-33. *To transition to forward flight, more lift and thrust must be generated to overcome the forces of weight and drag.*

any changes in power or in cyclic movement, the helicopter begins either to climb or to descend. Once straight-and-level flight is obtained, the pilot should make note of the power (torque setting) required and not make major adjustments to the flight controls. *[Figure 2-34]*

Airflow in Forward Flight

Airflow across the rotor disk in forward flight varies from airflow at a hover. In forward flight, air flows opposite the aircraft's flightpath. The velocity of this air flow equals the helicopter's forward speed. Because the rotor blades turn in a circular pattern, the velocity of airflow across a blade depends on the position of the blade in the plane of rotation at a given instant, its rotational velocity, and airspeed of the helicopter. Therefore, the airflow meeting each blade varies continuously as the blade rotates. The highest velocity of airflow occurs over the right side (3 o'clock position) of the helicopter (advancing blade in a rotor disk that turns counterclockwise) and decreases to rotational velocity over the nose. It continues to decrease until the lowest velocity of airflow occurs over the left side (9 o'clock position) of the helicopter (retreating blade). As the blade continues to rotate, velocity of the airflow then increases to rotational velocity over the tail. It continues to increase until the blade is back at the 3 o'clock position.

The advancing blade in *Figure 2-35,* position A, moves in the same direction as the helicopter. The velocity of the air meeting this blade equals rotational velocity of the blade plus wind velocity resulting from forward airspeed. The retreating blade (position C) moves in a flow of air moving in the opposite direction of the helicopter. The velocity of airflow meeting this blade equals rotational velocity of the blade minus wind velocity resulting from forward airspeed. The blades (positions B and D) over the nose and tail move essentially at right angles to the airflow created by forward airspeed; the velocity of airflow meeting these blades equals the rotational velocity. This results in a change to velocity of airflow all across the rotor disk and a change to the lift pattern of the rotor disk.

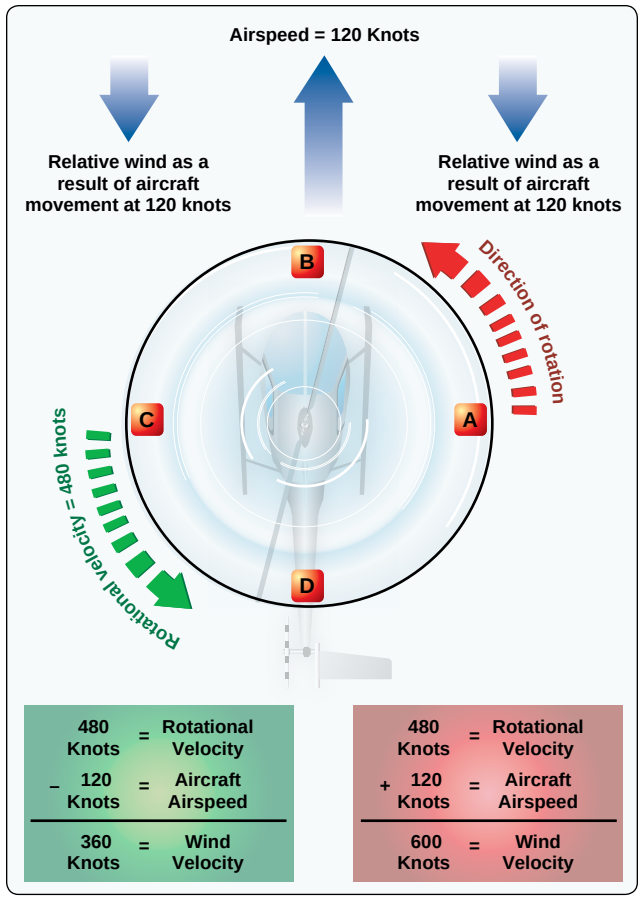


Figure 2-35. *Airflow in forward flight.*

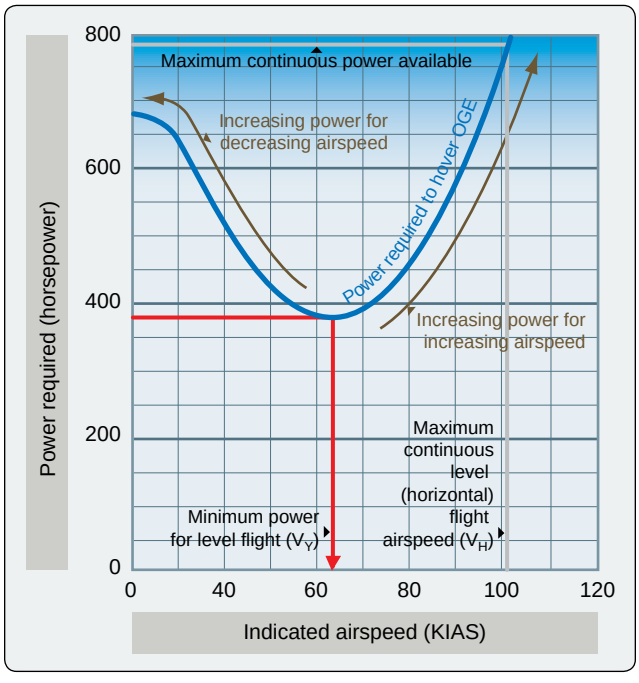


Figure 2-34. *Power versus airspeed chart.*

Advancing Blade

As the relative wind speed of the advancing blade increases, the blade gains lift and begins to flap up. It reaches its maximum upflap velocity at the 3 o'clock position, where the wind velocity is the greatest. This upflap creates a downward flow of air and has the same effect as increasing the induced flow velocity by imposing a downward vertical velocity vector to the relative wind which decreases the AOA.

Retreating Blade

As relative wind speed of the retreating blade decreases, the blade loses lift and begins to flap down. It reaches its maximum downflap velocity at the 9 o'clock position, where

wind velocity is the least. This downflap creates an upward flow of air and has the same effect as decreasing the induced flow velocity by imposing an upward velocity vertical vector to the relative wind which increases the AOA.

Dissymmetry of Lift

Dissymmetry of lift is the differential (unequal) lift between advancing and retreating halves of the rotor disk caused by the different wind flow velocity across each half. This difference in lift would cause the helicopter to be uncontrollable in any situation other than hovering in a calm wind. There must be a means of compensating, correcting, or eliminating this unequal lift to attain symmetry of lift.

When the helicopter moves through the air, the relative airflow through the main rotor disk is different on the advancing side from the retreating side. The relative wind encountered by the advancing blade is increased by the forward speed of the helicopter, while the relative wind speed acting on the retreating blade is reduced by the helicopter's forward airspeed. Therefore, as a result of the relative wind speed, the advancing blade side of the rotor disk can produce more lift than the retreating blade side. *[Figure 2-36]*

If this condition were allowed to exist, a helicopter with a counterclockwise main rotor blade rotation would roll to the left because of the difference in lift. In reality, the main rotor blades flap and feather automatically to equalize lift across the rotor disk. Articulated rotor disks, usually with three or more blades, incorporate a horizontal hinge (flapping hinge) to allow the individual rotor blades to move, or flap up and down as they rotate. A semi-rigid rotor disk (two blades) utilizes a teetering hinge, which allows the blades to flap as a unit. When one blade flaps up, the other blade flaps down.

As shown in *Figure 2-37*, as the rotor blade reaches the advancing side of the rotor disk (A), it reaches its maximum up flap velocity. When the blade flaps upward, the angle between the chord line and the resultant relative wind decreases. This decreases the AOA, which reduces the amount of lift produced by the blade. At position (C), the rotor blade is now at its maximum down flapping velocity. Due to down flapping, the angle between the chord line and the resultant relative wind increases. This increases the AOA and thus the amount of lift produced by the blade.

The combination of blade flapping and slow relative wind acting on the retreating blade normally limits the maximum forward speed of a helicopter. At a high forward speed, the retreating blade stalls because of a high AOA and slow relative wind speed. This situation is called retreating blade stall and is evidenced by a nose pitch up, vibration, and a rolling tendency—usually to the left in helicopters with counterclockwise blade rotation.

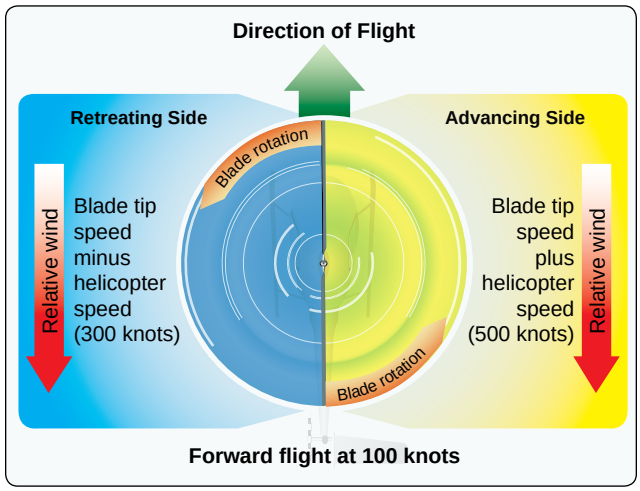


Figure 2-36. *The blade tip speed of this helicopter is approximately 400 knots. If the helicopter is moving forward at 100 knots, the relative windspeed on the advancing side is 500 knots. On the retreating side, it is only 300 knots. This difference in speed causes a dissymmetry of lift.*

Pilots can avoid retreating blade stall by not exceeding the never-exceed speed. This speed is designated V_{NE} and is indicated on a placard and marked on the airspeed indicator by a red line.

Blade flapping compensates for dissymmetry of lift in the following way. At a hover, equal lift is produced around the rotor disk with equal pitch (AOI) on all the blades and at all points in the rotor disk (disregarding compensation for translating tendency). The rotor disk is parallel to the horizon. To develop a thrust force, the rotor disk must be tilted in the desired direction of movement. Cyclic feathering changes the angle of incidence differentially around the rotor disk. For a counterclockwise rotation, forward cyclic movement decreases the angle of incidence on the right of the rotor disk and increases it on the left.

When transitioning to forward flight either from a hover or taking off from the ground, pilots must be aware that as the helicopter speed increases, translational lift becomes more effective and causes the nose to rise or pitch up (sometimes referred to as blowback). This tendency is caused by the combined effects of dissymmetry of lift and transverse flow. Pilots must correct for this tendency by maintaining a constant rotor disk attitude that will move the helicopter through the speed range in which blowback occurs. If the nose is permitted to pitch up while passing through this speed range, the aircraft may also tend to roll to the right. To correct for this tendency, the pilot must continuously move the cyclic forward as velocity of the helicopter increases until the takeoff is complete, and the helicopter has transitioned into forward flight.

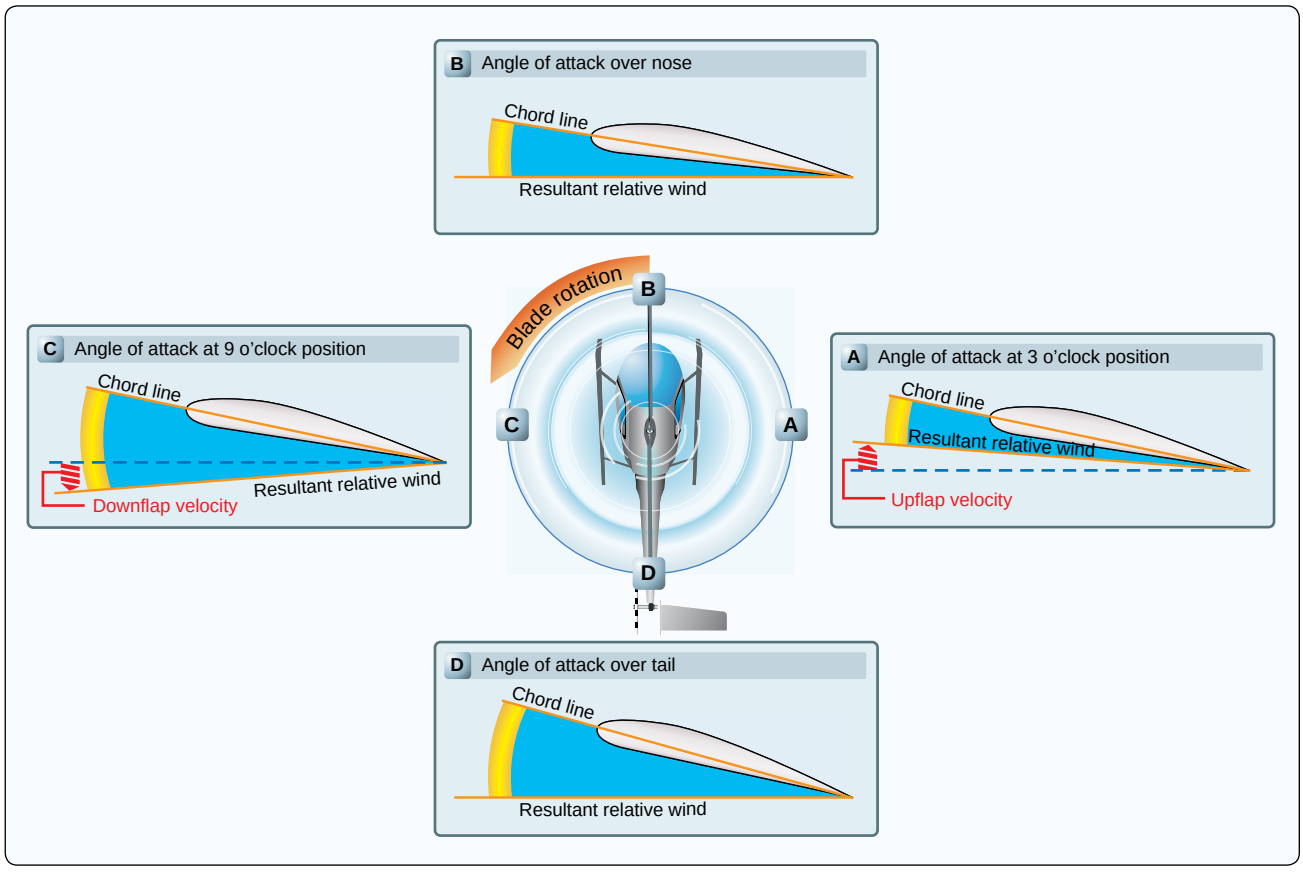


Figure 2-37. *The combined upward flapping (reduced lift) of the advancing blade and downward flapping (increased lift) of the retreating blade equalizes lift across the main rotor disk, counteracting dissymmetry of lift.*

Figure 2-38 illustrates the tilting forward of the rotor disk, which is the result of a change in pitch angle with forward cyclic. At a hover, the cyclic is centered and the pitch angle on the advancing and retreating blades is the same. At low forward speeds, moving the cyclic forward reduces pitch angle on the advancing blade and increases pitch angle on the retreating blade. This causes a slight rotor disk tilt. At higher forward speeds, the pilot must continue to move the cyclic forward. This further reduces pitch angle on the advancing blade and further increases pitch angle on the retreating blade. As a result, there is even more tilt to the rotor disk than at lower speeds.

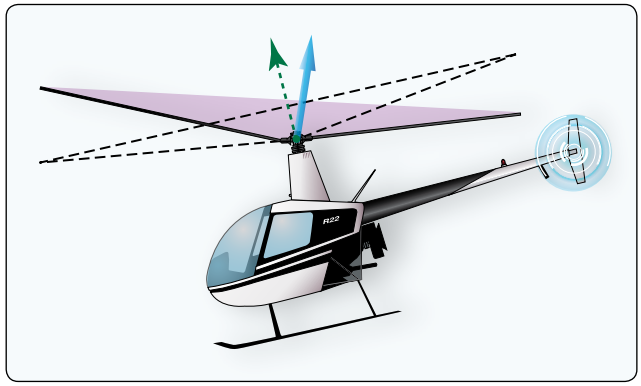


Figure 2-38. *To compensate for blowback, you must move the cyclic forward.*

A horizontal lift component (thrust) generates higher helicopter airspeed. The higher airspeed induces blade flapping to maintain symmetry of lift. The combination of flapping and cyclic feathering maintains symmetry of lift and desired attitude on the rotor disk and helicopter.

Translational Lift

Improved rotor efficiency resulting from directional flight is called translational lift. The efficiency of the hovering rotor disk is greatly improved with each knot of incoming wind gained by horizontal movement of the aircraft or surface wind. As the incoming wind produced by aircraft movement or surface wind enters the rotor disk, turbulence and vortices are left behind and the flow of air becomes more horizontal. In addition, the tail rotor becomes more aerodynamically efficient during the transition from hover to forward flight. *Figures 2-39* and *2-40* show the different airflow patterns at different speeds and how airflow affects the efficiency of the tail rotor.

Effective Translational Lift (ETL)

While transitioning to forward flight at about 16 to 24 knots, the helicopter goes through effective translational lift (ETL). As mentioned earlier in the discussion on translational lift, the rotor blades become more efficient as forward airspeed increases. Between 16 and 24 knots, the rotor disk completely outruns the recirculation of old vortices and begins to work in relatively undisturbed air. The flow of air through the rotor disk is more horizontal, which reduces induced flow and drag with a corresponding increase in angle of attach and lift. The additional lift available at this speed is referred to as the ETL, which makes the rotor disk operate more efficiently. This increased efficiency continues with increased airspeed until the best climb airspeed is reached, and total drag is at its lowest point.

As speed increases, translational lift becomes more effective, nose rises or pitches up, and aircraft rolls to the right. The combined effects of dissymmetry of lift, gyroscopic precession, and transverse flow effect cause this tendency. It is important to understand these effects and anticipate correcting for them. Once the helicopter is transitioning through ETL, the pilot needs to apply forward and left lateral cyclic input to maintain a constant rotor-disk attitude. *[Figure 2-41]*

Translational Thrust

Translational thrust occurs when the tail rotor becomes more aerodynamically efficient during the transition from hover to forward flight. As the tail rotor works in progressively less turbulent air, this improved efficiency produces more antitorque thrust, causing the nose of the aircraft to yaw left

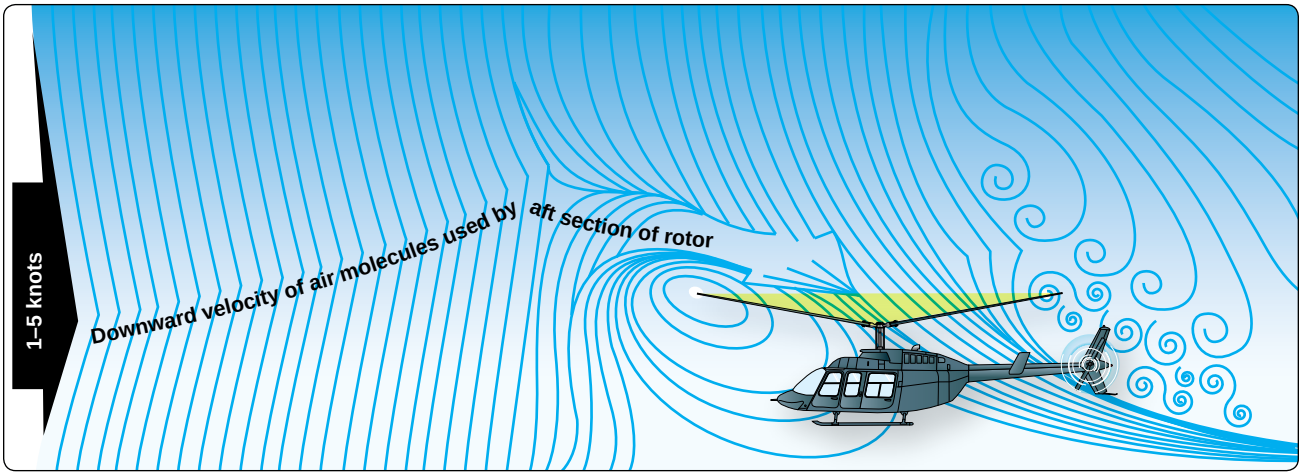


Figure 2-39. *The airflow pattern for 1–5 knots of forward airspeed. Note how the downwind vortex is beginning to dissipate and induced flow down through the rear of the rotor disk is more horizontal.*

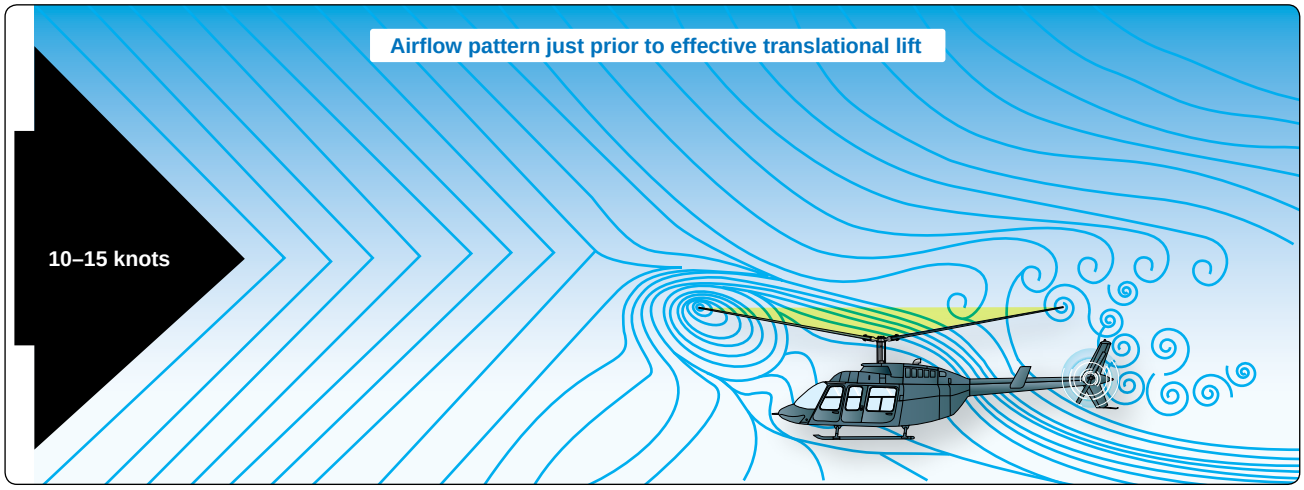


Figure 2-40. *An airflow pattern at a speed of 10–15 knots. At this increased airspeed, the airflow continues to become more horizontal. The leading edge of the downwash pattern is being overrun and is well back under the nose of the helicopter.*

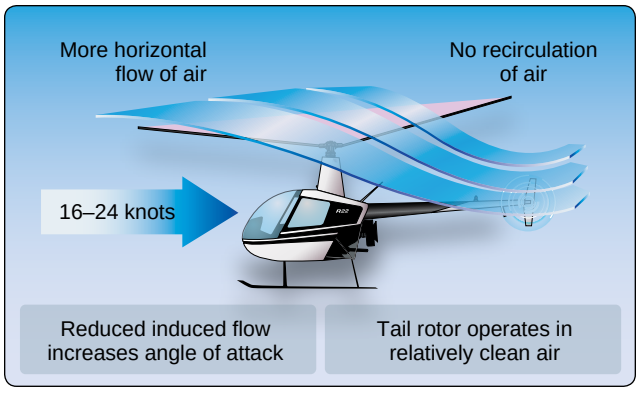


Figure 2-41. *Effective translational lift is easily recognized in actual flight by a transient induced aerodynamic vibration and increased performance of the helicopter.*

(with a main rotor turning counterclockwise) and forces the pilot to apply right pedal (decreasing the AOA in the tail rotor blades) in response. In addition, during this period, the airflow affects the horizontal components of the stabilizer found on most helicopters which tends to bring the nose of the helicopter to a more level attitude.

Induced Flow

As the rotor blades rotate, they generate what is called rotational relative wind. This airflow is characterized as flowing parallel and opposite the rotor's plane of rotation and striking perpendicular to the rotor blade's leading edge. This rotational relative wind is used to generate lift. As rotor blades produce lift, air is accelerated over the foil and projected downward. Anytime a helicopter is producing lift, it moves large masses of air vertically and down through the rotor disk. This downwash or induced flow can significantly change the efficiency of the rotor disk. Rotational relative wind combines with induced flow to form the resultant relative wind. As induced flow increases, resultant relative wind becomes less horizontal. Since AOA is determined by measuring the difference between the chord line and the resultant relative wind, as the resultant relative wind becomes less horizontal, AOA decreases. *[See Figure 2-21]*

Transverse Flow Effect

As the helicopter accelerates in forward flight, induced flow drops to near zero at the forward disk area and increases at the aft disk area. These differences in lift between the fore and aft portions of the rotor disk are called transverse flow effect. [*Figure 2-41]* This increases the AOA at the front disk area causing the rotor blade to flap up and reduces AOA at the aft disk area causing the rotor blade to flap down. Because the rotor acts like a gyro, maximum displacement occurs 90° in the direction of rotation. The result is a tendency for the helicopter to roll slightly to the right as it accelerates through approximately 20 knots or if the headwind is approximately 20 knots.

Transverse flow effect is recognized by increased vibrations of the helicopter at airspeeds around 12 to 15 knots and can be produced by forward flight or from the wind while in a hover. This vibration happens at an airspeed just below ETL on takeoff and after passing through ETL during landing. The vibration happens close to the same airspeed as ETL because that is when the greatest lift differential exists between the front and rear portions of the rotor system. As such, some pilots confuse the vibration felt by transverse flow effect with passing through ETL. To counteract transverse flow effect, a cyclic input to the left may be needed.

Sideward Flight

In sideward flight, the tip-path plane is tilted in the direction that flight is desired. This tilts the total lift-thrust vector sideward. In this case, the vertical or lift component is still straight up and weight straight down, but the horizontal or thrust component now acts sideward with drag acting to the opposite side. *[Figure 2-42]*

Sideward flight can be a very unstable condition due to the parasitic drag of the fuselage combined with the lack of horizontal stabilizer for that direction of flight. Increased altitudes help with control and the pilot must always scan in the direction of flight. Movement of the cyclic in the intended direction of flight causes the helicopter to move, controls the rate of speed, and ground track, but the collective and pedals are key to successful sideward flight. Just as in forward flight, the collective keeps the helicopter from contacting the ground and the pedals help maintain the correct heading; even in sideward flight, the tail of the helicopter should remain behind you. Inputs to the cyclic should be smooth and controlled, and the pilot should always be aware of the tip-path plane in relation to the ground. *[Figure 2-43]*

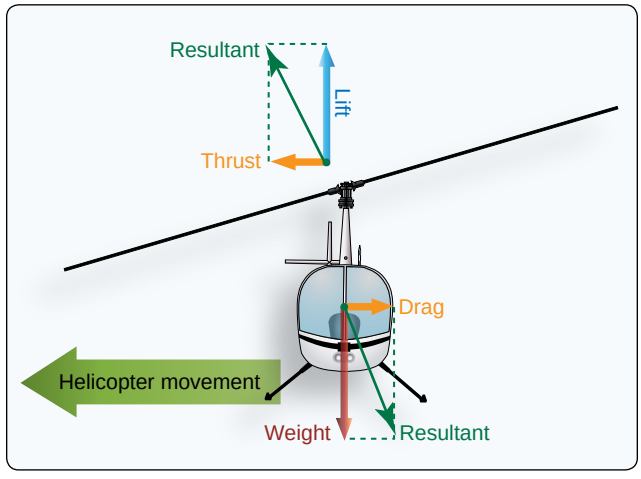


Figure 2-42. *Forces acting on the helicopter during sideward flight.*

Contacting the ground with the skids during sideward flight will most likely result in a dynamic rollover event before the pilot has a chance to react. Extreme caution should be used when maneuvering the helicopter sideways to avoid such hazards from happening. Refer to Chapter 11, Helicopter Hazards and Emergencies.

Rearward Flight

For rearward flight, the tip-path plane is tilted rearward, which, in turn, tilts the lift-thrust vector rearward. Drag now acts forward with the lift component straight up and weight straight down. *[Figure 2-44]*

Pilots must be aware of the hazards of rearward flight. Because of the position of the horizontal stabilizer, the tail end of the helicopter tends to pitch downward in rearward flight, causing the probability of hitting the ground to be greater than in forward flight. Another factor to consider in rearward flight is skid design. Most helicopter skids are not turned upward in the back, and any contact with the ground during rearward flight can put the helicopter in an uncontrollable position leading to tail rotor contact with the ground. Pilots must do a thorough scan of the area before attempting to hover rearward, looking for obstacles and terrain changes. Slower airspeeds can help mitigate risk and maintain a higher-than-normal hover altitude.

Turning Flight

In forward flight, the rotor disk is tilted forward, which also tilts the total lift-thrust force of the rotor disk forward. When

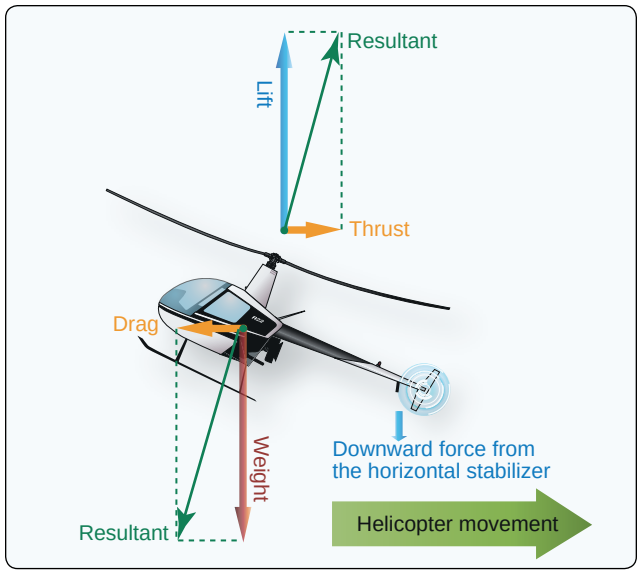


Figure 2-44. *Forces acting on the helicopter during rearward flight.*

resulting in lift being separated into two components. Lift acting upward and opposing weight is called the vertical component of lift. Lift acting horizontally and opposing inertia (centrifugal force) is the horizontal component of lift (centripetal force). *[Figure 2-45]*

As the angle of bank increases, the total lift force is tilted more toward the horizontal, thus causing the rate of turn to increase because more lift is acting horizontally. Since the resultant lifting force acts more horizontally, the effect of lift acting

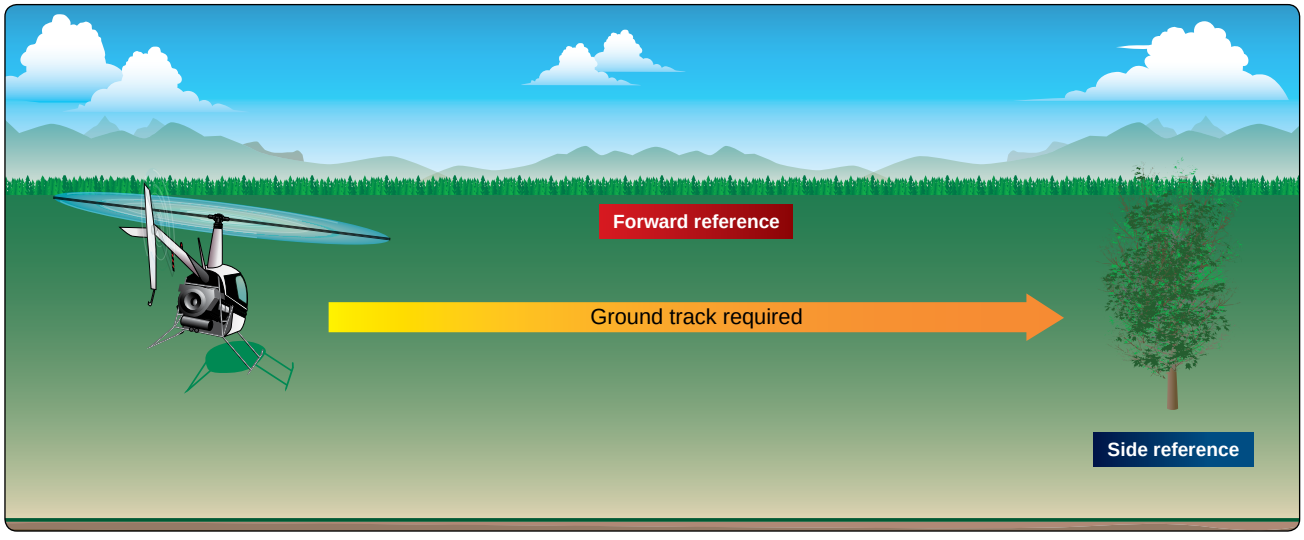


Figure 2-43. *Forces acting on the helicopter during sideward flight.*

the helicopter is banked, the rotor disk is tilted sideward

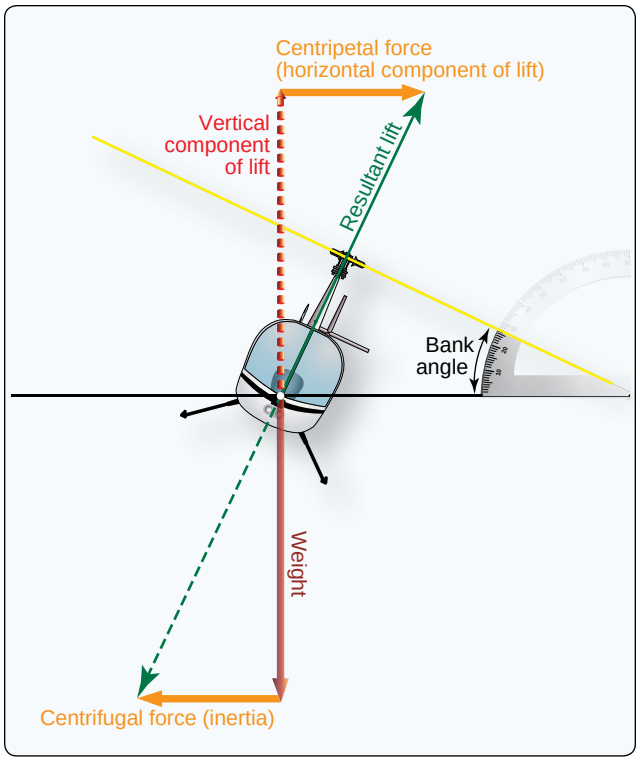


Figure 2-45. *Forces acting on the helicopter during turning flight.*

vertically is decreased. To compensate for this decreased vertical lift, the AOA of the rotor blades must be increased in order to maintain altitude. The steeper the angle of bank is, the greater the AOA of the rotor blades required to maintain altitude. Thus, with an increase in bank and a greater AOA, the resultant lifting force increases, and the rate of turn is higher. Simply put, collective pitch must be increased in order to maintain altitude and airspeed while turning. Collective pitch controls the angle of incidence and along with other factors, determines the overall AOA in the rotor disk.

Autorotation

Autorotation is the state of flight where the main rotor disk of a helicopter is being turned by the action of air moving up through the rotor rather than engine power driving the rotor. In normal, powered flight, air is drawn into the main rotor disk from above and exhausted downward, but during autorotation, air moves up into the rotor disk from below as the helicopter descends. Autorotation is permitted mechanically by a freewheeling unit, which is a special clutch mechanism that allows the main rotor to continue turning even if the engine is not running. If the engine fails, the freewheeling unit automatically disengages the engine from the main rotor allowing the main rotor to rotate freely. It is the means by which a helicopter can be landed safely in the event of an engine failure; consequently, all helicopters must demonstrate this capability in order to be certified. *[Figure 2-46]* If a decision is made to attempt an engine restart in flight (the parameters for this emergency procedure will be different for each helicopter and must be precisely followed) the pilot must reengage the engine starter switch to start the engine. Once the engine is started, the freewheeling unit will reengage the engine with the main rotor.

Vertical Autorotation

Most autorotations are performed with forward speed. For simplicity, the following aerodynamic explanation is based on a vertical autorotative descent (no forward speed) in still air. Under these conditions, the forces that cause the blades to turn are similar for all blades regardless of their position in the plane of rotation. Therefore, dissymmetry of lift resulting from helicopter airspeed is not a factor.

During vertical autorotation, the rotor disk is divided into three regions (as illustrated in *Figure 2-47)*: driven region,

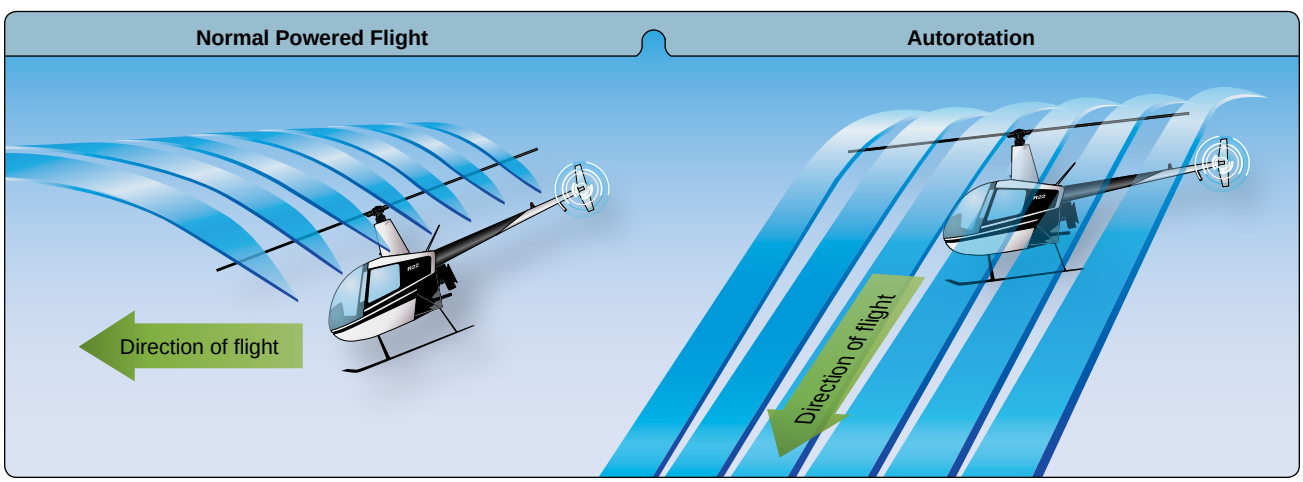


Figure 2-46. *During an autorotation, the upward flow of relative wind permits the main rotor blades to rotate at their normal speed. In effect, the blades are "gliding" in their rotational plane.*

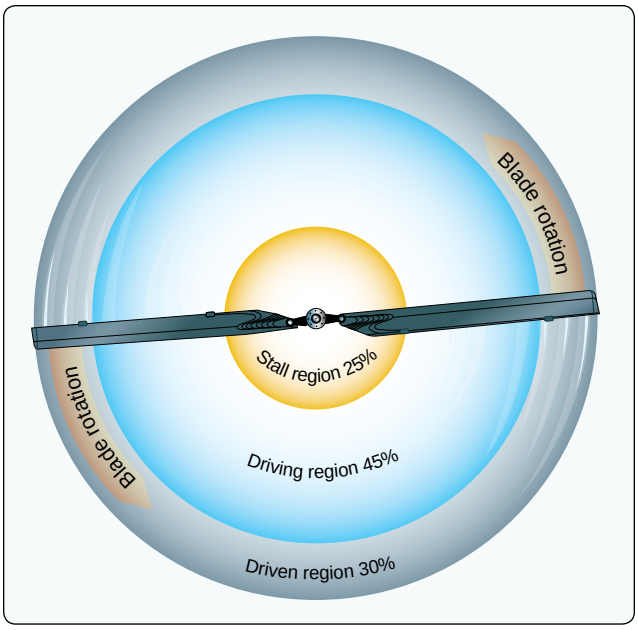


Figure 2-47. *Blade regions during autorotational descent.*

driving region, and stall region. *Figure 2-48* shows three blade sections that illustrate force vectors. Part A is the driven region, B and D are points of equilibrium, part C is the driving region, and part E is the stall region. Force vectors are different in each region because rotational relative wind is slower near the blade root and increases continually toward the blade tip. Also, blade twist gives a more positive AOA in the driving region than in the driven region. The combination of the inflow up through the rotor with rotational relative wind produces different combinations of aerodynamic force at every point along the blade.

The driven region, also called the propeller region, is nearest the blade tips. Normally, it consists of about 30 percent of the radius. In the driven region, part A of *Figure 2-48*, the TAF acts behind the axis of rotation, resulting in an overall drag force. The driven region produces some lift, but that lift is offset by drag. The overall result is a deceleration in the rotation of the blade. The size of this region varies with the blade pitch, rate of descent, and rotor rpm. When changing autorotative rpm blade pitch, or rate of descent, the size of the driven region in relation to the other regions also changes.

There are two points of equilibrium on the blade—one between the driven region and the driving region, and one between the driving region and the stall region. At points of equilibrium, TAF is aligned with the axis of rotation. Lift and drag are produced, but the total effect produces neither acceleration nor deceleration.

The driving region, or autorotative region, normally lies between 25 to 70 percent of the blade radius. Part C of *Figure 2-48* shows the driving region of the blade, which produces the forces needed to turn the blades during autorotation. Total aerodynamic force in the driving region is inclined slightly forward of the axis of rotation, producing a continual acceleration force. This inclination supplies thrust, which tends to accelerate the rotation of the blade. Driving region size varies with blade pitch setting, rate of descent, and rotor rpm.

By controlling the size of this region, a pilot can adjust autorotative rpm. For example, if the collective pitch is raised, the pitch angle increases in all regions. This causes the point of equilibrium to move inboard along the blade's span, thus increasing the size of the driven region. The stall region also becomes larger while the driving region becomes smaller. Reducing the size of the driving region causes the acceleration force of the driving region and rpm to decrease. A constant rotor rpm is achieved by adjusting the collective pitch so blade acceleration forces from the driving region are balanced with the deceleration forces from the driven and stall regions.

The inner 25 percent of the rotor blade is referred to as the stall region and operates above its maximum AOA (stall angle), causing drag, which tends to slow rotation of the blade. Part E of *Figure 2-48* depicts the stall region.

Autorotation (Forward Flight)

Autorotative force in forward flight is produced in exactly the same manner as when the helicopter is descending vertically in still air. However, because forward speed changes the inflow of air up through the rotor disk, all three regions move outboard along the blade span on the retreating side of the disk where AOA is larger. *[Figure 2-49]* With lower AOA on the advancing side blade, more of the blade falls in the driven region. On the retreating side, more of the blade is in the stall region. A small section near the root experiences a reversed flow; therefore, the size of the driven region on the retreating side is reduced.

Prior to landing from an autorotative descent (or autorotation), the pilot must flare the helicopter in order to decelerate. The pilot initiates the flare by applying aft cyclic. As the helicopter flares back, the airflow patterns change around the blades causing the rpm to increase. Pilots must adjust the collective as necessary to keep the rpm within operating limits.

Chapter Summary

This chapter introduced the basics of aerodynamic fundamentals and theory and how they relate to flying a helicopter. This chapter also explained how aerodynamics affect helicopter flight and how important it is for pilots to understand aerodynamic principles and be prepared to react to these effects. For additional information on aerodynamics, refer to the aerodynamics of flight portion of the Pilot's Handbook of Aeronautical Knowledge.

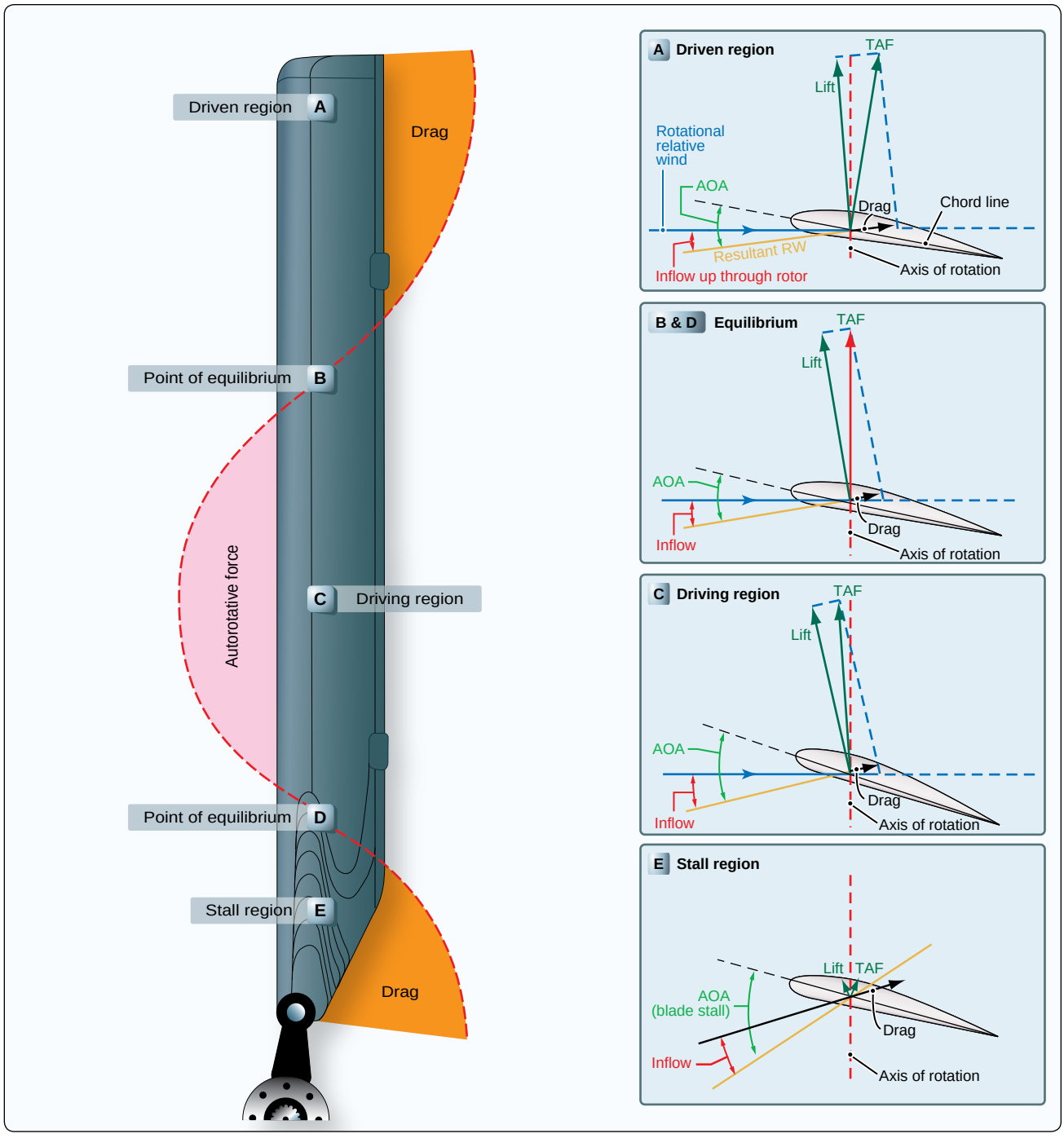


Figure 2-48. *Force vectors in vertical autorotation descent.*

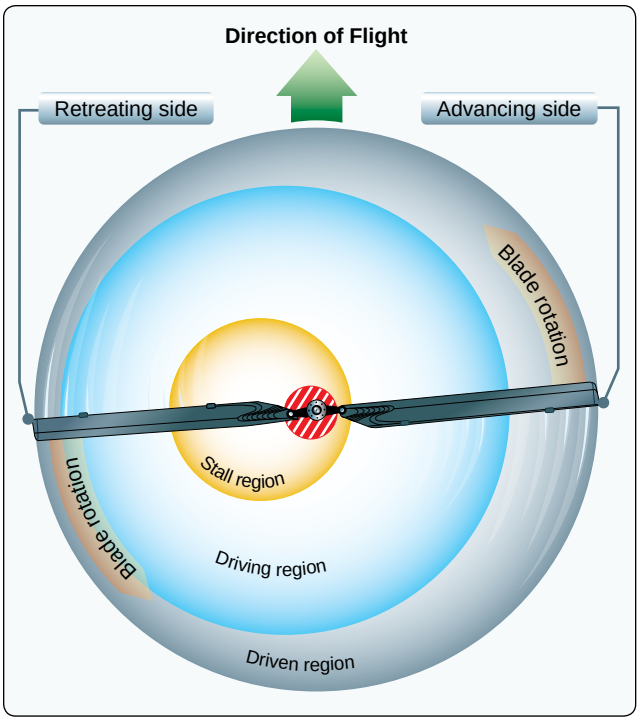


Figure 2-49. *Blade regions in forward autorotation descent.*

Chapter 3

Helicopter Flight Controls

Introduction

There are three major controls in a helicopter that the pilot must use during flight. They are the collective pitch control, the cyclic pitch control, and the antitorque pedals or tail rotor control. In addition to these major controls, the pilot must also use the throttle control, which is usually mounted directly to the collective pitch control in order to fly the helicopter.

In this chapter, the control systems described are not limited to the single main rotor type helicopter but are employed in one form or another in most helicopter configurations. All examples in this chapter refer to a counterclockwise main rotor blade rotation as viewed from above. If flying a helicopter with a clockwise rotation, left and right references must be reversed, particularly in the areas of rotor blade pitch change, antitorque pedal movement, and tail rotor thrust.

Collective Pitch Control

The collective pitch control (or simply “collective” or “thrust lever”) is located on the left side of the pilot’s seat and is operated with the left hand. The collective is used to make changes to the pitch angle of the main rotor blades and does this simultaneously, or collectively, as the name implies. As the collective pitch control is raised, there is a simultaneous and equal increase in pitch angle of all main rotor blades; as it is lowered, there is a simultaneous and equal decrease in pitch angle. This is done through a series of mechanical linkages and the amount of movement in the collective lever determines the amount of blade pitch change. *[Figure 3-1]* An adjustable friction control helps prevent inadvertent collective pitch movement.

Changing the pitch angle on the blades changes the angle of incidence on each blade. With a change in angle of incidence comes a change in drag, which affects the speed or revolutions per minute (rpm) of the main rotor. As the pitch angle increases, angle of incidence increases, drag increases, and rotor rpm decreases. Decreasing pitch angle decreases both angle of incidence and drag, while rotor rpm increases. In order to maintain a constant rotor rpm, which is essential in helicopter operations, a proportionate change in power is required to compensate for the change in drag. This is accomplished with the throttle control or governor, which automatically adjusts engine power.

Throttle Control

The function of the throttle is to regulate engine rpm. If the correlator or governor system does not maintain the desired rpm when the collective is raised or lowered, or if those systems are not installed, the throttle must be moved manually with the twist grip in order to maintain rpm. In most helicopters, rotating the twist-grip throttle away from the pilot (counter-clockwise), increases engine rpm; rotating the twist-grip throttle towards the pilot (clockwise) decreases engine rpm. [Figure 3-2]

Governor/Correlator

A governor is a sensing device that senses rotor and engine rpm and makes the necessary adjustments in order to keep rotor rpm constant. In normal operations, once the rotor rpm is set, the governor keeps the rpm constant, and there is no need to make any throttle adjustments. Governors are common on all turbine helicopters (as it is a function of the fuel control system of the turbine engine) and used on some piston powered helicopters.

A correlator is a mechanical connection between the collective lever and the engine throttle. When the collective lever is raised, power is automatically increased; when lowered, power is decreased. This system maintains rpm close to the desired value, but still requires adjustment of the throttle for fine tuning.

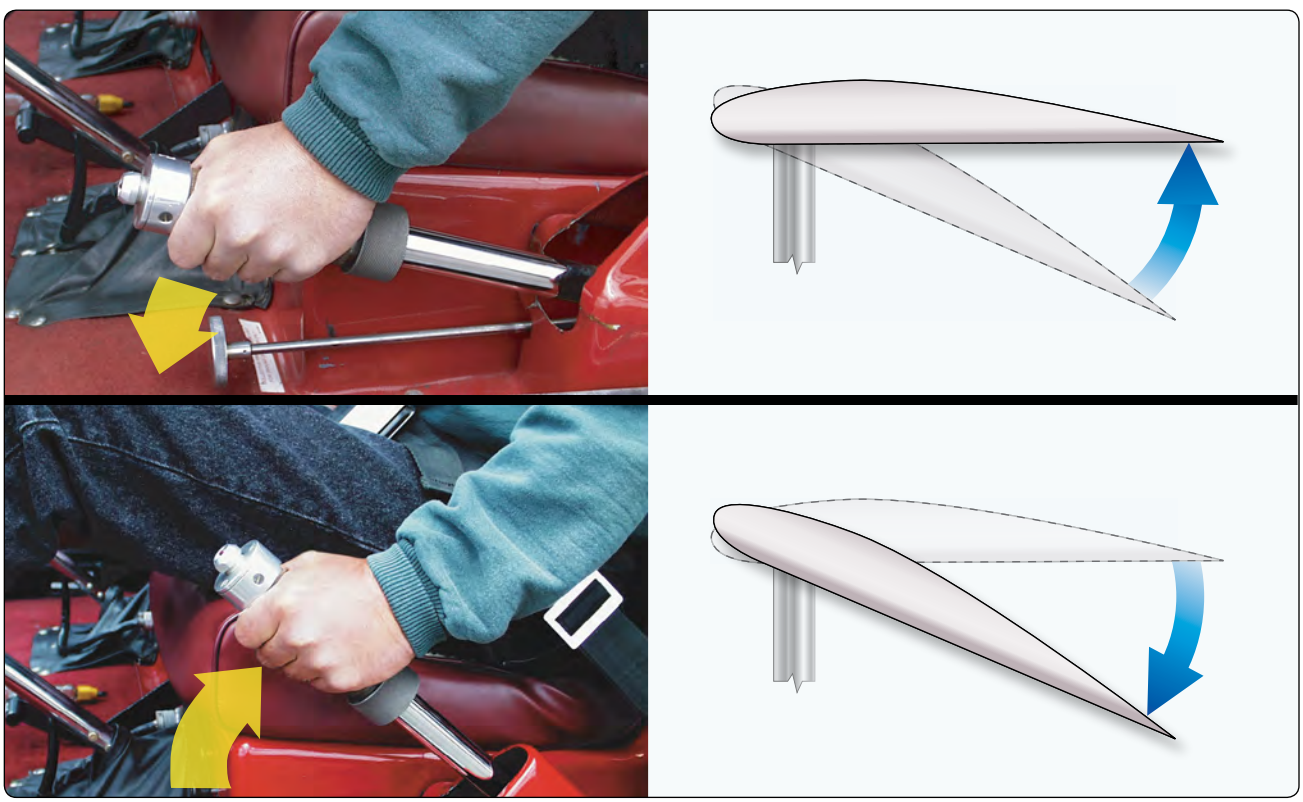


Figure 3-1. *Raising the collective pitch control increases the pitch angle, or angle of incidence, by the same amount on all blades.*

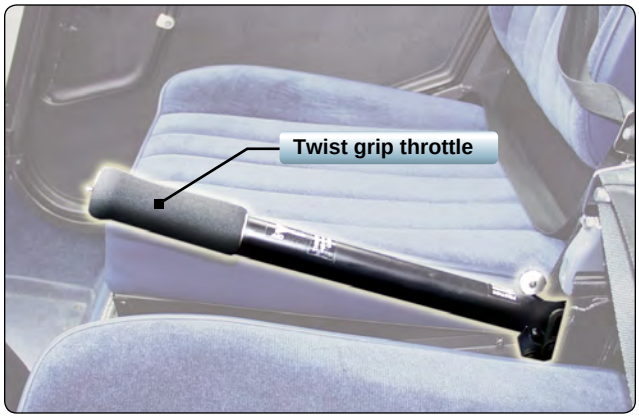


Figure 3-2. *A twist grip throttle is usually mounted on the end of the collective lever. The throttles on some turbine helicopters are mounted on the overhead panel or on the floor in the cockpit.*

Some helicopters do not have correlators or governors and require coordination of all collective and throttle movements. When the collective is raised, the throttle must be increased; when the collective is lowered, the throttle must be decreased. As with any aircraft control, large adjustments of either collective pitch or throttle should be avoided. All corrections should be made through the use of smooth pressure.

In piston helicopters, the collective pitch is the primary control for manifold pressure, and the throttle is the primary control for rpm. However, the collective pitch control also influences rpm, and the throttle also influences manifold pressure; therefore, each is considered to be a secondary control of the other's function. Both the tachometer (rpm indicator) and the manifold pressure gauge must be analyzed to determine which control to use. *Figure 3-3* illustrates this relationship.

if rpm is	and manifold pressure is	Solution
LOW	LOW	Increasing the throttle increases manifold pressure and rpm
LOW	HIGH	Lowering the collective pitch decreases manifold pressure and increases rpm
HIGH	LOW	Raising the collective pitch increases manifold pressure and decreases rpm
HIGH	HIGH	Reducing the throttle decreases manifold pressure and rpm

Figure 3-3. *Relationship between rpm, manifold pressure, collective, and throttle.*

Cyclic Pitch Control

The cyclic pitch control (or simply "cyclic") is usually projected upward from the cockpit floor, between the pilot's legs or between the two pilot seats in some models. *[Figure 3-4]* This primary flight control allows the pilot to fly the helicopter in any direction of travel: forward, rearward, left, and right. As discussed in Chapter 2, Aerodynamics of Flight, the total lift force is always perpendicular to the tip-path plane of the main rotor. The purpose of the cyclic pitch control is to tilt the tip-path plane in the direction of the desired horizontal direction. The cyclic controls the rotor disk tilt versus the horizon, which directs the rotor disk thrust to enable the pilot to control the direction of travel of the helicopter.

The rotor disk tilts in the same direction the cyclic pitch control is moved. If the cyclic is moved forward, the rotor disk tilts forward; if the cyclic is moved aft, the disk tilts aft, and so on. Because the rotor disk acts like a gyro, the mechanical linkages for the cyclic control rods are rigged in such a way that they



Figure 3-4. *The cyclic pitch control may be mounted vertically between the pilot's knees or on a teetering bar from a single cyclic located in the center of the helicopter. The cyclic can pivot in all directions.*

decrease the pitch angle of the rotor blade approximately 90° before it reaches the direction of cyclic displacement and increase the pitch angle of the rotor blade approximately 90° after it passes the direction of displacement. An increase in pitch angle increases AOA; a decrease in pitch angle decreases AOA. For example, if the cyclic is moved forward, the AOA decreases as the rotor blade passes the right side of the helicopter and increases on the left side. This results in maximum downward deflection of the rotor blade in front of the helicopter and maximum upward deflection behind it, causing the rotor disk to tilt forward.

Antitorque Pedals

The antitorque pedals, located on the cabin floor by the pilot's feet, control the pitch and therefore the thrust of the tail rotor blades or other antitorque system. See Chapter 5, Helicopter Components, Sections, and Systems, for a discussion on these other systems. *[Figure 3-5]* Newton's Third Law was discussed in Chapter 2, General Aerodynamics, stating that for every action there is an equal and opposite reaction. This law applies to the helicopter fuselage and its rotation in the opposite direction of the main rotor blades unless counteracted and controlled. To make flight possible and to compensate for this torque, most helicopter designs incorporate an antitorque rotor or tail rotor. The antitorque pedals allow the pilot to control the pitch angle of the tail rotor blades, which in forward flight puts the helicopter in longitudinal trim and, while at a hover, enables the pilot to turn the helicopter 360°. The antitorque pedals are connected to the pitch change mechanism on the tail rotor gearbox and allow the pitch angle on the tail rotor blades to be increased or decreased.



Figure 3-5. *Antitorque pedals compensate for changes in torque and control heading in a hover.*

Heading Control

The tail rotor is used to control the heading of the helicopter while hovering or when making hovering turns, as well as counteracting the torque of the main rotor. Hovering turns are commonly referred to as "pedal turns."

At speeds above translational lift, the pedals are used to compensate for torque to put the helicopter in longitudinal trim, so that coordinated flight can be maintained. The cyclic control is used to change heading by making a turn to the desired direction.

The thrust of the tail rotor depends on the pitch angle of the tail rotor blades. This pitch angle can be positive, negative, or zero. A positive pitch angle tends to move the tail to the right. A negative pitch angle moves the tail to the left, while no thrust is produced with a zero pitch angle. The maximum positive pitch angle of the tail rotor is generally greater than the maximum negative pitch angle available. This is because the primary purpose of the tail rotor is to counteract the torque of the main rotor. The capability for tail rotors to produce thrust to the left (negative pitch angle) is necessary, because during autorotation the drag of the transmission tends to yaw the nose to the left, or in the same direction the main rotor is turning.

From the neutral position, applying right pedal causes the nose of the helicopter to yaw right and the tail to swing to the left. Pressing on the left pedal has the opposite effect: the nose of the helicopter yaws to the left and the tail swings right. *[Figure 3-6]*

With the antitorque pedals in the neutral position, the tail rotor has a medium positive pitch angle. In medium positive pitch, the tail rotor thrust approximately equals the torque of the main rotor during cruise flight, so the helicopter maintains a constant heading in level flight.

A vertical fin or stabilizer is used in many single-rotor helicopters to help aid in heading control. The fin is designed to optimize directional stability in flight with a zero tail rotor thrust setting. The size of the fin is crucial to this design. If the surface is too large, the tail rotor thrust may be blocked. Heading control would be more difficult at slower airspeeds and at a hover and the vertical fin would then weathervane.

Helicopters that are designed with tandem rotors do not have an antitorque rotor. The helicopter is designed with both rotor systems rotating in opposite directions to counteract the torque rather than a tail rotor. Directional antitorque pedals

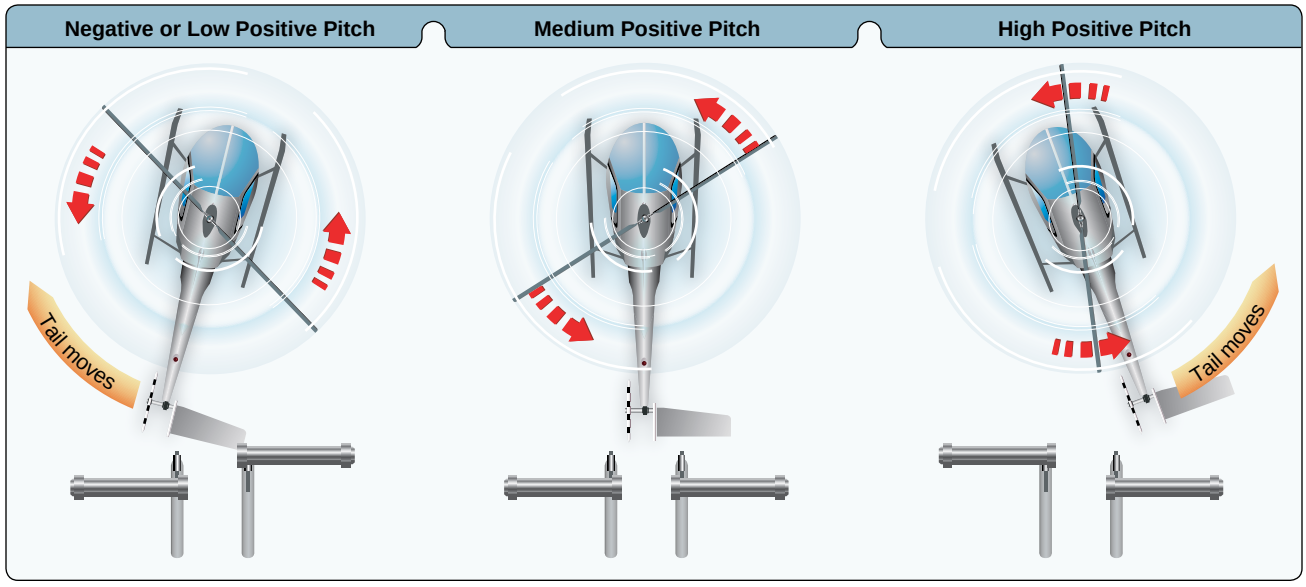


Figure 3-6. *Tail rotor pitch angle and thrust in relation to pedal positions during cruising flight.*

are used for directional control of the aircraft while in flight, as well as while taxiing with the forward gear off the ground.

In intermeshing rotor systems, which are a set of two rotors turning in opposite directions with each rotor mast mounted on the helicopter with a slight angle to the other so that the blades intermesh without colliding, and a coaxial rotor systems, which are a pair of rotors mounted one above the other on the same shaft and turning in opposite directions, the heading pedals control the heading of the helicopter while at a hover by imbalancing torque between the rotors, allowing for the torque to turn the helicopter.

Chapter Summary

This chapter introduced the pilot to the major flight controls and how they work in relation to each other. The chapter also correlates the use of flight controls and aerodynamics and how the two work together to make flight possible.

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]*

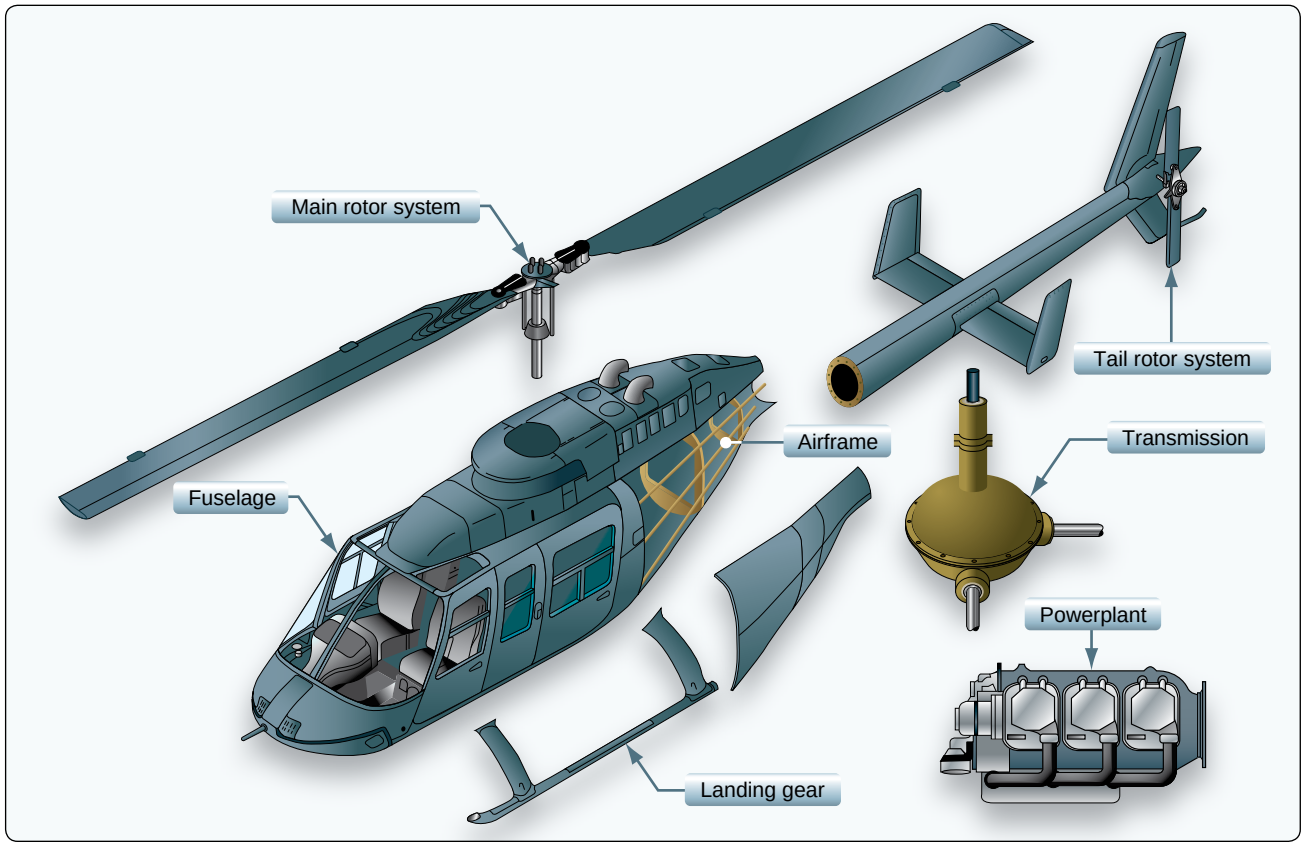


Figure 4-1. *The major components of a helicopter are the airframe, fuselage, landing gear, powerplant, transmission, main rotor system,and tail rotor system.*

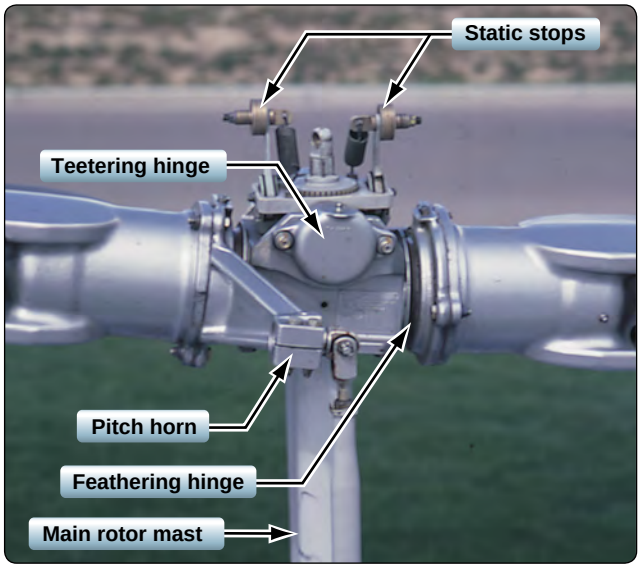


Figure 4-2. *The teetering hinge allows the main rotor hub to tilt, and the feathering hinge enables the pitch angle of the blades to change.*

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

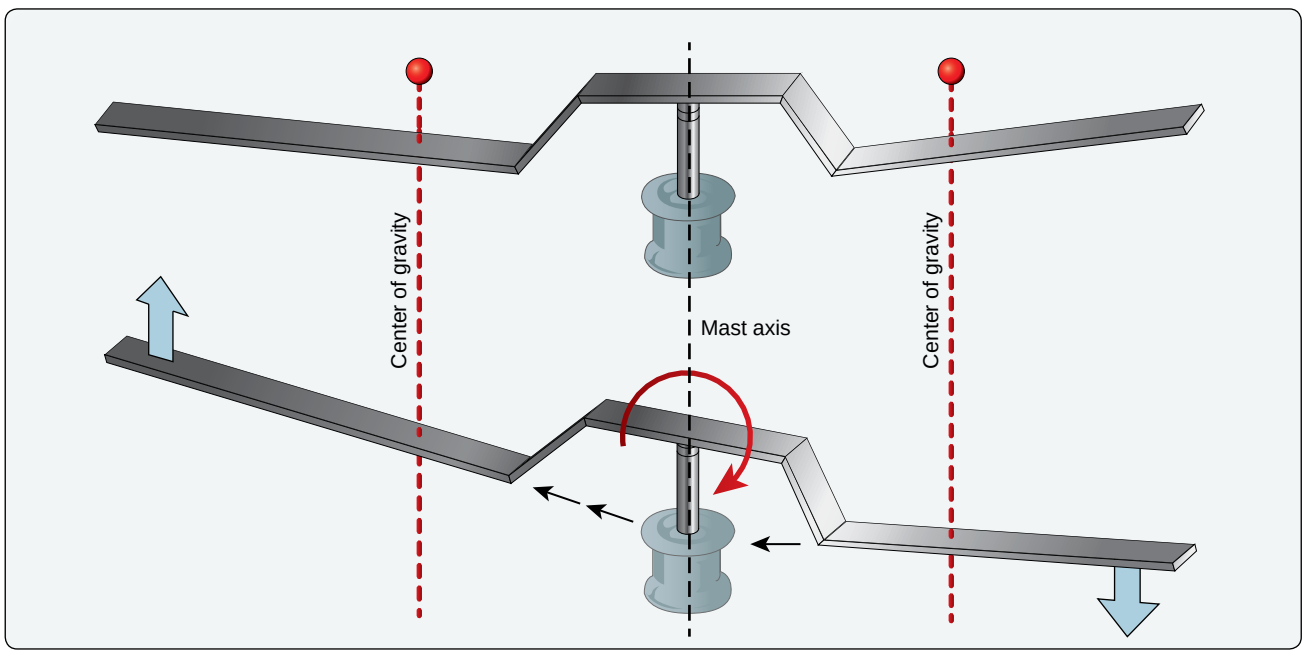


Figure 4-3. *With an underslung rotor, the center of gravity (CG) remains in the same approximate location relative to the mast before and after rotor tilt.*

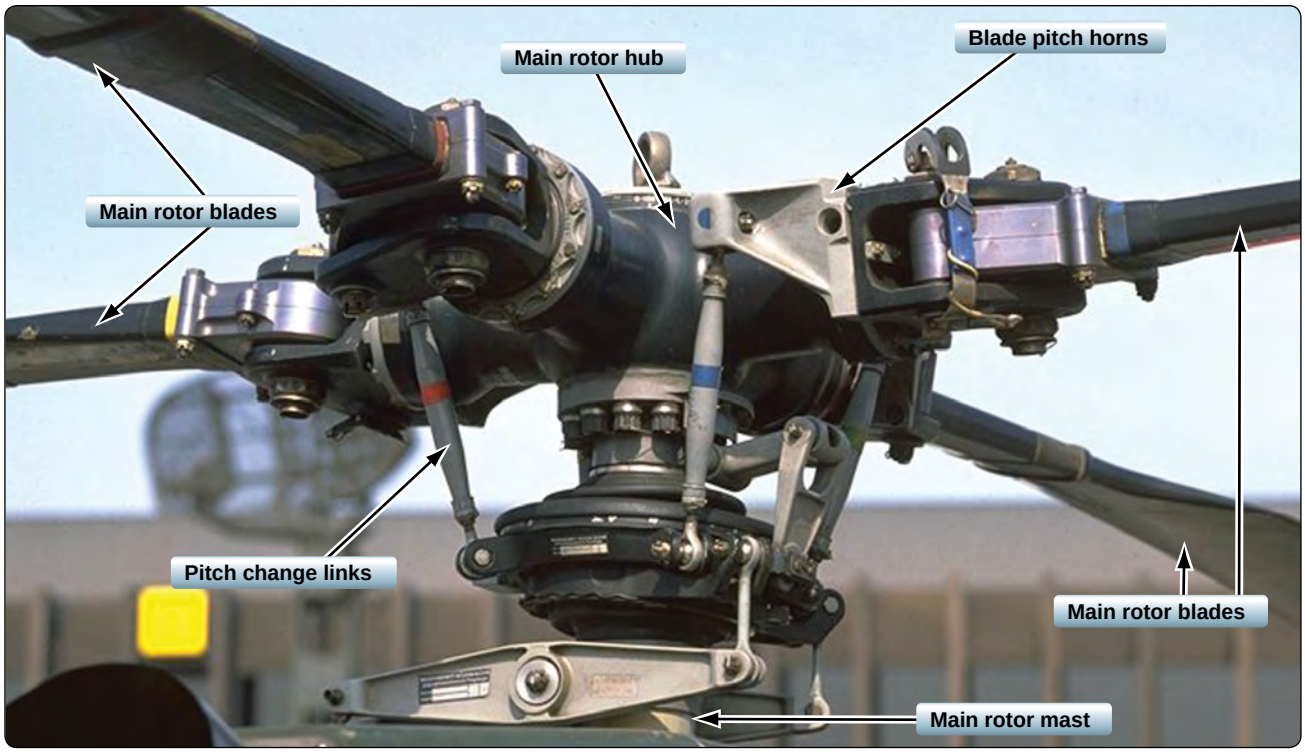


Figure 4-4. *Four-blade hingeless (rigid) main rotor. Rotor blades are comprised of glass fiber reinforced material. The hub is a single piece of forged rigid titanium.*

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.*

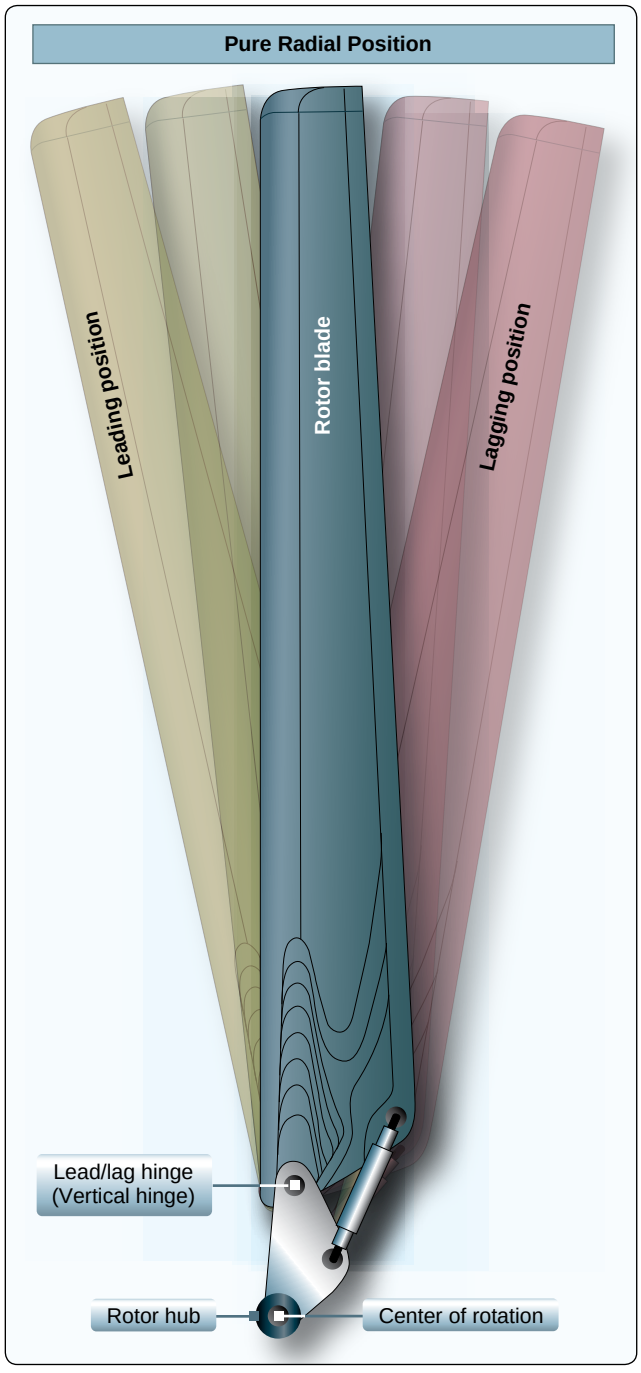


Figure 4-6. *Lead/lag hinge allows the rotor blade to move back and forth in plane.*

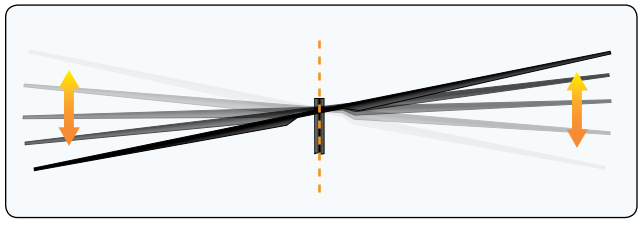


Figure 4-7. *Fully articulated flapping hub.*

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

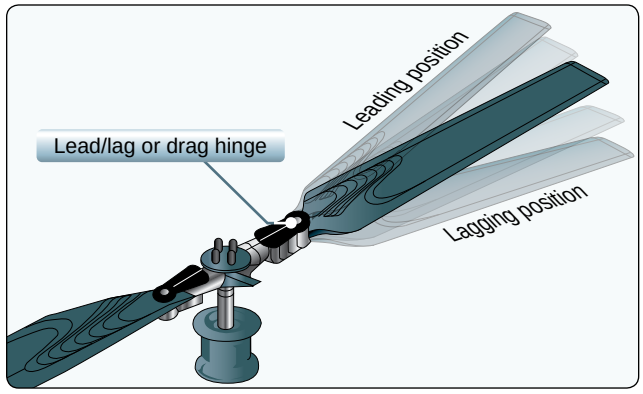


Figure 4-8. *Fully articulated rotor blade with flapping hinge.*

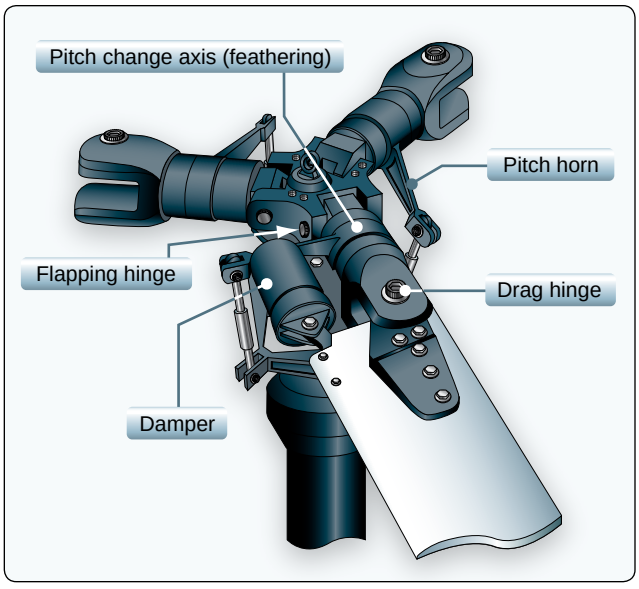


Figure 4-9. *Drag hinge.*

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]*

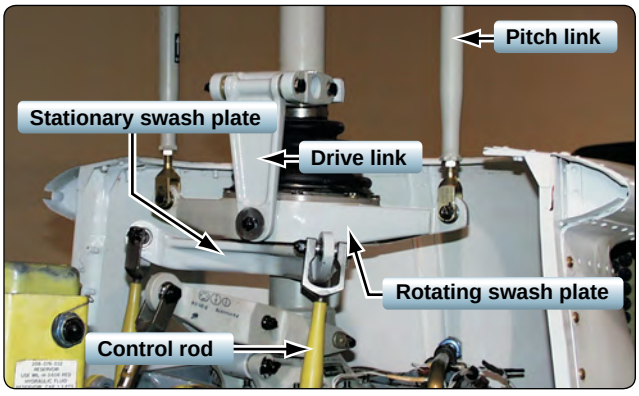


Figure 4-11. *Stationary and rotating swash plate.*

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.

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

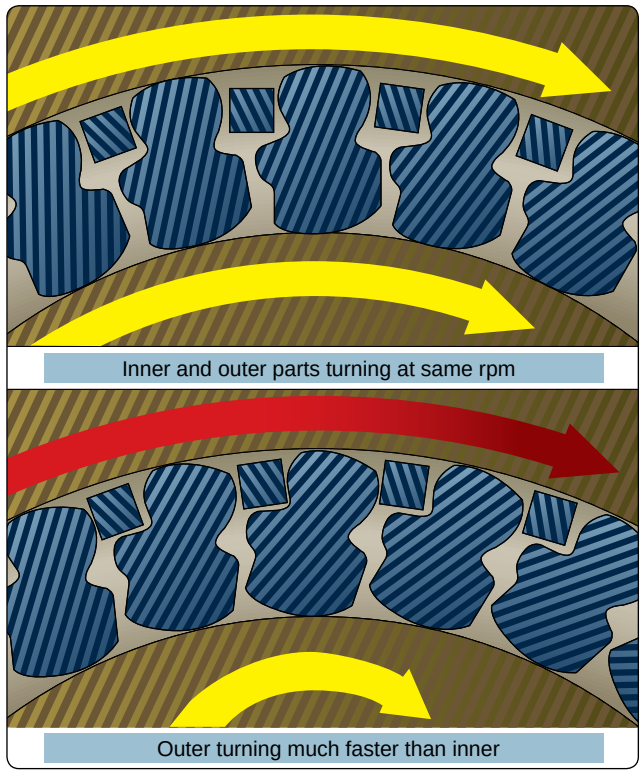


Figure 4-12. *Freewheeling unit in normal drive position and freewheeling position. Note that in the top example, the engine output shaft (inner part) drives the rotor shaft (outer part) at the same speed (normal flight). In the bottom example, the rotor shaft (outer part) breaks free under autorotation,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

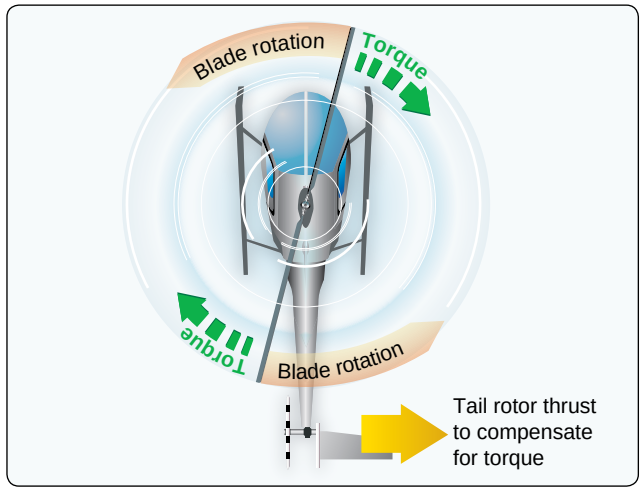


Figure 4-13. *Antitorque rotor produces thrust to oppose torque.*

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.

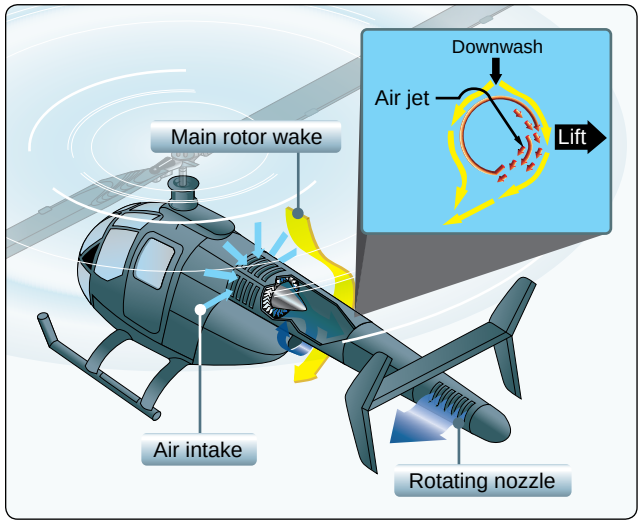


Figure 4-15. *While in a hover, Coanda effect supplies approximately two-thirds of the lift necessary to maintain directional control. The rest is created by directing the thrust from the controllable rotating nozzle.*

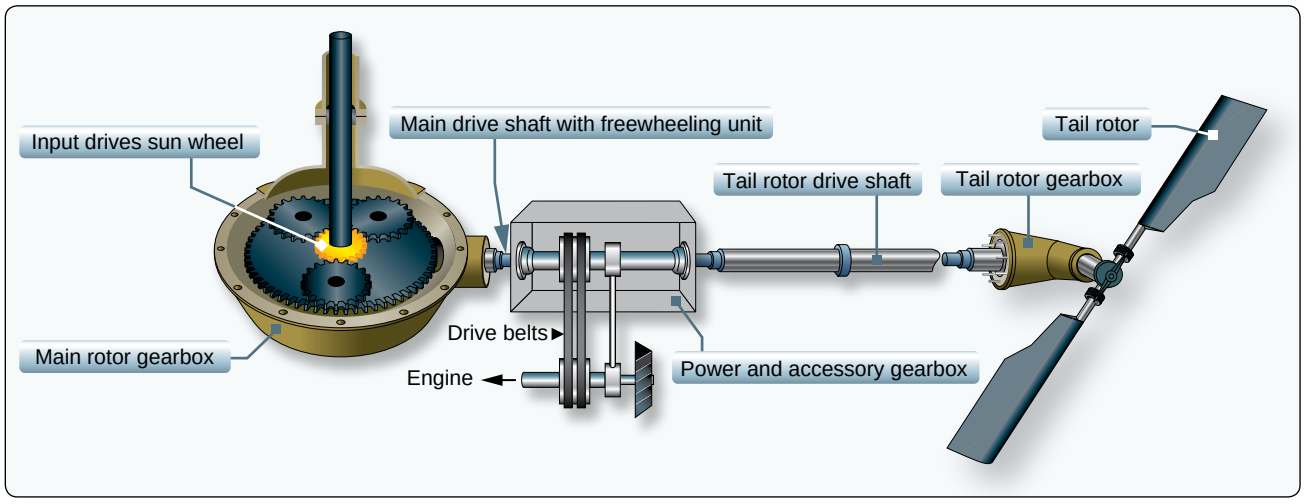


Figure 4-16. *The tail rotor driveshaft is connected to both the main transmission and the tail rotor transmission.*

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]*

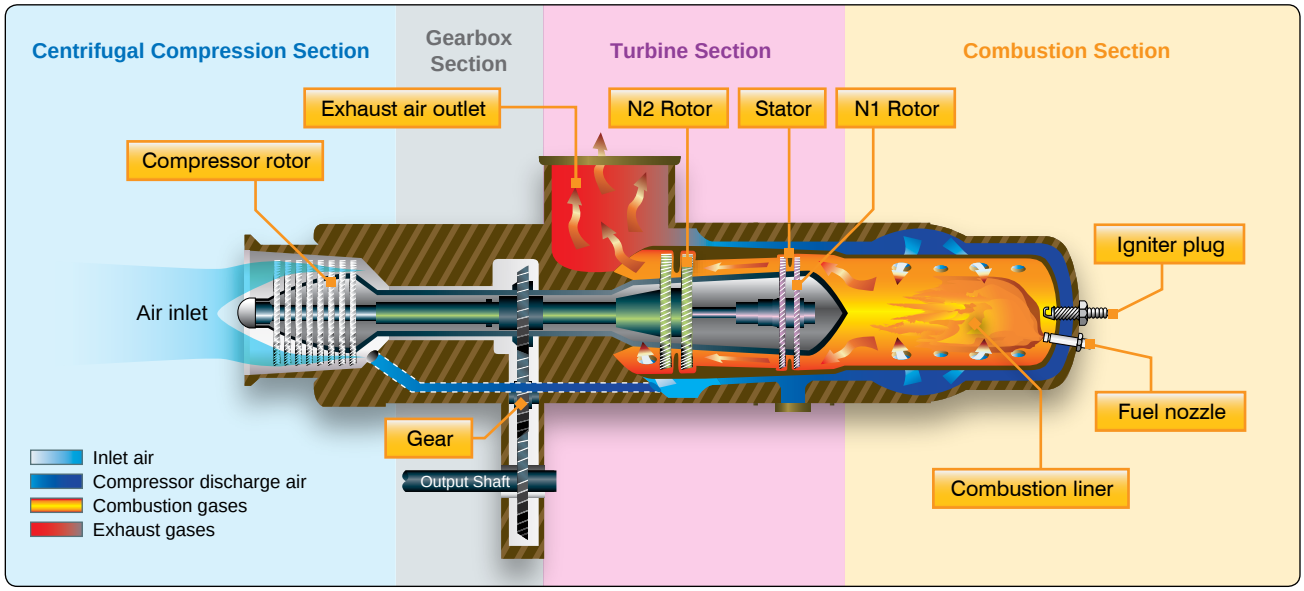


Figure 4-17. *Many helicopters use a turboshaft engine as shown above to drive the main transmission and rotor systems. The main difference between a turboshaft and a turbojet engine is that most of the energy produced by the expanding gases is used to drive a turbine rather than producing thrust through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

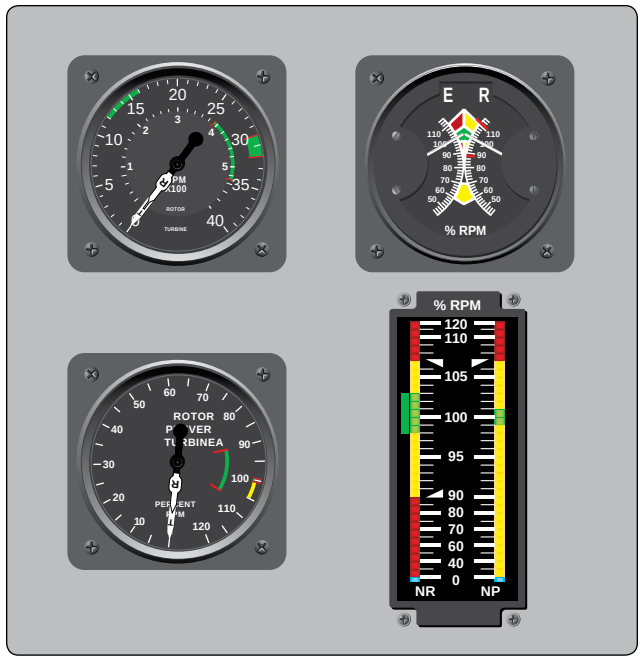


Figure 4-18. *Various types of dual-needle tachometers.*

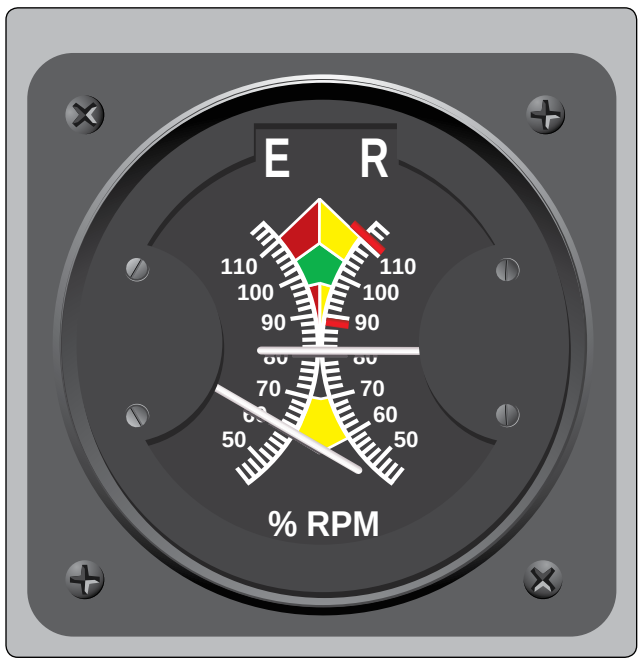


Figure 4-19. *A "split" or divided needle condition is a result of a sudden loss of engine power.*

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.

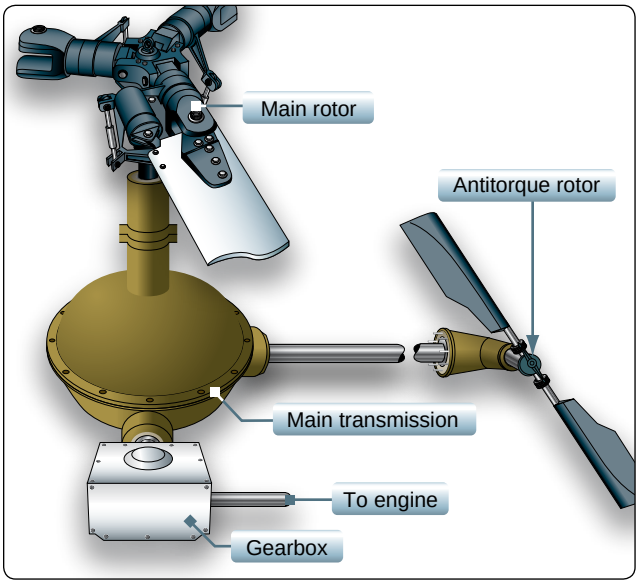


Figure 4-20. *The main rotor transmission reduces engine output rpm to optimum rotor rpm.*

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]*

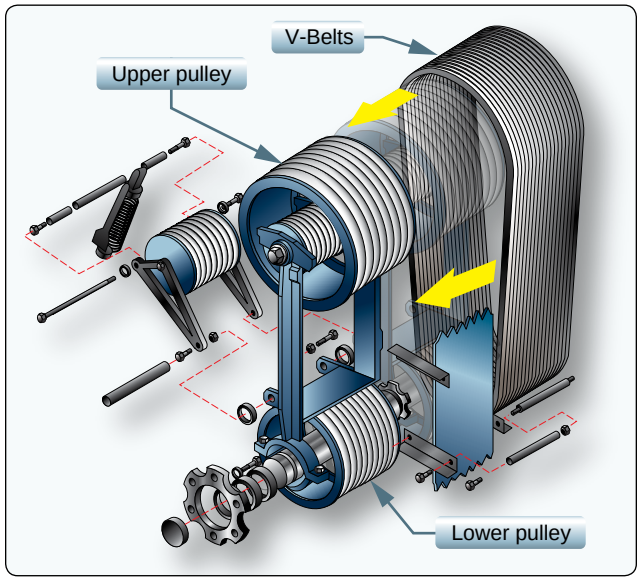


Figure 4-21. *Idler or manual clutch.*

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.

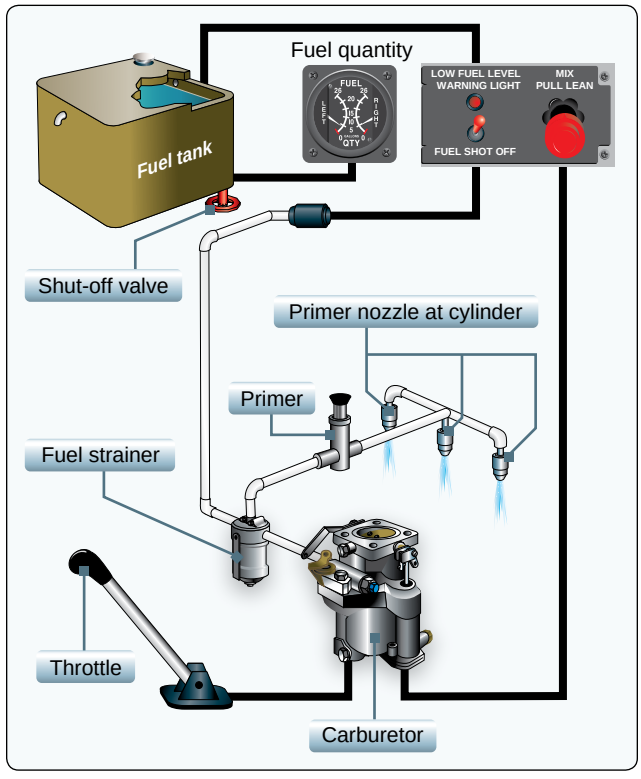


Figure 4-22. *A typical gravity feed fuel system, in a helicopter with a reciprocating engine, contains the components shown here.*

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

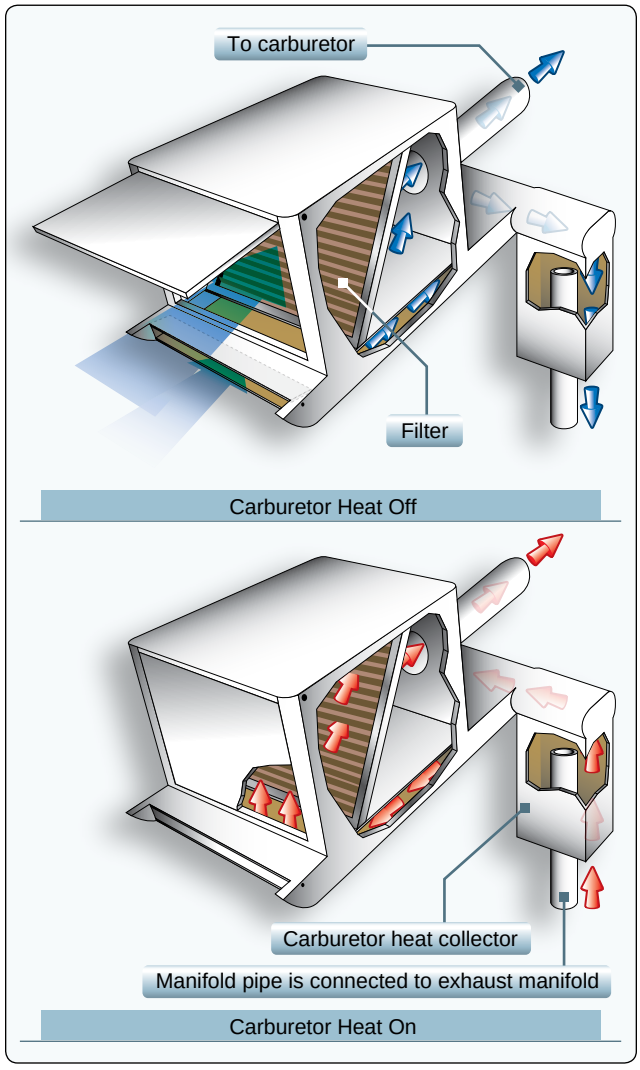


Figure 4-23. *When the carburetor heat is turned ON, normal air flow is blocked, and heated air from an alternate source flows through the filter to the carburetor.*

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

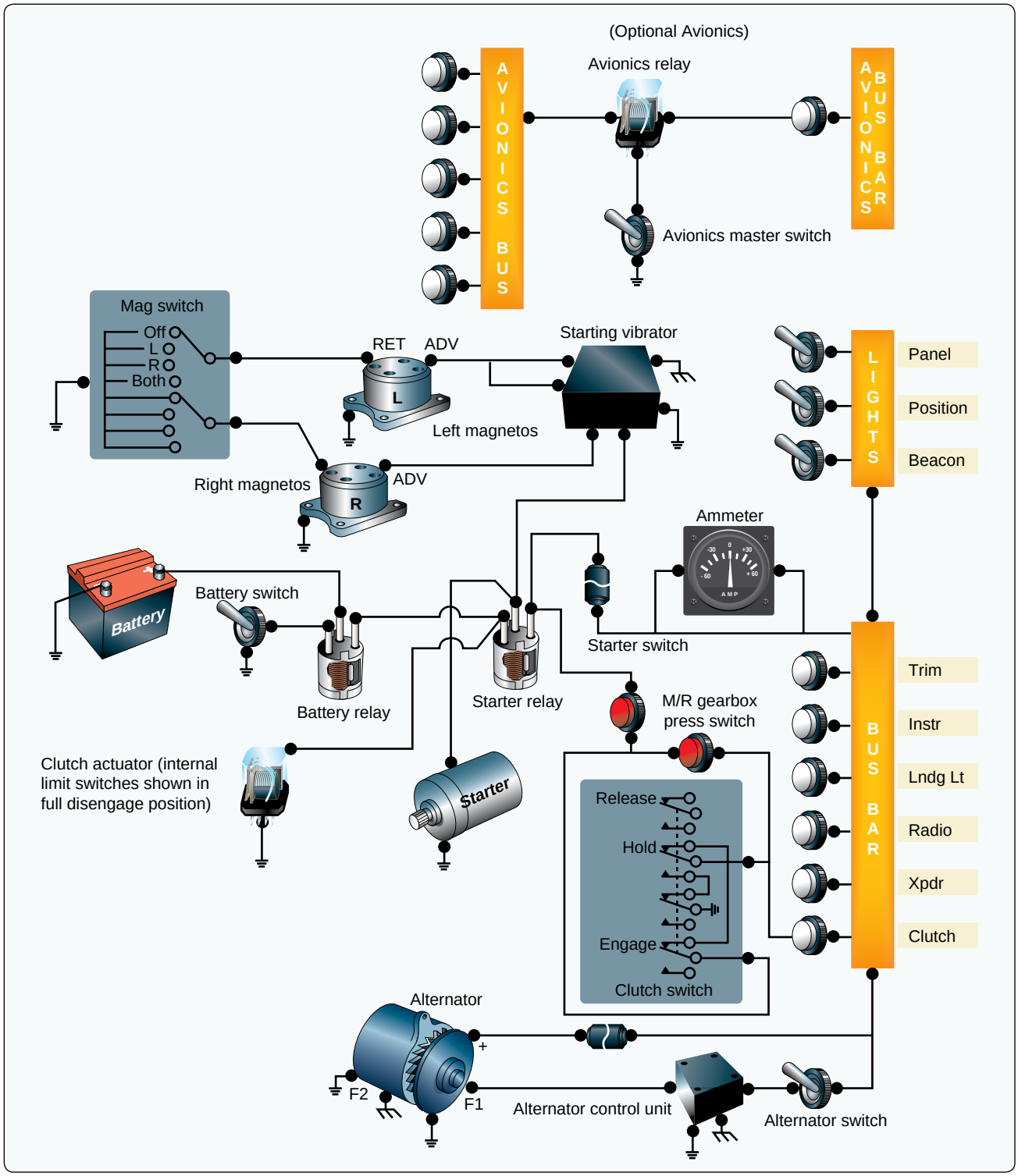


Figure 4-24. *An electrical system schematic like this sample is included in most POHs. Notice that the various bus bar accessories are protected by circuit breakers. However, ensure that all electrical equipment is turned off before starting the engine. This protects sensitive components, particularly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

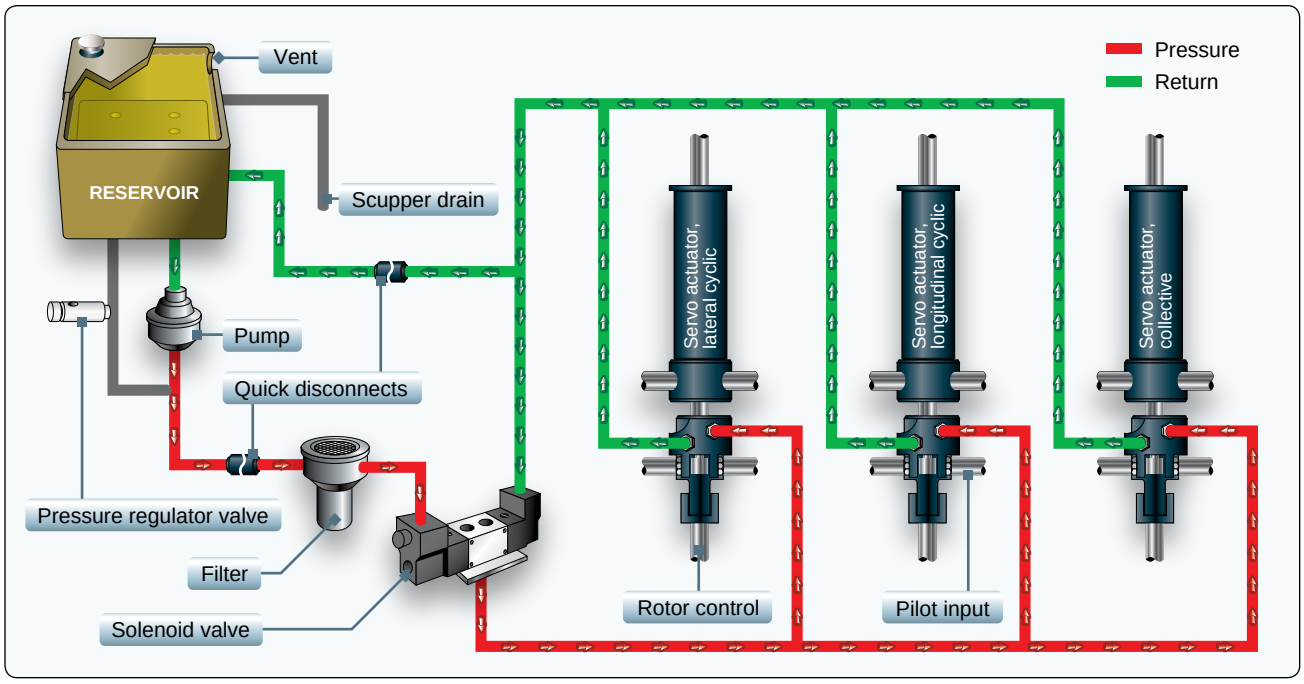


Figure 4-25. *A typical hydraulic system for helicopters in the light to medium range.*

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 electro-mechanical 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.

Chapter 5

Rotorcraft Flight Manual

Introduction

Title 14 of the Code of Federal Regulations (14 CFR) part 91 requires pilot compliance with the operating limitations specified in approved rotorcraft flight manuals, markings, and placards. Originally, flight manuals were often characterized by a lack of essential information and followed whatever format and content the manufacturer deemed appropriate. This changed with the acceptance of the General Aviation Manufacturers Association (GAMA) specification for a Pilot's Operating Handbook, which established a standardized format for all general aviation airplane and rotorcraft flight manuals. The term "Pilot's Operating Handbook (POH)" is often used in place of "Rotorcraft Flight Manual (RFM)."



However, if "Pilot's Operating Handbook" is used as the main title instead of "Rotorcraft Flight Manual," a statement must be included on the title page indicating that the document is the Federal Aviation Administration (FAA) approved Rotorcraft Flight Manual (RFM). *[Figure 5-1]*

Not including the preliminary pages, an FAA-approved RFM may contain as many as ten sections. These sections are: General Information; Operating Limitations; Emergency Procedures; Normal Procedures; Performance; Weight and Balance; Aircraft and Systems Description; Handling, Servicing, and Maintenance Supplements; and Safety and Operational Tips. Manufacturers have the option of including a tenth section on safety and operational tips and an alphabetical index at the end of the handbook.

Preliminary Pages

While RFMs may appear similar for the same make and model of aircraft, each flight manual is unique since it contains specific information about a particular aircraft, such as the equipment installed, and weight and balance information. Therefore, manufacturers are required to include the serial number and registration on the title page to identify the aircraft to which the flight manual belongs. If a flight manual does not indicate a specific aircraft registration and serial number, it is limited to general study purposes only.

Most manufacturers include a table of contents, which identifies the order of the entire manual by section number and title. In addition, some helicopters may include a log of changes or a revision page to track changes to the manual. Usually, each section also contains its own table of contents. Page numbers reflect the section being read, 1-1, 2-1, 3-1, and so on. If the flight manual is published in looseleaf form, each section is usually marked with a divider tab indicating the section number or title, or both. The emergency procedures section may have a red tab for quick identification and reference.

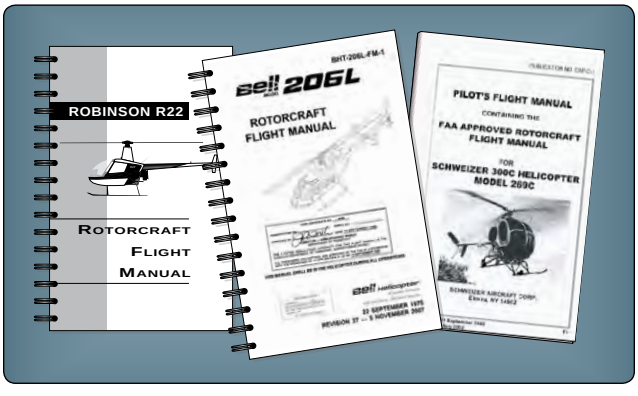


Figure 5-1. *The RFM is a regulatory document in terms of the maneuvers, procedures, and operating limitations described therein.*

General Information (Section 1)

The general information section provides the basic descriptive information on the rotorcraft and the powerplant. In some manuals there is a three-view drawing of the rotorcraft that provides the dimensions of various components, including the overall length and width, and the diameter of the rotor systems. This is a good place for pilots to quickly familiarize themselves with the aircraft. Pilots need to be aware of the dimensions of the helicopter since they often must decide the suitability of an operations area for themselves, as well as hanger space, landing pad, and ground handling needs.

Pilots can find definitions, abbreviations, explanations of symbology, and some of the terminology used in the manual at the end of this section. At the option of the manufacturer, metric and other conversion tables may also be included.

Operating Limitations (Section 2)

The operating limitations section contains only those limitations required by regulation or that are necessary for the safe operation of the rotorcraft, powerplant, systems, and equipment. It includes operating limitations, instrument markings, color coding, and basic placards. Some of the areas included are: airspeed, altitude, rotor, and powerplant limitations, including fuel and oil requirements; weight and loading distribution; and flight limitations.

Instrument Markings

Instrument markings may include, but are not limited to, green, red, and yellow ranges for the safe operation of the aircraft. The green marking indicates a range of continuous operation. The red range indicates the maximum or minimum operation allowed while the yellow range indicates a caution or transition area.

Airspeed Limitations

Airspeed limitations are shown on the airspeed indicator by color coding and on placards or graphs in the aircraft. A red line on the airspeed indicator shows the airspeed limit beyond which structural damage could occur. This is called the never exceed speed, or V_{NE}. The normal operating speed range is depicted by a green arc. A blue or a red cross-hatched line is sometimes added to show the maximum autorotation speed. *[Figure 5-2]*

Other airspeed limitations may be included in this section of the RFM. Examples include reduced V_{NE} when doors are removed, maximum airspeed for level flight with maximum continuous power (V_H), or restrictions when carrying an external load. Pilots need to understand and adhere to all airspeed limitations appropriate to the make, model, and configuration of the helicopter being flown.

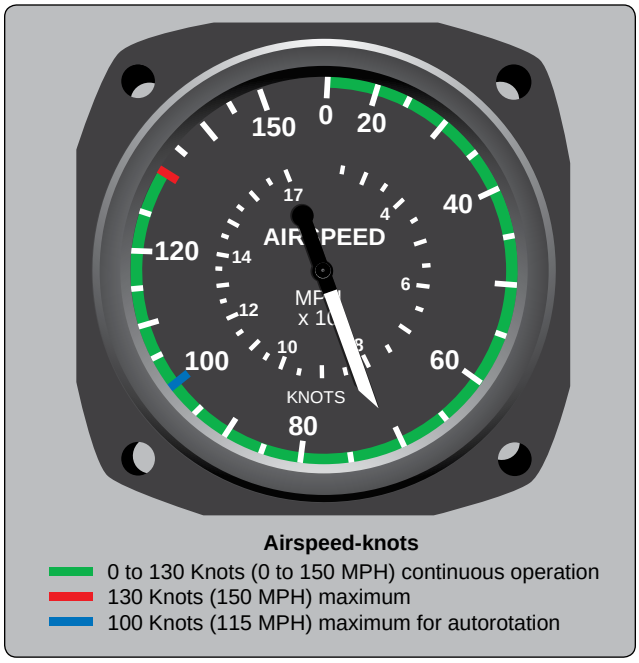


Figure 5-2. *Typical airspeed indicator limitations and markings.*

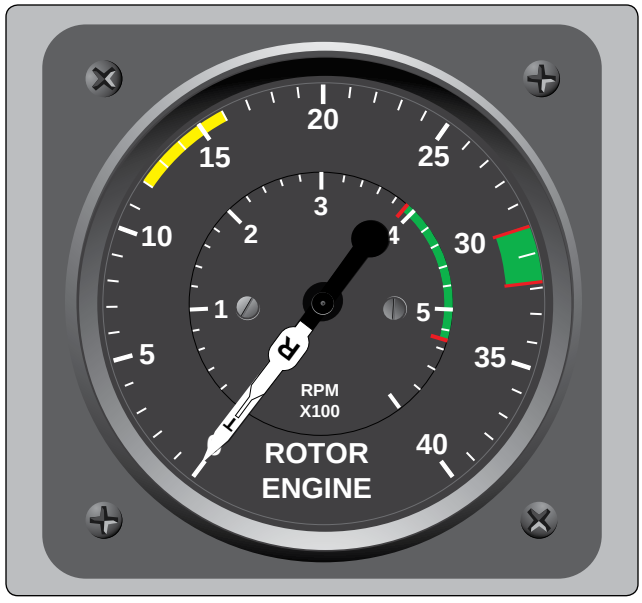


Figure 5-3. *Markings on a typical dual-needle tachometer in a reciprocating-engine helicopter. The outer band shows the limits of the superimposed needles when the engine is turning the rotor. The inner band indicates the power-off limits.*

Altitude Limitations

If the rotorcraft has a maximum operating density altitude (see page 7-2), it is indicated in this section of the flight manual. Sometimes the maximum altitude varies based on different gross weights.

Rotor Limitations

Low rpm does not produce sufficient lift, and high rpm may cause structural damage, therefore rotor rpm limitations have minimum and maximum values. A green arc depicts the normal operating range with red lines showing the minimum and maximum limits. *[Figure 5-3]*

There are two different rotor rpm limitations: power-on and power-off. Power-on limitations apply anytime the engine is turning the rotor and is depicted by a fairly narrow green band. A yellow arc may be included to show a transition range, which means that operation within this range is limited due to the possibility of increased vibrations or harmonics. This range may be associated with tailboom dynamic modes. Power-off limitations apply anytime the engine is not turning the rotor, such as when in an autorotation. In this case, the green arc is wider than the power-on arc, indicating a larger operating range.

Powerplant Limitations

The powerplant limitations area describes operating limitations on the helicopter's engine including such items as rpm range, power limitations, operating temperatures, and fuel and oil requirements. Most turbine engines and some reciprocating engines have a maximum power and a maximum continuous power rating. The "maximum power" rating is the maximum power the engine can generate and is usually limited by time. The maximum power range is depicted by a yellow arc on the engine power instruments, with a red line indicating the maximum power that must not be exceeded. "Maximum continuous power" is the maximum power the engine can generate continually and is depicted by a green arc. *[Figure 5-4]*

Manifold pressure is a measure of vacuum at the intake manifold. It is the difference between the air pressure (or vacuum) inside the intake manifold and the relative atmospheric pressure of the air around the engine. The red line on a manifold pressure gauge indicates the maximum amount of power. A yellow arc on the gauge warns of pressures approaching the limit of rated power.

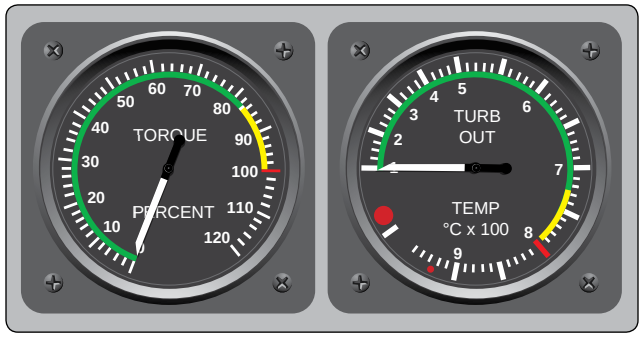


Figure 5-4. *Torque and turbine outlet temperature (TOT) gauges are commonly used with turbine-powered aircraft.*

[Figure 5-5] A placard near the gauge lists the maximum readings for specific conditions.

Weight and Loading Distribution

The weight and loading distribution section of the manufacturer's RFM contains the maximum certificated weights, as well as the center of gravity (CG) range. The location of the reference datum used in balance computations should also be included in this section. Weight and balance computations are not provided here, but rather in the weight and balance section of the RFM.

Flight Limitations

This area lists any maneuvers which are prohibited, such as acrobatic flight or flight into known icing conditions. If the rotorcraft can only be flown in visual flight rules (VFR) conditions, it is noted in this area. Also included are the minimum crew requirements, and the pilot seat location, if applicable, from which solo flights must be conducted.

Placards

All rotorcraft generally have one or more placards displayed that have a direct and important bearing on the safe operation of the rotorcraft. These placards are located in a conspicuous place within the cabin and normally appear in the limitations section. Since V_{NE} varies with altitude, this placard can be found in all helicopters. *[Figure 5-6]*

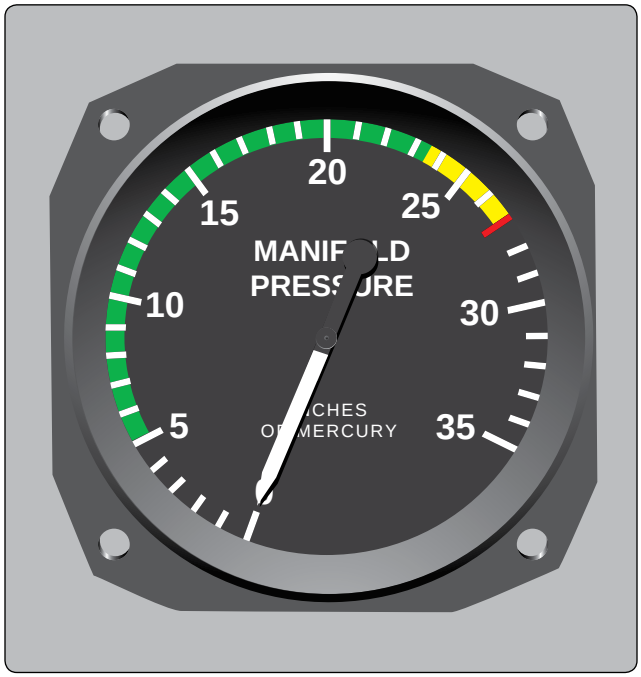


Figure 5-5. *The manifold pressure gauge is an engine instrument typically used in piston aircraft engines to measure the pressure inside the induction system of an engine. Manifold pressure is a measurement of vacuum and the measurement is taken at the intake manifold.*

Press Alt. (1,000 ft.)	V_{NE}—MPH IAS							Gross Weight
F OAT	2	4	6	8	10	12	14	
0	109	109	105	84	61	--	--	More than 1,700 lb
20	109	109	94	72	49	--	--	
40	109	103	81	59	--	--	--	
60	109	91	70	48	--	--	--	
80	109	80	59	--	--	--	--	
100	109	70	48	--	--	--	--	
0	**109**	**109**	**109**	**109**	**98**	**77**	**58**	1,700 lb or less
20	**109**	**109**	**109**	**109**	**85**	**67**	**48**	
40	**109**	**109**	**109**	**96**	**75**	**57**	**--**	
60	**109**	**109**	**108**	**84**	**66**	**48**	**--**	
80	**109**	**109**	**95**	**74**	**57**	**--**	**--**	
100	**109**	**108**	**84**	**66**	**48**	**--**	**--**	

Maximum V_{NE} Doors off—102 MPH IAS

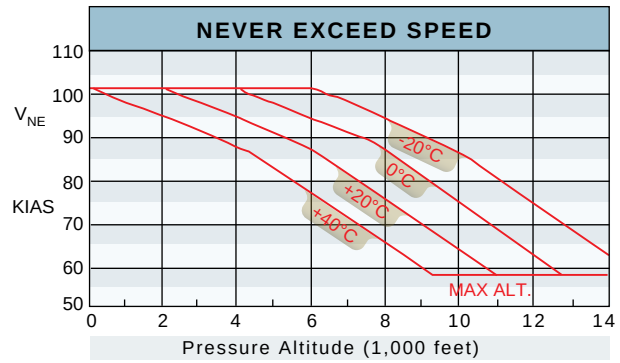


Figure 5-6. *Various VNE placards.*

Emergency Procedures (Section 3)

Concise checklists describing the recommended procedures and airspeeds for coping with various types of emergencies or critical situations can be found in this section. Some of the emergencies covered include: engine failure in a hover and at altitude, tail rotor failures, fires, and systems failures. The procedures for restarting an engine and for ditching in the water might also be included.

Manufacturers may first show the emergencies checklists in an abbreviated form with the order of items reflecting the sequence of action. This is followed by amplified checklists providing additional information to clarify the procedure. To be prepared for an abnormal or emergency situation, learn the first steps of each checklist, if not all the steps. If time permits, refer to the checklist to make sure all items have been covered. For more information on emergencies, refer to Chapter 11, Helicopter Emergencies and Hazards.

Manufacturers are encouraged to include an optional area titled Abnormal Procedures, which describes recommended procedures for handling malfunctions that are not considered to be emergencies. This information would most likely be found in larger helicopters.

Normal Procedures (Section 4)

The normal procedures section is the section most frequently used. It usually begins with a listing of airspeeds that may enhance the safety of normal operations. It is a good idea to learn the airspeeds that are used for normal flight operations. The next part of the section includes several checklists, which cover the preflight inspection, before-starting procedure, how to start the engine, rotor engagement, ground checks, takeoff, approach, landing, and shutdown. Some manufacturers also include the procedures for practice autorotations. To avoid skipping an important step, always use a checklist when one is available. More information on maneuvers can be found in Chapter 9, Basic Flight Maneuvers, and Chapter 10, Advanced Flight Maneuvers.

Performance (Section 5)

The performance section contains all the information required by the regulations and any additional performance information the manufacturer determines may enhance a pilot's ability to operate the helicopter safely. Although the performance section is not in the limitation section and is therefore not a limitation, operation outside or beyond the flight-tested and documented performance section can be expensive, slightly hazardous, or outright dangerous to life and property. If the helicopter is certificated under 14 CFR part 29, then the performance section may very well be a restrictive limitation. In any event, a pilot should determine the performance available and plan to stay within those parameters.

These charts, graphs, and tables vary in style, but all contain the same basic information. Some examples of the performance information that can be found in most flight manuals include a calibrated versus indicated airspeed conversion graph, hovering ceiling versus gross weight charts, and a height-velocity diagram. *[Figure 5-7]* For information on how to use the charts, graphs, and tables, refer to Chapter 7, Helicopter Performance.

Weight and Balance (Section 6)

The weight and balance section should contain all the information required by the FAA that is necessary to calculate weight and balance. To help compute the proper data, most manufacturers include sample problems. Weight and balance is detailed in Chapter 6, Weight and Balance.

Aircraft and Systems Description (Section 7)

The aircraft and systems description section is an excellent place to study all the systems found on an aircraft. The manufacturers should describe the systems in a manner that is understandable to most pilots. For larger, more complex helicopters, the manufacturer may assume a higher degree of knowledge. For more information on helicopter systems, refer to Chapter 4, Helicopter Components, Sections, and Systems.

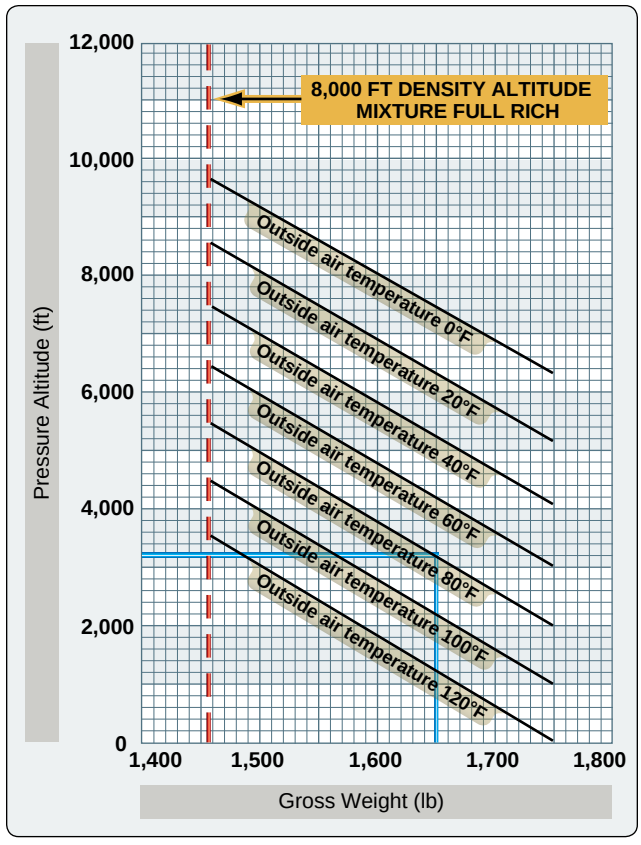


Figure 5-7. *One of the performance charts in the performance section is the In Ground Effect Hover Ceiling versus Gross Weight chart. This chart can be used to determine how much weight can be carried and still operate at a specific pressure altitude or, if carrying a specific weight, detrmine that specific altitude limitation.*

Handling, Servicing, and Maintenance (Section 8)

The handling, servicing, and maintenance section describes the maintenance and inspections recommended by the manufacturer, as well as those required by the regulations, and airworthiness directive (AD) compliance procedures. There are also suggestions on how the pilot/operator can ensure that the work is done properly.

This section also describes preventative maintenance that may be accomplished by certificated pilots, as well as the manufacturer's recommended ground handling procedures, including considerations for hangaring, tie down, and general storage procedures for the helicopter.

Supplements (Section 9)

The supplements section describes pertinent information necessary to operate optional equipment installed on the helicopter that would not be installed on a standard aircraft. Some of this information may be supplied by the aircraft manufacturer, or by the maker of the optional equipment. The information is then inserted into the flight manual at the time the equipment is installed.

Since civilian manuals are not updated to the extent of military manuals, the pilot must learn to read the supplements after determining what equipment is installed and amend their daily use checklists to integrate the supplemental instructions and procedures. This is why air carriers must furnish checklists to their crews. Those checklists furnished to the crews must incorporate all procedures from any and all equipment actually installed in the aircraft and the approved company procedures.

Safety and Operational Tips (Section 10)

The safety and operational tips section is optional and contains a review of information that could enhance the safety of the operation. Manufacturers may include best operating practices and other recommended procedures for the enhancement of safety and reducing accidents. Some examples of the information that might be covered include physiological factors, general weather information, fuel conservation procedures, external load warnings, low rotor rpm considerations, and recommendations that if not adhered to, could lead to an emergency.

Chapter Summary

This chapter familiarized the reader with the RFM. It detailed each section and explained how to follow and better understand the flight manual to enhance safety of flight.

Chapter 6

Weight and Balance

Introduction

It is vital to comply with weight and balance limits established for helicopters. Operating above the maximum weight limitation compromises the structural integrity of the helicopter and adversely affects performance. Balance is also critical because, on some fully loaded helicopters, center of gravity (CG) deviations as small as three inches can dramatically change a helicopter's handling characteristics. Operating a helicopter that is not within the weight and balance limitations is unsafe. Refer to FAA-H-8083-1 (as revised), Aircraft Weight and Balance Handbook, for more detailed information.



Weight

When determining if a helicopter is within the weight limits, consider the weight of the basic helicopter, crew, passengers, cargo, and fuel. Although the effective weight (load factor) varies during maneuvering flight, this chapter primarily addresses the weight of the loaded helicopter while at rest.

It is critical to understand that the maximum allowable weight may change during the flight. When operations include out of ground effect (OGE) hovers and confined areas, planning must be done to ensure that the helicopter is capable of lifting the weight during all phases of flight. The weight may be acceptable during the early morning hours, but as the density altitude increases during the day, the maximum allowable weight may have to be reduced to keep the helicopter within its capability.

The following terms are used when computing a helicopter's weight:

- Basic Empty Weight
- Maximum Gross Weight
- Weight Limitations

Basic Empty Weight

The starting point for weight computations is the basic empty weight. This is the weight of the standard helicopter, optional equipment, unusable fuel, and all operating fluids including engine and transmission oil, and hydraulic fluid for those aircraft so equipped. Some helicopters might use the term "licensed empty weight," which is nearly the same as basic empty weight, except that it does not include full engine and transmission oil, just undrainable oil. If flying a helicopter that lists a licensed empty weight, be sure to add the weight of the oil to the computations.

Maximum Gross Weight

The maximum weight of the helicopter is referred to its maximum gross weight. Most helicopters have an internal maximum gross weight, which refers to the weight within the helicopter structure and an external maximum gross weight, which refers to the weight of the helicopter with an external load. The external maximum weight may vary depending on where it is attached to the helicopter. Some large cargo helicopters may have several attachment points for sling load or winch operations. These helicopters can carry a tremendous amount of weight when the attachment point is directly under the CG of the aircraft.

Weight Limitations

Weight limits are necessary to guarantee the structural integrity of the helicopter, enable pilots to predict helicopter performance and insure aircraft controllability. Although aircraft manufacturers build in safety factors, a pilot should never intentionally exceed the load limits for which a helicopter is certificated.

Operating below a minimum weight could adversely affect the handling characteristics of the helicopter. During single-pilot operations in some helicopters, a pilot needs to use a large amount of forward cyclic to maintain a hover. By adding ballast to the helicopter, the neutral cyclic position can be shifted toward the center of its range, thus giving a greater range of control outward from neutral in every direction. When operating at or below the minimum weight of the helicopter, additional weight also improves autorotational characteristics since the autorotational descent can be established sooner. In addition, operating below minimum weight could prevent achieving the desirable rotor revolutions per minute (rpm) during autorotations.

Operating above a maximum weight could result in structural deformation or failure during flight if encountering excessive load factors, strong wind gusts, or turbulence. Weight and maneuvering limitations also are factors in establishing fatigue life of components. Overweight, meaning overstressed, parts fail sooner than anticipated. Therefore, premature failure is a major consideration in determination of fatigue life and life cycles of parts.

Although a helicopter is certificated for a specified maximum gross weight, it is not safe to take off with this load under some conditions. Anything that adversely affects takeoff, climb, hovering, and landing performance may require off-loading of fuel, passengers, or baggage to some weight less than the published maximum. Factors that can affect performance include high altitude, high temperature, and high humidity conditions, which result in a high-density altitude. In-depth performance planning is critical when operating in these conditions.

Balance

Helicopter performance is not only affected by gross weight, but also by the position of that weight. It is essential to load the aircraft within the allowable CG range specified in the rotorcraft flight manual's (RFM) weight and balance limitations. Loading outside approved limits can result in insufficient control travel for safe operation.

Center of Gravity

The pilot should ensure that the helicopter is properly balanced and within its center of gravity limitations, so that minimal cyclic input is required during hovering flight, except for any wind corrections. Since the fuselage acts as a pendulum suspended from the rotor, changing the CG changes the angle at which the aircraft hangs from the rotor. When the CG is directly under the rotor mast, the helicopter hangs horizontally; if the CG is too far forward of the mast, the helicopter hangs

with its nose tilted down; if the CG is too far aft of the mast, the nose tilts up. *[Figure 6-1]*

CG Forward of Forward Limit

A forward CG may occur when a heavy pilot and passenger take off without baggage or proper ballast located aft of the rotor mast. This situation becomes worse if the fuel tanks are located aft of the rotor mast because as fuel burns the CG continues to shift forward.

This condition is easily recognized when coming to a hover following a vertical takeoff. The helicopter has a nose-low attitude, and excessive rearward displacement of the cyclic control is needed to maintain a hover in a no-wind condition. Do not continue flight in this condition, since a pilot could rapidly lose rearward cyclic control as fuel is consumed. A pilot may also find it impossible to decelerate sufficiently to bring the helicopter to a stop. In the event of engine failure and the resulting autorotation, there may not be enough cyclic control to flare properly for the landing.

A forward CG is not as obvious when hovering into a strong wind, since less rearward cyclic displacement is required than when hovering with no wind. When determining whether a critical balance condition exists, it is essential to consider the wind velocity and its relation to the rearward displacement of the cyclic control.

CG Aft of Aft Limit

Without proper ballast in the cockpit, exceeding the aft CG may occur when:

- A lightweight pilot takes off solo with a full load of fuel located aft of the rotor mast.
- A lightweight pilot takes off with maximum baggage allowed in a baggage compartment located aft of the rotor mast.
- A lightweight pilot takes off with a combination of baggage and substantial fuel where both are aft of the rotor mast.

A pilot can recognize the aft CG condition when coming to a hover following a vertical takeoff. The helicopter will have a tail-low attitude and will need excessive forward displacement of cyclic control to maintain a hover in a no-wind condition. When facing upwind, even greater forward cyclic is needed.

If flight is continued in this condition, it may be impossible to fly in the upper allowable airspeed range due to inadequate forward cyclic authority to maintain a nose-low attitude. In addition, with an extreme aft CG, gusty or rough air could accelerate the helicopter to a speed faster than that produced with full forward cyclic control. In this case, dissymmetry of lift and blade flapping could cause the rotor disk to tilt aft. With full forward cyclic control already applied, a pilot might not be able to lower the rotor disk, resulting in possible loss of control, or the rotor blades striking the tailboom.

Lateral Balance

For smaller helicopters, it is generally unnecessary to determine the lateral CG for normal flight instruction and passenger flights. This is because helicopter cabins are relatively narrow and most optional equipment is located near the centerline. However, some helicopter manuals specify the seat from which a pilot must conduct solo flight. In addition, if there is an unusual situation that could affect the lateral CG, such as a heavy pilot and a full load of fuel on one side of the helicopter, its position should be checked against the CG envelope. If carrying external loads in a position that requires large lateral cyclic control displacement to maintain level flight, fore and aft cyclic effectiveness could be limited dramatically. Manufacturers generally account for known lateral CG displacements by locating external attachment points opposite the lateral imbalance. Examples are placement of hoist systems attached to the side, and wing stores commonly used on military aircraft for external fuel pods or armament systems.

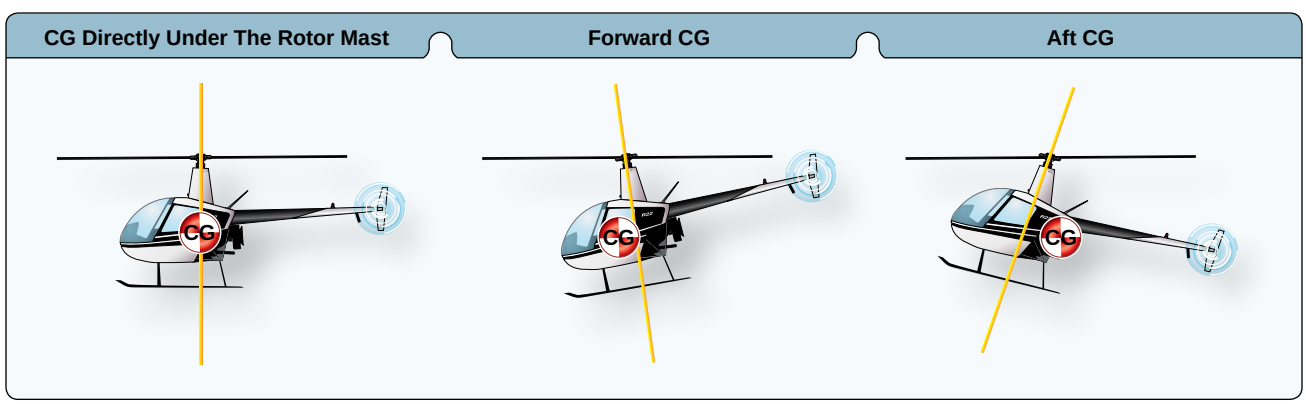


Figure 6-1. *The location of the CG strongly influences how the helicopter handles.*

Weight and Balance Calculations

When determining whether a helicopter is properly loaded, two questions must be answered:

1. Is the gross weight less than or equal to the maximum allowable gross weight?
2. Is the CG within the allowable CG range, and will it stay within the allowable range throughout the duration of flight including all loading configurations that may be encountered?

To answer the first question, just add the weight of the items comprising the useful load (pilot, passengers, fuel, oil [if applicable] cargo, and baggage) to the basic empty weight of the helicopter. Ensure that the total weight does not exceed the maximum allowable gross weight.

To answer the second question, use CG or moment information from loading charts, tables, or graphs in the RFM. It is important to note that any weight and balance computation is only as accurate as the information provided. Therefore, ask passengers what they weigh and add a few pounds to account for the additional weight of clothing, especially during the winter months. Baggage should be weighed on a scale, if practical. If a scale is not available, compute personal loading values according to each individual estimate. *Figure 6-2* indicates the standard weights for specific operating fluids. These values are used when computing a helicopter's balance.

Reference Datum

Balance is determined by the location of the CG, which is usually described as a given number of inches from the reference datum. The horizontal reference datum is an imaginary vertical plane or point, arbitrarily fixed somewhere along the longitudinal axis of the helicopter, from which all horizontal distances are measured for weight and balance purposes. There is no fixed rule for its location. It may be located at the rotor mast, the nose of the helicopter, or even at a point in space ahead of the helicopter. *[Figure 6-3]*

Aviation Gasoline (AVGAS)	6 lb/gal
Jet Fuel (JP-4)	6.5 lb/gal
Jet Fuel (JP-5)	6.8 lb/gal
Reciprocating Engine Oil	7.5 lb/gal*
Turbine Engine Oil	Varies between 6 and 8 lb/gal*
Water	8.35 lb/gal

*Oil weight is given in pounds per gallon while oil capacity is usually given in quarts; therefore, convert the amount of oil to gallons before calculating its weight. Remember, four quarts equal one gallon.

Figure 6-2. *When making weight and balance computations, always use actual weights if they are available, especially if the helicopter is loaded near the weight and balance limits.*

The lateral reference datum is usually located at the center of the helicopter. The location of the reference datum is established by the manufacturer and is defined in the RFM. *[Figure 6-4]*

Chapter Summary

This chapter discusses the importance of computing the weight and balance of the helicopter. The chapter also discusses the common terms and meanings associate with weight and balance.

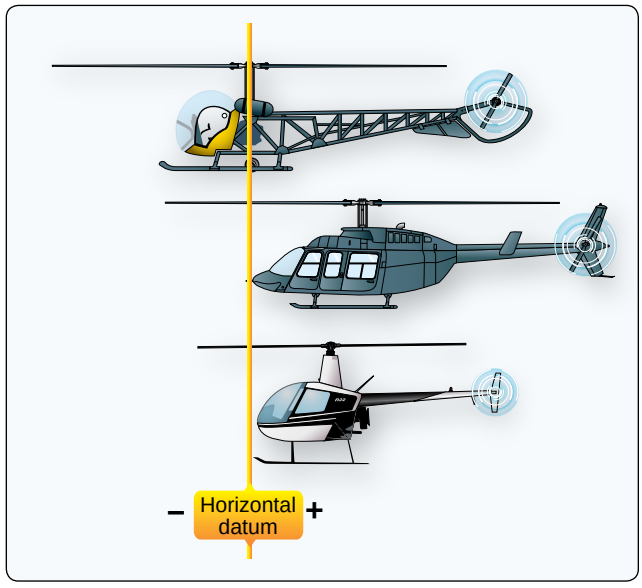


Figure 6-3. *While the horizontal reference datum can be anywhere the manufacturer chooses, some manufacturers choose the datum line at or ahead of the most forward structural point on the helicopter, in which case all moments are positive. This aids in simplifying calculations. Other manufacturers choose the datum line at some point in the middle of the helicopter, in which case moments produced by weight in front of the datum are negative and moments produced by weight aft of the datum are positive.*

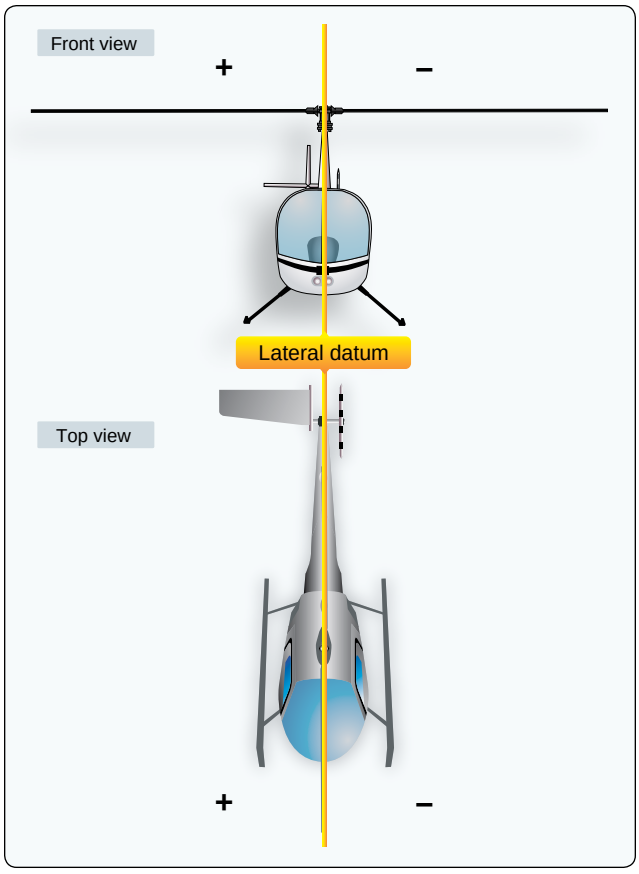


Figure 6-4. *The lateral reference datum is located longitudinally through the center of the helicopter; therefore, there are positive and negative values.*

Chapter 7

Helicopter Performance

Introduction

A pilot's ability to predict the performance of a helicopter is extremely important. It helps to determine how much weight the helicopter can carry before takeoff, if the helicopter can safely hover at a specific altitude and temperature, the distance required to climb above obstacles, and what the maximum climb rate will be.



Factors Affecting Performance

A helicopter's performance is dependent on the power output of the engine and the lift produced by the rotors, whether it is the main rotor(s) or tail rotor. Any factor that affects engine and rotor efficiency affects performance. The three major factors that affect performance are density altitude, weight, and wind. The Pilot's Handbook of Aeronautical Knowledge, FAA-H-8083-25 (as revised), discusses these factors in great detail.

Moisture (Humidity)

Humidity alone is usually not considered an important factor in calculating density altitude and helicopter performance; however, it does contribute. There are no rules of thumb used to compute the effects of humidity on density altitude, but some manufacturers include charts with 80 percent relative humidity columns as additional information. There appears to be an approximately 3–4 percent reduction in performance compared to dry air at the same altitude and temperature, so expect a decrease in hovering and takeoff performance in high humidity conditions. Although 3–4 percent seems insignificant, it can be the cause of a mishap when already operating at the limits of the helicopter.

Weight

Weight is one of the most important factors because the pilot can control it. Most performance charts include weight as one of the variables. By reducing the weight of the helicopter, a pilot may be able to take off or land safely at a location that otherwise would be impossible. However, if ever in doubt about whether a takeoff or landing can be performed safely, delay your takeoff until more favorable density altitude conditions exist. If airborne, try to land at a location that has more favorable conditions, or one where a landing can be made that does not require a hover.

In addition, at higher gross weights, the increased power required to hover produces more torque, which means more antitorque thrust is required. In some helicopters during high altitude operations, the maximum antitorque produced by the tail rotor during a hover may not be sufficient to overcome torque even if the gross weight is within limits.

Winds

Wind direction and velocity also affect hovering, takeoff, and climb performance. Translational lift occurs any time there is relative airflow over the rotor disk. This occurs whether the relative airflow is caused by helicopter movement or by the wind. Assuming a headwind, as wind speed increases, translational lift increases, resulting in less power required to hover.

The wind direction is also an important consideration. Headwinds are the most desirable as they contribute to the greatest increase in performance. Strong crosswinds and tailwinds may require the use of more tail rotor thrust to maintain directional control. This increased tail rotor thrust absorbs power from the engine, which means there is less power available to the main rotor for the production of lift. Some helicopters even have a critical wind azimuth or maximum safe relative wind chart. Operating the helicopter beyond these limits could cause loss of tail rotor effectiveness.

Takeoff and climb performance is greatly affected by wind. When taking off into a headwind, effective translational lift is achieved earlier, resulting in more lift and a steeper climb angle. When taking off with a tailwind, more distance is required to accelerate through translation lift.

Performance Charts

In developing performance charts, aircraft manufacturers make certain assumptions about the condition of the helicopter and the ability of the pilot. It is assumed that the helicopter is in good operating condition, calm wind, and the engine is developing its rated power. The pilot is assumed to be following normal operating procedures and to have average flying abilities. Average means a pilot capable of doing each of the required tasks correctly and at the appropriate times.

Using these assumptions, the manufacturer develops performance data for the helicopter based on actual flight tests. However, they do not test the helicopter under each and every condition shown on a performance chart. Instead, they evaluate specific data and mathematically derive the remaining data.

Height/Velocity Diagram

The height/velocity (H/V) diagram shows the combinations of airspeed and height above the ground, which will allow an average pilot to successfully complete a landing after an engine failure. By carefully studying the height/velocity diagram, a pilot is able to avoid the combinations of altitude and airspeed that may not allow sufficient time or altitude to enter a stabilized autorotative descent. Refer to *Figure 7-1* during the remainder of the discussion on the height/velocity diagram.

In the simplest explanation, the H/V diagram is a diagram in which the shaded areas should be avoided, as the pilot may be unable to complete an autorotation landing without damage. The H/V diagram usually contains a takeoff profile, where the diagram can be traversed from zero height and zero speed to

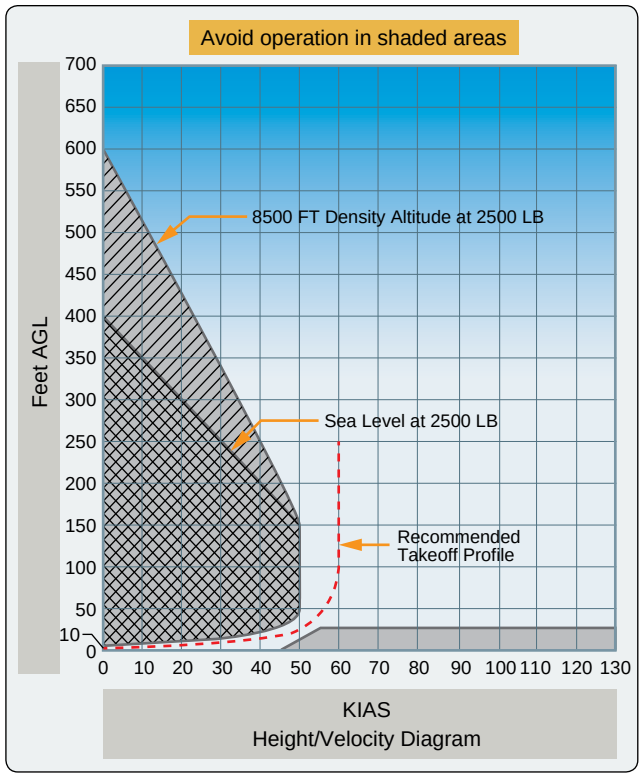


Figure 7-1. *Sample height/velocity diagram for a Robinson Model R44 II.*

cruise, without entering the shaded areas or with minimum exposure to shaded areas.

The grey portion on the left side of the diagram marks a flight profile that probably does not allow the pilot to complete an autorotation successfully, primarily due to having insufficient airspeed to enter an autorotative profile in time to avoid a crash. The shaded area on the lower right is dangerous due to the airspeed and proximity to the ground resulting in dramatically reduced reaction time for the pilot in the case of mechanical failure, or other in-flight emergencies. This shaded area at the lower right is not portrayed in H/V diagrams for multiengine helicopters capable of safely hovering and flying with a single engine failure.

The following examples further illustrate the relevance of the H/V diagram to a single-engine helicopter.

At low heights with low airspeed, such as a hover taxi, the pilot can simply use the kinetic energy from the rotor disk to cushion the landing with collective, converting rotational inertia to lift. The aircraft is in a safe part of the H/V diagram. At the extreme end of the scale (e.g., a three-foot hover taxi at walking pace) even a complete failure to recognize the power loss resulting in an uncushioned landing would probably be survivable.

As the airspeed increases without an increase in height, there comes a point at which the pilot's reaction time would be insufficient to react with a flare in time to prevent a high speed, and thus probably fatal, ground impact. Another thing to consider is the length of the tailboom and the response time of the helicopter flight controls at slow airspeeds and low altitudes. Even small increases in height give the pilot much greater time to react; therefore, the bottom right part of the H/V diagram is usually a shallow gradient. If airspeed is above ideal autorotation speed, the pilot's instinct is usually to flare to convert speed to height and increase rotor rpm through coning, which also immediately gets them out of the dead man's curve.

Conversely, an increase in height without a corresponding increase in airspeed puts the aircraft above a survivable uncushioned impact height, and eventually above a height where rotor inertia can be converted to sufficient lift to enable a survivable landing. This occurs abruptly with airspeeds much below the ideal autorotative speed (typically 40–80 knots). The pilot must have enough time to accelerate to autorotation speed in order to autorotate successfully; this directly relates to a requirement for height. Above a certain height the pilot can achieve autorotation speed even from a zero knot start, thus putting high OGE hovers outside the curve.

The typical safe takeoff profile involves initiation of forward flight from a 2–3 feet landing gear height, only gaining altitude as the helicopter accelerates through translational lift, as airspeed approaches a safe autorotative speed. At this point, some of the increased thrust available may be used to attain safe climb airspeed, which will keep the helicopter out of the shaded or hatched areas of the H/V diagram. Although helicopters are not restricted from conducting maneuvers that will place them in the shaded area of the H/V diagram, it is important for pilots to understand that operation in those shaded areas exposes pilot, aircraft, and passengers to a certain hazard should the engine or driveline malfunction. The pilot should always evaluate the risk of the maneuver versus the operational value.

The Effect of Weight Versus Density Altitude

The height/velocity diagram *[Figure 7-1]* depicts altitude and airspeed situations from which a successful autorotation can be made. The time required, and therefore, altitude necessary to attain a steady state autorotative descent, is dependent on the weight of the helicopter and the density altitude. For this reason, the H/V diagram is valid only when the helicopter is operated in accordance with the gross weight versus density altitude chart. If published, this chart is found in the RFM for the particular helicopter. *[Figure 7-2]* The gross weight

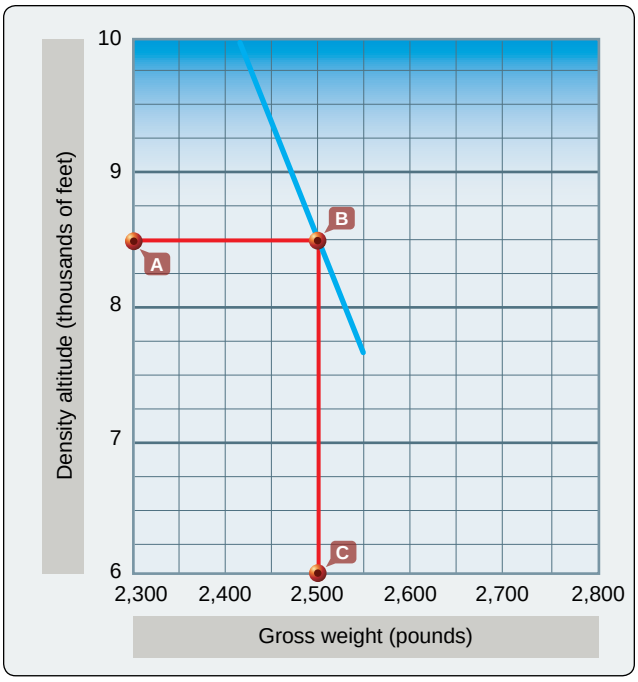


Figure 7-2. *Gross weight versus density altitude.*

versus density altitude chart is not intended to provide a restriction to gross weight, but to be an advisory of the autorotative capability of the helicopter during takeoff and climb. A pilot must realize, however, that at gross weights above those recommended by the gross weight versus density altitude chart, the values are unknown.

Assuming a density altitude of 8,500 feet, the height/velocity diagram in *Figure 7-1* would be valid up to a gross weight of approximately 2,500 pounds. This is found by entering the graph in *Figure 7-2* at a density altitude of 8,500 feet (point A), then moving horizontally to the solid line (point B). Moving vertically to the bottom of the graph (point C), with the existing density altitude, the maximum gross weight under which the height/velocity diagram is applicable is 2,500 pounds.

The production of performance charts and diagrams for helicopters are regulatory as set out in Title 14 of the Code of Federal Regulations (14 CFR) Part 27, Airworthiness Standards. These charts establish safer parameters for operation. Although not regulatory, the pilot should carry out a full risk assessment to carefully consider the higher risk before operating within the shaded areas of the height/velocity diagram.

Autorotational Performance

Most autorotational performance charts state that autorotational descent performance is a function of indicated airspeed (IAS) and is essentially unaffected by density altitude and gross weight. Keep in mind that, at some point, the potential energy expended during the autorotation is converted into kinetic energy for the flare and touchdown phase of the maneuver. It is at that point that increased density altitudes and heavier gross weights have a great impact on the successful completion of the autorotation. The rotor disk must be able to overcome the downward momentum of the helicopter and provide enough lift to cushion the landing. With increased density altitudes and gross weights, the lift potential is reduced and a higher collective pitch angle (angle of incidence) is required.

During autorotation gravity provides the source of energy powering the rotor by causing upflow up through the rotor during descent. This is the same as saying that potential energy is being traded for kinetic energy to turn the rotor as the aircraft descends.

In *Figure 7-3*, the S-300 curve shows the various combinations of horizontal and vertical speeds that supply the required energy to keep the rotor turning at a constant 471 rpm. For example, an airspeed of 54 mph with a corresponding vertical speed of 1,600 feet per minute (fpm) will provide enough kinetic energy to maintain the rotor at a 471 rpm. The rotor does not care if the air is coming from the front or the bottom so long as the total is sufficient to maintain the rpm. Any point on the curve will maintain rotor speed. However, the pilot does care because if he or she, for example, glides at 30 knots, the corresponding rate of descent will be over 2,200 fpm. Since there is little airspeed for a deceleration (or “flare”) to reduce the rate of decent before touchdown, the collective pitch application (increasing blade pitch and giving a final temporary increase in lift before the blades slow down) may be insufficient to arrest the rate of descent.

Students who fully comprehend this relationship understand why training autorotations are usually limited to airspeeds between the minimum rate of descent airspeed and the maximum range airspeed (usually about 25 percent faster than the minimum rate of descent airspeed).

Referencing a curve similar to the one shown in *Figure 7-3* is useful to understand the consequences of not maintaining the target airspeed when executing an autorotation. Simply put, the pilot should know why airspeed is the most significant factor affecting the rate of descent.

Hovering Performance

Helicopter performance revolves around whether or not the helicopter can be hovered. More power is required during the hover than in any other flight regime. Obstructions aside, if a hover can be maintained, a takeoff can be made, especially with the additional benefit of translational lift. Hover charts are provided for in ground effect (IGE) hover and out of ground effect (OGE) hover under various conditions of

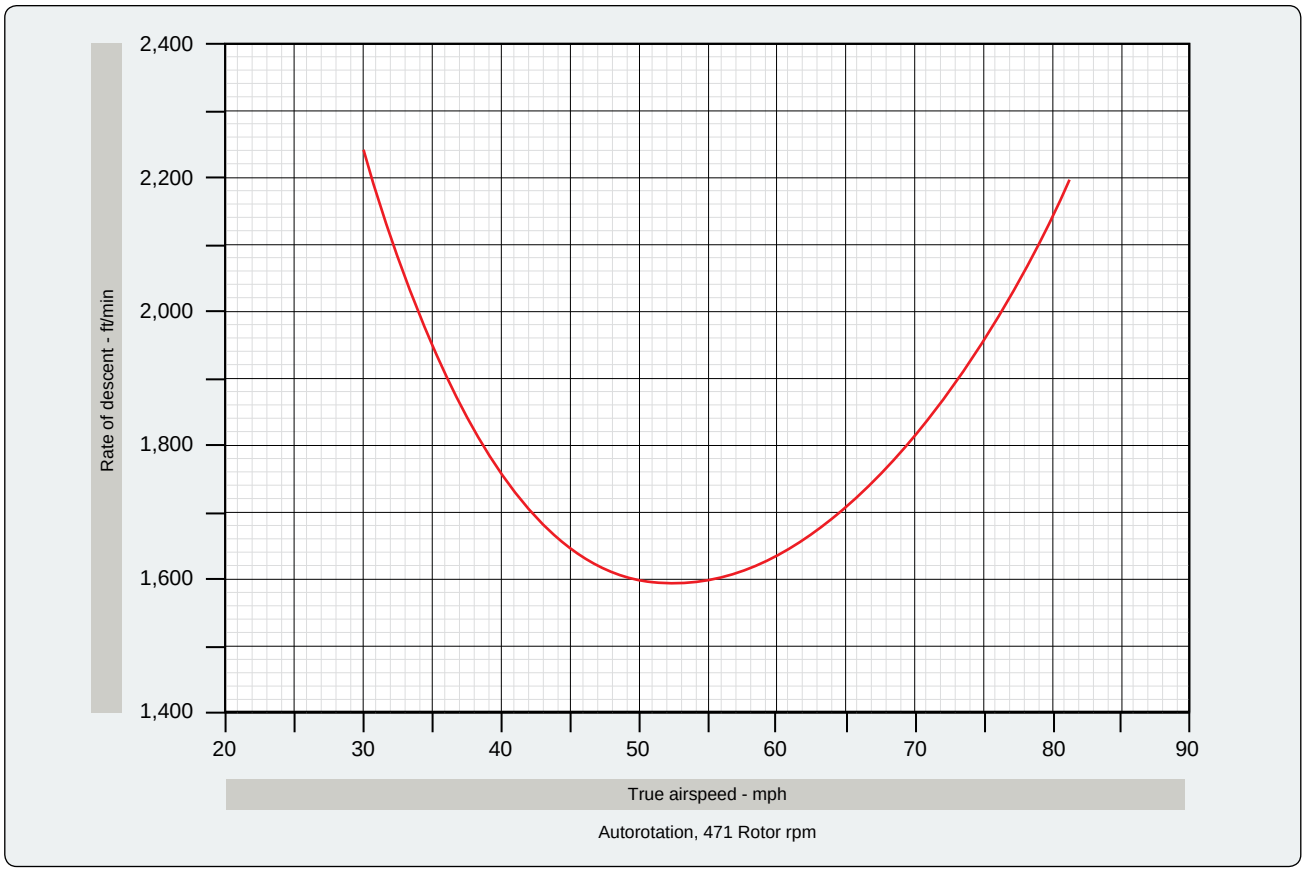


Figure 7-3. *An autorotation curve for the S-300 shows the various combinations of horizontal and vertical speeds that supply the required energy to keep the rotor turning at a constant 471 rpm.*

gross weight, altitude, temperature, and power. The IGE hover ceiling is usually higher than the OGE hover ceiling because of the added lift benefit produced by ground effect. See Chapter 2, Aerodynamics of Flight, for more details on IGE and OGE hover. A pilot should always plan an OGE hover when landing in an area that is uncertain or unverified. As density altitude increases, more power is required to hover. At some point, the power required is equal to the power available. This establishes the hovering ceiling under the existing conditions. Any adjustment to the gross weight by varying fuel, payload, or both, affects the hovering ceiling. The heavier the gross weight, the lower the hovering ceiling. As gross weight is decreased, the hover ceiling increases.

Sample Hover Problem 1

You are to fly a photographer to a remote location to take pictures of the local wildlife. Using *Figure 7-4*, can you safely hover in ground effect at your departure point with the following conditions?

A. Pressure Altitude.....8,000 feet
B. Temperature.....+15 °C
C. Takeoff Gross Weight.....1,250 lb
rpm.....104 percent

First enter the chart at 8,000 feet pressure altitude (point A), then move right until reaching a point midway between the +10 °C and +20 °C lines (point B). From that point, proceed down to find the maximum gross weight where a 2 foot hover can be achieved. In this case, it is approximately 1,280 pounds (point C).

Since the gross weight of your helicopter is less than this, you can safely hover with these conditions.

Sample Hover Problem 2

Once you reach the remote location in the previous problem, you will need to hover OGE for some of the pictures. The pressure altitude at the remote site is 9,000 feet, and you will use 50 pounds of fuel getting there. (The new gross weight is now 1,200 pounds.) The temperature will remain at +15 °C. Using *Figure 7-5*, can you accomplish the mission?

Enter the chart at 9,000 feet (point A) and proceed to point B (+15 °C). From there, determine that the maximum gross

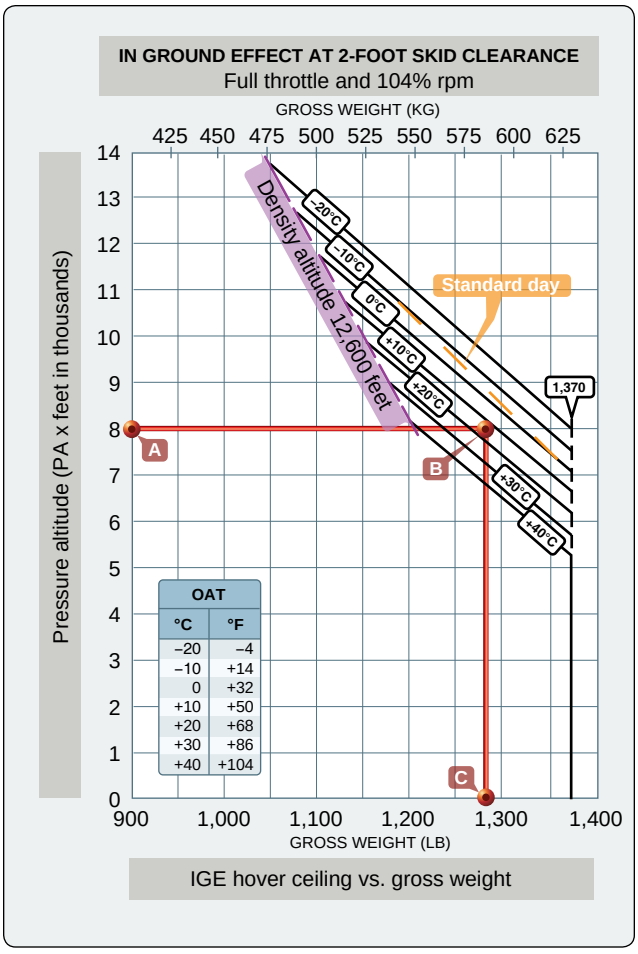


Figure 7-4. *In ground effect hovering ceiling versus gross weight chart.*

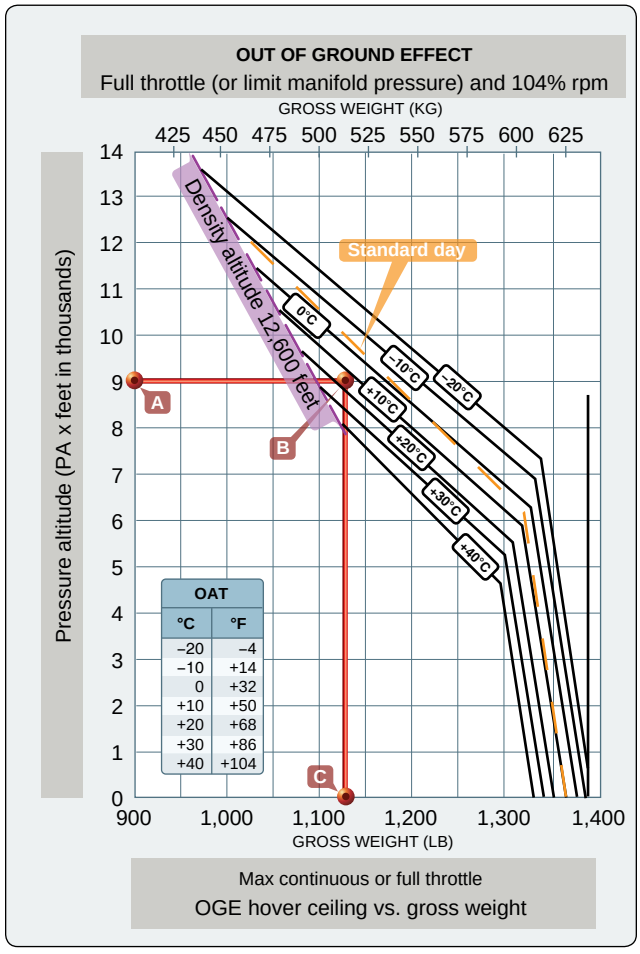


Figure 7-5. *Out of ground effect hover ceiling versus gross weight chart.*

weight to hover OGE is approximately 1,130 pounds (point C). Since your gross weight is higher than this value, you will not be able to hover in these conditions. To accomplish the mission, you will need to remove approximately 70 pounds before you begin the flight.

These two sample problems emphasize the importance of determining the gross weight and hover ceiling throughout the entire flight operation. Being able to hover at the takeoff location with a specific gross weight does not ensure the same performance at the landing point. If the destination point is at a higher density altitude because of higher elevation, temperature, and/or relative humidity, more power is required to hover there. You should be able to predict whether hovering power will be available at the destination by knowing the temperature and wind conditions, using the performance charts in the helicopter flight manual, and making certain power checks during hover and in flight prior to commencing the approach and landing.

For helicopters with dual engines, performance charts provide torque amounts for both engines.

Sample Hover Problem 3

Using *Figure 7-6*, determine what torque is required to hover. Use the following conditions:

A. Pressure Altitude . . . .9,500 feet
B. Outside Air Temperature . . . . . 0 °C
C. Gross Weight. . . . . 4,250 lb
D. Desired Skid Height . . . . . 5 feet

First, enter the chart at 9,500 feet pressure altitude, then move right to outside air temperature, 0 °C. From that point, move down to 4,250 pounds gross weight and then move left to 5-foot skid height. Drop down to read 66 percent torque required to hover.

Climb Performance

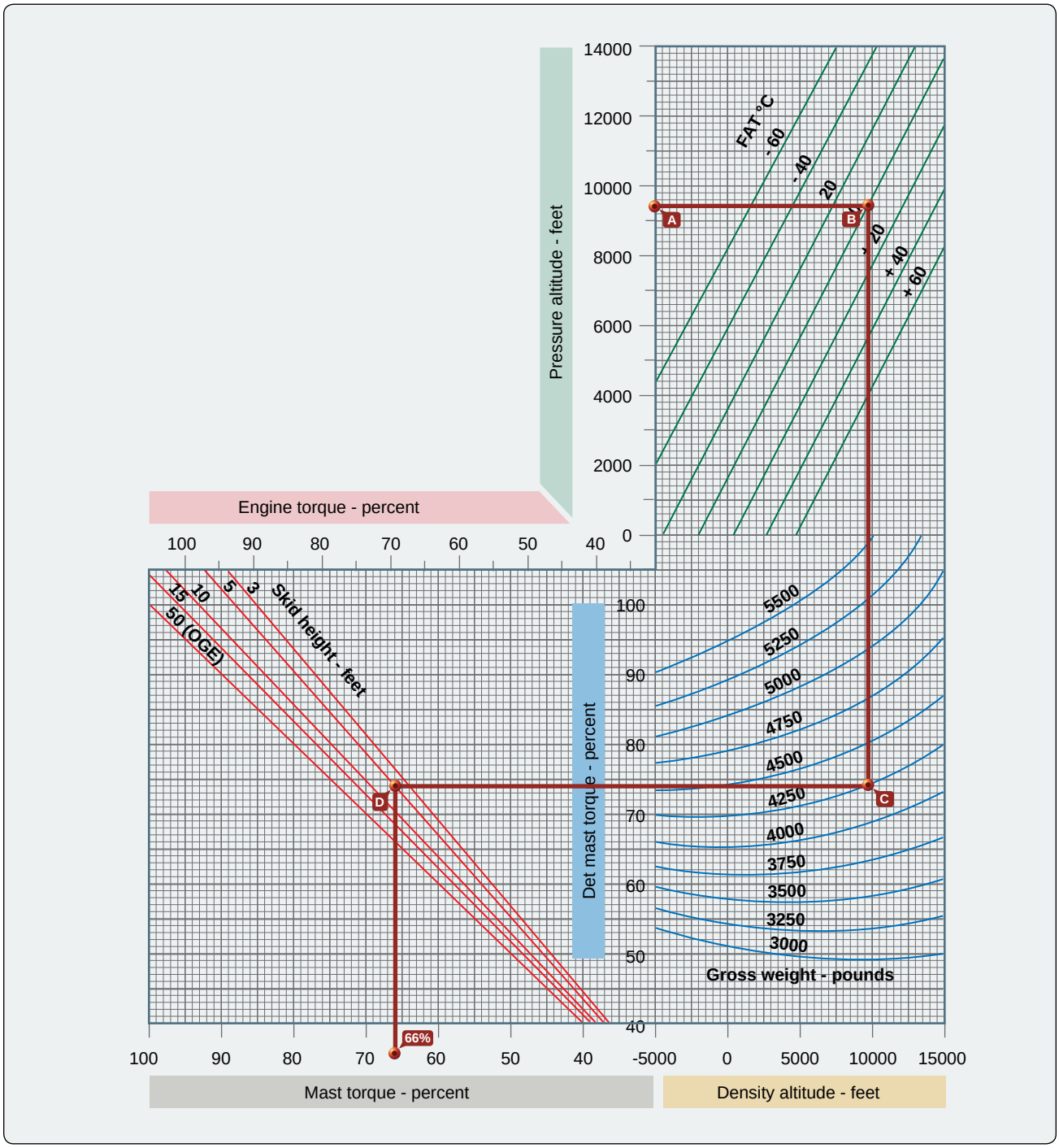


Figure 7-6. *Torque required for cruise or level flight.*

Most of the factors affecting hover and takeoff performance also affect climb performance. In addition, turbulent air, pilot techniques, and overall condition of the helicopter can cause climb performance to vary.

A helicopter flown at the best rate-of-climb speed (V_Y) obtains the greatest gain in altitude over a given period of time. This speed is normally used during the climb after all obstacles have been cleared and is usually maintained until reaching cruise altitude. Rate of climb must not be confused with angle of climb. Angle of climb is a function of altitude gained over a given distance. The V_Y results in the highest climb rate, but not the steepest climb angle, and may not be sufficient to clear obstructions. The best angle of climb speed (V_X) depends upon the power available. If there is a surplus of power available,

the helicopter can climb vertically, so V_X is zero.

Wind direction and speed have an effect on climb performance, but it is often misunderstood. Airspeed is the speed at which the helicopter is moving through the atmosphere and is unaffected by wind. Atmospheric wind affects only the groundspeed, or speed at which the helicopter is moving over the Earth's surface. Thus, the only climb performance affected by atmospheric wind is the angle of climb and not the rate of climb.

When planning for climb performance, it is first important to plan for torque settings at level flight. Climb performance charts show the change in torque, above or below torque, required for level flight under the same gross weight and atmospheric conditions to obtain a given rate of climb or descent.

Sample Cruise or Level Flight Problem

Determine torque setting for cruise or level flight using *Figure 7-7*. Use the following conditions:

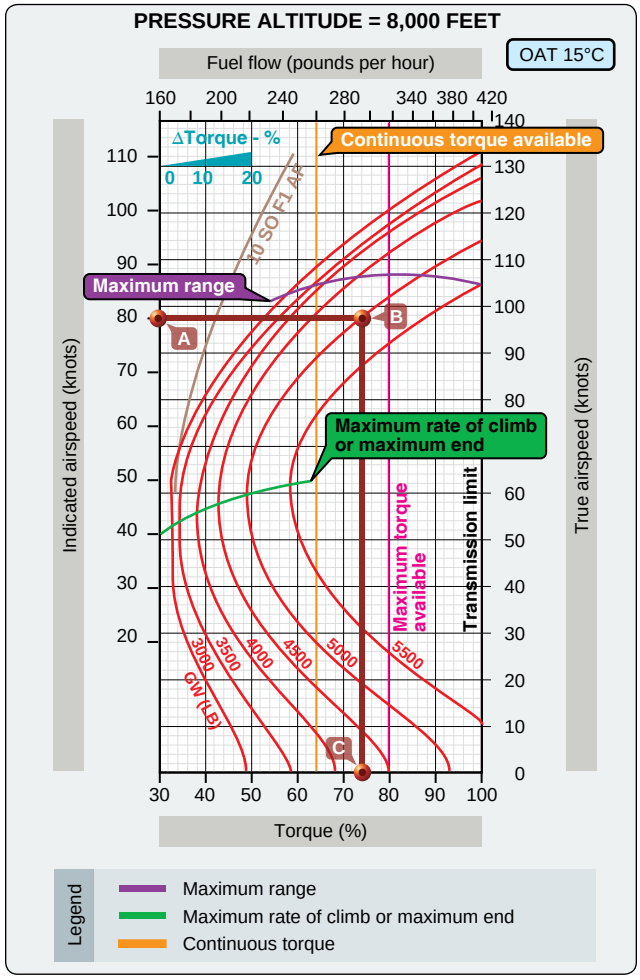


Figure 7-7. *Maximum rate-of-climb chart.*

Pressure Altitude..... 8,000 feet

Outside Air Temperature..... +15 °C

A. Indicated Airspeed.....80 knots

B. Maximum Gross Weight.....5,000 lb

With this chart, first confirm that it is for a pressure altitude of 8,000 feet with an OAT of 15°. Begin on the left side at 80 knots indicated airspeed (point A) and move right to maximum gross weight of 5,000 lb (point B). From that point, proceed down to the torque reading for level flight, which is 74 percent torque (point C). This torque setting is used in the next problem to add or subtract cruise/descent torque percentage from cruise flight.

Sample Climb Problem

Determine climb/descent torque percentage using *Figure 7-8*. Use the following conditions:

A. Rate of Climb or Descent. . . . . 500 fpm

B. Maximum Gross Weight . . . . . 5,000 lb

With this chart, first locate a 500-fpm rate of climb or descent (point A), and then move to the right to a maximum gross

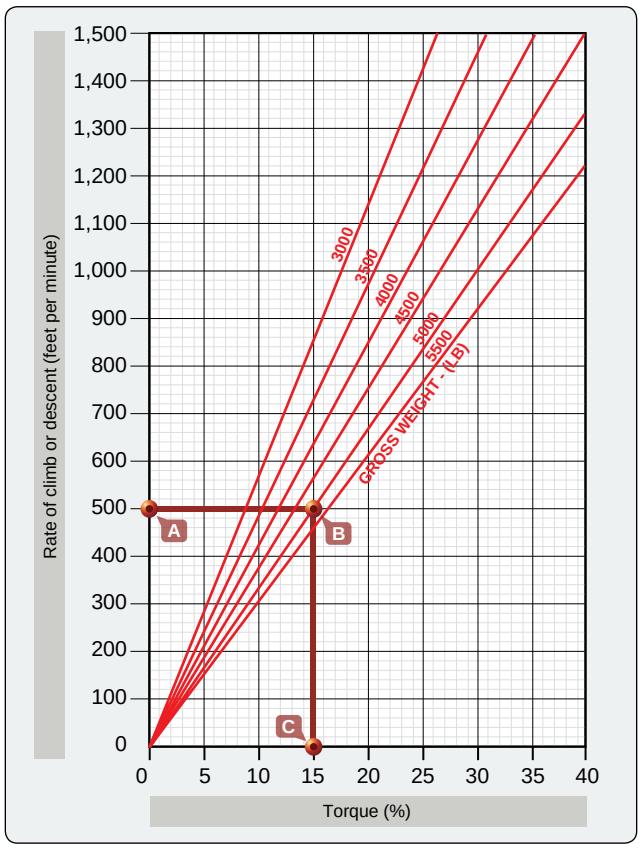


Figure 7-8. *Climb/descent torque percentage chart.*

weight of 5,000 lb (point B). From that point, proceed down to the torque percentage, which is 15 percent torque (point C). For climb or descent, 15 percent torque should be added/subtracted from the 74 percent torque needed for level flight. For example, if the numbers were to be used for a climb torque, the pilot would adjust torque settings to 89 percent for optimal climb performance.

Chapter Summary

This chapter discussed the factors affecting performance: density altitude, weight, and wind. Five sample problems were also given with performance charts to calculate different flight conditions and determine the performance of the helicopter.

Chapter 8

Ground Procedures and Flight Preparations

Introduction

Once a pilot takes off, it is up to him or her to make sound, safe decisions throughout the flight. It is equally important for the pilot to use the same diligence when conducting a preflight inspection, making maintenance decisions, refueling, and conducting ground operations. This chapter discusses the responsibility of the pilot regarding ground safety in and around the helicopter and when preparing to fly.



Preflight

Before any flight, ensure the helicopter is airworthy by inspecting it according to the rotorcraft flight manual (RFM), pilot's operating handbook (POH), or other information supplied either by the operator or the manufacturer. Remember that it is the responsibility of the pilot in command (PIC) to ensure the aircraft is in an airworthy condition.

In preparation for flight, the use of a checklist is important so that no item is overlooked. *[Figure 8-1]* Follow the manufacturer's suggested outline for both the inside and outside inspection. This ensures that all the items the manufacturer feels are important are checked. If supplemental equipment has been added to the helicopter, these procedures should be included on the checklist as well.

Minimum Equipment Lists (MELs) and Operations with Inoperative Equipment

Title 14 of the Code of Federal Regulations (14 CFR) requires that all aircraft instruments and installed equipment be operative prior to each departure. However, when the Federal Aviation Administration (FAA) adopted the minimum equipment list (MEL) concept for 14 CFR part 91 operations, flights were allowed with inoperative items, as long as the inoperative items were determined to be nonessential for safe flight. At the same time, it allowed part 91 operators, without an MEL, to defer repairs on nonessential equipment within the guidelines of part 91.



Figure 8-1. *The pilot in command is responsible for the airworthy condition of the aircraft and using checklists to ensure proper inspection of the helicopter prior to flight.*

There are two primary methods of deferring maintenance on rotorcraft operating under part 91. They are the deferral provision of 14 CFR part 91, section 91.213(d) and an FAA-approved MEL.

The deferral provision of 14 CFR section 91.213(d) is widely used by most pilot/operators. Its popularity is due to simplicity and minimal paperwork. When inoperative equipment is found during preflight or prior to departure, the decision should be to cancel the flight, obtain maintenance prior to flight, determine if the flight can be made under the limitations imposed by the defective equipment, or to defer the item or equipment.

Maintenance deferrals are not used for in-flight discrepancies. The manufacturer's RFM/POH procedures are to be used in those situations. The discussion that follows is an example of a pilot who wishes to defer maintenance that would ordinarily be required prior to flight.

If able to use the deferral provision of 14 CFR section 91.213(d), the pilot determines whether the inoperative equipment is required by type design or 14 CFR. If the inoperative item is not required, and the helicopter can be safely operated without it, the deferral may be made. The inoperative item shall be deactivated or removed and an INOPERATIVE placard placed near the appropriate switch, control, or indicator. If deactivation or removal involves maintenance (removal always does), it must be accomplished by certificated maintenance personnel.

For example, if the position lights (installed equipment) were discovered to be inoperative prior to a daytime flight, the pilot would follow the requirements of 14 CFR section 91.213(d). The pilot must then decide if the flight can be accomplished prior to night, when the lights will be needed.

The deactivation may be a process as simple as the pilot positioning a circuit breaker to the *off* position, or as complex as rendering instruments or equipment totally inoperable. Complex maintenance tasks require a certificated and appropriately rated maintenance person to perform the deactivation. In all cases, the item or equipment must be placarded INOPERATIVE.

When an operator requests an MEL, and a Letter of Authorization (LOA) is issued by the FAA, then the use of the MEL becomes mandatory for that helicopter. All maintenance deferrals must be accomplished in accordance with the terms and conditions of the MEL and the operator-generated procedures document.

The use of an MEL for rotorcraft operated under part 91 also allows for the deferral of inoperative items or equipment. The primary guidance becomes the FAA-approved MEL issued to that specific operator and N-numbered helicopter.

The FAA has developed master minimum equipment lists (MMELs) for rotorcraft in current use. Upon written request by a rotorcraft operator, the local FAA Flight Standards District Office (FSDO) may issue the appropriate make and model MMEL, along with an LOA, and the preamble. The operator then develops operations and maintenance (O&M) procedures from the MMEL. This MMEL with O&M procedures now becomes the operator's MEL. The MEL, LOA, preamble, and procedures document developed by the operator must be on board the helicopter when it is operated.

The FAA considers an approved MEL to be a supplemental type certificate (STC) issued to an aircraft by serial number and registration number. It therefore becomes the authority to operate that aircraft in a condition other than originally type certificated.

With an approved MEL, if the position lights were discovered inoperative prior to a daytime flight, the pilot would make an entry in the maintenance record or discrepancy record provided for that purpose. The item is then either repaired or deferred in accordance with the MEL. Upon confirming that daytime flight with inoperative position lights is acceptable in accordance with the provisions of the MEL, the pilot would leave the position lights switch *off*, open the circuit breaker (or whatever action is called for in the procedures document), and placard the position light switch as INOPERATIVE.

There are exceptions to the use of the MEL for deferral. For example, should a component fail that is not listed in the MEL as deferrable (the rotor tachometer, engine tachometer, or cyclic trim, for example), then repairs are required to be performed prior to departure. If maintenance or parts are not readily available at that location, a special flight permit can be obtained from the nearest FSDO. This permit allows the helicopter to be flown to another location for maintenance. This allows an aircraft that may not currently meet applicable airworthiness requirements, but is capable of safe flight, to be operated under the restrictive special terms and conditions attached to the special flight permit.

Deferral of maintenance is not to be taken lightly, and due consideration should be given to the effect an inoperative component may have on the operation of a helicopter, particularly if other items are inoperative. Further information regarding MELs and operations with inoperative equipment can be found in AC 9 1-67, Minimum Equipment Requirements for General Aviation Operations Under FAR Part 91.

Engine Start and Rotor Engagement

During the engine start, rotor engagement, and systems ground check, use the manufacturer's checklists. If a problem arises, have it checked before continuing. Prior to performing these tasks, however, make sure the area around and above the helicopter is clear of personnel and equipment. Position the rotor blades so that they are not aligned with the fuselage. This may prevent the engine from being started with the blades still fastened. For a two-bladed rotor system, position the blades so that they are perpendicular to the fuselage and easily seen from the cockpit. Helicopters are safe and efficient flying machines as long as they are operated within the parameters established by the manufacturer.

Rotor Safety Considerations

The exposed nature of the main and tail rotors deserves special caution. Exercise extreme care when taxiing near hangars or obstructions since the distance between the rotor blade tips and obstructions is very difficult to judge. *[Figure 8-2]* In addition, the tail rotor of some helicopters cannot be seen from the cabin. Therefore, when hovering backward or turning in those helicopters, allow plenty of room for tail rotor clearance. It is a good practice to glance over your shoulder to maintain this clearance

Another rotor safety consideration is the thrust a helicopter generates. The main rotor system is capable of blowing sand, dust, snow, ice, and water at high velocities for a significant distance causing injury to nearby people and damage to buildings, automobiles, and other aircraft. Loose snow, sand, or soil can severely reduce visibility and obscure outside visual references. There is also the possibility of sand and snow being ingested into the engine intake, which can overwhelm filters and cutoff air to the engine or allow unfiltered air into the engine, leading to premature failure. Any airborne debris near the helicopter can be ingested into the engine air intake or struck by the main and tail rotor blades.



Figure 8-2. *Exercise extreme caution when hovering near buildings or other aircraft.*

Aircraft Servicing

The helicopter rotor blades are usually stopped, and both the aircraft and the refueling unit properly grounded prior to any refueling operation. The pilot should ensure that the proper grade of fuel and the proper additives, when required, are being dispensed.

Refueling of a turbine aircraft while the blades are turning, known as "hot refueling," may be practical for certain types of operation. However, this can be hazardous if not properly conducted. Pilots should remain at the flight controls; and refueling personnel should be knowledgeable about the proper refueling procedures and properly briefed for specific helicopter makes and models.

The pilot may need to train the refueling personnel on proper hot refueling procedures for that specific helicopter. The pilot should explain communication signs or calls, normal servicing procedures, and emergency procedures as a minimum. At all times during the refueling process, the pilot should remain vigilant and ready to immediately shut down the engine(s) and egress the aircraft. Several accidents have occurred due to hot refueling performed by improperly trained personnel.

Refueling units should be positioned to ensure adequate rotor blade clearance. Persons not involved with the refueling operation should keep clear of the area. Smoking must be prohibited in and around the aircraft during all refueling operations.

If operations dictate that the pilot must leave the helicopter during refueling operations, the throttle should be rolled back to flight idle and flight control friction firmly applied to prevent uncommanded control movements. The pilot should be thoroughly trained on setting the controls and egressing/ingressing the helicopter.

Safety in and Around Helicopters

People have been injured, some fatally, in helicopter accidents that would not have occurred had they been informed of the proper method of boarding or deplaning. *[Figure 8-3]* A properly briefed passenger should never be endangered by a spinning rotor. The simplest method of avoiding accidents of this sort is to stop the rotors before passengers are boarded or allowed to depart. Because this action is not always practicable, and to realize the vast and unique capabilities of the helicopter, it is often necessary to take on passengers or have them exit the helicopter while the engine and rotors are turning. To avoid accidents, it is essential that all persons associated with helicopter operations, including passengers, be made aware of all possible hazards and instructed how those hazards can be avoided.

Ramp Attendants and Aircraft Servicing Personnel

These personnel should be instructed as to their specific duties and the proper method of fulfilling them. In addition, the ramp attendant should be taught to:

1. Keep passengers and unauthorized persons out of the helicopter landing and takeoff area.
2. Brief passengers on the best way to approach and board a helicopter with its rotors turning.

Persons directly involved with boarding or deplaning passengers, aircraft servicing, rigging, or hooking up external loads, etc., should be instructed as to their duties. It would be difficult, if not impossible, to cover each and every type of operation related to helicopters. A few of the more obvious and common ones are covered below.

Passengers

Passengers increase the responsibility, workload, and risk for the pilot. The workload and distractions seem magnified to inexperienced pilots while they are developing confidence and ability to operate in the aviation environment. Inexperienced pilots should consider building up their passenger carrying experience while remaining in good flying conditions and in a familiar area.

All persons boarding a helicopter while its rotors are turning should be briefed on the safest means of doing so. The pilot in command (PIC) should always brief the passengers prior to engine start to ensure complete understanding of all procedures. The exact procedures may vary slightly from one helicopter model to another, but the following should suffice as a generic guide.

When boarding—

1. Stay away from the rear of the helicopter.
2. Approach or leave the helicopter in a crouching manner.
3. Approach from the side of the helicopter but never out of the pilot's line of vision. Certain rotor system designs allow for rotor blades to pass closer to the ground towards the front of the helicopter. For that reason, it is generally accepted for personnel to approach from the side of the helicopter. Helicopters designed to be loaded from the rear require personnel to exercise extreme caution due to tailrotor hazards.
4. Carry tools horizontally, below waist level—never upright or over the shoulder.
5. Hold firmly onto hats and loose articles.
6. Never reach up or dart after a hat or other object that might be blown off or away.
7. Protect eyes by shielding them with a hand or by

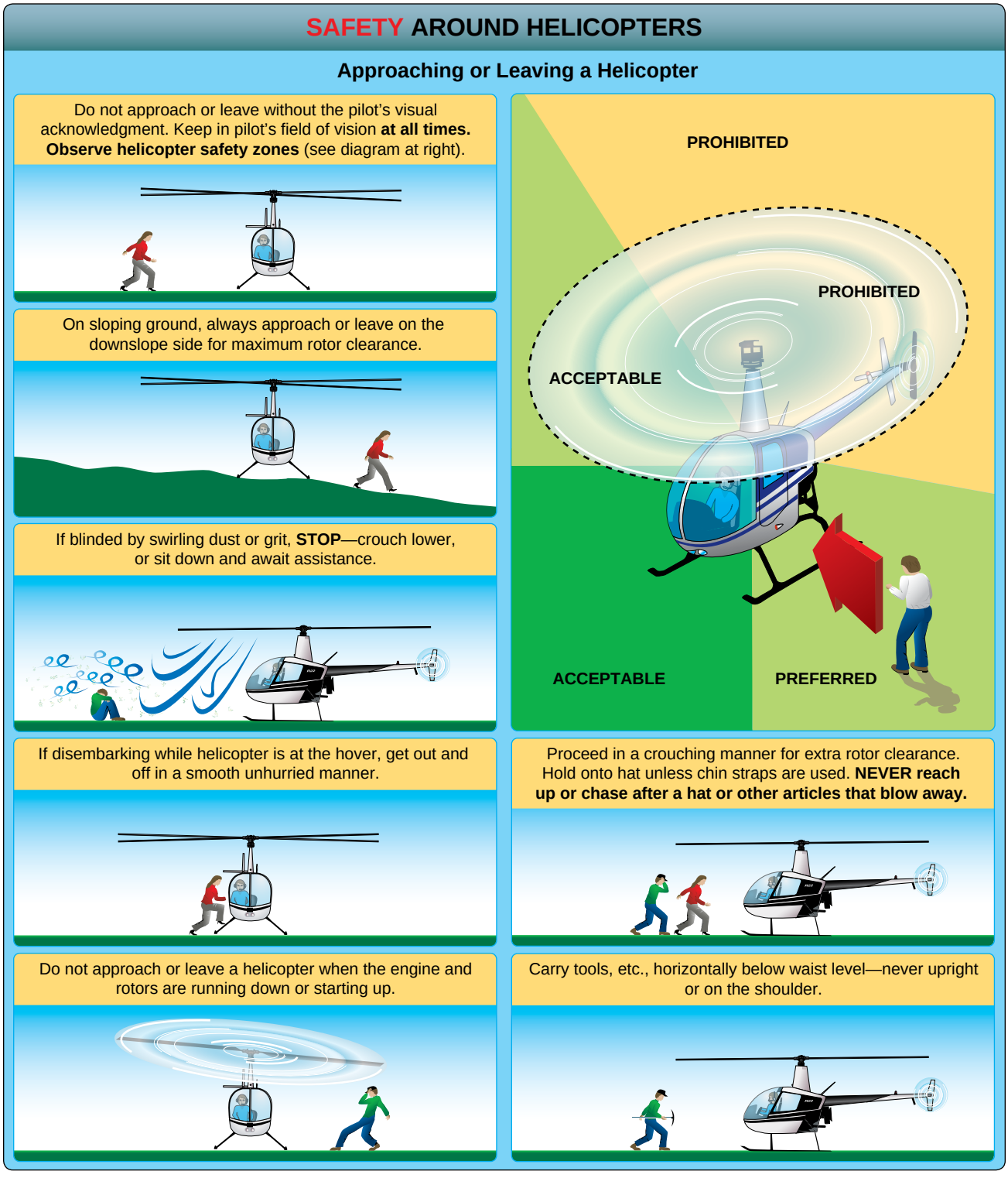


Figure 8-3. *Safety procedures for approaching or leaving a helicopter.*

squinting.

8. If suddenly blinded by dust or a blowing object, stop and crouch lower; better yet, sit down and wait for help.
9. Never grope or feel your way toward or away from the helicopter.
10. Protect hearing by wearing earplugs or earmuffs.

Since few helicopters carry cabin attendants, the pilot must conduct the pretakeoff and prelanding briefings, usually before takeoff due to noise and cockpit layout. The type of operation dictates what sort of briefing is necessary. All briefings should include the following:

1. Passengers should be briefed and understand the proper use of seatbelts, doors, and headsets/intercom system.
2. The safe entry and exit paths (away from the tail rotor and within the pilot's view).
3. If possible, remove front passenger flight controls and ensure all passenger personal items, such as cameras and mobile phones are secure.
4. For over water flights, the location and use of flotation gear and other survival equipment that are onboard. Pilot instructions should include how and when to exit the helicopter should ditching or a water landing occur.
5. For flights over rough or isolated terrain, the pilot should brief all occupants regarding the location of maps and survival equipment.
6. Passengers should be informed as to what actions and precautions to take in the event of an emergency, such as the body position for best spinal protection against a high vertical impact (erect with back firmly against the seat back); and when and how to exit. Ensure that passengers are aware of the location of the fire extinguisher, survival equipment and, if equipped, how to use and locate the Emergency Position Indicator Radio Beacon (EPIRB).

When passengers are approaching or leaving a helicopter that is sitting on a slope with the rotors turning, they should approach and depart downhill. This affords the greatest distance between the rotor blades and the ground. If this involves walking around the helicopter, they should always go around the front—never the rear.

Pilot at the Flight Controls

Many helicopter operators have been lured into a "quick turnaround" ground operation to avoid delays at airport terminals and to minimize stop/start cycles of the engine. As part of this quick turn-around, the pilot might leave the cockpit with the engine and rotors turning. Such an operation can be extremely hazardous if a gust of wind disturbs the rotor disk, or the collective flight control moves causing lift to be generated by the rotor system. Either occurrence may cause the helicopter to roll or pitch, resulting in a rotor blade striking the tail boom or the ground. Good operating procedures dictate that, generally, pilots remain at the flight controls whenever the engine is running, and the rotors are turning.

If operations require the pilot to leave the cockpit to refuel, the throttle should be rolled back to flight idle and all controls firmly frictioned to prevent uncommanded control movements. The pilot should be well trained on setting controls and exiting the cockpit without disturbing the flight or power controls.

After Landing and Securing

When the flight is terminated, park the helicopter where it does not interfere with other aircraft and is not a hazard to people during shutdown. For many helicopters, it is advantageous to land with the wind coming from the right over the tail boom (counterrotating blades). This tends to lift the blades over the tail boom but lowers the blades in front of the helicopter. This action decreases the likelihood of a main rotor strike to the tail boom due to gusty winds. Rotor downwash can cause damage to other aircraft in close proximity, and spectators may not realize the danger or see the rotors turning. Passengers should remain in the helicopter with their seats belts secured until the rotors have stopped turning. During the shutdown and postflight inspection, follow the manufacturer's checklist. Any discrepancies should be noted and, if necessary, reported to maintenance personnel.

Chapter Summary

This chapter explained the importance of preflight and safety when conducting helicopter ground operations. Proper procedures for engine run-up, refueling, and ground safety were detailed and the responsibilities of the pilot when maintenance issues occur before flight.

Chapter 9

Basic Flight Maneuvers

Introduction

From the previous chapters, it should be apparent that no two helicopters perform the same way. Even when flying the same model of helicopter, wind, temperature, humidity, weight, and equipment make it difficult to predict just how the helicopter will perform. Therefore, this chapter presents the basic flight maneuvers in a way that would apply to the majority of helicopters. In most cases, the techniques described apply to small training helicopters with:

- A single, main rotor rotating in a counterclockwise direction (looking downward on the rotor).
- An antitorque system.

Where a technique differs, it is noted. For example, a power increase on a helicopter with a clockwise rotor system requires right antitorque pedal pressure instead of left pedal pressure. In many cases, the terminology "apply proper pedal pressure" is used to indicate both types of rotor systems. However, when discussing throttle coordination to maintain proper rotations per minute (rpm), there is no differentiation between those helicopters with a governor and those without. In a sense, the governor is doing the work for you. In addition, instead of using the terms "collective pitch control" and "cyclic pitch control" throughout the chapter, these controls are referred to as just "collective" and "cyclic."

Because helicopter performance varies with weather conditions and aircraft loading, specific nose attitudes and power settings are not detailed in this handbook. In addition, this chapter does not detail every attitude of a helicopter in the various flight maneuvers, nor every move that must be made in order to perform a given maneuver.

When a maneuver is presented, there is a brief description, followed by the technique to accomplish the maneuver. In most cases, there is a list of common errors at the end of the discussion.

The Four Fundamentals

There are four fundamentals of flight upon which all maneuvers are based: straight-and-level flight, turns, climbs, and descents. All controlled flight maneuvers consist of one or more of these four fundamentals of flight. If a student pilot is able to perform these maneuvers well, and the student's proficiency is based on accurate "feel" and control analysis rather than mechanical movements, the ability to perform any assigned maneuver is only a matter of obtaining a clear visual and mental conception of it. The flight instructor must impart a good knowledge of these basic elements to the student and must combine them and plan their practice so that proper performance of each is instinctive without conscious effort. The importance of this to the success of flight training cannot be overemphasized. As the student progresses to more complex maneuvers, discounting any difficulties in visualizing the maneuvers, most student difficulties are caused by a lack of training, practice, or understanding of the principles of one or more of these fundamentals.

Guidelines

Good practices to follow during maneuvering flight include:

1. Move the cyclic only as fast as trim, torque, and rotor speed can be maintained. When entering a maneuver and the trim, rotor, or torque reacts quicker than anticipated, pilot limitations have been exceeded. If continued, an aircraft limitation will be exceeded. Perform the maneuver with less intensity until all aspects of the machine can be controlled. The pilot must be aware of the sensitivity of the flight controls due to the high speed of the main rotor.
2. Anticipate changes in aircraft performance due to loading or environmental condition. The normal collective increase to check rotor speed at sea level standard (SLS) may not be sufficient at 4,000 feet pressure altitude (PA) and 95 °F.
3. The following flight characteristics may be expected during maneuvering flight and will be discussed and demonstrated by your Flight Instructor:
    - Left turns, torque increases (more antitorque). This applies to most helicopters, but not all.
    - Right turns, torque decreases (less antitorque). This applies to most helicopters, but not all.
    - Application of aft cyclic, torque decreases and rotor speed increases.
    - Application of forward cyclic (especially when immediately following aft cyclic application), torque increases and rotor speed decreases.
    - Always leave a way out.
    - Know where the winds are.
    - Engine failures can occur during power changes and cruise flight. One possible cause of engine failure during cruise flight can be attributed to the pilot ignoring carburetor air temperatures, which could lead to carburetor icing and, subsequently, engine failure.
    - Crew coordination is critical. Everyone needs to be fully aware of what is going on, and each crewmember has a specific duty.
    - In steep turns, the nose drops. In most cases, energy (airspeed) must be traded to maintain altitude as the required excess engine power may not be available (to maintain airspeed in a 2G/60° turn, rotor thrust/engine power must increase by 100 percent). Failure to anticipate this at low altitude endangers the crew and passengers. The rate of pitch change is proportional to gross weight and density altitude.
    - Normal helicopter landings usually require high power settings, with terminations to a hover requiring the highest power setting.
    - The cyclic position relative to the horizon determines the helicopter's travel and attitude.

Straight-and-Level Flight

Straight-and-level flight is flight in which constant altitude and heading are maintained. The attitude of the rotor disk relative to the horizon determines the airspeed. The horizontal stabilizer design determines the helicopter's attitude when stabilized at an airspeed and altitude. Altitude is primarily controlled by use of the collective.

Technique

To maintain forward flight, the rotor tip-path plane must be tilted forward to obtain the necessary horizontal thrust component from the main rotor. By doing this, it causes the nose of the helicopter to lower which in turn will cause the airspeed to increase. In order to counteract this, the pilot must find the correct power setting to maintain level flight by adjusting the collective. *[Figure 9-1]* The horizontal stabilizer aids in trimming the helicopter about its transverse, horizontal axis, and reduces the amount of nose tuck that would occur. On several helicopters, it is designed as a negative lift airfoil, which produces a lifting force in a downward direction.

When in straight-and-level flight, any increase in the collective, while holding airspeed constant, causes the helicopter to climb. A decrease in the collective, while holding airspeed constant, causes the helicopter to descend. A change in the collective requires a coordinated change of the throttle to maintain a constant rpm. Additionally, the antitorque pedals need to keep the helicopter in trim around the vertical axis.

To increase airspeed in straight-and-level flight, apply forward pressure on the cyclic and raise the collective as necessary to maintain altitude. To decrease airspeed, apply rearward pressure on the cyclic and lower the collective, as necessary, to maintain altitude.



Figure 9-1. *Maintain straight-and-level flight by adjusting the rotor tip-path plane forward but adjusting the collective as necessary to maintain a constant airspeed and altitude. The natural horizon line can be used as an aid in maintaining straight-and-level flight. If the horizon line begins to rise, slight power may be required or the nose of the helicopter may be too low. If the horizon line is slowly dropping, some power may need to be taken out or the nose of the helicopter may be too high, requiring a cyclic adjustment.*

Although the cyclic is sensitive, there is a slight delay in control reaction, and it is necessary to anticipate actual movement of the helicopter. When making cyclic inputs to control the altitude or airspeed of a helicopter, take care not to overcontrol. If the nose of the helicopter rises above the level-flight attitude, apply forward pressure to the cyclic to bring the nose down. If this correction is held too long, the nose drops too low. Since the helicopter continues to change attitude momentarily after the controls reach neutral, return the cyclic to neutral slightly before the desired attitude is reached. This principle holds true for any cyclic input.

Since helicopters are not very stable, but are inherently very controllable, if a gust or turbulence causes the nose to drop, the nose tends to continue to drop instead of returning to a straight-and-level attitude as it would on a fixed-wing aircraft. Therefore, a pilot must remain alert and fly the helicopter at all times.

Common Errors

1. Failure to trim the helicopter properly, tending to hold antitorque pedal pressure and opposite cyclic. This is commonly called cross-controlling.
2. Failure to maintain desired airspeed.
3. Failure to hold proper control position to maintain desired ground track.
4. Failure to allow helicopter to stabilize at new airspeed.

Turns

A turn is a maneuver used to change the heading of the helicopter. The aerodynamics of a turn were previously discussed in Chapter 2, Aerodynamics of Flight.

Technique

Before beginning any turn, the area in the direction of the turn must be cleared not only at the helicopter's altitude, but also above and below. To enter a turn from straight-and-level flight, apply sideward pressure on the cyclic in the direction the turn is to be made. This is the only control movement needed to start the turn. Do not use the pedals to assist the turn. Use the pedals only to compensate for torque to keep the helicopter in trim around the vertical axis. *[Figure 9-2]* Keeping the fuselage in the correct streamlined position around the vertical axis facilitates the helicopter flying forward with the least drag. Trim is indicated by a yaw string in the center, or a centered ball on a turn and slip indicator. A yaw string (also referred to as a slip string) is a tool used to indicate slip or skid during flight. It is simply a string attached to the nose or canopy of an aircraft so that it is visible to the pilot during flight. The string measures sideslip and offers a visual cue to the pilot in order to make yaw corrections.

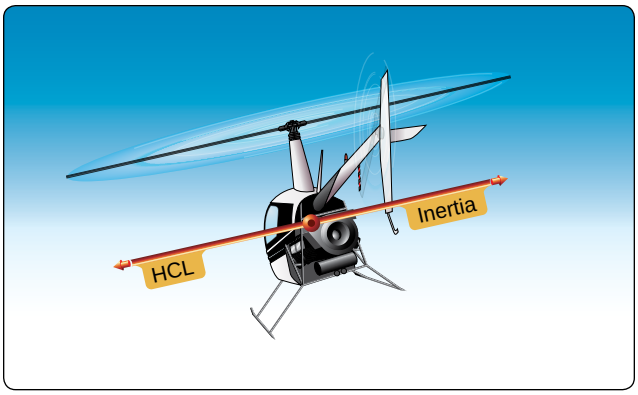


Figure 9-2. *During a level, coordinated turn, the rate of turn is commensurate with the angle of bank used, and inertia and horizontal component of lift (HCL) are equal.*

How fast the helicopter banks depends on how much lateral cyclic pressure is applied. How far the helicopter banks (the steepness of the bank) depends on how long the cyclic is displaced. After establishing the proper bank angle, return the cyclic toward the neutral position. When the bank is established, returning the cyclic to neutral (or holding it inclined relative to the horizon) will maintain the helicopter at that bank angle. Increase the collective and throttle to maintain altitude and rpm. As the torque increases, increase the proper antitorque pedal pressure to maintain longitudinal trim. Depending on the degree of bank, additional forward cyclic pressure may be required to maintain airspeed.

Rolling out of the turn to straight-and-level flight is the same as the entry into the turn, except that pressure on the cyclic is applied in the opposite direction. Since the helicopter continues to turn as long as there is any bank, start the rollout before reaching the desired heading.

The discussion on level turns is equally applicable to making turns while climbing or descending. The only difference is that the helicopter is in a climbing or descending attitude rather than that of level flight. If a so-called simultaneous entry (entering a turn while, at the same time, climbing or descending) is desired, merely combine the techniques of both maneuvers—climb or descent entry and turn entry. When recovering from a climbing or descending turn, the desired heading and altitude are rarely reached at the same time. If the heading is reached first, stop the turn and maintain the climb or descent until reaching the desired altitude. On the other hand, if the altitude is reached first, establish the level flight attitude and continue the turn to the desired heading.

Slips

A slip occurs when the helicopter slides sideways toward the center of the turn. *[Figure 9-3]* It is caused by an insufficient amount of antitorque pedal in the direction of the turn, or too much in the direction opposite the turn, in relation to the amount of power used. In other words, if you hold improper antitorque pedal pressure, which keeps the nose from following the turn, the helicopter slips sideways toward the center of the turn.

Skids

A skid occurs when the helicopter slides sideways away from the center of the turn. *[Figure 9-4]* It is caused by too much antitorque pedal pressure in the direction of the turn, or by too little in the direction opposite the turn in relation to the amount of power used. If the helicopter is forced to turn faster with increased pedal pressure instead of by increasing the degree of the bank, it skids sideways away from the center of the turn instead of flying in its normal curved path.

In summary, a skid occurs when the rate of turn is too great for the amount of bank being used, and a slip occurs when the rate of turn is too low for the amount of bank being used. *[Figure 9-5]*

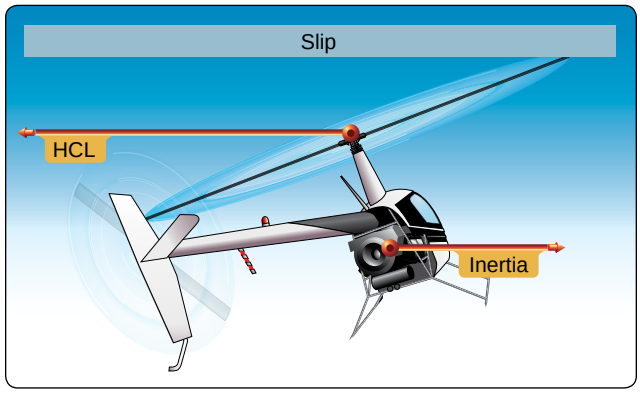


Figure 9-3. *During a slip, the rate of turn is too low for the angle of bank used, and the horizontal component of lift (HCL) exceeds inertia.*

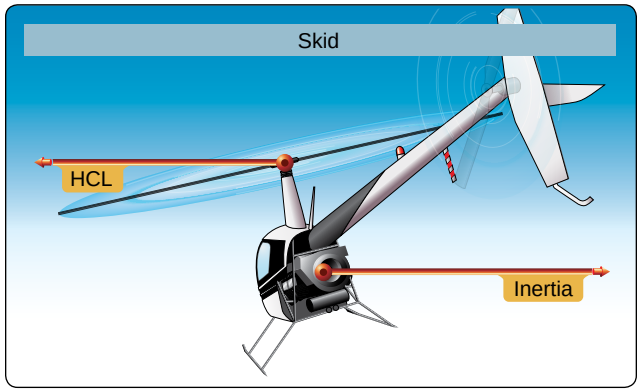


Figure 9-4. *During a skid, the rate of turn is too great for the angle of bank used, and inertia exceeds the horizontal component of lift (HCL).*

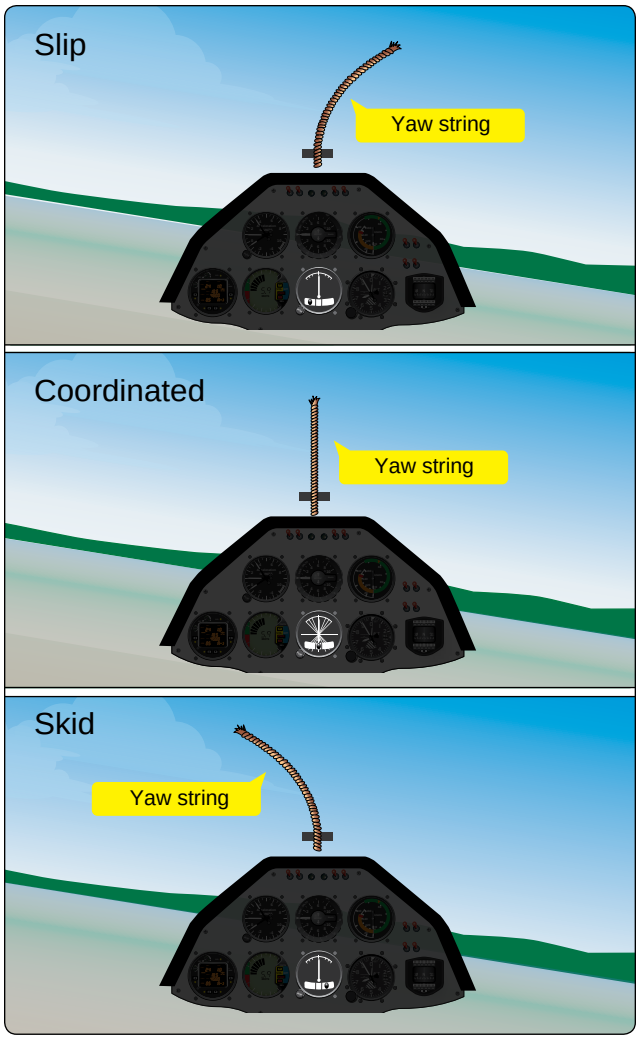


Figure 9-5. *Cockpit view of a slip and skid.*

Normal Climb

The entry into a climb from a hover has already been described in the Normal Takeoff from a Hover subsection; therefore, this discussion is limited to a climb entry from cruising flight.

Technique

To enter a climb in a helicopter while maintaining airspeed, the first actions are increasing the collective and throttle, and adjusting the pedals as necessary to maintain a centered ball in the slip/skid indicator. Moving the collective up requires a slight aft movement of the cyclic to direct all of the increased power into lift and maintain the airspeed. Remember, a helicopter can climb with the nose down and descend with the nose up. Helicopter attitude changes mainly reflect acceleration or deceleration, not climb or descent. Therefore, the climb attitude is approximately the same as level flight in a stable climb, depending on the aircraft's horizontal stabilizer design.

If the pilot wishes to climb faster, with a decreased airspeed, then the climb can be initiated with aft cyclic. Depending on initial or entry airspeed for the climb, the climb can be accomplished without increasing the collective, if a much slower airspeed is acceptable. However, as the airspeed decreases, the airflow over the vertical fin decreases necessitating more antitorque (left) pedal application.

To level off from a climb, start adjusting the attitude to the level flight attitude a few feet prior to reaching the desired altitude. The amount of lead depends on the rate of climb at the time of level-off (the higher the rate of climb, the more the lead). Generally, the lead is 10 percent of the climb rate. For example, if the climb rate is 500 feet per minute (fpm), you should lead the level-off by 50 feet.

To begin the level-off, apply forward cyclic to adjust and maintain a level flight attitude, which can be slightly nose low. Maintain climb power until the airspeed approaches the desired cruising airspeed, then lower the collective to obtain cruising power and adjust the throttle to obtain and maintain cruising rpm. Throughout the level-off, maintain longitudinal trim with the antitorque pedals.

Common Errors

1. Failure to maintain proper power and airspeed.
2. Holding too much or too little antitorque pedal.
3. In the level-off, decreasing power before adjusting the nose to cruising attitude.

Normal Descent

A normal descent is a maneuver in which the helicopter loses altitude at a controlled rate in a controlled attitude.

Technique

To establish a normal descent from straight-and-level flight at cruising airspeed, lower the collective to obtain proper power, adjust the throttle to maintain rpm, and increase right antitorque pedal pressure to maintain heading in a counterclockwise rotor system (or left pedal pressure in a clockwise system). If cruising airspeed is the same as or slightly above descending airspeed, simultaneously apply the necessary cyclic pressure to obtain the approximate descending attitude. If the pilot wants to decelerate, the cyclic must be moved aft. If the pilot desires to descend with increased airspeed, then forward cyclic is all that is required if airspeed remains under the limit. As the helicopter stabilizes at any forward airspeed, the fuselage attitude will streamline due to the airflow over the horizontal stabilizer. As the airspeed changes, the airflow over the vertical stabilizer or fin changes, so the pedals must be adjusted for trim.

The pilot should always remember that the total lift and thrust vectoring is controlled by the cyclic. If a certain airspeed is desired, it will require a certain amount of cyclic and collective movement for level flight. If the cyclic is moved, the thrust-versus-lift ratio is changed. Aft cyclic directs more power to lift, and altitude increases. Forward cyclic directs more power to thrust, and airspeed increases. If the collective is not changed and there is a change only in cyclic, the total thrust to lift ratio does not change: aft cyclic results in a climb, and forward cyclic results in a descent with the corresponding airspeed changes.

To level off from the descent, lead the desired altitude by approximately 10 percent of the rate of descent. For example, a 500-fpm rate of descent would require a 50-foot lead. At this point, increase the collective to obtain cruising power, adjust the throttle to maintain rpm, and increase left antitorque pedal pressure to maintain heading (right pedal pressure in a clockwise rotor system). Adjust the cyclic to obtain cruising airspeed and a level flight attitude as the desired altitude is reached.

Common Errors

1. Failure to maintain constant angle of decent during training.
2. Failure to level-off the aircraft sufficiently, which results in recovery below the desired altitude.
3. Failure to adjust antitorque pedal pressures for changes in power.

Vertical Takeoff to a Hover

A vertical takeoff to a hover involves flying the helicopter from the ground vertically to a skid height of two to three feet, while maintaining a constant heading. Once the desired skid height is achieved, the helicopter should remain nearly motionless over a reference point at a constant altitude and on a constant heading. The maneuver requires a high degree of concentration and coordination.

Technique

The pilot on the controls needs to clear the area left, right, and above to perform a vertical takeoff to a hover. The pilot should remain focused outside the aircraft and obtain clearance to take off from the controlling tower. If necessary, the pilot who is not on the controls assists in clearing the aircraft and provides adequate warning of any obstacles and any unannounced or unusual drift/altitude changes.

Heading control, direction of turn, and rate of turn at hover are all controlled by using the pedals. Hover height, rate of ascent, and the rate of descent are controlled by using the collective. Helicopter position and the direction of travel are controlled by the cyclic.

After receiving the proper clearance and ensuring that the area is clear of obstacles and traffic, begin the maneuver with the collective in the down position and the cyclic in a neutral position, or slightly into the wind. Very slowly increase the collective until the helicopter becomes light on the skids or wheels. As collective and torque increases, antitorque must be adjusted as well. Therefore, as the aircraft begins to get light on the landing gear, apply appropriate antitorque pedal to maintain aircraft heading. Continue to apply pedals as necessary to maintain heading and coordinate the cyclic for a vertical ascent. As the helicopter slowly leaves the ground, check for proper attitude control response and helicopter center of gravity. A slow ascent will allow stopping if responses are outside the normal parameters indicating hung or entangled landing gear, center of gravity problems, or control issues. If a roll or tilt begin, decrease the collective and determine the cause of the roll or tilt. Upon reaching the desired hover altitude, adjust the flight controls as necessary to maintain position over the intended hover area. Student pilots should be reminded that while at a hover, the helicopter is rarely ever level. Helicopters usually hover left side low due to the tail rotor thrust being counteracted by the main rotor tilt. A nose low or high condition is generally caused by loading. Once stabilized, check the engine instruments and note the power required to hover.

Excessive movement of any flight control requires a change in the other flight controls. For example, if the helicopter drifts to one side while hovering, the pilot naturally moves the cyclic in the opposite direction. When this is done, part of the vertical thrust is diverted, resulting in a loss of altitude. To maintain altitude, increase the collective. This increases drag on the blades and tends to slow them down. To counteract the drag and maintain rpm, increase the throttle. Increased throttle means increased torque, so the pilot must add more pedal pressure to maintain the heading. This can easily lead to overcontrolling the helicopter. However, as level of proficiency increases, problems associated with overcontrolling decrease. Helicopter controls are usually more driven by pressure than by gross control movements.

Common Errors

1. Failing to ascend vertically as the helicopter becomes airborne.
2. Pulling excessive collective to become airborne, causing the helicopter to gain too much altitude.
3. Overcontrolling the antitorque pedals, which not only changes the heading of the helicopter, but also changes the rpm.

4. Reducing throttle rapidly in situations in which proper rpm has been exceeded, usually resulting in exaggerated heading changes and loss of lift, resulting in loss of altitude.
5. Failing to ascend slowly.

Hovering

A stationary hover is a maneuver in which the helicopter is maintained in nearly motionless flight over a reference point at a constant altitude and on a constant heading.

Technique

To maintain a hover over a point, use sideview and peripheral vision to look for small changes in the helicopter's attitude and altitude. When these changes are noted, make the necessary control inputs before the helicopter starts to move from the point. To detect small variations in altitude or position, the main area of visual attention needs to be some distance from the aircraft, using various points on the helicopter or the tip-path plane as a reference. Looking too closely or looking down leads to overcontrolling. Obviously, in order to remain over a certain point, know where the point is, but do not focus all attention there.

As with a takeoff, the pilot controls altitude with the collective and maintains a constant rpm with the throttle. The cyclic is used to maintain the helicopter's position; the pedals, to control heading. To maintain the helicopter in a stabilized hover, make small, smooth, coordinated corrections. As the desired effect occurs, remove the correction in order to stop the helicopter's movement. For example, if the helicopter begins to move rearward, apply a small amount of forward cyclic pressure. However, neutralize this pressure just before the helicopter comes to a stop, or it will begin to move forward.

After experience is gained, a pilot develops a certain "feel" for the helicopter. Small deviations can be felt and seen, so you can make the corrections before the helicopter actually moves. A certain relaxed looseness develops, and controlling the helicopter becomes second nature, rather than a mechanical response.

Common Errors

1. Tenseness and slow reactions to movements of the helicopter.
2. Failure to allow for lag in cyclic and collective pitch, which leads to overcontrolling. It is very common for a student to get ahead of the helicopter. Due to inertia, it requires some small time period for the helicopter to respond.
3. Confusing attitude changes for altitude changes, which results in improper use of the controls.
4. Hovering too high, creating a hazardous flight condition. The height velocity chart should be referenced to determine the maximum skid height to hover and safely recover the helicopter should a malfunction occur.
5. Hovering too low, resulting in occasional touchdown.
6. Becoming overly confident over prepared surfaces when taking off to a hover. Be aware that dynamic rollover accidents usually occur over a level surface.

Hovering Turn

A hovering turn is a maneuver performed at hovering height in which the nose of the helicopter is rotated either left or right while maintaining position over a reference point on the surface. Hovering turns can also be made around the mast or tail of the aircraft. The maneuver requires the coordination of all flight controls and demands precise control near the surface. A pilot should maintain a constant altitude, rate of turn, and rpm.

Technique

Initiate the turn in either direction by applying anti-torque pedal pressure toward the desired direction. It should be noted that during a turn to the left, more power is required because left pedal pressure increases the pitch angle of the tail rotor, which, in turn, requires additional power from the engine. A turn to the right requires less power. (On helicopters with a clockwise rotating main rotor, right pedal increases the pitch angle and, therefore, requires more power.)

As the turn begins, use the cyclic as necessary (usually into the wind) to keep the helicopter over the desired spot. To continue the turn, add more pedal pressure as the helicopter turns to the crosswind position. This is because the wind is striking the tail surface and tail rotor area, making it more difficult for the tail to turn into the wind. As pedal pressures increase due to crosswind forces, increase the cyclic pressure into the wind to maintain position. Use the collective with the throttle to maintain a constant altitude and rpm. *[Figure 9-6]*

After the 90° portion of the turn, decrease pedal pressure slightly to maintain the same rate of turn. Approaching the 180°, or downwind portion, anticipate opposite pedal pressure due to the tail moving from an upwind position to a downwind position. At this point, the rate of turn has a tendency to increase at a rapid rate due to the tendency of the tail surfaces to weathervane. Because of the tailwind condition,

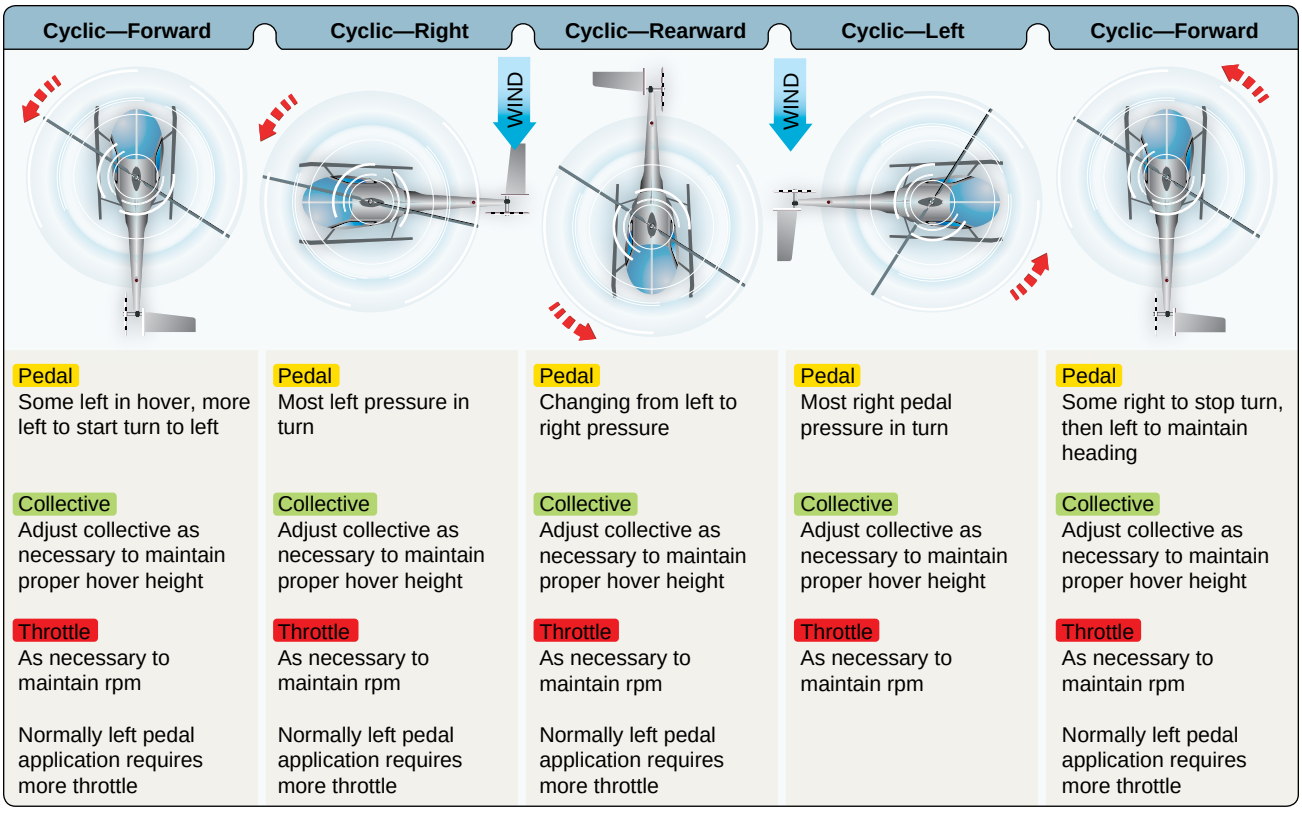


Figure 9-6. *Left turns in helicopters with a counterclockwise rotating main rotor are more difficult to execute because the tail rotor demands more power. This requires you to compensate with additional left pedal and increased throttle. Refer to this graphic throughout the remainder of the discussion on a hovering turn to the left.*

hold rearward cyclic pressure to keep the helicopter over the same spot.

The horizontal stabilizer has a tendency to lift the tail during a tailwind condition. This is the most difficult portion of the hovering turn. Horizontal and vertical stabilizers have several different designs and locations, including the canted stabilizers used on some Hughes and Schweizer helicopters. The primary purpose of the vertical stabilizer is to unload the work of the antitorque system and to aid in trimming the helicopter in flight should the antitorque system fail. The horizontal stabilizer provides for a more usable CG range and aids in trimming the helicopter longitudinally.

Because of the helicopter's tendency to weathervane, maintaining the same rate of turn from the 180° position actually requires some pedal pressure opposite the direction of turn. If a pilot does not apply opposite pedal pressure, the helicopter tends to turn at a faster rate. The amount of pedal pressure and cyclic deflection throughout the turn depends on the wind velocity. As the turn is finished on the upwind heading, apply opposite pedal pressure to stop the turn. Gradually apply forward cyclic pressure to keep the helicopter from drifting.

Control pressures and direction of application change continuously throughout the turn. The most dramatic change is the pedal pressure (and corresponding power requirement) necessary to control the rate of turn as the helicopter moves through the downwind portion of the maneuver.

Turns can be made in either direction; however, in a high wind condition, the tail rotor may not be able to produce enough thrust, which means the pilot cannot control a turn to the right in a counterclockwise rotor system. Therefore, if control is ever questionable, first attempt to make a 90° turn to the left. If sufficient tail rotor thrust exists to turn the helicopter crosswind in a left turn, a right turn can be successfully controlled. The opposite applies to helicopters with clockwise rotor systems. In this case, start the turn to the right. Hovering turns should be avoided in winds strong enough to preclude sufficient aft cyclic control to maintain the helicopter on the selected surface reference point when headed downwind. Check the flight manual for the manufacturer's recommendations for this limitation.