Disk area. The area swept by the blades of the rotor. It is a circle with its center at the hub and has a radius of one blade length.

Disk loading. The total helicopter weight divided by the rotor disk area.

Dissymmetry of lift. The unequal lift across the rotor disk resulting from the difference in the velocity of air over the advancing blade half and the velocity of air over the retreating blade half of the rotor disk area.

Drag. An aerodynamic force on a body acting parallel and opposite to relative wind.

Dual rotor. A rotor system utilizing two main rotors.

Dynamic rollover. The tendency of a helicopter to continue rolling when the critical angle is exceeded, if one gear is on the ground, and the helicopter is pivoting around that point.

Feathering. The action that changes the pitch angle of the rotor blades by rotating them around their feathering (spanwise) axis.

Feathering axis. The axis about which the pitch angle of a rotor blade is varied. Sometimes referred to as the spanwise axis.

Feedback. The transmittal of forces, which are initiated by aerodynamic action on rotor blades, to the cockpit controls.

Flapping. The vertical movement of a blade about a flapping hinge.

Flapping hinge. The hinge that permits the rotor blade to flap and thus balance the lift generated by the advancing and retreating blades.

Flare. A maneuver accomplished prior to landing to slow a helicopter.

Free turbine. A turboshaft engine with no physical connection between the compressor and power output shaft.

Freewheeling unit. A component of the transmission or power train that automatically disconnects the main rotor from the engine when the engine stops or slows below the equivalent rotor rpm.

Fully articulated rotor system. See articulated rotor system.

Gravity. See weight.

Gross weight. The sum of the basic empty weight and useful load.

Ground effect. A usually beneficial influence on helicopter performance that occurs while flying close to the ground. It results from a reduction in upwash, downwash, and bladetip vortices, which provide a corresponding decrease in induced drag.

Ground resonance. Selfexcited vibration occurring whenever the frequency of oscillation of the blades about the lead-lag axis of an articulated rotor becomes the same as the natural frequency of the fuselage.

Gyroscopic procession. An inherent quality of rotating bodies, which causes an applied force to be manifested 90° in the direction of rotation from the point where the force is applied.

Human factors. The study of how people interact with their environment. In the case of general aviation, it is the study of how pilot performance is influenced by such issues as the design of cockpits, the function of the organs of the body, the effects of emotions, and the interaction and communication with other participants in the aviation community, such as other crew members and air traffic control personnel.

Hunting. Movement of a blade with respect to the other blades in the plane of rotation, sometimes called leading or lagging.

In ground effect (IGE) hover. Hovering close to the surface (usually less than one rotor diameter distance above the surface) under the influence of ground effect.

Induced drag. That part of the total drag that is created by the production of lift.

Induced flow. The component of air flowing vertically through the rotor system resulting from the production of lift.

Inertia. The property of matter by which it will remain at rest or in a state of uniform motion in the same direction unless acted upon by some external force.

Isogonic line. Lines on charts that connect points of equal magnetic variation.

Knot. A unit of speed equal to one nautical mile per hour.

L_{DMAX}. The maximum ratio between total lift (L) and total drag (D). This point provides the best glide speed. Any deviation from the best glide speed increases drag and reduces the distance you can glide.

Lateral vibration. A vibration in which the movement is in a lateral direction, such as imbalance of the main rotor.

Lead and flag. The fore (lead) and aft (lag) movement of the rotor blade in the plane of rotation.

Licensed empty weight. Basic empty weight not including full engine oil, just undrainable oil.

Lift. One of the four main forces acting on a helicopter. It acts perpendicular to the relative wind.

Load factor. The ratio of a specified load weight to the total weight of the aircraft.

Married needles. A term used when two hands of an instrument are superimposed over each other, as on the engine/rotor tachometer.

Mast. The component that supports the main rotor.

Mast bumping. Action of the rotor head striking the mast, occurring on underslung rotors only.

Navigational aid (NAVAID). Any visual or electronic device, airborne or on the surface, that provides point-to-point guidance information, or position data, to aircraft in flight.

Night. The time between the end of evening civil twilight and the beginning of morning civil twilight, as published in the American Air Almanac.

Normally aspirated engine. An engine that does not compensate for decreases in atmospheric pressure through turbocharging or other means.

One-to-one vibration. A low frequency vibration having one beat per revolution of the rotor. This vibration can be either lateral, vertical, or horizontal.

Out of ground effect (OGE) hover. Hovering a distance greater than one disk diameter above the surface. Because induced drag is greater while hovering out of ground effect, it takes more power to achieve a hover out of ground effect.

Parasite drag. The part of total drag created by the form or shape of helicopter parts.

Payload. The term used for the combined weight of passengers, baggage, and cargo.

Pendular action. The lateral or longitudinal oscillation of the fuselage due to its suspension from the rotor system.

Pitch angle. The angle between the chord line of the rotor blade and the reference plane of the main rotor hub or the rotor plane of rotation.

Pressure altitude. The height above the standard pressure level of 29.92 "Hg. It is obtained by setting 29.92 in the barometric pressure window and reading the altimeter.

Profile drag. Drag incurred from frictional or parasitic resistance of the blades passing through the air. It does not change significantly with the angle of attack of the airfoil section, but it increases moderately as airspeed increases.

Resultant relative wind. Airflow from rotation that is modified by induced flow.

Retreating blade. Any blade, located in a semicircular part of the rotor disk, in which the blade direction is opposite to the direction of flight.

Retreating blade stall. A stall that begins at or near the tip of a blade in a helicopter because of the high angles of attack required to compensate for dissymmetry of lift.

Rigid rotor. A rotor system permitting blades to feather, but not flap or hunt.

Rotational velocity. The component of relative wind produced by the rotation of the rotor blades.

Rotor. A complete system of rotating airfoils creating lift for a helicopter.

Rotor brake. A device used to stop the rotor blades during shutdown.

Rotor disk area. See disk area.

Rotor force. The force produced by the rotor, comprised of rotor lift and rotor drag.

Semirigid rotor. A rotor system in which the blades are fixed to the hub, but are free to flap and feather.

Settling with power. See vortex ring state.

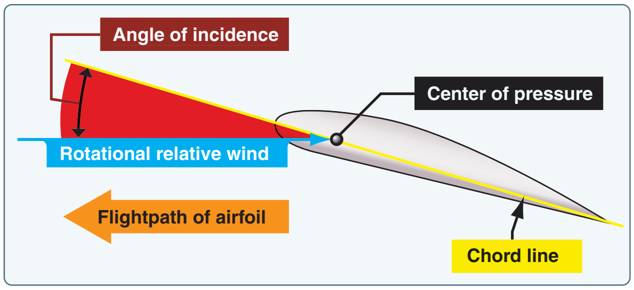

Figure 2-17. *Rotational relative wind.*

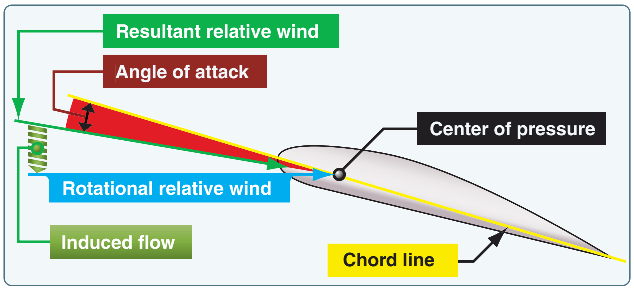

Figure 2-18. *Resultant relative wind.*

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 system 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 2-19]*

In Ground Effect (IGE)

Ground effect is the increased efficiency of the rotor system 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 system 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 2-20]*

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 settling with power and is discussed at length in a later chapter. 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 2-21]*

Rotor Blade Angles

There are two angles that enable a rotor system 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 the rotor hub. It is a mechanical angle rather than an aerodynamic angle and is sometimes referred to as blade pitch angle. *[Figure 2-22]* 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 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.

Angle of Attack

AOA is the angle between the airfoil chord line and resultant relative wind. *[Figure 2-23]* AOA 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).

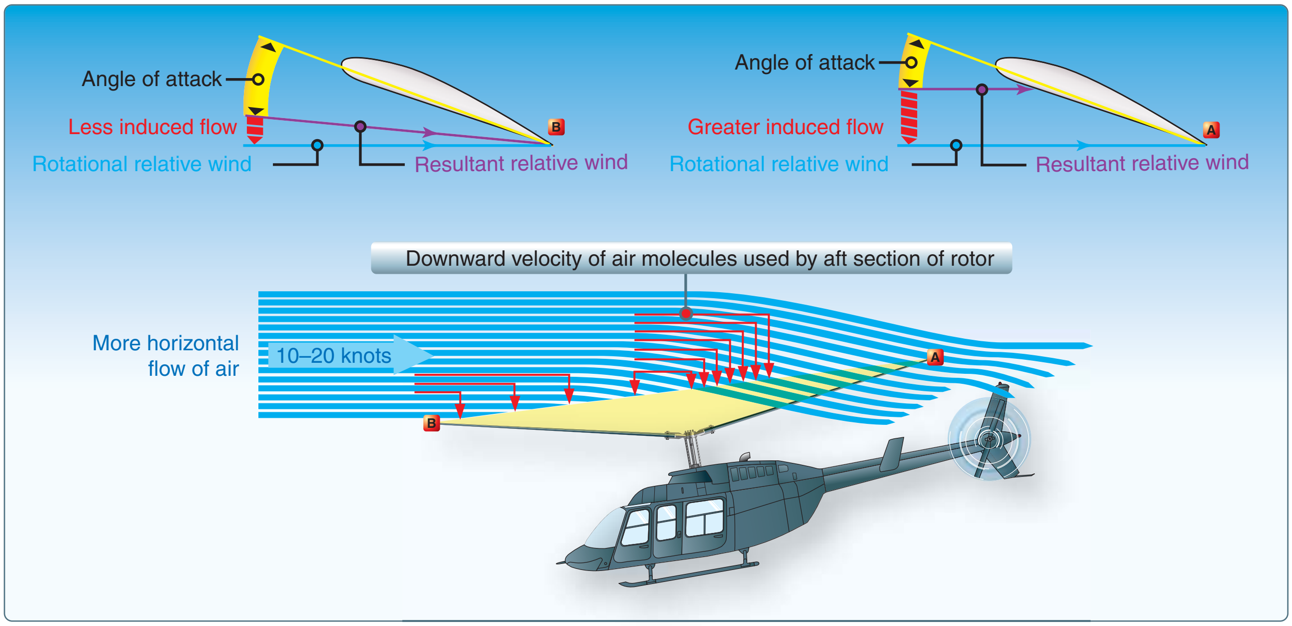

Figure 2-19. *A helicopter in forward flight, or hovering with a headwind or crosswind, has more molecules of air entering the aft portion of the rotor blade. Therefore, the angle of attack is less and the induced flow is greater at the rear of the rotor disk.*

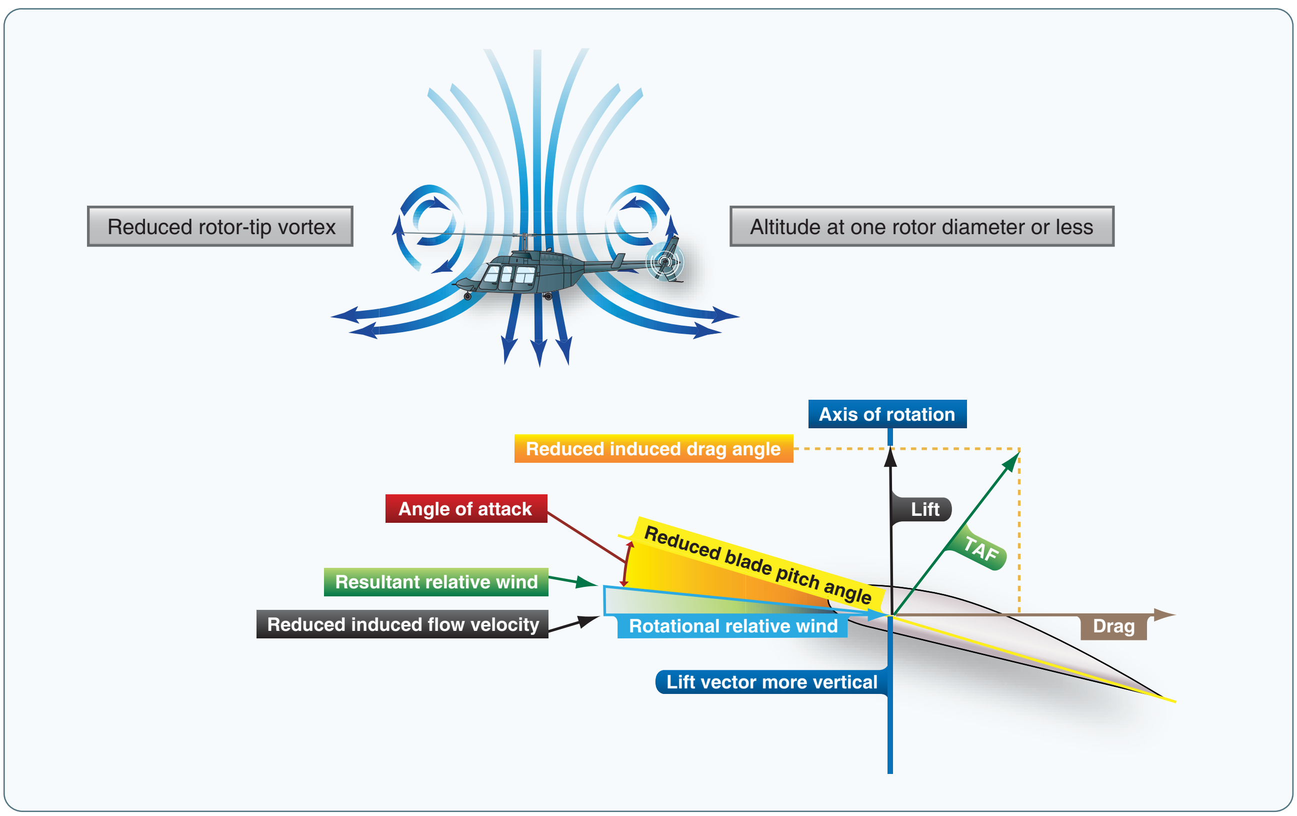

Figure 2-20. *In ground effect (IGE).*

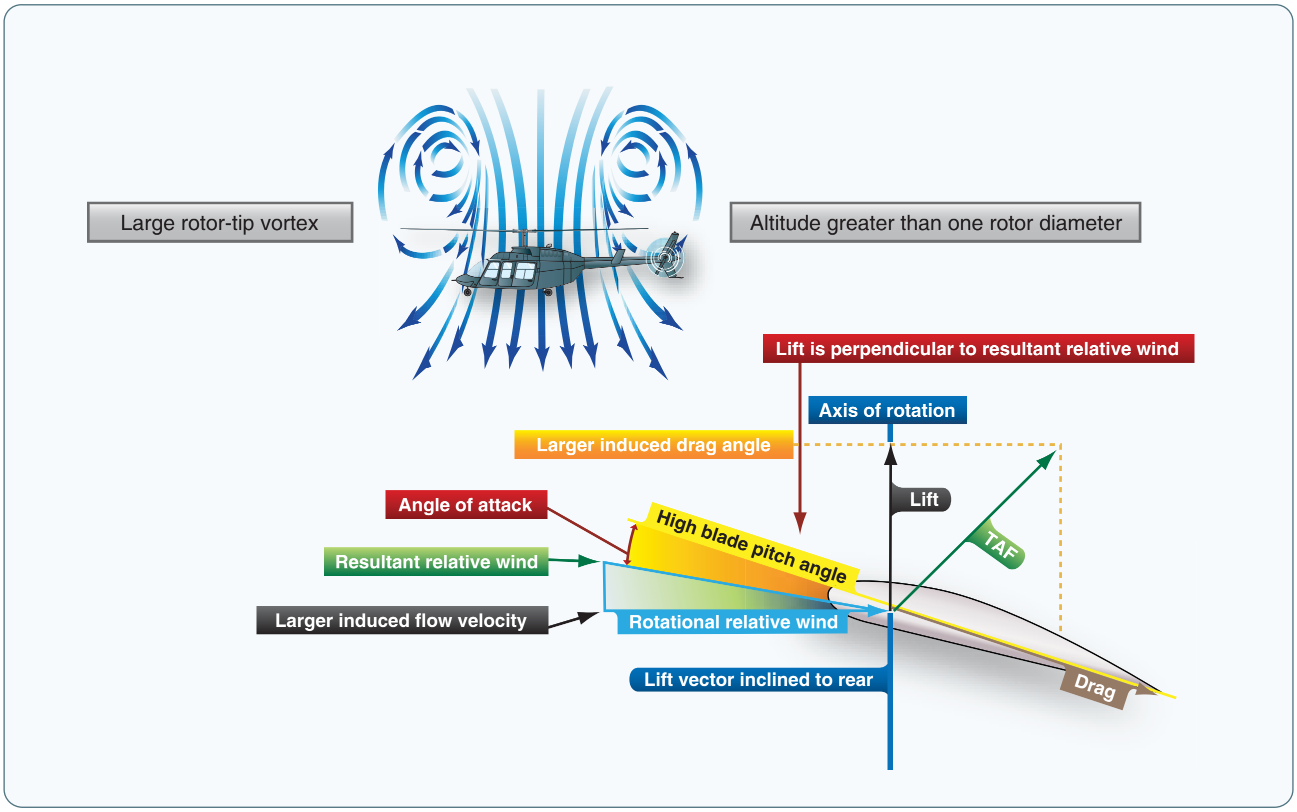

Figure 2-21. *Out of ground effect (OGE).*

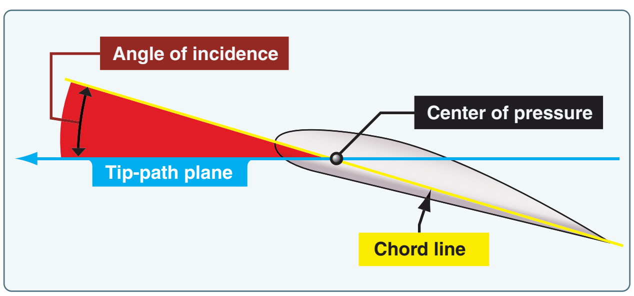

Figure 2-22. *Angle of incidence.*

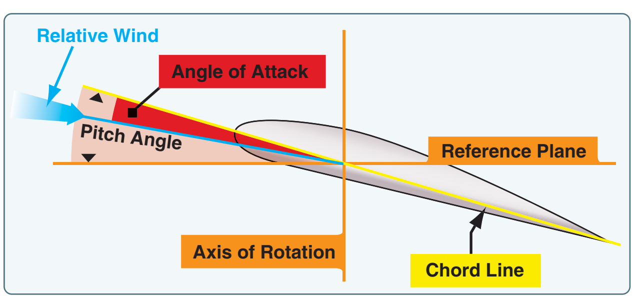

Figure 2-23. *The AOA is the angle between the airfoil chord line and resultant relative wind.*

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.

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 spanwise 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 system.

Cyclic feathering changes angle of incidence differentially around the rotor system. Cyclic feathering creates a differential lift in the rotor system by changing the AOA differentially across the rotor system. Aviators use cyclic feathering to control attitude of the rotor system. It is the means to control rearward tilt of the rotor (blowback) caused

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 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 3, 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.

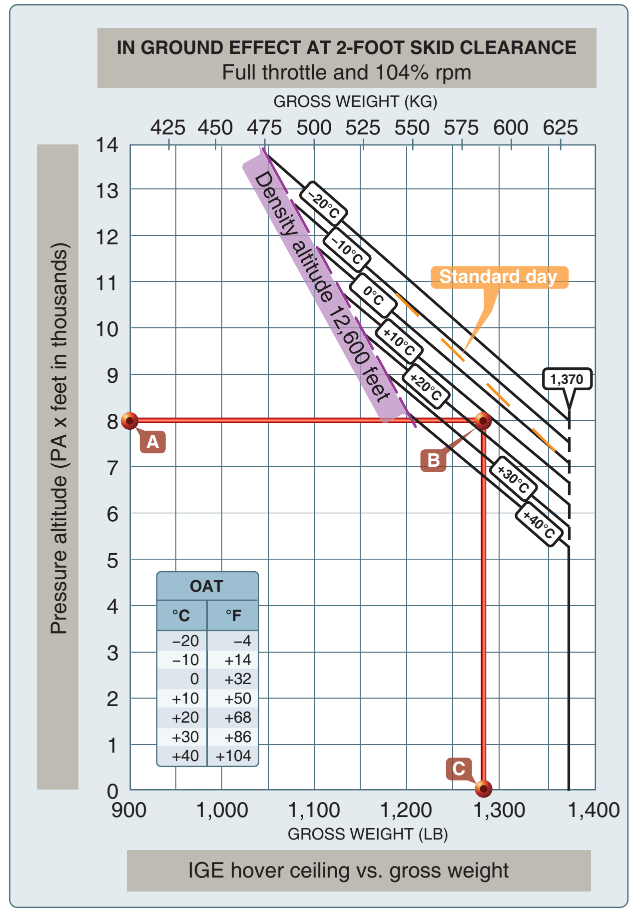

Figure 7-1. *In ground effect hovering ceiling versus gross weight chart.*

Sample Hover Problem 1

You are to fly a photographer to a remote location to take pictures of the local wildlife. Using *Figure 7-1*, 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.

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 0 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 and airspeed approaches a safe autorotative speed. At this point, some of the increased thrust available may be used to attain safe climb airspeed and 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 chart, 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 11-3]* 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 11-4]* The gross weight 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.

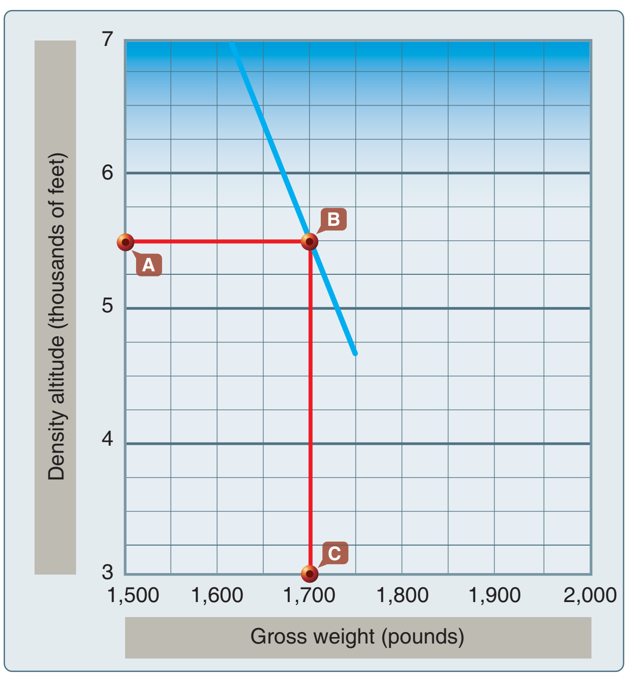

Figure 11-4. *Gross weight versus density altitude.*

Assuming a density altitude of 5,500 feet, the height/velocity diagram in *Figure 11-3* would be valid up to a gross weight of approximately 1,700 pounds. This is found by entering the graph in *Figure 11-4* at a density altitude of 5,500 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 1,700 pounds.

Charts and diagrams for helicopters set out in Title 14 of the Code of Federal Regulations (14 CFR) Part 27, Airworthiness Standards: Normal Category Rotorcraft, are advisory in nature and not regulatory. However, these charts do establish the safe parameters for operation. It is important to remember these guidelines establish the tested capabilities of the helicopter. Unless the pilot in command (PIC) is a certificated test pilot, operating a helicopter beyond its established capabilities can be considered careless and reckless operation, especially if this action results is death or injury.

Common Errors

1. Performing hovers higher than performed during training for hovering autorotations and practiced proficiency.
2. Excessively nose-low takeoffs. The forward landing gear would impact before the pilot could assume a landing attitude.
3. Adding too much power for takeoff.
4. Not maintaining landing gear aligned with takeoff path until transitioning to a crab heading to account for winds.

Settling With Power (Vortex Ring State)

Vortex ring state describes an aerodynamic condition in which a helicopter may be in a vertical descent with 20 percent up to maximum power applied, and little or no climb performance. The term "settling with power" comes from the fact that the helicopter keeps settling even though full engine power is applied.

In a normal out-of-ground-effect (OGE) hover, the helicopter is able to remain stationary by propelling a large mass of air down through the main rotor. Some of the air is recirculated near the tips of the blades, curling up from the bottom of the rotor system and rejoining the air entering the rotor from the top. This phenomenon is common to all airfoils and is known as tip vortices. Tip vortices generate drag and degrade airfoil efficiency. As long as the tip vortices are small, their only effect is a small loss in rotor efficiency. However, when the helicopter begins to descend vertically, it settles into its own downwash, which greatly enlarges the tip vortices. In this vortex ring state, most of the power developed by the engine is wasted in circulating the air in a doughnut pattern around the rotor.

In addition, the helicopter may descend at a rate that exceeds the normal downward induced-flow rate of the inner blade sections. As a result, the airflow of the inner blade sections is upward relative to the disk. This produces a secondary vortex ring in addition to the normal tip vortices. The secondary vortex ring is generated about the point on the blade where the airflow changes from up to down. The result is an unsteady turbulent flow over a large area of the disk. Rotor efficiency is lost even though power is still being supplied from the engine. *[Figure 11-5]*

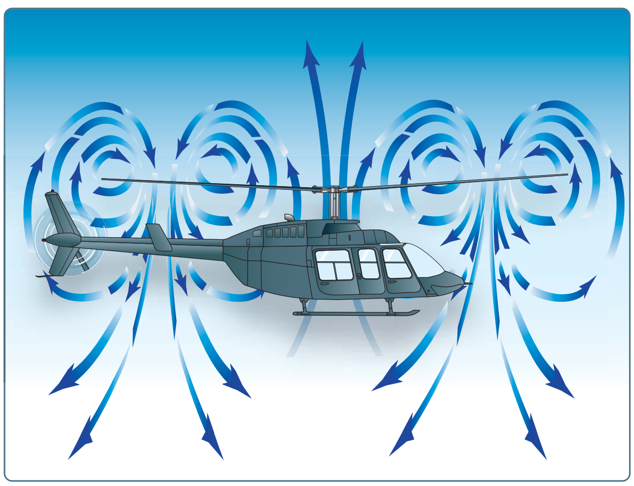

Figure 11-5. *Vortex ring state.*

A fully developed vortex ring state is characterized by an unstable condition in which the helicopter experiences uncommanded pitch and roll oscillations, has little or no collective authority, and achieves a descent rate that may approach 6,000 feet per minute (fpm) if allowed to develop.

A vortex ring state may be entered during any maneuver that places the main rotor in a condition of descending in a column of disturbed air and low forward airspeed. Airspeeds that are below translational lift airspeeds are within this region of susceptibility to settling with power aerodynamics. This condition is sometimes seen during quick-stop type maneuvers or during recovery from autorotation.

The following combination of conditions is likely to cause settling in a vortex ring state in any helicopter:

1. A vertical or nearly vertical descent of at least 300 fpm. (Actual critical rate depends on the gross weight, rpm, density altitude, and other pertinent factors.)
2. The rotor system must be using some of the available engine power (20–100 percent).
3. The horizontal velocity must be slower than effective translational lift.

Some of the situations that are conducive to a settling with power condition are: any hover above ground effect altitude, specifically attempting to hover OGE at altitudes above the hovering ceiling of the helicopter, attempting to hover OGE without maintaining precise altitude control, pinnacle or rooftop helipads when the wind is not aligned with the landing direction, and downwind and steep power approaches in which airspeed is permitted to drop below 10 knots depending on the type of helicopter.

When recovering from a settling with power condition, the pilot tends first to try to stop the descent by increasing collective pitch. However, this only results in increasing the stalled area of the rotor, thereby increasing the rate of descent. Since inboard portions of the blades are stalled, cyclic control may be limited. Recovery is accomplished by increasing airspeed, and/or partially lowering collective pitch. In many helicopters, lateral cyclic combined with lateral tailrotor thrust will produce the quickest exit from the hazard assuming that there are no barriers in that direction. In a fully developed vortex ring state, the only recovery may be to enter autorotation to break the vortex ring state.

Tandem rotor helicopters should maneuver laterally to achieve clean air in both rotors at the same time.

For settling with power demonstrations and training in recognition of vortex ring state conditions, all maneuvers should be performed at an altitude of 2000–3000 feet AGL to allow sufficient altitude for entry and recovery.

To enter the maneuver, come to an OGE hover, maintaining little or no airspeed (any direction), decrease collective to begin a vertical descent, and as the turbulence begins, increase collective. Then allow the sink rate to increase to 300 fpm or more as the attitude is adjusted to obtain airspeed of less than 10 knots. When the aircraft begins to shudder, the application of additional up collective increases the vibration and sink rate. As the power is increased, the rate of sink of the aircraft in the column of air will increase.