



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

Attachment 3 – Helicopter Flying Handbook, Chapter 11

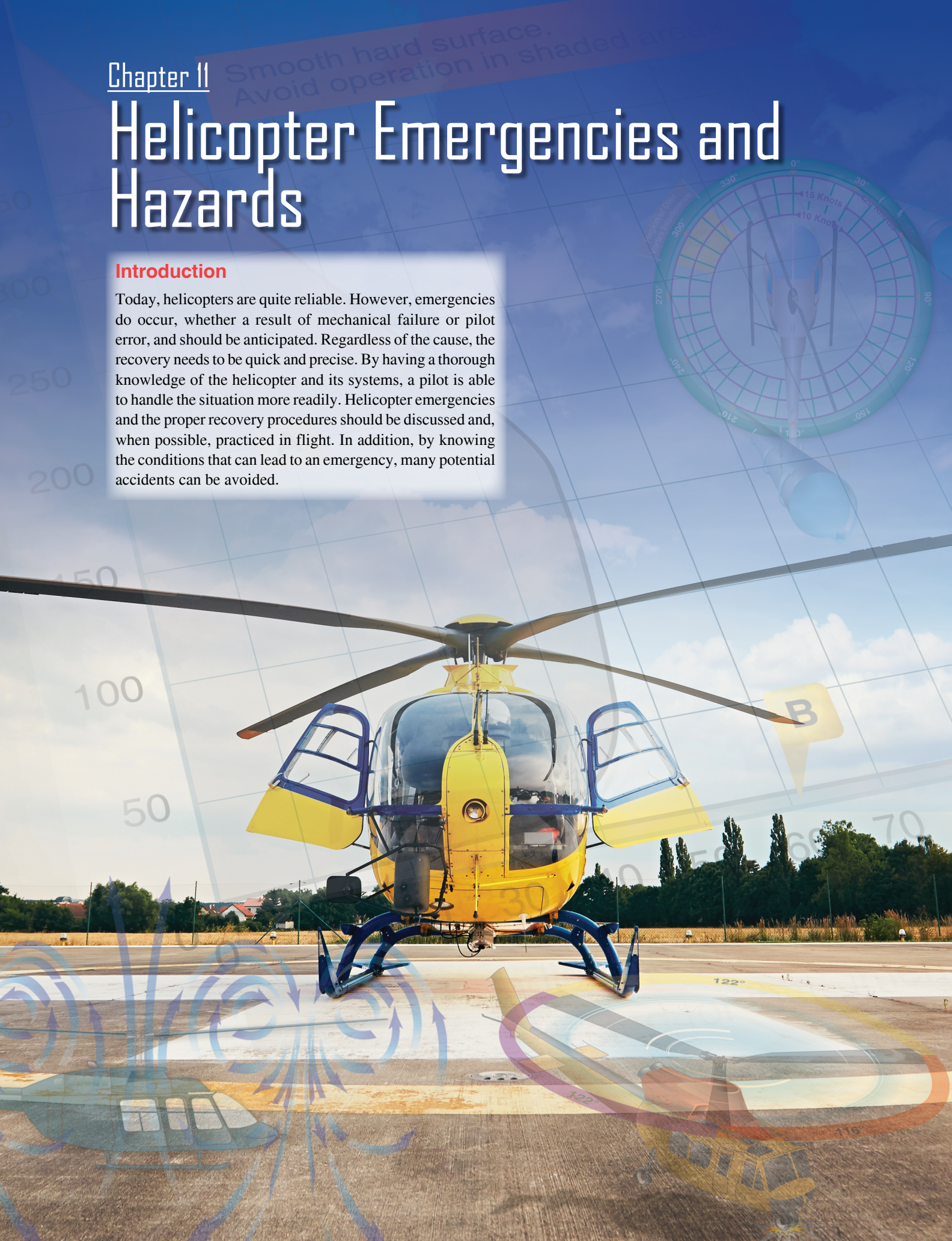
OPERATIONAL FACTORS / HUMAN PERFORMANCE

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Helicopter Emergencies and Hazards

Introduction

Today, helicopters are quite reliable. However, emergencies do occur, whether a result of mechanical failure or pilot error, and should be anticipated. Regardless of the cause, the recovery needs to be quick and precise. By having a thorough knowledge of the helicopter and its systems, a pilot is able to handle the situation more readily. Helicopter emergencies and the proper recovery procedures should be discussed and, when possible, practiced in flight. In addition, by knowing the conditions that can lead to an emergency, many potential accidents can be avoided.



Autorotation

In a helicopter, an autorotative descent is a power-off maneuver in which the engine is disengaged from the main rotor disk and the rotor blades are driven solely by the upward flow of air through the rotor. [Figure 11-1] In other words, the engine is no longer supplying power to the main rotor.

The most common reason for an autorotation is failure of the engine or drive line, but autorotation may also be performed in the event of a complete tail rotor failure, since there is virtually no torque produced in an autorotation. In both cases, maintenance has often been a contributing factor to the failure. Engine failures are also caused by fuel contamination or exhaustion as well resulting in a forced autorotation.

If the engine fails, the freewheeling unit automatically disengages the engine from the main rotor, allowing it to rotate freely. Essentially, the freewheeling unit disengages anytime the engine revolutions per minute (rpm) is less than the rotor rpm.

At the instant of engine failure, the main rotor blades are producing lift and thrust from their angle of attack (AOA) and velocity. By lowering the collective (which must be done immediately in case of an engine failure), lift and drag are reduced, and the helicopter begins an immediate descent, thus producing an upward flow of air through the rotor disk. This upward flow of air through the rotor disk provides sufficient thrust to maintain rotor rpm throughout the descent. Since the tail rotor is driven by the main rotor transmission during autorotation, heading control is maintained with the antitorque pedals as in normal flight.

Several factors affect the rate of descent in autorotation: bank angle, density altitude, gross weight, rotor rpm, trim condition, and airspeed. The primary ways to control the rate of descent are with airspeed and rotor rpm. Higher or lower airspeed is obtained with the cyclic pitch control just as in normal powered flight. In theory, a pilot has a choice in the angle of descent, varying, from straight vertical to maximum horizontal range (which is the minimum angle of descent). Rate of descent is high at zero airspeed and decreases to a minimum at approximately 50–60 knots, depending upon the particular helicopter and the factors just mentioned. As the airspeed increases beyond that which gives minimum rate of descent, the rate of descent increases again.

When landing from an autorotation, the only energy available to arrest the descent rate and ensure a soft landing is the kinetic energy stored in the rotor blades. Tip weights can greatly increase this stored energy. A greater amount of rotor energy is required to stop a helicopter with a high rate of descent than is required to stop a helicopter that is descending more slowly. Therefore, autorotative descents at very low or very high airspeeds are more critical than those performed at the minimum rate of descent airspeed. Refer to the height/velocity diagram discussion in Chapter 7, Helicopter Performance.

Each type of helicopter has a specific airspeed and rotor rpm at which a power-off glide is most efficient. The specific airspeed is somewhat different for each type of helicopter, but certain factors affect all configurations in the same manner. In general, rotor rpm maintained in the low green area (see Figure 5-3) gives more distance in an autorotation. Heavier helicopter weights may require more collective to control rotor rpm. Some helicopters need slight adjustments to minimum rotor rpm settings for winter versus summer

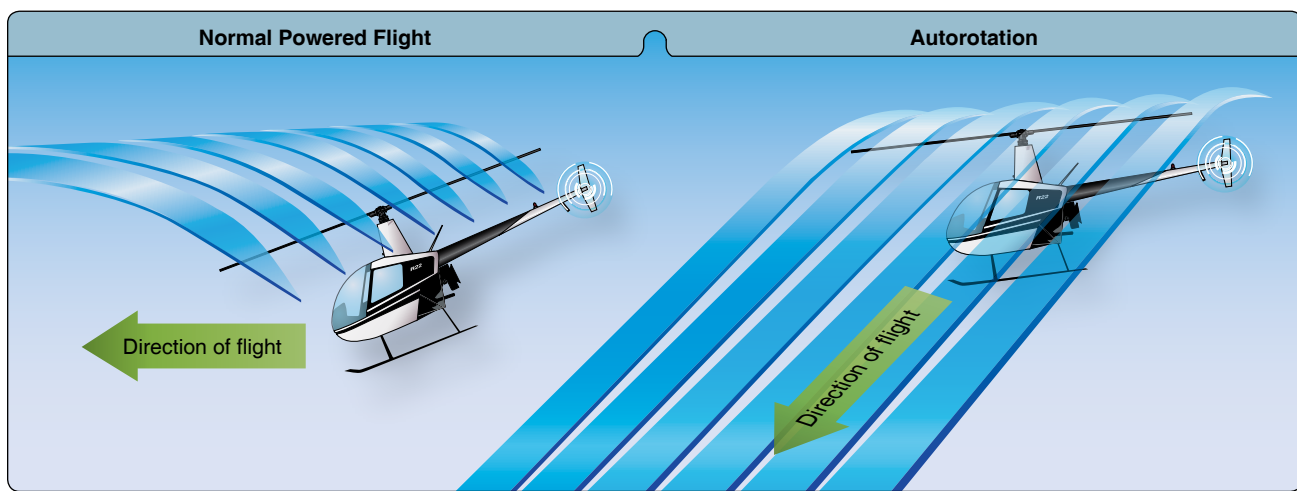


Figure 11-1. During an autorotation, the upward flow of relative wind permits the main rotor blades to rotate at their normal speed. In effect, the blades are “gliding” in their rotational plane.

conditions, and high altitude versus sea level flights. For specific autorotation airspeed and rotor rpm combinations for a particular helicopter, refer to the Rotorcraft Flight Manual (RFM). The specific airspeed and rotor rpm for autorotation is established for each type of helicopter based on average weather, calm wind conditions, and normal loading. When the helicopter is operated with heavy loads in high density altitude or gusty wind conditions, best performance is achieved from a slightly increased airspeed in the descent. For autorotation at low density altitude and light loading, best performance is achieved from a slight decrease in normal airspeed. Following this general procedure of fitting airspeed and rotor rpm to existing conditions, a pilot can achieve approximately the same glide angle in any set of circumstances, and thereby estimate the touchdown point accurately.

It is important that pilots experience autorotations from various airspeeds. This provides better understanding of the necessary flight control inputs to achieve the desired airspeed, rotor rpm and autorotation performance, such as the maximum glide or minimum descent airspeed. The decision to use the appropriate airspeed and rotor rpm for the given conditions should be instinctive to reach a suitable landing area. The helicopter glide ratio is much less than that of a fixed-wing aircraft and takes some getting used to. The flare to land at 80 knots indicated airspeed (KIAS) will be significantly greater than that from 55 KIAS. Rotor rpm control is critical at these points to ensure adequate rotor energy for cushioning the landing.

Use collective pitch control to manage rotor rpm. If rotor rpm builds too high during an autorotation, raise the collective sufficiently to decrease rpm back to the normal operating range, then reduce the collective to maintain proper rotor rpm. If the collective increase is held too long, the rotor rpm may decay rapidly. The pilot would have to lower the collective in order to regain rotor rpm. If the rpm begins decreasing, the pilot must again lower the collective. Always keep the rotor rpm within the established recommended range for the helicopter being flown.

RPM Control

Rotor rpm in low inertia rotor systems has been studied in simulator flight evaluations which indicate that the simultaneous application of aft cyclic, down collective, and alignment with the relative wind (trim) at a wide range of airspeeds, including cruise airspeeds, is critical for all operations during the entry of an autorotation. The applicable Rotorcraft Flight Manual (RFM) should be consulted to determine the appropriate procedure(s) for safely entering an autorotation. This is vitally important since the procedure(s) for safely entering an autorotation may vary with specific makes and/or models of helicopters. A basic discussion of

the aerodynamics and control inputs for single rotor systems is in order here.

Helicopter pilots must understand the use of the collective for rotor rpm control during power off autorotations in a turn. Upward movement of the collective reduces the rpm and downward movement increases the rpm. Cyclic movement is primarily associated with attitude/airspeed control in powered flight but may not be given the credit appropriate for rotor rpm control during practice and emergency power off autorotations. As long as the line of cyclic movement is parallel with the flight path of the helicopter (trimmed), the aft movement of the cyclic also creates greater air flow up through the bottom of the rotor disk and contributes to an increase in rotor rpm. If the flight path is 10 degrees to the right of the longitudinal axis of the helicopter, theoretically, the cyclic should be moved 10 degrees aft and left of the longitudinal axis to get maximum air up through the rotor system.

As the pilot lowers the collective in reaction to a loss of power during cruise flight there may be a tendency for the nose of the helicopter to pitch down. As a result, the pilot may tend to lean forward slightly, which delays the application of simultaneous aft cyclic to prevent the pitch change and associated loss of rotor rpm. A slight gain in altitude at cruise airspeed during the power off entry into an autorotation should not be of great concern as is the case for the execution of practice or actual quick stops.

Various accident investigations have concluded that, when faced with a real power failure at cruise airspeed, pilots are not simultaneously applying down collective, aft cyclic, and antitorque pedal inputs in a timely manner. Low inertia rotor systems store less kinetic energy during autorotation and, as a result, rotor rpm decays rapidly during deceleration and touchdown. Conversely, less energy is required to regain safe rotor rpm during autorotation entry and autorotative descent. The pilot should immediately apply simultaneous down collective, aft cyclic and trim the helicopter for entry into an autorotation initiated at cruise airspeed. If rotor rpm has been allowed to decrease, or has inadvertently decreased below acceptable limits, an application of aft cyclic may help rebuild rotor rpm. This application of aft cyclic must be made at least at a moderate rate and may be combined with a turn, either left or right, to increase airflow through the rotor system. This will work to increase rotor rpm. Care should be maintained to not over-speed the rotor system as this is attempted.

Risk Management during Autorotation Training

The following sections describe enhanced guidelines for autorotations during rotorcraft/helicopter flight training, as stated in Advisory Circular (AC) 61-140. There are

risks inherent in performing autorotations in the training environment, and in particular the 180-degree autorotation. This section describes an acceptable means, but not the only means, of training applicants for a rotorcraft/helicopter airman certificate to meet the qualifications for various rotorcraft/helicopter ratings. You may use alternate methods for training if you establish that those methods meet the requirements of the Helicopter Flying Handbook (HFH), FAA practical test standards (PTS), and the Rotorcraft Flight Manual (RFM).

Straight-In Autorotation

A straight-in autorotation is one made from altitude with no turns. Winds have a great effect on an autorotation. Strong headwinds cause the glide angle to be steeper due to the slower groundspeed. For example, if the helicopter is maintaining 60 KIAS and the wind speed is 15 knots, then the groundspeed is 45 knots. The angle of descent will be much steeper, although the rate of descent remains the same. The speed at touchdown and the resulting ground run depend on the groundspeed and amount of deceleration. The greater the degree of deceleration, or flare, and the longer it is held, the slower the touchdown speed and the shorter the ground run. Caution must be exercised at this point as the tail rotor will be the component of the helicopter closest to the ground. If timing is not correct and a landing attitude not set at the appropriate time, the tail rotor may contact the ground causing a forward pitching moment of the nose and possible damage to the helicopter.

A headwind is a contributing factor in accomplishing a slow touchdown from an autorotative descent and reduces the amount of deceleration required. The lower the speed desired at touchdown, the more accurate the timing and speed of the flare must be, especially in helicopters with low-inertia rotor disks. If too much collective is applied too early during the final stages of the autorotation, the kinetic energy may be depleted, resulting in little or no cushioning effect available. This could result in a hard landing with corresponding damage to the helicopter. It is generally better practice to accept more ground run than a harder landing with minimal groundspeed. As proficiency increases, the amount of ground run may be reduced.

Technique (How to Practice)

Refer to *Figure 11-2* (position 1). From level flight at the appropriate airspeed (cruise or the manufacturer's recommended airspeed), 500–700 feet above ground level (AGL), and heading into the wind, smoothly but firmly lower the collective to the full down position. Use aft cyclic to prevent a nose low attitude while maintaining rotor rpm in the green arc with collective. If the collective is in the full down position, the rotor rpm is then being controlled by

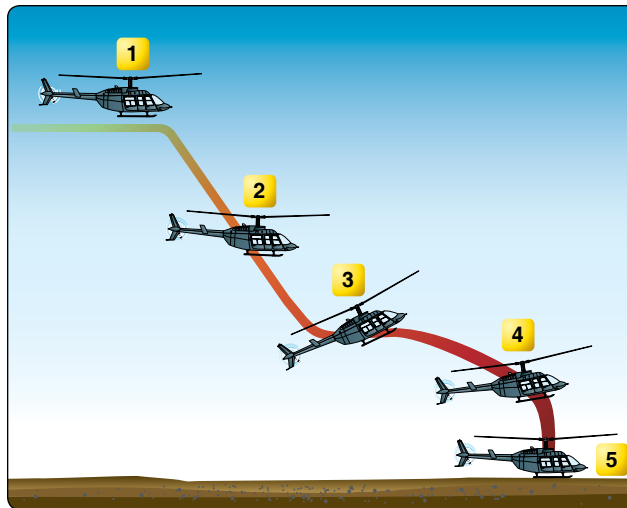


Figure 11-2. Straight-in autorotation.

the mechanical pitch stops. During maintenance, the rotor stops must be set to allow minimum autorotational rpm with a light loading. This means that collective will still be able to be reduced even under conditions of extreme reduction of vertical loading (e.g., very low helicopter weight, at very low-density altitude). After entering an autorotation, collective pitch must be adjusted to maintain the desired rotor rpm.

Coordinate the collective movement with proper antitorque pedal for trim, and apply cyclic control to maintain proper airspeed. Once the collective is fully lowered, decrease throttle to ensure a clean split/separation of the needles. This means that the rotor rpm increases to a rate higher than that of the engine—a clear indication that the freewheeling unit has allowed the engine to disconnect. After splitting the needles, readjust the throttle to keep engine rpm above normal idling speed, but not high enough to cause rejoining of the needles. See the RFM for the manufacturer's recommendations for autorotation rate of descent.

At position 2, adjust attitude with cyclic to obtain the manufacturer's recommended autorotation (or best gliding) speed. Adjust collective as necessary to maintain rotor rpm in the lower part of the green arc (see page 11-2). Aft cyclic movements cause an increase in rotor rpm, which is then controlled by a small increase in collective. Avoid a large collective increase, which results in a rapid decay of rotor rpm, and leads to "chasing the rpm." Avoid looking straight down in front of the aircraft. Continually crosscheck attitude, trim, rotor rpm, and airspeed.

At the altitude recommended by the manufacturer (position 3), begin the flare with aft cyclic to reduce forward airspeed and decrease the rate of descent. Maintain heading with the antitorque pedals. During the flare, maintain rotor rpm in

the green range. In the execution of the flare, care must be taken that the cyclic be moved rearward neither so abruptly that it causes the helicopter to climb, nor so slowly that it fails to arrest the descent, which may allow the helicopter to settle so rapidly that the tail rotor strikes the ground. In most helicopters, the proper flare attitude is that resulting in a groundspeed of a slow run. When forward motion decreases to the desired groundspeed—usually the lowest possible speed (position 4)—move the cyclic forward to place the helicopter in the proper attitude for landing.

This action gives the student an idea of airframe attitude to avoid, because a pilot should never allow ground contact unless the helicopter is more nose-low than that attitude. Limiting the flare to that attitude may result in slightly faster touchdown speeds but will eliminate the possibility of tail rotor impact on level surfaces.

The landing gear height at this time should be approximately 3–15 feet AGL, depending on the altitude recommended by the manufacturer. As the apparent groundspeed and altitude decrease, the helicopter must be returned to a more level attitude for touchdown by applying forward cyclic. Some helicopters can be landed on the heels in a slightly nose high attitude to help decrease the forward groundspeed, whereas others must land skids or landing gear level, in order to spread the landing loads equally to all of the landing gear. Extreme caution should be used to avoid an excessive nose high and tail low attitude below 10 feet. The helicopter must be close to the landing attitude to keep the tail rotor from contacting the surface.

At this point, if a full touchdown landing is to be performed, allow the helicopter to descend vertically (position 5). This collective application uses some of the kinetic energy in the rotor disk to help slow the descent rate of the helicopter. When the collective is raised, the opposite antitorque pedal used in powered flight will be needed due to the friction within the transmission/drive train. Touch down in a level flight attitude.

Control response with increased pitch angles will be slightly different than normal. With a decrease in main rotor rpm, the antitorque authority is reduced (the pedals react more slowly), requiring larger control inputs to maintain heading at touchdown.

Some helicopters, such as the Schweizer 300, have a canted tail stabilizer. With a canted stabilizer, it is crucial that the pilot apply the appropriate pedal input at all times during the autorotation. If not the tailboom tends to swing to the right, which allows the canted stabilizer to raise the tail. This can

result in a severe nose tuck which is quickly corrected with right pedal application.

A power recovery can be made during training in lieu of a full touchdown landing. Refer to the section on power recovery for the correct technique.

After the helicopter has come to a complete stop after touchdown, lower the collective pitch to the full-down position. Do not try to stop the forward ground run with aft cyclic, as the main rotor blades can strike the tail boom. By lowering the collective slightly during the ground run, an increase in weight is placed on the landing carriage, slowing the helicopter; however, this is dependent on the condition of the landing surface.

One common error is the holding of the helicopter off the surface, versus cushioning it onto the surface during an autorotation. Holding the helicopter in the air by using all of the rotor rpm kinetic energy usually causes the helicopter to have a hard landing, which results in the blades flexing down and contacting the tail boom. The rotor rpm should be used to cushion the helicopter on to the surface for a controlled, smooth landing instead of allowing the helicopter to drop the last few inches.

Common Errors

1. Not understanding the importance of an immediate entry into autorotation upon powerplant or driveline failure.
2. Failing to use sufficient antitorque pedal when power is reduced.
3. Lowering the nose too abruptly when power is reduced, thus placing the helicopter in a dive.
4. Failing to maintain proper rotor rpm during the descent.
5. Applying up-collective pitch at an excessive altitude, resulting in a hard landing, loss of heading control, and possible damage to the tail rotor and main rotor blade stops.
6. Failing to level the helicopter or achieve the manufacturers preferred landing attitude.
7. Failing to minimize or eliminate lateral movement during ground contact. (Similar for items 8 and 9)
8. Failing to maintain ground track in the air and keeping the landing gear aligned with the direction of travel during touchdown and ground contact.
9. Failing (in a practice run) to go around if not within limits and specified criteria for safe autorotation.

Autorotation with Turns

Turns (or a series of turns) can be made during autorotation to facilitate landing into the wind or avoiding obstacles. Turns during autorotation should be made early so that the remainder of the autorotation is flown identically to a straight-in autorotation. The most common turns in an autorotation are 90 degrees and 180 degrees. The following technique describes an autorotation with a 180-degree turn.

The pilot establishes the aircraft on a downwind heading at the recommended airspeed, and parallel to the intended touchdown point. Then, taking the wind into account, the pilot establishes the ground track approximately 200 feet laterally from the desired course line to the touchdown point. In strong crosswind conditions, the pilot should be prepared to adjust the downwind leg closer or farther out, as appropriate. The pilot uses the autorotation entry airspeed recommended by the RFM. When abeam the intended touchdown point, the pilot smoothly reduces collective, then reduces power to the engine to show a split between the rotor rpm and engine rpm and simultaneously applies appropriate anti-torque pedal and cyclic to maintain proper attitude/airspeed. Throughout the autorotation, the pilot should continually crosscheck the helicopter's attitude, rotor rpm, airspeed, and verify that the helicopter is in trim (centered trim ball).

After the descent and autorotation airspeed is established, the pilot initiates the 180-degree turn. For training operations, initially roll into a bank of at least 30 degrees, but no more than 60 degrees. It is important to maintain the proper airspeed, rotor rpm, and trim (centered trim ball) throughout the turn. Changes in the helicopter's attitude and the angle of bank causes a corresponding change in rotor rpm within normal limits. Do not allow the nose to pitch up or down excessively during the maneuver, as it may cause undesirable rotor rpm excursions.

Pitot-static airspeed indications may be unreliable or lag during an autorotational turn. The pilot should exercise caution to avoid using excessive aircraft pitch attitudes and to avoid chasing airspeed indications in an autorotational turn.

Note: Approaching the 90-degree point, check the position of the landing area. The second 90 degrees of the turn should end with a roll-out on a course line to the landing area. If the helicopter is too close, decrease the bank angle (to increase the radius of turn); if too far out, increase the bank angle (to decrease the radius of the turn). A bank angle of no more than 60 degrees should be encountered during this turn. Monitor the trim ball (along with one's kinesthetic sense) and adjust as necessary with cyclic and anti-torque pedal to maintain coordinated flight. Prior to passing through 200 feet above ground level (AGL), if landing or making a

surface-level power recovery, the turn should be completed, and the helicopter aligned with the intended touchdown area. Upon reaching the course line, set the appropriate crosswind correction. If the collective pitch was increased to control the rpm, it may need to be lowered on rollout to prevent decay in rotor rpm.

This maneuver should be aborted at any point the following criteria is not met: if the helicopter is not in a stabilized approach to landing profile (i.e., it is not aligned as close as possible into the wind with the touchdown point, after completing the 180-degree turn); if the rotor rpm is not within limits; if the helicopter is not at a proper attitude/airspeed; or if the helicopter is not under proper control at 200 feet AGL. It is essential that the pilot on the controls (or a certificated flight instructor (CFI), when intervening) immediately abort the maneuver and execute a smooth power recovery and go-around. It is important for the CFI who is intervening at this point to remember that the go-around is a far safer option than trying to recover lost rotor rpm and reestablish or recover to the hover or even the preferred hover taxi.

From all entry positions, but particularly true of the 180-degree entry, a primary concern is getting the aircraft into the course line with as much altitude as possible. Once the collective has been lowered and the engine set to flight idle, the helicopter will lose altitude. A delayed turn will result in a lower altitude when arriving on the course line. Additionally, an uncoordinated flight condition (trim-ball not centered) results in an increased sink rate, which may be unrecoverable if not corrected.

During the turn to the course line, the pilot should use a scan pattern to see outside as well as inside the cockpit. Of primary importance outside is maintaining the appropriate descending attitude and a proper turn rate. Essential items to scan inside are rotor rpm and centered trim ball. Rotor rpm will build anytime "G" forces are applied to the rotor system. Usually, this occurs in the turn to the course line and during the deceleration flare.

Throughout the maneuver, rotor rpm should be maintained in the range recommended in the RFM. Rotor rpm outside of the recommended range results in a higher rate of descent and less glide-ratio. When the rotor rpm exceeds the desired value as a result of increased G load in the turn, timely use of up collective will increase the pitch of the blades and slow the rotor to the desired rpm. In an autorotation, rotor rpm is the most critical element, as it provides the lift required to stabilize an acceptable rate of descent and the energy necessary to cushion the landing. Collective should be lowered to the full down position to maintain rotor rpm immediately following a loss of power. However, rapid or

abrupt collective movement could lead to mast bumping in some rotorcraft with teetering rotor systems.

Energy is a very important property of all rotating components, and the kinetic energy stored in the rotor system is used to cushion the landing. More lift is produced at the bottom of an autorotation by raising the collective, which increases the angle of attack of the blades. The rotor rpm will also rapidly decay at this point and it is essential to properly time the flare and the final collective pull to fully arrest the descent and cushion the landing. Upon arriving into the course line prior to the flare, the scan should focus almost entirely outside. The scan should include:

- The horizon for attitude, ground track, and nose alignment;
- the altitude to set the flare and for closure (groundspeed); and
- the instrument cross-check of airspeed, rotor rpm, and engine rpm in the descent.

Every autorotational flare will be different depending on the existing wind conditions, airspeed, density altitude (DA), and the aircraft gross weight. A pilot operating a helicopter at a high DA needs to take into account the effects on the control of the helicopter when recovering from an aborted autorotation.

Some effects to consider are:

- Higher rate of descent.
- Reduced rotor rpm builds in autorotation.
- Low initial rotor rpm response in autorotation.
- The requirement for a higher flare height.
- Reduced engine power performance.

Common Errors

The following common errors should be prevented:

1. Entering the maneuver at an improper altitude or airspeed.
2. Entering the maneuver without a level attitude (or not in coordinated flight).
3. Entering the maneuver and not correcting from the initial deceleration to a steady state attitude (which allows excessive airspeed loss in the descent).
4. Improper transition into the descent on entry.
5. Improper use of anti-torque on entry.
6. Failure to establish the appropriate crosswind correction, allowing the aircraft to drift.
7. Failure to maintain coordinated flight through the turn.

8. Failure to maintain rotor rpm within the RFM recommended range.
9. Excessive yaw when increasing collective to slow rate of descent during power recovery autorotations.
10. During power recovery autorotations, a delay in reapplying power.
11. Initial collective pull either too high or too low.
12. Improper flare (too much or not enough).
13. Flaring too low or too high (AGL).
14. Failure to maintain heading when reapplying power.
15. Not landing with a level attitude.
16. Landing with aircraft not aligned with the direction of travel.
17. Insufficient collective cushioning during full autorotations.
18. Abrupt control inputs on touchdown during full autorotations.

Practice Autorotation with a Power Recovery

A power recovery is used to terminate practice autorotations at a point prior to actual touchdown. After the power recovery, a landing can be made or a go-around initiated.

Technique (How to Practice)

At approximately 3–15 feet landing gear height AGL, depending upon the helicopter being used, begin to level the helicopter with forward cyclic control. Avoid excessive nose-high, tail-low attitude below 10 feet. Just prior to achieving level attitude, with the nose still slightly up, coordinate upward collective pitch control with an increase in the throttle to join the needles at operating rpm. The throttle and collective pitch must be coordinated properly.

If the throttle is increased too fast or too much, an engine overspeed can occur; if throttle is increased too slowly or too little in proportion to the increase in collective pitch, a loss of rotor rpm results. Use sufficient collective pitch to stop the descent, but keep in mind that the collective pitch application must be gradual to allow for engine response. Coordinate proper antitorque pedal pressure to maintain heading. When a landing is to be made following the power recovery, bring the helicopter to a hover and then descend to a landing.

In nearly all helicopters, when practicing autorotations with power recovery, the throttle should be at the flight setting at the beginning of the flare. As the rotor disk begins to dissipate its energy, the engine is up to speed as the needles join when the rotor decreases into the normal flight rpm.

Helicopters that do not have the throttle control located on the collective are generally exceptions to basic technique and require some additional prudence. The autorotation should be initiated with the power levers left in the “flight,” or normal, position. If a full touchdown is to be practiced, it is common technique to move the power levers to the idle position once the landing area can safely be reached. In most helicopters, the pilot is fully committed at that point to make a power-off landing. However, it may be possible to make a power recovery prior to passing through 100 feet AGL if the powerplant can recover within that time period and the instructor is very proficient. The pilot should comply with the RFM instructions in all cases.

When practicing autorotations to a power recovery, the differences between reciprocating engines and turbines may be profound. The reciprocating powerplant generally responds very quickly to power changes, especially power increases. Some turbines have delay times depending on the type of fuel control or governing system installed. Any reciprocating engine needing turbocharged boost to develop rated horse power may have significant delays to demands for increased power, such as in the power recovery. Power recovery in those helicopters with slower engine response times must have the engines begin to develop enough power to rejoin the needles by approximately 100 feet AGL.

If a go-around is to be made, the cyclic control should be moved forward to resume forward flight. In transition from a practice autorotation to a go-around, exercise caution to avoid an altitude-airspeed combination that would place the helicopter in an unsafe area of its height/velocity diagram.

This is one of the most difficult maneuvers to perform due to the concentration needed when transitioning from powered flight to autorotation and then back again to powered flight. For helicopters equipped with the power control on the collective, engine power must be brought from flight power to idle power and then back to a flight power setting. A delay during any of these transitions can seriously affect rotor rpm placing the helicopter in a situation that cannot be recovered.

The cyclic must be adjusted to maintain the required airspeed without power, and then used for the deceleration flare, followed by the transition to level hovering flight. Additionally, the cyclic must be adjusted to remove the compensation for translating tendency. The tail rotor is no longer needed to produce antitorque thrust until almost maximum power is applied to the rotor disk for hovering flight, when the tail rotor must again compensate for the main rotor torque, which also demands compensation for the tail rotor thrust and translating tendency.

The pedals must be adjusted from a powered flight anti-torque trim setting to the opposite trim setting to compensate for transmission drag and any unneeded vertical fin thrust countering the now nonexistent torque and then reset to compensate for the high power required for hovering flight.

All of the above must be accomplished during the 23 seconds of the autorotation, and the quick, precise control inputs must be made in the last 5 seconds of the maneuver.

Common Errors

1. Initiating recovery too late, which requires a rapid application of controls and results in overcontrolling.
2. Failure to obtain and maintain a level attitude near the surface.
3. Failure to coordinate throttle and collective pitch properly, which results in either an engine overspeed or a loss of rotor rpm.
4. Failure to coordinate proper antitorque pedal with the increase in power.
5. Late engine power engagement causing excessive temperature or torque, or rpm drop.
6. Failure to go around if not within limits and specified criteria for safe autorotation.

Practicing Power Failure in a Hover

Power failure in a hover, also called hovering autorotation, is practiced so that a pilot can automatically make the correct response when confronted with engine stoppage or certain other emergencies while hovering. The techniques discussed in this section are for helicopters with a counterclockwise rotor disk and an antitorque rotor.

Technique (How to Practice)

To practice hovering autorotation, establish a normal hovering height (approximately 2–3 feet) for the particular helicopter being used, considering load and atmospheric conditions. Keep the helicopter headed into the wind and hold maximum allowable rpm.

To simulate a power failure, firmly roll the throttle to the engine idle position. This disengages the driving force of the engine from the rotor, thus eliminating torque effect. As the throttle is closed, apply proper antitorque pedal to maintain heading. Usually, a slight amount of right cyclic control is necessary to keep the helicopter from drifting to the left, to compensate for the loss of tail rotor thrust. However, use cyclic control, as required, to ensure a vertical descent and a level attitude. Do not adjust the collective on entry.

Helicopters with low inertia rotor disks settle immediately. Keep a level attitude and ensure a vertical descent with cyclic control while maintaining heading with the pedals. Any lateral movement must be avoided to prevent dynamic rollover. As rotor rpm decays, cyclic response decreases, so compensation for the winds will require more cyclic input. At approximately 1 foot AGL, apply upward collective control, as necessary, to slow the descent and cushion the landing without arresting the rate of descent above the surface. Usually, the full amount of collective is required just as the landing gear touches the surface. As upward collective control is applied, the throttle must be held in the idle detent position to prevent the engine from re-engaging. The idle detention position is a ridged stop position between idle and off in which the idle release button snaps into, prevent accidental throttle off.

Helicopters with high-inertia rotor disks settle more slowly after the throttle is closed. In this case, when the helicopter has settled to approximately 1 foot AGL, apply upward collective control while holding the throttle in the idle detent position to slow the descent and cushion the landing. The timing of collective control application and the rate at which it is applied depend upon the particular helicopter being used, its gross weight, and the existing atmospheric conditions. Cyclic control is used to maintain a level attitude and to ensure a vertical descent. Maintain heading with antitorque pedals.

When the weight of the helicopter is entirely resting on the landing gear, cease application of upward collective. When the helicopter has come to a complete stop, lower the collective pitch to the full-down position.

The timing of the collective movement is a very important consideration. If it is applied too soon, the remaining rpm may not be sufficient to make a soft landing. On the other hand, if it is applied too late, surface contact may be made before sufficient blade pitch is available to cushion the landing. The collective must not be used to hold the helicopter off the surface, causing a blade stall. Low rotor rpm and ensuing blade stall can result in a total loss of rotor lift, allowing the helicopter to fall to the surface and possibly resulting in blade strikes to the tail boom and other airframe damage such as landing gear damage, transmission mount deformation, and fuselage cracking.

Common Errors

1. Failure to use sufficient proper antitorque pedal when power is reduced.
2. Failure to stop all sideward or backward movement prior to touchdown.
3. Failure to apply up-collective pitch properly, resulting in a hard touchdown.

4. Failure to touch down in a level attitude.
5. Failure to roll the throttle completely to idle.
6. Failure to hover at a safe altitude for the helicopter type, atmospheric conditions, and the level of training/proficiency of the pilot.
7. Failure to go around if not within limits and specified criteria for safe autorotation.

Vortex Ring State

Vortex ring state (formerly referenced as settling-with-power) 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 previously used term settling-with-power came 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 disk 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 11-3]

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



Figure 11-3. *Vortex ring state.*

that are below translational lift airspeeds are within this region of susceptibility to vortex ring state 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 disk must be using some of the available engine power (20–100 percent).
3. The horizontal velocity must be slower than effective translational lift.

Situations that are conducive to a vortex ring state condition are attempting to hover OGE without maintaining precise altitude control, and approaches, especially steep approaches, with a tailwind component.

When recovering from a vortex ring state 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. The traditional recovery is accomplished by increasing airspeed, and/or partially lowering collective to exit the vortex. In most helicopters, lateral cyclic thrust combined with an increase in power and lateral antitorque thrust will produce the quickest exit from the hazard. This technique, known as the Vuichard Recovery (named after the Swiss examiner from the Federal Office of Civil Aviation who developed it) recovers by eliminating the descent rate as opposed to exiting the vortex. If the vortex ring state and the corresponding descent rate is allowed to progress to what is

called the windmill brake state, the point where the airflow is completely up through the rotor, the only recovery may be an autorotation.

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

For vortex ring state demonstrations and training in recognition and recovery should be performed from a safe altitude to allow recovery no less than 1000 feet AGL or the manufacturer's recommended altitude, whichever is higher.

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.

If altitude is sufficient, some time can be spent in the vortices, to enable the pilot to develop a healthy knowledge of the maneuver. However, helicopter pilots would normally initiate recovery at the first indication of vortex ring state. Recovery should be initiated at the first sign of vortex ring state by applying forward cyclic to increase airspeed and/ or simultaneously reducing collective. The recovery is complete when the aircraft passes through effective translational lift and a normal climb is established.

Common Errors—Traditional Recovery

1. Too much lateral speed for entry into vortex ring state.
2. Excessive decrease of collective.

Common Errors—Vuichard Recovery

1. Excessive lateral cyclic
2. Failure to maintain heading

Retreating Blade Stall

In forward flight, the relative airflow through the main rotor disk is different on the advancing and retreating side. The relative airflow over the advancing side is higher due to the forward speed of the helicopter, while the relative airflow on the retreating side is lower. This dissymmetry of lift increases as forward speed increases.

To generate the same amount of lift across the rotor disk, the advancing blade flaps up while the retreating blade flaps down. This causes the AOA to decrease on the advancing

blade, which reduces lift, and increase on the retreating blade, which increases lift. At some point as the forward speed increases, the low blade speed on the retreating blade, and its high AOA cause a stall and loss of lift.

Retreating blade stall is a factor in limiting a helicopter's never-exceed speed (V_{NE}) and its development can be felt by a low frequency vibration, pitching up of the nose, and a roll in the direction of the retreating blade. High weight, low rotor rpm, high density altitude, turbulence and/or steep, abrupt turns are all conducive to retreating blade stall at high forward airspeeds. As altitude is increased, higher blade angles are required to maintain lift at a given airspeed. Thus, retreating blade stall is encountered at a lower forward airspeed at altitude. Most manufacturers publish charts and graphs showing a V_{NE} decrease with altitude.

When recovering from a retreating blade stall condition caused by high airspeed, moving the cyclic aft only worsens the stall as aft cyclic produces a flare effect, thus increasing the AOA. Pushing forward on the cyclic also deepens the stall as the AOA on the retreating blade is increased. While the first step in a proper recovery is usually to reduce collective, RBS should be evaluated in light of the relevant factors discussed in the previous paragraph and addressed accordingly. For example, if a pilot at high weight and high DA is about to conduct a high reconnaissance prior to a confined area operation where rolling into a steep turn causes onset of RBS, the recovery is to roll out of the turn. If the cause is low rotor rpm, then increase the rpm.

Common Errors

1. Failure to recognize the combination of contributing factors leading to retreating blade stall.
2. Failure to compute V_{NE} limits for altitudes to be flown.

Ground Resonance

Helicopters with articulating rotors (usually designs with three or more main rotor blades) are subject to ground resonance, a destructive vibration phenomenon that occurs at certain rotor speeds when the helicopter is on the ground. Ground resonance is a mechanical design issue that results from the helicopter's airframe having a natural frequency that can be intensified by an out-of-balance rotor. The unbalanced rotor disk vibrates at the same frequency (or multiple thereof) of the airframe's resonant frequency, and the harmonic oscillation increases because the engine is adding power to the system, increasing the magnitude (amplitude) of the vibrations until the structure or structures fail. This condition can cause a helicopter to self-destruct in a matter of seconds.

Hard contact with the ground on one corner (and usually with wheel-type landing gear) can send a shockwave to the main rotor head, resulting in the blades of a three-blade rotor disk moving from their normal 120° relationship to each other. This movement occurs along the drag hinge and could result in something like 122° , 122° , and 116° between blades. [Figure 11-4] When another part of the landing gear strikes the surface, the unbalanced condition could be further aggravated.

If the rpm is low, the only corrective action to stop ground resonance is to close the throttle immediately and fully lower the collective to place the blades in low pitch. If the rpm is in the normal operating range, fly the helicopter off the ground, and allow the blades to rephase themselves automatically. Then, make a normal touchdown. If a pilot lifts off and allows the helicopter to firmly re-contact the surface before the blades are realigned, a second shock could move the blades again and aggravate the already unbalanced condition. This could lead to a violent, uncontrollable oscillation.

This situation does not occur in rigid or semi-rigid rotor disks because there is no drag hinge. In addition, skid-type landing gear is not as prone to ground resonance as wheel-type landing gear, since the rubber tires' resonant frequency typically can match that of the spinning rotor, unlike the condition of a rigid landing gear.

Dynamic Rollover

A helicopter is susceptible to a lateral rolling tendency, called dynamic rollover, when it is in contact with the surface



Figure 11-4. Ground resonance.

during takeoffs or landings. For dynamic rollover to occur, some factor must first cause the helicopter to roll or pivot around a skid or landing gear wheel, until its critical rollover angle is reached. The angle at which dynamic rollover occurs will vary based on helicopter type. Then, beyond this point, main rotor thrust continues the roll and recovery is impossible. After this angle is achieved, the cyclic does not have sufficient range of control to eliminate the thrust component and convert it to lift. If the critical rollover angle is exceeded, the helicopter rolls on its side regardless of the cyclic corrections made.

Dynamic rollover begins when the helicopter starts to pivot laterally around its skid or wheel. For dynamic rollover to occur the following three factors must be present:

1. A rolling moment
2. A pivot point other than the helicopter's normal CG
3. Thrust greater than weight

This can occur for a variety of reasons, including the failure to remove a tie down or skid-securing device, or if the skid or wheel contacts a fixed object while hovering sideward, or if the gear is stuck in ice, soft asphalt, or mud. Dynamic rollover may also occur if you use an improper landing or takeoff technique or while performing slope operations. Whatever the cause, dynamic rollover is possible if not using the proper corrective technique.

Once started, dynamic rollover cannot be stopped by application of opposite cyclic control alone. For example, the right skid contacts an object and becomes the pivot point while the helicopter starts rolling to the right. Even with full left cyclic applied, the main rotor thrust vector and its moment follows the aircraft as it continues rolling to the right. Quickly reducing collective pitch is the most effective way to stop dynamic rollover from developing. Dynamic rollover can occur with any type of landing gear and all types of rotor disks.

It is important to remember rotor blades have a limited range of movement. If the tilt or roll of the helicopter exceeds that range (5–8°), the controls (cyclic) can no longer command a vertical lift component and the thrust or lift becomes a lateral force that rolls the helicopter over. When limited rotor blade movement is coupled with the fact that most of a helicopter's weight is high in the airframe, another element of risk is added to an already slightly unstable center of gravity. Pilots must remember that in order to remove thrust, the collective must be lowered as this is the only recovery technique available.

Critical Conditions

Certain conditions reduce the critical rollover angle, thus increasing the possibility for dynamic rollover and reducing

the chance for recovery. The rate of rolling motion is also a consideration because, as the roll rate increases, there is a reduction of the critical rollover angle at which recovery is still possible. Other critical conditions include operating at high gross weights with thrust (lift) approximately equal to the weight.

Refer to *Figure 11-5*. The following conditions are most critical for helicopters with counterclockwise rotor rotation:

1. Right side skid or landing wheel down, since translating tendency adds to the rollover force.
2. Right lateral center of gravity (CG).
3. Crosswinds from the left.
4. Left yaw inputs.

For helicopters with clockwise rotor rotation, the opposite conditions would be true.

Cyclic Trim

When maneuvering with one skid or wheel on the ground, care must be taken to keep the helicopter cyclic control carefully adjusted. For example, if a slow takeoff is attempted and the cyclic is not positioned and adjusted to account for translating tendency, the critical recovery angle may be exceeded in less than two seconds. Control can be maintained if the pilot maintains proper cyclic position and does not allow the helicopter's roll and pitch rates to become too great. Fly the helicopter into the air smoothly while keeping movements of pitch, roll, and yaw small; do not allow any abrupt cyclic pressures.

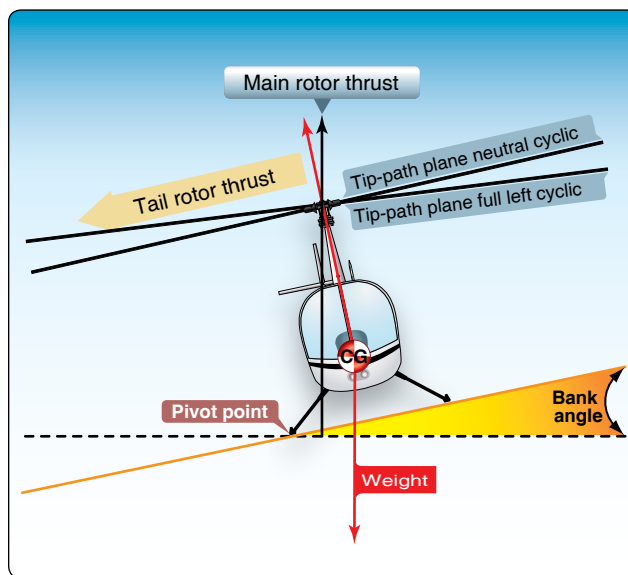


Figure 11-5. Forces acting on a helicopter with right skid on the ground.

Normal Takeoffs and Landings

Dynamic rollover is possible even during normal takeoffs and landings on relatively level ground, if one wheel or skid is on the ground and thrust (lift) is approximately equal to the weight of the helicopter. If the takeoff or landing is not performed properly, a roll rate could develop around the wheel or skid that is on the ground. When taking off or landing, perform the maneuver smoothly and carefully adjust the cyclic so that no pitch or roll movement rates build up, especially the roll rate. If the bank angle starts to increase to an angle of approximately $5\text{--}8^\circ$, and full corrective cyclic does not reduce the angle, the collective should be reduced to diminish the unstable rolling condition. Excessive bank angles can also be caused by landing gear caught in a tie down strap, or a tie down strap still attached to one side of the helicopter. Lateral loading imbalance (usually outside published limits) is another contributing factor.

Slope Takeoffs and Landings

During slope operations, excessive application of cyclic control into the slope, together with excessive collective pitch control, can result in the downslope skid or landing wheel rising sufficiently to exceed lateral cyclic control limits, and an upslope rolling motion can occur. [Figure 11-6]

When performing slope takeoff and landing maneuvers, follow the published procedures and keep the roll rates small. Slowly raise the downslope skid or wheel to bring the helicopter level, and then lift off. During landing, first touch down on the upslope skid or wheel, then slowly lower the downslope skid or wheel using combined movements of cyclic and collective. If the helicopter rolls approximately $5\text{--}8^\circ$ to the upslope side, decrease collective to correct the bank angle and return to level attitude, then start the landing procedure again.

Use of Collective

The collective is more effective in controlling the rolling motion than lateral cyclic, because it reduces the main rotor

thrust (lift). A smooth, moderate collective reduction, at a rate of less than approximately full up to full down in two seconds, may be adequate to stop the rolling motion. Take care, therefore, not to dump collective at an excessively high rate, as this may cause a main rotor blade to strike the fuselage. Additionally, if the helicopter is on a slope and the roll starts toward the upslope side, reducing collective too fast may create a high roll rate in the opposite direction. When the upslope skid or wheel hits the ground, the dynamics of the motion can cause the helicopter to bounce off the upslope skid or wheel, and the inertia can cause the helicopter to roll about the downslope ground contact point and over on its side. [Figure 11-7]

Under normal conditions on a slope, the collective should not be pulled suddenly to get airborne because a large and abrupt rolling moment in the opposite direction could occur. Excessive application of collective can result in the upslope skid or wheel rising sufficiently to exceed lateral cyclic control limits. This movement may be uncontrollable. If the helicopter develops a roll rate with one skid or wheel on the ground, the helicopter can roll over on its side.

Precautions

To help avoid dynamic rollover:

1. Always practice hovering autorotations into the wind, and be wary when the wind is gusty or greater than 10 knots.
2. Use extreme caution when hovering close to fences, sprinklers, bushes, runway/taxi lights, tiedown cables, deck nets, or other obstacles that could catch a skid or wheel. Aircraft parked on hot asphalt overnight might find the landing gear sunk in and stuck as the ramp cooled during the evening.

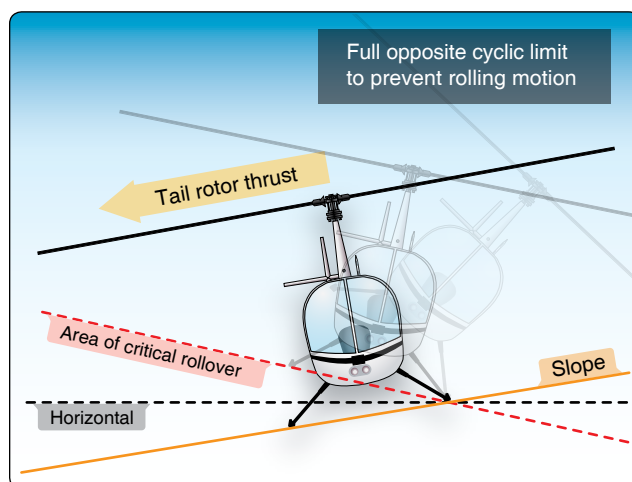


Figure 11-6. Upslope rolling motion.

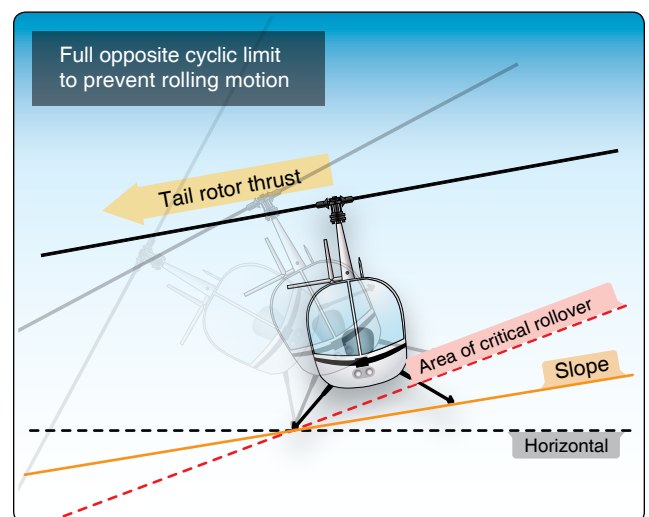


Figure 11-7. Downslope rolling motion.

3. Always use a two-step lift-off. Pull in just enough collective pitch control to be light on the skids or landing wheels and feel for equilibrium, then gently lift the helicopter into the air. 4. Hover high enough to have adequate skid or landing wheel clearance from any obstacles when practicing hovering maneuvers close to the ground, especially when practicing sideways or rearward flight.
5. Remember that when the wind is coming from the upslope direction, less lateral cyclic control is available.
6. Avoid tailwind conditions when conducting slope operations.
7. Remember that less lateral cyclic control is available due to the translating tendency of the tail rotor when the left skid or landing wheel is upslope. (This is true for counterclockwise rotor disks.)
8. Keep in mind that the lateral cyclic requirement changes when passengers or cargo are loaded or unloaded.
9. Be aware that if the helicopter utilizes interconnecting fuel lines that allow fuel to automatically transfer from one side of the helicopter to the other, the gravitational flow of fuel to the downslope tank could change the CG, resulting in a different amount of cyclic control application to obtain the same lateral result.
10. Do not allow the cyclic limits to be reached. If the cyclic control limit is reached, further lowering of the collective may cause mast bumping. If this occurs, return to a hover and select a landing point with a lesser degree of slope.
11. During a takeoff from a slope, begin by leveling the main rotor disk with the horizon or very slightly into the slope to ensure vertical lift and only enough lateral thrust to prevent sliding on the slope. If the upslope skid or wheel starts to leave the ground before the downslope skid or wheel, smoothly and gently lower the collective and check to see if the downslope skid or wheel is caught on something. Under these conditions, vertical ascent is the only acceptable method of lift-off.
12. Be aware that dynamic rollover can be experienced during flight operations on a floating platform if the platform is pitching/rolling while attempting to land or takeoff. Generally, the pilot operating on floating platforms (barges, ships, etc.) observes a cycle of seven during which the waves increase and then decrease to a minimum. It is that time of minimum wave motion that the pilot needs to use for the moment of landing or takeoff on floating platforms. Pilots operating from floating platforms should also exercise great caution concerning cranes, masts, nearby boats (tugs) and nets.

Low-G Conditions and Mast Bumping

“G” is an abbreviation for acceleration due to the earth’s gravity. A person standing on the ground or sitting in an aircraft in level flight is experiencing one G. An aircraft in a tight, banked turn with the pilot being pressed into the seat is experiencing more than one G or high-G conditions. A person beginning a downward ride in an elevator or riding down a steep track on a roller coaster is experiencing less than one G or low-G conditions. The best way for a pilot to recognize low G is a weightless feeling similar to the start of a downward elevator ride.

Helicopters rely on positive G to provide much or all of their response to pilot control inputs. The pilot uses the cyclic to tilt the rotor disk, and, at one G, the rotor is producing thrust equal to aircraft weight. The tilting of the thrust vector provides a moment about the center of gravity to pitch or roll the fuselage. In a low-G condition, the thrust and consequently the control authority are greatly reduced.

Although their control ability is reduced, multi-bladed (three or more blades) helicopters can generate some moment about the fuselage independent of thrust due to the rotor hub design with the blade attachment offset from the center of rotation. However, helicopters with two-bladed teetering rotors rely entirely on the tilt of the thrust vector for control. Therefore, low-G conditions can be catastrophic for two-bladed helicopters.

At lower speeds, such as initiation of a takeoff from hover or the traditional recovery from vortex ring state, forward cyclic maneuvers do not cause low G and are safe to perform. However, an abrupt forward cyclic input or pushover in a two-bladed helicopter can be dangerous and must be avoided, particularly at higher speeds. During a pushover from moderate or high airspeed, as the helicopter noses over, it enters a low-G condition. Thrust is reduced, and the pilot has lost control of fuselage attitude but may not immediately realize it. Tail rotor thrust or other aerodynamic factors will often induce a roll. The pilot still has control of the rotor disk, and may instinctively try to correct the roll, but the fuselage does not respond due to the lack of thrust. If the fuselage is rolling right, and the pilot puts in left cyclic to correct, the combination of fuselage angle to the right and rotor disk angle to the left becomes quite large and may exceed the clearances built into the rotor hub. This results in the hub contacting the rotor mast, which is known as mast bumping. [Figure 11-8] Low-G mast bumping has been the cause of numerous military and civilian fatal accidents. It was initially encountered during nap-of-the-earth flying, a very low-altitude tactical flight technique used by the military where

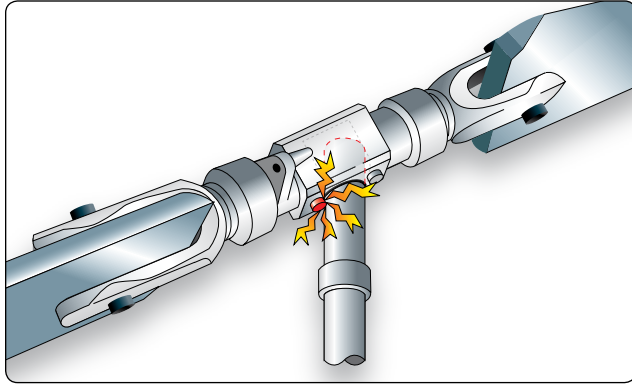


Figure 11-8. Result of improper corrective action in a low-G condition.

the aircraft flies following the contours of the geographical terrain. The accident sequence may be extremely rapid, and the energy and inertia in the rotor system can sever the mast or allow rotor blades to strike the tail or other portions of the helicopter.

Turbulence, especially severe downdrafts, can also cause a low-G condition and, when combined with high airspeed, may lead to mast bumping. Typically, helicopters handle turbulence better than a light airplane due to smaller surface area of the rotor blades. During flight in turbulence, momentary excursions in airspeed, altitude, and attitude are to be expected. Pilots should respond with smooth, gentle control inputs and avoid overcontrolling. Most importantly, pilots should slow down, as mast bumping is less likely at lower airspeeds.

Pilots can avoid mast bumping accidents as follows:

- Avoid abrupt forward cyclic inputs in two-bladed helicopters. Airplane pilots may find this a difficult habit to break because pushing the nose down is an accepted collision avoidance maneuver in an airplane. Helicopter pilots would accomplish the same rapid descent by lowering the collective, and airplane pilots should train to make this instinctual.
- Recognize the weightless feeling associated with the onset of low G and quickly take corrective action before the situation becomes critical.
- Recognize that uncommanded right roll for helicopters with main rotors which rotate counter-clockwise when viewed from above indicates that loss of control is imminent, and immediate corrective action must be taken.
- Recover from a low-G situation by first gently applying aft cyclic to restore normal G before

attempting to correct any roll.

- If turbulence is expected or encountered, reduce power and use a slower than normal cruise speed. Turbulence (where high rotor flapping angles are already present), and higher airspeeds (where the controls are more sensitive) both increase susceptibility to low-G conditions.
- Use a flight simulator to learn to recognize and experience low G conditions that result in mast bumping, its correct recovery technique, and the consequences of using incorrect recovery actions. Refer to Chapter 14, Simulation.

Multi-bladed rotors may experience a phenomenon similar to mast bumping known as droop stop pounding if flapping clearances are exceeded, but because they retain some control authority at low G, occurrences are less common than for teetering rotors.

Low Rotor RPM and Rotor Stall

Rotor rpm is a critically important parameter for all helicopter operations. Just as airplanes will not fly below a certain airspeed, helicopters will not fly below a certain rotor rpm. Safe rotor rpm ranges are marked on the helicopter's tachometer and specified in the RFM. If the pilot allows the rotor rpm to fall below the safe operating range, the helicopter is in a low rpm situation. If the rotor rpm continues to fall, the rotor will eventually stall.

Rotor stall should not be confused with retreating blade stall, which occurs at high forward speeds and over a small portion of the retreating blade tip. Retreating blade stall causes vibration and control problems, but the rotor is still very capable of providing sufficient lift to support the weight of the helicopter. Rotor stall, however, can occur at any airspeed, and the rotor quickly stops producing enough lift to support the helicopter, causing it to lose lift and descend rapidly.

Rotor stall is very similar to the stall of an airplane wing at low airspeeds. The airplane wing relies on airspeed to produce the required airflow over the wing, whereas the helicopter relies on rotor rpm. As the airspeed of the airplane decreases or the speed of the helicopter rotor slows down, the AOA of the wing/rotor blade must be increased to support the weight of the aircraft. At a critical angle (about 15°), the airflow over the wing or the rotor blade will separate and stall, causing a sudden loss of lift and increase in drag (refer to Chapter 2, Aerodynamics of Flight). An airplane pilot recovers from a stall by lowering the nose to reduce the AOA and adding power to restore normal airflow over the wing. However, the falling helicopter is experiencing upward

airflow through the rotor disk, and the resulting AOA is so high that even full down collective will not restore normal airflow. In the helicopter when the rotor stalls, it does not do so symmetrically because any forward airspeed will produce a higher airflow on the advancing side than on the retreating side. This causes the retreating blade to stall first, and its weight makes it descend as it moves aft while the advancing blade is climbing as it goes forward. The resulting low aft blade and high forward blade become a rapid aft tilting of the rotor disc sometimes referred to as rotor “blow back” or “flap back.” As the helicopter begins to descend, the upward flow of air acting on the bottom surfaces of the tail boom and any horizontal stabilizers tend to pitch the aircraft nose down. These two effects, combined with any aft cyclic by the pilot attempting to keep the aircraft level, allow the rotor blades to blow back and contact the tail boom, in some cases actually severing the tail boom. Since the tail rotor is geared to the main rotor, in many helicopters the loss of main rotor rpm also causes a significant loss of tail rotor thrust and a corresponding loss of directional control.

Rotor stalls in helicopters are not recoverable. At low altitude, rotor stall will result in an accident with significant damage to the helicopter, and at altitudes above approximately 50 feet the accident will likely be fatal. Consequently, early recognition of the low rotor rpm condition and proper recovery technique is imperative.

Low rotor rpm can occur during power-off and power-on operations. During power-off flight, a low rpm situation can be caused by the failure to quickly lower the collective after an engine failure or by raising the collective at too great a height above ground at the bottom of an autorotation. However, more common are power-on rotor stall accidents. These occur when the engine is operating normally but the pilot demands more power than is available by pulling up too much on the collective. Known as “overpitching,” this can easily occur at higher density altitudes where the engine is already producing its maximum horsepower and the pilot raises the collective. The corresponding increased AOA of the blades requires more engine horsepower to maintain the speed of the blades; however, the engine cannot produce any additional horsepower, so the speed of the blades decreases. A similar situation can occur with a heavily loaded helicopter taking off from a confined area. Other causes of a power-on low rotor rpm condition include the pilot rolling the throttle the wrong way in helicopters not equipped with a governor or a governor failure in helicopters so equipped.

As the rpm decreases, the amount of horsepower the engine can produce also decreases. Engine horsepower is directly proportional to its rpm, so a 10 percent loss in rpm due to overpitching, or one of the other scenarios above, will

result in a 10 percent loss in the engine’s ability to produce horsepower, making recovery even slower and more difficult than it would otherwise be. With less power from the engine and less lift from the decaying rotor rpm, the helicopter will start to settle. If the pilot raises the collective to stop the settling, the situation will feed upon itself rapidly leading to rotor stall.

There are a number of ways the pilot can recognize the low rotor rpm situation. Visually, the pilot can not only see the rotor rpm indicator decrease but also the change in torque will produce a yaw; there will also be a noticeable decrease in engine noise, and at higher airspeeds or in turns, an increase in vibration. Many helicopters have a low rpm warning system that alerts the pilot to the low rotor rpm condition.

To recover from the low rotor rpm condition the pilot must simultaneously lower the collective, increase throttle if available and apply aft cyclic to maintain a level attitude. At higher airspeeds, additional aft cyclic may be used to help recover lost rpm. Recovery should be accomplished immediately before investigating the problem and must be practiced to become a conditioned reflex.

System Malfunctions

By following the manufacturer’s recommendations regarding operating limits and procedures and periodic maintenance and inspections, many system and equipment failures can be eliminated. Certain malfunctions or failures can be traced to some error on the part of the pilot; therefore, appropriate flying techniques and use of threat and error management may help to prevent an emergency

Antitorque System Failure

Antitorque failure usually falls into one of two categories. One is failure of the power drive portion of the tail rotor disk resulting in a complete loss of antitorque. The other category covers mechanical control failures prohibiting the pilot from changing or controlling tail rotor thrust even though the tail rotor may still be providing antitorque thrust.

Tail rotor drive system failures include driveshaft failures, tail rotor gearbox failures, or a complete loss of the tail rotor itself. In any of these cases, the loss of antitorque normally results in an immediate spinning of the helicopter’s nose. The helicopter spins to the right in a counterclockwise rotor disk and to the left in a clockwise system. This discussion is for a helicopter with a counterclockwise rotor disk. The severity of the spin is proportionate to the amount of power being used and the airspeed. An antitorque failure with a high-power setting at a low airspeed results in a severe spinning to the

right. At low power settings and high airspeeds, the spin is less severe. High airspeeds tend to streamline the helicopter and keep it from spinning.

If a tail rotor failure occurs, power must be reduced in order to reduce main rotor torque. The techniques differ depending on whether the helicopter is in flight or in a hover, but ultimately require an autorotation. If a complete tail rotor failure occurs while hovering, enter a hovering autorotation by rolling off the throttle. If the failure occurs in forward flight, enter a normal autorotation by lowering the collective and rolling off the throttle. If the helicopter has enough forward airspeed (close to cruising speed) when the failure occurs, and depending on the helicopter design, the vertical stabilizer may provide enough directional control to allow the pilot to maneuver the helicopter to a more desirable landing sight. Applying slight cyclic control opposite the direction of yaw compensates for some of the yaw. This helps in directional control, but also increases drag. Care must be taken not to lose too much forward airspeed because the streamlining effect diminishes as airspeed is reduced. Also, more altitude is required to accelerate to the correct airspeed if an autorotation is entered at a low airspeed.

The throttle or power lever on some helicopters is not located on the collective and readily available. Faced with the loss of antitorque, the pilot of these models may need to achieve forward flight and let the vertical fin stop the yawing rotation. With speed and altitude, the pilot will have the time to set up for an autorotative approach and set the power control to idle or off as the situation dictates. At low altitudes, the pilot may not be able to reduce the power setting and enter the autorotation before impact.

A mechanical control failure limits or prevents control of tail rotor thrust and is usually caused by a stuck or broken control rod or cable. While the tail rotor is still producing antitorque thrust, it cannot be controlled by the pilot. The amount of antitorque depends on the position at which the controls jam or fail. Once again, the techniques differ depending on the amount of tail rotor thrust, but an autorotation is generally not required.

The specific manufacturer's procedures should always be followed. The following is a generalized description of procedures when more specific procedures are not provided.

Landing—Stuck Left Pedal

A stuck left pedal (high power setting), which might be experienced during takeoff or climb conditions, results in the left yaw of the helicopter nose when power is reduced. Rolling off the throttle and entering an autorotation only makes matters worse. The landing profile for a stuck left

pedal is best described as a normal-to-steep approach angle to arrive approximately 2–3 feet landing gear height above the intended landing area as translational lift is lost. The steeper angle allows for a lower power setting during the approach and ensures that the nose remains to the right.

Upon reaching the intended touchdown area and at the appropriate landing gear height, increase the collective smoothly to align the nose with the landing direction and cushion the landing. A small amount of forward cyclic is helpful to stop the nose from continuing to the right and directs the aircraft forward and down to the surface. In certain wind conditions, the nose of the helicopter may remain to the left with zero to near zero groundspeed above the intended touchdown point. If the helicopter is not turning, simply lower the helicopter to the surface. If the nose of the helicopter is turning to the right and continues beyond the landing heading, roll the throttle toward flight idle, which is the amount necessary to stop the turn while landing. Flight idle is an engine rpm in flight at a given altitude with the throttle set to the minimum, or idle, position. The flight idling rpm typically increase with an increase in altitude. If the helicopter is beginning to turn left, the pilot should be able to make the landing prior to the turn rate becoming excessive. However, if the turn rate begins to increase prior to the landing, simply add power to make a go-around and return for another landing.

Landing—Stuck Neutral or Right Pedal

The landing profile for a stuck neutral or a stuck right pedal is a low-power approach terminating with a running or roll-on landing. The approach profile can best be described as a shallow to normal approach angle to arrive approximately 2–3 feet landing gear height above the intended landing area with a minimum airspeed for directional control. The minimum airspeed is one that keeps the nose from continuing to yaw to the right.

Upon reaching the intended touchdown area and at the appropriate landing gear height, reduce the throttle as necessary to overcome the yaw effect if the nose of the helicopter remains to the right of the landing heading. The amount of throttle reduction will vary based on power applied and winds. The higher the power setting used to cushion the landing, the more the throttle reduction will be. A coordinated throttle reduction and increased collective will result in a very smooth touchdown with some forward groundspeed. If the nose of the helicopter is to the left of the landing heading, a slight increase in collective or aft cyclic may be used to align the nose for touchdown. The decision to land or go around has to be made prior to any throttle reduction. Using airspeeds slightly above translational lift may be helpful to

ensure that the nose does not continue yawing to the right. If a go-around is required, increasing the collective too much or too rapidly with airspeeds below translational lift may cause a rapid spinning to the right.

Once the helicopter has landed and is sliding/rolling to a stop, the heading can be controlled with a combination of collective, cyclic and throttle. To turn the nose to the right, raise the collective or apply aft cyclic. The throttle may be increased as well if it is not in the full open position. To turn the nose to the left, lower the collective or apply forward cyclic. The throttle may be decreased as well if it is not already at flight idle.

Loss of Tail Rotor Effectiveness (LTE)

Loss of tail rotor effectiveness (LTE) or an unanticipated yaw is defined as an uncommanded, rapid yaw towards the advancing blade which does not subside of its own accord. It can result in the loss of the aircraft if left unchecked. It is very important for pilots to understand that LTE is caused by an aerodynamic interaction between the main rotor and tail rotor and not caused from a mechanical failure. Some helicopter types are more likely to encounter LTE due to the normal certification thrust produced by having a tail rotor that, although meeting certification standards, is not always able to produce the additional thrust demanded by the pilot.

A helicopter is a collection of compromises. Compare the size of an airplane propeller to that of a tail rotor. Then, consider the horsepower required to run the propeller. For example, a Cessna 172P is equipped with a 160-horsepower (HP) engine. A Robinson R-44 with a comparably sized tail rotor is rated for a maximum of 245 HP. If you assume the tail rotor consumes 50 HP, only 195 HP remains to drive the main rotor. If the pilot were to apply enough collective to require 215 HP from the engine, and enough left pedal to require 50 HP for the tail rotor, the resulting engine overload would lead to one of two outcomes: slow down (reduction in rpm) or premature failure. In either outcome, antitorque would be insufficient and total lift might be less than needed to remain airborne.

Every helicopter design requires some type of antitorque system to counteract main rotor torque and prevent spinning once the helicopter lifts off the ground. A helicopter is heavy, and the powerplant places a high demand on fuel. Weight penalizes performance, but all helicopters must have an antitorque system, which adds weight. Therefore, the tail rotor is certified for normal flight conditions. Environmental forces can overwhelm any aircraft, rendering the inherently unstable helicopter especially vulnerable.

As with any aerodynamic condition, it is very important for

pilots to not only to understand the definition of LTE, but more importantly, how and why it happens, how to avoid it, and lastly, how to correct it once it is encountered. We must first understand the capabilities of the aircraft or even better what it is not capable of doing. For example, if you were flying a helicopter with a maximum gross weight of 5,200 lb, would you knowingly try to take on fuel, baggage and passengers causing the weight to be 5,500 lb? A wise professional pilot should not ever exceed the certificated maximum gross weight or performance flight weight for any aircraft. The manuals are written for safety and reliability. The limitations and emergency procedures are stressed because lapses in procedures or exceeding limitations can result in aircraft damage or human fatalities. At the very least, exceeding limitations will increase the costs of maintenance and ownership of any aircraft and especially helicopters.

Overloaded parts may fail before their designed lifetime. There are no extra parts in helicopters. The respect and discipline pilots exercise in following flight manuals should also be applied to understanding aerodynamic conditions. If flight envelopes are exceeded, the end results can be catastrophic.

LTE is an aerodynamic condition and is the result of a control margin deficiency in the tail rotor. It can affect all single-rotor helicopters that utilize a tail rotor. The design of main and tail rotor blades and the tail boom assembly can affect the characteristics and susceptibility of LTE but will not nullify the phenomenon entirely. Translational lift is obtained by any amount of clean air through the main rotor disk. Chapter 2, Aerodynamics of Flight, discusses translational lift with respect to the main rotor blade, explaining that the more clean air there is going through the rotor disk, the more efficient it becomes. The same holds true for the tail rotor. As the tail rotor works in less turbulent air, it reaches a point of translational thrust. At this point, the tail rotor becomes aerodynamically efficient and the improved efficiency produces more antitorque thrust. The pilot can determine when the tail rotor has reached translational thrust. As more antitorque thrust is produced, the nose of the helicopter yaws to the left (opposite direction of the tail rotor thrust), forcing the pilot to correct with right pedal application (actually decreasing the left pedal). This, in turn, decreases the AOA in the tail rotor blades. Pilots should be aware of the characteristics of the helicopter they fly and be particularly aware of the amount of tail rotor pedal typically required for different flight conditions.

LTE is a condition that occurs when the flow of air through a tail rotor is altered in some way, by altering the angle or speed at which the air passes through the rotating blades of the tail rotor disk. As discussed in the previous paragraph, an effective tail rotor relies on a stable and relatively undisturbed

airflow in order to provide a steady and constant antitorque reaction. The pitch and AOA of the individual blades will determine the thrust. A change to either of these alters the amount of thrust generated. A pilot's yaw pedal input causes a thrust reaction from the tail rotor. Altering the amount of thrust delivered for the same yaw input creates an imbalance. Taking this imbalance to the extreme will result in the loss of effective control in the yawing plane, and LTE will occur.

This alteration of tail rotor thrust can be affected by numerous external factors. The main factors contributing to LTE are:

1. Airflow and downdraft generated by the main rotor blades interfering with the airflow entering the tail rotor assembly.
2. Main blade vortices developed at the main blade tips entering the tail rotor disk.
3. Turbulence and other natural phenomena affecting the airflow surrounding the tail rotor.
4. A high-power setting, hence large main rotor pitch angle, induces considerable main rotor blade downwash and hence more turbulence than when the helicopter is in a low power condition.
5. A slow forward airspeed, typically at speeds where translational lift and translational thrust are in the process of change and airflow around the tail rotor will vary in direction and speed.
6. The airflow relative to the helicopter;
 - a. Worst case—relative wind within $\pm 15^\circ$ of the 10 o'clock position, generating vortices that can blow directly into the tail rotor. This is dictated by the characteristics of the helicopters aerodynamics of tailboom position, tail rotor size and position relative to the main rotor and vertical stabilizer, size and shape. [Figure 11-9]
 - b. Weathercock stability—tailwinds from 120° to 240° [Figure 11-10], such as left crosswinds, causing high pilot workload.
 - c. Tail rotor vortex ring state (210° to 330°). [Figure 11-11] Winds within this region will result in the development of the vortex ring state of the tail rotor.
7. Combinations (a, b, c) of these factors in a particular situation can easily require more antitorque than the helicopter can generate and in a particular environment LTE can be the result.

Certain flight activities lend themselves to being at higher risk of LTE than others. For example, power line and pipeline patrol sectors, low speed aerial filming/photography as well as in the Police and Helicopter Emergency Medical Services

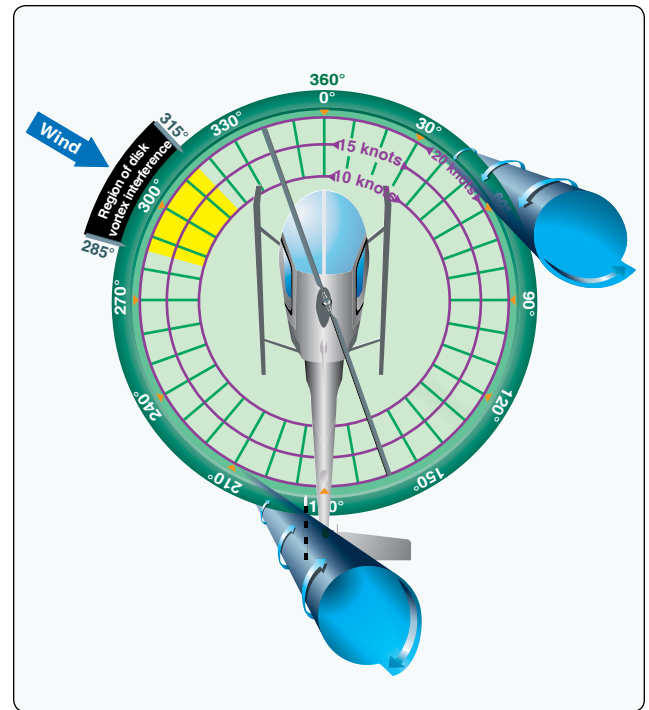


Figure 11-9. Main rotor disk vortex interference.

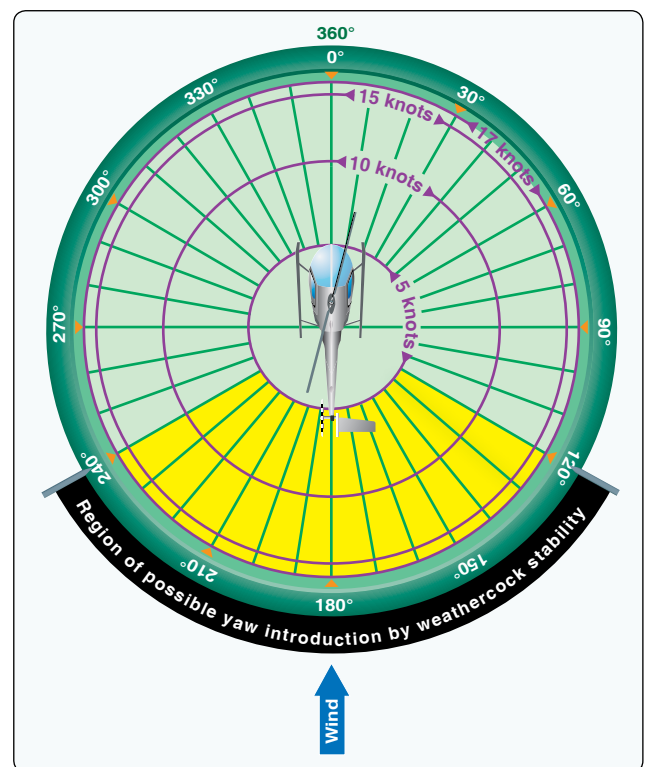


Figure 11-10. Weathercock stability.

(EMS) environments can find themselves in low-and-slow situations over geographical areas where the exact wind speed and direction are hard to determine.

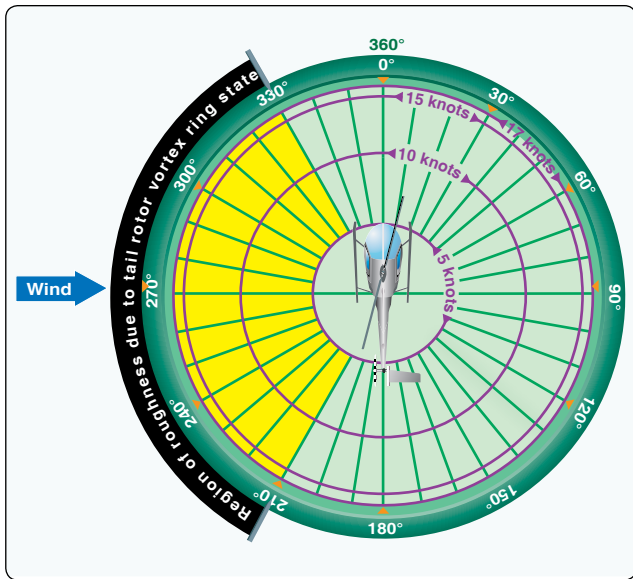


Figure 11-11. Tail rotor vortex ring state.

Unfortunately, the aerodynamic conditions that a helicopter is susceptible to are not explainable in black and white terms. LTE is no exception. There are a number of contributing factors, but what is more important in preventing LTE is to note them, and then to associate them with situations that should be avoided. Whenever possible, pilots should learn to avoid the following combinations:

1. Low and slow flight outside of ground effect.
2. Winds from $\pm 15^\circ$ of the 10 o'clock position and probably on around to 5 o'clock position [Figure 11-9]
3. Tailwinds that may alter the onset of translational lift and translational thrust, and hence induce high power demands and demand more anti-torque (left pedal) than the tail rotor can produce.
4. Low speed downwind turns.
5. Large changes of power at low airspeeds.
6. Low speed flight in the proximity of physical obstructions that may alter a smooth airflow to both the main rotor and tail rotor.

Pilots who put themselves in situations where the combinations above occur should know that they are likely to encounter LTE. The key is not to put the helicopter in a compromising condition, while at the same time being educated enough to recognize the onset of LTE and being prepared to react quickly to it before the helicopter cannot be controlled.

Early detection of LTE, followed by the immediate flight control application of corrective action, applying forward cyclic to regain airspeed, applying right pedal not left as

necessary to maintain rotor rpm, and reducing the collective (thus reducing the high-power demand on the tail rotor), is the key to a safe recovery. Pilots should always set themselves up when conducting any maneuver to have enough height and space available to recover in the event they encounter an aerodynamic situation such as LTE.

Understanding the aerodynamic phenomenon of LTE is by far the most important factor in preventing an LTE-related accident, and maintaining the ability and option either to go around if making an approach or pull out of a maneuver safely and re-plan, is always the safest option. Having the ability to fly away from a situation and re-think the possible options should always be part of a pilot's planning process in all phases of flight. Unfortunately, there have been many pilots who have idled a good engine and fully functioning tail rotor disk and autorotated a perfectly airworthy helicopter to the crash site because they misunderstood or misperceived both the limitations of the helicopter and the aerodynamic situation.

Main Rotor Disk Interference (285–315°)

Refer to Figure 11-9. Winds at velocities of 10–30 knots from the left front cause the main rotor vortex to be blown into the tail rotor by the relative wind. This main rotor disk vortex causes the tail rotor to operate in an extremely turbulent environment. During a right turn, the tail rotor experiences a reduction of thrust as it comes into the area of the main rotor disk vortex. The reduction in tail rotor thrust comes from the airflow changes experienced at the tail rotor as the main rotor disk vortex moves across the tail rotor disk.

The effect of the main rotor disk vortex initially increases the AOA of the tail rotor blades, thus increasing tail rotor thrust. The increase in the AOA requires that right pedal pressure be added to reduce tail rotor thrust in order to maintain the same rate of turn. As the main rotor vortex passes the tail rotor, the tail rotor AOA is reduced. The reduction in the AOA causes a reduction in thrust and right yaw acceleration begins. This acceleration can be surprising, since previously adding right pedal to maintain the right turn rate. This thrust reduction occurs suddenly, and if uncorrected, develops into an uncontrollable rapid rotation about the mast. When operating within this region, be aware that the reduction in tail rotor thrust can happen quite suddenly, and be prepared to react quickly to counter this reduction with additional left pedal input.

Weathercock Stability (120–240°)

In this region, the helicopter attempts to weathervane, or weathercock, its nose into the relative wind. [Figure 11-10] Unless a resisting pedal input is made, the helicopter starts a slow, uncommanded turn either to the right

or left, depending upon the wind direction. If the pilot allows a right yaw rate to develop and the tail of the helicopter moves into this region, the yaw rate can accelerate rapidly. In order to avoid the onset of LTE in this downwind condition, it is imperative to maintain positive control of the yaw rate and devote full attention to flying the helicopter.

Tail Rotor Vortex Ring State (210–330°)

Winds within this region cause a tail rotor vortex ring state to develop. [Figure 11-11] The result is a nonuniform, unsteady flow into the tail rotor. The vortex ring state causes tail rotor thrust variations, which result in yaw deviations. The net effect of the unsteady flow is an oscillation of tail rotor thrust. Rapid and continuous pedal movements are necessary to compensate for the rapid changes in tail rotor thrust when hovering in a left crosswind. Maintaining a precise heading in this region is difficult, but this characteristic presents no significant problem unless corrective action is delayed. However, high pedal workload, lack of concentration, and overcontrolling can lead to LTE.

When the tail rotor thrust being generated is less than the thrust required, the helicopter yaws to the right. When hovering in left crosswinds, concentrate on smooth pedal coordination and do not allow an uncommanded right yaw to develop. If a right yaw rate is allowed to build, the helicopter can rotate into the wind azimuth region where weathercock stability then accelerates the right turn rate. Pilot workload during a tail rotor vortex ring state is high. Do not allow a right yaw rate to increase.

LTE at Altitude

At higher altitudes where the air is thinner, tail rotor thrust and efficiency are reduced. Because of the high-density altitude, powerplants may be much slower to respond to power changes. When operating at high altitudes and high gross weights, especially while hovering, the tail rotor thrust may not be sufficient to maintain directional control, and LTE can occur. In this case, the hovering ceiling is limited by tail rotor thrust and not necessarily power available. In these conditions, gross weights need to be reduced and/or operations need to be limited to lower density altitudes. This may not be noted as criteria on the performance charts.

Reducing the Onset of LTE

To help reduce the onset of LTE, follow these steps:

1. Maintain maximum power-on rotor rpm. If the main rotor rpm is allowed to decrease, the antitorque thrust available is decreased proportionally.
2. Avoid tailwinds below airspeeds of 30 knots. If loss of translational lift occurs, it results in an increased

power demand and additional antitorque pressures.

3. Avoid OGE operations and high-power demand situations below airspeeds of 30 knots at low altitudes.
4. Be especially aware of wind direction and velocity when hovering in winds of about 8–12 knots. A loss of translational lift results in an unexpected high power demand and an increased antitorque requirement.
5. Be aware that if a considerable amount of left pedal is being maintained, a sufficient amount of left pedal may not be available to counteract an unanticipated right yaw.
6. Be alert to changing wind conditions, which may be experienced when flying along ridge lines and around buildings.
7. Execute right turns slowly. This limits the effects of rotating inertia, and decreases loading on the tailrotor to control yawing.

Recovery Technique (Uncontrolled Right Yaw)

If a sudden unanticipated right yaw occurs, the following recovery technique should be performed. Apply full left pedal. Simultaneously, apply forward cyclic control to increase speed. If altitude permits, reduce power. As recovery is affected, adjust controls for normal forward flight. A recovery path must always be planned, especially when terminating to an OGE hover and executed immediately if an uncommanded yaw is evident.

Collective pitch reduction aids in arresting the yaw rate but may cause an excessive rate of descent. Any large, rapid increase in collective to prevent ground or obstacle contact may further increase the yaw rate and decrease rotor rpm. The decision to reduce collective must be based on the pilot's assessment of the altitude available for recovery.

If the rotation cannot be stopped and ground contact is imminent, an autorotation may be the best course of action. Maintain full left pedal until the rotation stops, then adjust to maintain heading. For more information on LTE, see Advisory Circular (AC) 90-95, Unanticipated Right Yaw in Helicopters.

Main Drive Shaft or Clutch Failure

The main drive shaft, located between the engine and the main rotor transmission, provides engine power to the main rotor transmission. In some helicopters, particularly those with piston engines, a drive belt is used instead of a drive shaft. A failure of the drive shaft clutch or belt has the same effect as an engine failure because power is no longer provided to the main rotor and an autorotation must be initiated. There are a few differences, however, that need to be taken into

consideration. If the drive shaft or belt breaks, the lack of any load on the engine results in an overspeed. In this case, the throttle must be closed in order to prevent any further damage. In some helicopters, the tail rotor drive system continues to be powered by the engine even if the main drive shaft breaks. In this case, when the engine unloads, a tail rotor overspeed can result. If this happens, close the throttle immediately and enter an autorotation. The pilot must be knowledgeable of the specific helicopter's system and failure modes.

Pilots should keep in mind that when there is any suspected mechanical malfunction, first and foremost they should always attempt to maintain rotor rpm. If the rotor rpm is at the normal indication with normal power settings, an instrument failure might be occurring, and it would be best to fly the helicopter to a safe landing area. If the rotor rpm is in fact decreasing or low, then there is a drive line failure.

Hydraulic Failure

Many helicopters incorporate the use of hydraulic actuators to overcome high control forces. A 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. A switch in the cockpit can turn the system off, although it is left on during normal conditions. A pressure indicator in the cockpit may be installed to monitor the system.

An impending hydraulic failure can be recognized by a grinding or howling noise from the pump or actuators, increased control forces and feedback, and limited control movement. The required corrective action is stated in detail in the RFM. In most cases, airspeed needs to be reduced in order to reduce control forces. The hydraulic switch and circuit breaker should be checked and recycled. If hydraulic power is not restored, make a shallow approach to a running or roll-on landing. This technique is used because it requires less control force and pilot workload. Additionally, the hydraulic system should be disabled by placing the switch in the off position. The reason for this is to prevent an inadvertent restoration of hydraulic power, which may lead to overcontrolling near the ground.

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 are installed. Some helicopters use hydraulic accumulators to store pressure that can be used for a short time while in an emergency if the hydraulic pump fails. This gives enough time to land the helicopter with normal control.

Governor or Fuel Control Failure

Governors and fuel control units automatically adjust engine power to maintain rotor rpm when the collective pitch is changed. If the governor or fuel control unit fails, any change in collective pitch requires manual adjustment of the throttle to maintain correct rpm. In the event of a high side failure, the engine and rotor rpm tend to increase above the normal range due to the engine being commanded to put out too much power. If the rpm cannot be reduced and controlled with the throttle, close the throttle and enter an autorotation. If the failure is on the low side, the engine output is allowed to go below the collective and normal rpm may not be attainable, even if the throttle is manually controlled. In this case, the collective has to be lowered to maintain rotor rpm. A running or roll-on landing may be performed if the engine can maintain sufficient rotor rpm. If there is insufficient power, enter an autorotation. As stated previously in this chapter, before responding to any type of mechanical failure, pilots should confirm that rotor rpm is not responding to flight control inputs. If the rotor rpm can be maintained in the green operating range, the failure is in the instrument, and not mechanical.

Abnormal Vibration

With the many rotating parts found in helicopters, some vibration is inherent. A pilot needs to understand the cause and effect of helicopter vibrations because abnormal vibrations cause premature component wear and may even result in structural failure. With experience, a pilot learns what vibrations are normal and those that are abnormal and can then decide whether continued flight is safe or not. Helicopter vibrations are categorized into low, medium, or high frequency.

Low-Frequency Vibrations

Low-frequency vibrations (100–500 cycles per minute) usually originate from the main rotor disk. The main rotor operational range, depending on the helicopter, is usually between 320 and 500 rpm. A rotor blade that is out of track or balance will cause a cycle to occur with every rotation. The vibration may be felt through the controls, the airframe, or a combination of both. The vibration may also have a definite direction of push or thrust. It may be vertical, lateral, horizontal, or even a combination of these. Normally, the direction of the vibration can be determined by concentrating on the feel of the vibration, which may push a pilot up and down, backwards and forwards, or in the case of a blade being out of phase, from side to side. The direction of the vibration and whether it is felt in the controls or the airframe is important information for the mechanic when he or she troubleshoots the source. Out-of-track or out-of-balance main rotor blades, damaged blades,

worn bearings, dampers out of adjustment, or worn parts are possible causes of low frequency vibrations.

Medium- and High-Frequency Vibrations

Medium-frequency vibrations (1,000–2,000 cycles per minute) range between the low frequencies of the main rotor (100–500 cycles per minute) and the high frequencies (2,100 cycles per minute or higher) of the engine and tail rotor. Depending on the helicopter, medium-frequency vibration sources may be engine and transmission cooling fans, and accessories such as air conditioner compressors, or driveline components. Medium-frequency vibrations are felt through the entire airframe, and prolonged exposure to the vibrations will result in greater pilot fatigue.

Most tail rotor vibrations fall into the high-frequency range (2,100 cycles per minute or higher) and can be felt through the tail rotor pedals as long as there are no hydraulic actuators to dampen out the vibration. This vibration is felt by the pilot through his or her feet, which are usually “put to sleep” by the vibration. The tail rotor operates at approximately a 6:1 ratio with the main rotor, meaning for every one rotation of the main rotor the tail rotor rotates 6 times. A main rotor operating rpm of 350 means the tail rotor rpm would be 2,100 rpm. Any imbalance in the tail rotor disk is very harmful as it can cause cracks to develop and rivets to work loose. Piston engines usually produce a normal amount of high-frequency vibration, which is aggravated by engine malfunctions, such as spark plug fouling, incorrect magneto timing, carburetor icing and/or incorrect fuel/air mixture. Vibrations in turbine engines are often difficult to detect as these engines operate at a very high rpm. Turbine engine vibration can be at 30,000 rpm internally, but common transmission speeds are in the 1,000 to 3,000 rpm range for the output shaft. The vibrations in turbine engines may be short lived as the engine disintegrates rapidly when damaged due to high rpm and the forces present.

Tracking and Balance

Modern equipment used for tracking and balancing the main and tail rotor blades can also be used to detect other vibrations in the helicopter. These systems use accelerometers mounted around the helicopter to detect the direction, frequency, and intensity of the vibration. The built-in software can then analyze the information, pinpoint the origin of the vibration, and suggest the corrective action.

The use of a system such as a health and usage monitoring system (HUMS) provides the operator the ability to record engine and transmission performance and provide rotor track and balance. This system has been around for over 30 years and is now becoming more affordable, more capable, and more commonplace in the rotorcraft industry.

Multiengine Emergency Operations

Single-Engine Failure

When one engine has failed, the helicopter can often maintain altitude and airspeed until a suitable landing site can be selected. Whether or not this is possible becomes a function of such combined variables as aircraft weight, density altitude, height above ground, airspeed, phase of flight, and single-engine capability. Environmental response time and control technique may be additional factors. Caution must be exercised to correctly identify the malfunctioning engine since there is no telltale yawing as occurs in most multiengine airplanes. Shutting down the wrong engine could be disastrous!

Even when flying multiengine powered helicopters, rotor rpm must be maintained at all costs, because fuel contamination has been documented as the cause for both engines failing in flight.

Dual-Engine Failure

The flight characteristics and the required crew member control responses after a dual-engine failure are similar to those during a normal power-on descent. Full control of the helicopter can be maintained during autorotational descent. In autorotation, as airspeed increases above 70–80 KIAS, the rate of descent and glide distance increase significantly. As airspeed decreases below approximately 60 KIAS, the rate of descent increases and glide distance decreases.

Lost Procedures

Pilots become lost while flying for a variety of reasons, such as disorientation, flying over unfamiliar territory, or visibility that is low enough to render familiar terrain unfamiliar. When a pilot becomes lost, the first order of business is to fly the aircraft; the second is to implement lost procedures. Keep in mind that the pilot workload will be high, and increased concentration will be necessary. If lost, always remember to look for the practically invisible hazards, such as wires, by searching for their support structures, such as poles or towers, which are almost always near roads.

If lost, follow common sense procedures.

- Try to locate any large landmarks, such as lakes, rivers, towers, railroad tracks, or Interstate highways. If a landmark is recognized, use it to find the helicopter's location on the sectional chart. If flying near a town or city, a pilot may be able to read the name of the town on a water tower or even land to ask for directions.
- If no town or city is nearby, the first thing a pilot should do is climb. An increase in altitude increases radio and navigation reception range as well as radar coverage.

- Navigation aids, dead reckoning, and pilotage are skills that can be used as well.
- Do not forget air traffic control (ATC)—controllers assist pilots in many ways, including finding a lost helicopter. Once communication with ATC has been established, follow their instructions.

These common-sense procedures can be easily remembered by using the four Cs: Climb, Communicate, Confess, and Comply.

- Climb for a better view, improved communication and navigation reception, and terrain avoidance.
- Communicate by calling the nearest flight service station (FSS)/automated flight service station (AFSS) on 122.2 MHz. If the FSS/AFSS does not respond, call the nearest control tower, center, or approach control. For frequencies, check the chart in the vicinity of the last known position. If that fails, switch to the emergency radio frequency (121.5 MHz) and transponder code (7700).
- Report the lost situation to ATC and request help.
- Comply with controller instructions.

Pilots should understand the services provided by ATC and the resources and options available. These services enable pilots to focus on aircraft control and help them make better decisions in a time of stress.

When contacting ATC, pilots should provide as much information as possible because ATC uses the information to determine what kind of assistance it can provide with available assets and capabilities. Information requirements vary depending on the existing situation, but at a minimum a pilot should provide the following information:

- Aircraft identification and type
- Nature of the emergency
- Aviator's desires

To reduce the chances of getting lost in the first place, use flight following through active contact with an aircraft during flight either by radio or through automated flight following systems when it is available, monitor checkpoints no more than 25 miles apart, keep navigation aids such as Very High-Frequency Omni-Directional Range (VOR) tuned in, and maintain good situational awareness. Flight following provides ongoing surveillance information to assist pilots in avoiding collisions with other aircraft.

Getting lost is a potentially dangerous situation for any aircraft, especially when low on fuel. Due to the helicopter's unique ability to land almost anywhere, pilots have more flexibility than other aircraft as to landing site. An inherent

risk associated with being lost is waiting too long to land in a safe area. Helicopter pilots should land before fuel exhaustion occurs because maneuvering with low fuel levels could cause the engine to stop due to fuel starvation as fuel sloshes or flows away from the pickup port in the tank.

If lost and low on fuel, it is advisable to make a precautionary landing. Preferably, land near a road or in an area that would allow space for another helicopter to safely land and provide assistance. Having fuel delivered is a minor inconvenience when compared to having an accident. Once on the ground, pilots may seek assistance.

VFR Flight into Instrument Meteorological Conditions

Helicopters, unlike airplanes, generally operate under Visual Flight Rules (VFR) and require pilots to maintain aircraft control by visual cues. However, when unforecast weather leads to degraded visibility, the pilot may be at increased risk of Inadvertent flight into Instrument Meteorological Conditions (IIMC). During an IIMC encounter, the pilot may be unprepared for the loss of visual reference, resulting in a reduced ability to continue safe flight. IIMC is a life-threatening emergency for any pilot. To capture these IIMC events, the Commercial Aviation Safety Team (CAST) and International Civil Aviation Organization (ICAO) Common Taxonomy Team (CICCT) categorizes this occurrence as Unintended flight in Instrument Meteorological Conditions (UIMC). This term is also recognized by the National Transportation Safety Board (NTSB) and Federal Aviation Administration (FAA). It is used to classify occurrences (accidents and incidents) at a high level to improve the capacity to focus on common safety issues and complete analysis of the data in support of safety initiatives.

The onset of IIMC may occur gradually or suddenly, has no simple procedural exit, and is unlike flight training by reference to while in Visual Meteorological Conditions (VMC). Most training helicopters are not equipped or certified to fly under Instrument Flight Rules (IFR). Therefore, General Aviation (GA) helicopter pilots may not have the benefit of flight in actual Instrument Meteorological Conditions (IMC) during their flight training. Helicopter pilots that encounter IIMC may experience physiological illusions which can lead to spatial disorientation and loss of aircraft control. Even with some instrument training, many available and accessible helicopters are not equipped with the proper augmented safety systems or autopilots, which would significantly aid in helicopter control during an IIMC emergency. The need to use outside visual references is natural for helicopter pilots because much of their flight training is based upon visual cues, not on flight instruments. This primacy can only be overcome through significant instrument training. Additionally, instrument flight may be

intimidating to some and too costly for others. As a result, many helicopter pilots choose not to seek an instrument rating.

While commercial helicopter operators often prefer their pilots to be instrument rated, fatal accidents still occur as a result of IIMC. Many accidents can be traced back to the pilot's inability to recover the helicopter after IIMC is encountered, even with adequate equipment installed. Therefore, whether instrument rated or not, all pilots should understand that avoiding IIMC is critical.

A good practice for any flight is to set and use personal minimums, which should be more conservative than those required by regulations for VFR flight. In addition, a thorough preflight and understanding of weather conditions that may contribute to the risk of IMC developing along a planned route of flight is essential for safety. Pilots should recognize deteriorating weather conditions so the route of flight can be changed or a decision made to terminate the flight and safely land at a suitable area, well before IIMC occurs. If weather conditions deteriorate below the pilot's personal minimums during flight, a pilot who understands the risks of IIMC knows that he or she is at an en route decision point, where it is necessary to either turn back to the departure point or immediately land somewhere safe to wait until the weather has cleared. Pilots should recognize that descent below a predetermined minimum altitude above ground level (AGL) (for example, 500 feet AGL) to avoid clouds or, slowing the helicopter to a predetermined minimum airspeed (for example, slowing to 50 KIAS) to reduce the rate of closure from the deteriorating weather conditions, indicates the decision point had been reached. Ceilings that are lower than reported and/or deteriorating visibility along the route of flight should trigger the decision to discontinue and amend the current route to avoid IIMC.

If the helicopter pilot is instrument rated, it is advisable to maintain instrument currency and proficiency as this may aid the pilot in a safe recovery from IIMC. A consideration for instrument rated pilots when planning a VFR flight should include a review of published instrument charts for safe operating altitudes, e.g. minimum safe altitude (MSA), minimum obstruction clearance altitude (MOCA), minimum in VMC throughout a flight: off-route altitude (MORA), etc. If IIMC occurs, the pilot may consider a climb to a safe altitude. Once the helicopter is stabilized, the pilot should declare an emergency with air traffic control (ATC). It is imperative that the pilot commit to controlling the helicopter and remember to aviate, navigate, and finally communicate. Often communication is attempted first, as it is natural to look for help in stressful situations. This may distract the pilot from maintaining control of the helicopter.

If the pilot is not instrument rated, instrument current nor proficient, or is flying a non-IFR equipped helicopter, remaining in VMC is paramount. Pilots who are not trained or proficient in flight solely by reference to instruments have a tendency to attempt to maintain flight by visual ground reference, which tends to result in flying at lower altitudes, just above the trees or by following roads. The thought process is that, "as long as I can see what is below me, I can continue to my intended destination." Experience and statistical data indicate that attempting to continue VFR flight into IMC can often lead to a fatal outcome as pilots often fixate on what they see below them and are unable to see the hazards ahead of them (e.g., power lines, towers, rising terrain, etc.). By the time the pilot sees the hazard, it is either too late to avoid a collision, or while successfully maneuvering to avoid an obstacle, the pilot becomes disoriented.

Flying at night involves even more conservative personal minimums to ensure safety and avoidance of IIMC than daytime flying. At night, deteriorating weather conditions may be difficult to detect. Therefore, pilots should ensure that they not only receive a thorough weather briefing, but that they remain vigilant for unforecasted weather during their flight. The planned route should include preselected landing sites that will provide options to the pilot in the event a precautionary landing is required to avoid adverse weather conditions. As a pilot gains night flight experience their ability to assess weather during a flight will improve.

Below are some basic guidelines to assist a pilot to remain in VMC throughout a flight:

1. Slowly turn around if threatened by deteriorating visual cues and proceed back to VMC or to the first safe landing area if the weather ahead becomes questionable. Remember that prevention is paramount.
2. Do not proceed further on a course when the terrain ahead is not clearly discernible.
3. Delay or consider cancelling the flight if weather conditions are already questionable, could deteriorate significantly based on forecasts, or if you are uncertain whether the flight can be conducted safely. Often, a gut feeling can provide a warning that unreasonable risks are present.
4. Always have a safe landing area (such as large open areas or airports) in mind for every route of flight.

There are five basic steps that every pilot should be familiar with, and which should be executed immediately at the onset of IIMC, if applicable. However, remember that if you are not trained to execute the following maneuvers solely by reference to instruments, or your aircraft is not equipped

with such instruments, this guidance may be less beneficial to you and loss of helicopter control may occur:

1. Level the “wings” – level the bank angle using the attitude indicator.
2. Attitude – set a climb attitude that achieves a safe climb speed appropriate to your type of helicopter. This is often no more than 10° of pitch up on the attitude indicator.
3. Airspeed – verify that the attitude selected has achieved the desired airspeed. It is critical to recognize that slower airspeeds, closer to effective translational lift, may require large control inputs and will decrease stability, making recover impossible while in UIMC.
4. Power – adjust to a climb power setting relative to the desired airspeed. This should be executed concurrent with steps 2 and 3.
5. Heading and Trim – pick a heading known to be free of obstacles and maintain it. This will likely be the heading you were already on, which was planned and briefed. Set the heading bug, if installed, to avoid overcontrolling your bank. Maintain coordinated flight so that an unusual attitude will not develop.

Try to avoid immediately turning 180°. Turning around is not always the safest route and executing a turn immediately after UIMC may lead to spatial disorientation. If a 180° turn is the safest option, first note the heading you are on then begin the turn to the reciprocal heading, but only after stable flight is achieved (items 1 through 5 above) and maintain a constant rate of turn appropriate to the selected airspeed.

Each encounter with UIMC is unique, and no single procedure can ensure a safe outcome. Considerations in determining the best course of action upon encountering UIMC should include, at a minimum, terrain, obstructions, freezing levels, aircraft performance and limitations, and availability of ATC services.

There are new technologies being developed regarding aircraft design, enhanced and lower-cost technologies, and aircraft certification. Because of this promising future, much of the discussion and guidance in this chapter may one day become irrelevant. As helicopters integrate more into the National Airspace System, the IFR infrastructure and instrument training will become more prevalent. In the future, UIMC may no longer be the emergency that ends with a fatality but rather associated with proper prevention, skilled recovery techniques along with the aid of emerging new life saving avionics technology. A helicopter instrument rating may be a life-saving addition to a pilot’s level of

EMERGENCY EQUIPMENT AND SURVIVAL GEAR	
	Food cannot be subject to deterioration due to heat or cold. There should be at least 10,000 calories for each person on board, and it should be stored in a sealed waterproof container. It should have been inspected within the previous 6 months, verifying the amount and satisfactory condition of the contents.
	A supply of water
	Cooking utensils
	Matches in a waterproof container
	A portable compass
	An ax weighing at least 2.5 pounds with a handle not less than 28 inches in length
	A flexible saw blade or equivalent cutting tool
	30 feet of snare wire and instructions for use
	Fishing equipment, including still-fishing bait and gill net with not more than a two-inch mesh
	Mosquito nets or netting and insect repellent sufficient to meet the needs of all persons aboard, when operating in areas where insects are likely to be hazardous
	A signaling mirror
	At least three pyrotechnic distress signals
	A sharp, quality jackknife or hunting knife
	A suitable survival instruction manual
	Flashlight with spare bulbs and batteries
	Portable emergency locator transmitter (ELT) with spare batteries
	Stove with fuel or a self-contained means of providing heat for cooking
	Tent(s) to accommodate everyone on board
	Additional items for winter operations: <ul style="list-style-type: none"> • Winter sleeping bags for all persons when the temperature is expected to be below 7 °C • Two pairs of snow shoes • Spare ax handle • Ice chisel • Snow knife or saw knife

Figure 11-12. *Emergency equipment and survival gear.*

certification. Please refer to the Instrument Flying Handbook (FAA-H-8083-15, as revised); Advanced Avionics Handbook (FAA-H-8083-6, as revised); and the Pilot’s Handbook of Aeronautical Knowledge (FAA-H-8083-25, as revised) for further exploration of IFR operations and how to obtain an instrument rating.

When faced with deteriorating weather, planning and prevention, not recovery, are the best strategies to eliminate UIMC-related accidents and fatalities.

Emergency Equipment and Survival Gear

Both Canada and Alaska require pilots to carry survival gear. Always carry survival gear when flying over rugged and desolate terrain. The items suggested in *Figure 11-12* are both weather and terrain dependent. The pilot also needs to consider how much storage space the helicopter has and how the equipment being carried affects the overall weight and balance of the helicopter.

Chapter Summary

Emergencies should always be anticipated. Knowledge of the helicopter, possible malfunctions and failures, and methods of recovery can help the pilot avoid accidents and be a safer pilot. Helicopter pilots should always expect the worse hazards and possible aerodynamic effects and plan for a safe exit path or procedure to compensate for the hazard.