Airplane Flying Handbook (FAA-H-8083-3C)

Chapter 7: Ground Reference Maneuvers

Introduction

During initial training, pilots learn how various flight control pressure inputs affect the airplane. After achieving a sufficient level of competence, the pilot is ready to apply this skill and maintain the airplane, not only at the correct attitude and power configuration, but also along an appropriate course relative to objects on the ground. This skill is the basis for traffic patterns, survey, photographic, sight-seeing, aerial application (crop dusting), and various other flight profiles requiring specific flightpaths referenced to points on the surface.

Ground reference maneuvers are the principal flight maneuvers that combine the four fundamentals (straight-and-level, turns, climbs, and descents) into a set of integrated skills that the pilot uses in everyday flight activity. From every takeoff to every landing, a pilot exercises these skills to control the airplane. Therefore, a pilot needs to develop the proper coordination, timing, and attention in order to accurately and safely maneuver the airplane with regard to the required attitudes and ground references.

The pilot should be introduced by their instructor to ground reference maneuvers as soon as the pilot shows proficiency in the four fundamentals. Ground reference maneuvers call for manipulation of the flight controls using necessary control pressures to affect the airplane's attitude and position by using the outside natural horizon and ground-based references with brief periods of scanning the flight instruments.

Maneuvering by Reference to Ground Objects

Ground reference maneuvers train the pilot to accurately place the airplane in relationship to specific references and maintain a desired ground track. While vision is the most utilized sense, other senses are actively involved at different levels. For example, the amount of pressure needed to overcome flight control surface forces provides tactile feedback as to the airplane's airspeed and aerodynamic load.

It is a common error for beginning pilots to fixate on a specific reference, such as a single location on the ground or a spot on the natural horizon. A pilot fixating on any one reference loses the ability to determine rate, which significantly degrades a pilot's performance. By visually scanning across several references, the pilot learns how to determine the rate of closure to a specific point. In addition, the pilot should scan between several visual references to determine relative motion and to determine if the airplane is maintaining, or drifting to or from, the desired ground track. Consider a skilled automobile driver in a simple intersection turn; the driver does not merely turn the steering wheel some degree and hope that it will work out. The driver picks out several references, such as an island to their side, a painted lane line, or the opposing curb, and uses those references to make almost imperceptible adjustments to the amount of deflection on the steering wheel. At the same time, the driver adjusts the pressure on the accelerator pedal to smoothly join the new lane. In the same manner, multiple references are required to precisely control the airplane in reference to the ground.

Not all ground-based references are visually equal. Awareness of typical visual illusions helps a pilot select appropriate references. For example, larger objects or references may appear closer than they actually are when compared to smaller objects or references. Prevailing visibility has a significant effect on the pilot's perception of the distance to a reference. Excellent visibility with clear skies tends to make an object or reference appear closer than when compared to a hazy day with poor visibility. Rain can alter the visual image in a manner creating an illusion of being at a higher than actual altitude, and brighter objects or references may appear closer than dimmer objects. However, if using references of similar size and proportion, pilots find ground reference maneuvers easier to execute.

Ground-based references can be numerous. Examples include breakwaters, canals, fence lines, field boundaries, highways, railroad tracks, roads, pipe lines, power lines, water tanks, and many other objects; however, choices can be limited by geography, population density, infrastructure, or structures. The pilot should consider the type of maneuver being performed, altitude at which the maneuver will be performed, emergency landing requirements, density of structures, wind direction, visibility, and the type of airspace when selecting a ground-based reference.

Ground reference maneuvers develop a pilot's division of attention skill. A pilot needs to control the airplane's attitude while tracking a specific path over the ground. In addition, the pilot should be able to scan for hazards such as other aircraft, prepare for an emergency landing should the need arise, and scan the flight and engine instruments at regular intervals to ensure that a pending situation, such as decreasing oil pressure, does not turn into an unexpected incident.

Ground reference maneuvers place the airplane in a low altitude environment with associated hazards. Pilots should look for other aircraft, including helicopters, and look for obstructions such as radio towers and wires. In addition, pilots should consider engine failure and have one or more locations available for an emergency landing. Pilots should always clear the area with two 90° clearing turns looking to the left and the right, as well as above and below the airplane. The maneuver area should not cause disturbances and be well away from any open air assembly of persons, congested areas of a city, town, or settlement, or herd of livestock. Before performing any maneuver, the pilot should complete the required checklist items, make any radio announcements (such as on a practice area frequency), and safety clearing turns. As a general note, a ground reference maneuver should not exceed a bank angle of 45° or an airspeed greater than the maneuvering speed. As part of preflight planning, the pilot should determine the predicted (POH/AFM) stall speed at 50° or at the highest bank angle expected during the maneuver to assure there will be a safety margin above the stall speed during the maneuver.

Drift and Ground Track Control

Wind direction and velocity variations create the need for flightpath corrections during a ground reference maneuver. In a similar way that water currents affect the progress of a boat or ship, wind directly influences the path that the airplane travels in reference to the ground. Whenever the airplane is in flight, the movement of the air directly affects the actual ground track of the airplane.

For example, an airplane is traveling at 90 knots (90 nautical miles per hour) and the wind is blowing from right to left at 10 knots. The airplane continues forward at 90 knots but also travels left 10 nautical miles for every hour of flight time. If the airplane, in this example doubles its speed to 180 knots, it still drifts laterally to the left 10 nautical miles every hour. Unless in still air, traveling to a point on the surface requires compensation for the movement of the air mass.

Ground reference maneuvers are generally flown at altitudes between 600 and 1,000 feet above ground level (AGL). The pilot should consider the following when selecting the maneuvering altitude:

- The lower the maneuvering altitude, the faster the airplane appears to travel in relation to the ground.
- Drift should be easily recognizable from both sides of the airplane.
- The altitude should provide obstruction clearance of no less than 500 feet vertically above the obstruction and 2,000 feet horizontally.
- In the event of an engine failure, lower altitudes equate to less time to configure the airplane and reduced gliding distance before a forced landing.
- What specific altitude or altitude range does the testing standard call for?

Correcting Drift During Straight-and-Level Flight

When flying straight and level and following a selected straight-line direct ground track, the preferred method of correcting for wind drift is to angle the airplane sufficiently into the wind to cancel the effect of the sideways drift caused by the wind. The wind's speed, the angle between the wind direction and the airplane's longitudinal axis, and the airspeed of the airplane determine the required wind correction angle. For example, an airplane with an airspeed of 100 knots in an air mass moving at 20 knots directly from the side, should turn 12° into the wind to cancel the airplane's drift. If the wind in the above example is only 10 knots, the wind correction angle required to cancel the drift is six degrees. When the drift has been neutralized by heading the airplane into the wind, the airplane will fly the direct straight ground track.

To further illustrate this point, if a boat is crossing a river and the river's current is completely still, the boat could head directly to a point on the opposite shore on a straight course without any drift. However, rivers tend to have a downstream current that needs to be considered if the captain wants the boat to arrive at the opposite shore using a direct straight path. Any downstream current pushes the boat sideways and downstream at the speed of the current. To counteract this downstream movement, the boat needs to move upstream at the same speed as the river is moving the boat downstream. This is accomplished by angling the boat upstream to counteract the downstream flow. If done correctly, the boat follows a direct straight track across the river to the intended destination point. A slower forward speed of the boat or a faster river current requires a greater angle to counteract the drift. *[Figure 7-1]*

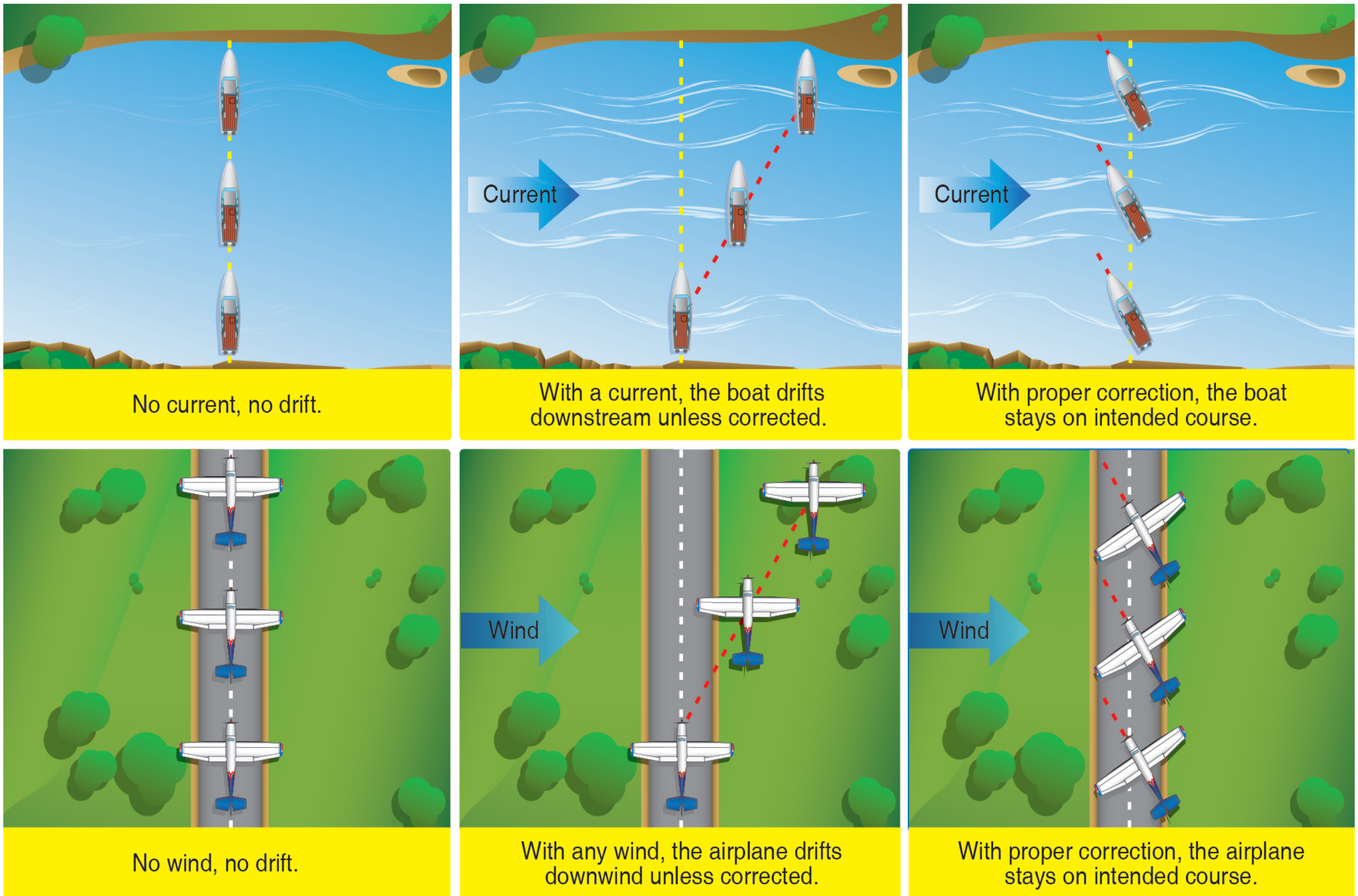

Figure 7-1. *Wind drift.*

As soon as the pilot lifts off the surface and levels the wings in a crosswind, the airplane begins tracking sideways. The force of the crosswind acts on the mass of the airplane, and the speed of drift increases up to the speed of the crosswind component. A wind that is directly to the right or the left (at a 90° angle) will cause the airplane to accelerate sideways at the same speed as the wind. When the wind is halfway between the side and the nose of the airplane (at a 45° angle), it causes a sideways drift up to just over 70 percent of the total speed of the wind. It should be understood that pilots do not calculate the required drift correction angles for ground reference maneuvers; they merely use the references and adjust the airplane's relationship to those references to cancel any drift. The groundspeed of the airplane is also affected by the wind. As the wind direction becomes parallel to the airplane's longitudinal axis, the magnitude of the wind's effect on the groundspeed is greater; as the wind becomes perpendicular to the longitudinal axis, the magnitude of the wind's effect on the groundspeed is less. In general, When the wind is blowing straight into the nose of the airplane, the groundspeed will be less than the airspeed. When the wind is blowing from directly behind the airplane, the groundspeed will be faster than the airspeed. In other words, when the airplane is headed upwind, the groundspeed is decreased; when headed downwind, the groundspeed is increased.

Constant Radius During Turning Flight

In a no-wind condition, a pilot may make a constant-radius turn over the ground using a fixed bank angle. If wind is present, however, a pilot will observe a change in the radius of a turn while maintaining that same constant bank angle. *[Figure 7-2]* As groundspeed increases, the observed radius of the turn increases. Conversely, as groundspeed decreases, the radius of the turn over the ground will decrease. For a ground-referenced constant-radius turn, the pilot compensates for changes in groundspeed by varying the bank angle throughout the turn. When groundspeed increases, the pilot banks more steeply to maintain a constant-radius turn over the ground. The converse is also true: when groundspeed decreases, the pilot uses a shallower bank.

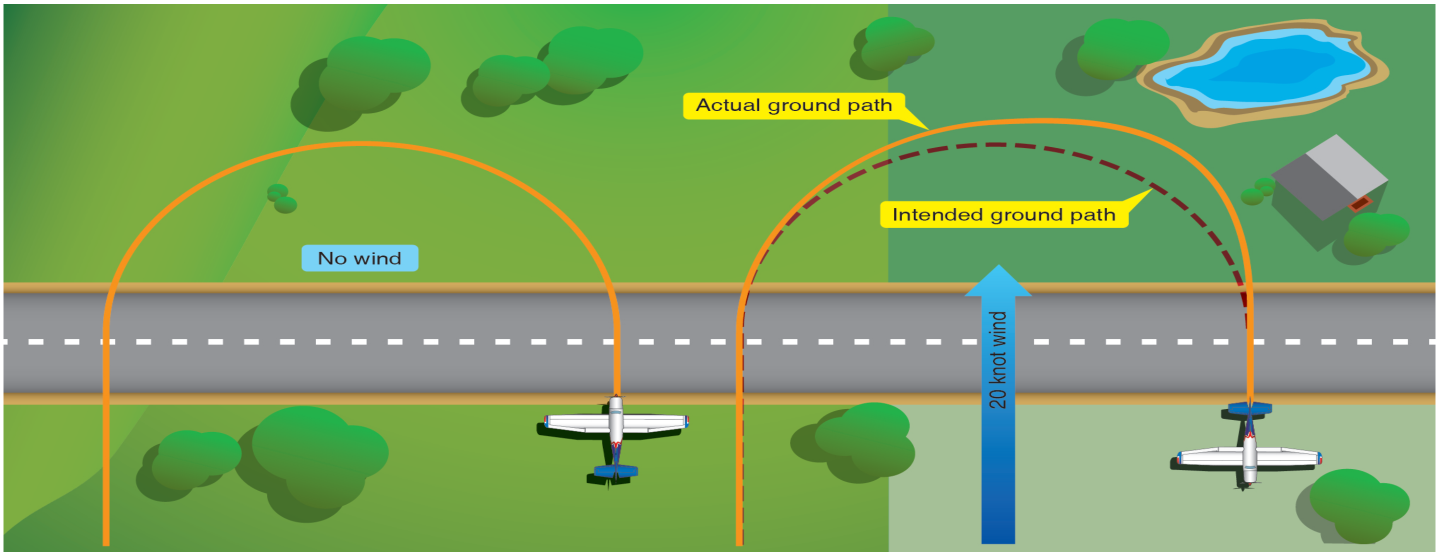

Figure 7-2. *Effect of wind during a turn.*

For a given true airspeed, the radius of turn in the air varies proportionally with the bank angle. To maintain a constant radius over the ground, the bank angle used is proportional to groundspeed. For example, an airplane is in the downwind position at 100 knots groundspeed. In this example, the wind is 10 knots, meaning that the airplane has an airspeed of 90 knots (for this discussion, assume true, calibrated, and indicated airspeed are all the same). If the pilot starts a turn using a 45° bank angle, the turn radius over the ground at that moment is approximately 890 feet. As the airplane turns, the groundspeed decreases and the bank angle needs to be reduced in order to maintain the same turn radius of 890 feet over the ground. At the upwind point of the turn, the bank angle should be approximately 33°. In another example, if the downwind is flown at an airspeed of 90 knots in a 10 knot tailwind with a desired turn radius of 2,000 feet, the bank angle would be approximately 24°. The bank angle flying upwind would be approximately 16°.

Put another way, at a higher groundspeed, there is less time to turn the airplane while trying to maintain a ground-referenced constant-radius turn. The pilot increases the bank angle in order to increase the rate of turn, and the increased rate of turn offsets the reduced time available to make the turn. Conversely, when flying at a lower groundspeed, the pilot reduces the angle of bank and rate of turn to compensate for the additional time taken while making the turn. With some experience, pilots may notice how wind direction affects the time needed for various segments of ground-referenced turns.

To demonstrate the effect that wind has on turns, the pilot should select a straight-line ground reference, such as a road or railroad track. *[Figure 7-3]* Choosing a straight-line ground reference that is parallel to the wind, the airplane would be flown into the wind and directly over the selected straight-line ground reference. Once a straight-line ground reference is established, the pilot makes a 360° constant medium-banked turn. As the airplane completes the 360° turn, it should return directly over the straight-line ground reference but downwind from the starting point. Choosing a straight-line ground reference that has a crosswind, and using the same 360° constant medium-banked turn, demonstrates how the airplane drifts away from the reference even as the pilot holds a constant bank angle. In both examples, the path over the ground is not circular, although in reference to the air, the airplane flew a perfect continuous radius.

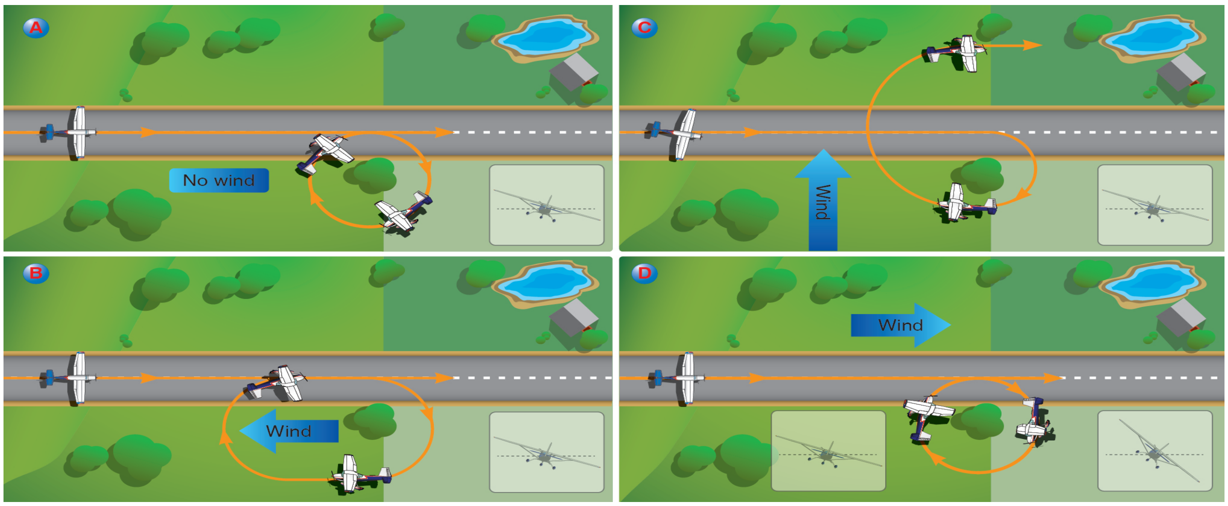

Figure 7-3. *Effect of wind during turn.*

In order to compensate for the effects of wind drift, the pilot adjusts the bank angle as the groundspeed changes throughout the turn. Where groundspeed is the fastest, such as when the airplane is headed downwind, the bank angle should be steepest. Where groundspeed is the slowest, such as when the airplane is headed upwind, the bank angle should be shallow. It is necessary to increase or decrease the angle of bank, which increases or decreases the rate of turn, to achieve the desired constant radius track over the ground.

Ground reference maneuvers should always be entered from a downwind position. This allows the pilot to establish the steepest bank angle required to maintain a constant radius ground track. If the bank is too steep, the pilot should immediately exit the maneuver and re-establish a lateral position that is further from the ground reference. The pilot should avoid bank angles in excess of 45°due to the increased stalling speed.

Tracking Over and Parallel to a Straight Line

The pilot should first be introduced to ground reference maneuvers by correcting for the effects of a crosswind over a straight-line ground reference, such as road or railroad tracks. If a straight road or railroad track is unavailable, the pilot should choose multiple references (three minimum) which line up along a straight path. The reference line should be suitably long so the pilot has sufficient time to understand the concepts of wind correction and practice the maneuver. Initially, the maneuver should be flown directly over the ground reference line with the pilot angling the airplane's longitudinal axis into the wind sufficiently such as to cancel the effect of drift. The pilot should scan between far ahead and close to the airplane to practice tracking multiple references.

When proficiency has been demonstrated by flying directly over the ground reference line, the pilot should then practice flying a straight parallel path that is offset from the ground reference. The offset parallel path should not be more than three-fourths of a mile from the reference line. The maneuver should be flown offset from the ground references with the pilot angling the airplane's longitudinal axis into the wind sufficiently to cancel the effect of drift while maintaining a parallel track.

Rectangular Course

A principal ground reference maneuver is the rectangular course. *[Figure 7-4]* The rectangular course is a training maneuver in which the airplane maintains an equal distance from all sides of the selected rectangular references. The maneuver is accomplished to replicate the airport traffic pattern that an airplane typically maneuvers while landing. While performing the rectangular course maneuver, the pilot should maintain a constant altitude, airspeed, and distance from the ground references. The maneuver assists the pilot in practicing the following:

- Maintaining a specific relationship between the airplane and the ground.
- Dividing attention between the flightpath, ground-based references, manipulating the flight controls, and scanning for outside hazards and instrument indications.
- Adjusting the bank angle during turns to correct for groundspeed changes in order to maintain constant-radius turns.
- Rolling out from a turn with the required wind correction angle to compensate for any drift caused by the wind.
- Establishing and correcting the wind correction angle in order to maintain the track over the ground.
- Preparing the pilot for the airport traffic pattern and subsequent landing pattern practice.

To fly the rectangular course, the pilot should first locate a square field, a rectangular field, or an area with suitable ground references on all four sides. Note that a square meets the definition of a rectangle. As previously mentioned, this area should be selected consistent with safe practices. The airplane should be flown parallel to and at an equal distance between one-half to three-fourths of a mile away from the field boundaries or selected ground references. The flightpath should be positioned outside the field boundaries or selected ground references so that the references may be easily observed from either pilot seat. It is not practical to fly directly above the field boundaries or selected ground references. The pilot should avoid flying close to the references, as this will require the pilot to turn using very steep bank angles, thereby increasing aerodynamic load factor and the airplane's stall speed, especially in the downwind to crosswind turn.

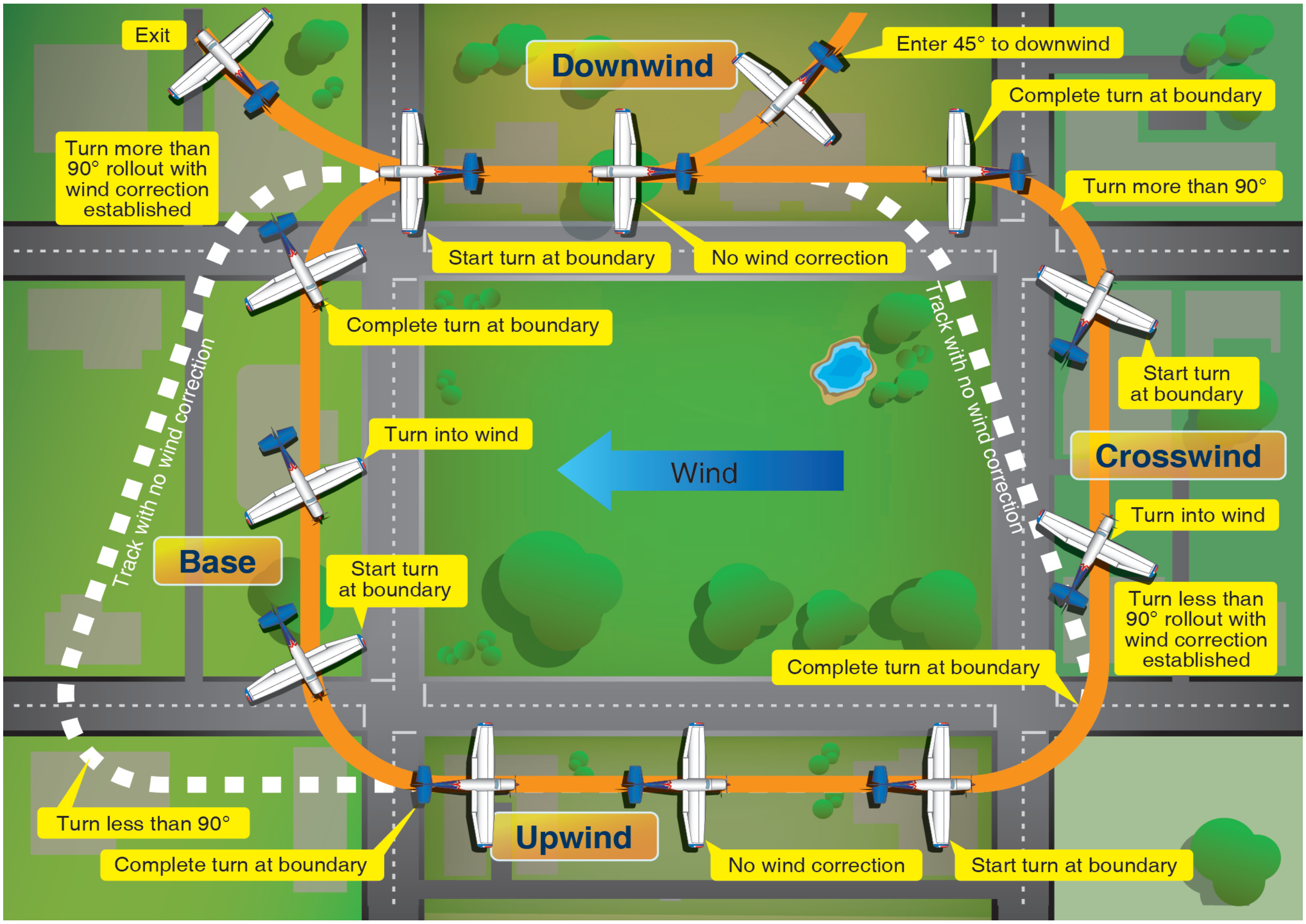

Figure 7-4. *Rectangular course.*

The entry into the maneuver should be accomplished downwind. This places the wind on the tail of the airplane and results in an increased groundspeed. There should be no wind correction angle if the wind is directly on the tail of the airplane; however, a real-world situation often results in some drift correction. The turn from the downwind leg onto the base leg is entered with a relatively steep bank angle. The pilot should roll the airplane into a steep bank with rapid, but not excessive, coordinated aileron and rudder pressures. As the airplane turns onto the following base leg, the tailwind lessens and becomes a crosswind; the bank angle is reduced gradually with coordinated aileron and rudder pressures. The pilot should be prepared for the lateral drift and compensate by turning more than 90° angling toward the inside of the rectangular course.

The next leg is where the airplane turns from a base leg position to the upwind leg. Ideally, on the upwind, the wind is directly on the nose of the airplane resulting in a direct headwind and decreased groundspeed; however, some drift correction may be necessary. The pilot should roll the airplane into a medium-banked turn with coordinated aileron and rudder pressures. As the airplane turns onto the upwind leg, the crosswind lessens and becomes a headwind, and the bank angle is gradually reduced with coordinated aileron and rudder pressures. Because the pilot was angled into the wind on the base leg, the turn to the upwind leg is less than 90°.

The next leg is where the airplane turns from an upwind leg position to the crosswind leg. The pilot should slowly roll the airplane into a shallow-banked turn, as the developing crosswind drifts the airplane into the inside of the rectangular course with coordinated aileron and rudder pressures. As the airplane turns onto the crosswind leg, the headwind lessens and becomes a crosswind. As the turn nears completion, the bank angle is reduced with coordinated aileron and rudder pressures. To compensate for the crosswind, the pilot maintains an angle into the wind, toward the outside of the rectangular course, which requires the turn to be less than 90°.

The final turn is back to the downwind leg, which requires a medium-banked angle and a turn greater than 90°. The groundspeed will be increasing as the turn progresses and the bank should be held and then rolled out in a rapid, but not excessive, manner using coordinated aileron and rudder pressures.

For the maneuver to be executed properly, the pilot should visually utilize the ground-based, nose, and wingtip references to properly position the airplane in attitude and in orientation to the rectangular course. In order to maintain a constant ground-based radius during the turns, each turn requires the bank angle to be adjusted to compensate for the changing groundspeed—the higher the groundspeed, the steeper the bank. If the groundspeed is initially higher and then decreases throughout the turn, the bank angle should progressively decrease throughout the turn. The converse is also true, if the groundspeed is initially slower and then increases throughout the turn, the bank angle should progressively increase throughout the turn until rollout is started. Also, the rate for rolling in and out of the turn should be adjusted to prevent drifting in or out of the course. When the wind is from a direction that could drift the airplane into the course, the banking roll rate should be slow. When the wind is from a direction that could drift the airplane to the outside of the course, the banking roll rate should be quick.

The following are the most common errors made while performing rectangular courses:

1. Failure to adequately clear the surrounding area for safety hazards, initially and throughout the maneuver.
2. Failure to establish a constant, level altitude prior to entering the maneuver.
3. Failure to maintain altitude during the maneuver.
4. Failure to properly assess wind direction.
5. Failure to establish the appropriate wind correction angle.
6. Failure to apply coordinated aileron and rudder pressure, resulting in slips and skids.
7. Failure to manipulate the flight controls in a smooth and continuous manner.
8. Failure to properly divide attention between airplane control and orientation with ground references.
9. Failure to execute turns with accurate timing.

Turns Around a Point

Turns around a point are a logical extension of both the rectangular course and S-turns across a road. The maneuver is a 360° constant radius turn around a single ground-based reference point. *[Figure 7-5]* The principles are the same in any turning ground reference maneuver—higher groundspeeds require steeper banks and slower ground speeds require shallower banks. The objectives of turns around a point are as follows:

- Maintaining a specific relationship between the airplane and the ground.
- Dividing attention between the flightpath, ground-based references, manipulating the flight controls, and scanning for outside hazards and instrument indications.
- Adjusting the bank angle during turns to correct for groundspeed changes in order to maintain a constant radius turn—steeper bank angles for higher ground speeds, shallow bank angles for slower groundspeeds.
- Improving competency in managing the quickly-changing bank angles.
- Establishing and adjusting the wind correction angle in order to maintain the track over the ground.
- Developing the ability to compensate for drift in quickly-changing orientations.
- Developing further awareness that the radius of a turn is correlated to the bank angle.

To perform a turn around a point, the pilot needs to complete at least one 360° turn; however, to properly assess wind direction, velocity, bank required, and other factors related to turns in wind, the pilot should complete two or more turns. As in other ground reference maneuvers, when wind is present, the pilot adjusts the airplane's bank and wind correction angle to maintain a constant radius turn around a point. In contrast to the ground reference maneuvers discussed previously, in which turns were approximately limited to either 90° or 180°, turns around a point are consecutive 360° turns, where pilot constantly adjusts the bank angle and the resulting rate of turn as the airplane sequences through the various wind directions. The pilot should make these adjustments by applying coordinated aileron and rudder pressure throughout the turn.

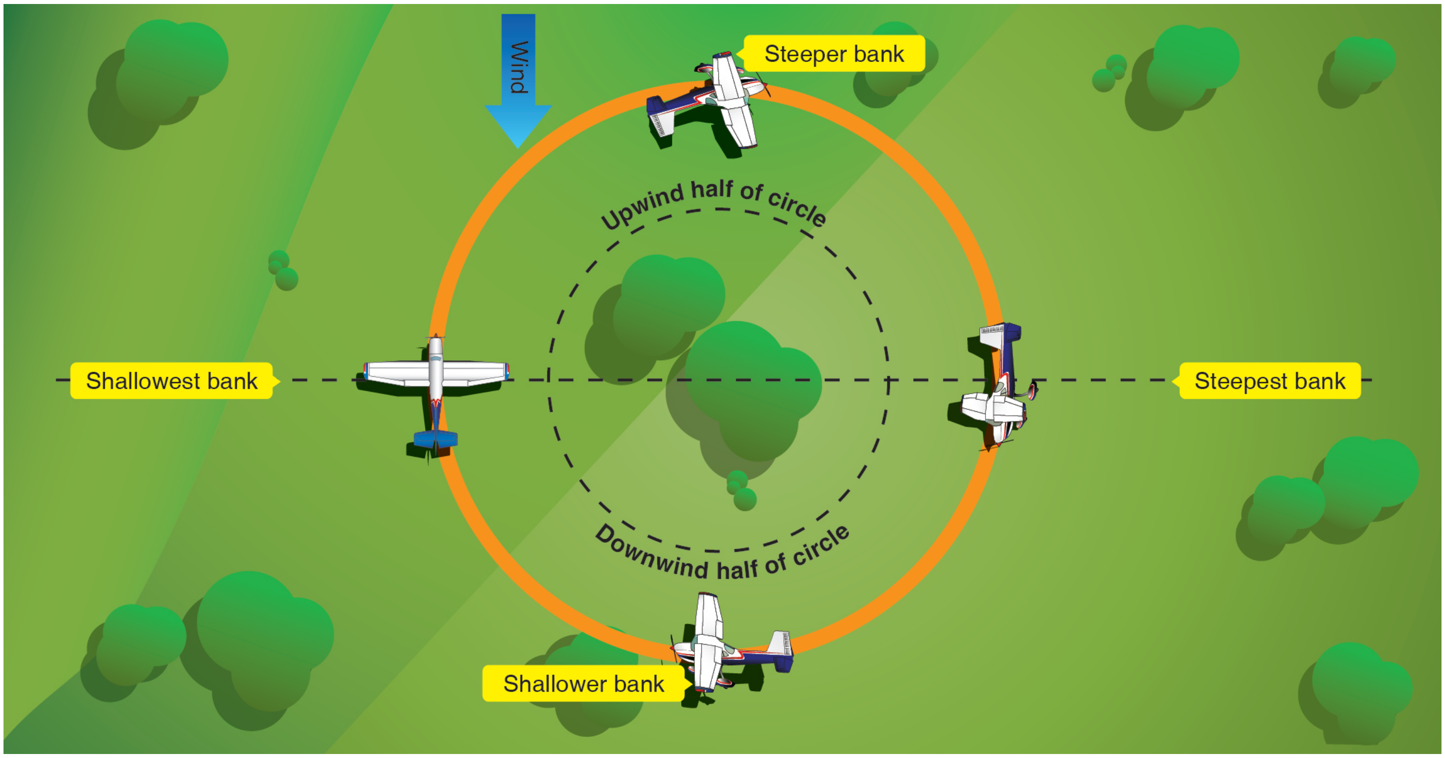

Figure 7-5. *Turns around a point.*

When performing a turn around a point, the pilot should select a prominent, ground-based reference that is easily distinguishable yet small enough to present a precise reference. The pilot should enter the maneuver downwind, where the groundspeed is at its fastest, at the appropriate radius of turn and distance from the selected ground-based reference point. In a high-wing airplane, the lowered wing may block the view of the ground reference point, especially in airplanes with side-by-side seating during a left turn (assuming that the pilot is flying from the left seat). To prevent this, the pilot may need to change the maneuvering altitude or the desired turn radius. The pilot should ensure that the reference point is visible at all times throughout the maneuver, even with the wing lowered in a bank.

Upon entering the maneuver, depending on the wind's speed, it may be necessary to roll into the initial bank at a rapid rate so that the steepest bank is set quickly to prevent the airplane from drifting outside of the desired turn radius. This is best accomplished by repeated practice and assessing the required roll in rate. Thereafter, the pilot should gradually decrease the angle of bank until the airplane is headed directly upwind. As the upwind becomes a crosswind and then a downwind, the pilot should gradually steepen the bank to the steepest angle upon reaching the initial point of entry.

During the downwind half of the turn, the pilot should progressively adjust the airplane's heading toward the inside of the turn. During the upwind half, the pilot should progressively adjust the airplane's heading toward the outside of the turn. Put another way, the airplane's heading should be ahead of its position over the ground during the downwind half of the turn and behind its position during the upwind half. Remember that the goal is to make a constant-radius turn over the ground and, because the airplane is flying through a moving air mass, the pilot should constantly adjust the bank angle to achieve this goal.

The following are the most common errors in the performance of turns around a point:

1. Failure to adequately clear the surrounding area for safety hazards, initially and throughout the maneuver.
2. Failure to establish a constant, level altitude prior to entering the maneuver.
3. Failure to maintain altitude during the maneuver.
4. Failure to properly assess wind direction.
5. Failure to properly execute constant-radius turns.
6. Failure to manipulate the flight controls in a smooth and continuous manner.
7. Failure to establish the appropriate wind correction angle.
8. Failure to apply coordinated aileron and rudder pressure, resulting in slips or skids.

S-Turns

An S-turn is a ground reference maneuver in which the airplane's ground track resembles two opposite but equal half-circles on each side of a selected ground-based straight-line reference. *[Figure 7-6]* This ground reference maneuver presents a practical application for the correction of wind during a turn. The objectives of S-turns across a road (or line) are as follows:

- Maintaining a specific relationship between the airplane and the ground.
- Dividing attention between the flightpath, ground-based references, manipulating the flight controls, and scanning for outside hazards and instrument indications.
- Adjusting the bank angle during turns to correct for groundspeed changes in order to maintain a constant-radius turn—steeper bank angles for higher groundspeeds, shallow bank angles for slower groundspeeds.
- Rolling out from a turn with the required wind correction angle to compensate for any drift cause by the wind.
- Establishing and correcting the wind correction angle in order to maintain the track over the ground.
- Developing the ability to compensate for drift in quickly-changing orientations.
- Arriving at specific points on required headings.

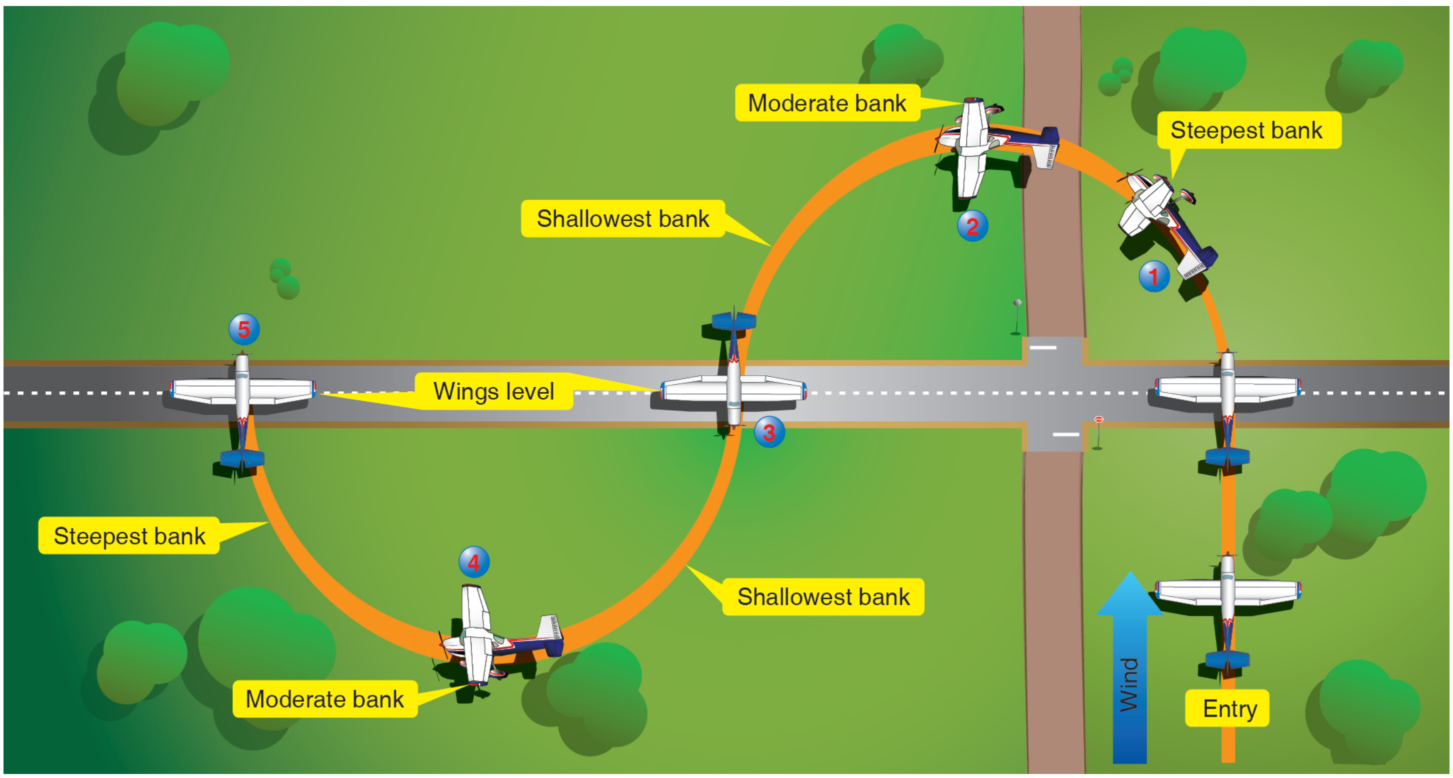

Figure 7-6. *S-turns.*

With the airplane in the downwind position, the maneuver consists of crossing a straight-line ground reference at a 90° angle and immediately beginning a 180° constant-radius turn. The pilot will then adjust the roll rate and bank angle for drift effects and changes in groundspeed, and re-cross the straight-line ground reference in the opposite direction just as the first 180° constant-radius turn is completed. The pilot will then immediately begin a second 180° constant-radius turn in the opposite direction, adjusting the roll rate and bank angle for drift effects and changes in groundspeed, again re-crossing the straight-line ground reference as the second 180° constant-radius turn is completed. If the straight-line ground reference is of sufficient length, the pilot may complete as many as can be safely accomplished.

In the same manner as the rectangular course, it is standard practice to enter ground-based maneuvers downwind where groundspeed is greatest. As such, the roll into the turn should be rapid, but not aggressive, and the angle of bank should be steepest when initiating the turn. As the turn progresses, the bank angle and the rate of rollout should be decreased as the groundspeed decreases to ensure that the turn's radius is constant. During the first turn, when the airplane is at the 90° point, it will be directly crosswind. In addition to the rate of rollout and bank angle, the pilot should control the wind correction angle throughout the turn.

Controlling the wind correction angle during a turn can be complex to understand. The concept may be understood by comprehending the difference between the number of degrees that the airplane has turned over the ground versus the number of degrees that the airplane has turned in the air. As an example, assume the airplane is exactly crosswind, meaning directly at a point that is 90° to the straight-lined ground reference. In this example, if the wind requires a 10° wind correction angle (for this example, this is a left turn with the crosswind from the left), the airplane would be at a heading that is 10° ahead when directly over the 90° ground reference point. In other words, the first 90° track over the ground would result in a heading change of 100° and the last 90° track over the ground would result in 80° of heading change.

As the turn progresses from a downwind position to an upwind position, the pilot should gradually decrease the bank angle with coordinated aileron and rudder pressure. The pilot should reference the airplane's nose, wingtips, and the ground references and adjust the rollout timing so that the wings become level just as the airplane crosses the straight-line ground reference at the proper heading, altitude, and airspeed. As the airplane re-crosses the straight-lined ground reference, the opposite turn begins—there should be no delay in rolling out from one turn and rolling into the next turn. Because the airplane is now upwind, the roll in should be smooth and gentle and the initial bank angle should be shallow. As the turn progresses, the wind changes from upwind, to crosswind, to downwind. In a similar manner described above, the pilot should adjust the bank angle to correct for changes in groundspeed. As the groundspeed increases, the pilot should increase the bank angle to maintain a constant-radius turn over the ground. At the 90° crosswind position, the airplane should also have the correct wind correction angle. As the airplane turns downwind and the groundspeed increases, the bank angle should be increased so that the rate of turn maintains a constant-radius turn.

The following are the most common errors made while performing S-turns across a road:

1. Failure to adequately clear surrounding area for safety hazards, initially and throughout the maneuver.
2. Failure to establish a constant, level altitude prior to entering the maneuver.
3. Failure to maintain altitude during the maneuver.
4. Failure to properly assess wind direction.
5. Failure to properly execute constant-radius turns.
6. Failure to manipulate the flight controls in a smooth and continuous manner when transitioning into turns.
7. Failure to establish the appropriate wind correction angle.
8. Failure to apply coordinated aileron and rudder pressure, resulting in slips or skids.

Elementary Eights

Elementary eights are a family of maneuvers in which each individual maneuver is one that the airplane tracks a path over the ground similar to the shape of a figure eight. There are various types of eights, progressing from the elementary to advanced types. Each eight is intended to develop a pilot's flight control coordination skills, strengthen their awareness relative to the selected ground references, and enhance division of attention so that flying becomes more instinctive than mechanical. Eights require a greater degree of focused attention to the selected ground references; however, the real significance of eights is that the pilot develops the ability to fly with precision.

Elementary eights include eights along a road, eights across a road, and eights around pylons. Each of these maneuvers is a variation of a turn around a point. Each eight uses two ground reference points about which the airplane turns first in one direction and then the opposite direction—like a figure eight.

Eights maneuvers are designed for the following purposes:

- Further development of the pilot's skill in maintaining a specific relationship between the airplane and the ground references.

- Improving the pilot's ability to divide attention between the flightpath and ground-based references, manipulation of the flight controls, and scanning for outside hazards and instrument indications during both turning and straight-line flight.

- Developing the pilot's skills to visualize each specific segment of the maneuver and the maneuver as a whole, prior to execution.

- Developing a pilot's ability to intuitively manipulate flight controls to adjust the bank angle during turns to correct for groundspeed changes in order to maintain constant-radius turns and proper ground track between ground references.

Eights Along a Road

An eight along a road is a ground reference maneuver in which the ground track consists of two opposite 360° adjacent turns. An imaginary line drawn through the center of each 360° turn is perpendicular to the straight-line ground reference (road, railroad tracks, fence line, pipeline right-of-way, etc.) as illustrated in Figure 7-7. Like the other ground reference maneuvers, the objective is to further develop division of attention while compensating for drift, maintaining orientation with ground references, and maintaining a constant altitude.

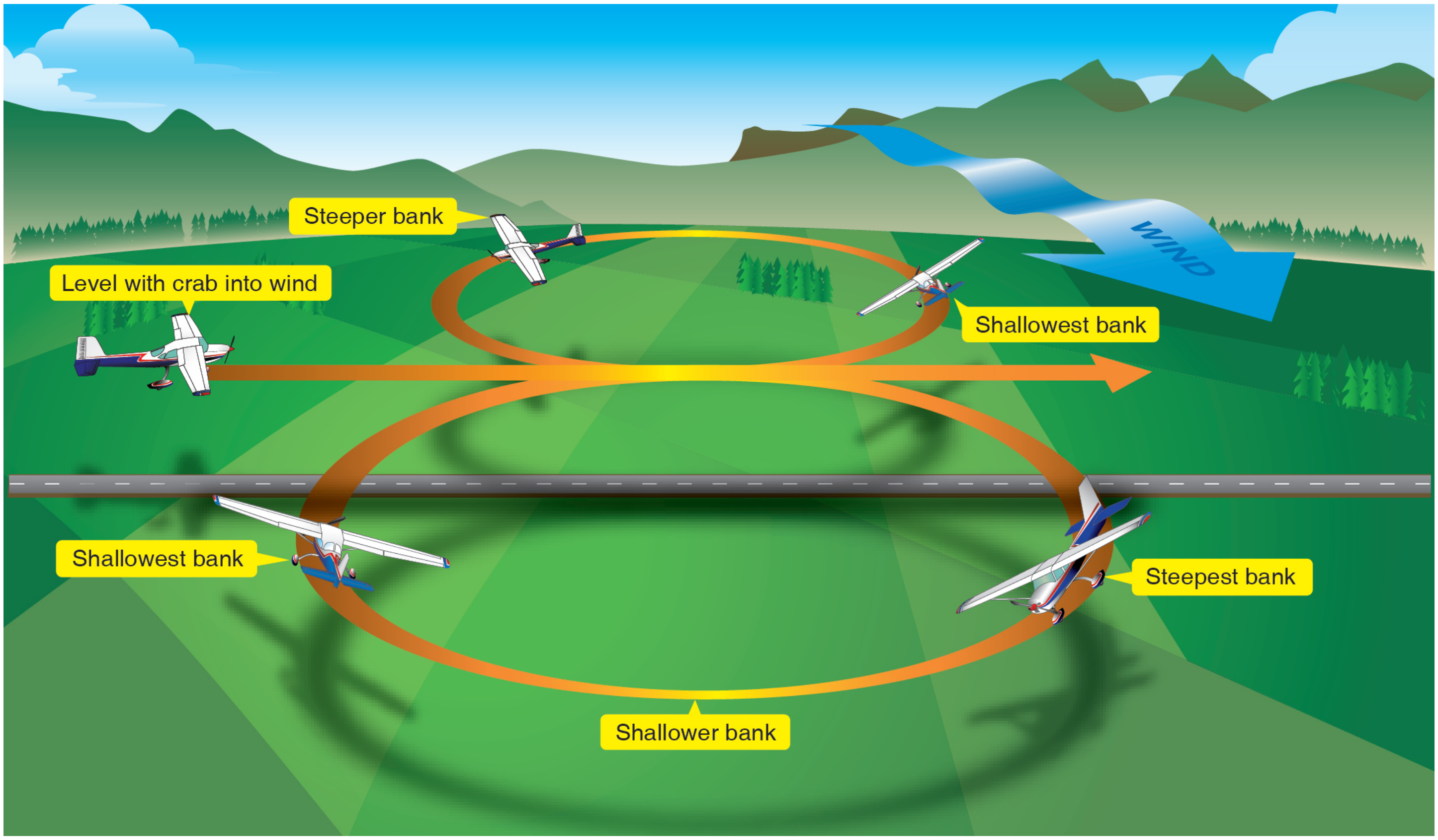

Figure 7-7. *Eights along a road.*

Although eights along a road may be performed with the wind blowing parallel or perpendicular to the straight-line ground reference, only the perpendicular wind situation is explained since the principles involved are common to each. The pilot should select a straight-line ground reference that is perpendicular to the wind and position the airplane parallel to and directly above the straight-line ground reference. Since this places the airplane in a crosswind position, the pilot should compensate for the wind drift with an appropriate wind correction angle.

The following description is illustrated in *Figure 7-7*. The airplane is initially in a crosswind position, perpendicular to the wind, and over the ground-based reference. The first turn should be to the right toward a downwind position starting with a steepening bank. When the entry is made into the turn, it requires that the turn begin with a medium bank and gradually steepen to its maximum bank angle when the airplane is directly downwind. As the airplane turns from downwind to crosswind, the bank angle needs to be gradually reduced since groundspeed is decreasing; however, 1/2 of the reduction in groundspeed occurs during the first 2/3 of the turn from downwind to crosswind.

The pilot needs to control the bank angle as well as the rate at which the bank angle is reduced so that the wind correction angle is correct. Assuming that the wind is coming from the right side of the airplane, the airplane heading should be slightly ahead of its position over the ground. When the airplane completes the first 180° of ground track, it is directly crosswind, and the airplane should be at the maximum wind correction angle.

As the turn is continued toward the upwind, the airplane’s groundspeed is decreasing, which requires the pilot to reduce the bank angle to slow the rate of turn. If the pilot does not reduce the bank angle, the continued high rate of turn would cause the turn to be completed prematurely. Another way to explain this effect is—the wind is drifting the airplane downwind at the same time its groundspeed is slowing. If the airplane has a steeper-than-required bank angle, its rate of turn will be too fast and the airplane will complete the turn before it has had time to return to the ground reference.

When the airplane is directly upwind, which is at 270° into the first turn, the bank angle should be shallow with no wind correction. As the airplane turns crosswind again, the airplane's groundspeed begins increasing; therefore, the pilot should adjust the bank angle and corresponding rate of turn proportionately in order to reach the ground reference at the completion of the 360° ground track. The pilot may vary the bank angle to correct for any previous errors made in judging the returning rate and closure rate. The pilot should time the rollout so that the airplane is straight-and-level over the starting point with enough drift correction to hold it over the straight-line ground reference. Assuming that the wind is now from the left, the airplane should be banked at a left wind correction angle.

After momentarily flying straight-and-level with the established wind correction, along the ground reference, the pilot should roll the airplane into a medium bank-turn in the opposite direction to begin the 360° turn on the upwind side of the ground reference. The wind will decrease the airplane's groundspeed and drift the airplane back toward the ground reference; therefore, the pilot should decrease the bank slowly during the first 90° of the upwind turn in order to establish a constant radius. During the next 90° of turn, the pilot should increase the bank angle, since the groundspeed is increasing, to maintain a constant radius and establish the proper wind correction angle before reaching the 180° upwind position.

As the remaining 180° of turn continues, the wind becomes a tailwind and then a crosswind. Consistent with previous downwind and crosswind descriptions, the pilot should increase the bank angle as the airplane reaches the downwind position and decrease the bank angle as the airplane reaches the crosswind position. Further, the rate of roll-in and roll-out should be consistent with how fast the groundspeed changes during the turn. Remember, when turning from an upwind or downwind position to a crosswind position, 1/2 of the groundspeed change occurs during the first 2/3 of the 90° turn. The final 1/2 of the change in groundspeed occurs during the last 1/3 of the turn. In contrast, when turning from a crosswind position to an upwind or downwind position, the first 1/2 of the groundspeed change occurs during the first 1/3 of the 90° turn. The final 1/2 of the change in groundspeed occurs during the last 2/3 of the turn.

To successfully perform eights along a ground reference, the pilot should be able to smoothly and accurately coordinate changes in bank angle to maintain a constant-radius turn and counteract drift. The speed in which the pilot can anticipate these corrections directly affects the accuracy of the overall maneuver and the amount of attention that can be directed toward scanning for outside hazards and instrument indications.

Eights Across a Road

This maneuver is a variation of eights along a road and involves the same principles and techniques. The primary difference is that at the completion of each loop of the figure eight, the airplane should cross an intersection or a specific ground reference point. *[Figure 7-8]*

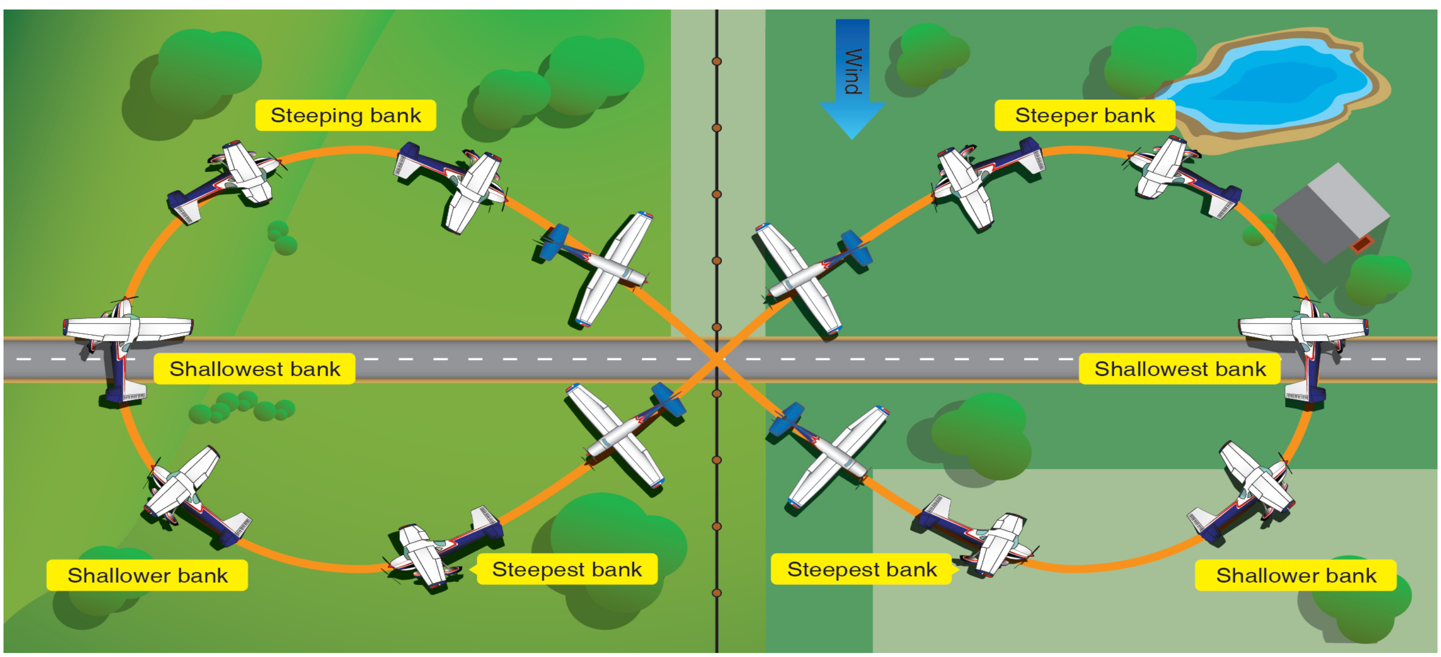

Figure 7-8. *Eights across a road.*

The loops should be across the road and the wind should be perpendicular to the loops. Each time the reference is crossed, the crossing angle should be the same, and the wings of the airplane should be level. The eights may also be performed by rolling from one bank immediately to the other, directly over the reference.

Eights Around Pylons

Eights around pylons is a ground reference maneuver with the same principles and techniques of correcting for wind drift as used in turns around a point and the same objectives as other ground track maneuvers. Eights around pylons utilizes two ground reference points called "pylons." Turns around each pylon are made in opposite directions to follow a ground track in the form of a figure 8. *[Figure 7-9]*

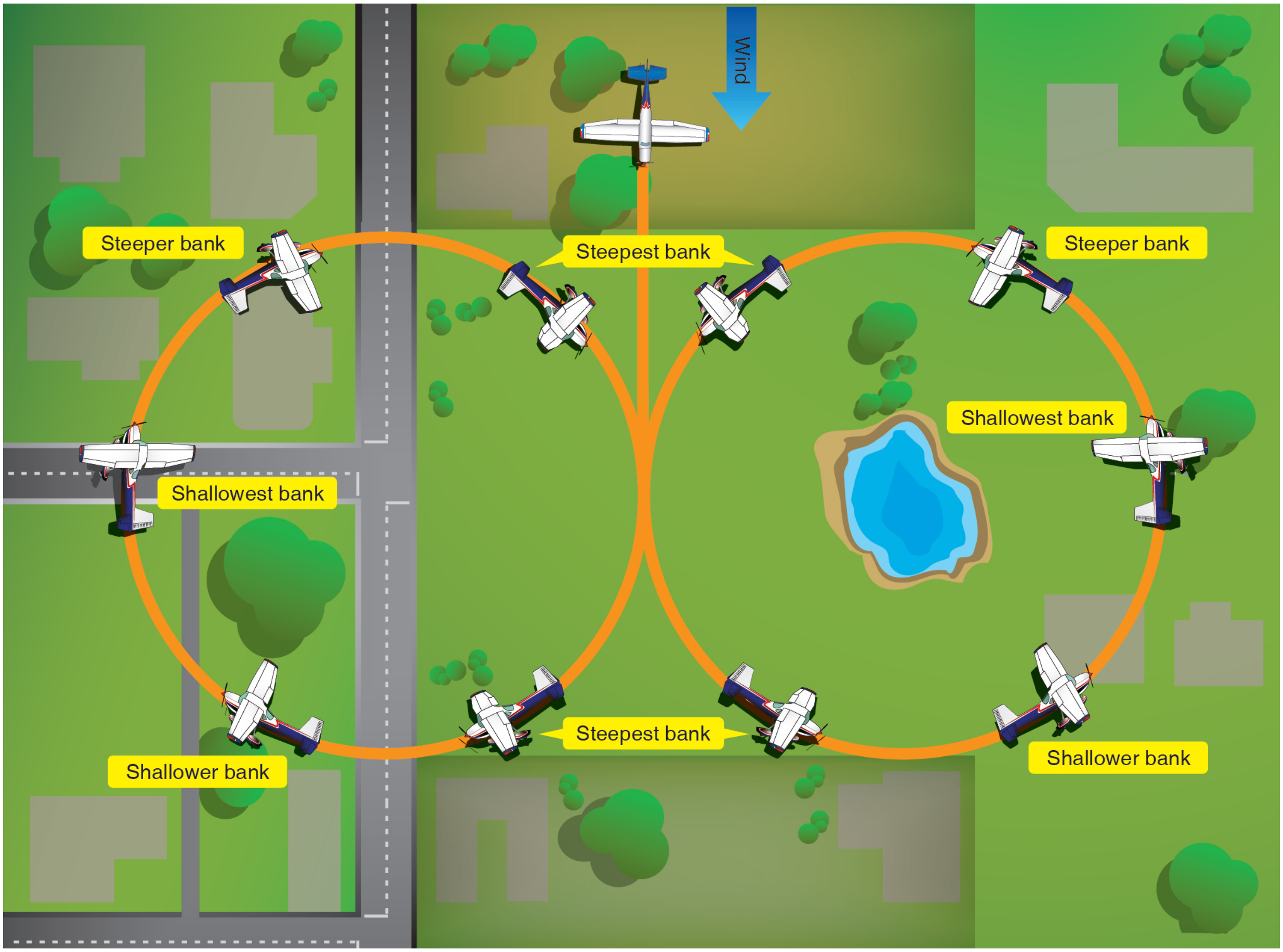

Figure 7-9. *Eights around pylons.*

The pattern involves flying downwind between the pylons and upwind outside of the pylons. It may include a short period of straight-and-level flight while proceeding diagonally from one pylon to the other. The pylons should be on a line perpendicular to the wind. The maneuver should be started with the airplane on a downwind heading while passing mid-way between the pylons. The distance between the pylons and the wind velocity determines the initial angle of bank required to maintain a constant turn radius from the pylons during each turn. The steepest banks are necessary just after each turn entry and just before the rollout from each turn where the airplane is headed downwind and the groundspeed is highest. The shallowest banks are when the airplane is headed directly upwind and the groundspeed is lowest.

As in other ground reference maneuvers, the rate at which the bank angle changes depends on the wind velocity. If the airplane proceeds diagonally from one turn to the other, the rollout from each turn needs to be completed on the proper heading with sufficient wind correction angle to ensure that after brief straight-and-level flight, the airplane arrives at the point where a turn of the same radius can be made around the other pylon. The straight-and-level flight segments should be tangent to both circular patterns.

Common Errors

Common errors in the performance of elementary eights are:

1. Failure to adequately clear the surrounding area for safety hazards, initially and throughout the maneuver.
2. Poor selection of ground references.
3. Failure to establish a constant, level altitude prior to entering the maneuver.
4. Failure to maintain adequate altitude control during the maneuver.
5. Failure to properly assess wind direction.
6. Failure to properly execute constant-radius turns.
7. Failure to manipulate the flight controls in a smooth and continuous manner.
8. Failure to establish the appropriate wind correction angles.
9. Failure to apply coordinated aileron and rudder pressure, resulting in slips or skids.
10. Failure to maintain orientation as the maneuver progresses.

Eights on Pylons

The eights on pylons is the most advanced and difficult of the ground-reference maneuvers. Because of the techniques involved, the eights on pylons are unmatched for developing intuitive control of the airplane. Similar to eights around pylons except altitude is varied to maintain a specific visual reference to the pivot points.

When performing eights on pylons, the pilot imagines there is a line parallel to the airplane's lateral axis that extends from the pilot's eyes to the pylon. Along this line, the airplane appears to pivot as it turns around the pylon. In other words, if a taut string extended from the pilot's eyes to the pylon, the string would remain parallel to lateral axis as the airplane makes a turn around the pylon. The goal of eights on pylons is to keep the line from the pilot's eyes to the pylon parallel to the lateral axis. The string should not be at an angle to the lateral axis while the airplane flies around the pylon. *[Figure 7-10]* When explaining eights on pylons, instructors sometimes use the term "wingtip" to represent the proper visual reference line to the pylon. This interpretation is not correct. High-wing, low-wing, swept-wing, and tapered-wing airplanes, as well as those with tandem or side-by-side seating, all present different angles from the pilot's eye to the wingtip. *[Figure 7-11]*

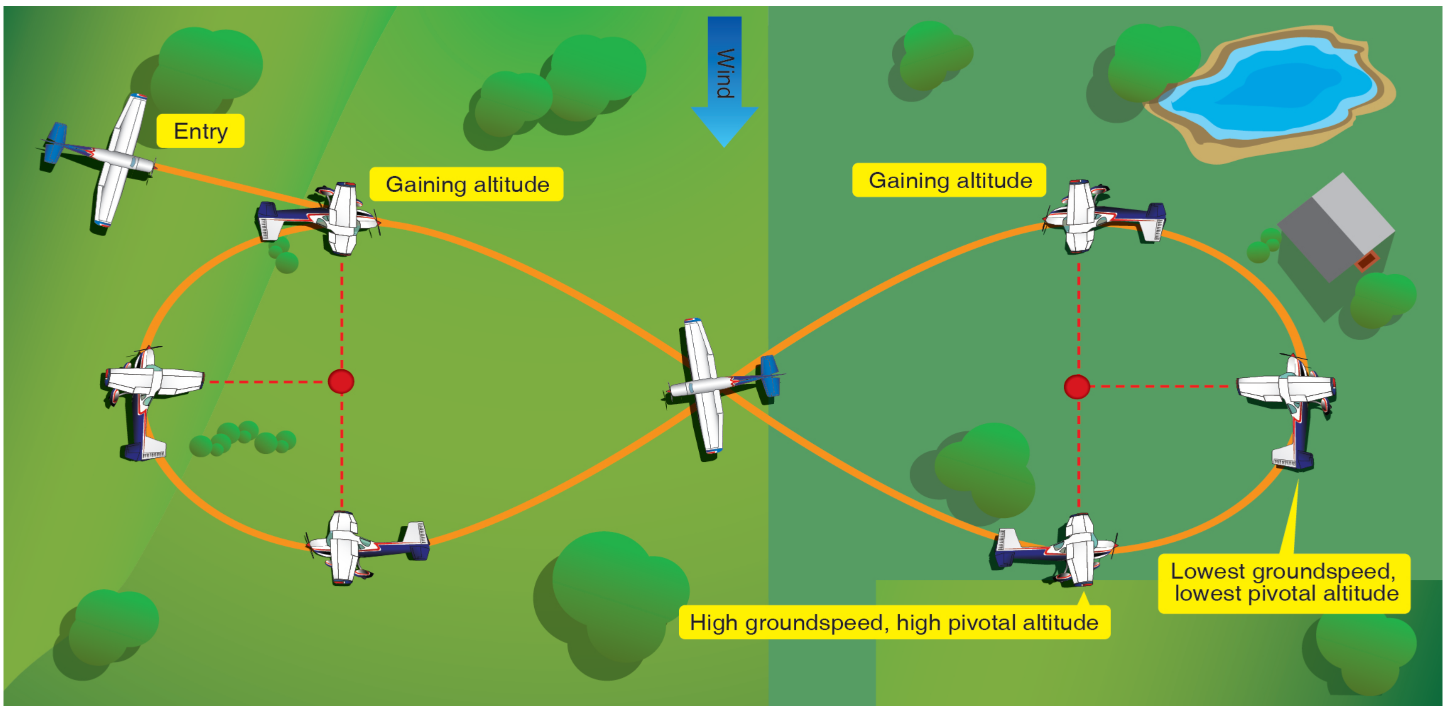

Figure 7-10. *Eights on pylons.*

The visual reference line, while not necessarily on the wingtip itself, may be positioned in relation to the wingtip (ahead, behind, above, or below), and differs for each pilot and from each seat in the airplane. This is especially true in tandem (fore and aft) seat airplanes. In side-by-side type airplanes, there is very little variation in the visual reference lines for different people, if those people are seated with their eyes at approximately the same level. Therefore, in the correct performance of eights on pylons, as in other maneuvers requiring a lateral reference, the pilot should use a visual reference line that, from eye level, parallels the lateral axis of the airplane.

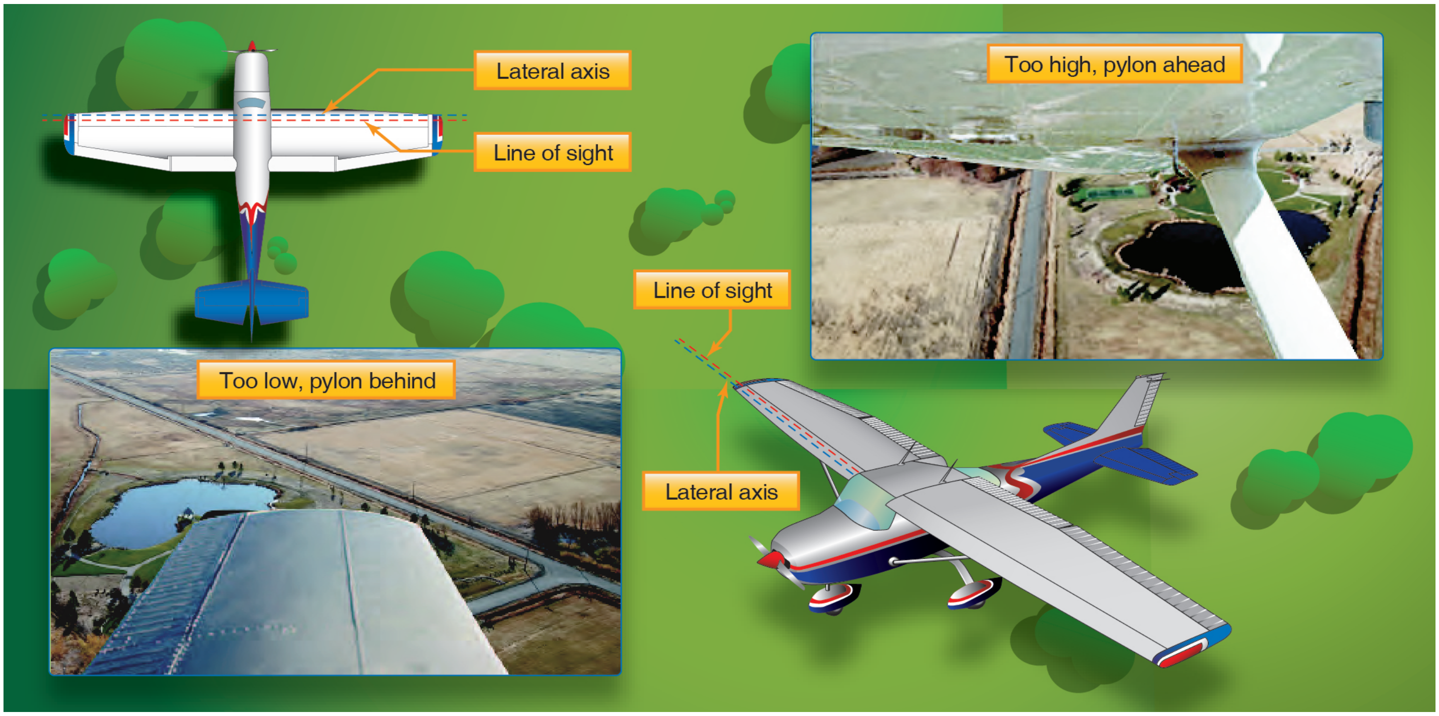

Figure 7-11. *Line of sight.*

The altitude that is appropriate for eights on pylons is called the "pivotal altitude" and is determined by the airplane's groundspeed. In previous ground-track maneuvers, the airplane flies a prescribed path over the ground and the pilot attempts to maintain the track by correcting for the wind. With eights on pylons, the pilot maintains lateral orientation to a specific spot on the ground. This develops the pilot's ability to maneuver the airplane accurately while dividing attention between the flightpath and the selected pylons on the ground.

An explanation of the pivotal altitude is also essential. First, a good rule of thumb for estimating the pivotal altitude is to square the groundspeed, then divide by 15 (if the groundspeed is in miles per hour) or divide by 11.3 (if the groundspeed is in knots), and then add the mean sea level (MSL) altitude of the ground reference. The pivotal altitude is the altitude at which, for a given groundspeed, the projection of the visual reference line to the pylon appears to pivot. Visually, a taut string, if extended from the pilot's eyes to the pylon, would remain parallel to lateral axis as the airplane makes a turn around the pylon. *[Figure 7-12]* The pivotal altitude does not vary with the angle of bank unless the bank is steep enough to affect the groundspeed.

Groundspeed		Approximate Pivotal Altitude
Knots	MPH	
87	100	670
91	105	735
96	110	810
100	115	885
104	120	960
109	125	1050
113	130	1130

Figure 7-12. *Speed versus pivotal altitude.*

Distance from the pylon affects the angle of bank. At any altitude above that pivotal altitude, the projected reference line appears to move rearward in a circular path in relation to the pylon. Conversely, when the airplane is below the pivotal altitude, the projected reference line appears to move forward in a circular path. *[Figure 7-13]* To demonstrate this, the pilot will fly at maneuvering speed and at an altitude below the pivotal altitude, and then place the airplane in a medium-banked turn. The projected visual reference line appears to move forward along the ground (pylon appears to move back) as the airplane turns. The pilot then executes a climb to an altitude well above the pivotal altitude. When the airplane is again at maneuvering speed, it is placed in a medium-banked turn. At the higher altitude, the projected visual reference line appears to move backward across the ground (pylon appears to move forward).

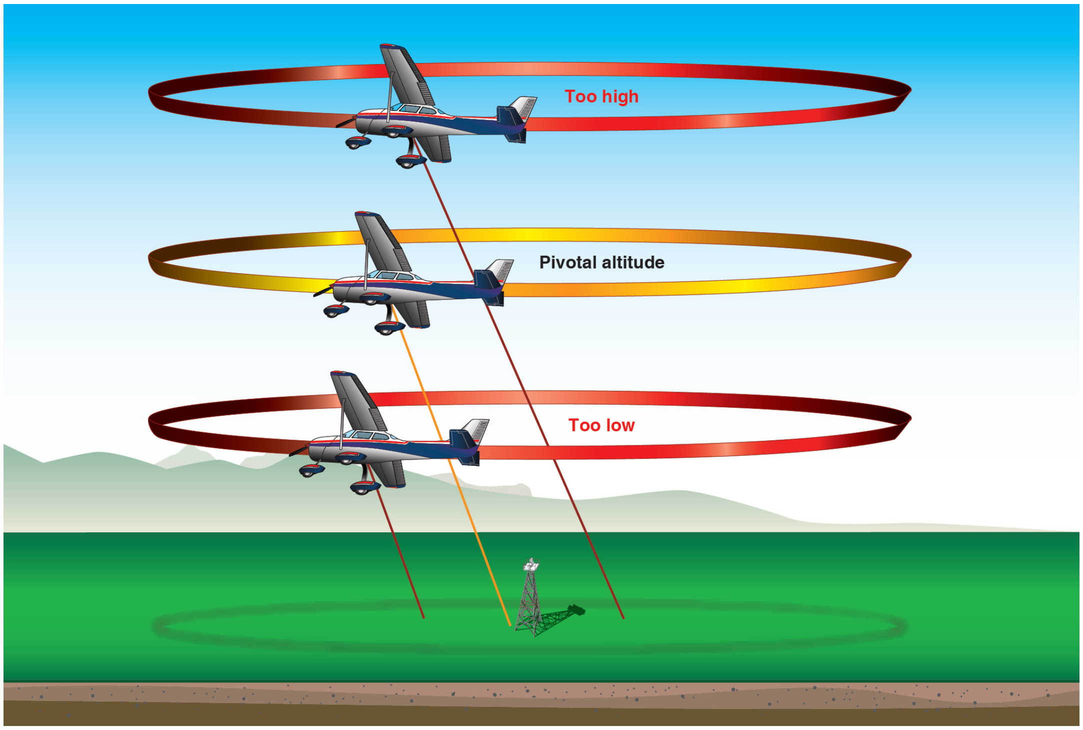

Figure 7-13. *Effect of different altitudes on line of sight.*

After demonstrating the maneuver at a high altitude, the pilot should reduce power and begin a descent at maneuvering speed in a continuing medium-bank turn around the pylon. The apparent backward movement of the projected visual reference line with respect to the pylon will slow down as altitude is lost and will eventually stop for an instant. If the pilot continues the descent below the pivotal altitude, the projected visual reference line with respect to the pylon will begin to move forward.

The altitude at which the visual reference line ceases to move across the ground is the pivotal altitude. If the airplane descends below the pivotal altitude, the pilot should increase power to maintain airspeed while regaining altitude to the point at which the projected reference line moves neither backward nor forward but actually pivots on the pylon. In this way, the pilot can determine the pivotal altitude of the airplane.

The pivotal altitude changes with variations in groundspeed. Since the headings throughout turns continuously vary from downwind to upwind, the groundspeed constantly changes. This results in the proper pivotal altitude varying slightly throughout the turn. The pilot should adjust for this by climbing or descending, as necessary, to hold the visual reference line on the pylons.

Selecting proper pylons is an important factor of successfully performing eights on pylons. They should be sufficiently prominent so the pilot can view them when completing the turn around one pylon and heading for the next. They should also be adequately spaced to provide time for planning the turns but not spaced so far apart that they cause unnecessary straight-and-level flight between the pylons. The distance between the pylons should allow for the straight-and-level flight segment to last from 3 to 5 seconds. The selected pylons should also be at the same elevation, since differences of over a few feet necessitate climbing or descending between each turn. The pilot should select two pylons along a line that lies perpendicular to the direction of the wind.

The pilot should estimate the pivotal altitude during preflight planning. Weather reports and consultation with other pilots flying in the area may provide both the wind direction and velocity. If the references are previously known (many flight instructors already have these ground-based references selected), the sectional chart will provide the MSL of the references, the Pilot's Operating Handbook (POH) provides the range of maneuvering airspeeds (based on weight), and the wind direction and velocity can be estimated to calculate the appropriate pivotal altitudes. The pilot should calculate the pivotal altitude for each position: upwind, downwind, and crosswind.

The pilot should begin the eight on pylons maneuver by flying diagonally crosswind between the pylons to a point downwind from the first pylon, so that the first turn can be made into the wind. As the airplane approaches a position where the pylon appears to be just ahead of the wingtip, the pilot should begin the turn by lowering the upwind wing to the point where the visual reference line aligns with the pylon. The reference line should appear to pivot on the pylon. As the airplane heads upwind, the groundspeed decreases, which lowers the pivotal altitude. As a result, the pilot should descend to hold the visual reference line on the pylon. As the turn progresses on the upwind side of the pylon, the wind becomes more of a crosswind. Since this maneuver does not require the turn to be completed at a constant radius, the pilot does not need to apply drift correction to complete the turn.

If the visual reference line appears to move ahead of the pylon (pylon appears to move back), the pilot should increase altitude. If the visual reference line appears to move behind the pylon (pylon appears to move ahead), the pilot should decrease altitude. Deflecting the rudder to yaw the airplane and force the wing and reference line forward or backward to the pylon places the airplane in uncoordinated flight, at low altitude, with steep bank angles and should not be attempted.

As the airplane turns toward a downwind heading, the pilot should rollout from the turn to allow the airplane to proceed diagonally to a point tangent on the downwind side of the second pylon. The pilot should complete the rollout with the proper wind correction angle to correct for wind drift, so that the airplane arrives at a point downwind from the second pylon that is equal in distance from the pylon as the corresponding point was from the first pylon at the beginning of the maneuver.

At this point, the pilot should begin a turn in the opposite direction by lowering the upwind wing to the point where the visual reference line aligns with the pylon. The pilot should then continue the turn the same way the corresponding turn was performed around the first pylon but in the opposite direction.

With prompt correction, and a very fine control pressures, it is possible to hold the visual reference line directly on the pylon even in strong winds. The pilot may make corrections for temporary variations, such as those caused by gusts or inattention, by reducing the bank angle slightly to fly relatively straight to bring forward a lagging visual reference line or by increasing the bank angle temporarily to turn back a visual reference line that has moved ahead. With practice, these corrections may become slight enough to be barely noticeable. It is important to understand that variations in pylon position are according to the apparent movement of the visual reference line. Attempting to correct pivotal altitude by the using the altimeter is ineffective.

Eights on pylons are performed at bank angles ranging from shallow to steep. *[Figure 7-14]* The pilot should understand that the bank chosen does not alter the pivotal altitude. As proficiency is gained, the instructor should increase the complexity of the maneuver by directing the learner to enter at a distance from the pylon that results in a specific bank angle at the steepest point in the pylon turn.

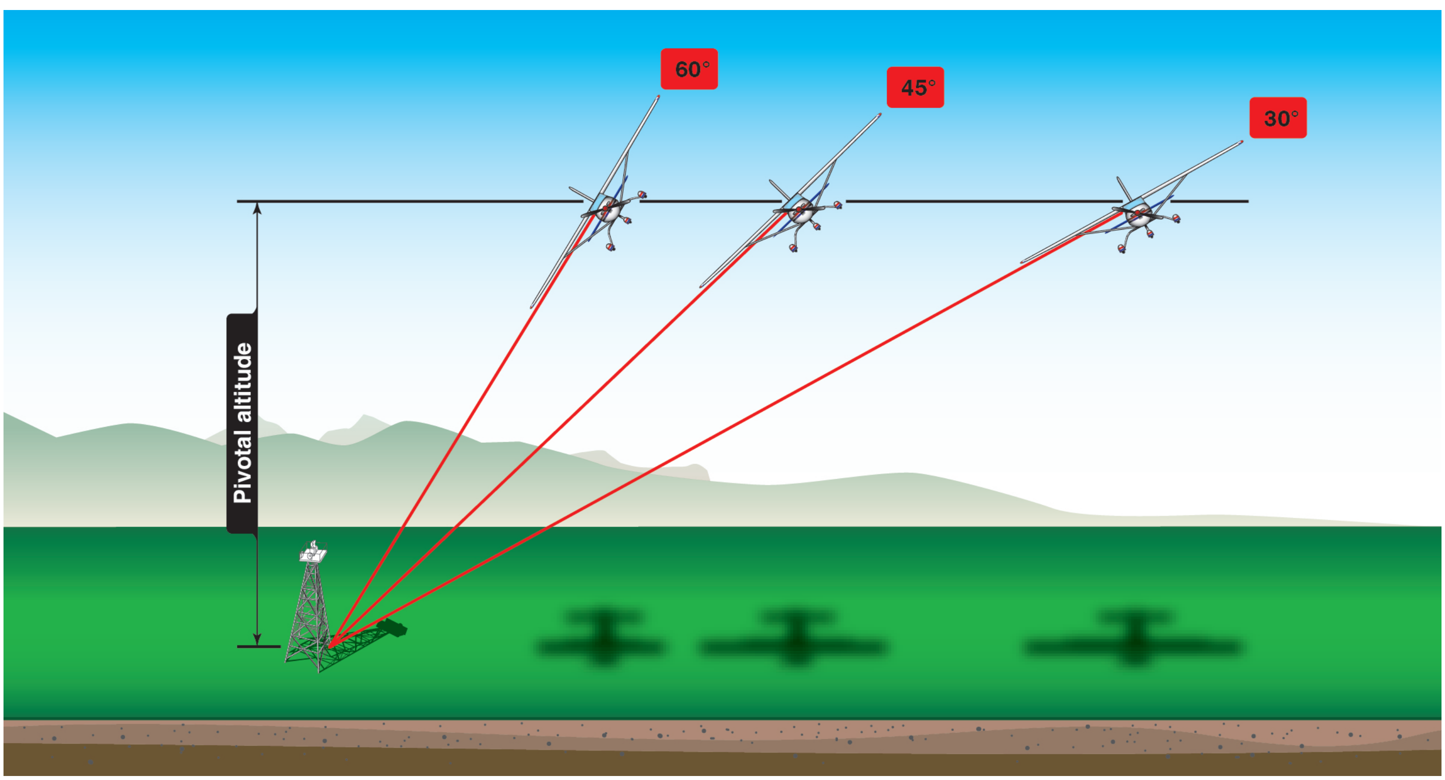

Figure 7-14. *Bank angle versus pivotal altitude.*

Common Errors

The most common error in attempting to hold a pylon is incorrect use of the rudder. When the projection of the visual reference line moves forward with respect to the pylon, many pilots tend to apply inside rudder pressure to yaw the wing backward. When the reference line moves behind the pylon, pilots tend to apply outside rudder pressure to yaw the wing forward. The pilot should use the rudder only for coordination.

Other common errors in the performance of eights on pylons are:

1. Failure to adequately clear the surrounding area for safety hazards, initially and throughout the maneuver.
2. Skidding or slipping in turns (whether trying to hold the pylon with rudder or not).
3. Excessive gain or loss of altitude.
4. Poor choice of pylons.
5. Not entering the pylon turns into the wind.
6. Failure to assume a heading when flying between pylons that will compensate sufficiently for drift.
7. Failure to time the bank so that the turn entry is completed with the pylon in position.
8. Abrupt control usage.
9. Inability to select pivotal altitude.

Chapter Summary

Ground reference maneuvers require planning and high levels of vigilance to ensure that the practice and performance of these maneuvers are executed where the safety to groups of people, livestock, communities, and the pilot is not compromised. While training to perform ground reference maneuvers, a pilot learns coordination, timing, and division of attention to maneuver the airplane accurately in reference to flight attitudes and specific ground references. After mastering ground reference maneuvers, the pilot should be able to command the airplane to specific pitch, roll, and yaw attitudes, correct for the effects of wind drift, and control the airplane's orientation in relation to ground-based references. While safety is paramount in all aspects of flying, ground reference maneuvers focus on mitigation of risk during low altitude flying. With these enhanced skills, the pilot also significantly improves their competency in everyday flight maneuvers, such as straight-and-level, turns, climbs, and descents.