Chapter 5, Section I

Airplane Basic Flight Maneuvers

Using Analog Instrumentation

Introduction

Instrument flying techniques differ according to aircraft type, class, performance capability, and instrumentation. Therefore, the procedures and techniques that follow need to be modified to suit individual aircraft. Recommended procedures, performance data, operating limitations, and flight characteristics of a particular aircraft are available in the Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) for study before practicing the flight maneuvers.

The flight maneuvers discussed here in Chapter 5-I assume the use of a single-engine, propeller-driven small airplane with retractable gear and flaps and a panel with instruments representative of those discussed earlier in Chapter 3, Flight Instruments. With the exception of the instrument takeoff, all of the maneuvers can be performed on "partial panel," with the attitude gyro and heading indicator covered or inoperative.

Figure 5-1. *Pitch Attitude and Airspeed in Level Flight, Slow Cruise Speed.*

Figure 5-2. *Pitch Attitude and Airspeed in Level Flight, Fast Cruise Speed.*

Straight-and-Level Flight

Pitch Control

The pitch attitude of an airplane is the angle between the longitudinal axis of the airplane and the actual horizon. In level flight, the pitch attitude varies with airspeed and load. For training purposes, the latter factor can normally be disregarded in small airplanes. At a constant airspeed, there is only one specific pitch attitude for level flight. At slow cruise speeds, the level flight attitude is nose high with indications as in *Figure 5-1*; at fast cruise speeds, the level-flight attitude is nose low. *[Figure 5-2] Figure 5-3* shows the indications for the attitude at normal cruise speeds. The instruments used to determine the pitch attitude of the aircraft are the attitude indicator, the altimeter, the vertical speed indicator (VSI), and the airspeed indicator (ASI).

Attitude Indicator

The attitude indicator gives the direct indication of pitch attitude. The desired pitch attitude is gained by using the elevator control to raise or lower the miniature aircraft in relation to the horizon bar. This corresponds to the way pitch attitude is adjusted in visual flight by raising or lowering the nose of the airplane in relation to the natural horizon. However, unless the airspeed is constant, and until the level flight attitude for that airspeed has been identified and established, there is no way to know whether level flight as

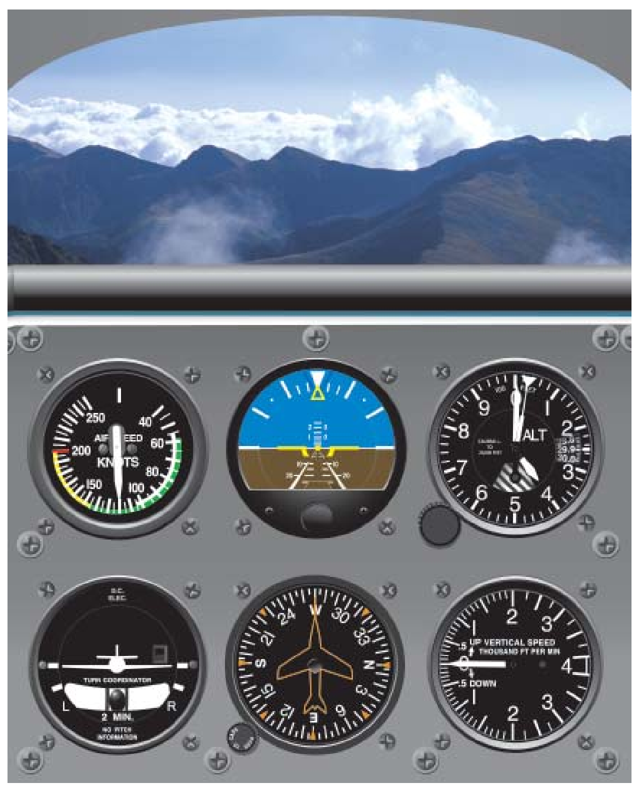


Figure 5-3. *Pitch Attitude and Airspeed in Level Flight, Normal Cruise Speed.*

indicated on the attitude indicator is resulting in level flight as shown on the altimeter, VSI, and ASI. If the miniature aircraft of the attitude indicator is properly adjusted on the ground before takeoff, it shows approximately level flight at normal cruise speed when the pilot completes the level off from a climb. If further adjustment of the miniature aircraft is necessary, the other pitch instruments must be used to maintain level flight while the adjustment is made.

To practice pitch control for level flight using only the attitude indicator, use the following exercise. Restrict the displacement of the horizon bar to a one-half bar width, a bar width up or down, then a one-and-one-half bar width. One-half, one, and one-and-one-half bar width nose-high attitudes are shown in *Figures 5-4, 5-5,* and *5-6*.

Figure 5-4. *Pitch Correction for Level Flight, One-Half Bar Width.*

Figure 5-5. *Pitch Correction for Level Flight, One Bar Width.*

Figure 5-6. *Pitch Correction for Level Flight, One-and-One-Half Bar Width.*

An instructor pilot can demonstrate these normal pitch corrections and compare the indications on the attitude indicator with the airplane's position to the natural horizon.

Pitch attitude changes for corrections to level flight by reference to instruments are much smaller than those commonly used for visual flight. With the airplane correctly trimmed for level flight, the elevator displacement and the control pressures necessary to effect these standard pitch changes are usually very slight. The following are a few helpful hints to help determine how much elevator control pressure is required.

First, a tight grip on the controls makes it difficult to feel control pressure changes. Relaxing and learning to control the aircraft usually takes considerable conscious effort during the early stages of instrument training.

Second, make smooth and small pitch changes with positive pressure. With practice, a pilot can make these small pitch corrections up or down, "freezing" (holding constant) the one-half, full, and one-and-one-half bar widths on the attitude indicator.

Third, with the airplane properly trimmed for level flight, momentarily release all pressure on the elevator control when becoming aware of tenseness. This is a reminder that the airplane is stable; except under turbulent conditions, it will maintain level flight if left alone. Even when no control change is called for, it will be difficult to resist the impulse to move the controls. This may be one of the most difficult initial training problems in instrument flight.

Altimeter

At constant power, any deviation from level flight (except in turbulent air) is the result of a pitch change. Therefore, the altimeter gives an indirect indication of the pitch attitude in level flight, assuming constant power. Since the altitude should remain constant when the airplane is in level flight, any deviation from the desired altitude signals the need for a pitch change. If the aircraft is gaining altitude, the nose must be lowered. *[Figures 5-7* and *5-8]*

Figure 5-7. *Using the Altimeter for Pitch Interpretation, a High Altitude Means a Nose-High Pitch Attitude.*

Figure 5-8. *Pitch Correction Following Altitude Increase—Lower Nose to Correct Altitude Error.*

The rate of movement of the altimeter needle is as important as its direction of movement in maintaining level flight without the use of the attitude indicator. An excessive pitch deviation from level flight results in a relatively rapid change of altitude; a slight pitch deviation causes a slow change. Thus, if the altimeter needle moves rapidly clockwise, assume a considerable nose-high deviation from level flight attitude. Conversely, if the needle moves slowly counterclockwise to indicate a slightly nose-low attitude, assume that the pitch correction necessary to regain the desired altitude is small. As the altimeter is added to the attitude indicator in a cross-check, a pilot will learn to recognize the rate of movement of the altimeter needle for a given pitch change as shown on the attitude indicator.

To practice precision control of pitch in an airplane without an attitude indicator, make small pitch changes by visual reference to the natural horizon, and note the rate of movement of the altimeter. Note what amount of pitch change gives the slowest steady rate of change on the altimeter. Then practice small pitch corrections by accurately interpreting and controlling the rate of needle movement.

An instructor pilot can demonstrate an excessive nose-down deviation (indicated by rapid movement of the altimeter needle) and then, as an example, show the result of improper corrective technique. The normal impulse is to make a large pitch correction in a hurry, but this inevitably leads to overcontrolling. The needle slows down, then reverses direction, and finally indicates an excessive nose-high deviation. The result is tension on the controls, erratic control response, and increasingly extreme control movements. The correct technique, which is slower and smoother, will return the airplane to the desired attitude more quickly, with positive control and no confusion.

When a pitch error is detected, corrective action should be taken promptly, but with light control pressures and two distinct changes of attitude: (1) a change of attitude to stop the needle movement and (2) a change of attitude to return to the desired altitude.

When the altimeter indicates an altitude deviation, apply just enough elevator pressure to decrease the rate of needle movement. If it slows down abruptly, ease off some of the pressure until the needle continues to move, but ease off slowly. Slow needle movement means the airplane attitude is close to level flight. Add slightly more corrective pressure to stop the direction of needle movement. At this point level flight is achieved; a reversal of needle movement means the aircraft has passed through it. Relax control pressures carefully, continuing to cross-check since changing airspeed will cause changes in the effectiveness of a given control pressure. Next, adjust the pitch attitude with elevator pressure for the rate of change of altimeter needle movement that is correlated with normal pitch corrections, and return to the desired altitude.

As a rule of thumb, for errors of less than 100 feet, use a half bar width correction. *[Figures 5-9* and *5-10]* For errors in excess of 100 feet, use an initial full bar width correction. *[Figures 5-11* and *5-12]* Practice predetermined altitude changes using the altimeter alone, then in combination with the attitude indicator.

Vertical Speed Indicator (VSI)

The VSI, like the altimeter, gives an indirect indication of pitch attitude and is both a trend and a rate instrument. As a trend instrument, it shows immediately the initial vertical movement of the airplane, which disregarding turbulence can be considered a reflection of pitch change. To maintain level flight, use the VSI in conjunction with the altimeter and attitude indicator. Note any positive or negative trend of the needle from zero and apply a very light corrective elevator

Figure 5-9. *Altitude Error, Less Than 100 Feet.*

Figure 5-10. *Pitch Correction, Less Than 100 Feet—One-Half Bar Low to Correct Altitude Error.*

Figure 5-11. *Altitude Error, Greater Than 100 Feet.*

Figure 5-12. *Pitch Correction, Greater Than 100 Feet—One Bar Correction Initially.*

pressure. As the needle returns to zero, relax the corrective pressure. If control pressures have been smooth and light, the needle reacts immediately and slowly, and the altimeter shows little or no change of altitude. As a rate instrument, the VSI requires consideration of lag characteristics.

Lag refers to the delay involved before the needle attains a stable indication following a pitch change. Lag is directly proportional to the speed and magnitude of a pitch change. If a slow, smooth pitch change is initiated, the needle moves with minimum lag to a point of deflection corresponding to the extent of the pitch change, and then stabilizes as the aerodynamic forces are balanced in the climb or descent. A large and abrupt pitch change produces erratic needle movement, a reverse indication, and introduces greater time delay (lag) before the needle stabilizes. Pilots are cautioned not to chase the needle when flight through turbulent conditions produces erratic needle movements. The apparent lag in airspeed indications with pitch changes varies greatly among different airplanes and is due to the time required for the airplane to accelerate or decelerate when the pitch attitude is changed. There is no appreciable lag due to the construction or operation of the instrument. Small pitch changes, smoothly executed, result in an immediate change of airspeed.

When using the VSI as a rate instrument and combining it with the altimeter and attitude indicator to maintain level flight, a pilot should know that the amount the altimeter needle moves from the desired altitude governs the rate which should be used to return to that altitude. A rule of thumb is to make an attitude change that will result in a vertical-speed rate approximately double the error in altitude. For example, if altitude is off by 100 feet, the rate of return to the desired altitude should be approximately 200 feet per minute (fpm). If it is off by more than 100 feet, the correction should be correspondingly greater, but should never exceed the optimum rate of climb or descent for the airplane at a given airspeed and configuration.

A deviation of more than 200 fpm from the desired rate of return is considered overcontrolling. For example, if attempting to change altitude by 200 feet, a rate in excess of 400 fpm indicates overcontrolling.

When returning to an altitude, the VSI is the primary pitch instrument. Occasionally, the VSI is slightly out of calibration and may indicate a climb or descent when the airplane is in level flight. If the instrument cannot be adjusted, take the error into consideration when using it for pitch control. For example, if the needle indicates a descent of 200 fpm while in level flight, use this indication as the zero position.

Airspeed Indicator (ASI)

The ASI presents an indirect indication of the pitch attitude. In non-turbulent conditions with a constant power setting and pitch attitude, airspeed remains constant. *[Figure 5-13]* As the pitch attitude lowers, airspeed increases, and the nose should be raised. *[Figure 5-14]* As the pitch attitude rises, airspeed decreases, and the nose should be lowered. *[Figure 5-15]* A rapid change in airspeed indicates a large pitch change, and a slow change of airspeed indicates a small pitch change.

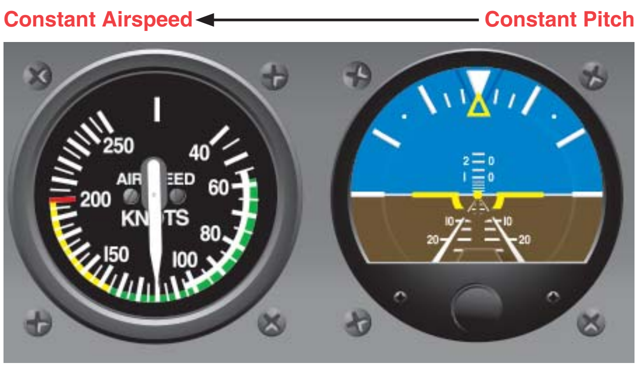


Figure 5-13. *Constant Power Plus Constant Pitch Equals Constant Speed.*

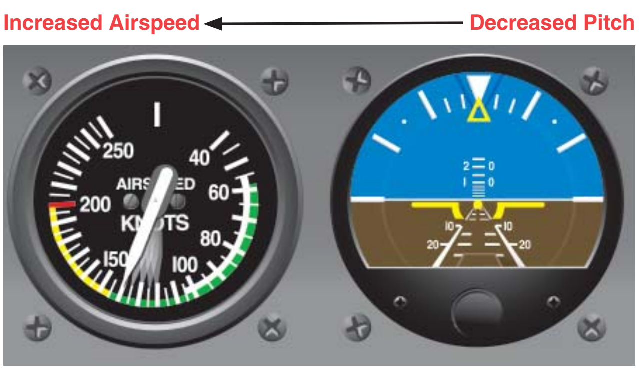


Figure 5-14. *Constant Power Plus Decreased Pitch Equals Increased Airspeed.*

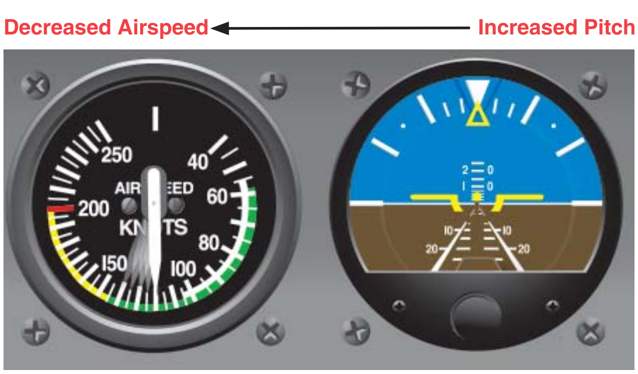


Figure 5-15. *Constant Power Plus Increased Pitch Equals Decreased Airspeed.*

Pitch control in level flight is a question of cross-check and interpretation of the instrument panel for the instrument information that enables a pilot to visualize and control pitch attitude. Regardless of individual differences in cross-check technique, all pilots should use the instruments that give the best information for controlling the airplane in any given maneuver. Pilots should also check the other instruments to aid in maintaining the primary instruments at the desired indication.

As noted previously, the primary instrument is the one that gives the most pertinent information for a particular maneuver. It is usually the one that should be held at a constant indication. Which instrument is primary for pitch control in level flight, for example? This question should be considered in the context of specific airplane, weather conditions, pilot experience, operational conditions, and other factors. Attitude changes must be detected and interpreted instantly for immediate control action in high-performance airplanes. On the other hand, a reasonably proficient instrument pilot in a slower airplane may rely more on the altimeter for primary pitch information, especially if it is determined that too much reliance on the attitude indicator fails to provide the necessary precise attitude information. Whether the pilot decides to regard the altimeter or the attitude indicator as primary depends on which approach will best help control the attitude. In this handbook, the altimeter is normally considered as the primary pitch instrument during level flight.

Bank Control

The bank attitude of an airplane is the angle between the airplane's wings and the natural horizon. To maintain a straight-and-level flight path, the wings of the airplane are kept level with the horizon (assuming the airplane is in coordinated flight). The instruments used for bank control are the attitude indicator, the heading indicator, and the turn coordinator. *Figure 5-16* illustrates coordinated flight. The aircraft is banked left with the attitude indicator and turn coordinator indicating the bank. The heading indicator indicates a left turn by apparent clockwise rotation of the compass card behind the airplane silhouette.

Attitude Indicator

The attitude indicator shows any change in bank attitude directly and instantly and is, therefore, a direct indicator. On the standard attitude indicator, the angle of bank is shown pictorially by the relationship of the miniature aircraft to the artificial horizon bar, and by the alignment of the pointer with the banking scale at the top of the instrument. On the face of the standard three-inch instrument, small angles of bank can be difficult to detect by reference to the miniature aircraft, especially if leaning to one side or changing a seating position

Figure 5-16. *Instruments Used for Bank Control.*

slightly. The position of the scale pointer is a good check against the apparent miniature aircraft position. Disregarding precession error, small deviations from straight coordinated flight can be readily detected on the scale pointer. The banking index may be graduated as shown in *Figure 5-17*, or it may be graduated in 30° increments.

The instrument depicted in *Figure 5-17* has a scale pointer that moves in the same direction of bank shown by the miniature aircraft. In this case, the aircraft is in a left 15° bank. Precession errors in this instrument are common

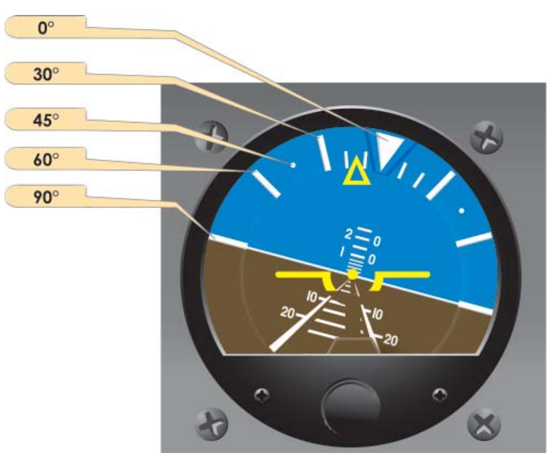


Figure 5-17. *Bank Interpretation with the Attitude Indicator.*

and predictable, but the obvious advantage of the attitude indicator is an immediate indication of both pitch attitude and bank attitude in a single glance. Even with the precession errors associated with many attitude indicators, the quick attitude presentation requires less visual effort and time for positive control than other flight instruments.

Heading Indicator

The bank attitude of an aircraft in coordinated flight is shown indirectly on the heading indicator, since banking results in a turn and change in heading. Assuming the same airspeed in both instances, a rapid movement of the heading indicator (azimuth card in a directional gyro) indicates a large angle of bank, whereas slow movement reflects a small angle of bank. Note the rate of movement of the heading indicator and compare it to the attitude indicator's degrees of bank. The attitude indicator's precession error makes a precise check of heading information necessary in order to maintain straight flight.

When deviations from straight flight are noted on the heading indicator, correct to the desired heading using a bank angle no greater than the number of degrees to be turned. In any case, limit bank corrections to a bank angle no greater than that required for a standard rate turn. Use of larger bank angles requires a very high level of proficiency, and normally results in overcontrolling and erratic bank control.

Turn Coordinator

The miniature aircraft of the turn coordinator gives an indirect indication of the bank attitude of the airplane. When the miniature aircraft is level, the airplane is in straight flight. When the miniature airplane is aligned with one of the alignment marks and the aircraft is rolling to the left or right the indication represents the roll rate, with the alignment marks indicating a roll of 3° per second in the direction of the miniature aircraft. This can be seen in level flight when a bank is introduced either to the left or the right. The turn coordinator's indicator will indicate the rolling motion although there is no turn being made. Conversely, a pedal input to the right or left causes the aircraft to turn momentarily about its vertical axis (with no rolling motion) with an indication of turn on the turn coordinator. After the turn becomes stabilized and the aircraft is no longer rolling, the turn coordinator displays the rate of turn with the alignment marks equaling a turn of 3° per second. The turn coordinator is able to display both roll and turn parameters because its electrically powered gyroscope is canted at an angle. As a result, the turn-and-slip indicator provides both roll and turn indications. Autopilots in general aviation today use this instrument in determining both roll and turn information. After the completion of a turn, return to straight flight is accomplished by coordinated aileron and rudder pressure to level the miniature aircraft. Include the miniature aircraft in the cross-check and correct for even the smallest deviations from the desired position. When this instrument is used to maintain straight flight, control pressures must be applied very lightly and smoothly.

The ball of the turn coordinator is actually a separate instrument, conveniently located under the miniature aircraft because the two instruments are used together. The ball instrument indicates the quality of the turn. If the ball is off center, the airplane is slipping or skidding. That is, if the coordinator's miniature airplane is tilted right and the ball is displaced to the right, the aircraft is in a skid. *[Figure 5-18]* If however, the miniature airplane is tilted to the right with the ball off-center to the left, the aircraft is in a slip. *[Figure 5-19]* If the wings are level and the airplane is properly trimmed, the ball will remain in the center, and the airplane will be in straight flight. If the ball is not centered, the airplane is improperly trimmed.

Figure 5-18. *Skid Indication.*

Figure 5-19. *Slip Indication.*

To maintain straight-and-level flight with proper trim, note the direction of ball displacement. If the ball is to the left of center and the left wing is low, apply left rudder pressure to center the ball and correct the slip. At the same time apply right aileron pressure as necessary to level the wings, cross-checking the heading indicator and attitude indicator while centering the ball. If the wings are level and the ball is displaced from the center, the airplane is skidding. Note the direction of ball displacement, and use the same corrective technique as for an indicated slip. Center the ball (left ball/left rudder, right ball/right rudder), use aileron as necessary for bank control, and retrim.

To trim the airplane using only the turn coordinator, use aileron pressure to level the miniature aircraft and rudder pressure to center the ball. Hold these indications with control pressures, gradually releasing them while applying rudder trim sufficient to relieve all rudder pressure. Apply aileron trim, if available, to relieve aileron pressure. With a full instrument panel, maintain a wings level attitude by reference to all available instruments while trimming the airplane.

Turn-and-Slip Indicator (Needle and Ball)

Unlike the turn coordinator that provides three indications (roll, turn, and trim), the turn-and-slip indicator provides two: turn-rate and trim. Although the turn-and-slip indicator needle provides an indication of turn only, it provides an indirect indication of aircraft attitude when used with roll indicators such as a heading indicator or magnetic compass. As with the turn coordinator (after stabilizing from a roll), when the turn-and-slip indicator's needle is aligned with the alignment marks the aircraft is in a standard turn of 3° per second or 360° in 2 minutes.

The ball of the turn-and-bank indicator provides important trim in the same manner that the ball in the turn coordinator does. *Figures 5-18* and *5-19* provide a comparison of the two instruments.

Power Control

Power produces thrust which, with the appropriate angle of attack of the wing, overcomes the forces of gravity, drag, and inertia to determine airplane performance.

Power control must be related to its effect on altitude and airspeed, since any change in power setting results in a change in the airspeed or the altitude of the airplane. At any given airspeed, the power setting determines whether the airplane is in level flight, in a climb, or in a descent. If the power is increased in straight-and-level flight and the airspeed held constant, the airplane climbs. If power is decreased while the airspeed is held constant, the airplane descends. On the other hand, if altitude is held constant, the power applied will determine the airspeed.

The relationship between altitude and airspeed determines the need for a change in pitch or power. If the airspeed is not the desired value, always check the altimeter before deciding that a power change is necessary. Think of altitude and airspeed as interchangeable; altitude can be traded for airspeed by lowering the nose, or convert airspeed to altitude by raising the nose. If altitude is higher than desired and airspeed is

Figure 5-20. *Airspeed Low and Altitude High—Lower Pitch.*

low, or vice versa, a change in pitch alone may return the airplane to the desired altitude and airspeed. *[Figure 5-20]* If both airspeed and altitude are high or if both are low, then a change in both pitch and power is necessary in order to return to the desired airspeed and altitude. *[Figure 5-21]*

For changes in airspeed in straight-and-level flight, pitch, bank, and power must be coordinated in order to maintain constant altitude and heading. When power is changed to vary airspeed in straight-and-level flight, a single-engine, propeller-driven airplane tends to change attitude around all axes of movement. Therefore, to maintain constant altitude and heading, apply various control pressures in proportion to the change in power. When power is added to increase airspeed, the pitch instruments indicate a climb unless forward elevator control pressure is applied as the airspeed changes. With an increase in power, the airplane tends to yaw and roll to the left unless counteracting aileron and rudder pressures are applied. Keeping ahead of these changes requires increasing cross-check speed, which varies with the type of airplane and its torque characteristics, the extent of power and speed change involved.

Power Settings

Power control and airspeed changes are much easier when approximate power settings necessary to maintain various airspeeds in straight-and-level flight are known in advance. However, to change airspeed by any appreciable amount, the common procedure is to underpower or overpower on initial power changes to accelerate the rate of airspeed change. (For small speed changes, or in airplanes that decelerate or accelerate rapidly, overpowering or underpowering is not necessary.)

Consider the example of an airplane that requires 23" mercury (Hg) of manifold pressure to maintain a normal cruising airspeed of 120 knots, and 18" Hg of manifold pressure to maintain an airspeed of 100 knots. The reduction in airspeed from 120 knots to 100 knots while maintaining straight-and-level flight is discussed below and illustrated in *Figures 5-22, 5-23,* and *5-24*.

Instrument indications, prior to the power reduction, are shown in *Figure 5-22*. The basic attitude is established and maintained on the attitude indicator. The specific pitch, bank, and power control requirements are detected on these primary instruments:

Altimeter—Primary Pitch
Heading Indicator—Primary Bank
Airspeed Indicator—Primary Power

Supporting pitch-and-bank instruments are shown in *Figure 5-23*. Note that the supporting power instrument is the manifold pressure gauge (or tachometer if the propeller is fixed pitch). However, when a smooth power reduction to approximately 15" Hg (underpower) is made, the manifold pressure gauge becomes the primary power instrument. *[Figure 5-23]* With practice, power setting can be changed with only a brief glance at the power instrument, by sensing

Figure 5-21. *Airspeed and Altitude High—Lower Pitch and Reduce Power.*

Figure 5-22. *Straight-and-Level Flight (Normal Cruising Speed).*

Figure 5-23. *Straight-and-Level Flight (Airspeed Decreasing).*

the movement of the throttle, the change in sound, and the changes in the feel of control pressures.

As thrust decreases, increase the speed of the cross-check and be ready to apply left rudder, back-elevator, and aileron control pressure the instant the pitch-and-bank instruments show a deviation from altitude and heading. As proficiency is obtained, a pilot learns to cross-check, interpret, and control the changes with no deviation of heading and altitude. Assuming smooth air and ideal control technique, as airspeed decreases, a proportionate increase in airplane pitch attitude is required to maintain altitude. Similarly, effective torque control means counteracting yaw with rudder pressure.

As the power is reduced, the altimeter is primary for pitch, the heading indicator is primary for bank, and the manifold pressure gauge is momentarily primary for power (at 15" Hg in this example). Control pressures should be trimmed off as the airplane decelerates. As the airspeed approaches the desired airspeed of 100 knots, the manifold pressure is adjusted to approximately 18" Hg and becomes the supporting power instrument. The ASI again becomes primary for power. *[Figure 5-24]*

Airspeed Changes in Straight-and-Level Flight

Practice of airspeed changes in straight-and-level flight provides an excellent means of developing increased proficiency in all three basic instrument skills, and brings out some common errors to be expected during training in straight-and-level flight. Having learned to control the airplane in a clean configuration (minimum drag conditions), increase proficiency in cross-check and control by practicing speed changes while extending or retracting the flaps and landing gear. While practicing, be sure to comply with the airspeed limitations specified in the POH/AFM for gear and flap operation.

Sudden and exaggerated attitude changes may be necessary in order to maintain straight-and-level flight as the landing gear is extended and the flaps are lowered in some airplanes. The nose tends to pitch down with gear extension, and when flaps are lowered, lift increases momentarily (at partial flap settings) followed by a marked increase in drag as the flaps near maximum extension.

Control technique varies according to the lift and drag characteristics of each airplane. Accordingly, knowledge of the power settings and trim changes associated with different combinations of airspeed, gear and flap configurations will reduce instrument cross-check and interpretation problems.

For example, assume that in straight-and-level flight instruments indicate 120 knots with power at 23" Hg/2,300 revolutions per minute (rpm), gear and flaps up. After reduction in airspeed, with gear and flaps fully extended, straight-and-level flight at the same altitude requires 25" Hg manifold pressure/2,500 rpm. Maximum gear extension speed is 115 knots; maximum flap extension speed is 105

Figure 5-24. *Straight-and-Level Flight (Reduced Airspeed Stabilized).*

knots. Airspeed reduction to 95 knots, gear and flaps down, can be made in the following manner:

1. Maintain rpm at 2,500, since a high power setting will be used in full drag configuration.
2. Reduce manifold pressure to 10" Hg. As the airspeed decreases, increase cross-check speed.
3. Make trim adjustments for an increased angle of attack and decrease in torque.
4. Lower the gear at 115 knots. The nose may tend to pitch down and the rate of deceleration increases. Increase pitch attitude to maintain constant altitude, and trim off some of the back-elevator pressures. If full flaps are lowered at 105 knots, cross-check, interpretation, and control must be very rapid. A simpler technique is to stabilize attitude with gear down before lowering the flaps.
5. Since 18" Hg manifold pressure will hold level flight at 100 knots with the gear down, increase power smoothly to that setting until the ASI shows approximately 105 knots, and retrim. The attitude indicator now shows approximately two-and-a-half bar width nose-high in straight-and-level flight.
6. Actuate the flap control and simultaneously increase power to the predetermined setting (25" Hg) for the desired airspeed, and trim off the pressures necessary to hold constant altitude and heading. The attitude indicator now shows a bar width nose-low in straight-and-level flight at 95 knots.

Proficiency in straight-and-level flight is attained when a pilot can consistently maintain constant altitude and heading with smooth pitch, bank, power, and trim control during the pronounced changes in aircraft attitude.

Trim Technique

Proper trim technique is essential for smooth and precise aircraft control during all phases of flight. By relieving all control pressures, it is much easier to hold a given attitude constant, and devote more attention to other flight deck duties.

An aircraft is trimmed by applying control pressures to establish a desired attitude, then adjusting the trim so the aircraft will maintain that attitude when the flight controls are released. Trim the aircraft for coordinated flight by centering the ball of the turn-and-slip indicator, by using rudder trim in the direction the ball is displaced from the center. Differential power control on multiengine aircraft is an additional factor affecting coordinated flight. Use balanced power or thrust, when possible, to aid in maintaining coordinated flight.

Changes in attitude, power, or configuration will require a trim adjustment in most cases. Using trim alone to establish a change in aircraft attitude invariably leads to erratic aircraft control. Smooth and precise attitude changes are best attained by a combination of control pressures and trim adjustments. Therefore, when used correctly, trim adjustment is an aid to smooth aircraft control.

Common Errors in Straight-and-Level Flight

Pitch

Pitch errors usually result from the following faults:

1. Improper adjustment of the attitude indicator's miniature aircraft to the wings level attitude. Following the initial level off from a climb, check the attitude indicator and make any necessary adjustment in the miniature aircraft for level flight indication at normal cruise airspeed.
2. Insufficient cross-check and interpretation of pitch instruments. For example, the airspeed indication is low. The pilot, believing a nose-high attitude exists, applies forward pressure without noting that a low power setting is the cause of the airspeed discrepancy. Increase cross-check speed to include all relevant instrument indications before making a control input.
3. Uncaging the attitude indicator (if caging feature is present) when the airplane is not in level flight. The altimeter and heading indicator must be stabilized with airspeed indication at normal cruise before pulling out the caging knob, to obtain correct indications in straight-and-level flight at normal cruise airspeed.
4. Failure to interpret the attitude indicator in terms of the existing airspeed.
5. Late pitch corrections. Pilots commonly like to leave well enough alone. When the altimeter indicates a 20 foot error, there is a reluctance to correct it, perhaps because of fear of overcontrolling. If overcontrolling is the anticipated error, practice small corrections and find the cause of overcontrolling. If any deviation is tolerated, errors will increase.
6. Chasing the vertical speed indications. This tendency can be corrected by proper cross-check of other pitch instruments, as well as by increasing overall understanding of instrument characteristics.
7. Using excessive pitch corrections for the altimeter evaluation. Rushing a pitch correction by making a large pitch change usually aggravates the existing error, saving neither time nor effort.

8. Failure to maintain established pitch corrections, a common error associated with cross-check and trim errors. For example, having established a pitch change to correct an altitude error, there is a tendency to slow down the cross-check, waiting for the airplane to stabilize in the new pitch attitude. To maintain the attitude, continue to cross-check and trim off the pressures.
9. Fixations during cross-check. After initiating a heading correction, for example, there is a tendency to become preoccupied with bank control and miss errors in pitch attitude. Likewise, during an airspeed change, unnecessary gazing at the power instrument is common. A small error in power setting is of less consequence than large altitude and heading errors. The airplane will not decelerate any faster by staring at the manifold pressure gauge.

Heading

Heading errors usually result from the following faults:

1. Failure to cross-check the heading indicator, especially during changes in power or pitch attitude.
2. Misinterpretation of changes in heading, with resulting corrections in the wrong direction.
3. Failure to note and remember a preselected heading.
4. Failure to observe the rate of heading change and its relation to bank attitude.
5. Overcontrolling in response to heading changes, especially during changes in power settings.
6. Anticipating heading changes with premature application of rudder control.
7. Failure to correct small heading deviations. Unless zero error in heading is the goal, a pilot will tolerate larger and larger deviations. Correction of a 1° error takes a lot less time and concentration than correction of a 20° error.
8. Correcting with improper bank attitude. If correcting a 10° heading error with 20° of bank, the airplane will roll past the desired heading before the bank is established, requiring another correction in the opposite direction. Do not multiply existing errors with errors in corrective technique.
9. Failure to note the cause of a previous heading error and thus repeating the same error. For example, the airplane is out of trim, with a left wing low tendency. Repeated corrections for a slight left turn are made, yet trim is ignored.
10. Failure to set the heading indicator properly or failure to uncage it.

Power

Power errors usually result from the following faults:

1. Failure to know the power settings and pitch attitudes appropriate to various airspeeds and airplane configurations.
2. Abrupt use of throttle.
3. Failure to lead the airspeed when making power changes. For example, during airspeed reduction in level flight, especially with gear and flaps extended, adjust the throttle to maintain the slower speed before the airspeed actually reaches the desired speed. Otherwise, the airplane will decelerate to a speed lower than that desired, resulting in additional power adjustments. The amount of lead depends upon how fast the airplane responds to power changes.
4. Fixation on airspeed or manifold pressure instruments during airspeed changes, resulting in erratic control of both airspeed and power.

Trim

Trim errors usually result from the following faults:

1. Improper adjustment of seat or rudder pedals for comfortable position of legs and feet. Tension in the ankles makes it difficult to relax rudder pressures.
2. Confusion about the operation of trim devices, which differ among various airplane types. Some trim wheels are aligned appropriately with the airplane's axes; others are not. Some rotate in a direction contrary to what is expected.
3. Faulty sequence in trim technique. Trim should be used not as a substitute for control with the wheel (stick) and rudders, but to relieve pressures already held to stabilize attitude. As proficiency is gained, little conscious effort will be required to trim off the pressures as they occur.
4. Excessive trim control. This induces control pressures that must be held until the airplane is trimmed properly. Use trim frequently and in small amounts.
5. Failure to understand the cause of trim changes. Lack of understanding the basic aerodynamics related to basic instrument skills will cause a pilot to continually lag behind the airplane.

Straight Climbs and Descents

Climbs

For a given power setting and load condition, there is only one attitude that will give the most efficient rate of climb. The airspeed and climb power setting that will determine this climb attitude are given in the performance data found in the POH/AFM. Details of the technique for entering a climb vary according to airspeed on entry and the type of climb (constant airspeed or constant rate) desired. (Heading and trim control are maintained as discussed in Straight-and-Level Flight.)

Entry

To enter a constant-airspeed climb from cruising airspeed, raise the miniature aircraft to the approximate nose-high indication for the predetermined climb speed. The attitude will vary according to the type of airplane. Apply light back-elevator pressure to initiate and maintain the climb attitude. The pressures will vary as the airplane decelerates. Power may be advanced to the climb power setting simultaneously with the pitch change, or after the pitch change is established and the airspeed approaches climb speed. If the transition from level flight to climb is smooth, the VSI will show an immediate trend upward, continue to move slowly, and then stop at a rate appropriate to the stabilized airspeed and attitude. (Primary and supporting instruments for the climb entry are shown in *Figure 5-25*.)

Once the airplane stabilizes at a constant airspeed and attitude, the ASI is primary for pitch and the heading indicator remains primary for bank. *[Figure 5-26]* Monitor the tachometer or manifold pressure gauge as the primary power instrument to ensure the proper climb power setting is being maintained. If the climb attitude is correct for the power setting selected, the airspeed will stabilize at the desired speed. If the airspeed is low or high, make an appropriately small pitch correction.

To enter a constant airspeed climb, first complete the airspeed reduction from cruise airspeed to climb speed in straight-and-level flight. The climb entry is then identical to entry from cruising airspeed, except that power must be increased simultaneously to the climb setting as the pitch attitude is increased. Climb entries on partial panel are more easily and accurately controlled if entering the maneuver from climbing speed.

The technique for entering a constant rate climb is very similar to that used for entry to a constant-airspeed climb from climb airspeed. As the power is increased to the approximate setting for the desired rate, simultaneously raise the miniature aircraft to the climbing attitude for the desired airspeed and rate of climb. As the power is increased, the ASI is primary for pitch control until the vertical speed approaches the desired value. As the vertical speed needle stabilizes, it becomes primary for pitch control and the ASI becomes primary for power control. *[Figure 5-27]*

Figure 5-25. *Climb Entry for Constant Airspeed Climb.*

Figure 5-26. *Stabilized Climb at Constant Airspeed.*

Figure 5-27. *Stabilized Climb at Constant Rate.*

Pitch and power corrections must be promptly and closely coordinated. For example, if the vertical speed is correct, but the airspeed is low, add power. As the power is increased, the miniature aircraft must be lowered slightly to maintain constant vertical speed. If the vertical speed is high and the airspeed is low, lower the miniature aircraft slightly and note the increase in airspeed to determine whether or not a power change is also necessary. *[Figure 5-28]* Familiarity with the approximate power settings helps to keep pitch and power corrections at a minimum.

Leveling Off

To level off from a climb and maintain an altitude, it is necessary to start the level off before reaching the desired altitude. The amount of lead varies with rate of climb and pilot technique. If the airplane is climbing at 1,000 fpm, it will continue to climb at a decreasing rate throughout the transition to level flight. An effective practice is to lead the altitude by 10 percent of the vertical speed shown (500 fpm/ 50-foot lead, 1,000 fpm/100-foot lead).

To level off at cruising airspeed, apply smooth, steady forward-elevator pressure toward level flight attitude for the speed desired. As the attitude indicator shows the pitch change, the vertical speed needle will move slowly toward zero, the altimeter needle will move more slowly, and the airspeed will show acceleration. *[Figure 5-29]* When the altimeter, attitude indicator, and VSI show level flight, constant changes in pitch and torque control will have to be made as the airspeed increases. As the airspeed approaches cruising speed, reduce power to the cruise setting. The amount of lead depends upon the rate of acceleration of the airplane.

To level off at climbing airspeed, lower the nose to the pitch attitude appropriate to that airspeed in level flight. Power is simultaneously reduced to the setting for that airspeed as the pitch attitude is lowered. If power reduction is at a rate proportionate to the pitch change, airspeed will remain constant.

Descents

A descent can be made at a variety of airspeeds and attitudes by reducing power, adding drag, and lowering the nose to a predetermined attitude. The airspeed will eventually stabilize at a constant value. Meanwhile, the only flight instrument providing a positive attitude reference, is the attitude indicator. Without the attitude indicator (such as during a partial panel descent), the ASI, the altimeter, and the VSI will show varying rates of change until the airplane decelerates to a constant airspeed at a constant attitude. During the transition, changes in control pressure and trim, as well as cross-check and interpretation, must be accurate to maintain positive control.

Figure 5-28. *Airspeed Low and Vertical Speed High—Reduce Pitch.*

Figure 5-29. *Level Off at Cruising Speed.*

Entry

The following method for entering descents is effective with or without an attitude indicator. First, reduce airspeed to a selected descent airspeed while maintaining straight-and-level flight, then make a further reduction in power (to a predetermined setting). As the power is adjusted, simultaneously lower the nose to maintain constant airspeed, and trim off control pressures.

During a constant airspeed descent, any deviation from the desired airspeed calls for a pitch adjustment. For a constant rate descent, the entry is the same, but the VSI is primary for pitch control (after it stabilizes near the desired rate), and the ASI is primary for power control. Pitch and power must be closely coordinated when corrections are made, as they are in climbs. *[Figure 5-30]*

Leveling Off

The level off from a descent must be started before reaching the desired altitude. The amount of lead depends upon the rate of descent and control technique. With too little lead, the airplane will tend to overshoot the selected altitude unless technique is rapid. Assuming a 500 fpm rate of descent, lead the altitude by 100–150 feet for a level off at an airspeed higher than descending speed. At the lead point, add power to the appropriate level flight cruise setting. *[Figure 5-31]* Since the nose will tend to rise as the airspeed increases, hold forward elevator pressure to maintain the vertical speed at the descending rate until approximately 50 feet above the altitude, and then smoothly adjust the pitch attitude to the level flight attitude for the airspeed selected.

To level off from a descent at descent airspeed, lead the desired altitude by approximately 50 feet, simultaneously adjusting the pitch attitude to level flight and adding power to a setting that will hold the airspeed constant. *[Figure 5-32]* Trim off the control pressures and continue with the normal straight-and-level flight cross-check.

Common Errors in Straight Climbs and Descents

Common errors result from the following faults:

1. Overcontrolling pitch on climb entry. Until the pitch attitudes related to specific power settings used in climbs and descents are known, larger than necessary pitch adjustments are made. One of the most difficult habits to acquire during instrument training is to restrain the impulse to disturb a flight attitude until the result is known. Overcome the inclination to make a large control movement for a pitch change, and learn to apply small control pressures smoothly, cross-checking rapidly for the results of the change, and continuing with the pressures as instruments show the desired results. Small pitch changes can be easily controlled, stopped, and corrected; large changes are more difficult to control.

Figure 5-30. *Constant Airspeed Descent, Airspeed High—Reduce Power.*

Figure 5-31. *Level Off Airspeed Higher Than Descent Airspeed.*

Figure 5-32. *Level Off at Descent Airspeed.*

2. Failure to vary the rate of cross-check during speed, power, or attitude changes or climb or descent entries.
3. Failure to maintain a new pitch attitude. For example, raising the nose to the correct climb attitude, and as the airspeed decreases, either overcontrol and further increase the pitch attitude, or allow the nose to lower. As control pressures change with airspeed changes, cross-check must be increased and pressures readjusted.
4. Failure to trim off pressures. Unless the airplane is trimmed, there will be difficulty in determining whether control pressure changes are induced by aerodynamic changes or by the pilot's own movements.
5. Failure to learn and use proper power settings.
6. Failure to cross-check both airspeed and vertical speed before making pitch or power adjustments.
7. Improper pitch and power coordination on slow-speed level offs, due to slow cross-check of airspeed and altimeter indications.
8. Failure to cross-check the VSI against the other pitch control instruments, resulting in chasing the vertical speed.
9. Failure to note the rate of climb or descent to determine the lead for level offs, resulting in overshooting or undershooting the desired altitude.
10. Ballooning (allowing the nose to pitch up) on level offs from descents, resulting from failure to maintain descending attitude with forward-elevator pressure as power is increased to the level flight cruise setting.
11. Failure to recognize the approaching straight-and-level flight indications as level off is completed. Maintain an accelerated cross-check until positively established in straight-and-level flight.

Turns

Standard Rate Turns

A standard rate turn is one in which the pilot will do a complete 360° circle in two minutes, or 3° per second. A standard rate turn, although always 3° per second, will require higher angles of bank as airspeed increases. To enter a standard rate level turn, apply coordinated aileron and rudder pressures in the desired direction of turn. Pilots commonly roll into turns at a much too rapid rate. During initial training in turns, base control pressures on the rate of cross-check and interpretation. Maneuvering an airplane faster than the capability to keep up with the changes in instrument indications only creates the need to make corrections.

A rule of thumb to determine the approximate angle of bank required for a standard rate turn is to use 15 percent of the true airspeed. A simple way to determine this amount is to divide the airspeed by 10 and add one-half the result. For example, at 100 knots, approximately 15° of bank is required (100 ÷ 10 = 10 + 5 = 15); at 120 knots, approximately 18° of bank is needed for a standard rate turn.

On the roll-in, use the attitude indicator to establish the approximate angle of bank, and then check the turn coordinator's miniature aircraft for a standard rate turn indication or the aircraft's turn-and-bank indicator. Maintain the bank for this rate of turn, using the turn coordinator's miniature aircraft as the primary bank reference and the attitude indicator as the supporting bank instrument. *[Figure 5-33]* Note the exact angle of bank shown on the banking scale of the attitude indicator when the turn coordinator indicates a standard rate turn.

During the roll-in, check the altimeter, VSI, and attitude indicator for the necessary pitch adjustments as the vertical lift component decreases with an increase in bank. If constant airspeed is to be maintained, the ASI becomes primary for power, and the throttle must be adjusted as drag increases. As the bank is established, trim off the pressures applied during pitch and power changes.

To recover to straight-and-level flight, apply coordinated aileron and rudder pressures opposite to the direction of the turn. Strive for the same rate of roll-out used to roll into the turn; fewer problems will be encountered in estimating the lead necessary for roll-out on exact headings, especially on partial panel maneuvers. Upon initiation of the turn recovery, the attitude indicator becomes the primary bank instrument. When the airplane is approximately level, the heading indicator is the primary bank instrument as in straight-and-level flight. Pitch, power, and trim adjustments are made as changes in vertical lift component and airspeed occur. The ball should be checked throughout the turn, especially if control pressures are held rather than trimmed off.

Some airplanes are very stable during turns, requiring only slight trim adjustments that permit hands-off flight while the airplane remains in the established attitude. Other airplanes require constant, rapid cross-check and control during turns to correct overbanking tendencies. Due to the interrelationship of pitch, bank, and airspeed deviations during turns, cross-check must be fast in order to prevent an accumulation of errors.

Turns to Predetermined Headings

As long as an airplane is in a coordinated bank, it continues to turn. Thus, the roll-out to a desired heading must be started before the heading is reached. The amount of lead varies with the relationship between the rate of turn, angle of bank, and rate of recovery. For small heading changes, use a bank angle that does not exceed the number of degrees to be turned. Lead the desired heading by one-half the number of degrees of bank used. For example, if a 10° bank is used during a change in heading, start the roll-out 5° before reaching the desired heading. For larger changes in heading, the amount

Figure 5-33. *Standard Rate Turn, Constant Airspeed.*

of lead varies since the angle of bank for a standard rate turn varies with the true airspeed.

Practice with a lead of one-half the angle of bank until the precise lead a given technique requires is determined. If rates of roll-in and roll-out are consistent, the precise amount of lead suitable to a particular roll-out technique can be determined.

Timed Turns

A timed turn is a turn in which the clock and the turn coordinator are used to change heading by a specific number of degrees in a given time. For example, in a standard rate turn (3° per second), an airplane turns 45° in 15 seconds; in a half standard rate turn, the airplane turns 45° in 30 seconds.

Prior to performing timed turns, the turn coordinator should be calibrated to determine the accuracy of its indications. *[Figure 5-34]* Establish a standard rate turn as indicated by the turn coordinator, and as the sweep-second hand of the clock passes a cardinal point (12, 3, 6, 9), check the heading on the heading indicator. While holding the indicated rate of turn constant, note the indicated heading changes at 10 second intervals. If the airplane turns more than or less than 30° in that interval, a respectively larger or smaller deflection of the miniature aircraft of the turn coordinator is necessary to produce a standard rate turn. After calibrating the turn coordinator during turns in each direction, note the corrected deflections, if any, and apply them during all timed turns.

The same cross-check and control technique is used in making a timed turn that is used to execute turns to predetermined headings, except the clock is substituted for the heading indicator. The miniature aircraft of the turn coordinator is primary for bank control, the altimeter is primary for pitch control, and the ASI is primary for power control. Start the roll-in when the clock's second hand passes a cardinal point, hold the turn at the calibrated standard rate indication (or half-standard rate for small heading changes), and begin the roll-out when the computed number of seconds has elapsed. If the rates of roll-in and roll-out are the same, the time taken during entry and recovery does not need to be considered in the time computation.

Practice timed turns with a full instrument panel and check the heading indicator for the accuracy of turns. If the turns are executed without the gyro heading indicator, use the magnetic compass at the completion of the turn to check turn accuracy, taking compass deviation errors into consideration.

Compass Turns

In most small airplanes, the magnetic compass is the only direction-indicating instrument independent of other airplane instruments and power sources. Because of its operating characteristics, called compass errors, pilots are prone to use it only as a reference for setting the heading indicator, but knowledge of magnetic compass characteristics permits full use of the instrument to turn the airplane to correct and maintain headings.

Figure 5-34. *Turn Coordinator Calibration.*

Remember the following points when making turns to magnetic compass headings or when using the magnetic compass as a reference for setting the heading indicator:

1. If on a north heading and a turn is started to the east or west, the compass indication lags, or indicates a turn in the opposite direction.
2. If on a south heading and a turn is started toward the east or west, the compass indication precedes the turn, indicating a greater amount of turn than is actually occurring.
3. When on an east or west heading, the compass indicates correctly when starting a turn in either direction.
4. If on an east or west heading, acceleration results in a north turn indication; deceleration results in a south turn indication.
5. When maintaining a north or south heading, no error results from diving, climbing, or changing airspeed.

With an angle of bank between 15° and 18°, the amount of lead or lag to be used when turning to northerly or southerly headings varies with, and is approximately equal to, the latitude of the locality over which the turn is being made. When turning to a heading of north, the lead for roll-out must include the number of degrees of change of latitude, plus the lead normally used in recovery from turns. During a turn to a south heading, maintain the turn until the compass passes south the number of degrees of latitude, minus normal roll-out lead. *[Figure 5-35]*

For example, when turning from an easterly direction to north, where the latitude is 30°, start the roll-out when the compass reads 37° (30° plus one-half the 15° angle of bank, or whatever amount is appropriate for the rate of roll-out). When turning from an easterly direction to south, start the roll-out when the magnetic compass reads 203° (180° plus 30° minus one-half the angle of bank). When making similar turns from a westerly direction, the appropriate points at which to begin the roll-out would be 323° for a turn to north, and 157° for a turn to south.

When turning to a heading of east or west from a northerly direction, start the roll-out approximately 10° to 12° before the east or west indication is reached. When turning to an east or west heading from a southerly direction, start the rollout approximately 5° before the east or west indication is reached. When turning to other headings, the lead or lag must be interpolated.

Abrupt changes in attitude or airspeed and the resulting erratic movements of the compass card make accurate interpretations of the instrument very difficult. Proficiency in compass turns depends on knowledge of compass characteristics, smooth control technique, and accurate bank-and-pitch control.

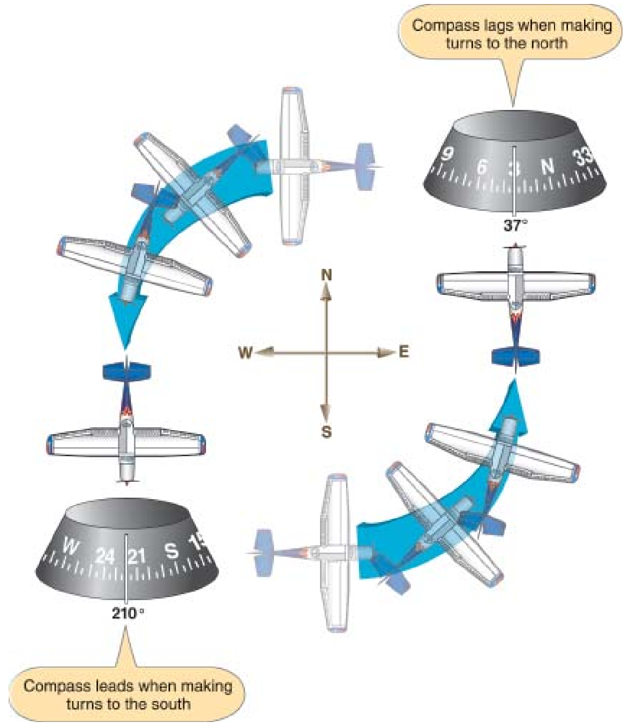


Figure 5-35. *North and South Turn Error.*

Steep Turns

For purposes of instrument flight training in conventional airplanes, any turn greater than a standard rate is considered steep. *[Figure 5-36]* The exact angle of bank at which a normal turn becomes steep is unimportant. What is important is learning to control the airplane with bank attitudes in excess of those normally used on instruments. Practicing steep turns will not only increase proficiency in the basic instrument flying skills, but also enable smooth, quick, and confident reactions to unexpected abnormal flight attitudes under instrument flight conditions.

Pronounced changes occur in the effects of aerodynamic forces on aircraft control at progressively greater bank attitudes. Skill in cross-check, interpretation, and control is increasingly necessary in proportion to the amount of these changes, though the techniques for entering, maintaining, and recovering from the turn are the same in principle for steep turns as for shallower turns.

Enter a steep turn in the same way as a shallower turn, but prepare to cross-check rapidly as the turn steepens. Because of the greatly reduced vertical lift component, pitch control is usually the most difficult aspect of this maneuver. Unless immediately noted and corrected with a pitch increase, the loss of vertical lift results in rapid movement of the altimeter, vertical speed, and airspeed needles. The faster the rate of bank change, the more suddenly the lift changes occur. If a cross-check is fast enough to note the immediate need for pitch changes, smooth, steady back elevator pressure will maintain constant altitude. However, overbanking to excessively steep angles without adjusting pitch as the bank changes occur, requires increasingly stronger elevator pressure. The loss of vertical lift and increase in wing loading finally reach a point at which further application of back-elevator pressure tightens the turn without raising the nose.

Figure 5-36. *Steep Left Turn.*

How does a pilot recognize overbanking and low pitch attitude? What should a pilot do to correct them? If a rapid downward movement of the altimeter needle or vertical speed needle, together with an increase in airspeed, is observed despite application of back elevator pressure, the airplane is in a diving spiral. *[Figure 5-37]* Immediately shallow the bank with smooth and coordinated aileron and rudder pressures, hold or slightly relax elevator pressure, and increase the cross-check of the attitude indicator, altimeter, and VSI. Reduce power if the airspeed increase is rapid. When the vertical speed trends upward, the altimeter needle will move slower as the vertical lift increases. When the elevator is effective in raising the nose, hold the bank attitude shown on the attitude indicator and adjust elevator control pressures smoothly for the nose-high attitude appropriate to the bank maintained. If pitch control is consistently late on entries to steep turns, rollout immediately to straight-and-level flight and analyze possible errors. Practice shallower turns initially and learn the attitude changes and control responses required, then increase the banks as a quicker and more accurate cross-check and control techniques are developed.

The power necessary to maintain constant airspeed increases as the bank and drag increase. With practice, the power

Figure 5-37. *Diving Spiral.*

settings appropriate to specific bank attitudes are learned, and adjustments can be made without undue attention to airspeed and power instruments. During training in steep turns, as in any other maneuver, attend to the most important tasks first. Keep the pitch attitude relatively constant, and more time can be devoted to cross-check and instrument interpretation.

During recovery from steep turns to straight-and-level flight, elevator and power control must be coordinated with bank control in proportion to the changes in aerodynamic forces. Back elevator pressures must be released and power decreased. The common errors associated with steep turns are the same as those discussed later in this section. Remember, errors are more exaggerated, more difficult to correct, and more difficult to analyze unless rates of entry and recovery are consistent with the level of proficiency in the three basic instrument flying skills.

Climbing and Descending Turns

To execute climbing and descending turns, combine the technique used in straight climbs and descents with the various turn techniques. The aerodynamic factors affecting lift and power control must be considered in determining power settings, and the rate of cross-check and interpretation must be increased to enable control of bank as well as pitch changes.

Change of Airspeed During Turns

Changing airspeed during turns is an effective maneuver for increasing proficiency in all three basic instrument skills. Since the maneuver involves simultaneous changes in all components of control, proper execution requires rapid cross-check and interpretation as well as smooth control. Proficiency in the maneuver will also contribute to confidence in the instruments during attitude and power changes involved in more complex maneuvers. Pitch and power control techniques are the same as those used during changes in airspeed in straight-and-level flight.

The angle of bank necessary for a given rate of turn is proportional to the true airspeed. Since the turns are executed at a standard rate, the angle of bank must be varied in direct proportion to the airspeed change in order to maintain a constant rate of turn. During a reduction of airspeed, decrease the angle of bank and increase the pitch attitude to maintain altitude and a standard rate turn.

The altimeter and turn coordinator indications should remain constant throughout the turn. The altimeter is primary for pitch control and the miniature aircraft of the turn coordinator is primary for bank control. The manifold pressure gauge (or tachometer) is primary for power control while the airspeed is changing. As the airspeed approaches the new indication, the ASI becomes primary for power control.

Two methods of changing airspeed in turns may be used. In the first method, airspeed is changed after the turn is established. *[Figure 5-38]* In the second method, the airspeed change is initiated simultaneously with the turn entry. The first method is easier, but regardless of the method used, the rate of cross-check must be increased as power is reduced. As the airplane decelerates, check the altimeter and VSI for necessary pitch changes and the bank instruments for required bank changes. If the miniature aircraft of the turn coordinator indicates a deviation from the desired deflection, adjust the bank. Adjust

Figure 5-38. *Change of Airspeed During Turn.*

pitch attitude to maintain altitude. When approaching the desired airspeed, pitch attitude becomes primary for power control and the manifold pressure gauge (or tachometer) is adjusted to maintain the desired airspeed. Trim is important throughout the maneuver to relieve control pressures.

Until control technique is very smooth, frequent cross-check of the attitude indicator is essential to prevent overcontrolling and to provide approximate bank angles appropriate to the changing airspeeds.

Common Errors in Turns

Pitch

Pitch errors result from the following faults:

1. Preoccupation with bank control during turn entry and recovery. If 5 seconds are required to roll into a turn, check the pitch instruments as bank pressures are initiated. If bank control pressure and rate of bank change are consistent, a sense of the time required for an attitude change will be developed. During the interval, check pitch, power, and trim—as well as bank—controlling the total attitude instead of one factor at a time.
2. Failure to understand or remember the need for changing the pitch attitude as the vertical lift component changes, resulting in consistent loss of altitude during entries.
3. Changing the pitch attitude before it is necessary. This fault is very likely if a cross-check is slow and rate of entry too rapid. The error occurs during the turn entry due to a mechanical and premature application of back-elevator control pressure.
4. Overcontrolling the pitch changes. This fault commonly occurs with the previous error.
5. Failure to properly adjust the pitch attitude as the vertical lift component increases during the roll-out, resulting in consistent gain in altitude on recovery to headings.
6. Failure to trim during turn entry and following turn recovery (if turn is prolonged).
7. Failure to maintain straight-and-level cross-check after roll-out. This error commonly follows a perfectly executed turn.
8. Erratic rates of bank change on entry and recovery, resulting from failure to cross-check the pitch instruments with a consistent technique appropriate to the changes in lift.

Bank

Bank and heading errors result from the following faults:

1. Overcontrolling, resulting in overbanking upon turn entry, overshooting and undershooting headings, as well as aggravated pitch, airspeed, and trim errors.
2. Fixation on a single bank instrument. On a 90° change of heading, for example, leave the heading indicator out of the cross-check for approximately 20 seconds after establishing a standard rate turn, since at 3° per second the turn will not approach the lead point until that time has elapsed. Make the cross-check selective, checking only what needs to be checked at the appropriate time.
3. Failure to check for precession of the horizon bar following recovery from a turn. If the heading indicator shows a change in heading when the attitude indicator shows level flight, the airplane is turning. If the ball is centered, the attitude gyro has processed; if the ball is not centered, the airplane may be in a slipping or skidding turn. Center the ball with rudder pressure, check the attitude indicator and heading indicator, stop the heading change if it continues, and retrim.
4. Failure to use the proper degree of bank for the amount of heading change desired. Rolling into a 20° bank for a heading change of 10° will normally overshoot the heading. Use the bank attitude appropriate to the amount of heading change desired.
5. Failure to remember the heading to which the aircraft is being turned. This fault is likely when rushing the maneuver.
6. Turning in the wrong direction, due to misreading or misinterpreting the heading indicator, or to confusion regarding the location of points on the compass. Turn in the shortest direction to reach a given heading, unless there is a specific reason to turn the long way around. Study the compass rose and visualize at least the positions of the eight major points around the azimuth. A number of methods can be used to make quick computations for heading changes. For example, to turn from a heading of 305° to a heading of 110°, would a pilot turn right or left for the shortest way around? Subtracting 200 from 305 and adding 20, gives 125° as the reciprocal of 305°; therefore, execute the turn to the right. Likewise, to figure the reciprocal of a heading less than 180°, add 200 and subtract 20. Computations are done more quickly using multiples of 100s and 10s than by adding or subtracting 180° from the actual heading; therefore, the method suggested above may save time and confusion.

7. Failure to check the ball of the turn coordinator when interpreting the instrument for bank information. If the roll rate is reduced to zero, the miniature aircraft of the turn coordinator indicates only direction and rate of turn. Unless the ball is centered, do not assume the turn is resulting from a banked attitude.

Power

Power and airspeed errors result from the following faults:

1. Failure to cross-check the ASI as pitch changes are made.
2. Erratic use of power control. This may be due to improper throttle friction control, inaccurate throttle settings, chasing the airspeed readings, abrupt or overcontrolled pitch-and-bank changes, or failure to recheck the airspeed to note the effect of a power adjustment.
3. Poor coordination of throttle control with pitch-and-bank changes, associated with slow cross-check or failure to understand the aerodynamic factors related to turns.

Trim

Trim errors result from the following faults:

1. Failure to recognize the need for a trim change due to slow cross-check and interpretation. For example, a turn entry at a rate too rapid for a cross-check leads to confusion in cross-check and interpretation, with resulting tension on the controls.
2. Failure to understand the relationship between trim and attitude/power changes.
3. Chasing the vertical speed needle. Overcontrolling leads to tension and prevents sensing the pressures to be trimmed off.
4. Failure to trim following power changes.

Errors During Compass Turns

In addition to the faults discussed above, the following errors connected with compass turns should be noted:

1. Faulty understanding or computation of lead and lag.
2. Fixation on the compass during the roll-out. Until the airplane is in straight-and-level unaccelerated flight, it is unnecessary to read the indicated heading. Accordingly, after the roll-out, cross-check for straight-and-level flight before checking the accuracy of the turn.

Approach to Stall

Practicing approach to stall recoveries in various airplane configurations should build confidence in a pilot's ability to control the airplane in unexpected situations. Approach to stall should be practiced from straight flight and from shallow banks. The objective is to practice recognition and recovery from the approach to a stall.

Prior to stall recovery practice, select a safe altitude above the terrain, an area free of conflicting air traffic, appropriate weather, and the availability of radar traffic advisory service.

Approaches to stalls are accomplished in the following configurations:

1. Takeoff configuration—should begin from level flight near liftoff speed. Power should be applied while simultaneously increasing the angle of attack to induce an indication of a stall.
2. Clean configuration—should begin from a reduced airspeed, such as pattern airspeed, in level flight. Power should be applied while simultaneously increasing the angle of attack to induce an indication of a stall.
3. Approach or landing configuration—should be initiated at the appropriate approach or landing airspeed. The angle of attack should be smoothly increased to induce an indication of a stall.

Recoveries should be prompt in response to a stall warning device or an aerodynamic indication by smoothly reducing the angle of attack and applying maximum power, or as recommended by the POH/AFM. The recovery should be completed without an excessive loss of altitude, and on a predetermined heading, altitude, and airspeed.

Unusual Attitudes and Recoveries

An unusual attitude is an airplane attitude not normally required for instrument flight. Unusual attitudes may result from a number of conditions, such as turbulence, disorientation, instrument failure, confusion, preoccupation with flight deck duties, carelessness in cross-checking, errors in instrument interpretation, or lack of proficiency in aircraft control. Since unusual attitudes are not intentional maneuvers during instrument flight, except in training, they are often unexpected, and the reaction of an inexperienced or inadequately trained pilot to an unexpected abnormal flight attitude is usually instinctive rather than intelligent and deliberate. This individual reacts with abrupt muscular effort, which is purposeless and even hazardous in turbulent conditions, at excessive speeds, or at low altitudes. However, with practice, the techniques for rapid and safe recovery from unusual attitudes can be mastered.

When an unusual attitude is noted during the cross-check, the immediate problem is not how the airplane got there, but what it is doing and how to get it back to straight-and-level flight as quickly as possible.

Recognizing Unusual Attitudes

As a general rule, any time an instrument rate of movement or indication other than those associated with the basic instrument flight maneuvers is noted, assume an unusual attitude and increase the speed of cross-check to confirm the attitude, instrument error, or instrument malfunction.

Nose-high attitudes are shown by the rate and direction of movement of the altimeter needle, vertical speed needle, and airspeed needle, as well as the immediately recognizable indication of the attitude indicator (except in extreme attitudes). *[Figure 5-39]* Nose-low attitudes are shown by the same instruments, but in the opposite direction. *[Figure 5-40]*

Recovery from Unusual Attitudes

In moderate unusual attitudes, the pilot can normally reorient by establishing a level flight indication on the attitude indicator. However, the pilot should not depend on this instrument if the attitude indicator is the spillable type, because its upset limits may have been exceeded or it may have become inoperative due to mechanical malfunction. If it is the nonspillable-type instrument and is operating properly, errors up to 5° of pitch-and-bank may result and its indications are very difficult to interpret in extreme attitudes. As soon as the unusual attitude is detected, the recommended recovery procedures stated in the POH/AFM should be initiated. If there are no recommended procedures stated in the POH/AFM, the recovery should be initiated by reference to the ASI, altimeter, VSI, and turn coordinator.

Nose-High Attitudes

If the airspeed is decreasing, or below the desired airspeed, increase power (as necessary in proportion to the observed deceleration), apply forward elevator pressure to lower the nose and prevent a stall, and correct the bank by applying coordinated aileron and rudder pressure to level the miniature aircraft and center the ball of the turn coordinator. The corrective control applications are made almost simultaneously, but in the sequence given above. A level pitch attitude is indicated by the reversal and stabilization

Figure 5-39. *Unusual Attitude—Nose-High.*

Figure 5-40. *Unusual Attitude—Nose-Low.*

of the ASI and altimeter needles. Straight coordinated flight is indicated by the level miniature aircraft and centered ball of the turn coordinator.

Nose-Low Attitudes

If the airspeed is increasing, or is above the desired airspeed, reduce power to prevent excessive airspeed and loss of altitude. Correct the bank attitude with coordinated aileron and rudder pressure to straight flight by referring to the turn coordinator. Raise the nose to level flight attitude by applying smooth back elevator pressure. All components of control should be changed simultaneously for a smooth, proficient recovery. However, during initial training a positive, confident recovery should be made by the numbers, in the sequence given above. A very important point to remember is that the instinctive reaction to a nose-down attitude is to pull back on the elevator control.

After initial control has been applied, continue with a fast cross-check for possible overcontrolling, since the necessary initial control pressures may be large. As the rate of movement of altimeter and ASI needles decreases, the attitude is approaching level flight. When the needles stop and reverse direction, the aircraft is passing through level flight. As the indications of the ASI, altimeter, and turn coordinator stabilize, incorporate the attitude indicator into the cross-check.

The attitude indicator and turn coordinator should be checked to determine bank attitude and then corrective aileron and rudder pressures should be applied. The ball should be centered. If it is not, skidding and slipping sensations can easily aggravate disorientation and retard recovery. If entering the unusual attitude from an assigned altitude (either by an instructor or by air traffic control (ATC) if operating under instrument flight rules (IFR)), return to the original altitude after stabilizing in straight-and-level flight.

Common Errors in Unusual Attitudes

Common errors associated with unusual attitudes include the following faults:

1. Failure to keep the airplane properly trimmed. A flight deck interruption when holding pressures can easily lead to inadvertent entry into unusual attitudes.
2. Disorganized flight deck. Hunting for charts, logs, computers, etc., can seriously distract attention from the instruments.
3. Slow cross-check and fixations. The impulse is to stop and stare when noting an instrument discrepancy unless a pilot has trained enough to develop the skill required for immediate recognition.

4. Attempting to recover by sensory sensations other than sight. The discussion of disorientation in Chapter 1, Human Factors, indicates the importance of trusting the instruments.
5. Failure to practice basic instrument skills. All of the errors noted in connection with basic instrument skills are aggravated during unusual attitude recoveries until the elementary skills have been mastered.

Instrument Takeoff

Competency in instrument takeoffs will provide the proficiency and confidence necessary for use of flight instruments during departures under conditions of low visibility, rain, low ceilings, or disorientation at night. A sudden rapid transition from "visual" to "instrument" flight can result in serious disorientation and control problems.

Instrument takeoff techniques vary with different types of airplanes, but the method described below is applicable whether the airplane is single- or multiengine; tricycle gear or conventional gear.

Align the airplane with the centerline of the runway with the nosewheel or tailwheel straight. Lock the tailwheel, if so equipped, and hold the brakes firmly to avoid creeping while preparing for takeoff. Set the heading indicator with the nose index on the 5° mark nearest the published runway heading to allow instant detection of slight changes in heading during the takeoff. Make certain that the instrument is uncaged (if it has a caging feature) by rotating the knob after uncaging and checking for constant heading indication. If using an electric heading indicator with a rotatable needle, rotate the needle so that it points to the nose position, under the top index. Advance the throttle to an rpm that will provide partial rudder control. Release the brakes, advancing the power smoothly to takeoff setting.

During the takeoff roll, hold the heading constant on the heading indicator by using the rudder. In multiengine, propeller-driven airplanes, also use differential throttle to maintain direction. The use of brakes should be avoided, except as a last resort, as it usually results in overcontrolling and extending the takeoff roll. Once the brakes are released, any deviation in heading must be corrected instantly.

As the airplane accelerates, cross-check both heading indicator and ASI rapidly. The attitude indicator may precess to a slight nose-up attitude. As flying speed is approached (approximately 15–25 knots below takeoff speed), smoothly apply elevator control for the desired takeoff attitude on the attitude indicator. This is approximately a two bar width climb indication for most small airplanes.

Continue with a rapid cross-check of heading indicator and attitude indicator as the airplane leaves the ground. Do not pull it off; let it fly off while holding the selected attitude constant. Maintain pitch-and-bank control by referencing the attitude indicator, and make coordinated corrections in heading when indicated on the heading indicator. Cross-check the altimeter and VSI for a positive rate of climb (steady clockwise rotation of the altimeter needle, and the VSI showing a stable rate of climb appropriate to the airplane).

When the altimeter shows a safe altitude (approximately 100 feet), raise the landing gear and flaps, maintaining attitude by referencing the attitude indicator. Because of control pressure changes during gear and flap operation, overcontrolling is likely unless the pilot notes pitch indications accurately and quickly. Trim off control pressures necessary to hold the stable climb attitude. Check the altimeter, VSI, and airspeed for a smooth acceleration to the predetermined climb speed (altimeter and airspeed increasing, vertical speed stable). At climb speed, reduce power to climb setting (unless full power is recommended for climb by the POH/AFM and trim).

Throughout the instrument takeoff, cross-check and interpretation must be rapid, and control positive and smooth. During liftoff, gear and flap retraction, power reduction, and the changing control reactions demand rapid cross-check, adjustment of control pressures, and accurate trim changes.

Common Errors in Instrument Takeoffs

Common errors during the instrument takeoff include the following:

1. Failure to perform an adequate flight deck check before the takeoff. Pilots have attempted instrument takeoffs with inoperative airspeed indicators (pitot tube obstructed), gyros caged, controls locked, and numerous other oversights due to haste or carelessness.
2. Improper alignment on the runway. This may result from improper brake application, allowing the airplane to creep after alignment, or from alignment with the nosewheel or tailwheel cocked. In any case, the result is a built-in directional control problem as the takeoff starts.
3. Improper application of power. Abrupt application of power complicates directional control. Add power with a smooth, uninterrupted motion.
4. Improper use of brakes. Incorrect seat or rudder pedal adjustment, with feet in an uncomfortable position, frequently cause inadvertent application of brakes and excessive heading changes.

5. Overcontrolling rudder pedals. This fault may be caused by late recognition of heading changes, tension on the controls, misinterpretation of the heading indicator (and correcting in the wrong direction), failure to appreciate changing effectiveness of rudder control as the aircraft accelerates, and other factors. If heading changes are observed and corrected instantly with small movement of the rudder pedals, swerving tendencies can be reduced.
6. Failure to maintain attitude after becoming airborne. If the pilot reacts to seat-of-the-pants sensations when the airplane lifts off, pitch control is guesswork. The pilot may either allow excessive pitch or apply excessive forward elevator pressure, depending on the reaction to trim changes.
7. Inadequate cross-check. Fixations are likely during trim changes, attitude changes, gear and flap retractions, and power changes. Once an instrument or a control input is applied, continue the cross-check and note the effect during the next cross-check sequence.
8. Inadequate interpretation of instruments. Failure to understand instrument indications immediately indicates that further study of the maneuver is necessary.

Basic Instrument Flight Patterns

Flight patterns are basic maneuvers, flown by sole reference to the instruments rather than outside visual clues, for the purpose of practicing basic attitude flying. The patterns simulate maneuvers encountered on instrument flights such as holding patterns, procedure turns, and approaches. After attaining a reasonable degree of proficiency in basic maneuvers, apply these skills to the various combinations of individual maneuvers. The following practice flight patterns are directly applicable to operational instrument flying.

Racetrack Pattern

1. Time 3 minutes straight-and-level flight from A to B. *[Figure 5-41]* During this interval, reduce airspeed to the holding speed appropriate for the aircraft.
2. Start a 180° standard rate turn to the right at B. Roll-out at C on the reciprocal of the heading originally used at A.
3. Time a 1 minute straight-and-level flight from C to D.
4. Start a 180° standard rate turn to the right at D, rolling-out on the original heading.
5. Fly 1 minute on the original heading, adjusting the outbound leg so that the inbound segment is 1 minute.

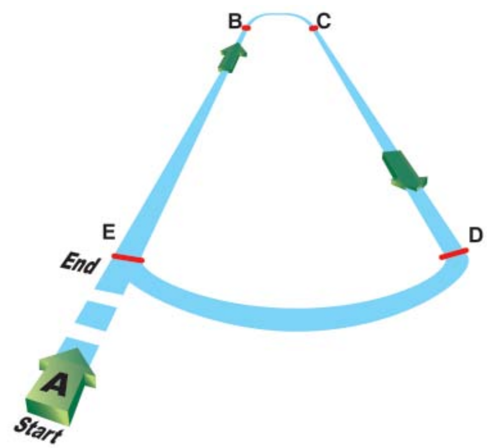


Figure 5-41. *Racetrack Pattern (Entire Pattern in Level Flight).*

NOTE*:* This pattern is an exercise combining use of the clock with basic maneuvers.

Procedure Turn

A procedure turn is a maneuver that facilitates:

- A reversal in flight direction.
- A descent from an initial approach fix or assigned altitude to a permissible altitude (usually the procedure turn altitude).
- An interception of the inbound course at a sufficient distance allowing the aircraft to become aligned with the final approach.

Procedure turn types include the 45° turn, the 80/260 turn, and the teardrop turn. All of these turns are normally conducted no more than 10 nautical miles (NM) from the primary airport. The procedure turn altitude generally provides a minimum of 1,000' obstacle clearance in the procedure turn area (not necessarily within the 10 NM arc around the primary airport). Turns may have to be increased or decreased but should not exceed 30° of a bank angle.

Standard 45° Procedure Turn

1. Start timing at point A (usually identified on approach procedures by a fix). For example, fly outbound on a heading of 360° for a given time (2 minutes, in this example). *[Figure 5-42]*
2. After flying outbound for 2 minutes (point B), turn left 45° to a heading of 315° using a standard rate turn. After roll-out and stabilizing, fly this new heading of 315° for 40 seconds and the aircraft will be at the approximate position of C.

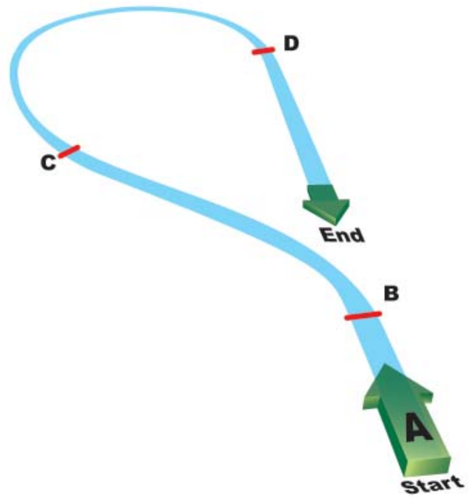


Figure 5-42. *Standard Procedure Turn (Entire Pattern in Level Flight).*

3. At point C, turn 225° right (using a standard rate turn) which will provide a heading of 180°. The timing is such that in a no wind environment, the pilot will be aligned with the final approach course of 180° at D. Wind conditions, however must be considered during the execution of the procedure turn. Compensating for wind may result in changes to outbound time, procedure turn heading and/or time and minor changes in the inbound turn.

80/260 Procedure Turn

1. Start timing at point A (usually identified on approach procedures by a fix). For example, fly outbound on a heading of 360° for 2 minutes. *[Figure 5-43]*

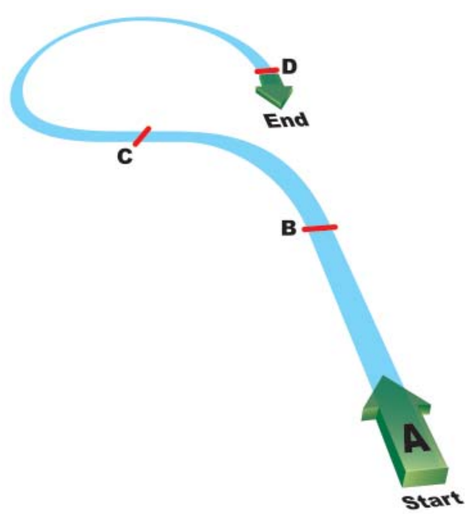


Figure 5-43. *80/260 Procedure Turn (Entire Pattern in Level Flight).*

2. At B, enter a left standard rate turn of 80° to a heading of 280°.
3. At the completion of the 80° turn to 280° (Point C), immediately turn right 260°, rolling-out on a heading of 180° (Point D) and also the reciprocal of the entry heading.

Teardrop Patterns

There are three typical teardrop procedure turns. A 30°, 20°, and a 10° teardrop pattern. The below steps indicate actions for all three starting on a heading of 360°. *[Figure 5-44]*

1. At point B (after stabilizing on the outbound course) turn left:
   - 30° to a heading of 330° and time for 1 minute
   - 20° to a heading of 340° and time for 2 minutes
   - 10° to a heading of 350° and time for 3 minutes
2. After the appropriate time above (Point C), make a standard rate turn to the right for:
   - 30° teardrop—210° to the final course heading of 180° (Point D)
   - 20° teardrop—200° to the final course heading of 180° (Point D)
   - 10° teardrop—190° to the final course heading of 180° (Point D)

By using the different teardrop patterns, a pilot is afforded the ability to manage time more efficiently. For instance, a 10° pattern for 3 minutes provides about three times the distance

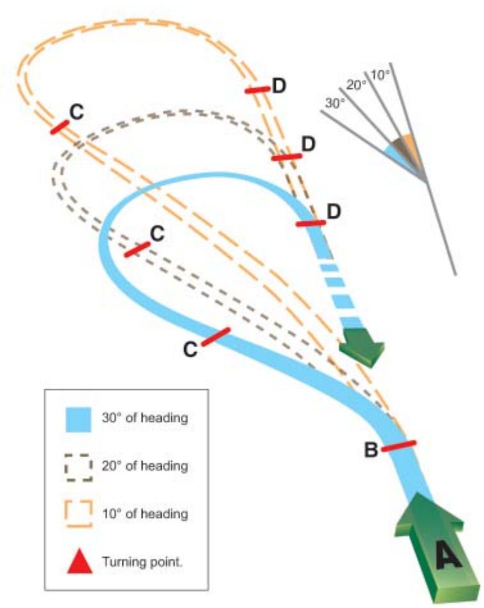


Figure 5-44. *Teardrop Pattern (Entire Pattern in Level Flight).*

(and time) than a 30° pattern. Pattern selection should be based upon an individual assessment of the procedure turn requirements to include wind, complexity, the individual preparedness, etc.

Circling Approach Patterns

Pattern I

1. At A, start timing for 2 minutes from A to B; reduce airspeed to approach speed. *[Figure 5-45]*
2. At B, make a standard rate turn to the left for 45°.
3. At the completion of the turn, time for 45 seconds to C.
4. At C, turn to the original heading; fly 1 minute to D, lowering the landing gear and flaps.
5. At D, turn right 180°, rolling-out at E on the reciprocal of the entry heading.
6. At E, enter a 500 fpm rate descent. At the end of a 500 foot descent, enter a straight constant-airspeed climb, retracting gear and flaps.

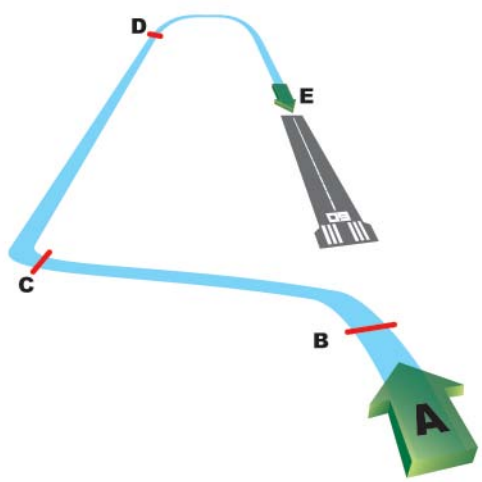


Figure 5-45. *Circling Approach Pattern I (Imaginary Runway).*

Pattern II

Steps:

1. At A, start timing for 2 minutes from A to B; reduce airspeed to approach speed. *[Figure 5-46]*
2. At B, make a standard rate turn to the left for 45°.
3. At the completion of the turn, time for 1 minute to C.
4. At C, turn right for 180° to D; fly for 1-1/2 minutes to E, lowering the landing gear and flaps.
5. At E, turn right for 180°, rolling-out at F.
6. At F, enter a 500 fpm rate descent. At the end of a 500 foot descent, enter a straight constant-airspeed climb, retracting gear and flaps.

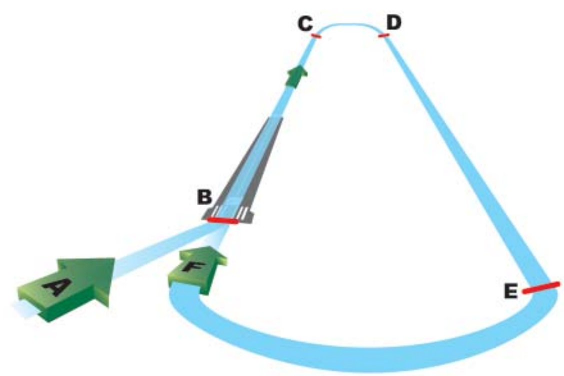


Figure 5-46. *Circling Approach Pattern II (Imaginary Runway).*

Chapter 5, Section II

Airplane Basic Flight Maneuvers

Using an Electronic Flight Display

Introduction

The previous chapters have laid the foundation for instrument flying. The pilot's ability to use and interpret the information displayed and apply corrective action is required to maneuver the aircraft and maintain safe flight. A pilot must recognize that each aircraft make and model flown may require a different technique. Aircraft weight, speed, and configuration changes require the pilot to vary his or her technique in order to perform successful attitude instrument flying. A pilot must become familiar with all sections of the Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) prior to performing any flight maneuver.

Chapter 5–II describes basic attitude instrument flight maneuvers and explains how to perform each one by interpreting the indications presented on the electronic flight display (EFD). In addition to normal flight maneuvers, "partial panel" flight will be addressed. With the exception of the instrument takeoff, all flight maneuvers can be performed on "partial panel" with the Attitude Heading Reference System (AHRS) unit simulated or rendered inoperative.

Straight-and-Level Flight

Pitch Control

The pitch attitude of an airplane is the angle between the longitudinal axis of the airplane and the actual horizon. In level flight, the pitch attitude varies with airspeed and load. For training purposes, the latter factor can normally be disregarded in small airplanes. At a constant airspeed, there is only one specific pitch attitude for level flight. At slow cruise speeds, the level flight attitude is nose-high with indications as in *Figure 5-47*; at fast cruise speeds, the level flight attitude is nose-low. *[Figure 5-48] Figure 5-49* shows the indications for the attitude at normal cruise speeds.

Figure 5-47. *Pitch Attitude and Airspeed in Level Flight, Slow Cruise Speed.*

The instruments that directly or indirectly indicate pitch on the Primary Flight Display (PFD) are the attitude indicator, altimeter, vertical speed indicator (VSI), airspeed indicator (ASI), and both airspeed and altitude trend indicators.

Attitude Indicator

The attitude indicator gives the pilot a direct indication of the pitch attitude. The increased size of the attitude display on the EFD system greatly increases situational awareness for the pilot. Most attitude indicators span the entire width of the PFD screen.

The aircraft pitch attitude is controlled by changing the deflection of the elevator. As the pilot pulls back on the control yoke causing the elevator to rise, the yellow chevron will begin to show a displacement up from the artificial horizon line. This is caused by the AHRS unit sensing the changing angle between the longitudinal plane of the earth and the longitudinal axis of the aircraft.

The attitude indicator displayed on the PFD screen is a representation of outside visual cues. Rather than rely on the natural horizon visible during visual flight rules (VFR) flight, the pilot must rely on the artificial horizon of the PFD screen.

During normal cruise airspeed, the point of the yellow chevron (aircraft symbol) will be positioned on the artificial horizon. Unlike conventional attitude indicators, the EFD attitude indicator does not allow for manipulating the position of the chevron in relationship to the artificial horizon. The position is fixed and therefore will always display the pitch angle as calculated by the AHRS unit.

Figure 5-48. *Pitch Attitude Decreasing and Airspeed Increasing—Indicates Need to Increase Pitch.*

Figure 5-49. *Various Pitch Attitudes (Right), Aircraft Shown in Level Flight.*

The attitude indicator only shows pitch attitude and does not indicate altitude. A pilot should not attempt to maintain level flight using the attitude indicator alone. It is important for the pilot to understand how small displacements both up and down can affect the altitude of the aircraft. To achieve this, the pilot should practice increasing the pitch attitude incrementally to become familiar with how each degree of pitch changes the altitude. *[Figures 5-50* and *5-51]* In both cases, the aircraft will slow and gain altitude.

The full height of the chevron is approximately 5° and provides an accurate reference for pitch adjustment. It is imperative that the pilot make the desired changes to pitch by referencing the attitude indicator and then trimming off any excess control pressures. Relieving these pressures will allow for a more stabilized flight and will reduce pilot work load. Once the aircraft is trimmed for level flight, the pilot must smoothly and precisely manipulate the elevator control forces in order to change the pitch attitude.

To master the ability to smoothly control the elevator, a pilot must develop a very light touch on the control yoke. The thumb and two fingers are normally sufficient to move the control yoke. The pilot should avoid griping the yoke with a full fist. When a pilot grips the yoke with a full fist, there is a tendency to apply excess pressures, thus changing the aircraft attitude.

Practice making smooth, small pitch changes both up and down until precise corrections can be made. With practice a pilot will be able to make pitch changes in 1° increments, smoothly controlling the attitude of the aircraft.

The last step in mastering elevator control is trim. Trimming the aircraft to relieve any control pressures is essential for smooth attitude instrument flight. To accomplish this, momentarily release the control yoke. Note which way the aircraft pitch attitude wants to move. Grasp the control yoke again and then reapply the pressure to return the attitude to the previous position. Apply trim in the direction of the control pressure. Small applications of trim will make large changes in the pitch attitude. Be patient and make multiple changes to trim, if necessary.

Once the aircraft is in trim, relax on the control yoke as much as practicable. When pressure is held on the yoke, unconscious pressures are applied to the elevator and ailerons which displaces the aircraft from its desired flight path. If the aircraft is in trim, in calm, non-turbulent air, a pilot should be able to release the control yoke and maintain level flight for extended periods of time. This is one of the hardest skills to learn prior to successfully flying in instrument meteorological conditions (IMC).

Figure 5-50. *Pitch Indications for Various Attitudes (1° through 5°).*

Figure 5-51. *Pitch Illustrated at 10°.*

Altimeter

At constant power, any deviation from level flight (except in turbulent air) must be the result of a pitch change. If the power is constant, the altimeter gives an indirect indication of the pitch attitude in level flight. Since the altitude should remain constant when the airplane is in level flight, any deviation from the desired altitude signals the need for a pitch change. For example, if the aircraft is gaining altitude, the nose must be lowered.

In the PFD, as the pitch starts to change, the altitude trend indicator on the altitude tape will begin to show a change in the direction of displacement. The rate at which the trend indicator grows and the altimeter numbers change aids the pilot in determining how much of a pitch change is necessary to stop the trend.

As a pilot becomes familiar with a specific aircraft's instruments, he or she learns to correlate pitch changes, altimeter tapes, and altitude trend indicators. By adding the altitude tape display and the altitude trend indicator into the scan along with the attitude indicator, a pilot starts to develop the instrument cross-check.

Partial Panel Flight

One important skill to practice is partial panel flight by referencing the altimeter as the primary pitch indicator. Practice controlling the pitch by referencing the altitude tape and trend indicator alone without the use of the attitude indicator. Pilots need to learn to make corrections to altitude deviations by referencing the rate of change of the altitude tape and trend indicator. When operating in IMC and in a partial panel configuration, the pilot should avoid abrupt changes to the control yoke. Reacting abruptly to altitude changes can lead to large pitch changes and thus a larger divergence from the initial altitude.

When a pilot is controlling pitch by the altitude tape and altitude trend indicators alone, it is possible to overcontrol the aircraft by making a larger than necessary pitch correction. Overcontrolling will cause the pilot to move from a nose-high attitude to a nose-low attitude and vice versa. Small changes to pitch are required to insure prompt corrective actions are taken to return the aircraft to its original altitude with less confusion.

When an altitude deviation occurs, two actions need to be accomplished. First, make a smooth control input to stop the needle movement. Once the altitude tape has stopped moving, make a change to the pitch attitude to start back to the entry altitude.

During instrument flight with limited instrumentation, it is imperative that only small and precise control inputs are made. Once a needle movement is indicated denoting a deviation in altitude, the pilot needs to make small control inputs to stop the deviation. Rapid control movements will only compound the deviation by causing an oscillation effect. This type of oscillation can quickly cause the pilot to become disoriented and begin to fixate on the altitude. Fixation on the altimeter can lead to a loss of directional control as well as airspeed control.

As a general rule of thumb, for altitude deviations less than 100 feet, utilize a pitch change of 1°, which equates to 1/5 of the thickness of the chevron. Small incremental pitch changes will allow the performance to be evaluated and will eliminate overcontrolling of the aircraft.

Instrumentation needs to be utilized collectively, but failures will occur which leave the pilot with only limited instrumentation. That is why partial panel flying training is important. If the pilot understands how to utilize each instrument independently, no significant change is encountered in carrying out the flight when other instruments fail.

VSI Tape

The VSI tape provides for an indirect indication of pitch attitude and gives the pilot a more immediate indication of a pending altitude deviation. In addition to trend information, the vertical speed also gives a rate indication. By using the VSI tape in conjunction with the altitude trend tape, a pilot will have a better understanding of how much of a correction needs to be made. With practice, the pilot will learn the performance of a particular aircraft and know how much pitch change is required in order to correct for a specific rate indication.

Unlike older analog VSIs, new glass panel displays have instantaneous VSIs. Older units had a lag designed into the system that was utilized to indicate rate information. The new glass panel displays utilize a digital air data computer that does not indicate a lag. Altitude changes are shown immediately and can be corrected for quickly.

The VSI tape should be used to assist in determining what pitch changes are necessary to return to the desired altitude. A good rule of thumb is to use a vertical speed rate of change that is double the altitude deviation. However, at no time should the rate of change be more than the optimum rate of climb or descent for the specific aircraft being flown. For example, if the altitude is off by 200 feet from the desired altitude, then a 400 feet per minute (fpm) rate of change would be sufficient to get the aircraft back to the original altitude. If the altitude has changed by 700 feet, then doubling that would necessitate a 1,400 fpm change. Most aircraft are not capable of that, so restrict changes to no more than optimum climb and descent. An optimum rate of change would vary between 500 and 1,000 fpm.

One error the instrument pilot encounters is overcontrolling. Overcontrolling occurs when a deviation of more than 200 fpm is indicated over the optimum rate of change. For example, an altitude deviation of 200 feet is indicated on the altimeter, a vertical speed rate of 400 feet should be indicated on the gauge. If the vertical speed rate showed 600 fpm (200 more than optimum), the pilot would be overcontrolling the aircraft.

When returning to altitude, the primary pitch instrument is the VSI tape. If any deviation from the desired vertical speed is indicated, make the appropriate pitch change using the attitude indicator.

As the aircraft approaches the target altitude, the vertical speed rate can be slowed in order to capture the altitude in a more stabilized fashion. Normally within 10 percent of the rate of climb or descent from the target altitude, begin to slow the vertical speed rate in order to level off at the target altitude. This will allow the pilot to level at the desired altitude without rapid control inputs or experiencing discomfort due to G-load.

Airspeed Indicator (ASI)

The ASI presents an indirect indication of the pitch attitude. At a constant power setting and pitch attitude, airspeed remains constant. As the pitch attitude lowers, airspeed increases, and the nose should be raised.

As the pitch attitude is increased, the nose of the aircraft will raise, which will result in an increase in the angle of attack as well as an increase in induced drag. The increased drag will begin to slow the momentum of the aircraft which will be indicated on the ASI. The airspeed trend indicator will show a trend as to where the airspeed will be in 6 seconds. Conversely, if the nose of the aircraft should begin to fall, the angle of attack as well as induced drag will decrease.

There is a lag associated with the ASI when using it as a pitch instrument. It is not a lag associated with the construction of the ASI, but a lag associated with momentum change. Depending on the rate of momentum change, the ASI may not indicate a pitch change in a timely fashion. If the ASI is being used as the sole reference for pitch change, it may not allow for a prompt correction. However, if smooth pitch changes are executed, modern glass panel displays are capable of indicating 1 knot changes in airspeed and also capable of projecting airspeed trends.

When flying by reference to flight instruments alone, it is imperative that all of the flight instruments be cross-checked for pitch control. By cross-checking all pitch related instruments, the pilot can better visualize the aircraft attitude at all times.

As previously stated, the primary instrument for pitch is the instrument that gives the pilot the most pertinent information for a specific parameter. When in level flight and maintaining a constant altitude, what instrument shows a direct indication of altitude? The only instrument that is capable of showing altitude is the altimeter. The other instruments are supporting instruments that are capable of showing a trend away from altitude, but do not directly indicate an altitude.

The supporting instruments forewarn of an impending altitude deviation. With an efficient cross-check, a proficient pilot will be better able to maintain altitude.

Bank Control

This discussion assumes the aircraft is being flown in coordinated flight which means the longitudinal axis of the aircraft is aligned with the relative wind. On the PFD, the attitude indicator shows if the wings are level. The turn rate indicator, slip/skid indicator, and the heading indicator also indicate whether or not the aircraft is maintaining a straight (zero bank) flight path.

Attitude Indicator

The attitude indicator is the only instrument on the PFD that has the capability of displaying the precise bank angle of the aircraft. This is made possible by the display of the roll scale depicted as part of the attitude indicator.

Figure 5-52 identifies the components that make up the attitude indicator display. Note that the top of the display is blue, representing sky, the bottom is brown, depicting dirt, and the white line separating them is the horizon. The lines parallel to the horizon line are the pitch scale which is marked in 5° increments and labeled every 10°. The pitch scale always remains parallel to the horizon.

The curved line in the blue area is the roll scale. The triangle on the top of the scale is the zero index. The hash marks on the scale represent the degree of bank. *[Figure 5-53]* The roll scale always remains in the same position relative to the horizon line.

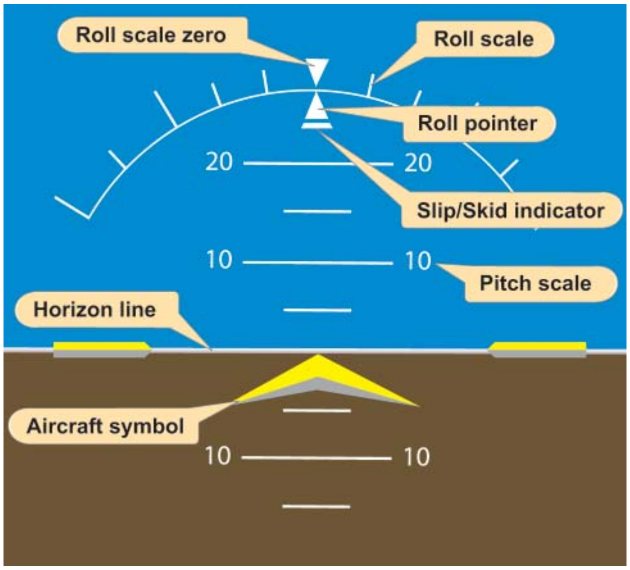


Figure 5-52. *Attitude Indicator.*

The roll pointer indicates the direction and degree of bank. *[Figure 5-53]* The roll pointer is aligned with the aircraft symbol. The roll pointer indicates the angle of the lateral axis of the aircraft compared to the natural horizon. The slip/skid indicator will show if the longitudinal axis of the aircraft is aligned with the relative wind, which is coordinated flight. With the roll index and the slip/skid indicator aligned, any deflection, either right or left of the roll index will cause the aircraft to turn in that direction. With the small graduations on the roll scale, it is easy to determine the bank angle within approximately 1°. In coordinated flight, if the roll index is aligned with the roll pointer, the aircraft is achieving straight flight.

An advantage of EFDs is the elimination of the precession error. Precession error in analog gauges is caused by forces being applied to a spinning gyro. With the new solid state instruments, precession error has been eliminated.

Since the attitude indicator is capable of showing precise pitch and bank angles, the only time that the attitude indicator will be a primary instrument is when attempting to fly at a specific bank angle or pitch angle. Other times, the attitude instrument can be thought of as a control instrument.

Horizontal Situation Indicator (HSI)

The HSI is a rotating 360° compass card that indicates magnetic heading. The HSI is the only instrument that is capable of showing exact headings. The magnetic compass can be used as a backup instrument in case of an HSI failure; however, due to erratic, unstable movements, it is more likely to be used a supporting instrument.

In order for the pilot to achieve the desired rate of change, it is important for him or her to understand the relationship

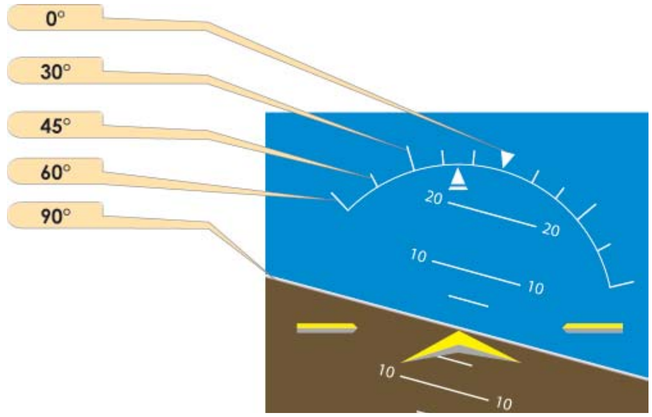


Figure 5-53. *Attitude Indicator Showing a 15° left bank.*

between the rate at which the HSI changes heading displays and the amount of bank angle required to meet that rate of change. A very small rate of heading change means the bank angle is small, and it will take more time to deviate from the desired straight flight path. A larger rate of heading change means a greater bank angle will happen at a faster rate.

Heading Indicator

The heading indicator is the large black box with a white number that indicates the magnetic heading of the aircraft. *[Figure 5-54]* The aircraft heading is displayed to the nearest degree. When this number begins to change, the pilot should be aware that straight flight is no longer being achieved.

Turn Rate Indicator

The turn rate indicator gives an indirect indication of bank. It is a magenta trend indicator capable of displaying half-standard as well as standard rate turns to both the left and right. The turn indicator is capable of indicating turns up to 4° per second by extending the magenta line outward from the standard rate mark. If the rate of turn has exceeded 4° per second, the

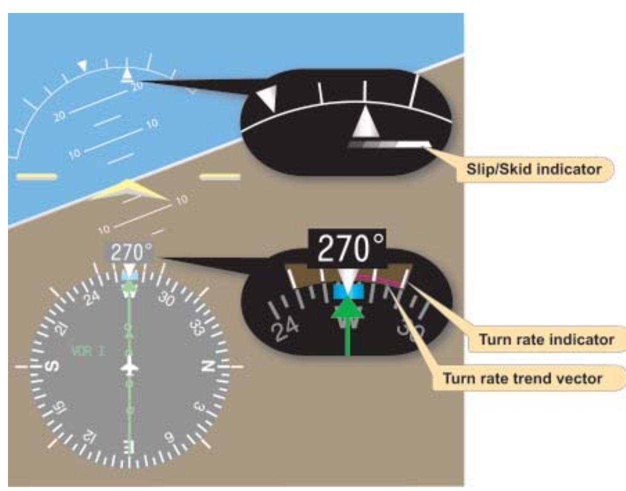


Figure 5-54. *Slip/Skid and Turn Rate Indicator.*

magenta line can not precisely indicate where the heading will be in the next 6 seconds, the magenta line freezes and an arrowhead will be displayed. This alerts the pilot to the fact that the normal range of operation has been exceeded.

Slip/Skid Indicator

The slip/skid indicator is the small portion of the lower segmented triangle displayed on the attitude indicator. This instrument depicts whether the aircraft's longitudinal axis is aligned with the relative wind. *[Figure 5-54]*

The pilot must always remember to cross-check the roll index to the roll pointer when attempting to maintain straight flight. Any time the heading remains constant and the roll pointer and the roll index are not aligned, the aircraft is in uncoordinated flight. To make a correction, the pilot should apply rudder pressure to bring the aircraft back to coordinated flight.

Power Control

Power produces thrust which, with the appropriate angle of attack of the wing, overcomes the forces of gravity, drag, and inertia to determine airplane performance.

Power control must be related to its effect on altitude and airspeed, since any change in power setting results in a change in the airspeed or the altitude of the airplane. At any given airspeed, the power setting determines whether the airplane is in level flight, in a climb, or in a descent. If the power is increased in straight-and-level flight and the airspeed held constant, the airplane will climb; if power is decreased while the airspeed is held constant, the airplane will descend. On the other hand, if altitude is held constant, the power applied will determine the airspeed.

The relationship between altitude and airspeed determines the need for a change in pitch or power. If the airspeed is off the desired value, always check the altimeter before deciding that a power change is necessary. Think of altitude and airspeed as interchangeable; altitude can be traded for airspeed by lowering the nose, or convert airspeed to altitude by raising the nose. If altitude is higher than desired and airspeed is low, or vice versa, a change in pitch alone may return the airplane to the desired altitude and airspeed. *[Figure 5-55]* If both airspeed and altitude are high or if both are low, then a change in both pitch and power is necessary in order to return to the desired airspeed and altitude. *[Figure 5-56]*

For changes in airspeed in straight-and-level flight, pitch, bank, and power must be coordinated in order to maintain constant altitude and heading. When power is changed to vary airspeed in straight-and-level flight, a single-engine, propeller-driven airplane tends to change attitude around all axes of movement. Therefore, to maintain constant altitude and heading, apply various control pressures in proportion to the change in power. When power is added to increase airspeed, the pitch instruments indicate a climb unless forward-elevator control pressure is applied as the airspeed changes. With an increase in power, the airplane tends to yaw and roll to the left unless counteracting aileron and rudder pressures are applied. Keeping ahead of these changes requires increasing cross-check speed, which varies with the type of airplane and its torque characteristics, the extent of power and speed change involved.

Power Settings

Power control and airspeed changes are much easier when approximate power settings necessary to maintain various airspeeds in straight-and-level flight are known in advance. However, to change airspeed by any appreciable amount, the common procedure is to underpower or overpower on initial power changes to accelerate the rate of airspeed change. (For small speed changes, or in airplanes that decelerate or accelerate rapidly, overpowering or underpowering is not necessary.)

Figure 5-55. *An aircraft decreasing in airspeed while gaining altitude. In this case, the pilot has decreased pitch.*

Figure 5-56. *Figure shows both an increase in speed and altitude where pitch adjustment alone is insufficient. In this situation, a reduction of power is also necessary.*

Consider the example of an airplane that requires 23" of manifold pressure (Hg) to maintain a normal cruising airspeed of 120 knots, and 18" Hg to maintain an airspeed of 100 knots. The reduction in airspeed from 120 knots to 100 knots while maintaining straight-and-level flight is discussed below and illustrated in *Figures 5-57, 5-58,* and *5-59*.

Instrument indications, prior to the power reduction, are shown in *Figure 5-57*. The basic attitude is established and maintained on the attitude indicator. The specific pitch, bank, and power control requirements are detected on these primary instruments:

Altimeter—Primary Pitch
Heading Indicator—Primary Bank
Airspeed Indicator—Primary Power

Supporting pitch and bank instruments are shown in *Figure 5-57*. Note that the supporting power instrument is the manifold pressure gauge (or tachometer if the propeller is fixed pitch). However, when a smooth power reduction to approximately 15" Hg (underpower) is made, the manifold pressure gauge becomes the primary power instrument. *[Figure 5-58]* With practice, power setting can be changed with only a brief glance at the power instrument, by sensing the movement of the throttle, the change in sound, and the changes in the feel of control pressures.

As the thrust decreases, increase the speed of the cross-check and be ready to apply left rudder, back-elevator, and aileron control pressure the instant the pitch-and-bank instruments show a deviation from altitude and heading. As proficiency is obtained, a pilot will learn to cross-check, interpret, and control the changes with no deviation of heading and altitude. Assuming smooth air and ideal control technique, as airspeed decreases, a proportionate increase in airplane pitch attitude is required to maintain altitude. Similarly, effective torque control means counteracting yaw with rudder pressure.

As the power is reduced, the altimeter is primary for pitch, the heading indicator is primary for bank, and the manifold pressure gauge is momentarily primary for power (at 15" Hg in *Figure 5-58*). Control pressures should be trimmed off as the airplane decelerates. As the airspeed approaches the desired airspeed of 100 knots, the manifold pressure is adjusted to approximately 18" Hg and becomes the supporting power instrument. The ASI again becomes primary for power. *[Figure 5-58]*

Airspeed Changes in Straight-and-Level Flight

Practice of airspeed changes in straight-and-level flight provides an excellent means of developing increased proficiency in all three basic instrument skills, and brings out some common errors to be expected during training in straight-and-level flight. Having learned to control the airplane in a clean configuration (minimum drag conditions), increase proficiency in cross-check and control by practicing speed changes while extending or retracting the flaps and landing gear. While practicing, be sure to comply with the airspeed limitations specified in the POH/AFM for gear and flap operation.

Figure 5-57. *Straight-and-Level Flight (Normal Cruising Speed).*

Figure 5-58. *Straight-and-Level Flight (Airspeed Decreasing).*

Figure 5-59. *Straight-and-Level Flight (Reduced Airspeed Stabilized).*

Sudden and exaggerated attitude changes may be necessary in order to maintain straight-and-level flight as the landing gear is extended and the flaps are lowered in some airplanes. The nose tends to pitch down with gear extension, and when flaps are lowered, lift increases momentarily (at partial flap settings) followed by a marked increase in drag as the flaps near maximum extension.

Control technique varies according to the lift and drag characteristics of each airplane. Accordingly, knowledge of the power settings and trim changes associated with different combinations of airspeed, gear, and flap configurations will reduce instrument cross-check and interpretation problems. *[Figure 5-60]*

For example, assume that in straight-and-level flight instruments indicate 120 knots with power at 23" Hg manifold pressure/2,300 revolutions per minute (rpm), gear and flaps up. After reduction in airspeed, with gear and flaps fully extended, straight-and-level flight at the same altitude requires 25" Hg manifold pressure/2,500 rpm. Maximum gear extension speed is 115 knots; maximum flap extension speed is 105 knots. Airspeed reduction to 95 knots, gear and flaps down, can be made in the following manner:

1. Maintain rpm at 2,500, since a high power setting will be used in full drag configuration.
2. Reduce manifold pressure to 10" Hg. As the airspeed decreases, increase cross-check speed.
3. Make trim adjustments for an increased angle of attack and decrease in torque.
4. Lower the gear at 115 knots. The nose may tend to pitch down and the rate of deceleration increases. Increase pitch attitude to maintain constant altitude, and trim off some of the back-elevator pressures. If full flaps are lowered at 105 knots, cross-check, interpretation, and control must be very rapid. A simpler technique is to stabilize attitude with gear down before lowering the flaps.
5. Since 18" Hg manifold pressure will hold level flight at 100 knots with the gear down, increase power smoothly to that setting as the ASI shows approximately 105 knots, and retrim. The attitude indicator now shows approximately two-and-a-half bar width nose-high in straight-and-level flight.
6. Actuate the flap control and simultaneously increase power to the predetermined setting (25" Hg) for the desired airspeed, and trim off the pressures necessary to hold constant altitude and heading. The attitude indicator now shows a bar width nose-low in straight-and-level flight at 95 knots.

Figure 5-60. *Cross-check Supporting Instruments.*

Trim Technique

Trim control is one of the most important flight habits to cultivate. Trimming refers to relieving any control pressures that need to be applied by the pilot to the control surfaces to maintain a desired flight attitude. The desired result is for the pilot to be able to take his or her hands off the control surfaces and have the aircraft remain in the current attitude. Once the aircraft is trimmed for hands-off flight, the pilot is able to devote more time to monitoring the flight instruments and other aircraft systems.

In order to trim the aircraft, apply pressure to the control surface that needs trimming and roll the trim wheel in the direction pressure is being held. Relax the pressure that is being applied to the control surface and monitor the primary instrument for that attitude. If the desired performance is achieved, fly hands off. If additional trimming is required, redo the trimming steps.

An aircraft is trimmed for a specific airspeed, not pitch attitude or altitude. Any time an aircraft changes airspeed there is a need to re-trim. For example, an aircraft is flying at 100 knots straight-and-level. An increase of 50 rpm will cause the airspeed to increase. As the airspeed increases, additional lift will be generated and the aircraft will climb. Once the additional thrust has stabilized at some higher altitude, the airspeed will again stabilize at 100 knots.

This demonstrates how trim is associated with airspeed and not altitude. If the initial altitude is to be maintained, forward pressure would need to be applied to the control wheel while the trim wheel needs to be rolled forward to eliminate any control pressures. Rolling forward on the trim wheel is equal to increasing for a trimmed airspeed. Any time the airspeed is changed, re-trimming will be required. Trimming can be accomplished during any transitional period; however, prior to final trimming, the airspeed must be held constant. If the airspeed is allowed to change, the trim will not be adjusted properly and the altitude will vary until the airspeed for which the aircraft is trimmed is achieved.

Common Errors in Straight-and-Level Flight

Pitch

Pitch errors usually result from the following errors:

1. Improper adjustment of the yellow chevron (aircraft symbol) on the attitude indicator.

   Corrective Action: Once the aircraft has leveled off and the airspeed has stabilized, make small corrections to the pitch attitude to achieve the desired performance. Cross-check the supporting instruments for validation.

2. Insufficient cross-check and interpretation of pitch instruments. *[Figure 5-61]*

Figure 5-61. *Insufficient cross-check. The problem is power and not nose-high. In this case, the pilot decreased pitch inappropriately.*

Example: The airspeed indication is low. The pilot, believing a nose-high pitch attitude exists, applies forward pressure without noting that a low power setting is the cause of the airspeed discrepancy.

Corrective Action: Increase the rate of cross-check of all the supporting flight instruments. Airspeed and altitude should be stabilized before making a control input.

3. Acceptance of deviations.

   Example: A pilot has an altitude range of ±100 feet according to the practical test standards for straight-and level-flight. When the pilot notices that the altitude has deviated by 60 feet, no correction is made because the altitude is holding steady and is within the standards.

   Corrective Action: The pilot should cross-check the instruments and, when a deviation is noted, prompt corrective actions should be taken in order to bring the aircraft back to the desired altitude. Deviations from altitude should be expected but not accepted.

4. Overcontrolling—Excessive Pitch Changes.

   Example: A pilot notices a deviation in altitude. In an attempt to quickly return to altitude, the pilot makes a large pitch change. The large pitch change destabilizes the attitude and compounds the error.

   Corrective Action: Small, smooth corrections should be made in order to recover to the desired altitude (0.5° to 2° depending on the severity of the deviation). Instrument flying is comprised of small corrections to maintain the aircraft attitude. When flying in IMC, a pilot should avoid making large attitude changes in order to avoid loss of aircraft control and spatial disorientation.

5. Failure to Maintain Pitch Corrections.

   Pitch changes need to be made promptly and held for validation. Many times pilots will make corrections and allow the pitch attitude to change due to not trimming the aircraft. It is imperative that any time a pitch change is made; the trim is readjusted in order to eliminate any control pressures that are being held. A rapid cross-check will aid in avoiding any deviations from the desired pitch attitude.

   Example: A pilot notices a deviation in altitude. A change in the pitch attitude is accomplished but no adjustment to the trim is made. Distractions cause the pilot to slow the cross-check and an inadvertent reduction in the pressure to the control column commences. The pitch attitude then changes, thus complicating recovery to the desired altitude.

   Corrective Action: The pilot should initiate a pitch change and then immediately trim the aircraft to relieve any control pressures. A rapid cross-check should be established in order to validate the desired performance is being achieved.

6. Fixation During Cross-Check.

   Devoting an unequal amount of time to one instrument either for interpretation or assigning too much importance to an instrument. Equal amounts of time should be spent during the cross-check to avoid an unnoticed deviation in one of the aircraft attitudes.

   Example: A pilot makes a correction to the pitch attitude and then devotes all of the attention to the altimeter to determine if the pitch correction is valid. During this time, no attention is paid to the heading indicator which shows a turn to the left. *[Figure 5-62]*

   Corrective Action: The pilot should monitor all instrumentation during the cross-check. Do not fixate on one instrument waiting for validation. Continue to scan all instruments to avoid allowing the aircraft to begin a deviation in another attitude.

Heading

Heading errors usually result from but are not limited to the following errors:

1. Failure to cross-check the heading indicator, especially during changes in power or pitch attitude.
2. Misinterpretation of changes in heading, with resulting corrections in the wrong direction.
3. Failure to note and remember a preselected heading.
4. Failure to observe the rate of heading change and its relation to bank attitude.
5. Overcontrolling in response to heading changes, especially during changes in power settings.
6. Anticipating heading changes with premature application of rudder pressure.
7. Failure to correct small heading deviations. Unless zero error in heading is the goal, a pilot will tolerate larger and larger deviations. Correction of a 1° error takes far less time and concentration than correction of a 20° error.
8. Correcting with improper bank attitude. If correcting a 10° heading error with a 20° bank correction, the aircraft will roll past the desired heading before the bank is established, requiring another correction in the opposite direction. Do not multiply existing errors with errors in corrective technique.

Figure 5-62. *The pilot has fixated on pitch and altitude, leaving bank indications unattended. Note the trend line to the left.*

9. Failure to note the cause of a previous heading error and thus repeating the same error. For example, the airplane is out of trim, with a left wing low tendency. Repeated corrections for a slight left turn are made, yet trim is ignored.

Power

Power errors usually result from but are not limited to the following errors:

1. Failure to become familiar with the aircraft's specific power settings and pitch attitudes.
2. Abrupt use of throttle.
3. Failure to lead the airspeed when making power changes, climbs or descents.

   Example: When leveling off from a descent, increase the power in order to avoid the airspeed from bleeding off due to the decrease in momentum of the aircraft. If the pilot waits to bring in the power until after the aircraft is established in the level pitch attitude, the aircraft will have already decreased below the speed desired which will require additional adjustment in the power setting.
4. Fixation on airspeed tape or manifold pressure indications during airspeed changes, resulting in erratic control of airspeed, power, as well as pitch and bank attitudes.

Trim

Trim errors usually result from the following faults:

1. Improper adjustment of seat or rudder pedals for comfortable position of legs and feet. Tension in the ankles makes it difficult to relax rudder pressures.
2. Confusion about the operation of trim devices, which differ among various airplane types. Some trim wheels are aligned appropriately with the airplane's axes; others are not. Some rotate in a direction contrary to expectations.
3. Failure to understand the principles of trim and that the aircraft is being trimmed for airspeed, not a pitch attitude.
4. Faulty sequence in trim techniques. Trim should be utilized to relieve control pressures, not to change pitch attitudes. The proper trim technique has the pilot holding the control wheel first and then trimming to relieve any control pressures. Continuous trim changes will be required as the power setting is changed. Utilize the trim continuously, but in small amounts.

Straight Climbs and Descents

Each aircraft will have a specific pitch attitude and airspeed that corresponds to the most efficient climb rate for a specified weight. The POH/AFM contains the speeds that will produce the desired climb. These numbers are based on maximum gross weight. Pilots must be familiar with how the speeds will vary with weight so they can compensate during flight.

Entry

Constant Airspeed Climb From Cruise Airspeed

To enter a constant airspeed climb from cruise airspeed, slowly and smoothly apply aft elevator pressure in order to raise the yellow chevron (aircraft symbol) until the tip points to the desired degree of pitch. *[Figure 5-63]* Hold the aft control pressure and smoothly increase the power to the climb power setting. This increase in power may be initiated either prior to initiating the pitch change or after having established the desired pitch setting. Consult the POH/AFM for specific climb power settings if anything other than a full power climb is desired. Pitch attitudes will vary depending on the type of aircraft being flown. As airspeed decreases, control forces will need to be increased in order to compensate for the additional elevator deflection required to maintain attitude. Utilize trim to eliminate any control pressures. By effectively using trim, the pilot will be better able to maintain the desired pitch without constant attention. The pilot is thus able to devote more time to maintaining an effective scan of all instrumentation.

The VSI should be utilized to monitor the performance of the aircraft. With a smooth pitch transition, the VSI tape should begin to show an immediate trend upward and stabilize on a

Figure 5-63. *Constant Airspeed Climb From Cruise Airspeed.*

rate of climb equivalent to the pitch and power setting being utilized. Depending on current weight and atmospheric conditions, this rate will be different. This will require the pilot to be knowledgeable of how weight and atmospheric conditions affect aircraft performance.

Once the aircraft is stabilized at a constant airspeed and pitch attitude, the primary flight instrument for pitch will be the ASI and the primary bank instrument will be the heading indicator. The primary power instrument will be the tachometer or the manifold pressure gauge depending on the aircraft type. If the pitch attitude is correct, the airspeed should slowly decrease to the desired speed. If there is any variation in airspeed, make small pitch changes until the aircraft is stabilized at the desired speed. Any change in airspeed will require a trim adjustment.

Constant Airspeed Climb from Established Airspeed

In order to enter a constant airspeed climb, first complete the airspeed reduction from cruise airspeed to climb airspeed. Maintain straight-and-level flight as the airspeed is reduced. The entry to the climb is similar to the entry from cruise airspeed with the exception that the power must be increased when the pitch attitude is raised. *[Figure 5-64]* Power added after the pitch change will show a decrease in airspeed due to the increased drag encountered. Power added prior to a pitch change will cause the airspeed to increase due to the excess thrust.

Constant Rate Climbs

Constant rate climbs are very similar to the constant airspeed climbs in the way the entry is made. As power is added,

Figure 5-64. *Constant-Airspeed Climb From Established Airspeed.*

smoothly apply elevator pressure to raise the yellow chevron to the desired pitch attitude that equates to the desired vertical speed rate. The primary instrument for pitch during the initial portion of the maneuver is the ASI until the vertical speed rate stabilizes and then the VSI tape becomes primary. The ASI then becomes the primary instrument for power. If any deviation from the desired vertical speed is noted, small pitch changes will be required in order to achieve the desired vertical speed. *[Figure 5-65]*

When making changes to compensate for deviations in performance, pitch, and power, pilot inputs need to be coordinated to maintain a stable flight attitude. For instance, if the vertical speed is lower than desired but the airspeed is correct, an increase in pitch will momentarily increase the vertical speed. However, the increased drag will quickly start to degrade the airspeed if no increase in power is made. A change to any one variable will mandate a coordinated change in the other.

Conversely, if the airspeed is low and the pitch is high, a reduction in the pitch attitude alone may solve the problem. Lower the nose of the aircraft very slightly to see if a power reduction is necessary. Being familiar with the pitch and power settings for the aircraft aids in achieving precise attitude instrument flying.

Leveling Off

Leveling off from a climb requires a reduction in the pitch prior to reaching the desired altitude. If no change in pitch is made until reaching the desired altitude, the momentum of the aircraft causes the aircraft to continue past the desired altitude throughout the transition to a level pitch attitude. The amount of lead to be applied depends on the vertical speed rate. A higher vertical speed requires a larger lead for level off. A good rule of thumb to utilize is to lead the level off by 10 percent of the vertical speed rate (1,000 fpm ÷ 10 = 100 feet lead).

To level off at the desired altitude, refer to the attitude display and apply smooth forward elevator pressure toward the desired level pitch attitude while monitoring the VSI and altimeter tapes. The rates should start to slow and airspeed should begin to increase. Maintain the climb power setting until the airspeed approaches the desired cruise airspeed. Continue to monitor the altimeter to maintain the desired altitude as the airspeed increases. Prior to reaching the cruise airspeed, the power must be reduced to avoid overshooting the desired speed. The amount of lead time that is required depends on the speed at which the aircraft accelerates. Utilization of the airspeed trend indicator can assist by showing how quickly the aircraft will arrive at the desired speed.

Figure 5-65. *Constant Rate Climbs.*

To level off at climbing airspeed, lower the nose to the appropriate pitch attitude for level flight with a simultaneous reduction in power to a setting that will maintain the desired speed. With a coordinated reduction in pitch and power there should be no change in the airspeed.

Descents

Descending flight can be accomplished at various airspeeds and pitch attitudes by reducing power, lowering the nose to a pitch attitude lower than the level flight attitude, or adding drag. Once any of these changes have been made, the airspeed will eventually stabilize. During this transitional phase, the only instrument that will display an accurate indication of pitch is the attitude indicator. Without the use of the attitude indicator (such as in partial panel flight), the ASI tape, the VSI tape, and the altimeter tape will show changing values until the aircraft stabilizes at a constant airspeed and constant rate of descent. The altimeter tape continues to show a descent. Hold pitch constant and allow the aircraft to stabilize. During any change in attitude or airspeed, continuous application of trim is required to eliminate any control pressures that need to be applied to the control yoke. An increase in the scan rate during the transition is important since changes are being made to the aircraft flight path and speed. *[Figure 5-66]*

Entry

Descents can be accomplished with a constant rate, constant airspeed or a combination. The following method can accomplish any of these with or without an attitude indicator. Reduce the power to allow the aircraft to decelerate to the desired airspeed while maintaining straight-and-level flight. As the aircraft approaches the desired airspeed, reduce the

Figure 5-66. *The top image illustrates a reduction of power and descending at 500 fpm to an altitude of 5,000 feet. The bottom image illustrates an increase in power and the initiation of leveling off.*

power to a predetermined value. The airspeed continues to decrease below the desired airspeed unless a simultaneous reduction in pitch is performed. The primary instrument for pitch is the ASI tape. If any deviation from the desired speed is noted, make small pitch corrections by referencing the attitude indicator and validate the changes made with the airspeed tape. Utilize the airspeed trend indicator to judge if the airspeed will be increasing and at what rate. Remember to trim off any control pressures.

The entry procedure for a constant rate descent is the same except the primary instrument for pitch is the VSI tape. The primary instrument for power will be the ASI. When performing a constant rate descent while maintaining a specific airspeed, coordinated use of pitch and power will be required. Any change in pitch directly affects the airspeed. Conversely, any change in airspeed will have a direct impact on vertical speed as long as the pitch is being held constant.

Leveling Off

When leveling off from a descent with the intention of returning to cruise airspeed, first start by increasing the power to cruise prior to increasing the pitch back toward the level flight attitude. A technique used to determine how soon to start the level off is to lead the level off by an altitude corresponding to 10 percent of the rate of descent. For example, if the aircraft is descending at 1,000 fpm, start the level off 100 feet above the level off altitude. If the pitch attitude change is started late, there is a tendency to overshoot the desired altitude unless the pitch change is made with a rapid movement. Avoid making any rapid changes that could lead to control issues or spatial disorientation. Once in level pitch attitude, allow the aircraft to accelerate to the desired speed. Monitor the performance on the airspeed and altitude tapes. Make adjustments to the power in order to correct any deviations in the airspeed. Verify that the aircraft is maintaining level flight by cross-checking the altimeter tape. If deviations are noticed, make an appropriate smooth pitch change in order to arrive back at desired altitude. Any change in pitch requires a smooth coordinated change to the power setting. Monitor the airspeed in order to maintain the desired cruise airspeed.

To level off at a constant airspeed, the pilot must again determine when to start to increase the pitch attitude toward the level attitude. If pitch is the only item that is changing, airspeed varies due to the increase in drag as the aircraft's pitch increases. A smooth coordinated increase in power will need to be made to a predetermined value in order to maintain speed. Trim the aircraft to relieve any control pressure that may have to be applied.

Common Errors in Straight Climbs and Descents

Climbing and descending errors usually result from but are not limited to the following errors:

1. Overcontrolling pitch on beginning the climb. Aircraft familiarization is the key to achieving precise attitude instrument flying. Until the pilot becomes familiar with the pitch attitudes associated with specific airspeeds, the pilot must make corrections to the initial pitch settings. Changes do not produce instantaneous and stabilized results; patience must be maintained while the new speeds and vertical speed rates stabilize. Avoid the temptations to make a change and then rush into making another change until the first one is validated. Small changes will produce more expeditious results and allow for a more stabilized flight path. Large changes to pitch and power are more difficult to control and can further complicate the recovery process.
2. Failure to increase the rate of instrument cross-check. Any time a pitch or power change is made, an increase in the rate a pilot cross-checks the instrument is required. A slow cross-check can lead to deviations in other flight attitudes.
3. Failure to maintain new pitch attitudes. Once a pitch change is made to correct for a deviation, that pitch attitude must be maintained until the change is validated. Utilize trim to assist in maintaining the new pitch attitude. If the pitch is allowed to change, it is impossible to validate whether the initial pitch change was sufficient to correct the deviation. The continuous changing of the pitch attitude delays the recovery process.
4. Failure to utilize effective trim techniques. If control pressures have to be held by the pilot, validation of the initial correction will be impossible if the pitch is allowed to vary. Pilots have the tendency to either apply or relax additional control pressures when manually holding pitch attitudes. Trim allows the pilot to fly without holding pressure on the control yoke.
5. Failure to learn and utilize proper power settings. Any time a pilot is not familiar with an aircraft's specific pitch and power settings, or does not utilize them, a change in flight paths will take longer. Learn pitch and power settings in order to expedite changing the flight path.
6. Failure to cross-check both airspeed and vertical speed prior to making adjustments to pitch and or power. It is possible that a change in one may correct a deviation in the other.

7. Uncoordinated use of pitch and power during level offs. During level offs, both pitch and power settings need to be made in unison in order to achieve the desired results. If pitch is increased before adding power, additional drag will be generated thereby reducing airspeed below the desired value.
8. Failure to utilize supporting pitch instruments which will lead to chasing the VSI. Always utilize the attitude indicator as the control instrument on which to change the pitch.
9. Failure to determine a proper lead time for level off from a climb or descent. Waiting too long can lead to overshooting the altitude.
10. Ballooning—Failure to maintain forward control pressure during level off as power is increased. Additional lift is generated causing the nose of the aircraft to pitch up.

Turns

Standard Rate Turns

The previous sections have addressed flying straight-and-level as well as climbs and descents. However, attitude instrument flying is not accomplished solely by flying in a straight line. At some point, the aircraft will need to be turned to maneuver along victor airways, global positioning system (GPS) courses, and instrument approaches. The key to instrument flying is smooth, controlled changes to pitch and bank. Instrument flying should be a slow but deliberate process that takes the pilot from departure airport to destination airport without any radical flight maneuvers.

A turn to specific heading should be made at standard rate. Standard rate is defined as a turning rate of 3° per second which will yield a complete 360° turn in 2 minutes. A turning rate of 3° per second will allow for a timely heading change, as well as allowing the pilot sufficient time to cross-check the flight instruments and avoid drastic changes to the aerodynamic forces being exerted on the aircraft. At no time should the aircraft be maneuvered faster than the pilot is comfortable cross-checking the flight instruments. Most autopilots are programmed to turn at standard rate.

Establishing A Standard Rate Turn

In order to initiate a standard rate turn, approximate the bank angle and then establish that bank angle on the attitude indicator. A rule of thumb to determine the approximate angle of bank is to use 15 percent of the true airspeed. A simple way to determine this amount is to divide the airspeed by 10 and add one-half the result. For example, at 100 knots, approximately 15° of bank is required (100/10 = 10 + 5 = 15); at 120 knots, approximately 18° of bank is needed for a standard-rate turn. Cross-check the turn rate indicator, located on the HSI, to determine if that bank angle is sufficient to deliver a standard rate turn. Slight modifications may need to be made to the bank angle in order to achieve the desired performance. The primary bank instrument in this case is the turn rate indicator since the goal is to achieve a standard rate turn. The turn rate indicator is the only instrument that can specifically indicate a standard rate turn. The attitude indicator is used only to establish a bank angle (control instrument) but can be utilized as a supporting instrument by cross-checking the bank angle to determine if the bank is greater or less than what was calculated.

As the aircraft rolls into the bank, the vertical component of lift will begin to decrease. *[Figure 5-67]* As this happens, additional lift must be generated to maintain level flight. Apply aft control pressure on the yoke sufficient to stop any altitude loss trend. With the increase in lift that needs to be generated, additional induced drag will also be generated. This additional drag will cause the aircraft to start to decelerate. To counteract this, apply additional thrust by adding power to the power lever. Once altitude and airspeed is being maintained, utilize the trim wheel to eliminate any control forces that need to be held on the control column.

When rolling out from a standard rate turn, the pilot needs to utilize coordinated aileron and rudder and roll-out to a wings level attitude utilizing smooth control inputs. The roll-out rate should be the same as the roll-in rate in order to estimate the lead necessary to arrive at the desired heading without over- or undershooting.

During the transition from the turn back to straight flight, the attitude indicator becomes the primary instrument for bank. Once the wings are level, the heading indicator becomes the primary instrument for bank. As bank decreases, the vertical component increases if the pitch attitude is not decreased sufficiently to maintain level flight. An aggressive cross-check keeps the altimeter stationary if forward control pressure is applied to the control column. As the bank angle is decreased, the pitch attitude should be decreased accordingly in order to arrive at the level pitch attitude when the aircraft reaches zero bank. Remember to utilize the trim wheel to eliminate any excess control forces that would otherwise need to be held.

Common Errors

1. One common error associated with standard rate turns is due to pilot inability to hold the appropriate bank angle that equates to a standard rate. The primary bank instrument during the turn is the turn rate indicator; however the bank angle varies slightly. With an

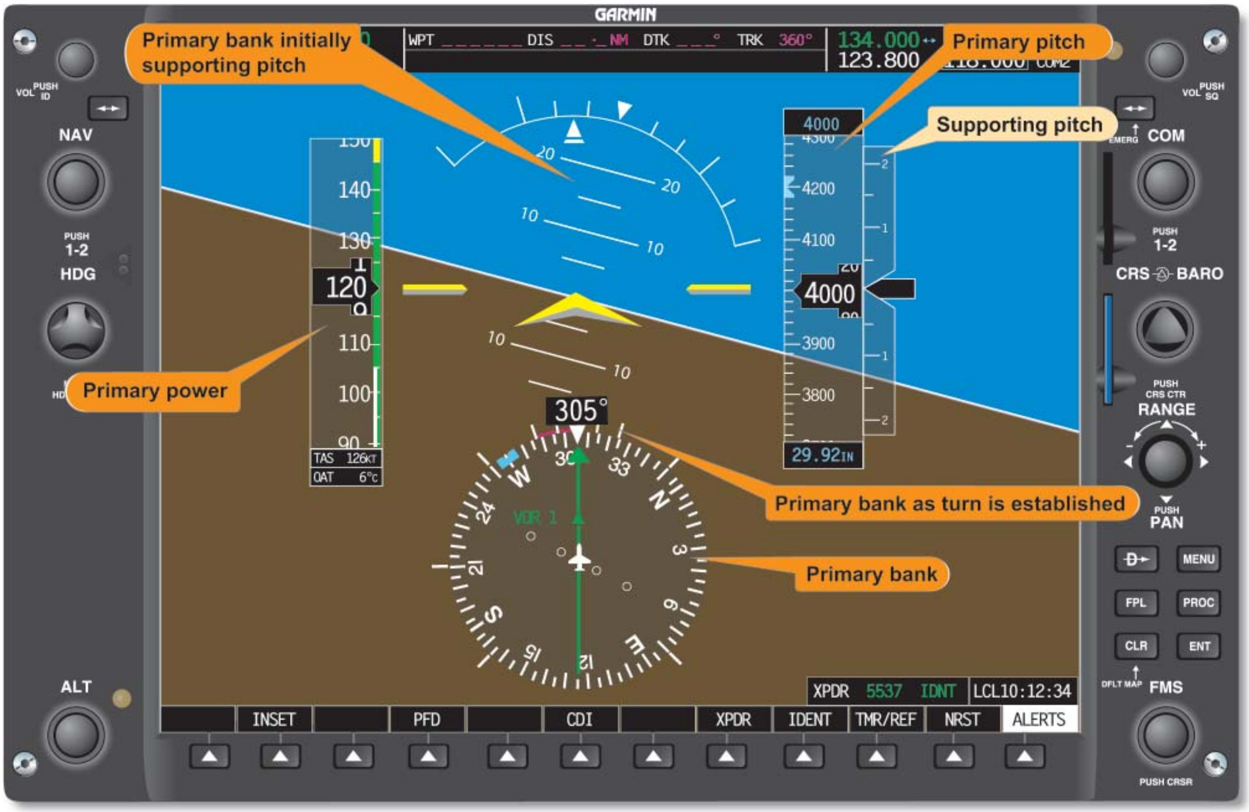


Figure 5-67. *Standard Rate Turn—Constant Airspeed.*

aggressive cross-check, a pilot should be able to minimize errors arising from over- or underbanking.

2. Another error normally encountered during standard rate turns is inefficient or lack of adequate cross-checking. Pilots need to establish an aggressive cross-check in order to detect and eliminate all deviations from altitude, airspeed, and bank angle during a maneuver.
3. Fixation is a major error associated with attitude instrument flying in general. Pilots training for their instrument rating tend to focus on what they perceive to be the most important task at hand and abandon their cross-check by applying all of their attention to the turn rate indicator. A modified radial scan works well to provide the pilot with adequate scanning of all instrumentation during the maneuver.

Turns to Predetermined Headings

Turning the aircraft is one of the most basic maneuvers that a pilot learns during initial flight training. Learning to control the aircraft, maintaining coordination, and smoothly rolling out on a desired heading are all keys to proficient attitude instrument flying.

EFDs allow the pilot to better utilize all instrumentation during all phases of attitude instrument flying by consolidating all traditional instrumentation onto the PFD. The increased size of the attitude indicator, which stretches the entire width of the multi-function display (MFD), allows the pilot to maintain better pitch control while the introduction of the turn rate indicator positioned directly on the compass rose aids the pilot in determining when to begin a roll-out for the desired heading.

When determining what bank angle to utilize when making a heading change, a general rule states that for a small heading change, do not use a bank angle that is greater than the total number of degrees of change needed. For instance, if a heading change of 20° is needed, a bank angle of not more than 20° is required. Another rule of thumb that better defines the bank angle is half the total number of degrees of heading change required, but never greater than standard rate. The exact bank angle that equates to a standard rate turn varies due to true airspeed.

With this in mind and the angle of bank calculated, the next step is determining when to start the roll-out process. For example:

An aircraft begins a turn from a heading of 030° to a heading of 120°. With the given airspeed, a standard rate turn has yielded a 15° bank. The pilot wants to begin a smooth coordinated roll-out to the desired heading when the heading indicator displays approximately 112°. The necessary calculations are:

15° bank (standard rate) ÷ 2 = 7.5°
120° – 7.5° = 112.5°

By utilizing this technique the pilot is better able to judge if any modifications need to be made to the amount of lead once the amount of over- or undershooting is established.

Timed Turns

Timed turns to headings are performed in the same fashion with an EFD as with an analog equipped aircraft. The instrumentation used to perform this maneuver is the turn rate indicator as well as the clock. The purpose of this maneuver is to allow the pilot to gain proficiency in scanning as well as to further develop the pilot's ability to control the aircraft without standard instrumentation.

Timed turns become essential when controlling the aircraft with a loss of the heading indicator. This may become necessary due to a loss of the AHRS unit or the magnetometer. In any case, the magnetic compass will still be available for navigation. The reason for timed turns instead of magnetic compass turns is the simplicity of the maneuver. Magnetic compass turns require the pilot to take into account various errors associated with the compass; timed turns do not.

Prior to initiating a turn, determine if the standard rate indication on the turn rate indicator will actually deliver a 3° per second turn. To accomplish this, a calibration must be made. Establish a turn in either direction at the indicated standard rate. Start the digital timer as the compass rolls past a cardinal heading. Stop the timer once the compass card rolls through another cardinal heading. Roll wings level and compute the rate of turn. If the turn rate indicator is calibrated and indicating correctly, 90° of heading change should take 30 seconds. If the time taken to change heading by 90° is more or less than 30 seconds, then a deflection above or below the standard rate line needs to be made to compensate for the difference. Once the calibration has been completed in one direction, proceed to the opposite direction. When both directions have been calibrated, apply the calibrated calculations to all timed turns.

In order to accomplish a timed turn, the amount of heading change needs to be established. For a change in heading from 120° to a heading of 360°, the pilot calculates the difference and divides that number by 3. In this case, 120° divided by 3° per second equals 40 seconds. This means that it would take 40 seconds for an aircraft to change heading 120° if that aircraft were held in a perfect standard rate turn. Timing for the maneuver should start as the aircraft begins rolling into the standard rate turn. Monitor all flight instruments during this maneuver. The primary pitch instrument is the altimeter. The primary power instrument is the ASI and the primary bank instrument is the turn rate indicator.

Once the calculated time expires, start a smooth coordinated roll-out. As long as the pilot utilizes the same rate of roll-in as roll-out, the time it takes for both will not need to be included in the calculations. With practice the pilot should level the wings on the desired heading. If any deviation has occurred, make small corrections to establish the correct heading.

Compass Turns

The magnetic compass is the only instrument that requires no other source of power for operation. In the event of an AHRS or magnetometer failure, the magnetic compass is the instrument the pilot uses to determine aircraft heading. For a more detailed explanation on the use of the magnetic compass, see page 5-21.

Steep Turns

For the purpose of instrument flight training, a steep turn is defined as any turn in excess of standard rate. A standard rate turn is defined as 3° per second. The bank angle that equates to a turn rate of 3° per second varies according to airspeed. As airspeed increases, the bank angle must be increased. The exact bank angle that equates to a standard rate turn is unimportant. Normal standard rate turn bank angles range from 10° to 20°. The goal of training in steep turn maneuvers is pilot proficiency in controlling the aircraft with excessive bank angles.

Training in excessive bank angles will challenge the pilot in honing cross-checking skills and improve altitude control throughout a wider range of flight attitudes. Although the current instrument flight check practical test standards (PTS) do not call for a demonstration of steep turns on the certification check flight, this does not eliminate the need for the instrument pilot-in-training to demonstrate proficiency to an instructor.

Training in steep turns teaches the pilot to recognize and to adapt to rapidly changing aerodynamic forces that necessitate an increase in the rate of cross-checking all flight instruments. The procedures for entering, maintaining and exiting a steep turn are the same as for shallower turns. Proficiency in instrument cross-check and interpretation is increased due to the higher aerodynamic forces and increased speed at which the forces are changing.

Performing the Maneuver

To enter a steep turn to the left, roll into a coordinated 45° bank turn to the left. An advantage that glass panel displays have over analog instrumentation is a 45° bank indication on the roll scale. This additional index on the roll scale allows the pilot to precisely roll into the desired bank angle instead of having to approximate it as is necessary with analog instrumentation. *[Figure 5-68]*

Figure 5-68. *Steep Left Turn.*

As soon as the bank angle increases from level flight, the vertical component of lift begins to decrease. If the vertical component of lift is allowed to continue to decrease, a pronounced loss of altitude is indicated on the altimeter along with the VSI tape, as well as the altitude trend indicator. Additionally, the airspeed will begin to increase due to the lowered pitch attitude. It is very important to have a comprehensive scan developed prior to training in steep turns. Utilization of all of the trend indicators, as well the VSI, altimeter, and ASI, is essential in learning to fly steep turns by reference to instruments alone.

In order to avoid a loss of altitude, the pilot begins to slowly increase back pressure on the control yoke in order to increase the pitch attitude. The pitch change required is usually no more than 3° to 5°, depending on the type of aircraft. As the pilot increases back pressure, the angle of attack increases, thus increasing the vertical component of lift. When a deviation in altitude is indicated, proper control force corrections need to be made. During initial training of steep turns, pilots have a tendency to overbank. Over banking is when the bank angle exceeds 50°. As the outboard wing begins to travel faster through the air it will begin to generate a greater and greater differential in lift compared to the inboard wing. As the bank angle continues to progress more and more steeply past 45°, the two components of lift (vertical and horizontal) become inversely proportionate.

Once the angle has exceeded 45°, the horizontal component of lift is now the greater force. If altitude should continue to decrease and the pilot only applies back yoke pressure, the aircraft's turn radius begins to tighten due to the increased horizontal force. If aft control pressure continues to increase, there will come a point where the loss of the vertical component of lift and aerodynamic wing loading prohibits the nose of the aircraft from being raised. Any increase in pitch only tightens the turning radius.

The key to successfully performing a steep turn by reference to instruments alone is the thorough understanding of the aerodynamics involved, as well as a quick and reliable cross-check. The pilot should utilize the trim to avoid holding control forces for any period of time. With time and practice, a flight instructor can demonstrate how to successfully fly steep turns with and without the use of trim. Once the aircraft is trimmed for the maneuver, accomplishing the maneuver will be virtually a hands-off effort. This allows additional time for cross-checking and interpreting the instruments.

It is imperative when correcting for a deviation in altitude, that the pilot modify the bank angle ±5° in order to vary the vertical component of lift, not just adjust back pressure. These two actions should be accomplished simultaneously.

During the recovery from steep turns to straight-and-level flight, aft control forces must be varied with the power control to arrive back at entry altitude, heading and airspeed.

Steps:

1. Perform clearing turns.
2. Roll left into a 45° bank turn and immediately begin to increase the pitch attitude by approximately 3° to 5°.
3. As the bank rolls past 30°, increase power to maintain the entry airspeed.
4. Apply trim to eliminate any aft control wheel forces.
5. Begin rolling out of the steep turn approximately 20° prior to the desired heading.
6. Apply forward control pressure and place the pitch attitude in the level cruise pitch attitude.
7. Reduce power to the entry power setting to maintain the desired airspeed.
8. Re-trim the aircraft as soon as practical or continue into a right hand steep turn and continue from step 3.

9. Once the maneuver is complete, establish cruise flight and accomplish all appropriate checklist items.

Unusual Attitude Recovery Protection

Unusual attitudes are some of the most hazardous situations for a pilot to be in. Without proper recovery training on instrument interpretation and aircraft control, a pilot can quickly aggravate an abnormal flight attitude into a potentially fatal accident.

Analog gauges require the pilot to scan between instruments to deduce the aircraft attitude. Individually, these gauges lack the necessary information needed for a successful recovery.

EFDs have additional features to aid in recognition and recovery from unusual flight attitudes. The PFD displays all the flight instruments on one screen. Each instrument is superimposed over a full-screen representation of the attitude indicator. With this configuration, the pilot no longer needs to transition from one instrument to another.

The new unusual attitude recovery protection allows the pilot to be able to quickly determine the aircraft's attitude and make a safe, proper and prompt recovery. Situational awareness is increased by the introduction of the large full-width artificial horizon depicted on the PFD. This now allows for the attitude indicator to be in view during all portions of the scan.

One problem with analog gauges is that the attitude indicator displays a complete blue or brown segment when the pitch attitude is increased toward 90° nose-up or nose-down.

With the EFDs, the attitude indicator is designed to retain a portion of both sky and land representation at all times. This improvement allows the pilot to always know the quickest way to return to the horizon. Situational awareness is greatly increased.

NOTE: The horizon line starts moving downward at approximately 47° pitch up. From this point on, the brown segment will remain visible to show the pilot the quickest way to return to the level pitch attitude. *[Figure 5-69]*

NOTE: The horizon line starts moving upward at approximately 27° pitch down. From this point on, the blue segment will remain visible to show the pilot the quickest way to return to the level pitch attitude. *[Figure 5-70]*

It is imperative to understand that the white line on the attitude indicator is the horizon line. The break between the blue and brown symbols is only a reference and should not be thought of as the artificial horizon.

Another important advancement is the development of the unusual attitude recovery protection that is built into the PFD software and made capable by the AHRS. In the case of a nose-high unusual attitude, the unusual attitude recovery protection displays red chevrons which point back to the horizon line.

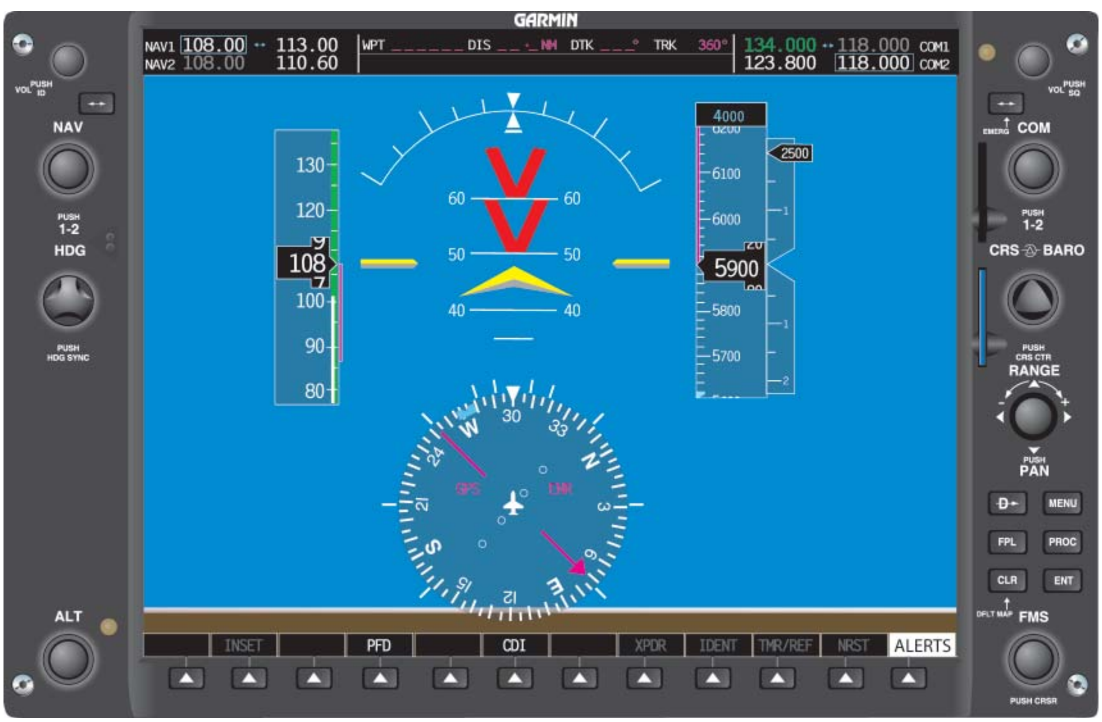


Figure 5-69. *Unusual Attitude Recovery Protection. Note the brown horizon line is visible at the bottom.*

Figure 5-70. *Horizon line starts moving upward at 27°. Note that the blue sky remains visible at 17° nose-down.*

These chevrons are positioned at 50° up on the attitude indicator. The chevrons appear when the aircraft approaches a nose-high attitude of 30°. The software automatically de-clutters the PFD leaving only airspeed, heading, attitude, altimeter, VSI tape, and the trend vectors. The de-cluttered information reappears when the pitch attitude falls below 25°.

For nose-low unusual attitudes, the chevrons are displayed when the pitch exceeds 15° nose-down. If the pitch continues to decrease, the unusual attitude recovery protection de-clutters the screen at 20° nose-down. The de-cluttered information reappears when the pitch increases above 15°.

Additionally, there are bank limits that trigger the unusual attitude protection. If the aircraft's bank increases beyond 60°, a continuation of the roll index occurs to indicate the shortest direction to roll the wings back to level. At 65°, the PFD de-clutters. All information reappears when the bank decreases below 60°.

In *Figure 5-71*, the aircraft has rolled past 60°. Observe the white line that continues from the end of the bank index. This line appears to indicate the shortest distance back to wings level.

When experiencing a failure of the AHRS unit, all unusual attitude protection is lost. The failure of the AHRS results in the loss of all heading and attitude indications on the PFD. In addition, all modes of the autopilot, except for roll and altitude hold, are lost.

The following picture series represents how important this technology is in increasing situational awareness, and how critical it is in improving safety.

Figure 5-72 shows the unusual attitude protection with valid AHRS and air data computer (ADC) inputs. The bright red chevrons pointing down to the horizon indicate a nose-high unusual attitude that can be easily recognized and corrected.

NOTE: The red chevrons point back to the level pitch attitude. The trend indicators show where the airspeed and altitude will be in 6 seconds. The trend indicator on the heading indicator shows which direction the aircraft is turning. The slip/skid indicator clearly shows if the aircraft is coordinated. This information helps the pilot determine which type of unusual attitude the aircraft has taken.

Now look at *Figure 5-73*. The display shows the same airspeed as the picture above; however, the AHRS unit has failed. The altimeter and the VSI tape are the only clear indications that the aircraft is in a nose-high attitude. The one key instrument that is no longer present is the slip/skid indicator. There is not a standby turn coordinator installed in the aircraft for the pilot to reference.

The magnetic compass indicates a heading is being maintained; however, it is not as useful as a turn coordinator or slip/skid indicator.

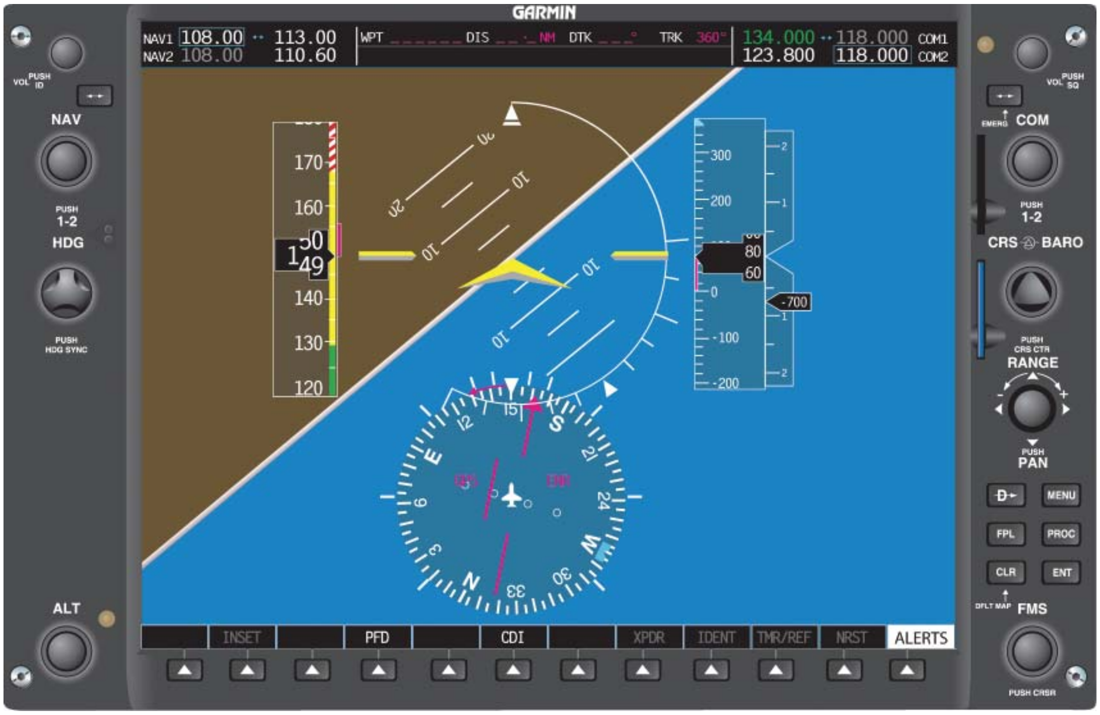


Figure 5-71. *Aircraft Rolled Past 60°.*

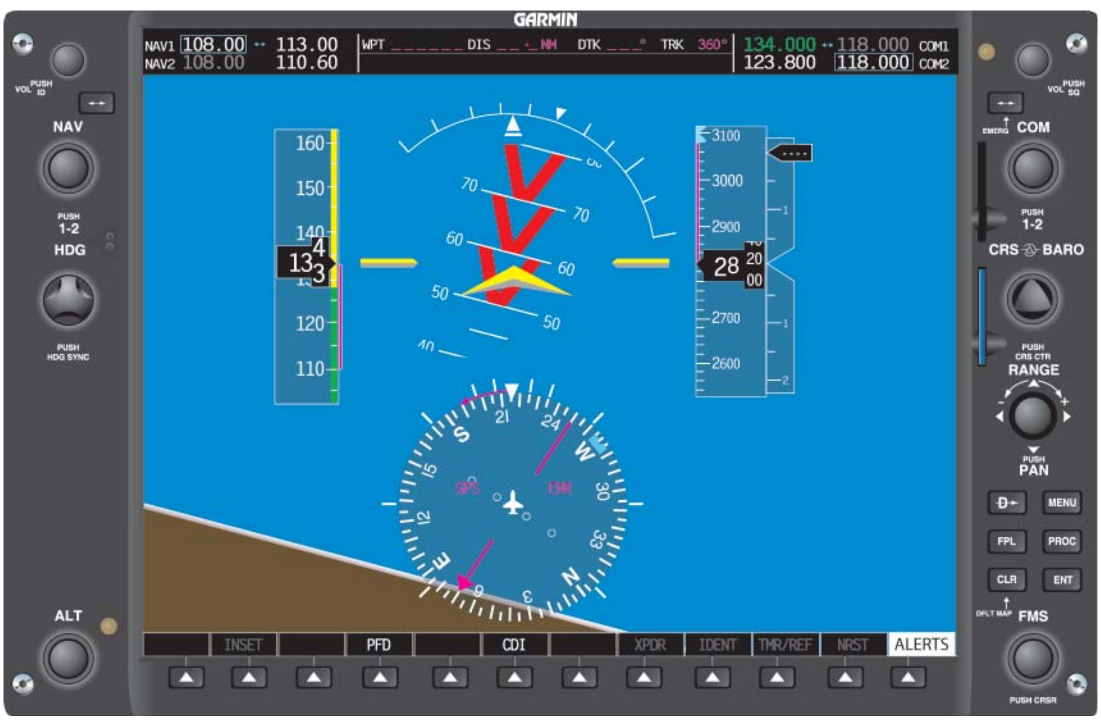


Figure 5-72. *Unusual Attitude Protection With Valid AHRS.*

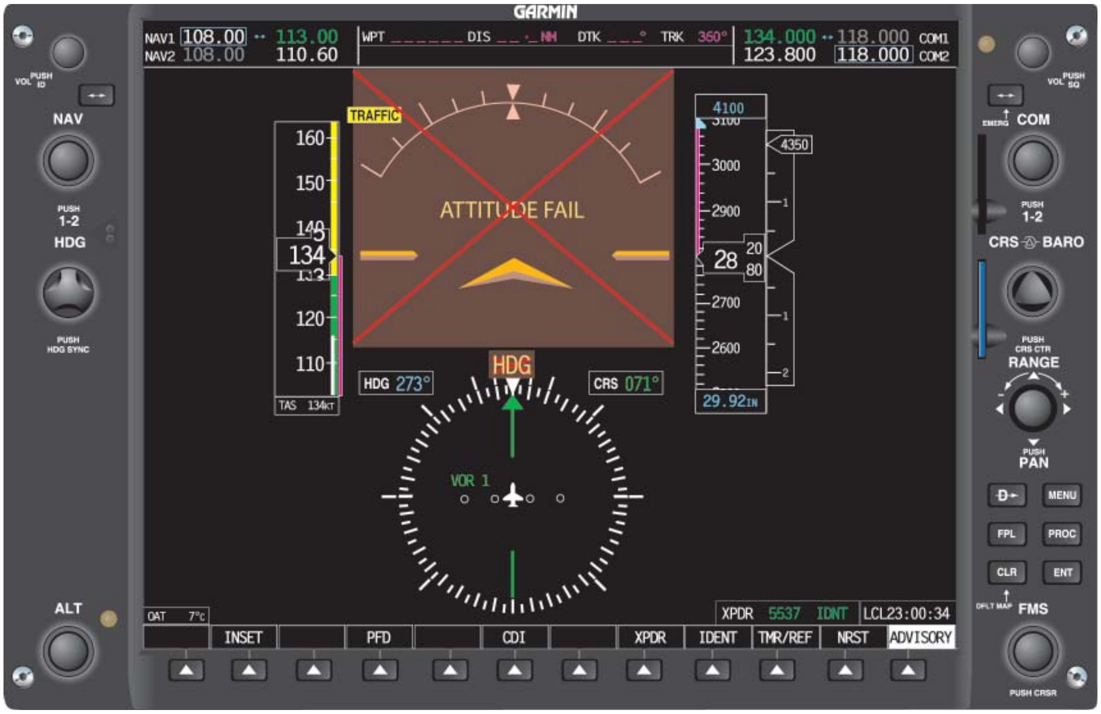


Figure 5-73. *AHRS Unit Failed.*

Figure 5-74 depicts an AHRS and ADC failure. In this failure scenario, there are no indications of the aircraft's attitude. The manufacturer recommends turning on the autopilot which is simply a wing leveler.

With a failure of the primary instrumentation on the PFD, the only references available are the stand-by instruments. The standby instrumentation consists of an analog ASI, attitude indicator, altimeter, and magnetic compass. There is no standby turn coordinator installed.

In extreme nose-high or nose-low pitch attitudes, as well as high bank angles, the analog attitude indicator has the potential to tumble, rendering it unusable.

Autopilot Usage

The autopilot is equipped with inputs from a turn coordinator installed behind the MFD screen. This turn coordinator is installed solely for the use of the autopilot to facilitate the roll mode. Roll mode, which is simply a wing leveler. This protection will always be available, barring a failure of the turn coordinator (to aid the pilot if the aircraft attains an unusual attitude).

NOTE: The pilot is not able to gain access to the turn coordinator. This instrument is installed behind the MFD panel. *[Figure 5-75]*

Most EFD equipped aircraft are coming from the factory with autopilots installed. However, the purchaser of the aircraft can specify if an autopilot is to be installed. Extreme caution should be utilized when flying an EFD equipped aircraft without an autopilot in IMC with an AHRS and ADC failure.

The autopilot should be utilized to reduce workload, which affords the pilot more time to monitor the flight. Utilization of the autopilot also decreases the chances of entry into an unusual attitude.

Flying an EFD equipped aircraft without the use of an autopilot has been shown to increase workload and decrease situational awareness for pilots first learning to flying the new system.

Common Errors Leading to Unusual Attitudes

The following errors have the potential to disrupt a pilot's situational awareness and lead to unusual attitudes.

1. Improper trimming techniques. A failure to keep the aircraft trimmed for level flight at all times can turn a momentary distraction into an emergency situation if the pilot stops cross-checking.
2. Poor crew resource management (CRM) skills. Failure to perform all single-pilot resource management duties efficiently. A major cause of CRM related accidents comes from the failure of the pilot to maintain an organized flight deck. Items that are being utilized for the flight portion should be neatly arranged for easy access. A disorganized flight deck

Figure 5-74. *AHRS ADC Failure.*

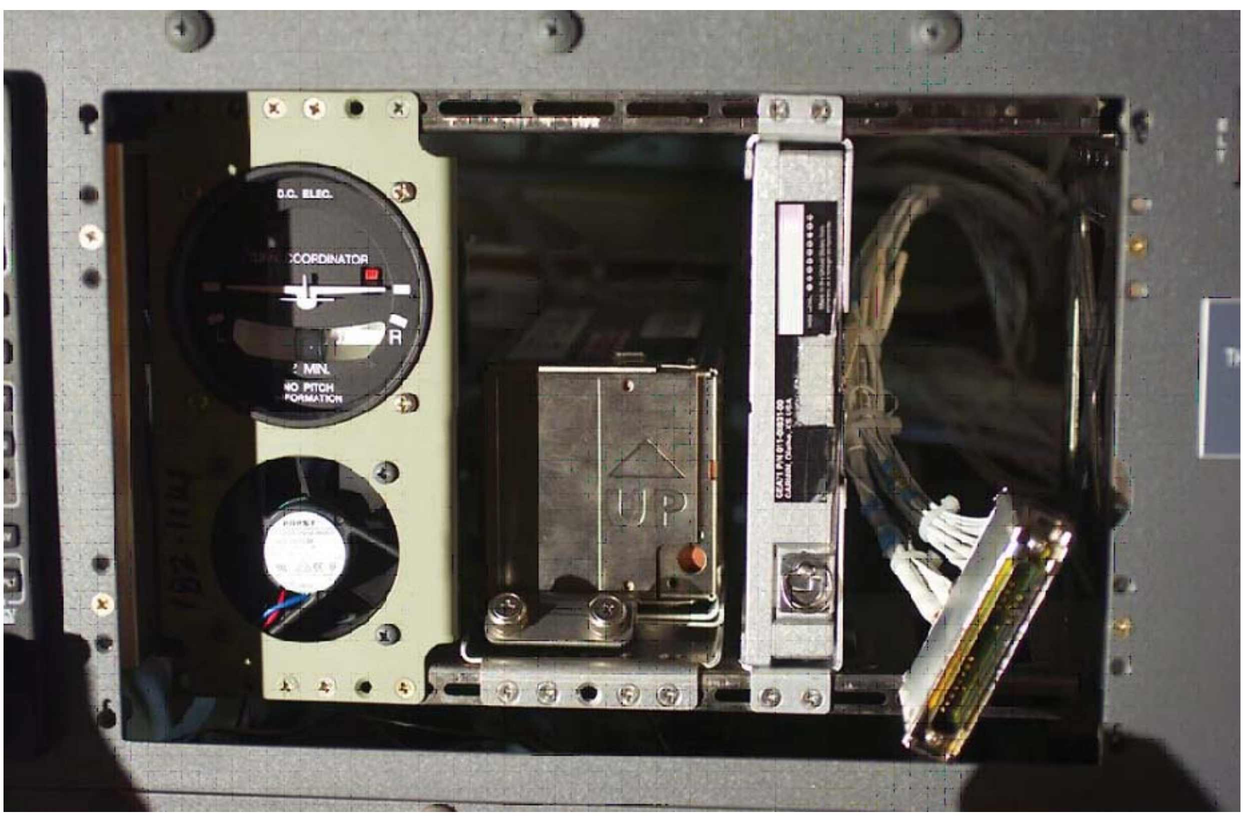


Figure 5-75. *This autopilot requires roll information from a turn coordinator.*

can lead to a distraction that causes the pilot to cease cross-checking the instruments long enough to enter an unusual attitude.

3. Fixation is displayed when a pilot focuses far too much attention on one instrument because he or she perceives something is wrong or a deviation is occurring. It is important for the instrument pilot to remember that a cross-check of several instruments for corroboration is more valuable than checking a single instrument.
4. Attempting to recover by sensory sensations other than sight. Recovery by instinct almost always leads to erroneous corrections due to the illusions that are prevalent during instrument flight.
5. Failure to practice basic attitude instrument flying. When a pilot does not fly instrument approach procedures or even basic attitude instrument flying maneuvers for long periods of time, skill levels diminish. Pilots should avoid flying in IMC if they are not proficient. They should seek a qualified instructor to receive additional instruction prior to entry into IMC.

Instrument Takeoff

The reason for learning to fly by reference to instruments alone is to expand a pilot's abilities to operate an aircraft in visibility less than VFR. Another valuable maneuver to learn is the instrument takeoff. This maneuver requires the pilot to maneuver the aircraft during the takeoff roll by reference to flight instruments alone with no outside visual reference. With practice, this maneuver becomes as routine as a standard rate turn.

The reason behind practicing instrument takeoffs is to reduce the disorientation that can occur during the transitional phase of quickly moving the eyes from the outside references inside to the flight instruments.

One EFD system currently offers what is trademarked as synthetic vision. Synthetic vision is a three-dimensional computer-generated representation of the terrain that lies ahead of the aircraft. The display shows runways as well as a depiction of the terrain features based on a GPS terrain database. Similar to a video game, the display generates a runway the pilot can maneuver down in order to maintain directional control. As long as the pilot tracks down the computer-generated runway, the aircraft will remain aligned with the actual runway.

Not all EFD systems have such an advanced visioning system. With all other systems, the pilot needs to revert to the standard procedures for instrument takeoffs. Each aircraft may require a modification to the maneuver; therefore, always obtain training on any new equipment to be used.

In order to accomplish an instrument takeoff, the aircraft needs to be maneuvered on the centerline of the runway facing the direction of departure with the nose or tail wheel straight. Assistance from the instructor may be necessary if the pilot has been taxiing while wearing a view limiting device. Lock the tail wheel, if so equipped, and hold the brakes firmly to prevent the aircraft from creeping. Cross-check the heading indicator on the PFD with the magnetic compass and adjust for any deviations noted on the compass card. Set the heading to the nearest 5° mark closest to the runway heading. This allows the pilot to quickly detect any deviations from the desired heading and allows prompt corrective actions during the takeoff roll. Using the omnibearing select (OBS) mode on the GPS, rotate the OBS selector until the needle points to the runway heading. This adds additional situational awareness during the takeoff roll. Smoothly apply power to generate sufficient rudder authority for directional control. Release the brakes and continue to advance the power to the takeoff setting.

As soon as the brakes are released, any deviation in heading needs to be corrected immediately. Avoid using brakes to control direction as this increases the takeoff roll, as well as provides the potential of overcontrolling the aircraft.

Continuously cross-check the ASI and the heading indicator as the aircraft accelerates. As the aircraft approaches 15-25 knots below the rotation speed, smoothly apply aft elevator pressure to increase the pitch attitude to the desired takeoff attitude (approximately 7° for most small airplanes). With the pitch attitude held constant, continue to cross-check the flight instruments and allow the aircraft to fly off of the runway. Do not pull the aircraft off of the runway. Pulling the aircraft off of the runway imposes left turning tendencies due to P-Factor, which will yaw the aircraft to the left and destabilize the takeoff.

Maintain the desired pitch and bank attitudes by referencing the attitude indicator and cross-check the VSI tape for an indication of a positive rate of climb. Take note of the magenta 6-second altimeter trend indicator. The trend should show positive. Barring turbulence, all trend indications should be stabilized. The airspeed trend indicator should not be visible at this point if the airspeed is being held constant. An activation of the airspeed trend indicator shows that the pitch attitude is not being held at the desired value and, therefore, the airspeed is changing. The desired performance is to be climbing at a constant airspeed and vertical speed rate. Use the ASI as the primary instrument for the pitch indication.

Once the aircraft has reached a safe altitude (approximately 100 feet for insufficient runway available for landing should an engine failure occur) retract the landing gear and flaps while referencing the ASI and attitude indicator to maintain the desired pitch. As the configuration is changed, an increase in aft control pressure is needed in order to maintain the desired pitch attitude. Smoothly increase the aft control pressure to compensate for the change in configuration. Anticipate the changes and increase the rate of cross-check. The airspeed tape and altitude tape increases while the VSI tape is held constant. Allow the aircraft to accelerate to the desired climb speed. Once the desired climb speed is reached, reduce the power to the climb power setting as printed in the POH/AFM. Trim the aircraft to eliminate any control pressures.

Common Errors in Instrument Takeoffs

Common errors associated with the instrument takeoff include, but are not limited to, the following:

1. Failure to perform an adequate flight deck check before the takeoff. Pilots have attempted instrument takeoff with inoperative airspeed indicators (pitot tube obstructed), controls locked, and numerous other oversights due to haste or carelessness. It is imperative to cross-check the ASI as soon as possible. No airspeed will be indicated until 20 knots of true airspeed is generated in some systems.
2. Improper alignment on the runway. This may result from improper brake applications, allowing the airplane to creep after alignment, or from alignment with the nosewheel or tailwheel cocked. In any case, the result is a built-in directional control problem as the takeoff starts.
3. Improper application of power. Abrupt applications of power complicate directional control. Power should be applied in a smooth and continuous manner to arrive at the takeoff power setting within approximately 3 seconds.
4. Improper use of brakes. Incorrect seat or rudder pedal adjustment, with feet in an uncomfortable position, frequently causes inadvertent application of brakes and excessive heading changes.
5. Overcontrolling rudder pedals. This fault may be caused by late recognition of heading changes, tension on the controls, misinterpretation of the heading indicator (and correcting in the wrong direction), failure to appreciate changing effectiveness of rudder control as the aircraft accelerates, and other factors. If heading changes are observed and corrected instantly with small movement of the rudder pedals, swerving tendencies can be reduced.
6. Failure to maintain attitude after becoming airborne. If the pilot reacts to seat-of-the-pants sensations when the airplane lifts off, pitch control is guesswork. The pilot may either allow excessive pitch or apply excessive forward-elevator pressure, depending on the reaction to trim changes.
7. Inadequate cross-check. Fixations are likely during the trim changes, attitude changes, gear and flap retractions, and power changes. Once an instrument or a control input is applied, continue the cross-check and note the effect control during the next cross-check sequence.
8. Inadequate interpretation of instruments. Failure to understand instrument indications immediately indicates that further study of the maneuver is necessary.

Basic Instrument Flight Patterns

After attaining a reasonable degree of proficiency in basic maneuvers, apply these skills to the various combinations of individual maneuvers. The practice flight patterns, beginning on page 5-30, are directly applicable to operational instrument flying.

Chapter 6

Helicopter Attitude Instrument Flying

Introduction

Attitude instrument flying in helicopters is essentially visual flying with the flight instruments substituted for the various reference points on the helicopter and the natural horizon. Control changes, required to produce a given attitude by reference to instruments, are identical to those used in helicopter visual flight rules (VFR) flight, and pilot thought processes are the same. Basic instrument training is intended to be a building block toward attaining an instrument rating.

Flight Instruments

When flying a helicopter with reference to the flight instruments, proper instrument interpretation is the basis for aircraft control. Skill, in part, depends on understanding how a particular instrument or system functions, including its indications and limitations (see Chapter 3, Flight Instruments). With this knowledge, a pilot can quickly interpret an instrument indication and translate that information into a control response.

Instrument Flight

To achieve smooth, positive control of the helicopter during instrument flight, three fundamental skills must be developed. They are instrument cross-check, instrument interpretation, and aircraft control.

Instrument Cross-Check

Cross-checking, sometimes referred to as scanning, is the continuous and logical observation of instruments for attitude and performance information. In attitude instrument flying, an attitude is maintained by reference to the instruments, which produces the desired result in performance. Due to human error, instrument error, and helicopter performance differences in various atmospheric and loading conditions, it is difficult to establish an attitude and have performance remain constant for a long period of time. These variables make it necessary to constantly check the instruments and make appropriate changes in the helicopter's attitude. The actual technique may vary depending on what instruments are installed and where they are installed, as well as pilot experience and proficiency level. This discussion concentrates on the six basic flight instruments. *[Figure 6-1]*

At first, there may be a tendency to cross-check rapidly, looking directly at the instruments without knowing exactly what information is needed. However, with familiarity and practice, the instrument cross-check reveals definite trends during specific flight conditions. These trends help a pilot control the helicopter as it makes a transition from one flight condition to another.

When full concentration is applied to a single instrument, a problem called fixation is encountered. This results from a natural human inclination to observe a specific instrument carefully and accurately, often to the exclusion of other instruments. Fixation on a single instrument usually results in poor control. For example, while performing a turn, there is a tendency to watch only the turn-and-slip indicator instead of including other instruments in the cross-check. This fixation on the turn-and-slip indicator often leads to a loss of altitude through poor pitch-and-bank control. Look at each

Figure 6-1. *In most situations, the cross-check pattern includes the attitude indicator between the cross-check of each of the other instruments. A typical cross-check might progress as follows: attitude indicator, altimeter, attitude indicator, vertical speed indicator, attitude indicator, heading indicator, attitude indicator, and so on.*

instrument only long enough to understand the information it presents, and then proceed to the next one. Similarly, too much emphasis can be placed on a single instrument, instead of relying on a combination of instruments necessary for helicopter performance information. This differs from fixation in that other instruments are included in a cross-check, but too much attention is placed on one particular instrument.

During performance of a maneuver, there is sometimes a failure to anticipate significant instrument indications following attitude changes. For example, during level off from a climb or descent, a pilot may concentrate on pitch control, while forgetting about heading or roll information. This error, called omission, results in erratic control of heading and bank.

In spite of these common errors, most pilots can adapt well to flight by instrument reference after instruction and practice. Many find that they can control the helicopter more easily and precisely by instruments.

Instrument Interpretation

The flight instruments together give a picture of what is happening. No one instrument is more important than the next; however, during certain maneuvers or conditions, those instruments that provide the most pertinent and useful information are termed primary instruments. Those which back up and supplement the primary instruments are termed supporting instruments. For example, since the attitude indicator is the only instrument that provides instant and direct aircraft attitude information, it should be considered primary during any change in pitch or bank attitude. After the new attitude is established, other instruments become primary, and the attitude indicator usually becomes the supporting instrument.

Aircraft Control

Controlling a helicopter is the result of accurately interpreting the flight instruments and translating these readings into correct control responses. Aircraft control involves adjustment to pitch, bank, power, and trim in order to achieve a desired flight path.

Pitch attitude control is controlling the movement of the helicopter about its lateral axis. After interpreting the helicopter's pitch attitude by reference to the pitch instruments (attitude indicator, altimeter, airspeed indicator, and vertical speed indicator (VSI)), cyclic control adjustments are made to affect the desired pitch attitude. In this chapter, the pitch attitudes depicted are approximate and vary with different helicopters.

Bank attitude control is controlling the angle made by the lateral tilt of the rotor and the natural horizon, or the movement of the helicopter about its longitudinal axis. After interpreting the helicopter's bank instruments (attitude indicator, heading indicator, and turn indicator), cyclic control adjustments are made to attain the desired bank attitude.

Power control is the application of collective pitch with corresponding throttle control, where applicable. In straight-and-level flight, changes of collective pitch are made to correct for altitude deviation if the error is more than 100 feet, or the airspeed is off by more than 10 knots. If the error is less than that amount, a pilot should use a slight cyclic climb or descent.

In order to fly a helicopter by reference to the instruments, it is important to know the approximate power settings required for a particular helicopter in various load configurations and flight conditions.

Trim, in helicopters, refers to the use of the cyclic centering button, if the helicopter is so equipped, to relieve all possible cyclic pressures. Trim also refers to the use of pedal adjustment to center the ball of the turn indicator. Pedal trim is required during all power changes.

The proper adjustment of collective pitch and cyclic friction helps a pilot relax during instrument flight. Friction should be adjusted to minimize overcontrolling and to prevent creeping, but not applied to such a degree that control movement is limited. In addition, many helicopters equipped for instrument flight contain stability augmentation systems or an autopilot to help relieve pilot workload.

Straight-and-Level Flight

Straight-and-level unaccelerated flight consists of maintaining the desired altitude, heading, airspeed, and pedal trim.

Pitch Control

The pitch attitude of a helicopter is the angular relation of its longitudinal axis to the natural horizon. If available, the attitude indicator is used to establish the desired pitch attitude. In level flight, pitch attitude varies with airspeed and center of gravity (CG). At a constant altitude and a stabilized airspeed, the pitch attitude is approximately level. *[Figure 6-2]*

Attitude Indicator

The attitude indicator gives a direct indication of the pitch attitude of the helicopter. In visual flight, attain the desired pitch attitude by using the cyclic to raise and lower the nose

Figure 6-2. *The flight instruments for pitch control are the airspeed indicator, attitude indicator, altimeter, and vertical speed indicator.*

of the helicopter in relation to the natural horizon. During instrument flight, follow exactly the same procedure in raising or lowering the miniature aircraft in relation to the horizon bar.

There is some delay between control application and resultant instrument change. This is the normal control lag in the helicopter and should not be confused with instrument lag. The attitude indicator may show small misrepresentations of pitch attitude during maneuvers involving acceleration, deceleration, or turns. This precession error can be detected quickly by cross-checking the other pitch instruments.

If the miniature aircraft is properly adjusted on the ground, it may not require readjustment in flight. If the miniature aircraft is not on the horizon bar after level off at normal cruising airspeed, adjust it as necessary while maintaining level flight with the other pitch instruments. Once the miniature aircraft has been adjusted in level flight at normal cruising airspeed, leave it unchanged so it gives an accurate picture of pitch attitude at all times.

When making initial pitch attitude corrections to maintain altitude, the changes of attitude should be small and smoothly applied. The initial movement of the horizon bar should not exceed one bar width high or low. *[Figure 6-3]* If a further adjustment is required, an additional correction of one-half bar normally corrects any deviation from the desired altitude. This one-and-one-half bar correction is normally the maximum pitch attitude correction from level flight attitude.

After making the correction, cross-check the other pitch instruments to determine whether the pitch attitude change is sufficient. If additional correction is needed to return to altitude, or if the airspeed varies more than 10 knots from that desired, adjust the power.

Altimeter

The altimeter gives an indirect indication of the pitch attitude of the helicopter in straight-and-level flight. Since the altitude should remain constant in level flight, deviation from the desired altitude indicates a need for a change in pitch attitude and power as necessary. When losing altitude, raise the pitch attitude and adjust power as necessary. When gaining altitude, lower the pitch attitude and adjust power as necessary. Indications for power changes are explained in the next paragraph.

The rate at which the altimeter moves helps to determine pitch attitude. A very slow movement of the altimeter indicates a small deviation from the desired pitch attitude, while a

Figure 6-3. *The initial pitch correction at normal cruise is one bar width or less.*

fast movement of the altimeter indicates a large deviation from the desired pitch attitude. Make any corrective action promptly, with small control changes. Also, remember that movement of the altimeter should always be corrected by two distinct changes. The first is a change of attitude to stop the altimeter movement; the second is a change of attitude to return smoothly to the desired altitude. If altitude and airspeed are more than 100 feet and 10 knots low, respectively, apply power in addition to an increase of pitch attitude. If the altitude and airspeed are high by more than 100 feet and 10 knots, reduce power and lower the pitch attitude.

There is a small lag in the movement of the altimeter; however, for all practical purposes, consider that the altimeter gives an immediate indication of a change, or a need for change in pitch attitude. Since the altimeter provides the most pertinent information regarding pitch in level flight, it is considered primary for pitch.

Vertical Speed Indicator (VSI)

The VSI gives an indirect indication of the pitch attitude of the helicopter and should be used in conjunction with the other pitch instruments to attain a high degree of accuracy and precision. The instrument indicates zero when in level flight. Any movement of the needle from the zero position shows a need for an immediate change in pitch attitude to return it to zero. Always use the VSI in conjunction with the altimeter in level flight. If a movement of the VSI is detected, immediately use the proper corrective measures to return it to zero. If the correction is made promptly, there is usually little or no change in altitude. If the needle of the VSI does not indicate zero, the altimeter indicates a gain or loss of altitude.

The initial movement of the vertical speed needle is instantaneous and indicates the trend of the vertical movement of the helicopter. A period of time is necessary for the VSI to reach its maximum point of deflection after a correction has been made. This time element is commonly referred to as instrument lag. The lag is directly proportional to the speed and magnitude of the pitch change. When employing smooth control techniques and small adjustments in pitch attitude are made, lag is minimized, and the VSI is easy to interpret.

Overcontrolling can be minimized by first neutralizing the controls and allowing the pitch attitude to stabilize, then readjusting the pitch attitude by noting the indications of the other pitch instruments.

Occasionally, the VSI may be slightly out of calibration. This could result in the instrument indicating a slight climb or descent even when the helicopter is in level flight. If the instrument cannot be calibrated properly, this error must be taken into consideration when using the VSI for pitch control. For example, if a descent of 100 feet per minute (fpm) is the vertical speed indication when the helicopter is in level flight, use that indication as level flight. Any deviation from that reading would indicate a change in attitude.

Airspeed Indicator

The airspeed indicator gives an indirect indication of helicopter pitch attitude. With a given power setting and pitch attitude, the airspeed remains constant. If the airspeed increases, the nose is too low and should be raised. If the airspeed decreases, the nose is too high and should be lowered. A rapid change in airspeed indicates a large change in pitch attitude, and a slow change in airspeed indicates a small change in pitch attitude. There is very little lag in the indications of the airspeed indicator. If, while making attitude changes, there is some lag between control application and change of airspeed, it is most likely due to cyclic control lag. Generally, a departure from the desired airspeed, due to an inadvertent pitch attitude change, also results in a change in altitude. For example, an increase in airspeed due to a low pitch attitude results in a decrease in altitude. A correction in the pitch attitude regains both airspeed and altitude.

Bank Control

The bank attitude of a helicopter is the angular relation of its lateral axis to the natural horizon. To maintain a straight course in visual flight, keep the lateral axis of the helicopter level with the natural horizon. Assuming the helicopter is in coordinated flight, any deviation from a laterally level attitude produces a turn. *[Figure 6-4]*

Attitude Indicator

The attitude indicator gives a direct indication of the bank attitude of the helicopter. For instrument flight, the miniature aircraft and the horizon bar of the attitude indicator are substituted for the actual helicopter and the natural horizon. Any change in bank attitude of the helicopter is indicated instantly by the miniature aircraft. For proper interpretation of this instrument, imagine being in the miniature aircraft. If the helicopter is properly trimmed and the rotor tilts, a turn begins. The turn can be stopped by leveling the miniature aircraft with the horizon bar. The ball in the turn-and-slip indicator should always be kept centered through proper pedal trim.

The angle of bank is indicated by the pointer on the banking scale at the top of the instrument. *[Figure 6-5]* Small bank angles, which may not be seen by observing the miniature aircraft, can easily be determined by referring to the banking scale pointer.

Figure 6-4. *The flight instruments used for bank control are the attitude, heading, and turn indicators.*

Pitch-and-bank attitudes can be determined simultaneously on the attitude indicator. Even though the miniature aircraft is not level with the horizon bar, pitch attitude can be established by observing the relative position of the miniature aircraft and the horizon bar.

The attitude indicator may show small misrepresentations of bank attitude during maneuvers that involve turns. This precession error can be detected immediately by closely cross-checking the other bank instruments during these maneuvers. Precession is normally noticed when rolling out of a turn. If, upon completion of a turn, the miniature aircraft is level and the helicopter is still turning, make a small change of bank attitude to center the turn needle and stop the movement of the heading indicator.

Heading Indicator

In coordinated flight, the heading indicator gives an indirect indication of a helicopter's bank attitude. When a helicopter is banked, it turns. When the lateral axis of a helicopter is level, it flies straight. Therefore, in coordinated flight when the heading indicator shows a constant heading, the helicopter is level laterally. A deviation from the desired heading indicates a bank in the direction the helicopter is turning. A small angle of bank is indicated by a slow change of heading; a large angle of bank is indicated by a rapid change of heading. If a turn is noticed, apply opposite cyclic until the heading indicator

Figure 6-5. *The banking scale at the top of the attitude indicator indicates varying degrees of bank. In this example, the helicopter is banked approximately 15° to the right.*

indicates the desired heading, simultaneously ensuring the ball is centered. When making the correction to the desired heading, do not use a bank angle greater than that required to achieve a standard rate turn. In addition, if the number of degrees of change is small, limit the bank angle to the number of degrees to be turned. Bank angles greater than these require more skill and precision in attaining the desired results. During straight-and-level flight, the heading indicator is the primary reference for bank control.

Turn Indicator

During coordinated flight, the needle of the turn-and-slip indicator gives an indirect indication of the bank attitude of the helicopter. When the needle is displaced from the vertical position, the helicopter is turning in the direction of the displacement. Thus, if the needle is displaced to the left, the helicopter is turning left. Bringing the needle back to the vertical position with the cyclic produces straight flight. A close observation of the needle is necessary to accurately interpret small deviations from the desired position.

Cross-check the ball of the turn-and-slip indicator to determine if the helicopter is in coordinated flight. *[Figure 6-6]* If the rotor is laterally level and pedal pressure properly compensates for torque, the ball remains in the center. To center the ball, level the helicopter laterally by reference to the other bank instruments, then center the ball with pedal trim. Torque correction pressures vary as power changes are made. Always check the ball after such changes.

Common Errors During Straight-and-Level Flight

1. Failure to maintain altitude
2. Failure to maintain heading
3. Overcontrolling pitch and bank during corrections
4. Failure to maintain proper pedal trim
5. Failure to cross-check all available instruments

Power Control During Straight-and-Level Flight

Establishing specific power settings is accomplished through collective pitch adjustments and throttle control, where necessary. For reciprocating-powered helicopters, power indication is observed on the manifold pressure gauge. For turbine-powered helicopters, power is observed on the torque gauge. (Although most Instrument Flight Rules (IFR)-certified helicopters are turbine powered, depictions within this chapter use a reciprocating-powered helicopter as this is where training is most likely conducted.)

At any given airspeed, a specific power setting determines whether the helicopter is in level flight, in a climb, or in a descent. For example, cruising airspeed maintained with cruising power results in level flight. If a pilot increases the power setting and holds the airspeed constant, the helicopter climbs. Conversely, if the pilot decreases power and holds the airspeed constant, the helicopter descends.

Figure 6-6. *Coordinated flight is indicated by centering of the ball.*

If the altitude is held constant, power determines the airspeed. For example, at a constant altitude, cruising power results in cruising airspeed. Any deviation from the cruising power setting results in a change of airspeed. When power is added to increase airspeed, the nose of the helicopter pitches up and yaws to the right in a helicopter with a counterclockwise main rotor blade rotation. *[Figure 6-7]* When power is reduced to decrease airspeed, the nose pitches down and yaws to the left. *[Figure 6-8]* The yawing effect is most pronounced in single-rotor helicopters, and is absent in helicopters with counter-rotating rotors. To counteract the yawing tendency of the helicopter, apply pedal trim during power changes.

To maintain a constant altitude and airspeed in level flight, coordinate pitch attitude and power control. The relationship between altitude and airspeed determines the need for a change in power and/or pitch attitude. If the altitude is constant and the airspeed is high or low, change the power to obtain the desired airspeed. During the change in power, make an accurate interpretation of the altimeter, then counteract any deviation from the desired altitude by an appropriate change of pitch attitude. If the altitude is low and the airspeed is high, or vice versa, a change in pitch attitude alone may return the helicopter to the proper altitude and airspeed. If both airspeed and altitude are low, or if both are high, changes in both power and pitch attitude are necessary.

To make power control easy when changing airspeed, it is necessary to know the approximate power settings for the various airspeeds at which the helicopter is flown. When the airspeed is to be changed by any appreciable amount, adjust the power so that it is over or under that setting necessary to maintain the new airspeed. As the power approaches the desired setting, include the manifold pressure in the cross-check to determine when the proper adjustment has been accomplished. As the airspeed is changing, adjust the pitch attitude to maintain a constant altitude. A constant heading should be maintained throughout the change. As the desired airspeed is approached, adjust power to the new cruising power setting and further adjust pitch attitude to maintain altitude. The instrument indications for straight-and-level flight at normal cruise and during the transition from normal cruise to slow cruise are illustrated in *Figures 6-9* and *6-10*. After the airspeed stabilizes at slow cruise, the attitude indicator shows an approximate level pitch attitude.

The altimeter is the primary pitch instrument during level flight, whether flying at a constant airspeed or during a change in airspeed. Altitude should not change during airspeed transitions, and the heading indicator remains the primary bank instrument. Whenever the airspeed is changed by an appreciable amount, the manifold pressure gauge is momentarily the primary instrument for power control. When the airspeed approaches the desired reading, the airspeed indicator again becomes the primary instrument for power control.

Figure 6-7. *Flight instrument indications in straight-and-level flight with power increasing.*

Figure 6-8. *Flight instrument indications in straight-and-level flight with power decreasing.*

Figure 6-9. *Flight instrument indications in straight-and-level flight at normal cruise speed.*

Figure 6-10. *Flight instrument indications in straight-and-level flight with airspeed decreasing.*

To produce straight-and-level flight, the cross-check of the pitch-and-bank instruments should be combined with the power control instruments. With a constant power setting, a normal cross-check should be satisfactory. When changing power, the speed of the cross-check must be increased to cover the pitch-and-bank instruments adequately. This is necessary to counteract any deviations immediately.

Common Errors During Airspeed Changes

1. Improper use of power
2. Overcontrolling pitch attitude
3. Failure to maintain heading
4. Failure to maintain altitude
5. Improper pedal trim

Straight Climbs (Constant Airspeed and Constant Rate)

For any power setting and load condition, there is only one airspeed that gives the most efficient rate of climb. To determine this, consult the climb data for the type of helicopter being flown. The technique varies according to the airspeed on entry and whether a constant airspeed or constant rate climb is made.

Entry

To enter a constant airspeed climb from cruise airspeed when the climb speed is lower than cruise speed, simultaneously increase power to the climb power setting and adjust pitch attitude to the approximate climb attitude. The increase in power causes the helicopter to start climbing and only very slight back cyclic pressure is needed to complete the change from level to climb attitude. The attitude indicator should be used to accomplish the pitch change. If the transition from level flight to a climb is smooth, the VSI shows an immediate upward trend and then stops at a rate appropriate to the stabilized airspeed and attitude. Primary and supporting instruments for climb entry are illustrated in *Figure 6-11*.

When the helicopter stabilizes at a constant airspeed and attitude, the airspeed indicator becomes primary for pitch. The manifold pressure continues to be primary for power and should be monitored closely to determine if the proper climb power setting is being maintained. Primary and supporting instruments for a stabilized constant airspeed climb are shown in *Figure 6-12*.

The technique and procedures for entering a constant rate climb are very similar to those previously described for a constant airspeed climb. For training purposes, a constant

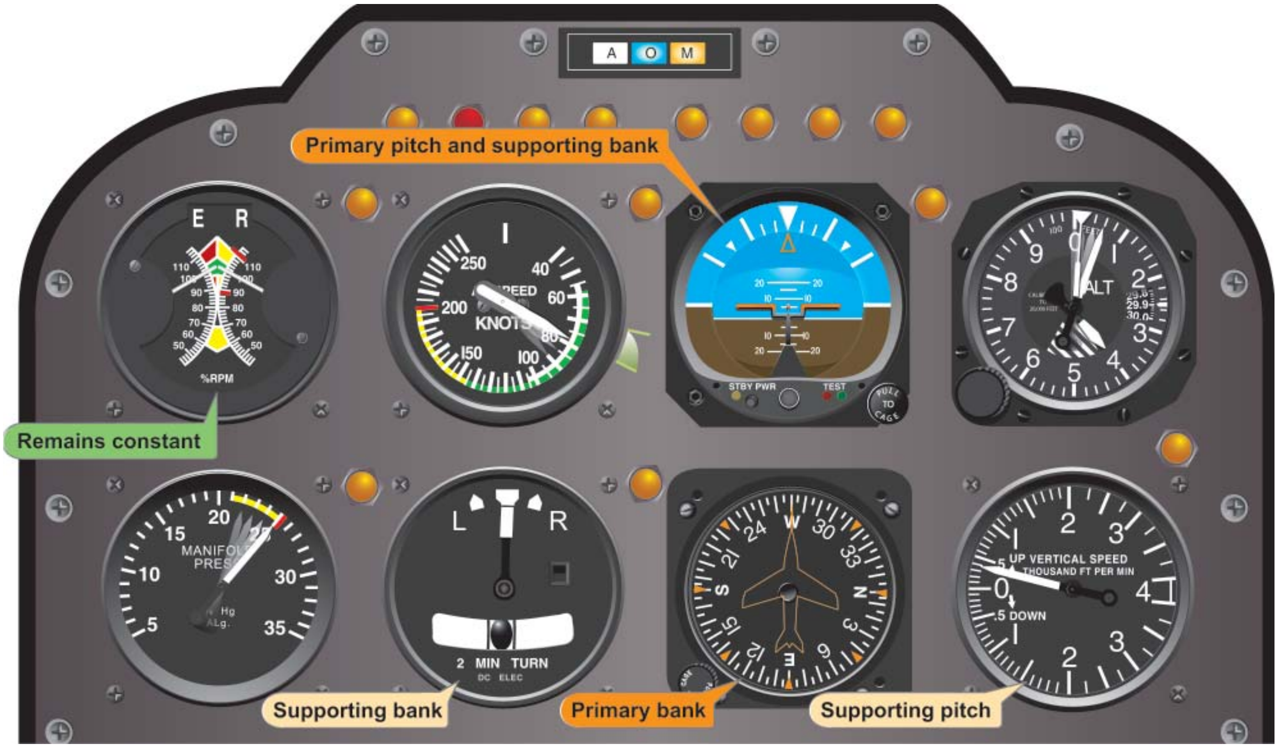


Figure 6-11. *Flight instrument indications during climb entry for a constant-airspeed climb.*

Figure 6-12. *Flight instrument indications in a stabilized constant-airspeed climb.*

rate climb is entered from climb airspeed. Use the rate appropriate for the particular helicopter being flown. Normally, in helicopters with low climb rates, 500 fpm is appropriate. In helicopters capable of high climb rates, use a rate of 1,000 fpm.

To enter a constant rate climb, increase power to the approximate setting for the desired rate. As power is applied, the airspeed indicator is primary for pitch until the vertical speed approaches the desired rate. At this time, the VSI becomes primary for pitch. Change pitch attitude by reference to the attitude indicator to maintain the desired vertical speed. When the VSI becomes primary for pitch, the airspeed indicator becomes primary for power. Primary and supporting instruments for a stabilized constant rate climb are illustrated in *Figure 6-13*. Adjust power to maintain desired airspeed. Pitch attitude and power corrections should be closely coordinated. To illustrate this, if the vertical speed is correct but the airspeed is low, add power. As power is increased, it may be necessary to lower the pitch attitude slightly to avoid increasing the vertical rate. Adjust the pitch attitude smoothly to avoid overcontrolling. Small power corrections are usually sufficient to bring the airspeed back to the desired indication.

Level Off

The level off from a constant airspeed climb must be started before reaching the desired altitude. Although the amount of lead varies with the type of helicopter being flown and pilot technique, the most important factor is vertical speed. As a rule of thumb, use 10 percent of the vertical velocity as the lead point. For example, if the rate of climb is 500 fpm, initiate the level off approximately 50 feet before the desired altitude. When the proper lead altitude is reached, the altimeter becomes primary for pitch. Adjust the pitch attitude to the level flight attitude for that airspeed. Cross-check the altimeter and VSI to determine when level flight has been attained at the desired altitude. If cruise airspeed is higher than climb airspeed, leave the power at the climb power setting until the airspeed approaches cruise airspeed, and then reduce it to the cruise power setting. The level off from a constant rate climb is accomplished in the same manner as the level off from a constant airspeed climb.

Straight Descents (Constant Airspeed and Constant Rate)

A descent may be performed at any normal airspeed the helicopter can attain, but the airspeed must be determined prior to entry. The technique is determined by the type of descent, a constant airspeed or a constant rate.

Entry

If airspeed is higher than descending airspeed, and a constant airspeed descent is desired, reduce power to a descent power setting and maintain a constant altitude using cyclic pitch control. This slows the helicopter. As the helicopter

Figure 6-13. *Flight Instrument Indications in a Stabilized Constant-Rate Climb.*

approaches the descending airspeed, the airspeed indicator becomes primary for pitch and the manifold pressure is primary for power. Holding the airspeed constant causes the helicopter to descend. For a constant rate descent, reduce the power to the approximate setting for the desired rate. If the descent is started at the descending airspeed, the airspeed indicator is primary for pitch until the VSI approaches the desired rate. At this time, the VSI becomes primary for pitch, and the airspeed indicator becomes primary for power. Coordinate power and pitch attitude control as previously described on page 6-10 for constant rate climbs.

Level Off

The level off from a constant airspeed descent may be made at descending airspeed or at cruise airspeed, if this is higher than descending airspeed. As in a climb level off, the amount of lead depends on the rate of descent and control technique. For a level off at descending airspeed, the lead should be approximately 10 percent of the vertical speed. At the lead altitude, simultaneously increase power to the setting necessary to maintain descending airspeed in level flight. At this point, the altimeter becomes primary for pitch, and the airspeed indicator becomes primary for power.

To level off at an airspeed higher than descending airspeed, increase the power approximately 100 to 150 feet prior to reaching the desired altitude. The power setting should be that which is necessary to maintain the desired airspeed in level flight. Hold the vertical speed constant until approximately 50 feet above the desired altitude. At this point, the altimeter becomes primary for pitch and the airspeed indicator becomes primary for power. The level off from a constant rate descent should be accomplished in the same manner as the level off from a constant airspeed descent.

Common Errors During Straight Climbs and Descents

1. Failure to maintain heading
2. Improper use of power
3. Poor control of pitch attitude
4. Failure to maintain proper pedal trim
5. Failure to level off on desired altitude

Turns

Turns made by reference to the flight instruments should be made at a precise rate. Turns described in this chapter are those not exceeding a standard rate of 3° per second as indicated on the turn-and-slip indicator. True airspeed determines the angle of bank necessary to maintain a standard rate turn. A rule of thumb to determine the approximate angle of bank required for a standard rate turn is to use 15 percent of the airspeed. A simple way to determine this amount is to divide the airspeed by 10 and add one-half the result. For example, at 60 knots approximately 9° of bank is required (60 ÷ 10 = 6, 6 + 3 = 9); at 80 knots approximately 12° of bank is needed for a standard rate turn.

To enter a turn, apply lateral cyclic in the direction of the desired turn. The entry should be accomplished smoothly, using the attitude indicator to establish the approximate bank angle. When the turn indicator indicates a standard rate turn, it becomes primary for bank. The attitude indicator now becomes a supporting instrument. During level turns, the altimeter is primary for pitch, and the airspeed indicator is primary for power. Primary and supporting instruments for a stabilized standard rate turn are illustrated in *Figure 6-14*. If an increase in power is required to maintain airspeed, slight forward cyclic pressure may be required since the helicopter tends to pitch up as collective pitch is increased. Apply pedal trim, as required, to keep the ball centered.

To recover to straight-and-level flight, apply cyclic in the direction opposite the turn. The rate of roll-out should be the same as the rate used when rolling into the turn. As the turn recovery is initiated, the attitude indicator becomes primary for bank. When the helicopter is approximately level, the heading indicator becomes primary for bank as in straight-and-level flight. Cross-check the airspeed indicator and ball closely to maintain the desired airspeed and pedal trim.

Turn to a Predetermined Heading

A helicopter turns as long as its lateral axis is tilted; therefore, the recovery must start before the desired heading is reached. The amount of lead varies with the rate of turn and piloting technique.

As a guide, when making a 3° per second rate of turn, use a lead of one-half the bank angle. For example, if using a 12° bank angle, use half of that, or 6°, as the lead point prior to the desired heading. Use this lead until the exact amount required by a particular technique can be determined. The bank angle should never exceed the number of degrees to be turned. As in any standard rate turn, the rate of recovery should be the same as the rate of entry. During turns to predetermined headings, cross-check the primary and supporting pitch, bank, and power instruments closely.

Timed Turns

A timed turn is a turn in which the clock and turn-and-slip indicator are used to change heading a definite number of degrees in a given time. For example, using a standard rate turn, a helicopter turns 45° in 15 seconds. Using a half-

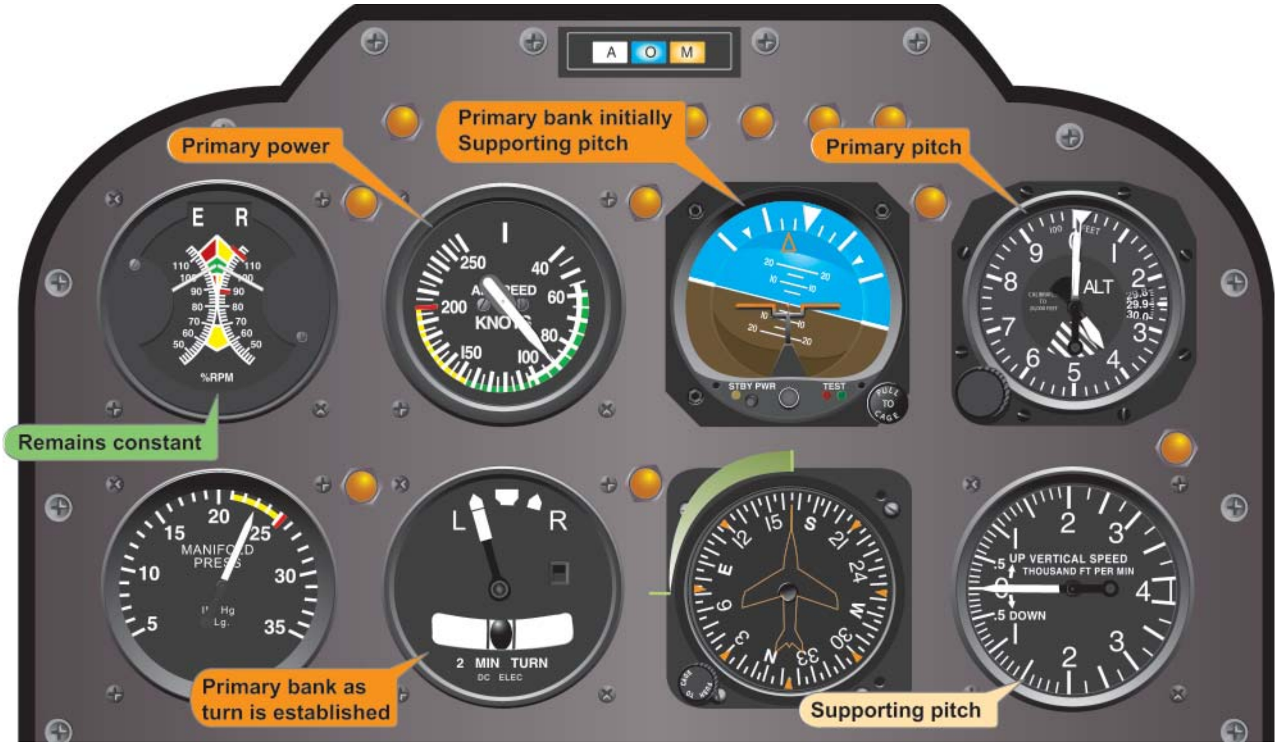


Figure 6-14. *Flight Instrument Indications in a Standard-Rate Turn to the Left.*

standard rate turn, the helicopter turns 45° in 30 seconds. Timed turns can be used if the heading indicator becomes inoperative.

Prior to performing timed turns, the turn coordinator should be calibrated to determine the accuracy of its indications. To do this, establish a standard rate turn by referring to the turn-and-slip indicator. Then, as the sweep second hand of the clock passes a cardinal point (12, 3, 6, or 9), check the heading on the heading indicator. While holding the indicated rate of turn constant, note the heading changes at 10-second intervals. If the helicopter turns more or less than 30° in that interval, a smaller or larger deflection of the needle is necessary to produce a standard rate turn. After the turn-and-slip indicator has been calibrated during turns in each direction, note the corrected deflections, if any, and apply them during all timed turns.

Use the same cross-check and control technique in making timed turns that is used to make turns to a predetermined heading, but substitute the clock for the heading indicator. The needle of the turn-and-slip indicator is primary for bank control, the altimeter is primary for pitch control, and the airspeed indicator is primary for power control. Begin the roll-in when the clock's second hand passes a cardinal point; hold the turn at the calibrated standard rate indication, or half-standard rate for small changes in heading; then begin the roll-out when the computed number of seconds has elapsed. If the roll-in and roll-out rates are the same, the time taken during entry and recovery need not be considered in the time computation.

If practicing timed turns with a full instrument panel, check the heading indicator for the accuracy of the turns. If executing turns without the heading indicator, use the magnetic compass at the completion of the turn to check turn accuracy, taking compass deviation errors into consideration.

Change of Airspeed in Turns

Changing airspeed in turns is an effective maneuver for increasing proficiency in all three basic instrument skills. Since the maneuver involves simultaneous changes in all components of control, proper execution requires a rapid cross-check and interpretation, as well as smooth control. Proficiency in the maneuver also contributes to confidence in the instruments during attitude and power changes involved in more complex maneuvers.

Pitch and power control techniques are the same as those used during airspeed changes in straight-and-level flight. As discussed previously, the angle of bank necessary for a given rate of turn is proportional to the true airspeed. Since the turns are executed at standard rate, the angle of bank must be varied in direct proportion to the airspeed change in order to maintain a constant rate of turn. During a reduction of airspeed, decrease the angle of bank and increase the pitch attitude to maintain altitude and a standard rate turn.

Altimeter and turn indicator readings should remain constant throughout the turn. The altimeter is primary for pitch control, and the turn needle is primary for bank control. Manifold pressure is primary for power control while the airspeed is changing. As the airspeed approaches the new indication, the airspeed indicator becomes primary for power control.

Two methods of changing airspeed in turns may be used. In the first method, airspeed is changed after the turn is established. In the second method, the airspeed change is initiated simultaneously with the turn entry. The first method is easier, but regardless of the method used, the rate of cross-check must be increased as power is reduced. As the helicopter decelerates, check the altimeter and VSI for needed pitch changes, and the bank instruments for needed bank changes. If the needle of the turn-and-slip indicator shows a deviation from the desired deflection, change the bank. Adjust pitch attitude to maintain altitude. When the airspeed approaches that desired, the airspeed indicator becomes primary for power control. Adjust the power to maintain the desired airspeed. Use pedal trim to ensure the maneuver is coordinated.

Until control technique is very smooth, frequently cross-check the attitude indicator to keep from overcontrolling and to provide approximate bank angles appropriate for the changing airspeeds.

Compass Turns

The use of gyroscopic heading indicators makes heading control very easy. However, if the heading indicator fails or the helicopter is not equipped with one, use the magnetic compass for heading reference. When making compass-only turns, a pilot needs to adjust for the lead or lag created by acceleration and deceleration errors so that the helicopter rolls out on the desired heading. When turning to a heading of north, the lead for the roll-out must include the number of degrees of latitude plus the lead normally used in recovery from turns. During a turn to a south heading, maintain the turn until the compass passes south the number of degrees of latitude, minus the normal roll-out lead. For example, when turning from an easterly direction to north, where the latitude is 30°, start the roll-out when the compass reads 37° (30° plus one-half the 15° angle of bank, or whatever amount is appropriate for the rate of roll-out). When turning from an easterly direction to south, start the roll-out when the magnetic compass reads 203° (180° plus 30° minus one-half the angle of bank). When making similar turns from a westerly direction, the appropriate points at which to begin the roll-out would be 323° for a turn to north, and 157° for a turn to south.

30° Bank Turn

A turn using 30° of bank is seldom necessary or advisable in instrument meteorological conditions (IMC), and is considered an unusual attitude in a helicopter. However, it is an excellent maneuver to practice to increase the ability to react quickly and smoothly to rapid changes of attitude. Even though the entry and recovery techniques are the same as for any other turn, it is more difficult to control pitch because of the decrease in vertical lift as the bank increases. Also, because of the decrease in vertical lift, there is a tendency to lose altitude and/or airspeed. Therefore, to maintain a constant altitude and airspeed, additional power is required. Do not initiate a correction, however, until the instruments indicate the need for one. During the maneuver, note the need for a correction on the altimeter and VSI, check the attitude indicator, and then make the necessary adjustments. After making a change, check the altimeter and VSI again to determine whether or not the correction was adequate.

Climbing and Descending Turns

For climbing and descending turns, the techniques described previously for straight climbs, descents, and standard rate turns are combined. For practice, simultaneously turn and start the climb or descent. The primary and supporting instruments for a stabilized constant airspeed left climbing turn are illustrated in *Figure 6-15*. The level off from a climbing or descending turn is the same as the level off from a straight climb or descent. To return to straight-and-level flight, stop the turn and then level off, or level off and then stop the turn, or simultaneously level off and stop the turn. During climbing and descending turns, keep the ball of the turn indicator centered with pedal trim.

Common Errors During Turns

1. Failure to maintain desired turn rate
2. Failure to maintain altitude in level turns
3. Failure to maintain desired airspeed
4. Variation in the rate of entry and recovery
5. Failure to use proper lead in turns to a heading
6. Failure to properly compute time during timed turns
7. Failure to use proper leads and lags during the compass turns
8. Improper use of power
9. Failure to use proper pedal trim

Unusual Attitudes

Any maneuver not required for normal helicopter instrument flight is an unusual attitude and may be caused by any one or combination of factors such as turbulence, disorientation, instrument failure, confusion, preoccupation with flight deck duties, carelessness in cross-checking, errors in instrument interpretation, or lack of proficiency in aircraft control. Due to the instability characteristics of the helicopter, unusual attitudes can be extremely critical. As soon as an unusual attitude is detected, make a recovery to straight-and-level flight as soon as possible with a minimum loss of altitude.

To recover from an unusual attitude, a pilot should correct bank-and-pitch attitude and adjust power as necessary. All components are changed almost simultaneously, with little lead of one over the other. A pilot must be able to perform this task with and without the attitude indicator. If the helicopter is in a climbing or descending turn, adjust bank, pitch, and power. The bank attitude should be corrected by referring to the turn-and-slip indicator and attitude indicator. Pitch attitude should be corrected by reference to the altimeter, airspeed indicator, VSI, and attitude indicator. Adjust power by referring to the airspeed indicator and manifold pressure.

Since the displacement of the controls used in recovery from unusual attitudes may be greater than those used for normal flight, make careful adjustments as straight-and-level flight is approached. Cross-check the other instruments closely to avoid overcontrolling.

Common Errors During Unusual Attitude Recoveries

1. Failure to make proper pitch correction
2. Failure to make proper bank correction
3. Failure to make proper power correction
4. Overcontrolling pitch and/or bank attitude
5. Overcontrolling power
6. Excessive loss of altitude

Emergencies

Emergencies during instrument flight are handled similarly to those occurring during VFR flight. A thorough knowledge of the helicopter and its systems, as well as good aeronautical knowledge and judgment, is the best preparation for emergency situations. Safe operations begin with preflight planning and a thorough preflight inspection. Plan a route of flight to include adequate landing sites in the event of an emergency landing. Make sure all resources, such as maps, publications, flashlights, and fire extinguishers are readily available for use in an emergency.

During any emergency, first fly the aircraft. This means ensure the helicopter is under control, and determine emergency

Figure 6-15. *Flight Instrument Indications for a Stabilized Left Climbing Turn at a Constant Airspeed.*

landing sites. Then perform the emergency checklist memory items, followed by items written in the rotorcraft flight manual (RFM). When all these items are under control, notify air traffic control (ATC). Declare any emergency on the last assigned ATC frequency. If one was not issued, transmit on the emergency frequency 121.5. Set the transponder to the emergency squawk code 7700. This code triggers an alarm or special indicator in radar facilities.

When experiencing most in-flight emergencies, such as low fuel or complete electrical failure, land as soon as possible. In the event of an electrical fire, turn off all nonessential equipment and land immediately. Some essential electrical instruments, such as the attitude indicator, may be required for a safe landing. A navigation radio failure may not require an immediate landing if the flight can continue safely. In this case, land as soon as practical. ATC may be able to provide vectors to a safe landing area. For specific details on what to do during an emergency, refer to the RFM for the helicopter.

Autorotations

Both straight-ahead and turning autorotations should be practiced by reference to instruments. This training ensures prompt corrective action to maintain positive aircraft control in the event of an engine failure.

To enter autorotation, reduce collective pitch smoothly to maintain a safe rotor RPM and apply pedal trim to keep the ball of the turn-and-slip indicator centered. The pitch attitude of the helicopter should be approximately level as shown by the attitude indicator. The airspeed indicator is the primary pitch instrument and should be adjusted to the recommended autorotation speed. The heading indicator is primary for bank in a straight-ahead autorotation. In a turning autorotation, a standard rate turn should be maintained by reference to the needle of the turn-and-slip indicator.

Common Errors During Autorotations

1. Uncoordinated entry due to improper pedal trim
2. Poor airspeed control due to improper pitch attitude
3. Poor heading control in straight-ahead autorotations
4. Failure to maintain proper rotor RPM
5. Failure to maintain a standard rate turn during turning autorotations

Servo Failure

Most helicopters certified for single-pilot IFR flight are required to have autopilots, which greatly reduces pilot workload. If an autopilot servo fails, however, resume manual control of the helicopter. The amount of workload increase depends on which servo fails. If a cyclic servo fails, a pilot may want to land immediately because the workload increases tremendously. If an antitorque or collective servo fails, continuing to the next suitable landing site might be possible.

Instrument Takeoff

The procedures and techniques described here should be modified as necessary to conform to those set forth in the operating instructions for the particular helicopter being flown. During training, instrument takeoffs should not be attempted except when receiving instruction from an appropriately certificated, proficient flight instructor pilot.

Adjust the miniature aircraft in the attitude indicator, as appropriate, for the aircraft being flown. After the helicopter is aligned with the runway or takeoff pad, to prevent forward movement of a helicopter equipped with a wheel-type landing gear, set the parking brakes or apply the toe brakes. If the parking brake is used, it must be unlocked after the takeoff has been completed. Apply sufficient friction to the collective pitch control to minimize overcontrolling and to prevent creeping. Excessive friction should be avoided since it limits collective pitch movement.

After checking all instruments for proper indications, start the takeoff by applying collective pitch and a predetermined power setting. Add power smoothly and steadily to gain airspeed and altitude simultaneously and to prevent settling to the ground. As power is applied and the helicopter becomes airborne, use the antitorque pedals initially to maintain the desired heading. At the same time, apply forward cyclic to begin accelerating to climbing airspeed. During the initial acceleration, the pitch attitude of the helicopter, as read on the attitude indicator, should be one- to two-bar widths low. The primary and supporting instruments after becoming airborne are illustrated in *Figure 6-16*. As the airspeed increases to the appropriate climb airspeed, adjust pitch gradually to climb attitude. As climb airspeed is reached, reduce power to the climb power setting and transition to a fully coordinated straight climb.

During the initial climb out, minor heading corrections should be made with pedals only until sufficient airspeed is attained to transition to fully coordinated flight. Throughout the instrument takeoff, instrument cross-check and interpretations must be rapid and accurate, and aircraft control positive and smooth.

Figure 6-16. *Flight Instrument Indications During an Instrument Takeoff.*

Common Errors During Instrument Takeoffs

1. Failure to maintain heading
2. Overcontrolling pedals
3. Failure to use required power
4. Failure to adjust pitch attitude as climbing airspeed is reached

Changing Technology

Advances in technology have brought about changes in the instrumentation found in all types of aircraft, including helicopters. Electronic displays commonly referred to as "glass cockpits" are becoming more common. Primary flight displays (PFDs) and multi-function displays (MFDs) are changing not only what information is available to a pilot but also how that information is displayed.

Illustrations of technological advancements in instrumentation are described as follows. In *Figure 6-17,* a typical PFD depicts an aircraft flying straight-and-level at 3,000 feet and 100 knots. *Figure 6-18* illustrates a nose-low pitch attitude in a right turn. MFDs can be configured to provide navigation information such as the moving map in *Figure 6-19* or information pertaining to aircraft systems as in *Figure 6-20*.

Figure 6-17. *PFD Indications During Straight-and-Level Flight.*

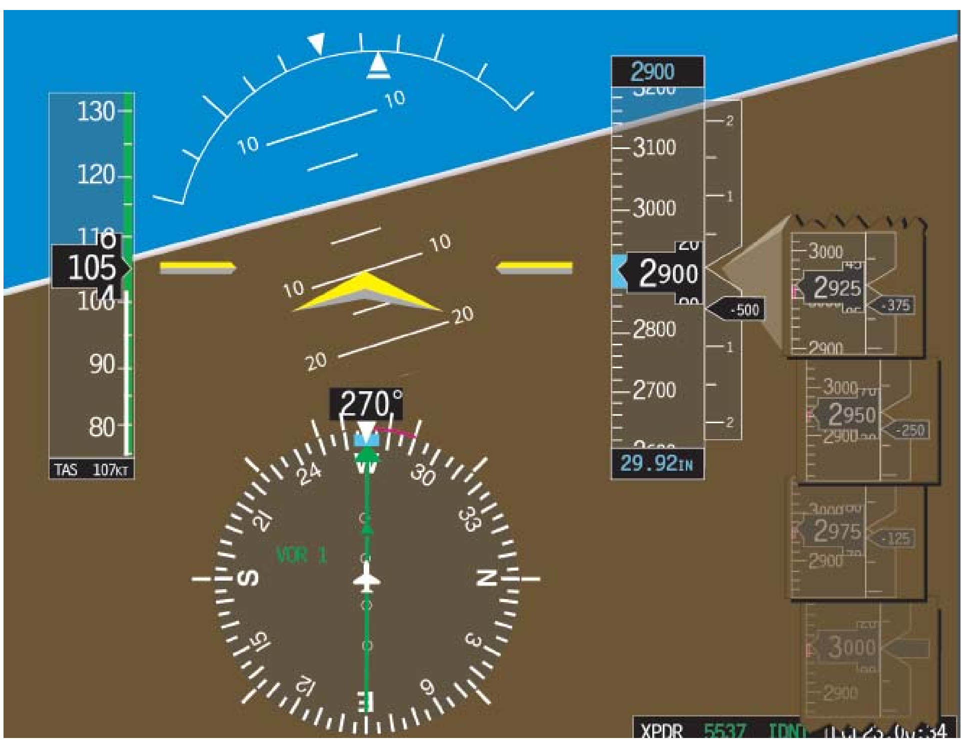


Figure 6-18. *PFD Indications During a Nose-Low Pitch Attitude in a Right Turn.*

Figure 6-19. *MFD Display of a Moving Map.*

Figure 6-20. *MFD Display of Aircraft Systems.*

Chapter 7

Navigation Systems

Introduction

This chapter provides the basic radio principles applicable to navigation equipment, as well as an operational knowledge of how to use these systems in instrument flight. This information provides the framework for all instrument procedures, including standard instrument departure procedures (SIDS), departure procedures (DPs), holding patterns, and approaches, because each of these maneuvers consists mainly of accurate attitude instrument flying and accurate tracking using navigation systems.

Basic Radio Principles

A radio wave is an electromagnetic (EM) wave with frequency characteristics that make it useful. The wave will travel long distances through space (in or out of the atmosphere) without losing too much strength. An antenna is used to convert electric current into a radio wave so it can travel through space to the receiving antenna, which converts it back into an electric current for use by a receiver.

How Radio Waves Propagate

All matter has a varying degree of conductivity or resistance to radio waves. The Earth itself acts as the greatest resistor to radio waves. Radiated energy that travels near the ground induces a voltage in the ground that subtracts energy from the wave, decreasing the strength of the wave as the distance from the antenna becomes greater. Trees, buildings, and mineral deposits affect the strength to varying degrees. Radiated energy in the upper atmosphere is likewise affected as the energy of radiation is absorbed by molecules of air, water, and dust. The characteristics of radio wave propagation vary according to the signal frequency and the design, use, and limitations of the equipment.

Ground Wave

A ground wave travels across the surface of the Earth. You can best imagine a ground wave's path as being in a tunnel or alley bounded by the surface of the Earth and by the ionosphere, which keeps the ground wave from going out into space. Generally, the lower the frequency, the farther the signal will travel.

Ground waves are usable for navigation purposes because they travel reliably and predictably along the same route day after day, and are not influenced by too many outside factors. The ground wave frequency range is generally from the lowest frequencies in the radio range (perhaps as low as 100 Hz) up to approximately 1,000 kHz (1 MHz). Although there is a ground wave component to frequencies above this, up to 30 MHz, the ground wave at these higher frequencies loses strength over very short distances.

Sky Wave

The sky wave, at frequencies of 1 to 30 MHz, is good for long distances because these frequencies are refracted or "bent" by the ionosphere, causing the signal to be sent back to Earth from high in the sky and received great distances away. *[Figure 7-1]* Used by high frequency (HF) radios in aircraft, messages can be sent across oceans using only 50 to 100 watts of power. Frequencies that produce a sky wave are not used for navigation because the pathway of the signal from transmitter to receiver is highly variable. The wave is "bounced" off of the ionosphere, which is always changing due to the varying amount of the sun's radiation reaching it (night/day and seasonal variations, sunspot activity, etc.). The sky wave is, therefore, unreliable for navigation purposes.

For aeronautical communication purposes, the sky wave (HF) is about 80 to 90 percent reliable. HF is being gradually replaced by more reliable satellite communication.

Space Wave

When able to pass through the ionosphere, radio waves of 15 MHz and above (all the way up to many GHz), are considered space waves. Most navigation systems operate with signals propagating as space waves. Frequencies above 100 MHz have nearly no ground or sky wave components. They are space waves, but (except for global positioning system (GPS)) the navigation signal is used before it reaches the ionosphere so the effect of the ionosphere, which can cause some propagation errors, is minimal. GPS errors caused by passage through the ionosphere are significant and are corrected for by the GPS receiver system.

Space waves have another characteristic of concern to users. Space waves reflect off hard objects and may be blocked if the object is between the transmitter and the receiver. Site and terrain error, as well as propeller/rotor modulation error in very high omnidirectional range (VOR) systems is caused by this bounce. Instrument landing system (ILS) course distortion is also the result of this phenomenon, which led to the need for establishment of ILS critical areas.

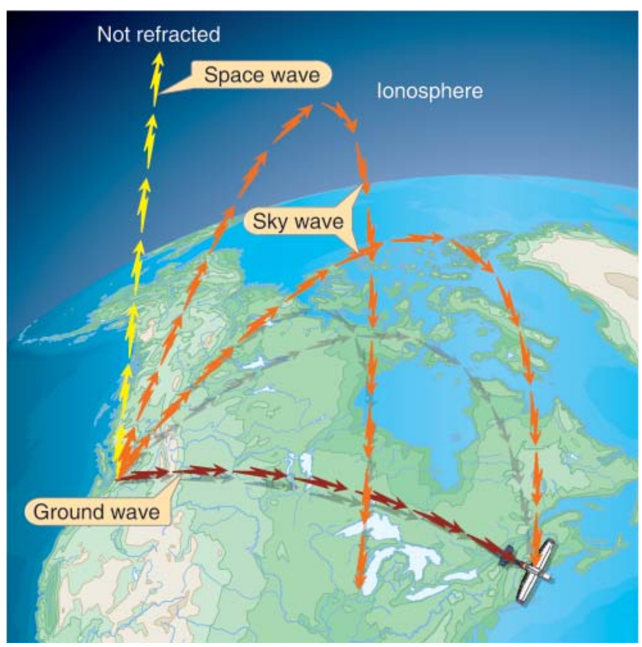


Figure 7-1. *Ground, Space, and Sky Wave Propogation.*

Generally, space waves are "line of sight" receivable, but those of lower frequencies will "bend" somewhat over the horizon. The VOR signal at 108 to 118 MHz is a lower frequency than distance measuring equipment (DME) at 962 to 1213 MHz. Therefore, when an aircraft is flown "over the horizon" from a VOR/DME station, the DME will normally be the first to stop functioning.

Disturbances to Radio Wave Reception

Static distorts the radio wave and interferes with normal reception of communications and navigation signals. Low-frequency airborne equipment such as automatic direction finder (ADF) and LORAN are particularly subject to static disturbance. Using very high frequency (VHF) and ultra-high frequency (UHF) frequencies avoids many of the discharge noise effects. Static noise heard on navigation or communication radio frequencies may be a warning of interference with navigation instrument displays. Some of the problems caused by precipitation static (P-static) are:

- Complete loss of VHF communications.
- Erroneous magnetic compass readings.
- Aircraft flying with one wing low while using the autopilot.
- High-pitched squeal on audio.
- Motorboat sound on audio.
- Loss of all avionics.
- Inoperative very-low frequency (VLF) navigation system.
- Erratic instrument readouts.
- Weak transmissions and poor radio reception.
- St. Elmo's Fire.

Traditional Navigation Systems

Nondirectional Radio Beacon (NDB)

The nondirectional radio beacon (NDB) is a ground-based radio transmitter that transmits radio energy in all directions. The ADF, when used with an NDB, determines the bearing from the aircraft to the transmitting station. The indicator may be mounted in a separate instrument in the aircraft panel. *[Figure 7-2]* The ADF needle points to the NDB ground station to determine the relative bearing (RB) to the transmitting station. It is the number of degrees measured clockwise between the aircraft's heading and the direction from which the bearing is taken. The aircraft's magnetic heading (MH) is the direction the aircraft is pointed with respect to magnetic north. The magnetic bearing (MB) is the direction to or from a radio transmitting station measured relative to magnetic north.

NDB Components

The ground equipment, the NDB, transmits in the frequency range of 190 to 535 kHz. Most ADFs will also tune the AM broadcast band frequencies above the NDB band (550 to 1650 kHz). However, these frequencies are not approved for navigation because stations do not continuously identify themselves, and they are much more susceptible to sky wave propagation especially from dusk to dawn. NDB stations are capable of voice transmission and are often used for transmitting the automated weather observing system (AWOS). The aircraft must be in operational range of the NDB. Coverage depends on the strength of the transmitting station. Before relying on ADF indications, identify the station by listening to the Morse code identifier. NDB stations are usually two letters or an alpha-numeric combination.

ADF Components

The airborne equipment includes two antennas, a receiver, and the indicator instrument. The "sense" antenna (non-directional) receives signals with nearly equal efficiency from all directions. The "loop" antenna receives signals better from two directions (bidirectional). When the loop and sense antenna inputs are processed together in the ADF radio, the result is the ability to receive a radio signal well in all directions but one, thus resolving all directional ambiguity. The indicator instrument can be one of four kinds: fixed-card ADF, rotatable compass-card ADF, or radio magnetic

Figure 7-2. *ADF Indicator Instrument and Receiver.*

indicator (RMI) with either one needle or dual needle. Fixed-card ADF (also known as the relative bearing indicator (RBI)) always indicates zero at the top of the instrument, with the needle indicating the RB to the station. *Figure 7-3* indicates an RB of 135°; if the MH is 045°, the MB to the station is 180°. (MH + RB = MB to the station.)

The movable-card ADF allows the pilot to rotate the aircraft's present heading to the top of the instrument so that the head of the needle indicates MB to the station and the tail indicates MB from the station. *Figure 7-4* indicates a heading of 045°, MB to the station of 180°, and MB from the station of 360°.

The RMI differs from the movable-card ADF in that it automatically rotates the azimuth card (remotely controlled by a gyrocompass) to represent aircraft heading. The RMI has two needles, which can be used to indicate navigation information from either the ADF or the VOR receiver. When a needle is being driven by the ADF, the head of the needle indicates the MB TO the station tuned on the ADF receiver. The tail of the needle is the bearing FROM the station. When a needle of the RMI is driven by a VOR receiver, the needle indicates where the aircraft is radially with respect to the VOR station. The needle points to the bearing TO the station, as read on the azimuth card. The tail of the needle points to the radial of the VOR the aircraft is currently on or crossing. *Figure 7-5* indicates a heading of 005°, the MB to the station is 015°, and the MB from the station is 195°.

Function of ADF

The ADF can be used to plot your position, track inbound and outbound, and intercept a bearing. These procedures are used to execute holding patterns and nonprecision instrument approaches.

Orientation

The ADF needle points TO the station, regardless of aircraft heading or position. The RB indicated is thus the angular relationship between the aircraft heading and the station, measured clockwise from the nose of the aircraft. Think of the nose/tail and left/right needle indications, visualizing the ADF dial in terms of the longitudinal axis of the aircraft. When the needle points to 0°, the nose of the aircraft points directly to the station; with the pointer on 210°, the station is 30° to the left of the tail; with the pointer on 090°, the station is off the right wingtip. The RB alone does not indicate aircraft position. The RB must be related to aircraft heading in order to determine direction to or from the station.

Station Passage

When you are near the station, slight deviations from the desired track result in large deflections of the needle. Therefore, it is important to establish the correct drift correction angle as soon as possible. Make small heading corrections (not over 5°) as soon as the needle shows a deviation from course, until it begins to rotate steadily toward a wingtip position or shows erratic left/right oscillations. You

Figure 7-3. *Relative bearing (RB) on a fixed-card indicator. Note that the card always indicates 360°, or north. In this case, the relative bearing to the station is 135° to the right. If the aircraft were on a magnetic heading of 360°, then the magnetic bearing (MB) would also be 135°.*

Figure 7-4. *Relative bearing (RB) on a movable-card indicator. By placing the aircraft's magnetic heading (MH) of 045° under the top index, the relative bearing (RB) of 135° to the right will also be the magnetic bearing (no wind conditions) which will take you to the transmitting station.*

Figure 7-5. *Radio magnetic indicator (RMI). Because the aircraft's magnetic heading is automatically changed, the relative bearing (RB), in this case 095°, will indicate the magnetic bearing (095°) to the station (no wind conditions) and the magnetic heading that will take you there.*

are abeam a station when the needle points 90° off your track. Hold your last corrected heading constant and time station passage when the needle shows either wingtip position or settles at or near the 180° position. The time interval from the first indications of station proximity to positive station passage varies with altitude—a few seconds at low levels to 3 minutes at high altitude.

Homing

The ADF may be used to "home" in on a station. Homing is flying the aircraft on any heading required to keep the needle pointing directly to the 0° RB position. To home in on a station, tune the station, identify the Morse code signal, and then turn the aircraft to bring the ADF azimuth needle to the 0° RB position. Turns should be made using the heading indicator. When the turn is complete, check the ADF needle and make small corrections as necessary.

Figure 7-6 illustrates homing starting from an initial MH of 050° and an RB of 300°, indicating a 60° left turn is needed to produce an RB of zero. Turn left, rolling out at 50° minus 60° equals 350°. Small heading corrections are then made to zero the ADF needle.

If there is no wind, the aircraft will home to the station on a direct track over the ground. With a crosswind, the aircraft will follow a circuitous path to the station on the downwind side of the direct track to the station.

Tracking

Tracking uses a heading that will maintain the desired track to or from the station regardless of crosswind conditions. Interpretation of the heading indicator and needle is done to maintain a constant MB to or from the station.

To track inbound, turn to the heading that will produce a zero RB. Maintain this heading until off-course drift is indicated by displacement of the needle, which will occur if there is a crosswind (needle moving left = wind from the left; needle moving right = wind from the right). A rapid rate of bearing change with a constant heading indicates either a strong crosswind or close proximity to the station or both. When there is a definite (2° to 5°) change in needle reading, turn in the direction of needle deflection to intercept the initial MB. The angle of interception must be greater than the number of degrees of drift, otherwise the aircraft will slowly drift due to the wind pushing the aircraft. If repeated often enough, the track to the station will appear circular and the distance greatly increased as compared to a straight track. The intercept angle depends on the rate of drift, the aircraft speed, and station proximity. Initially, it is standard to double the RB when turning toward your course.

For example, if your heading equals your course and the needle points 10° left, turn 20° left, twice the initial RB. *[Figure 7-7]* This will be your intercept angle to capture the RB. Hold this heading until the needle is deflected 20° in the opposite direction. That is, the deflection of the needle equals the interception angle (in this case 20°). The track has been intercepted, and the aircraft will remain on track as long as the RB remains the same number of degrees as the wind correction angle (WCA), the angle between the desired track and the heading of the aircraft necessary to keep the aircraft tracking over the desired track. Lead the interception to avoid overshooting the track. Turn 10° toward the inbound course. You are now inbound with a 10° left correction angle.

NOTE: In *Figure 7-7*, for the aircraft closest to the station, the WCA is 10° left and the RB is 10° right. If those values do not change, the aircraft will track directly to the station. If you observe off-course deflection in the original direction, turn again to the original interception heading. When the desired course has been re-intercepted, turn 5° toward the inbound course, proceeding inbound with a 15° drift correction. If the initial 10° drift correction is excessive, as shown by needle deflection away from the wind, turn to parallel the desired course and let the wind drift you back on course. When the needle is again zeroed, turn into the wind with a reduced drift correction angle.

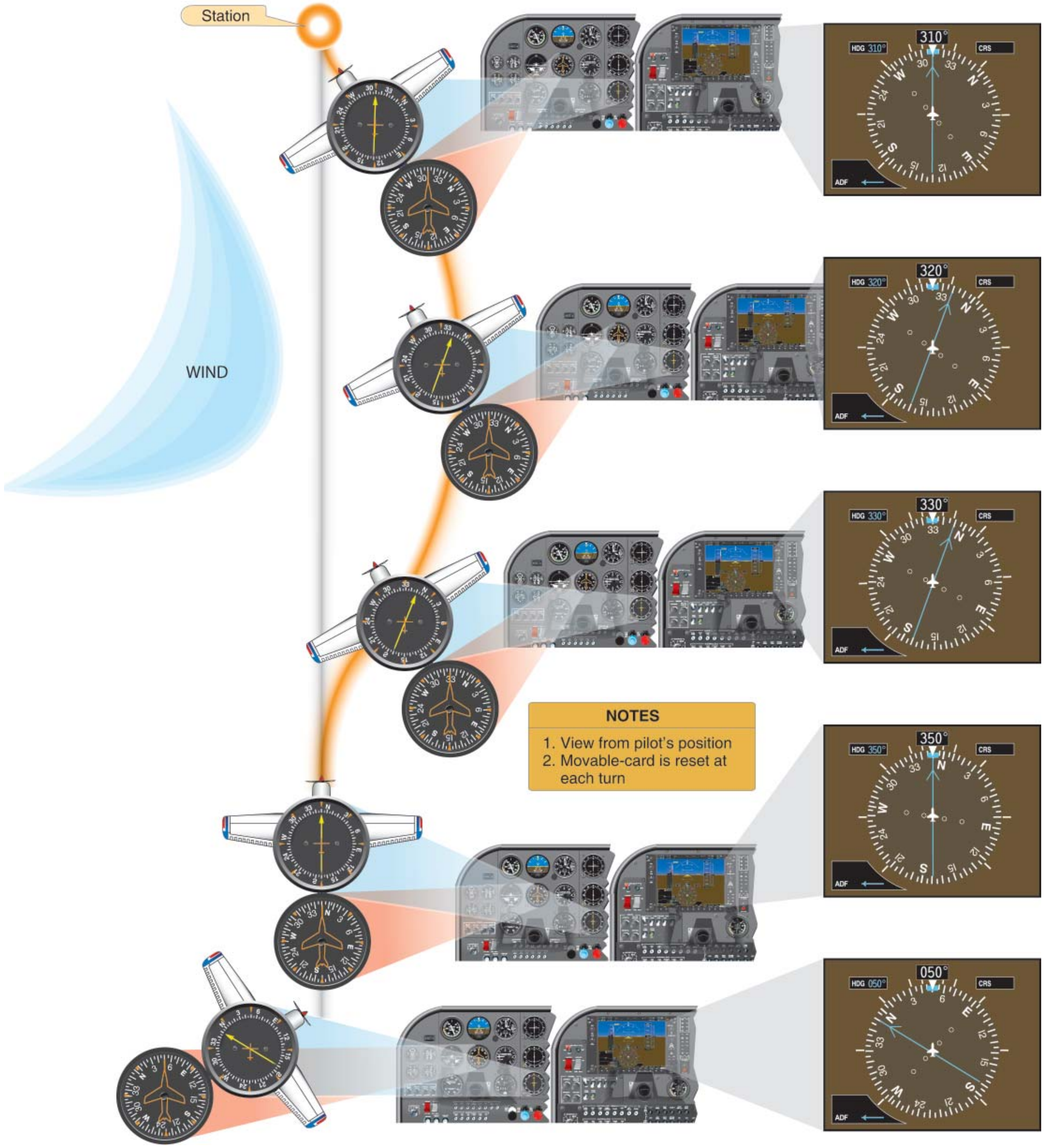


Figure 7-6. *ADF Homing With a Crosswind.*

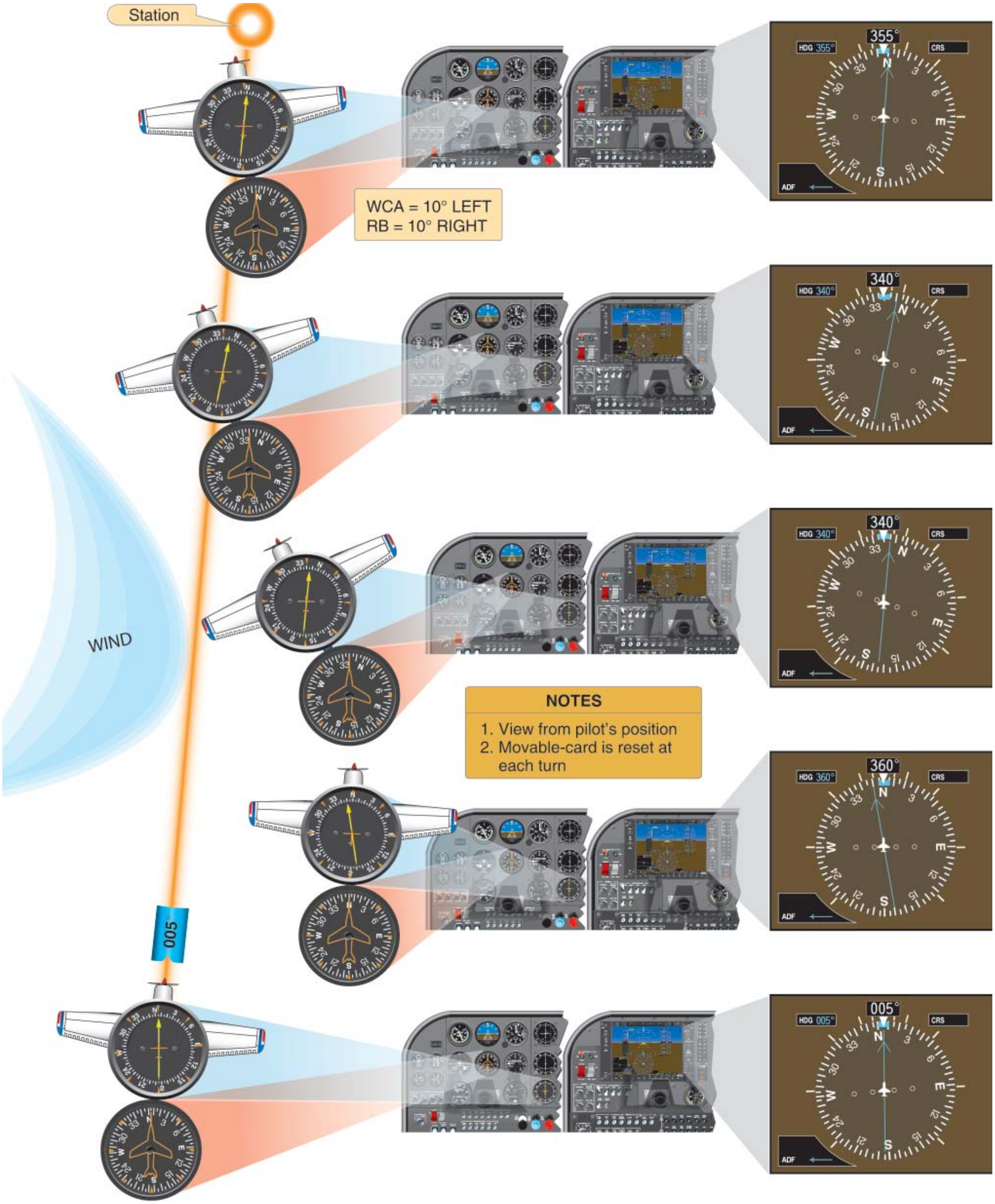


Figure 7-7. *ADF Tracking Inbound.*

To track outbound, the same principles apply: needle moving left = wind from the left, needle moving right = wind from the right. Wind correction is made toward the needle deflection. The only exception is while the turn to establish the WCA is being made, the direction of the azimuth needle deflections is reversed. When tracking inbound, needle deflection decreases while turning to establish the WCA, and needle deflection increases when tracking outbound. Note the example of course interception and outbound tracking in *Figure 7-8.*

Intercepting Bearings

ADF orientation and tracking procedures may be applied to intercept a specified inbound or outbound MB. To intercept an inbound bearing of 355°, the following steps may be used. *[Figure 7-9]*

1. Determine your position in relation to the station by paralleling the desired inbound bearing. In this case, turn to a heading of 355°. Note that the station is to the right front of the aircraft.
2. Determine the number of degrees of needle deflection from the nose of the aircraft. In this case, the needle's RB from the aircraft's nose is 40° to the right. A rule of thumb for interception is to double this RB amount as an interception angle (80°).
3. Turn the aircraft toward the desired MB the number of degrees determined for the interception angle which as indicated (in two above) is twice the initial RB (40°), or in this case 80°. Therefore, the right turn will be 80° from the initial MB of 355°, or a turn to 075° magnetic (355° + 80° + 075°).
4. Maintain this interception heading of 075° until the needle is deflected the same number of degrees "left" from the zero position as the angle of interception 080°, (minus any lead appropriate for the rate at which the bearing is changing).
5. Turn left 80° and the RB (in a no wind condition and with proper compensation for the rate of the ADF needle movement) should be 0°, or directly off the nose. Additionally, the MB should be 355° indicating proper interception of the desired course.

NOTE: The rate of an ADF needle movement or any bearing pointer for that matter will be faster as aircraft position becomes closer to the station or waypoint (WP).

Interception of an outbound MB can be accomplished by the same procedures as for the inbound intercept, except that it is necessary to substitute the 180° position for the zero position on the needle.

Operational Errors of ADF

Some of the common pilot-induced errors associated with ADF navigation are listed below to help you avoid making the same mistakes. The errors are:

1. Improper tuning and station identification. Many pilots have made the mistake of homing or tracking to the wrong station.
2. Positively identifying any malfunctions of the RMI slaving system or ignoring the warning flag.
3. Dependence on homing rather than proper tracking. This commonly results from sole reliance on the ADF indications, rather than correlating them with heading indications.
4. Poor orientation, due to failure to follow proper steps in orientation and tracking.
5. Careless interception angles, very likely to happen if you rush the initial orientation procedure.
6. Overshooting and undershooting predetermined MBs, often due to forgetting the course interception angles used.
7. Failure to maintain selected headings. Any heading change is accompanied by an ADF needle change. The instruments must be read in combination before any interpretation is made.
8. Failure to understand the limitations of the ADF and the factors that affect its use.
9. Overcontrolling track corrections close to the station (chasing the ADF needle), due to failure to understand or recognize station approach.
10. Failure to keep the heading indicator set so it agrees with the magnetic compass.

Very High Frequency Omnidirectional Range (VOR)

VOR is the primary navigational aid (NAVAID) used by civil aviation in the National Airspace System (NAS). The VOR ground station is oriented to magnetic north and transmits azimuth information to the aircraft, providing 360 courses TO or FROM the VOR station. When DME is installed with the VOR, it is referred to as a VOR/DME and provides both azimuth and distance information. When military tactical air navigation (TACAN) equipment is installed with the VOR, it is known as a VORTAC and provides both azimuth and distance information.

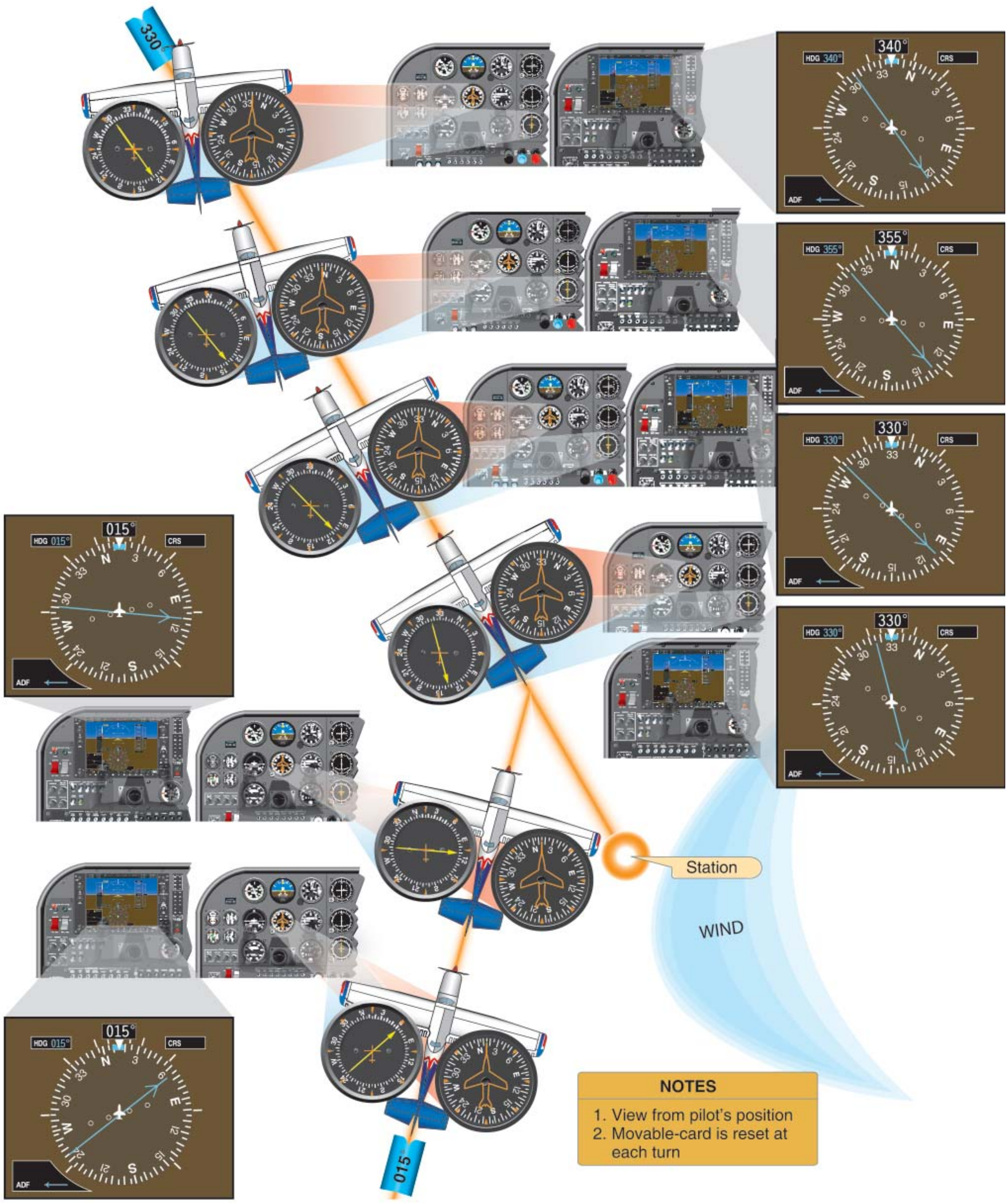


Figure 7-8. *ADF Interception and Tracking Outbound.*

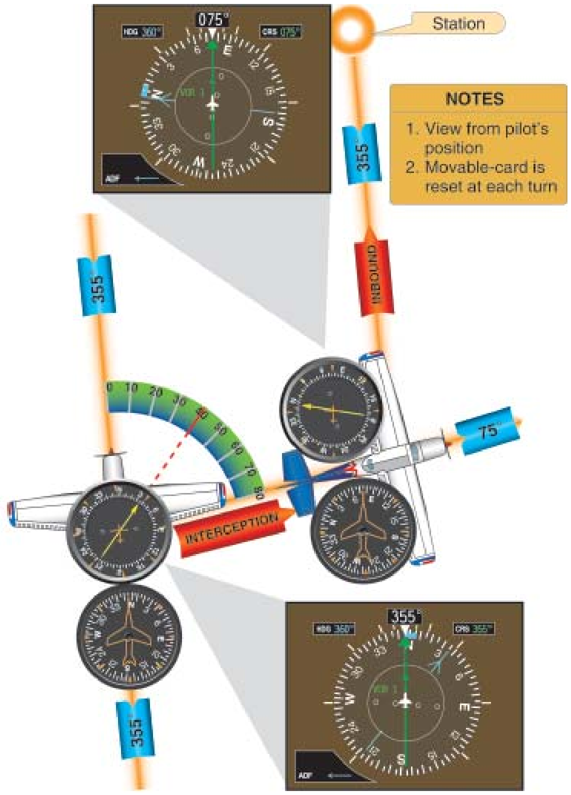


Figure 7-9. *Interception of Bearing.*

The courses oriented FROM the station are called radials. The VOR information received by an aircraft is not influenced by aircraft attitude or heading. *[Figure 7-10]* Radials can be envisioned to be like the spokes of a wheel on which the aircraft is on one specific radial at any time. For example, aircraft A (heading 180°) is inbound on the 360° radial; after crossing the station, the aircraft is outbound on the 180° radial at A1. Aircraft B is shown crossing the 225° radial. Similarly, at any point around the station, an aircraft can be located somewhere on a specific VOR radial. Additionally, a VOR needle on an RMI will always point to the course that will take you to the VOR station where conversely the ADF needle points to the station as a RB from the aircraft. In the example above, the ADF needle at position A would be pointed straight ahead, at A1 to the aircraft's 180° position (tail) and at B, to the aircraft's right.

The VOR receiver measures and presents information to indicate bearing TO or FROM the station. In addition to the navigation signals transmitted by the VOR, a Morse code signal is transmitted concurrently to identify the facility, as well as voice transmissions for communication and relay of weather and other information.

VORs are classified according to their operational uses. The standard VOR facility has a power output of approximately 200 watts, with a maximum usable range depending upon the aircraft altitude, class of facility, location of the facility, terrain conditions within the usable area of the facility, and other factors. Above and beyond certain altitude and distance limits, signal interference from other VOR facilities and a weak signal make it unreliable. Coverage is typically at least 40 miles at normal minimum instrument flight rules (IFR) altitudes. VORs with accuracy problems in parts of their service volume are listed in Notices to Airmen (NOTAMs) and in the Airport/Facility Directory (A/FD) under the name of the NAVAID.

VOR Components

The ground equipment consists of a VOR ground station, which is a small, low building topped with a flat white disc, upon which are located the VOR antennas and a fiberglass cone-shaped tower. *[Figure 7-11]* The station includes an automatic monitoring system. The monitor automatically turns off defective equipment and turns on the standby transmitter. Generally, the accuracy of the signal from the ground station is within 1°.

VOR facilities are aurally identified by Morse code, or voice, or both. The VOR can be used for ground-to-air communication without interference with the navigation signal. VOR facilities operate within the 108.0 to 117.95 MHz frequency band and assignment between 108.0 and 112.0

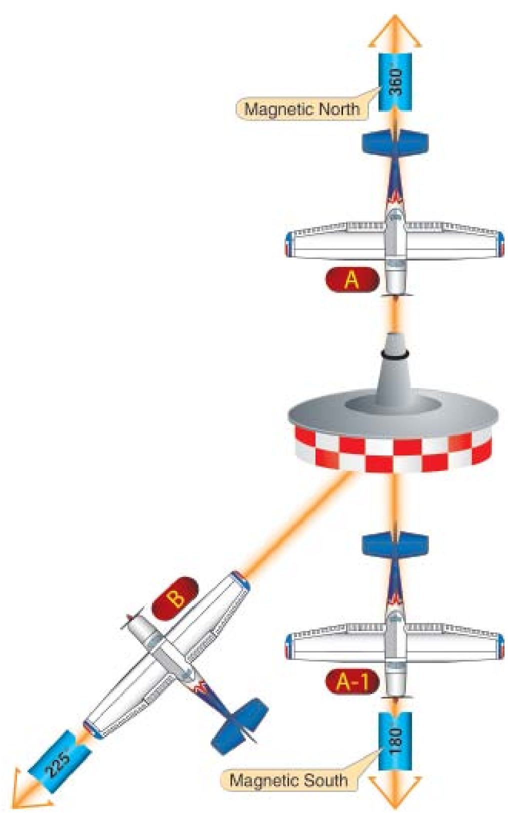


Figure 7-10. *VOR Radials.*

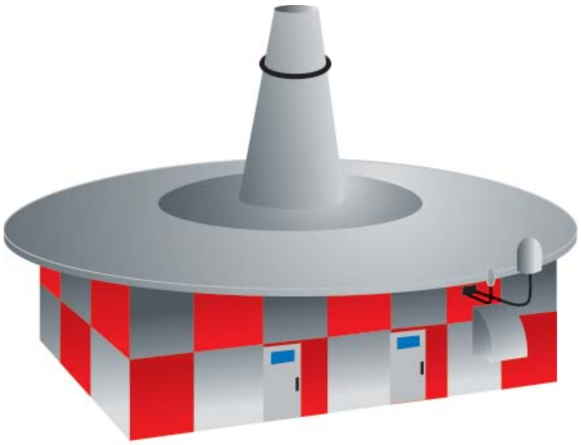


Figure 7-11. *VOR Transmitter (Ground Station).*

MHz is in even-tenth increments to preclude any conflict with ILS localizer frequency assignment, which uses the odd tenths in this range.

The airborne equipment includes an antenna, a receiver, and the indicator instrument. The receiver has a frequency knob to select any of the frequencies between 108.0 to 117.95 MHz. The On/Off/volume control turns on the navigation receiver and controls the audio volume. The volume has no effect on the operation of the receiver. You should listen to the station identifier before relying on the instrument for navigation.

VOR indicator instruments have at least the essential components shown in the instrument illustrated in *Figure 7-12.*

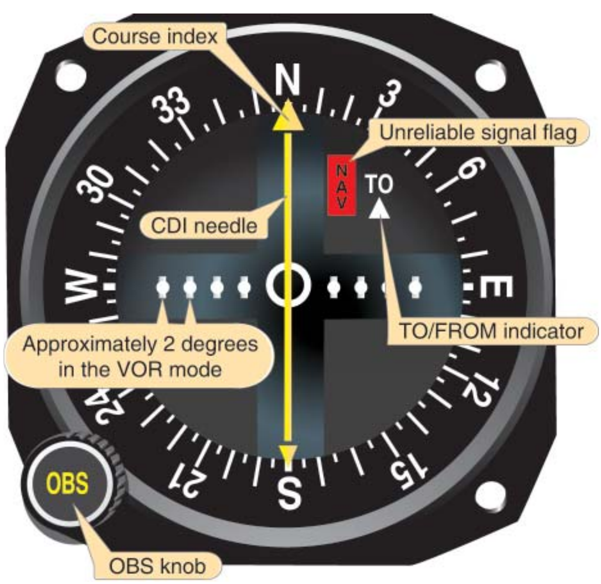


Figure 7-12. *The VOR Indicator Instrument.*

Omnibearing Selector (OBS)
The desired course is selected by turning the OBS knob until the course is aligned with the course index mark or displayed in the course window.

Course Deviation Indicator (CDI)
The deviation indicator is composed of an instrument face and a needle hinged to move laterally across the instrument face. The needle centers when the aircraft is on the selected radial or its reciprocal. Full needle deflection from the center position to either side of the dial indicates the aircraft is 12° or more off course, assuming normal needle sensitivity. The outer edge of the center circle is 2° off course; with each dot representing an additional 2°.

TO/FROM Indicator
The TO/FROM indicator shows whether the selected course will take the aircraft TO or FROM the station. It does not indicate whether the aircraft is heading to or from the station.

Flags or Other Signal Strength Indicators
The device that indicates a usable or an unreliable signal may be an "OFF" flag. It retracts from view when signal strength is sufficient for reliable instrument indications. Alternately, insufficient signal strength may be indicated by a blank or OFF in the TO/FROM window.

The indicator instrument may also be a horizontal situation indicator (HSI) which combines the heading indicator and CDI. *[Figure 7-13]* The combination of navigation information from VOR/Localizer (LOC) or from LORAN or GPS, with aircraft heading information provides a visual picture of the aircraft's location and direction. This decreases pilot workload especially with tasks such as course intercepts, flying a back-course approach, or holding pattern entry. (See

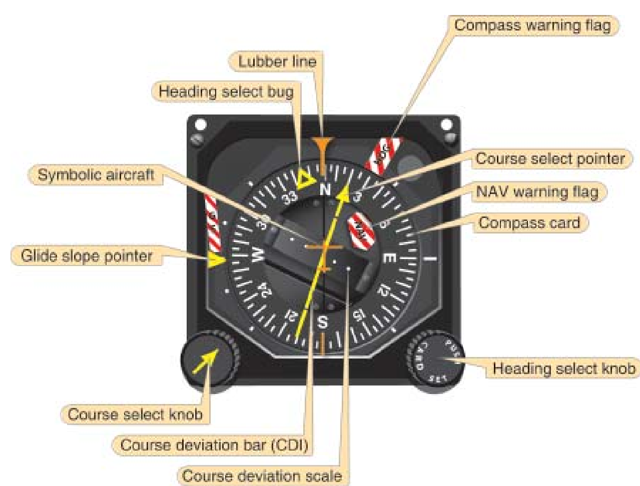


Figure 7-13. *A Typical Horizontal Situation Indicator (HSI).*

Chapter 3, Flight Instruments, for operational characteristics.) *[Figure 7-14]*

Function of VOR

Orientation

The VOR does not account for the aircraft heading. It only relays the aircraft direction from the station and will have the same indications regardless of which way the nose is pointing. Tune the VOR receiver to the appropriate frequency of the selected VOR ground station, turn up the audio volume, and identify the station's signal audibly. Then, rotate the OBS to center the CDI needle and read the course under or over the index.

In *Figure 7-12*, 360° TO is the course indicated, while in *Figure 7-15*, 180° TO is the course. The latter indicates that the aircraft (which may be heading in any direction) is, at this moment, located at any point on the 360° radial (line from the station) except directly over the station or very close to it, as between points I and S in *Figure 7-15*. The CDI will deviate from side to side as the aircraft passes over or nearly over the station because of the volume of space above the station where the zone of confusion exists. This zone of confusion is caused by lack of adequate signal directly above the station due to the radiation pattern of the station's antenna, and because the resultant of the opposing reference and variable signals is small and constantly changing.

The CDI in *Figure 7-15* indicates 180°, meaning that the aircraft is on the 180° or the 360° radial of the station. The TO/FROM indicator resolves the ambiguity. If the TO indicator is showing, then it is 180° TO the station. The FROM indication indicates the radial of the station the aircraft is presently on. Movement of the CDI from center, if it occurs at a relatively constant rate, indicates the aircraft is moving or drifting off the 180°/360° line. If the movement is rapid or fluctuating, this is an indication of impending station passage (the aircraft is near the station). To determine the aircraft's position relative to the station, rotate the OBS until FROM appears in the window, and then center the CDI needle. The index indicates the VOR radial where the aircraft is located. The inbound (to the station) course is the reciprocal of the radial.

If the VOR is set to the reciprocal of the intended course, the CDI will reflect reverse sensing. To correct for needle deflection, turn away from the needle. To avoid this reverse sensing situation, set the VOR to agree with the intended course.

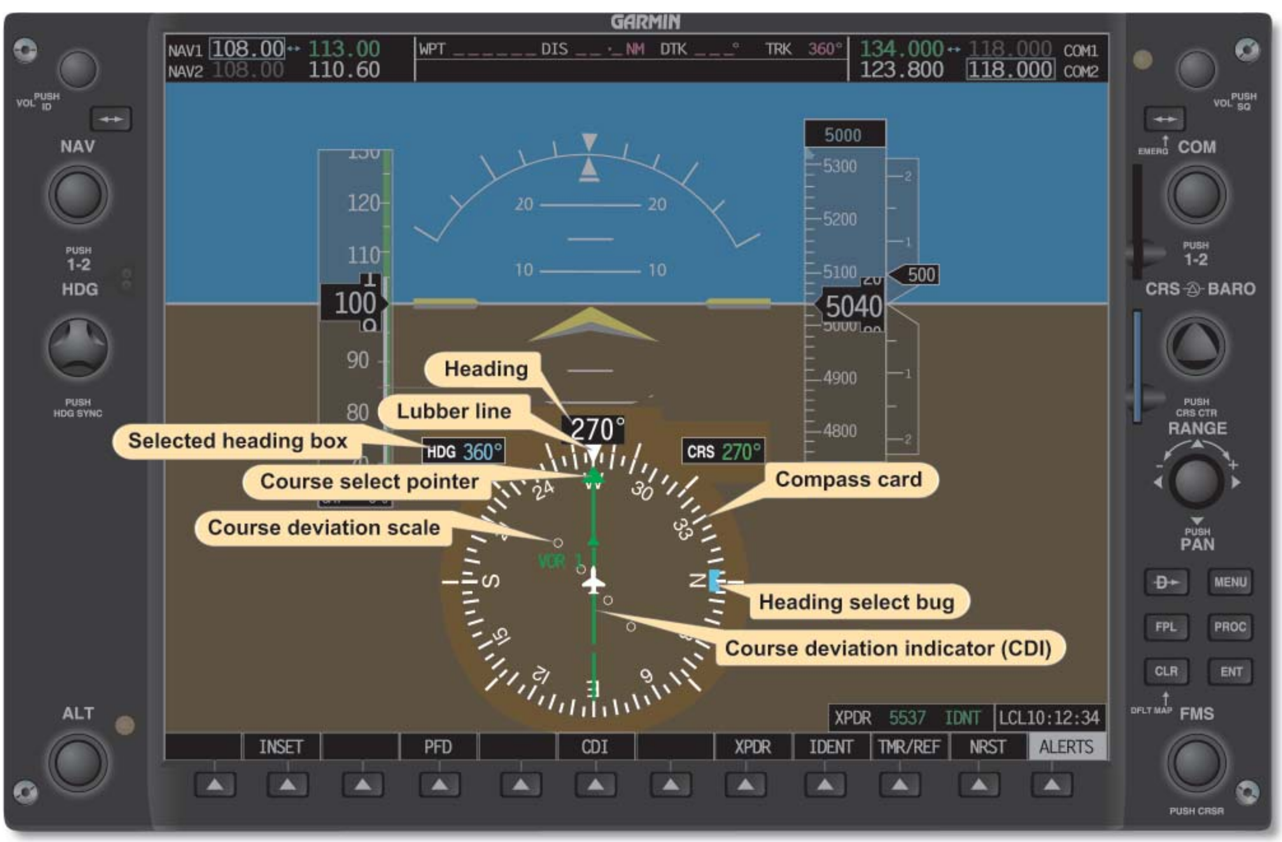


Figure 7-14. *An HSI display as seen on the pilot's primary flight display (PFD) on an electronic flight instrument. Note that only attributes related to the HSI are labeled.*

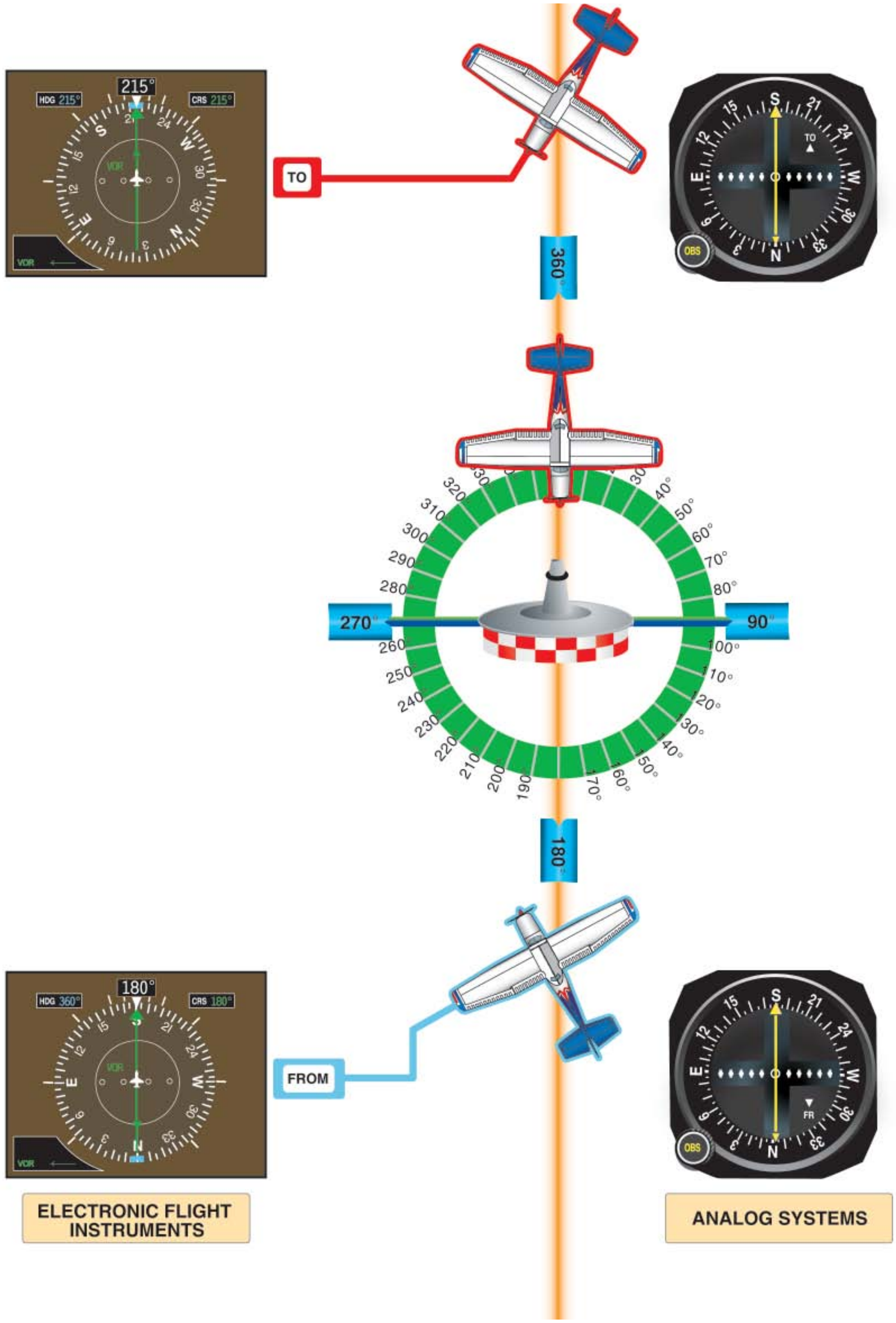


Figure 7-15. *CDI Interpretation. The CDI as typically found on analog systems (right) and as found on electronic flight instruments (left).*

A single NAVAID will allow a pilot to determine the aircraft's position relative to a radial. Indications from a second NAVAID are needed in order to narrow the aircraft's position down to an exact location on this radial.

Tracking TO and FROM the Station

To track to the station, rotate the OBS until TO appears, then center the CDI. Fly the course indicated by the index. If the CDI moves off center to the left, follow the needle by correcting course to the left, beginning with a 20° correction.

When flying the course indicated on the index, a left deflection of the needle indicates a crosswind component from the left. If the amount of correction brings the needle back to center, decrease the left course correction by half. If the CDI moves left or right now, it should do so much more slowly, and smaller heading corrections can be made for the next iteration.

Keeping the CDI centered will take the aircraft to the station. To track to the station, the OBS value at the index is not changed. To home to the station, the CDI needle is periodically centered, and the new course under the index is used for the aircraft heading. Homing will follow a circuitous route to the station, just as with ADF homing.

To track FROM the station on a VOR radial, you should first orient the aircraft's location with respect to the station and the desired outbound track by centering the CDI needle with a FROM indication. The track is intercepted by either flying over the station or establishing an intercept heading. The magnetic course of the desired radial is entered under the index using the OBS and the intercept heading held until the CDI centers. Then the procedure for tracking to the station is used to fly outbound on the specified radial.

Course Interception

If the desired course is not the one being flown, first orient the aircraft's position with respect to the VOR station and the course to be flown, and then establish an intercept heading. The following steps may be used to intercept a predetermined course, either inbound or outbound. Steps 1–3 may be omitted when turning directly to intercept the course without initially turning to parallel the desired course.

1. Turn to a heading to parallel the desired course, in the same direction as the course to be flown.
2. Determine the difference between the radial to be intercepted and the radial on which the aircraft is located (205° – 160° = 045°).
3. Double the difference to determine the interception angle, which will not be less than 20° nor greater than 90° (45° x 2 = 090°). 205° + 090° = 295° for the intercept)
4. Rotate the OBS to the desired radial or inbound course.
5. Turn to the interception heading.
6. Hold this heading constant until the CDI center, which indicates the aircraft is on course. (With practice in judging the varying rates of closure with the course centerline, pilots learn to lead the turn to prevent overshooting the course.)
7. Turn to the MH corresponding to the selected course, and follow tracking procedures inbound or outbound.

Course interception is illustrated in *Figure 7-16*.

VOR Operational Errors

Typical pilot-induced errors include:

1. Careless tuning and identification of station.
2. Failure to check receiver for accuracy/sensitivity.
3. Turning in the wrong direction during an orientation. This error is common until visualizing position rather than heading.
4. Failure to check the ambiguity (TO/FROM) indicator, particularly during course reversals, resulting in reverse sensing and corrections in the wrong direction.
5. Failure to parallel the desired radial on a track interception problem. Without this step, orientation to the desired radial can be confusing. Since pilots think in terms of left and right of course, aligning the aircraft position to the radial/course is essential.
6. Overshooting and undershooting radials on interception problems.
7. Overcontrolling corrections during tracking, especially close to the station.
8. Misinterpretation of station passage. On VOR receivers not equipped with an ON/OFF flag, a voice transmission on the combined communication and navigation radio (NAV/COM) in use for VOR may cause the same TO/FROM fluctuations on the ambiguity meter as shown during station passage. Read the whole receiver—TO/FROM, CDI, and OBS—before you make a decision. Do not utilize a VOR reading observed while transmitting.
9. Chasing the CDI, resulting in homing instead of tracking. Careless heading control and failure to bracket wind corrections make this error common.

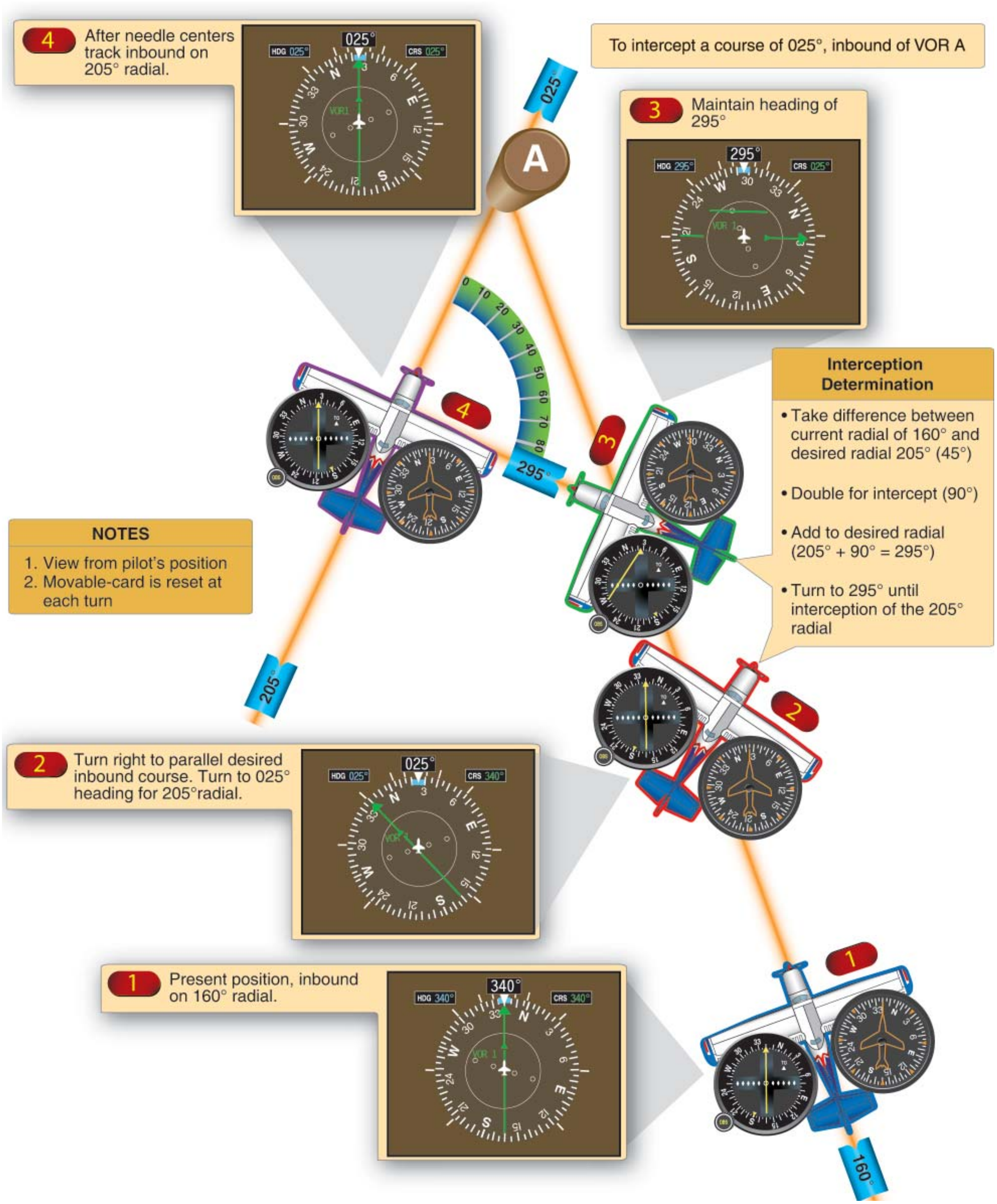


Figure 7-16. *Course Interception (VOR).*

VOR Accuracy

The effectiveness of the VOR depends upon proper use and adjustment of both ground and airborne equipment.

The accuracy of course alignment of the VOR is generally plus or minus 1°. On some VORs, minor course roughness may be observed, evidenced by course needle or brief flag alarm. At a few stations, usually in mountainous terrain, the pilot may occasionally observe a brief course needle oscillation, similar to the indication of "approaching station." Pilots flying over unfamiliar routes are cautioned to be on the alert for these vagaries, and in particular, to use the TO/FROM indicator to determine positive station passage.

Certain propeller revolutions per minute (RPM) settings or helicopter rotor speeds can cause the VOR CDI to fluctuate as much as plus or minus 6°. Slight changes to the RPM setting will normally smooth out this roughness. Pilots are urged to check for this modulation phenomenon prior to reporting a VOR station or aircraft equipment for unsatisfactory operation.

VOR Receiver Accuracy Check

VOR system course sensitivity may be checked by noting the number of degrees of change as the OBS is rotated to move the CDI from center to the last dot on either side. The course selected should not exceed 10° or 12° either side. In addition, Title 14 of the Code of Federal Regulations (14 CFR) part 91 provides for certain VOR equipment accuracy checks, and an appropriate endorsement, within 30 days prior to flight under IFR. To comply with this requirement and to ensure satisfactory operation of the airborne system, use the following means for checking VOR receiver accuracy:

1. VOR test facility (VOT) or a radiated test signal from an appropriately rated radio repair station.
2. Certified checkpoints on the airport surface.
3. Certified airborne checkpoints.

VOR Test Facility (VOT)

The Federal Aviation Administration (FAA) VOT transmits a test signal which provides users a convenient means to determine the operational status and accuracy of a VOR receiver while on the ground where a VOT is located. Locations of VOTs are published in the A/FD. Two means of identification are used. One is a series of dots and the other is a continuous tone. Information concerning an individual test signal can be obtained from the local flight service station (FSS.) The airborne use of VOT is permitted; however, its use is strictly limited to those areas/altitudes specifically authorized in the A/FD or appropriate supplement.

To use the VOT service, tune in the VOT frequency 108.0 MHz on the VOR receiver. With the CDI centered, the OBS should read 0° with the TO/FROM indication showing FROM or the OBS should read 180° with the TO/FROM indication showing TO. Should the VOR receiver operate an RMI, it would indicate 180° on any OBS setting.

A radiated VOT from an appropriately rated radio repair station serves the same purpose as an FAA VOT signal, and the check is made in much the same manner as a VOT with some differences.

The frequency normally approved by the Federal Communications Commission (FCC) is 108.0 MHz; however, repair stations are not permitted to radiate the VOR test signal continuously. The owner or operator of the aircraft must make arrangements with the repair station to have the test signal transmitted. A representative of the repair station must make an entry into the aircraft logbook or other permanent record certifying to the radial accuracy and the date of transmission.

Certified Checkpoints

Airborne and ground checkpoints consist of certified radials that should be received at specific points on the airport surface or over specific landmarks while airborne in the immediate vicinity of the airport. Locations of these checkpoints are published in the A/FD.

Should an error in excess of ±4° be indicated through use of a ground check, or ±6° using the airborne check, IFR flight shall not be attempted without first correcting the source of the error. No correction other than the correction card figures supplied by the manufacturer should be applied in making these VOR receiver checks.

If a dual system VOR (units independent of each other except for the antenna) is installed in the aircraft, one system may be checked against the other. Turn both systems to the same VOR ground facility and note the indicated bearing to that station. The maximum permissible variation between the two indicated bearings is 4°.

Distance Measuring Equipment (DME)

When used in conjunction with the VOR system, DME makes it possible for pilots to determine an accurate geographic position of the aircraft, including the bearing and distance TO or FROM the station. The aircraft DME transmits interrogating radio frequency (RF) pulses, which are received by the DME antenna at the ground facility. The signal triggers ground receiver equipment to respond to the interrogating aircraft. The airborne DME equipment measures the elapsed time between the interrogation signal sent by the aircraft and reception of the reply pulses from the ground station. This time measurement is converted into distance in nautical miles (NM) from the station.

Some DME receivers provide a groundspeed in knots by monitoring the rate of change of the aircraft's position relative to the ground station. Groundspeed values are accurate only when tracking directly to or from the station.

DME Components

VOR/DME, VORTAC, ILS/DME, and LOC/DME navigation facilities established by the FAA provide course and distance information from collocated components under a frequency pairing plan. DME operates on frequencies in the UHF spectrum between 962 MHz and 1213 MHz. Aircraft receiving equipment which provides for automatic DME selection assures reception of azimuth and distance information from a common source when designated VOR/DME, VORTAC, ILS/DME, and LOC/DME are selected. Some aircraft have separate VOR and DME receivers, each of which must be tuned to the appropriate navigation facility. The airborne equipment includes an antenna and a receiver.

The pilot-controllable features of the DME receiver include:

Channel (Frequency) Selector
Many DMEs are channeled by an associated VHF radio, or there may be a selector switch so a pilot can select which VHF radio is channeling the DME. For a DME with its own frequency selector, use the frequency of the associated VOR/DME or VORTAC station.

On/Off/Volume Switch
The DME identifier will be heard as a Morse code identifier with a tone somewhat higher than that of the associated VOR or LOC. It will be heard once for every three or four times the VOR or LOC identifier is heard. If only one identifier is heard about every 30 seconds, the DME is functional, but the associated VOR or LOC is not.

Mode Switch
The mode switch selects between distance (DIST) or distance in NMs, groundspeed, and time to station. There may also be one or more HOLD functions which permit the DME to stay channeled to the station that was selected before the switch was placed in the hold position. This is useful when you make an ILS approach at a facility that has no collocated DME, but there is a VOR/DME nearby.

Altitude
Some DMEs correct for slant-range error.

Function of DME

A DME is used for determining the distance from a ground DME transmitter. Compared to other VHF/UHF NAVAIDs, a DME is very accurate. The distance information can be used to determine the aircraft position or flying a track that is a constant distance from the station. This is referred to as a DME arc.

DME Arc

There are many instrument approach procedures (IAPs) that incorporate DME arcs. The procedures and techniques given here for intercepting and maintaining such arcs are applicable to any facility that provides DME information. Such a facility may or may not be collocated with the facility that provides final approach guidance.

As an example of flying a DME arc, refer to *Figure 7-17* and follow these steps:

1. Track inbound on the OKT 325° radial, frequently checking the DME mileage readout.
2. A 0.5 NM lead is satisfactory for groundspeeds of 150 knots or less; start the turn to the arc at 10.5 miles. At higher groundspeeds, use a proportionately greater lead.

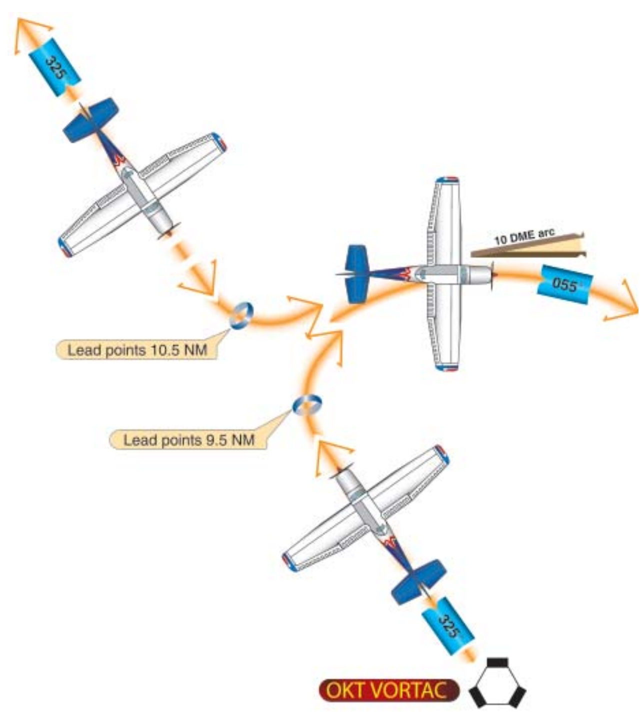


Figure 7-17. *DME Arc Interception.*

3. Continue the turn for approximately 90°. The roll-out heading will be 055° in a no wind condition.
4. During the last part of the intercepting turn, monitor the DME closely. If the arc is being overshot (more than 1.0 NM), continue through the originally planned roll-out heading. If the arc is being undershot, roll-out of the turn early.

The procedure for intercepting the 10 DME when outbound is basically the same, the lead point being 10 NM minus 0.5 NM, or 9.5 NM.

When flying a DME arc with wind, it is important to keep a continuous mental picture of the aircraft's position relative to the facility. Since the wind-drift correction angle is constantly changing throughout the arc, wind orientation is important. In some cases, wind can be used in returning to the desired track. High airspeeds require more pilot attention because of the higher rate of deviation and correction.

Maintaining the arc is simplified by keeping slightly inside the curve; thus, the arc is turning toward the aircraft and interception may be accomplished by holding a straight course. When outside the curve, the arc is "turning away" and a greater correction is required.

To fly the arc using the VOR CDI, center the CDI needle upon completion of the 90° turn to intercept the arc. The aircraft's heading will be found very near the left or right side (270° or 90° reference points) of the instrument. The readings at that side location on the instrument will give primary heading information while on the arc. Adjust the aircraft heading to compensate for wind and to correct for

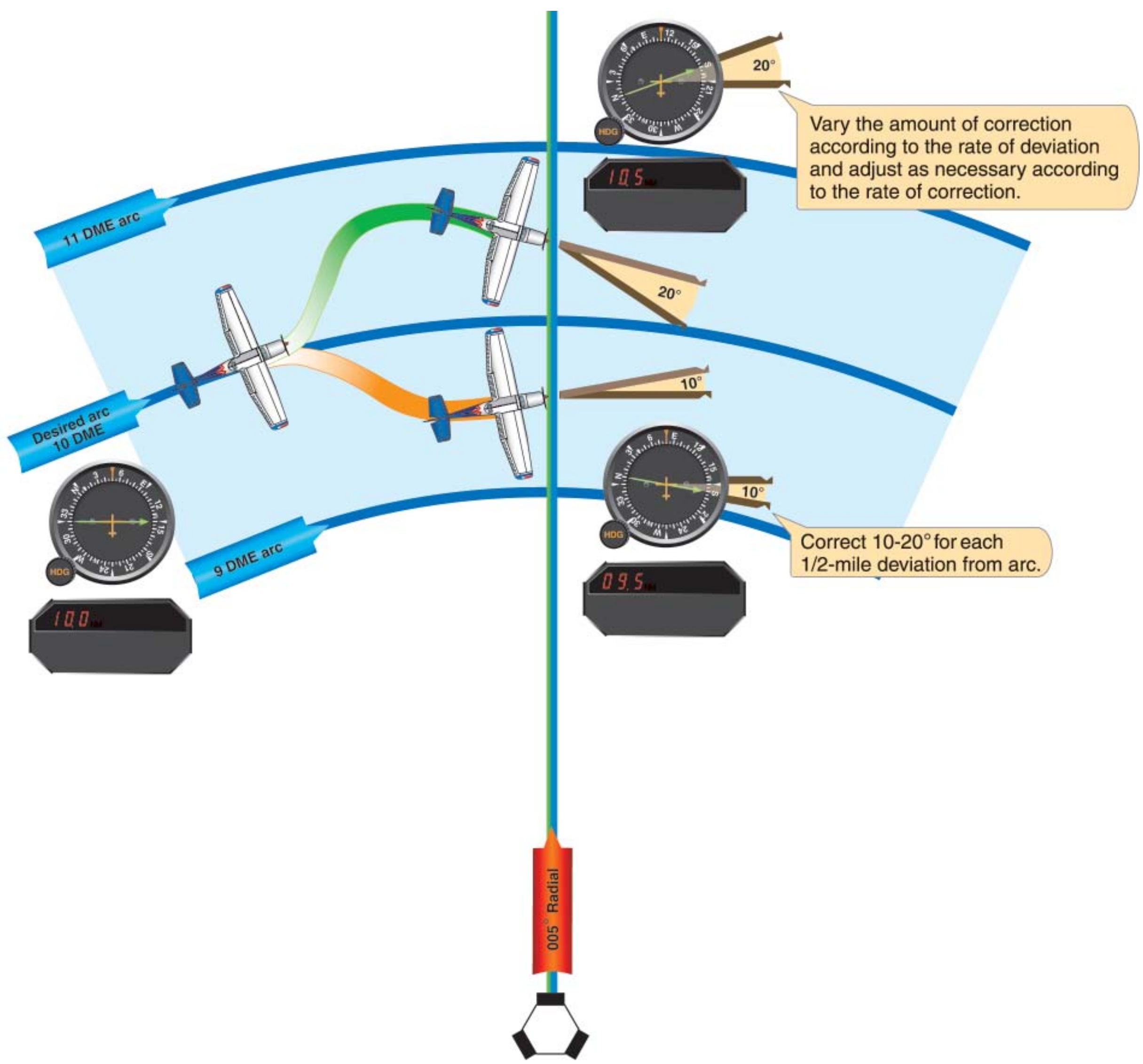


Figure 7-18. *Using DME and RMI To Maintain an Arc.*

distance to maintain the correct arc distance. Recenter the CDI and note the new primary heading indicated whenever the CDI gets 2°–4° from center.

With an RMI, in a no wind condition, pilots should theoretically be able to fly an exact circle around the facility by maintaining an RB of 90° or 270°. In actual practice, a series of short legs are flown. To maintain the arc in *Figure 7-18*, proceed as follows:

1. With the RMI bearing pointer on the wingtip reference (90° or 270° position) and the aircraft at the desired DME range, maintain a constant heading and allow the bearing pointer to move 5°–10° behind the wingtip. This will cause the range to increase slightly.
2. Turn toward the facility to place the bearing pointer 5–10° ahead of the wingtip reference, and then maintain heading until the bearing pointer is again behind the wingtip. Continue this procedure to maintain the approximate arc.
3. If a crosswind causes the aircraft to drift away from the facility, turn the aircraft until the bearing pointer is ahead of the wingtip reference. If a crosswind causes the aircraft to drift toward the facility, turn until the bearing is behind the wingtip.
4. As a guide in making range corrections, change the RB 10°–20° for each half-mile deviation from the desired arc. For example, in no-wind conditions, if the aircraft is 1/2 to 1 mile outside the arc and the bearing pointer is on the wingtip reference, turn the aircraft 20° toward the facility to return to the arc.

Without an RMI, orientation is more difficult since there is no direct azimuth reference. However, the procedure can be flown using the OBS and CDI for azimuth information and the DME for arc distance.

Intercepting Lead Radials

A lead radial is the radial at which the turn from the arc to the inbound course is started. When intercepting a radial from a DME arc, the lead will vary with arc radius and ground speed. For the average general aviation aircraft, flying arcs such as those depicted on most approach charts at speeds of 150 knots or less, the lead will be under 5°. There is no difference between intercepting a radial from an arc and intercepting it from a straight course.

With an RMI, the rate of bearing movement should be monitored closely while flying the arc. Set the course of the radial to be intercepted as soon as possible and determine the approximate lead. Upon reaching this point, start the intercepting turn. Without an RMI, the technique for radial interception is the same except for azimuth information, which is available only from the OBS and CDI.

The technique for intercepting a localizer from a DME arc is similar to intercepting a radial. At the depicted lead radial (LR 070° or LR 084° in *Figures 7-19, 7-20,* and *7-21*), a pilot having a single VOR/LOC receiver should set it to the localizer frequency. If the pilot has dual VOR/LOC receivers, one unit may be used to provide azimuth information and the other set to the localizer frequency. Since these lead radials provide 7° of lead, a half-standard rate turn should be used until the LOC needle starts to move toward center.

DME Errors

A DME/DME fix (a location based on two DME lines of position from two DME stations) provides a more accurate aircraft location than using a VOR and a DME fix.

DME signals are line-of-sight; the mileage readout is the straight line distance from the aircraft to the DME ground facility and is commonly referred to as slant range distance. Slant range refers to the distance from the aircraft's antenna to the ground station (A line at an angle to the ground transmitter. GPS systems provide distance as the horizontal measurement from the WP to the aircraft. Therefore, at 3,000 feet and 0.5 miles the DME (slant range) would read 0.6 NM while the GPS distance would show the actual horizontal distance of .5 DME. This error is smallest at low altitudes and/or at long ranges. It is greatest when the aircraft is closer to the facility, at which time the DME receiver will display altitude (in NM) above the facility. Slant range error is negligible if the aircraft is one mile or more from the ground facility for each 1,000 feet of altitude above the elevation of the facility.

Area Navigation (RNAV)

Area navigation (RNAV) equipment includes VOR/DME, LORAN, GPS, and inertial navigation systems (INS). RNAV equipment is capable of computing the aircraft position, actual track, groundspeed, and then presenting meaningful information to the pilot. This information may be in the form of distance, cross-track error, and time estimates relative to the selected track or WP. In addition, the RNAV equipment installations must be approved for use under IFR. The Pilot's Operating Handbook/Airplane Flight Manual (POH/AFM) should always be consulted to determine what equipment is installed, the operations that are approved, and the details of equipment use. Some aircraft may have equipment that allows input from more than one RNAV source, thereby providing a very accurate and reliable navigation source.

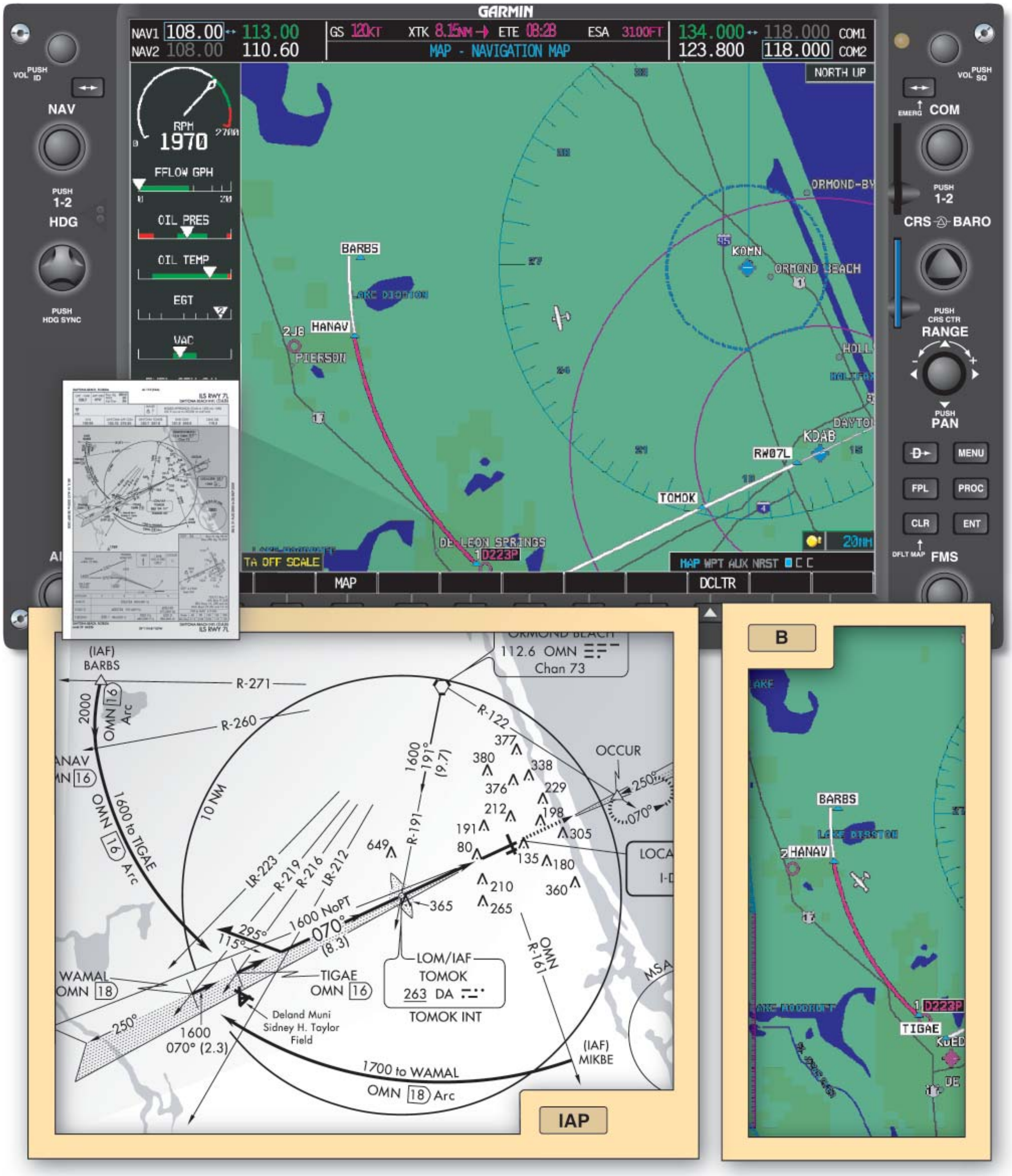


Figure 7-19. *An aircraft is displayed heading southwest to intercept the localizer approach, using the 16 NM DME Arc off of ORM.*

Figure 7-20. *The same aircraft illustrated in Figure 7-19 shown on the ORM radial near TIGAE intersection turning inbound for the localizer.*

Figure 7-21. *Aircraft is illustrated inbound on the localizer course.*

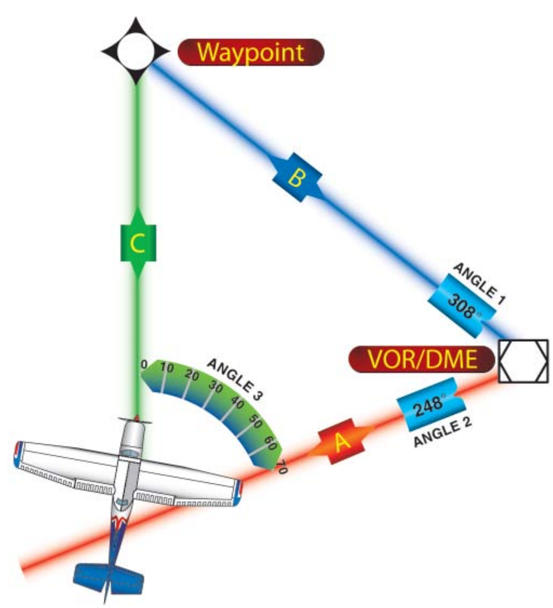


Figure 7-22. *RNAV Computation.*

VOR/DME RNAV

VOR RNAV is based on information generated by the present VORTAC or VOR/DME system to create a WP using an airborne computer. As shown in *Figure 7-22*, the value of side A is the measured DME distance to the VOR/DME. Side B, the distance from the VOR/DME to the WP, and angle 1 (VOR radial or the bearing from the VORTAC to the WP) are values set in the flight deck control. The bearing from the VOR/DME to the aircraft, angle 2, is measured by the VOR receiver. The airborne computer continuously compares angles 1 and 2 and determines angle 3 and side C, which is the distance in NMs and magnetic course from the aircraft to the WP. This is presented as guidance information on the flight deck display.

VOR/DME RNAV Components

Although RNAV flight deck instrument displays vary among manufacturers, most are connected to the aircraft CDI with a switch or knob to select VOR or RNAV guidance. There is usually a light or indicator to inform the pilot whether VOR or RNAV is selected. *[Figure 7-23]* The display includes the WP, frequency, mode in use, WP radial and distance, DME distance, groundspeed, and time to station.

Figure 7-23. *Onboard RNAV receivers have changed significantly. Originally, RNAV receivers typically computed combined data from VOR, VORTAC, and/or DME. That is generally not the case now. Today, GPS such as the GNC 300 and the Bendix King KLS 88 LORAN receivers compute waypoints based upon embedded databases and aircraft positional information.*

Most VOR/DME RNAV systems have the following airborne controls:

1. Off/On/Volume control to select the frequency of the VOR/DME station to be used.
2. MODE select switch used to select VOR/DME mode, with:
   a. Angular course width deviation (standard VOR operation); or
   b. Linear cross-track deviation as standard (±5 NM full scale CDI).
3. RNAV mode, with direct to WP with linear cross-track deviation of ±5 NM.
4. RNAV/APPR (approach mode) with linear deviation of ±1.25 NM as full scale CDI deflection.
5. WP select control. Some units allow the storage of more than one WP; this control allows selection of any WP in storage.
6. Data input controls. These controls allow user input of WP number or ident, VOR or LOC frequency, WP radial and distance.

While DME groundspeed readout is accurate only when tracking directly to or from the station in VOR/DME mode, in RNAV mode the DME groundspeed readout is accurate on any track.

Function of VOR/DME RNAV

The advantages of the VOR/DME RNAV system stem from the ability of the airborne computer to locate a WP wherever it is convenient, as long as the aircraft is within reception range of both nearby VOR and DME facilities. A series of these WPs make up an RNAV route. In addition to the published routes, a random RNAV route may be flown under IFR if it is approved by air traffic control (ATC). RNAV DPs and standard terminal arrival routes (STARs) are contained in the DP and STAR booklets.

VOR/DME RNAV approach procedure charts are also available. Note in the VOR/DME RNAV chart excerpt shown in *Figure 7-24* that the WP identification boxes contain the following information: WP name, coordinates, frequency, identifier, radial distance (facility to WP), and reference facility elevation. The initial approach fix (IAF), final approach fix (FAF), and missed approach point (MAP) are labeled.

To fly a route or to execute an approach under IFR, the RNAV equipment installed in the aircraft must be approved for the appropriate IFR operations.

In vertical navigation (VNAV) mode, vertical guidance is provided, as well as horizontal guidance in some installations. A WP is selected at a point where the descent begins, and another WP is selected where the descent ends. The RNAV equipment computes the rate of descent relative to the groundspeed; on some installations, it displays vertical guidance information on the GS indicator. When using this type of equipment during an instrument approach, the pilot must keep in mind that the vertical guidance information provided is not part of the nonprecision approach. Published nonprecision approach altitudes must be observed and complied with, unless otherwise directed by ATC.

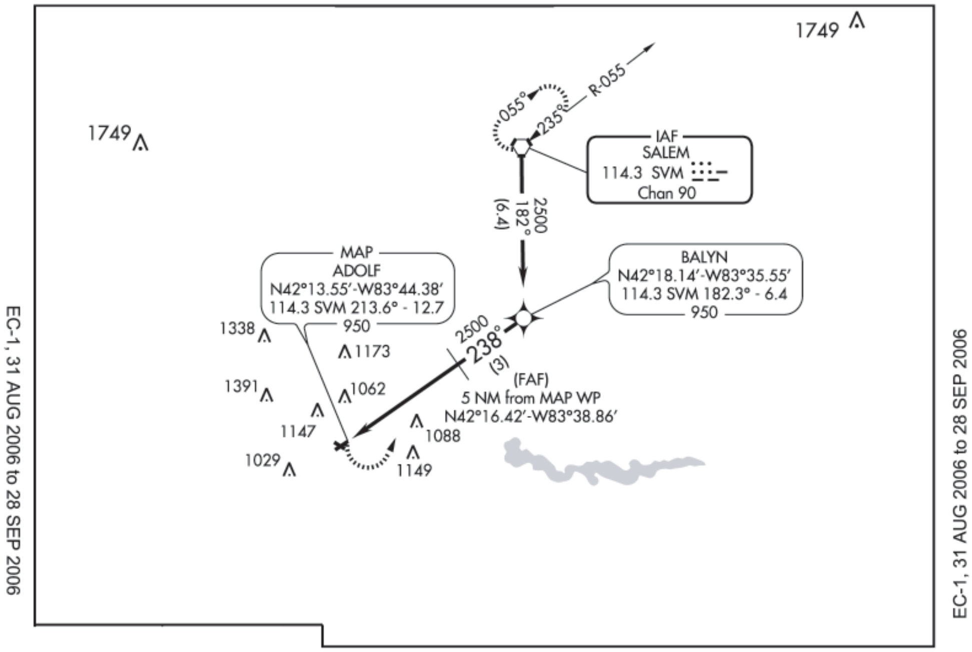


Figure 7-24. *VOR/DME RNAV Rwy 25 Approach (Excerpt).*

To fly to a WP using RNAV, observe the following procedure *[Figure 7-25]*:

1. Select the VOR/DME frequency.
2. Select the RNAV mode.
3. Select the radial of the VOR that passes through the WP (225°).
4. Select the distance from the DME to the WP (12 NM).
5. Check and confirm all inputs, and center the CDI needle with the TO indicator showing.
6. Maneuver the aircraft to fly the indicated heading plus or minus wind correction to keep the CDI needle centered.
7. The CDI needle will indicate distance off course of 1 NM per dot; the DME readout will indicate distance in NM from the WP; the groundspeed will read closing speed (knots) to the WP; and the time to station (TTS) will read time to the WP.

Figure 7-25. *Aircraft/DME/Waypoint Relationship.*

VOR/DME RNAV Errors

The limitation of this system is the reception volume. Published approaches have been tested to ensure this is not a problem. Descents/approaches to airports distant from the VOR/DME facility may not be possible because, during the approach, the aircraft may descend below the reception altitude of the facility at that distance.

Long Range Navigation (LORAN)

LORAN uses a network of land-based transmitters to provide an accurate long-range navigation system. The FAA and the United States Coast Guard (USCG) arranged the stations into chains. The signal from station is a carefully structured sequence of brief RF pulses centered at 100 kHz. At that frequency, signals travel considerable distances as ground waves, from which accurate navigation information is available. The airborne receiver monitors all of the stations within the selected chain, then measures the arrival time difference (TD) between the signals. All of the points having the same TD from a station pair create a line of position

Figure 7-26. *A control panel from a military aircraft after LORAN was first put into use. The receiver is remotely mounted and weighs over 25 pounds. Its size is about six times that of the LORAN fully integrated receiver.*

(LOP). The aircraft position is determined at the intersection of two or more LOPs. Then the computer converts the known location to latitude and longitude coordinates. *[Figure 7-26]*

While continually computing latitude/longitude fixes, the computer is able to determine and display:

1. Track over the ground since last computation;
2. Groundspeed by dividing distance covered since last computation by the time since last computation (and averaging several of these);
3. Distance to destination;
4. Destination time of arrival; and
5. Cross-track error.

The Aeronautical Information Manual (AIM) provides a detailed explanation of how LORAN works. LORAN is a very accurate navigation system if adequate signals are received. There are two types of accuracy that must be addressed in any discussion of LORAN accuracy.

Repeatable accuracy is the accuracy measured when a user notes the LORAN position, moves away from that location, then uses the LORAN to return to that initial LORAN position. Distance from that initial position is the error. Propagation and terrain errors will be essentially the same as when the first position was taken, so those errors are factored out by using the initial position. Typical repeatable accuracy for LORAN can be as good as 0.01 NM, or 60 feet, if the second position is determined during the day and within a short period of time (a few days).

Absolute accuracy refers to the ability to determine present position in space independently, and is most often used by pilots. When the LORAN receiver is turned on and position is determined, absolute accuracy applies. Typical LORAN absolute accuracy will vary from about 0.1 NM to as much as 2.5 NM depending on distance from the station, geometry of the TD LOP crossing angles, terrain and environmental conditions, signal-to-noise ratio (signal strength), and some design choices made by the receiver manufacturer.

Although LORAN use diminished with the introduction of Global Navigation Satellite Systems such as the United States' GPS, its use has since increased. Three items aided in this resurgence:

- In 1996, a commission called the Gore Commission evaluated GPS' long-term use as a sole navigation aid. Although GPS was hailed originally as the eventual sole NAVAID, which would replace the need for most currently existing NAVAIDs by the year 2020, the Commission questioned single-link failure potential and its effect on the NAS. For this reason, the forecasted decommissioning of the VOR has been amended and their expectant lifecycle extended into the future. Additionally, the use of LORAN continues to be evaluated for facilitating carrying GPS corrective timing signals.
- The GPS is controlled by the DOD presenting certain unforecasted uncertainties for commercial use on an uninterrupted basis.

As a result of these and other key factors, it was determined that LORAN would remain. In recognition of GPS vulnerabilities as a GNSS, there are plans to maintain other systems that could provide en route and terminal accuracy such as LORAN. Therefore as LORAN is further modernized it's a possibility that it may be used to augment GPS and provide backup to GPS during unlikely but potential outages. Or if combined with GPS and other systems such as newer miniaturized low-cost inertial navigation systems (INS), superior accuracy and seamless backup will always be available.

LORAN Components

The LORAN receiver incorporates a radio receiver, signal processor, navigation computer, control/display, and antenna. When turned on, the receivers go through an initialization or warm-up period, then inform the user they are ready to be programmed. LORAN receivers vary widely in their appearance, method of user programming, and navigation information display. Therefore, it is necessary to become familiar with the unit, including programming and output interpretation. The LORAN operating manual should be in the aircraft at all times and available to the pilot. IFR-approved LORAN units require that the manual be aboard and that the pilot be familiar with the unit's functions, before flight.

Function of LORAN

After initialization, select for the present location WP (the airport), and select GO TO in order to determine if the LORAN is functioning properly. Proper operation is indicated by a low distance reading (0 to 0.5 NM). The simplest mode of navigation is referred to as GO TO: you select a WP from one of the databases and choose the GO TO mode. Before use in flight, verify that the latitude and longitude of the chosen WP is correct by reference to another approved information source. An updatable LORAN database that supports the appropriate operations (e.g., en route, terminal, and instrument approaches) is required when operating under IFR.

In addition to displaying bearing, distance, time to the WP, and track and speed over the ground, the LORAN receiver may have other features such as flight planning (WP sequential storage), emergency location of several nearest airports, vertical navigation capabilities, and more.

LORAN Errors

System Errors

LORAN is subject to interference from many external sources, which can cause distortion of or interference with LORAN signals. LORAN receiver manufacturers install "notch filters" to reduce or eliminate interference. Proximity to 60 Hz alternating current power lines, static discharge, P-static, electrical noise from generators, alternators, strobes, and other onboard electronics may decrease the signal-to-noise ratio to the point where the LORAN receiver's performance is degraded.

Proper installation of the antenna, good electrical bonding, and an effective static discharge system are the minimum requirements for LORAN receiver operation. Most receivers have internal tests that verify the timing alignment of the receiver clock with the LORAN pulse, and measure and display signal-to-noise ratio. A signal will be activated to alert the pilot if any of the parameters for reliable navigation are exceeded on LORAN sets certified for IFR operations.

LORAN is most accurate when the signal travels over sea water during the day and least accurate when the signal comes over land and large bodies of fresh water or ice at night; furthermore, the accuracy degrades as distance from the station increases. However, LORAN accuracy is generally better than VOR accuracy.

Operational Errors

Some of the typical pilot-induced errors of LORAN operation are:

1. Use of a nonapproved LORAN receiver for IFR operations. The pilot should check the aircraft's POH/AFM LORAN supplement to be certain the unit's functions are well understood (this supplement must be present in the aircraft for approved IFR operations). There should be a copy of FAA Form 337, Major Repair and Alteration, present in the aircraft's records, showing approval of use of this model LORAN for IFR operations in this aircraft.
2. Failure to double-check the latitude/longitude values for a WP to be used. Whether the WP was accessed from the airport, NDB, VOR, or intersection database, the values of latitude and longitude should still be checked against the values in the A/FD or other approved source. If the WP data is entered in the user database, its accuracy must be checked before use.
3. Attempting to use LORAN information with degraded signals.

Advanced Technologies

Global Navigation Satellite System (GNSS)

The Global Navigation Satellite System (GNSS) is a constellation of satellites providing a high-frequency signal which contains time and distance that is picked up by a receiver thereby. *[Figure 7-27]* The receiver which picks up multiple signals from different satellites is able to triangulate its position from these satellites.

Figure 7-27. *A typical example (GNS 480) of a stand-alone GPS receiver and display.*

Three GNSSs exist today: the GPS, a United States system; the Russian GNSS (GLONASS); and Galileo, a European system.

1. GLONASS is a network of 24 satellites, which can be picked up by any GLONASS receiver, allowing the user to pinpoint their position.
2. Galileo is a network of 30 satellites that continuously transmit high-frequency radio signals containing time and distance data that can be picked up by a Galileo receiver with operational expectancy by 2008.
3. The GPS came on line in 1992 with 24 satellites, and today utilizes 30 satellites.

Global Positioning System (GPS)

The GPS is a satellite-based radio navigation system, which broadcasts a signal that is used by receivers to determine precise position anywhere in the world. The receiver tracks multiple satellites and determines a measurement that is then used to determine the user location. *[Figure 7-28]*

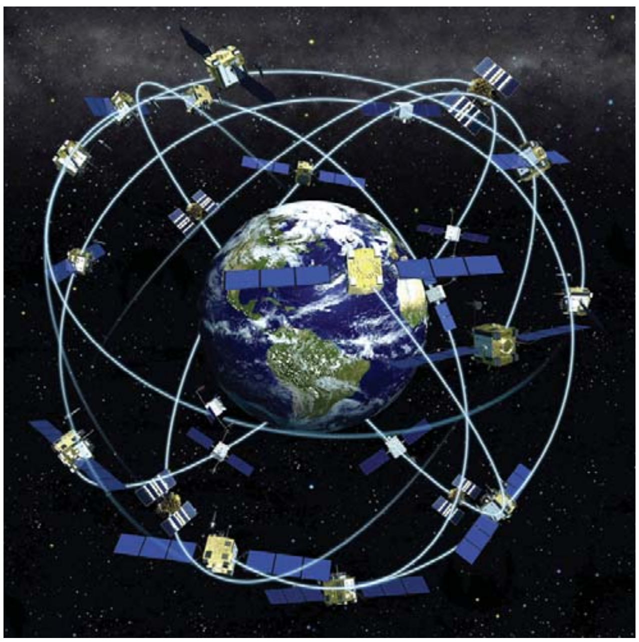


Figure 7-28. *Typical GPS Satellite Array.*

The Department of Defense (DOD) developed and deployed GPS as a space-based positioning, velocity, and time system. The DOD is responsible for operation of the GPS satellite constellation, and constantly monitors the satellites to ensure proper operation. The GPS system permits Earth-centered coordinates to be determined and provides aircraft position referenced to the DOD World Geodetic System of 1984 (WGS-84). Satellite navigation systems are unaffected by weather and provide global navigation coverage that fully meets the civil requirements for use as the primary means of navigation in oceanic airspace and certain remote areas. Properly certified GPS equipment may be used as a supplemental means of IFR navigation for domestic en route, terminal operations, and certain IAPs. Navigational values, such as distance and bearing to a WP and groundspeed, are computed from the aircraft's current position (latitude and longitude) and the location of the next WP. Course guidance is provided as a linear deviation from the desired track of a Great Circle route between defined WPs.

GPS may not be approved for IFR use in other countries. Prior to its use, pilots should ensure that GPS is authorized by the appropriate countries.

GPS Components

GPS consists of three distinct functional elements: space, control, and user.

The space element consists of over 30 Navstar satellites. This group of satellites is called a constellation. The satellites are in six orbital planes (with four in each plane) at about 11,000 miles above the Earth. At least five satellites are in view at all times. The GPS constellation broadcasts a pseudo-random code timing signal and data message that the aircraft equipment processes to obtain satellite position and status data. By knowing the precise location of each satellite and precisely matching timing with the atomic clocks on the satellites, the aircraft receiver/processor can accurately measure the time each signal takes to arrive at the receiver and, therefore, determine aircraft position.

The control element consists of a network of ground-based GPS monitoring and control stations that ensure the accuracy of satellite positions and their clocks. In its present form, it has five monitoring stations, three ground antennas, and a master control station.

The user element consists of antennas and receiver/processors on board the aircraft that provide positioning, velocity, and precise timing to the user. GPS equipment used while operating under IFR must meet the standards set forth in Technical Standard Order (TSO) C-129 (or equivalent); meet the airworthiness installation requirements; be "approved" for that type of IFR operation; and be operated in accordance with the applicable POH/AFM or flight manual supplement.

An updatable GPS database that supports the appropriate operations (e.g., en route, terminal, and instrument approaches) is required when operating under IFR. The aircraft GPS navigation database contains WPs from the geographic areas where GPS navigation has been approved for IFR operations. The pilot selects the desired WPs from the database and may add user-defined WPs for the flight.

Equipment approved in accordance with TSO C-115a, visual flight rules (VFR), and hand-held GPS systems do not meet the requirements of TSO C-129 and are not authorized for IFR navigation, instrument approaches, or as a principal instrument flight reference. During IFR operations, these units (TSO C-115a) may be considered only an aid to situational awareness.

Prior to GPS/WAAS IFR operation, the pilot must review appropriate NOTAMs and aeronautical information. This information is available on request from an Automated Flight Service Station. The FAA will provide NOTAMs to advise pilots of the status of the WAAS and level of service available.

Function of GPS

GPS operation is based on the concept of ranging and triangulation from a group of satellites in space which act as precise reference points. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which it can use a satellite).

The aircraft GPS receiver measures distance from a satellite using the travel time of a radio signal. Each satellite transmits a specific code, called a course/acquisition (CA) code, which contains information about satellite position, the GPS system time, and the health and accuracy of the transmitted data. Knowing the speed at which the signal traveled (approximately 186,000 miles per second) and the exact broadcast time, the distance traveled by the signal can be computed from the arrival time. The distance derived from this method of computing distance is called a pseudo-range because it is not a direct measurement of distance, but a measurement based on time. In addition to knowing the distance to a satellite, a receiver needs to know the satellite's exact position in space, its ephemeris. Each satellite transmits information about its exact orbital location. The GPS receiver uses this information to establish the precise position of the satellite.

Using the calculated pseudo-range and position information supplied by the satellite, the GPS receiver/processor mathematically determines its position by triangulation from several satellites. The GPS receiver needs at least four satellites to yield a three-dimensional position (latitude, longitude, and altitude) and time solution. The GPS receiver computes navigational values (distance and bearing to a WP, groundspeed, etc.) by using the aircraft's known latitude/longitude and referencing these to a database built into the receiver.

The GPS receiver verifies the integrity (usability) of the signals received from the GPS constellation through receiver autonomous integrity monitoring (RAIM) to determine if a satellite is providing corrupted information. RAIM needs a minimum of five satellites in view, or four satellites and a barometric altimeter baro-aiding to detect an integrity anomaly. For receivers capable of doing so, RAIM needs six satellites in view (or five satellites with baro-aiding) to isolate a corrupt satellite signal and remove it from the navigation solution.

Generally, there are two types of RAIM messages. One type indicates that there are not enough satellites available to provide RAIM and another type indicates that the RAIM has detected a potential error that exceeds the limit for the current phase of flight. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

Aircraft using GPS navigation equipment under IFR for domestic en route, terminal operations, and certain IAPs, must be equipped with an approved and operational alternate means of navigation appropriate to the flight. The avionics necessary to receive all of the ground-based facilities appropriate for the route to the destination airport and any required alternate airport must be installed and operational. Ground-based facilities necessary for these routes must also be operational. Active monitoring of alternative navigation equipment is not required if the GPS receiver uses RAIM for integrity monitoring. Active monitoring of an alternate means of navigation is required when the RAIM capability of the GPS equipment is lost. In situations where the loss of RAIM capability is predicted to occur, the flight must rely on other approved equipment, delay departure, or cancel the flight.

GPS Substitution

IFR En Route and Terminal Operations

GPS systems, certified for IFR en route and terminal operations, may be used as a substitute for ADF and DME receivers when conducting the following operations within the United States NAS.

1. Determining the aircraft position over a DME fix. This includes en route operations at and above 24,000 feet mean sea level (MSL) (FL 240) when using GPS for navigation.
2. Flying a DME arc.
3. Navigating TO/FROM an NDB/compass locator.
4. Determining the aircraft position over an NDB/compass locator.
5. Determining the aircraft position over a fix defined by an NDB/compass locator bearing crossing a VOR/LOC course.

6. Holding over an NDB/compass locator.

GPS Substitution for ADF or DME

Using GPS as a substitute for ADF or DME is subject to the following restrictions:

1. This equipment must be installed in accordance with appropriate airworthiness installation requirements and operated within the provisions of the applicable POH/AFM, or supplement.
2. The required integrity for these operations must be provided by at least en route RAIM, or equivalent.
3. WPs, fixes, intersections, and facility locations to be used for these operations must be retrieved from the GPS airborne database. The database must be current. If the required positions cannot be retrieved from the airborne database, the substitution of GPS for ADF and/or DME is not authorized
4. Procedures must be established for use when RAIM outages are predicted or occur. This may require the flight to rely on other approved equipment or require the aircraft to be equipped with operational NDB and/or DME receivers. Otherwise, the flight must be rerouted, delayed, canceled, or conducted under VFR.
5. The CDI must be set to terminal sensitivity (1 NM) when tracking GPS course guidance in the terminal area.
6. A non-GPS approach procedure must exist at the alternate airport when one is required. If the non-GPS approaches on which the pilot must rely require DME or ADF, the aircraft must be equipped with DME or ADF avionics as appropriate.
7. Charted requirements for ADF and/or DME can be met using the GPS system, except for use as the principal instrument approach navigation source.

NOTE: The following provides guidance, which is not specific to any particular aircraft GPS system. For specific system guidance, refer to the POH/AFM, or supplement, or contact the system manufacturer.

To Determine Aircraft Position Over a DME Fix:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. If the fix is identified by a five-letter name which is contained in the GPS airborne database, select either the named fix as the active GPS WP or the facility establishing the DME fix as the active GPS WP. When using a facility as the active WP, the only acceptable facility is the DME facility which is charted as the one used to establish the DME fix. If this facility is not in the airborne database, it is not authorized for use.
3. If the fix is identified by a five-letter name which is not contained in the GPS airborne database, or if the fix is not named, select the facility establishing the DME fix or another named DME fix as the active GPS WP.
4. When selecting the named fix as the active GPS WP, a pilot is over the fix when the GPS system indicates the active WP.
5. If selecting the DME providing facility as the active GPS WP, a pilot is over the fix when the GPS distance from the active WP equals the charted DME value, and the aircraft is established on the appropriate bearing or course.

To Fly a DME Arc:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select from the airborne database the facility providing the DME arc as the active GPS WP. The only acceptable facility is the DME facility on which the arc is based. If this facility is not in your airborne database, you are not authorized to perform this operation.
3. Maintain position on the arc by reference to the GPS distance instead of a DME readout.

To Navigate TO or FROM an NDB/Compass Locator:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select the NDB/compass locator facility from the airborne database as the active WP. If the chart depicts the compass locator collocated with a fix of the same name, use of that fix as the active WP in place of the compass locator facility is authorized.
3. Select and navigate on the appropriate course to or from the active WP.

To Determine Aircraft Position Over an NDB/ Compass Locator:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.

2. Select the NDB/compass locator facility from the airborne database. When using an NDB/compass locator, the facility must be charted and be in the airborne database. If the facility is not in the airborne database, pilots are not authorized to use a facility WP for this operation.
3. A pilot is over the NDB/compass locator when the GPS system indicates arrival at the active WP.

To Determine Aircraft Position Over a Fix Made up of an NDB/Compass Locator Bearing Crossing a VOR/LOC Course:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. A fix made up by a crossing NDB/compass locator bearing is identified by a five-letter fix name. Pilots may select either the named fix or the NDB/compass locator facility providing the crossing bearing to establish the fix as the active GPS WP. When using an NDB/compass locator, that facility must be charted and be in the airborne database. If the facility is not in the airborne database, pilots are not authorized to use a facility WP for this operation.
3. When selecting the named fix as the active GPS WP, pilot is over the fix when the GPS system indicates the pilot is at the WP.
4. When selecting the NDB/compass locator facility as the active GPS WP, pilots are over the fix when the GPS bearing to the active WP is the same as the charted NDB/compass locator bearing for the fix flying the prescribed track from the non-GPS navigation source.

To Hold Over an NDB/Compass Locator:

1. Verify aircraft GPS system integrity monitoring is functioning properly and indicates satisfactory integrity.
2. Select the NDB/compass locator facility from the airborne database as the active WP. When using a facility as the active WP, the only acceptable facility is the NDB/compass locator facility which is charted. If this facility is not in the airborne database, its use is not authorized.
3. Select nonsequencing (e.g., "HOLD" or "OBS") mode and the appropriate course in accordance with the POH/AFM, or supplement.
4. Hold using the GPS system in accordance with the POH/AFM, or supplement.

IFR Flight Using GPS

Preflight preparations should ensure that the GPS is properly installed and certified with a current database for the type of operation. The GPS operation must be conducted in accordance with the FAA-approved POH/AFM or flight manual supplement. Flightcrew members must be thoroughly familiar with the particular GPS equipment installed in the aircraft, the receiver operation manual, and the POH/AFM or flight manual supplement. Unlike ILS and VOR, the basic operation, receiver presentation to the pilot and some capabilities of the equipment can vary greatly. Due to these differences, operation of different brands, or even models of the same brand of GPS receiver under IFR should not be attempted without thorough study of the operation of that particular receiver and installation. Using the equipment in flight under VFR conditions prior to attempting IFR operation will allow further familiarization.

Required preflight preparations should include checking NOTAMs relating to the IFR flight when using GPS as a supplemental method of navigation. GPS satellite outages are issued as GPS NOTAMs both domestically and internationally. Pilots may obtain GPS RAIM availability information for an airport by specifically requesting GPS aeronautical information from an automated flight service station (AFSS) during preflight briefings. GPS RAIM aeronautical information can be obtained for a 3-hour period: the estimated time of arrival (ETA), and 1 hour before to 1 hour after the ETA hour, or a 24-hour time frame for a specific airport. FAA briefers will provide RAIM information for a period of 1 hour before to 1 hour after the ETA, unless a specific timeframe is requested by the pilot. If flying a published GPS departure, the pilot should also request a RAIM prediction for the departure airport. Some GPS receivers have the capability to predict RAIM availability. The pilot should also ensure that the required underlying ground-based navigation facilities and related aircraft equipment appropriate to the route of flight, terminal operations, instrument approaches for the destination, and alternate airports/heliports will be operational for the ETA. If the required ground-based facilities and equipment will not be available, the flight should be rerouted, rescheduled, canceled, or conducted under VFR.

Except for programming and retrieving information from the GPS receiver, planning the flight is accomplished in a similar manner to conventional NAVAIDs. Departure WP, DP, route, STAR, desired approach, IAF, and destination airport are entered into the GPS receiver according to the manufacturer's instructions. During preflight, additional information may be entered for functions such as ETA, fuel planning, winds aloft, etc.

When the GPS receiver is turned on, it begins an internal process of test and initialization. When the receiver is initialized, the user develops the route by selecting a WP or series of WPs, verifies the data, and selects the active flight plan. This procedure varies widely among receivers made by different manufacturers. GPS is a complex system, offering little standardization between receiver models. It is the pilot's responsibility to be familiar with the operation of the equipment in the aircraft.

The GPS receiver provides navigational values such as track, bearing, groundspeed, and distance. These are computed from the aircraft's present latitude and longitude to the location of the next WP. Course guidance is provided between WPs. The pilot has the advantage of knowing the aircraft's actual track over the ground. As long as track and bearing to the WP are matched up (by selecting the correct aircraft heading), the aircraft is going directly to the WP.

GPS Instrument Approaches

There is a mixture of GPS overlay approaches (approaches with "or GPS" in the title) and GPS stand-alone approaches in the United States.

NOTE: GPS instrument approach operations outside the United States must be authorized by the appropriate country authority.

While conducting these IAPs, ground-based NAVAIDs are not required to be operational and associated aircraft avionics need not be installed, operational, turned on, or monitored; however, monitoring backup navigation systems is always recommended when available.

Pilots should have a basic understanding of GPS approach procedures and practice GPS IAPs under visual meteorological conditions (VMC) until thoroughly proficient with all aspects of their equipment (receiver and installation) prior to attempting flight in instrument meteorological conditions (IMC). *[Figure 7-29]*

All IAPs must be retrievable from the current GPS database supplied by the manufacturer or other FAA-approved source. Flying point to point on the approach does not assure compliance with the published approach procedure. The proper RAIM sensitivity will not be available and the CDI sensitivity will not automatically change to 0.3 NM. Manually setting CDI sensitivity does not automatically change the RAIM sensitivity on some receivers. Some existing nonprecision approach procedures cannot be coded for use with GPS and will not be available as overlays.

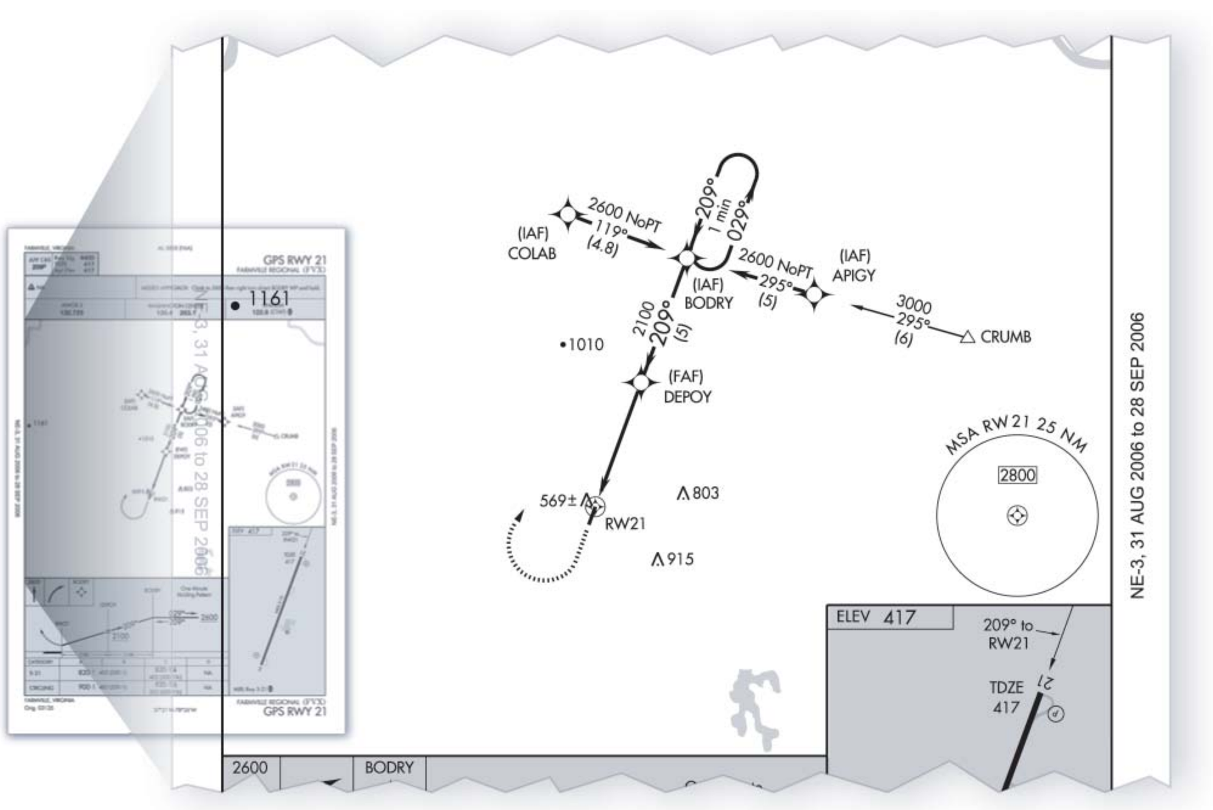


Figure 7-29. *A GPS Stand-Alone Approach.*

GPS approaches are requested and approved by ATC using the GPS title, such as "GPS RWY 24" or "RNAV RWY 35." Using the manufacturer's recommended procedures, the desired approach and the appropriate IAF are selected from the GPS receiver database. Pilots should fly the full approach from an initial approach waypoint (IAWP) or feeder fix unless specifically cleared otherwise. Randomly joining an approach at an intermediate fix does not ensure terrain clearance.

When an approach has been loaded in the flight plan, GPS receivers will give an "arm" annunciation 30 NM straight line distance from the airport/heliport reference point. The approach mode should be "armed" when within 30 NM distance so the receiver will change from en route CDI (±5 NM) and RAIM (±2 NM) sensitivity to ±1 NM terminal sensitivity. Where the IAWP is within 30 NM, a CDI sensitivity change will occur once the approach mode is armed and the aircraft is within 30 NM. Where the IAWP is beyond the 30 NM point, CDI sensitivity will not change until the aircraft is within 30 NM even if the approach is armed earlier. Feeder route obstacle clearance is predicated on the receiver CDI and RAIM being in terminal CDI sensitivity within 30 NM of the airport/heliport reference point; therefore, the receiver should always be armed no later than the 30 NM annunciation.

Pilots should pay particular attention to the exact operation of their GPS receivers for performing holding patterns and in the case of overlay approaches, operations such as procedure turns. These procedures may require manual intervention by the pilot to stop the sequencing of WPs by the receiver and to resume automatic GPS navigation sequencing once the maneuver is complete. The same WP may appear in the route of flight more than once and consecutively (e.g., IAWP, final approach waypoint (FAWP), missed approach waypoint (MAWP) on a procedure turn). Care must be exercised to ensure the receiver is sequenced to the appropriate WP for the segment of the procedure being flown, especially if one or more fly-over WPs are skipped (e.g., FAWP rather than IAWP if the procedure turn is not flown). The pilot may need to sequence past one or more fly-overs of the same WP in order to start GPS automatic sequencing at the proper place in the sequence of WPs.

When receiving vectors to final, most receiver operating manuals suggest placing the receiver in the nonsequencing mode on the FAWP and manually setting the course. This provides an extended final approach course in cases where the aircraft is vectored onto the final approach course outside of any existing segment which is aligned with the runway. Assigned altitudes must be maintained until established on a published segment of the approach. Required altitudes at WPs outside the FAWP or step-down fixes must be considered. Calculating the distance to the FAWP may be required in order to descend at the proper location.

When within 2 NM of the FAWP with the approach mode armed, the approach mode will switch to active, which results in RAIM and CDI sensitivity changing to the approach mode. Beginning 2 NM prior to the FAWP, the full scale CDI sensitivity will change smoothly from ±1 NM to ±0.3 NM at the FAWP. As sensitivity changes from ±1 NM to ±0.3 NM approaching the FAWP, and the CDI not centered, the corresponding increase in CDI displacement may give the impression the aircraft is moving further away from the intended course even though it is on an acceptable intercept heading. If digital track displacement information (cross-track error) is available in the approach mode, it may help the pilot remain position oriented in this situation. Being established on the final approach course prior to the beginning of the sensitivity change at 2 NM will help prevent problems in interpreting the CDI display during ramp-down. Requesting or accepting vectors, which will cause the aircraft to intercept the final approach course within 2 NM of the FAWP, is not recommended.

Incorrect inputs into the GPS receiver are especially critical during approaches. In some cases, an incorrect entry can cause the receiver to leave the approach mode. Overriding an automatically selected sensitivity during an approach will cancel the approach mode annunciation. If the approach mode is not armed by 2 NM prior to the FAWP, the approach mode will not become active at 2 NM prior to the FAWP and the equipment will flag. In these conditions, the RAIM and CDI sensitivity will not ramp down, and the pilot should not descend to minimum descent altitude (MDA), but fly to the MAWP and execute a missed approach. The approach active annunciator and/or the receiver should be checked to ensure the approach mode is active prior to the FAWP.

A GPS missed approach requires pilot action to sequence the receiver past the MAWP to the missed approach portion of the procedure. The pilot must be thoroughly familiar with the activation procedure for the particular GPS receiver installed in the aircraft and must initiate appropriate action after the MAWP. Activating the missed approach prior to the MAWP will cause CDI sensitivity to change immediately to terminal (±1 NM) sensitivity, and the receiver will continue to navigate to the MAWP. The receiver will not sequence past the MAWP. Turns should not begin prior to the MAWP. If the missed approach is not activated, the GPS receiver will display an extension of the inbound final approach course and the along track distance (ATD) will increase from the MAWP until it is manually sequenced after crossing the MAWP.

Missed approach routings in which the first track is via a course rather than direct to the next WP require additional action by the pilot to set the course. Being familiar with all of the required inputs is especially critical during this phase of flight.

Departures and Instrument Departure Procedures (DPs)

The GPS receiver must be set to terminal (±1 NM) CDI sensitivity and the navigation routes contained in the database in order to fly published IFR charted departures and DPs. Terminal RAIM should be provided automatically by the receiver. (Terminal RAIM for departure may not be available unless the WPs are part of the active flight plan rather than proceeding direct to the first destination.) Certain segments of a DP may require some manual intervention by the pilot, especially when radar vectored to a course or required to intercept a specific course to a WP. The database may not contain all of the transitions or departures from all runways and some GPS receivers do not contain DPs in the database. It is necessary that helicopter procedures be flown at 70 knots or less since helicopter departure procedures and missed approaches use a 20:1 obstacle clearance surface (OCS), which is double the fixed-wing OCS. Turning areas are based on this speed also. Missed approach routings in which the first track is via a course rather than direct to the next WP require additional action by the pilot to set the course. Being familiar with all of the required inputs is especially critical during this phase of flight.

GPS Errors

Normally, with 30 satellites in operation, the GPS constellation is expected to be available continuously worldwide. Whenever there are fewer than 24 operational satellites, GPS navigational capability may not be available at certain geographic locations. Loss of signals may also occur in valleys surrounded by high terrain, and any time the aircraft's GPS antenna is "shadowed" by the aircraft's structure (e.g., when the aircraft is banked).

Certain receivers, transceivers, mobile radios, and portable receivers can cause signal interference. Some VHF transmissions may cause "harmonic interference." Pilots can isolate the interference by relocating nearby portable receivers, changing frequencies, or turning off suspected causes of the interference while monitoring the receiver's signal quality data page.

GPS position data can be affected by equipment characteristics and various geometric factors, which typically cause errors of less than 100 feet. Satellite atomic clock inaccuracies, receiver/processors, signals reflected from hard objects (multi-path), ionospheric and tropospheric delays, and satellite data transmission errors may cause small position errors or momentary loss of the GPS signal.

System Status

The status of GPS satellites is broadcast as part of the data message transmitted by the GPS satellites. GPS status information is also available by means of the United States Coast Guard navigation information service: (703) 313-5907, or on the internet at http://www.navcen.uscg.gov/. Additionally, satellite status is available through the Notice to Airmen (NOTAM) system.

The GPS receiver verifies the integrity (usability) of the signals received from the GPS constellation through receiver autonomous integrity monitoring (RAIM) to determine if a satellite is providing corrupted information. At least one satellite, in addition to those required for navigation, must be in view for the receiver to perform the RAIM function; thus, RAIM needs a minimum of five satellites in view, or four satellites and a barometric altimeter (baro-aiding) to detect an integrity anomaly. For receivers capable of doing so, RAIM needs six satellites in view (or five satellites with baro-aiding) to isolate the corrupt satellite signal and remove it from the navigation solution.

RAIM messages vary somewhat between receivers; however, there are two most commonly used types. One type indicates that there are not enough satellites available to provide RAIM integrity monitoring and another type indicates that the RAIM integrity monitor has detected a potential error that exceeds the limit for the current phase of flight. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

Selective Availability. Selective Availability (SA) is a method by which the accuracy of GPS is intentionally degraded. This feature is designed to deny hostile use of precise GPS positioning data. SA was discontinued on May 1, 2000, but many GPS receivers are designed to assume that SA is still active. New receivers may take advantage of the discontinuance of SA based on the performance values in ICAO Annex 10, and do not need to be designed to operate outside of that performance.

GPS Familiarization

Pilots should practice GPS approaches under visual meteorological conditions (VMC) until thoroughly proficient with all aspects of their equipment (receiver and installation) prior to attempting flight by IFR in instrument meteorological conditions (IMC). Some of the tasks which the pilot should practice are:

1. Utilizing the receiver autonomous integrity monitoring (RAIM) prediction function;
2. Inserting a DP into the flight plan, including setting terminal CDI sensitivity, if required, and the conditions under which terminal RAIM is available for departure (some receivers are not DP or STAR capable);
3. Programming the destination airport;
4. Programming and flying the overlay approaches (especially procedure turns and arcs);
5. Changing to another approach after selecting an approach;
6. Programming and flying "direct" missed approaches;
7. Programming and flying "routed" missed approaches;
8. Entering, flying, and exiting holding patterns, particularly on overlay approaches with a second WP in the holding pattern;
9. Programming and flying a "route" from a holding pattern;
10. Programming and flying an approach with radar vectors to the intermediate segment;
11. Indication of the actions required for RAIM failure both before and after the FAWP; and
12. Programming a radial and distance from a VOR (often used in departure instructions).

Differential Global Positioning Systems (DGPS)

Differential global positioning systems (DGPS) are designed to improve the accuracy of global navigation satellite systems (GNSS) by measuring changes in variables to provide satellite positioning corrections.

Because multiple receivers receiving the same set of satellites produce similar errors, a reference receiver placed at a known location can compute its theoretical position accurately and can compare that value to the measurements provided by the navigation satellite signals. The difference in measurement between the two signals is an error that can be corrected by providing a reference signal correction.

As a result of this differential input accuracy of the satellite system can be increased to meters. The Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS) are examples of differential global positioning systems.

Wide Area Augmentation System (WAAS)

The WAAS is designed to improve the accuracy, integrity, and availability of GPS signals. WAAS allows GPS to be used, as the aviation navigation system, from takeoff through Category I precision approaches. The International Civil Aviation Organization (ICAO) has defined Standards for satellite-based augmentation systems (SBAS), and Japan and Europe are building similar systems that are planned to be interoperable with WAAS: EGNOS, the European Geostationary Navigation Overlay System, and MSAS, the Japanese Multifunctional Transport Satellite (MTSAT) Satellite-based Augmentation System. The result will be a worldwide seamless navigation capability similar to GPS but with greater accuracy, availability, and integrity.

Unlike traditional ground-based navigation aids, WAAS will cover a more extensive service area in which surveyed wide-area ground reference stations are linked to the WAAS network. Signals from the GPS satellites are monitored by these stations to determine satellite clock and ephemeris corrections. Each station in the network relays the data to a wide-area master station where the correction information is computed. A correction message is prepared and uplinked to a geostationary satellite (GEO) via a ground uplink and then broadcast on the same frequency as GPS to WAAS receivers within the broadcast coverage area. *[Figure 7-30]*

In addition to providing the correction signal, WAAS provides an additional measurement to the aircraft receiver, improving the availability of GPS by providing, in effect, an additional GPS satellite in view. The integrity of GPS is improved through real-time monitoring, and the accuracy is improved by providing differential corrections to reduce errors. *[Figure 7-31]* As a result, performance improvement is sufficient to enable approach procedures with GPS/WAAS glide paths. At this time the FAA has completed installation of 25 wide area ground reference systems, two master stations, and four ground uplink stations.

General Requirements

WAAS avionics must be certified in accordance with TSO-C145A, Airborne Navigation Sensors Using the GPS Augmented by the WAAS; or TSO-146A for stand-alone systems. GPS/WAAS operation must be conducted in accordance with the FAA-approved aircraft flight manual (AFM) and flight manual supplements. Flight manual supplements must state the level of approach procedure that the receiver supports.

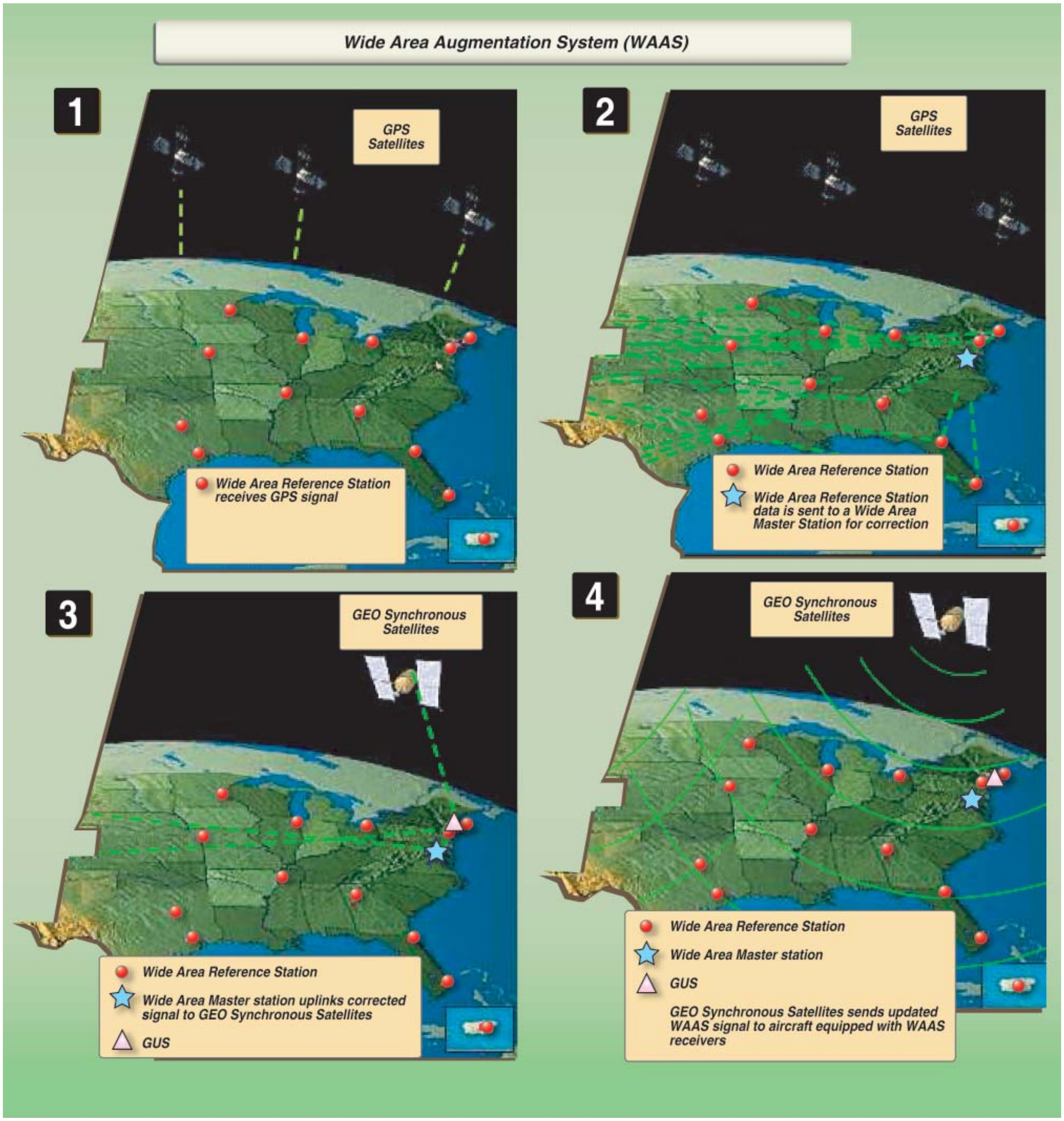


Figure 7-30. *WAAS Satellite Representation.*

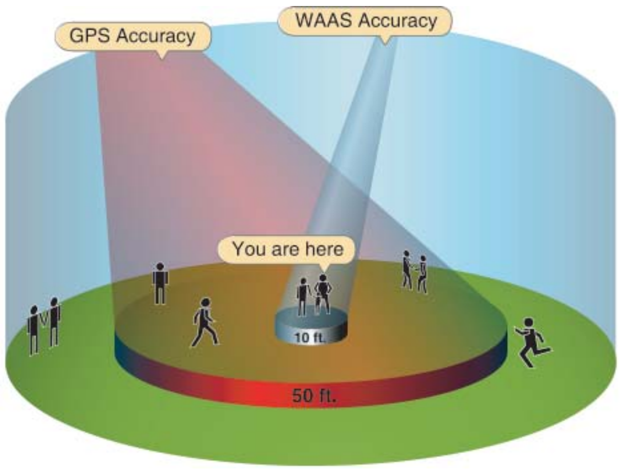


Figure 7-31. *WAAS Satellite Representation.*

Instrument Approach Capabilities

WAAS receivers support all basic GPS approach functions and will provide additional capabilities with the key benefit to generate an electronic glide path, independent of ground equipment or barometric aiding. This eliminates several problems such as cold temperature effects, incorrect altimeter setting or lack of a local altimeter source, and allows approach procedures to be built without the cost of installing ground stations at each airport. A new class of approach procedures which provide vertical guidance requirements for precision approaches has been developed to support satellite navigation use for aviation applications. These new procedures called Approach with Vertical Guidance (APV) include approaches such as the LNAV/VNAV procedures presently being flown with barometric vertical navigation.

Local Area Augmentation System (LAAS)

LAAS is a ground-based augmentation system which uses a GPS reference facility located on or in the vicinity of the airport being serviced. This facility has a reference receiver that measures GPS satellite pseudo-range and timing and retransmits the signal. Aircraft landing at LAAS-equipped airports are able to conduct approaches to Category I level and above for properly equipped aircraft. *[Figures 7-32* and *7-33]*

Inertial Navigation System (INS)

Inertial Navigation System (INS) is a system that navigates precisely without any input from outside of the aircraft. It is fully self-contained. The INS is initialized by the pilot, who enters into the system the exact location of the aircraft on the ground before the flight. The INS is also programmed with WPs along the desired route of flight.

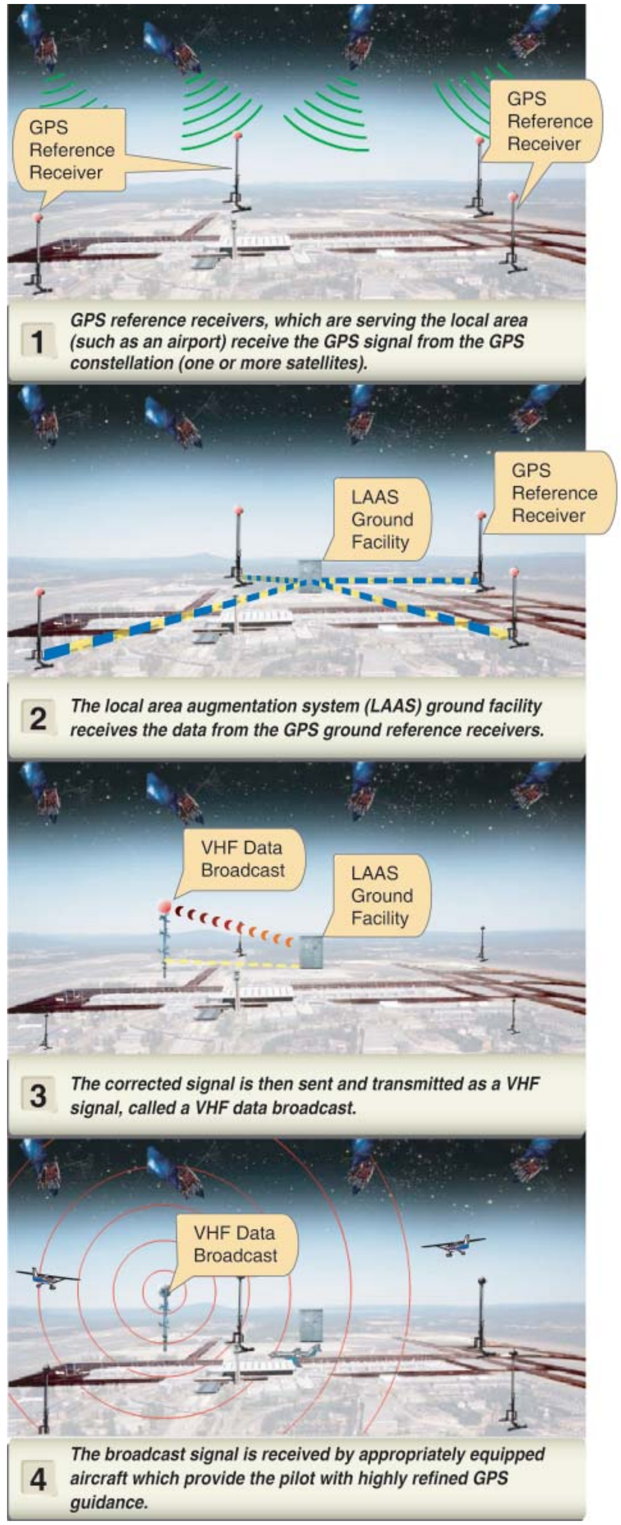


Figure 7-32. *LAAS Representation.*

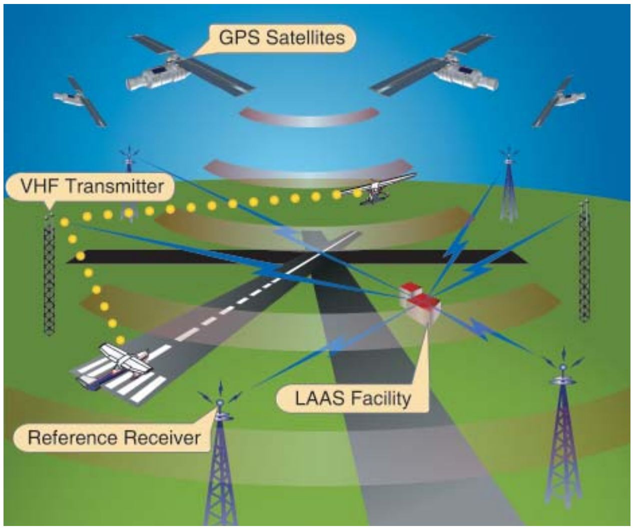


Figure 7-33. *LAAS Representation.*

INS Components

INS is considered a stand-alone navigation system, especially when more than one independent unit is onboard. The airborne equipment consists of an accelerometer to measure acceleration—which, when integrated with time, gives velocity—and gyros to measure direction.

Later versions of the INS, called inertial reference systems (IRS) utilize laser gyros and more powerful computers; therefore, the accelerometer mountings no longer need to be kept level and aligned with true north. The computer system can handle the added workload of dealing with the computations necessary to correct for gravitational and directional errors. Consequently, these newer systems are sometimes called strap down systems, as the accelerometers and gyros are strapped down to the airframe, rather than being mounted on a structure that stays fixed with respect to the horizon and true north.

INS Errors

The principal error associated with INS is degradation of position with time. INS computes position by starting with accurate position input which is changed continuously as accelerometers and gyros provide speed and direction inputs. Both accelerometers and gyros are subject to very small errors; as time passes, those errors probably accumulate.

While the best INS/IRS display errors of 0.1 to 0.4 NM after flights across the North Atlantic of 4 to 6 hours, smaller and less expensive systems are being built that show errors of 1 to 2 NM per hour. This accuracy is more than sufficient for a navigation system that can be combined with and updated by GPS. The synergy of a navigation system consisting of an INS/IRS unit in combination with a GPS resolves the errors and weaknesses of both systems. GPS is accurate all the time it is working but may be subject to short and periodic outages. INS is made more accurate because it is continually updated and continues to function with good accuracy if the GPS has moments of lost signal.

Instrument Approach Systems

Most navigation systems approved for en route and terminal operations under IFR, such as VOR, NDB, and GPS, may also be approved to conduct IAPs. The most common systems in use in the United States are the ILS, simplified directional facility (SDF), localizer directional aid (LDA), and microwave landing system (MLS). These systems operate independently of other navigation systems. There are new systems being developed, such as WAAS and LAAS. Other systems have been developed for special use.

Instrument Landing Systems (ILS)

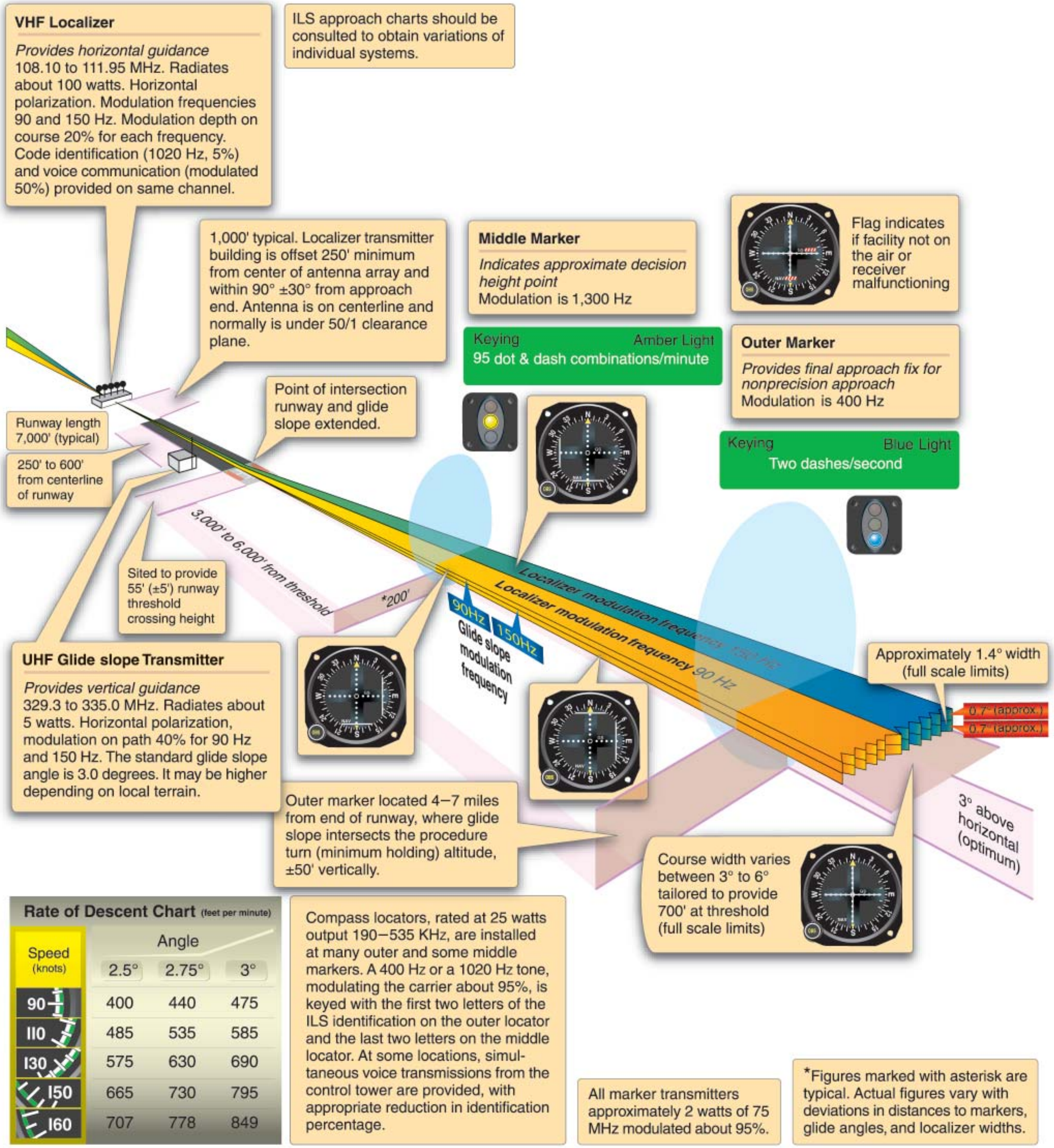
The ILS system provides both course and altitude guidance to a specific runway. The ILS system is used to execute a precision instrument approach procedure or precision approach. *[Figure 7-34]* The system consists of the following components:

1. A localizer providing horizontal (left/right) guidance along the extended centerline of the runway.
2. A glide slope (GS) providing vertical (up/down) guidance toward the runway touchdown point, usually at a 3° slope.
3. Marker beacons providing range information along the approach path.
4. Approach lights assisting in the transition from instrument to visual flight.

The following supplementary elements, though not specific components of the system, may be incorporated to increase safety and utility:

1. Compass locators providing transition from en route NAVAIDs to the ILS system and assisting in holding procedures, tracking the localizer course, identifying the marker beacon sites, and providing a FAF for ADF approaches.
2. DME collocated with the GS transmitter providing positive distance-to-touchdown information or DME associated with another nearby facility (VOR or stand-alone), if specified in the approach procedure.

ILS approaches are categorized into three different types of approaches based on the equipment at the airport and the experience level of the pilot. Category I approaches provide for approach height above touchdown of not less than 200 feet. Category II approaches provide for approach to a height above



Rate of Descent Chart (feet per minute)

Speed (knots)	Angle 2.5°	2.75°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

Figure 7-34. *Instrument Landing Systems.*

touchdown of not less than 100 feet. Category III approaches provide lower minimums for approaches without a decision height minimum. While pilots need only be instrument rated and the aircraft be equipped with the appropriate airborne equipment to execute Category I approaches, Category II and III approaches require special certification for the pilots, ground equipment, and airborne equipment.

ILS Components

Ground Components

The ILS uses a number of different ground facilities. These facilities may be used as a part of the ILS system, as well as part of another approach. For example, the compass locator may be used with NDB approaches.

Localizer

The localizer (LOC) ground antenna array is located on the extended centerline of the instrument runway of an airport, located at the departure end of the runway to prevent it from being a collision hazard. This unit radiates a field pattern, which develops a course down the centerline of the runway toward the middle markers (MMs) and outer markers (OMs), and a similar course along the runway centerline in the opposite direction. These are called the front and back courses, respectively. The localizer provides course guidance, transmitted at 108.1 to 111.95 MHz (odd tenths only), throughout the descent path to the runway threshold from a distance of 18 NM from the antenna to an altitude of 4,500 feet above the elevation of the antenna site. *[Figure 7-35]*

The localizer course width is defined as the angular displacement at any point along the course between a full "fly-left" (CDI needle fully deflected to the left) and a full "fly-right" indication (CDI needle fully deflected to the right). Each localizer facility is audibly identified by a three-letter designator, transmitted at frequent regular intervals. The ILS identification is preceded by the letter "I" (two dots). For example, the ILS localizer at Springfield, Missouri transmits the identifier ISGF. The localizer includes a voice feature on its frequency for use by the associated ATC facility in issuing approach and landing instructions.

The localizer course is very narrow, normally 5°. This results in high needle sensitivity. With this course width, a full-scale deflection shows when the aircraft is 2.5° to either side of the centerline. This sensitivity permits accurate orientation to the landing runway. With no more than one-quarter scale deflection maintained, the aircraft will be aligned with the runway.

Glide Slope (GS)

GS describes the systems that generate, receive, and indicate the ground facility radiation pattern. The glide path is the straight, sloped line the aircraft should fly in its descent from where the GS intersects the altitude used for approaching the FAF, to the runway touchdown zone. The GS equipment is housed in a building approximately 750 to 1,250 feet down the runway from the approach end of the runway, and between 400 and 600 feet to one side of the centerline.

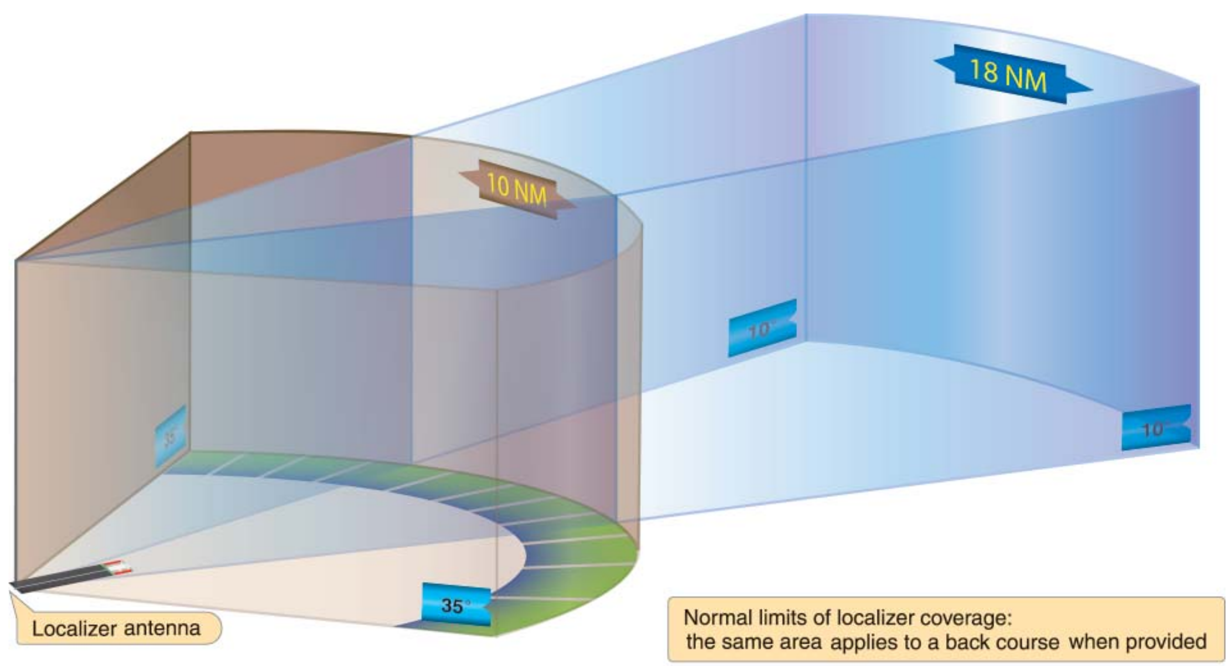


Figure 7-35. *Localizer Coverage Limits.*

The course projected by the GS equipment is essentially the same as would be generated by a localizer operating on its side. The GS projection angle is normally adjusted to 2.5° to 3.5° above horizontal, so it intersects the MM at about 200 feet and the OM at about 1,400 feet above the runway elevation. At locations where standard minimum obstruction clearance cannot be obtained with the normal maximum GS angle, the GS equipment is displaced farther from the approach end of the runway if the length of the runway permits; or, the GS angle may be increased up to 4°.

Unlike the localizer, the GS transmitter radiates signals only in the direction of the final approach on the front course. The system provides no vertical guidance for approaches on the back course. The glide path is normally 1.4° thick. At 10 NM from the point of touchdown, this represents a vertical distance of approximately 1,500 feet, narrowing to a few feet at touchdown.

Marker Beacons

Two VHF marker beacons, outer and middle, are normally used in the ILS system. *[Figure 7-36]* A third beacon, the inner, is used where Category II operations are certified. A marker beacon may also be installed to indicate the FAF on the ILS back course.

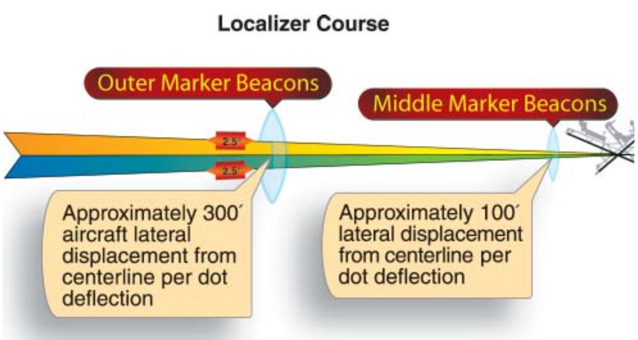


Figure 7-36. *Localizer receiver indications and aircraft displacement.*

The OM is located on the localizer front course 4–7 miles from the airport to indicate a position at which an aircraft, at the appropriate altitude on the localizer course, will intercept the glide path. The MM is located approximately 3,500 feet from the landing threshold on the centerline of the localizer front course at a position where the GS centerline is about 200 feet above the touchdown zone elevation. The inner marker (IM), where installed, is located on the front course between the MM and the landing threshold. It indicates the point at which an aircraft is at the decision height on the glide path during a Category II ILS approach. The back-course marker, where installed, indicates the back-course FAF.

Compass Locator

Compass locators are low-powered NDBs and are received and indicated by the ADF receiver. When used in conjunction with an ILS front course, the compass locator facilities are collocated with the outer and/or MM facilities. The coding identification of the outer locator consists of the first two letters of the three-letter identifier of the associated LOC. For example, the outer locator at Dallas/Love Field (DAL) is identified as "DA." The middle locator at DAL is identified by the last two letters "AL."

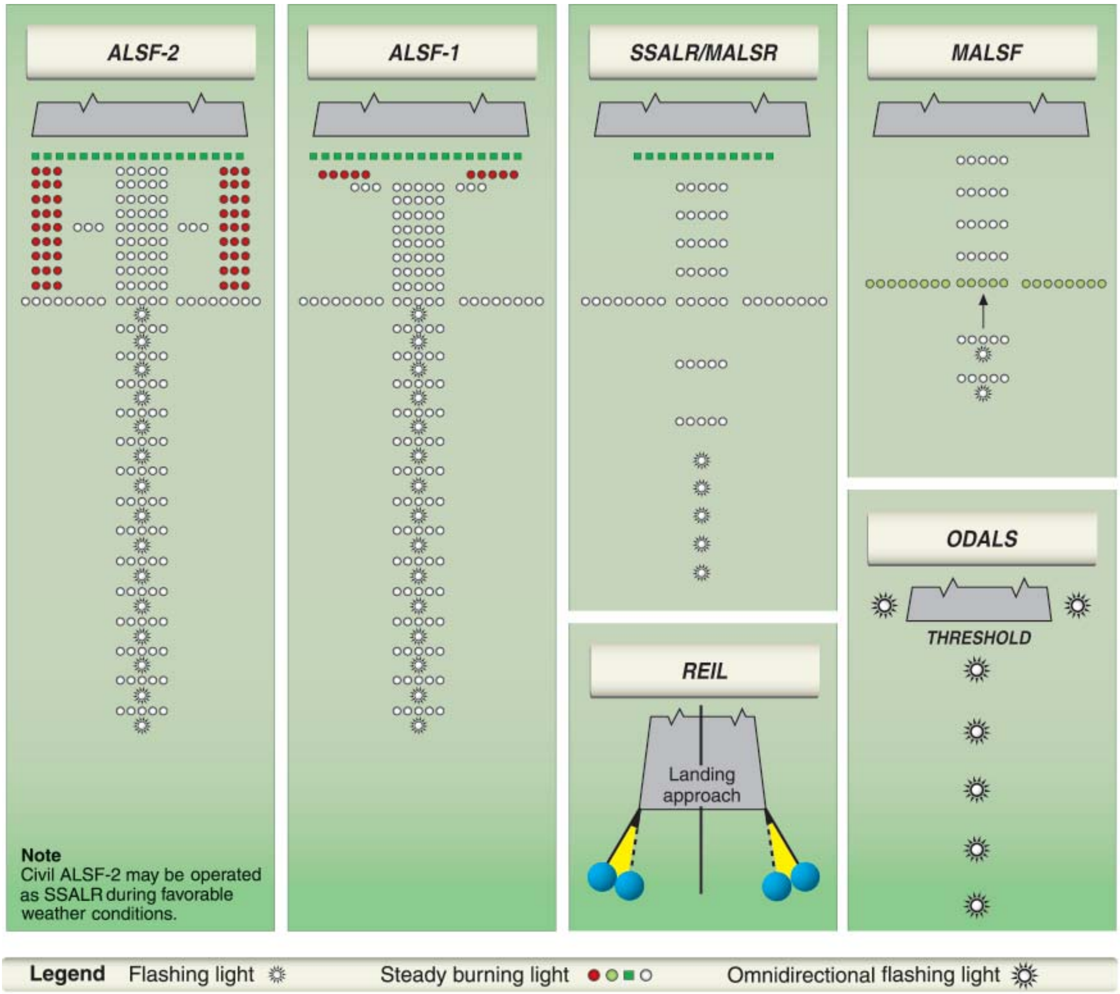
Approach Lighting Systems (ALS)

Normal approach and letdown on the ILS is divided into two distinct stages: the instrument approach stage using only radio guidance, and the visual stage, when visual contact with the ground runway environment is necessary for accuracy and safety. The most critical period of an instrument approach, particularly during low ceiling/visibility conditions, is the point at which the pilot must decide whether to land or execute a missed approach. As the runway threshold is approached, the visual glide path will separate into individual lights. At this point, the approach should be continued by reference to the runway touchdown zone markers. The ALS provides lights that will penetrate the atmosphere far enough from touchdown to give directional, distance, and glide path information for safe visual transition.

Visual identification of the ALS by the pilot must be instantaneous, so it is important to know the type of ALS before the approach is started. Check the instrument approach chart and the A/FD for the particular type of lighting facilities at the destination airport before any instrument flight. With reduced visibility, rapid orientation to a strange runway can be difficult, especially during a circling approach to an airport with minimum lighting facilities, or to a large terminal airport located in the midst of distracting city and ground facility lights. Some of the most common ALS systems are shown in *Figure 7-37.*

A high-intensity flasher system, often referred to as "the rabbit," is installed at many large airports. The flashers consist of a series of brilliant blue-white bursts of light flashing in sequence along the approach lights, giving the effect of a ball of light traveling towards the runway. Typically, "the rabbit" makes two trips toward the runway per second.

Runway end identifier lights (REIL) are installed for rapid and positive identification of the approach end of an instrument runway. The system consists of a pair of synchronized flashing lights placed laterally on each side of the runway threshold facing the approach area.



ALSF—Approach light system with sequenced flashing lights
SSALR—Simplified short approach light system with runway alignment indicator lights
MALSR—Medium intensity approach light system with runway alignment indicator lights
REIL—Runway end identification lights
MALSF—Medium intensity approach light system with sequenced flashing lights (and runway alignment)
ODALS—Omnidirectional approach light system

Figure 7-37. *Precision and Nonprecision ALS Configuration.*

The visual approach slope indicator (VASI) gives visual descent guidance information during the approach to a runway. The standard VASI consists of light bars that project a visual glide path, which provides safe obstruction clearance within the approach zone. The normal GS angle is 3°; however, the angle may be as high as 4.5° for proper obstacle clearance. On runways served by ILS, the VASI angle normally coincides with the electronic GS angle. Visual left/right course guidance is obtained by alignment with the runway lights. The standard VASI installation consists of either 2-, 3-, 4-, 6-, 12-, or 16-light units arranged in downwind and upwind light bars. Some airports serving long-bodied aircraft have three-bar VASIs which provide two visual glidepaths to the same runway. The first glide path encountered is the same as provided by the standard VASI. The second glide path is about 25 percent higher than the first and is designed for the use of pilots of long-bodied aircraft.

The basic principle of VASI is that of color differentiation between red and white. Each light projects a beam having a white segment in the upper part and a red segment in the lower part of the beam. From a position above the glide path the pilot sees both bars as white. Lowering the aircraft with respect to the glide path, the color of the upwind bars changes from white to pink to red. When on the proper glide path, the landing aircraft will overshoot the downwind bars and undershoot the upwind bars. Thus the downwind (closer) bars are seen as white and the upwind bars as red. From a position below the glide path, both light bars are seen as red. Moving up to the glide path, the color of the downwind

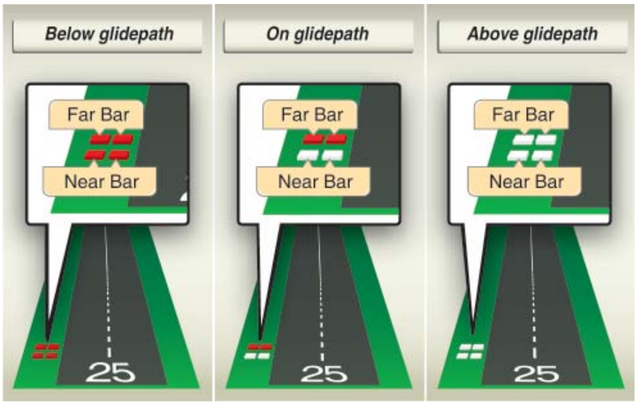


Figure 7-38. *Standard two-bar VASI.*

bars changes from red to pink to white. When below the glide path, as indicated by a distinct all-red signal, a safe obstruction clearance might not exist. A standard two-bar VASI is illustrated in *Figure 7-38*.

ILS Airborne Components

Airborne equipment for the ILS system includes receivers for the localizer, GS, marker beacons, ADF, DME, and the respective indicator instruments.

The typical VOR receiver is also a localizer receiver with common tuning and indicating equipment. Some receivers have separate function selector switches, but most switch between VOR and LOC automatically by sensing if odd tenths between 108 and 111.95 MHz have been selected. Otherwise, tuning of VOR and localizer frequencies is accomplished with the same knobs and switches, and the CDI indicates "on course" as it does on a VOR radial.

Though some GS receivers are tuned separately, in a typical installation the GS is tuned automatically to the proper frequency when the localizer is tuned. Each of the 40 localizer channels in the 108.10 to 111.95 MHz band is paired with a corresponding GS frequency.

When the localizer indicator also includes a GS needle, the instrument is often called a cross-pointer indicator. The crossed horizontal (GS) and vertical (localizer) needles are free to move through standard five-dot deflections to indicate position on the localizer course and glide path.

When the aircraft is on the glide path, the needle is horizontal, overlying the reference dots. Since the glide path is much narrower than the localizer course (approximately 1.4° from full up to full down deflection), the needle is very sensitive to displacement of the aircraft from on-path alignment. With the proper rate of descent established upon GS interception, very small corrections keep the aircraft aligned.

The localizer and GS warning flags disappear from view on the indicator when sufficient voltage is received to actuate the needles. The flags show when an unstable signal or receiver malfunction occurs.

The OM is identified by a low-pitched tone, continuous dashes at the rate of two per second, and a purple/blue marker beacon light. The MM is identified by an intermediate tone, alternate dots and dashes at the rate of 95 dot/dash combinations per minute, and an amber marker beacon light. The IM, where installed, is identified by a high-pitched tone, continuous dots at the rate of six per second, and a white marker beacon light. The back-course marker (BCM), where installed, is identified by a high-pitched tone with two dots at a rate of 72 to 75 two-dot combinations per minute, and a white marker beacon light. Marker beacon receiver sensitivity is selectable as high or low on many units. The low-sensitivity position gives the sharpest indication of position and should be used during an approach. The high-sensitivity position provides an earlier warning that the aircraft is approaching the marker beacon site.

ILS Function

The localizer needle indicates, by deflection, whether the aircraft is right or left of the localizer centerline, regardless of the position or heading of the aircraft. Rotating the OBS has no effect on the operation of the localizer needle, although it is useful to rotate the OBS to put the LOC inbound course under the course index. When inbound on the front course, or outbound on the back course, the course indication remains directional. (See *Figure 7-39,* aircraft C, D, and E.)

Unless the aircraft has reverse sensing capability and it is in use, when flying inbound on the back course or outbound on the front course, heading corrections to on-course are made opposite the needle deflection. This is commonly described as "flying away from the needle." (See *Figure 7-39*, aircraft A and B.) Back course signals should not be used for an approach unless a back course approach procedure is published for that particular runway and the approach is authorized by ATC.

Once you have reached the localizer centerline, maintain the inbound heading until the CDI moves off center. Drift corrections should be small and reduced proportionately as the course narrows. By the time you reach the OM, your drift correction should be established accurately enough on a well-executed approach to permit completion of the approach, with heading corrections no greater then 2°.

The heaviest demand on pilot technique occurs during descent from the OM to the MM, when you maintain the localizer course, adjust pitch attitude to maintain the

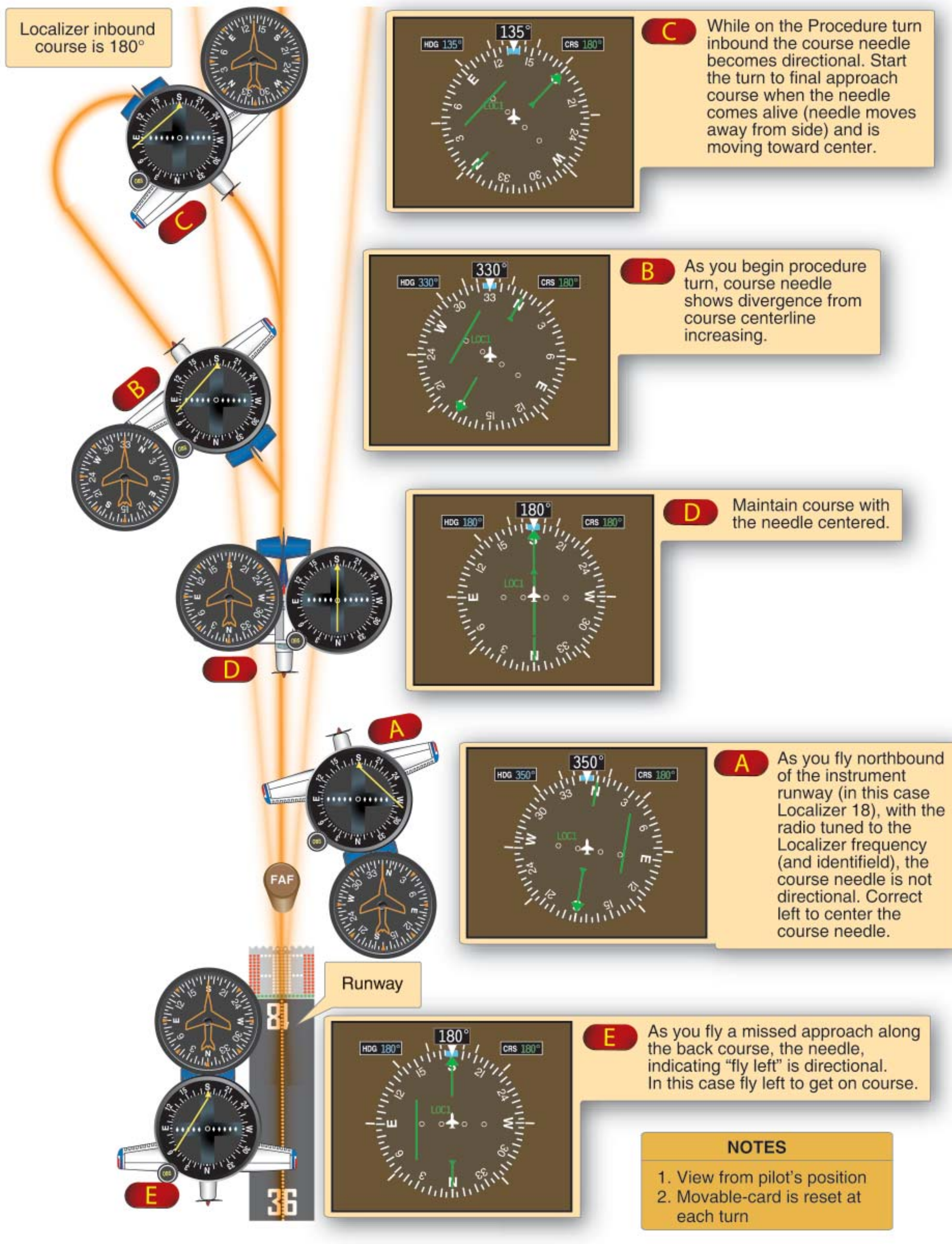


Figure 7-39. *Localizer Course Indications. To follow indications displayed in the aircraft, start from A and proceed through E.*

proper rate of descent, and adjust power to maintain proper airspeed. Simultaneously, the altimeter must be checked and preparation made for visual transition to land or for a missed approach. You can appreciate the need for accurate instrument interpretation and aircraft control within the ILS as a whole, when you notice the relationship between CDI and glide path needle indications, and aircraft displacement from the localizer and glide path centerlines.

Deflection of the GS needle indicates the position of the aircraft with respect to the glide path. When the aircraft is above the glide path, the needle is deflected downward. When the aircraft is below the glide path, the needle is deflected upward. *[Figure 7-40]*

ILS Errors

The ILS and its components are subject to certain errors, which are listed below. Localizer and GS signals are subject to the same type of bounce from hard objects as space waves.

1. Reflection. Surface vehicles and even other aircraft flying below 5,000 feet above ground level (AGL) may disturb the signal for aircraft on the approach.
2. False courses. In addition to the desired course, GS facilities inherently produce additional courses at higher vertical angles. The angle of the lowest of these false courses will occur at approximately 9°–12°. An aircraft flying the LOC/GS course at a constant altitude would observe gyrations of both the GS needle and GS warning flag as the aircraft passed through the various false courses. Getting established on one of these false courses will result in either confusion (reversed GS needle indications) or in the need for a very high descent rate. However, if the approach is conducted at the altitudes specified on the appropriate approach chart, these false courses will not be encountered.

Marker Beacons

The very low power and directional antenna of the marker beacon transmitter ensures that the signal will not be received any distance from the transmitter site. Problems with signal reception are usually caused by the airborne receiver not being turned on, or by incorrect receiver sensitivity.

Some marker beacon receivers, to decrease weight and cost, are designed without their own power supply. These units utilize a power source from another radio in the avionics stack, often the ADF. In some aircraft, this requires the ADF to be turned on in order for the marker beacon receiver to function, yet no warning placard is required. Another

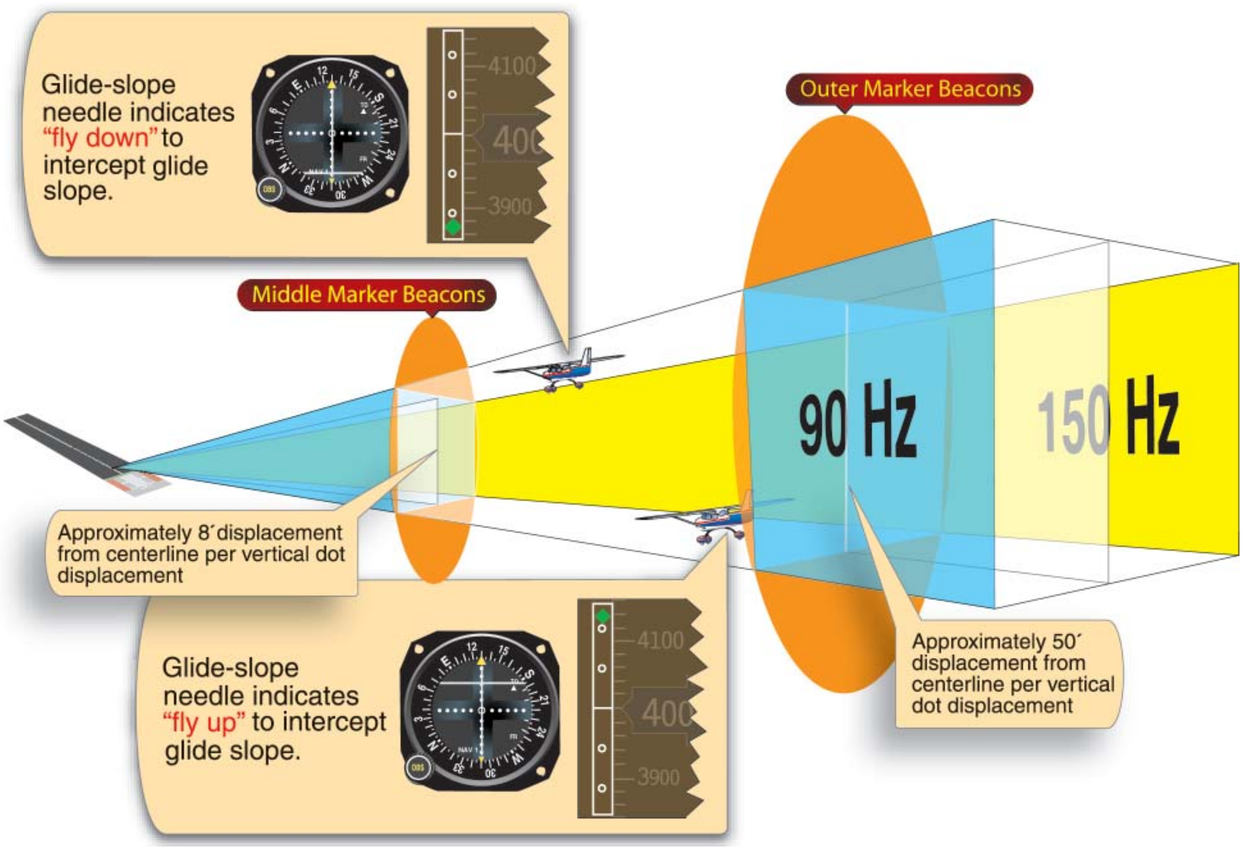


Figure 7-40. *Illustrates a GS receiver indication and aircraft displacement. An analog system is on the left and the same indication on the Garmin PFD on the right.*

source of trouble may be the "High/Low/Off" three-position switch, which both activates the receiver and selects receiver sensitivity. Usually, the "test" feature only tests to see if the light bulbs in the marker beacon lights are working. Therefore, in some installations, there is no functional way for the pilot to ascertain the marker beacon receiver is actually on except to fly over a marker beacon transmitter, and see if a signal is received and indicated (e.g., audibly, and visually via marker beacon lights).

Operational Errors

1. Failure to understand the fundamentals of ILS ground equipment, particularly the differences in course dimensions. Since the VOR receiver is used on the localizer course, the assumption is sometimes made that interception and tracking techniques are identical when tracking localizer courses and VOR radials. Remember that the CDI sensing is sharper and faster on the localizer course.
2. Disorientation during transition to the ILS due to poor planning and reliance on one receiver instead of on all available airborne equipment. Use all the assistance available; a single receiver may fail.
3. Disorientation on the localizer course, due to the first error noted above.
4. Incorrect localizer interception angles. A large interception angle usually results in overshooting, and possible disorientation. When intercepting, if possible, turn to the localizer course heading immediately upon the first indication of needle movement. An ADF receiver is an excellent aid to orient you during an ILS approach if there is a locator or NDB on the inbound course.
5. Chasing the CDI and glide path needles, especially when you have not sufficiently studied the approach before the flight.

Simplified Directional Facility (SDF)

The SDF provides a final approach course similar to the ILS localizer. The SDF course may or may not be aligned with the runway and the course may be wider than a standard ILS localizer, resulting in less precision. Usable off-course indications are limited to 35° either side of the course centerline. Instrument indications in the area between 35° and 90° from the course centerline are not controlled and should be disregarded.

The SDF must provide signals sufficient to allow satisfactory operation of a typical aircraft installation within a sector which extends from the center of the SDF antenna system to distances of 18 NM covering a sector 10° either side of centerline up to an angle 7° above the horizontal. The angle of convergence of the final approach course and the extended runway centerline must not exceed 30°. Pilots should note this angle since the approach course originates at the antenna site, and an approach continued beyond the runway threshold would lead the aircraft to the SDF offset position rather than along the runway centerline.

The course width of the SDF signal emitted from the transmitter is fixed at either 6° or 12°, as necessary, to provide maximum flyability and optimum approach course quality. A three-letter identifier is transmitted in code on the SDF frequency; there is no letter "I" (two dots) transmitted before the station identifier, as there is with the LOC. For example, the identifier for Lebanon, Missouri, SDF is LBO.

Localizer Type Directional Aid (LDA)

The LDA is of comparable utility and accuracy to a localizer but is not part of a complete ILS. The LDA course width is between 3° and 6° and thus provides a more precise approach course than an SDF installation. Some LDAs are equipped with a GS. The LDA course is not aligned with the runway, but straight-in minimums may be published where the angle between the runway centerline and the LDA course does not exceed 30°. If this angle exceeds 30°, only circling minimums are published. The identifier is three letters preceded by "I" transmitted in code on the LDA frequency. For example, the identifier for Van Nuys, California, LDA is I-BUR.

Microwave Landing System (MLS)

The MLS provides precision navigation guidance for exact alignment and descent of aircraft on approach to a runway. It provides azimuth, elevation, and distance. Both lateral and vertical guidance may be displayed on conventional course deviation indicators or incorporated into multipurpose flight deck displays. Range information can be displayed by conventional DME indicators and also incorporated into multipurpose displays. *[Figure 7-41]*

The system may be divided into five functions, which are approach azimuth, back azimuth, approach elevation, range; and data communications. The standard configuration of MLS ground equipment includes an azimuth station to perform functions as indicated above. In addition to providing azimuth navigation guidance, the station transmits basic data, which consists of information associated directly with the operation of the landing system, as well as advisory data on the performance of the ground equipment.

Approach Azimuth Guidance

The azimuth station transmits MLS angle and data on one of 200 channels within the frequency range of 5031 to 5091

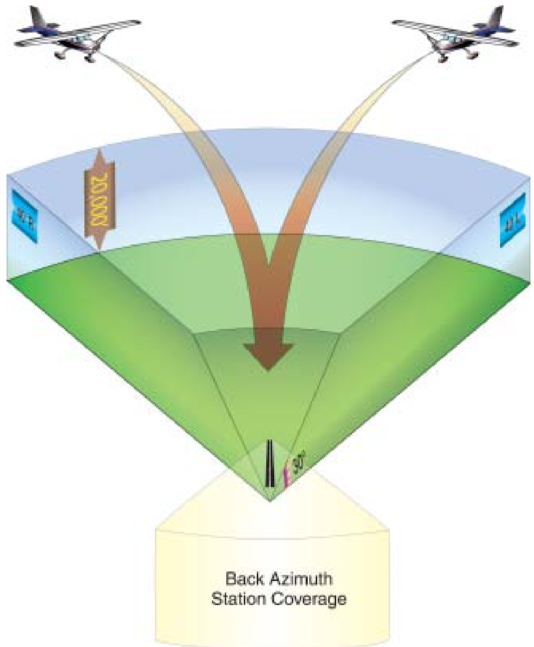


Figure 7-41. *MLS Coverage Volumes, 3-D Representation.*

MHz. The equipment is normally located about 1,000 feet beyond the stop end of the runway, but there is considerable flexibility in selecting sites. For example, for heliport operations the azimuth transmitter can be collocated with the elevation transmitter. The azimuth coverage extends laterally at least 40° on either side of the runway centerline in a standard configuration, in elevation up to an angle of 15° and to at least 20,000 feet, and in range to at least 20 NM.

MLS requires separate airborne equipment to receive and process the signals from what is normally installed in general aviation aircraft today. It has data communications capability, and can provide audible information about the condition of the transmitting system and other pertinent data such as weather, runway status, etc. The MLS transmits an audible identifier consisting of four letters beginning with the letter M, in Morse code at a rate of at least six per minute. The MLS system monitors itself and transmits ground-to-air data messages about the system's operational condition. During periods of routine or emergency maintenance, the coded identification is missing from the transmissions. At this time there are only a few systems installed.

Required Navigation Performance

RNP is a navigation system that provides a specified level of accuracy defined by a lateral area of confined airspace in which an RNP-certified aircraft operates. The continuing growth of aviation places increasing demands on airspace capacity and emphasizes the need for the best use of the available airspace. These factors, along with the accuracy of modern aviation navigation systems and the requirement for increased operational efficiency in terms of direct routings and track-keeping accuracy, have resulted in the concept of required navigation performance—a statement of the navigation performance accuracy necessary for operation within a defined airspace. RNP can include both performance and functional requirements, and is indicated by the RNP type. These standards are intended for designers, manufacturers, and installers of avionics equipment, as well as service providers and users of these systems for global operations. The minimum aviation system performance specification (MASPS) provides guidance for the development of airspace and operational procedures needed to obtain the benefits of improved navigation capability. *[Figure 7-42]*

The RNP type defines the total system error (TSE) that is allowed in lateral and longitudinal dimensions within a particular airspace. The TSE, which takes account of navigation system errors (NSE), computation errors, display errors and flight technical errors (FTE), must not exceed the specified RNP value for 95 percent of the flight time on any part of any single flight. RNP combines the accuracy standards laid out in the ICAO Manual (Doc 9613) with specific accuracy requirements, as well as functional and performance standards, for the RNAV system to realize a system that can meet future air traffic management requirements. The functional criteria for RNP address the need for the flight paths of participating aircraft to be both predictable and repeatable to the declared levels of accuracy. More information on RNP is contained in subsequent chapters.

The term RNP is also applied as a descriptor for airspace, routes, and procedures (including departures, arrivals, and IAPs). The descriptor can apply to a unique approach procedure or to a large region of airspace. RNP applies to navigation performance within a designated airspace, and includes the capability of both the available infrastructure (navigation aids) and the aircraft.

RNP type is used to specify navigation requirements for the airspace. The following are ICAO RNP Types: RNP-1.0, RNP-4.0, RNP-5.0, and RNP-10.0. The required performance is obtained through a combination of aircraft capability and the level of service provided by the corresponding navigation infrastructure. From a broad perspective:

Aircraft Capability + Level of Service = Access

In this context, aircraft capability refers to the airworthiness certification and operational approval elements (including avionics, maintenance, database, human factors, pilot procedures, training, and other issues). The level of service element refers to the NAS infrastructure, including published routes, signal-in-space performance and availability, and air

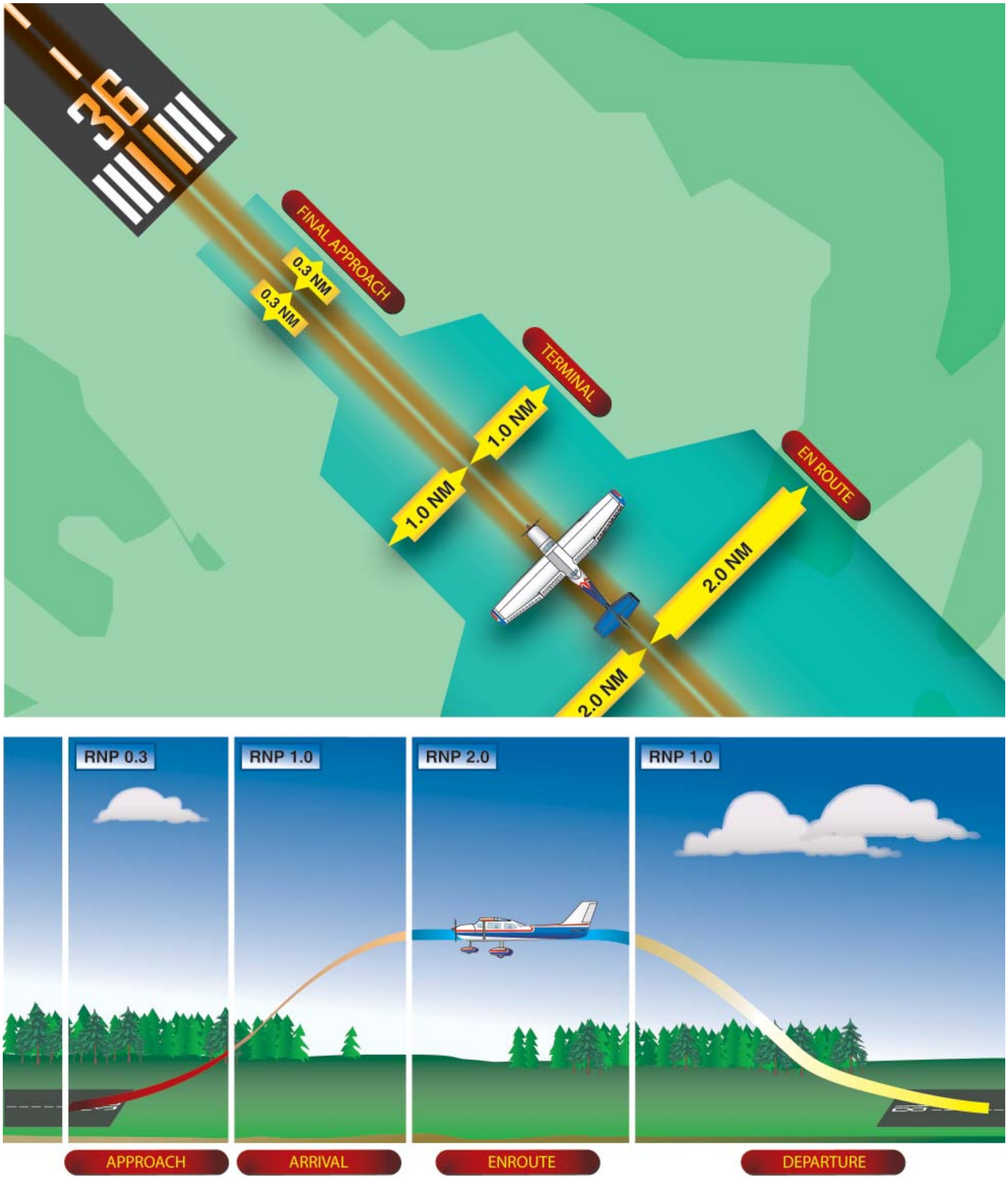


Figure 7-42. *Required Navigation Performance.*

traffic management. When considered collectively, these elements result in providing access. Access provides the desired benefit (airspace, procedures, routes of flight, etc.). RNP levels are actual distances from the centerline of the flight path, which must be maintained for aircraft and obstacle separation. Although additional FAA-recognized RNP levels may be used for specific operations, the United States currently supports three standard RNP levels:

- RNP 0.3 – Approach
- RNP 1.0 – Departure, Terminal
- RNP 2.0 – En route

RNP 0.3 represents a distance of 0.3 NM either side of a specified flight path centerline. The specific performance that is required on the final approach segment of an instrument approach is an example of this RNP level. At the present time, a 0.3 RNP level is the lowest level used in normal RNAV operations. Specific airlines, using special procedures, are approved to use RNP levels lower than RNP 0.3, but those levels are used only in accordance with their approved operations specifications (OpsSpecs). For aircraft equipment to qualify for a specific RNP type, it must maintain navigational accuracy at least 95 percent of the total flight time.

Flight Management Systems (FMS)

A flight management system (FMS) is not a navigation system in itself. Rather, it is a system that automates the tasks of managing the onboard navigation systems. FMS may perform other onboard management tasks, but this discussion is limited to its navigation function.

FMS is an interface between flight crews and flight-deck systems. FMS can be thought of as a computer with a large database of airport and NAVAID locations and associated data, aircraft performance data, airways, intersections, DPs, and STARs. FMS also has the ability to accept and store numerous user-defined WPs, flight routes consisting of departures, WPs, arrivals, approaches, alternates, etc. FMS can quickly define a desired route from the aircraft's current position to any point in the world, perform flight plan computations, and display the total picture of the flight route to the crew.

FMS also has the capability of controlling (selecting) VOR, DME, and LOC NAVAIDs, and then receiving navigational data from them. INS, LORAN, and GPS navigational data may also be accepted by the FMS computer. The FMS may act as the input/output device for the onboard navigation systems, so that it becomes the "go-between" for the crew and the navigation systems.

Function of FMS

At startup, the crew programs the aircraft location, departure runway, DP (if applicable), WPs defining the route, approach procedure, approach to be used, and routing to alternate. This may be entered manually, be in the form of a stored flight plan, or be a flight plan developed in another computer and transferred by disk or electronically to the FMS computer. The crew enters this basic information in the control/display unit (CDU). *[Figure 7-43]*

Once airborne, the FMS computer channels the appropriate NAVAIDs and takes radial/distance information, or channels two NAVAIDs, taking the more accurate distance information. FMS then indicates position, track, desired heading, groundspeed and position relative to desired track. Position information from the FMS updates the INS. In more sophisticated aircraft, the FMS provides inputs to the HSI, RMI, glass flight deck navigation displays, head-up display (HUD), autopilot, and autothrottle systems.

Figure 7-43. *Typical Display and Control Unit(s) in General Aviation. The Universal UNS-1 (left) controls and integrates all other systems. The Avidyne (center) and Garmin systems (right) illustrate and are typical of completely integrated systems. Although the Universal CDU is not typically found on smaller general aviation aircraft, the difference in capabilities of the CDUs and stand-alone sytems is diminishing each year.*

Head-Up Display (HUD)

The HUD is a display system that provides a projection of navigation and air data (airspeed in relation to approach reference speed, altitude, left/right and up/down GS) on a transparent screen between the pilot and the windshield. Other information may be displayed, including a runway target in relation to the nose of the aircraft. This allows the pilot to see the information necessary to make the approach while also being able to see out the windshield, which diminishes the need to shift between looking at the panel to looking outside. Virtually any information desired can be displayed on the HUD if it is available in the aircraft's flight computer, and if the display is user definable. *[Figure 7-44]*

Figure 7-44. *Example of a Head-Up Display (top) and a Head-Down Display (bottom). The head-up display presents information in front of the pilot along his/her normal field of view while a head-down display may present information beyond the normal head-up field of view.*

Radar Navigation (Ground Based)

Radar works by transmitting a pulse of RF energy in a specific direction. The return of the echo or bounce of that pulse from a target is precisely timed. From this, the distance traveled by the pulse and its echo is determined and displayed on a radar screen in such a manner that the distance and bearing to this target can be instantly determined. The radar transmitter must be capable of delivering extremely high power levels toward the airspace under surveillance, and the associated radar receiver must be able to detect extremely small signal levels of the returning echoes.

The radar display system provides the controller with a map-like presentation upon which appear all the radar echoes of aircraft within detection range of the radar facility. By means of electronically generated range marks and azimuth-indicating devices, the controller can locate each radar target with respect to the radar facility, or can locate one radar target with respect to another.

Another device, a video-mapping unit, generates an actual airway or airport map and presents it on the radar display equipment. Using the video-mapping feature, the air traffic controller not only can view the aircraft targets, but can see these targets in relation to runways, navigation aids, and hazardous ground obstructions in the area. Therefore, radar becomes a NAVAID, as well as the most significant means of traffic separation.

In a display presenting perhaps a dozen or more targets, a primary surveillance radar system cannot identify one specific radar target, and it may have difficulty "seeing" a small target at considerable distance—especially if there is a rain shower or thunderstorm between the radar site and the aircraft. This problem is solved with the Air Traffic Control Radar Beacon System (ATCRBS), sometimes called secondary surveillance radar (SSR), which utilizes a transponder in the aircraft. The ground equipment is an interrogating unit, in which the beacon antenna is mounted so it rotates with the surveillance antenna. The interrogating unit transmits a coded pulse sequence that actuates the aircraft transponder. The transponder answers the coded sequence by transmitting a preselected coded sequence back to the ground equipment, providing a strong return signal and positive aircraft identification, as well as other special data such as aircraft altitude.

Functions of Radar Navigation

The radar systems used by ATC are air route surveillance radar (ARSR), airport surveillance radar (ASR), and precision approach radar (PAR) and airport surface detection equipment

(ASDE). Surveillance radars scan through 360° of azimuth and present target information on a radar display located in a tower or center. This information is used independently or in conjunction with other navigational aids in the control of air traffic.

ARSR is a long-range radar system designed primarily to cover large areas and provide a display of aircraft while en route between terminal areas. The ARSR enables air route traffic control center (ARTCC) controllers to provide radar service when the aircraft are within the ARSR coverage. In some instances, ARSR may enable ARTCC to provide terminal radar services similar to but usually more limited than those provided by a radar approach control.

ASR is designed to provide relatively short-range coverage in the general vicinity of an airport and to serve as an expeditious means of handling terminal area traffic through observation of precise aircraft locations on a radarscope. Nonprecision instrument approaches are available at airports that have an approved surveillance radar approach procedure. ASR provides radar vectors to the final approach course and then azimuth information to the pilot during the approach. In addition to range (distance) from the runway, the pilot is advised of MDA, when to begin descent, and when the aircraft is at the MDA. If requested, recommended altitudes will be furnished each mile while on final.

PAR is designed to be used as a landing aid displaying range, azimuth, and elevation information rather than as an aid for sequencing and spacing aircraft. PAR equipment may be used as a primary landing aid, or it may be used to monitor other types of approaches. Two antennas are used in the PAR array, one scanning a vertical plane, and the other scanning horizontally. Since the range is limited to 10 miles, azimuth to 20°, and elevation to 7°, only the final approach area is covered. The controller's scope is divided into two parts. The upper half presents altitude and distance information, and the lower half presents azimuth and distance.

PAR is a system in which a controller provides highly accurate navigational guidance in azimuth and elevation to a pilot. Pilots are given headings to fly to direct them to and keep their aircraft aligned with the extended centerline of the landing runway. They are told to anticipate glide path interception approximately 10–30 seconds before it occurs and when to start descent. The published decision height (DH) is given only if the pilot requests it. If the aircraft is observed to deviate above or below the glide path, the pilot is given the relative amount of deviation by use of terms "slightly" or "well" and is expected to adjust the aircraft's rate of descent/ascent to return to the glide path. Trend information is also issued with respect to the elevation of the aircraft and may be modified by the terms "rapidly" and "slowly" (e.g., "well above glide path, coming down rapidly"). Range from touchdown is given at least once each mile. If an aircraft is observed by the controller to proceed outside of specified safety zone limits in azimuth and/or elevation and continue to operate outside these prescribed limits, the pilot will be directed to execute a missed approach or to fly a specified course unless the pilot has the runway environment (runway, approach lights, etc.) in sight. Navigational guidance in azimuth and elevation is provided to the pilot until the aircraft reaches the published decision altitude (DA)/DH. Advisory course and glide path information is furnished by the controller until the aircraft passes over the landing threshold, at which point the pilot is advised of any deviation from the runway centerline. Radar service is automatically terminated upon completion of the approach.

Airport Surface Detection Equipment

Radar equipment is specifically designed to detect all principal features on the surface of an airport, including aircraft and vehicular traffic, and to present the entire image on a radar indicator console in the control tower. It is used to augment visual observation by tower personnel of aircraft and/or vehicular movements on runways and taxiways.

Radar Limitations

1. It is very important for the aviation community to recognize the fact that there are limitations to radar service and that ATC controllers may not always be able to issue traffic advisories concerning aircraft which are not under ATC control and cannot be seen on radar.
2. The characteristics of radio waves are such that they normally travel in a continuous straight line unless they are "bent" by abnormal atmospheric phenomena such as temperature inversions; reflected or attenuated by dense objects such as heavy clouds, precipitation, ground obstacles, mountains, etc.; or screened by high terrain features.
3. Primary radar energy that strikes dense objects will be reflected and displayed on the operator's scope, thereby blocking out aircraft at the same range and greatly weakening or completely eliminating the display of targets at a greater range.
4. Relatively low altitude aircraft will not be seen if they are screened by mountains or are below the radar beam due to curvature of the Earth.
5. The amount of reflective surface of an aircraft will determine the size of the radar return. Therefore, a small light airplane or a sleek jet fighter will be more difficult to see on primary radar than a large commercial jet or military bomber.

6. All ARTCC radar in the conterminous United States and many ASR have the capability to interrogate Mode C and display altitude information to the controller from appropriately equipped aircraft. However, a number of ASR do not have Mode C display capability; therefore, altitude information must be obtained from the pilot.