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.

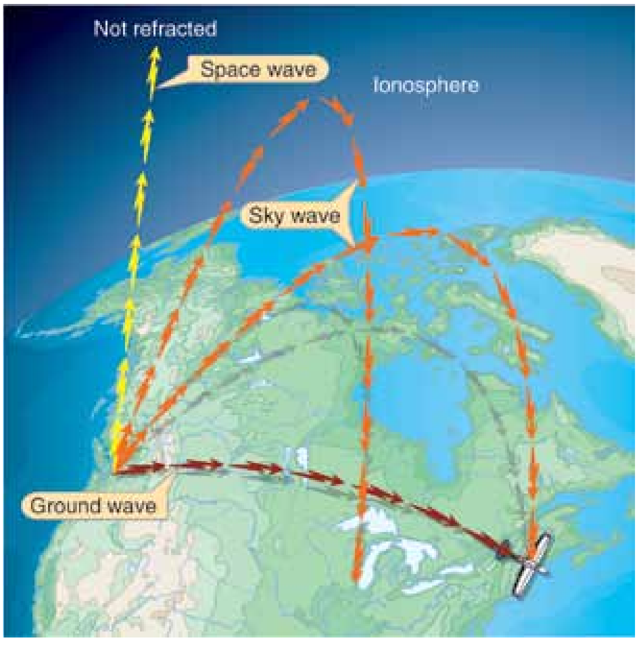


Figure 7-1. *Ground, Space, and Sky Wave Propogation.*

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 005°, and the MB from the station is 185°.

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 310°, indicating a 50° left turn is needed to produce an RB of zero. Turn left, rolling out at 50° minus 50° equals 360°. 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.

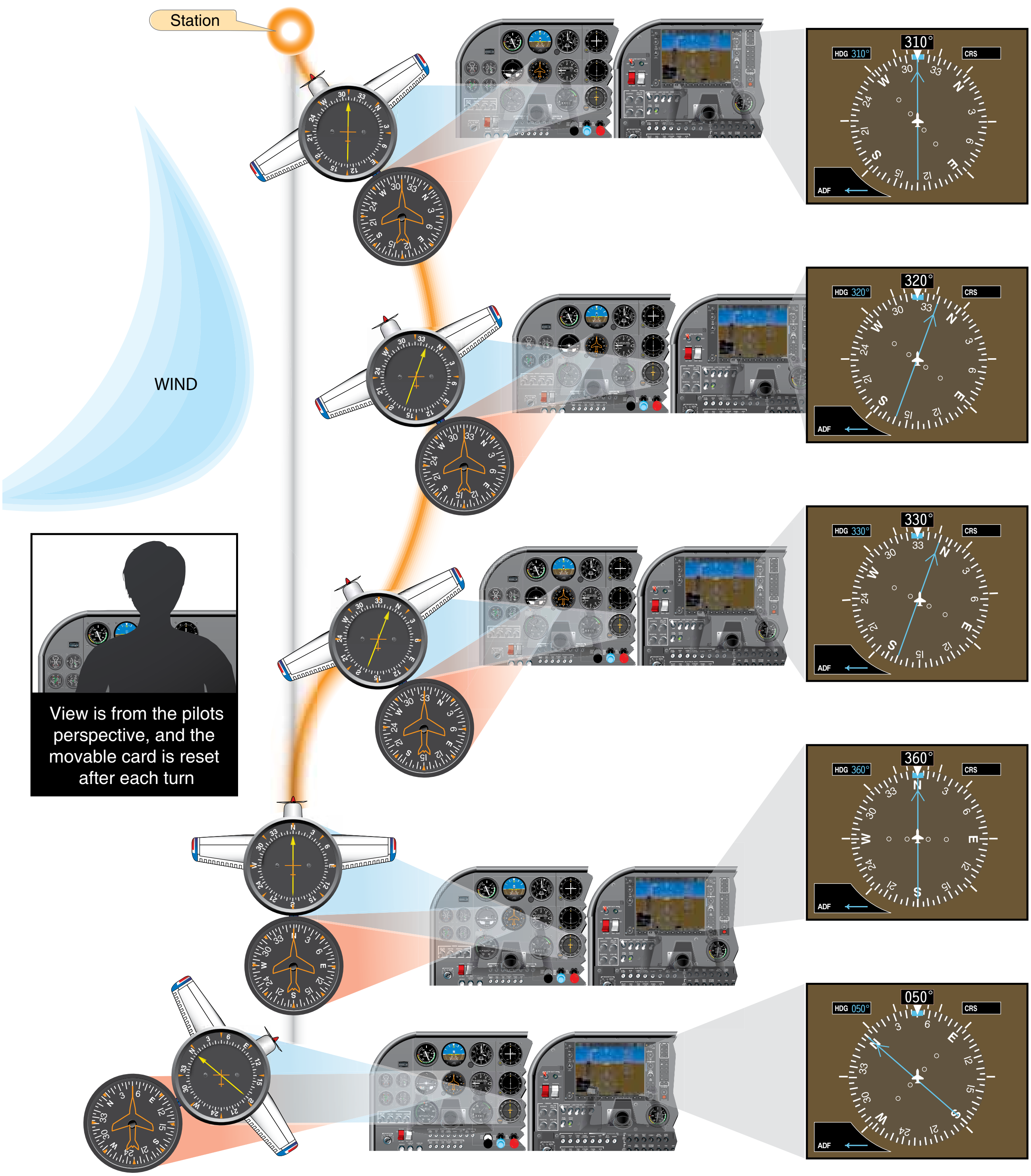


Figure 7-6. *ADF Homing With a Crosswind.*

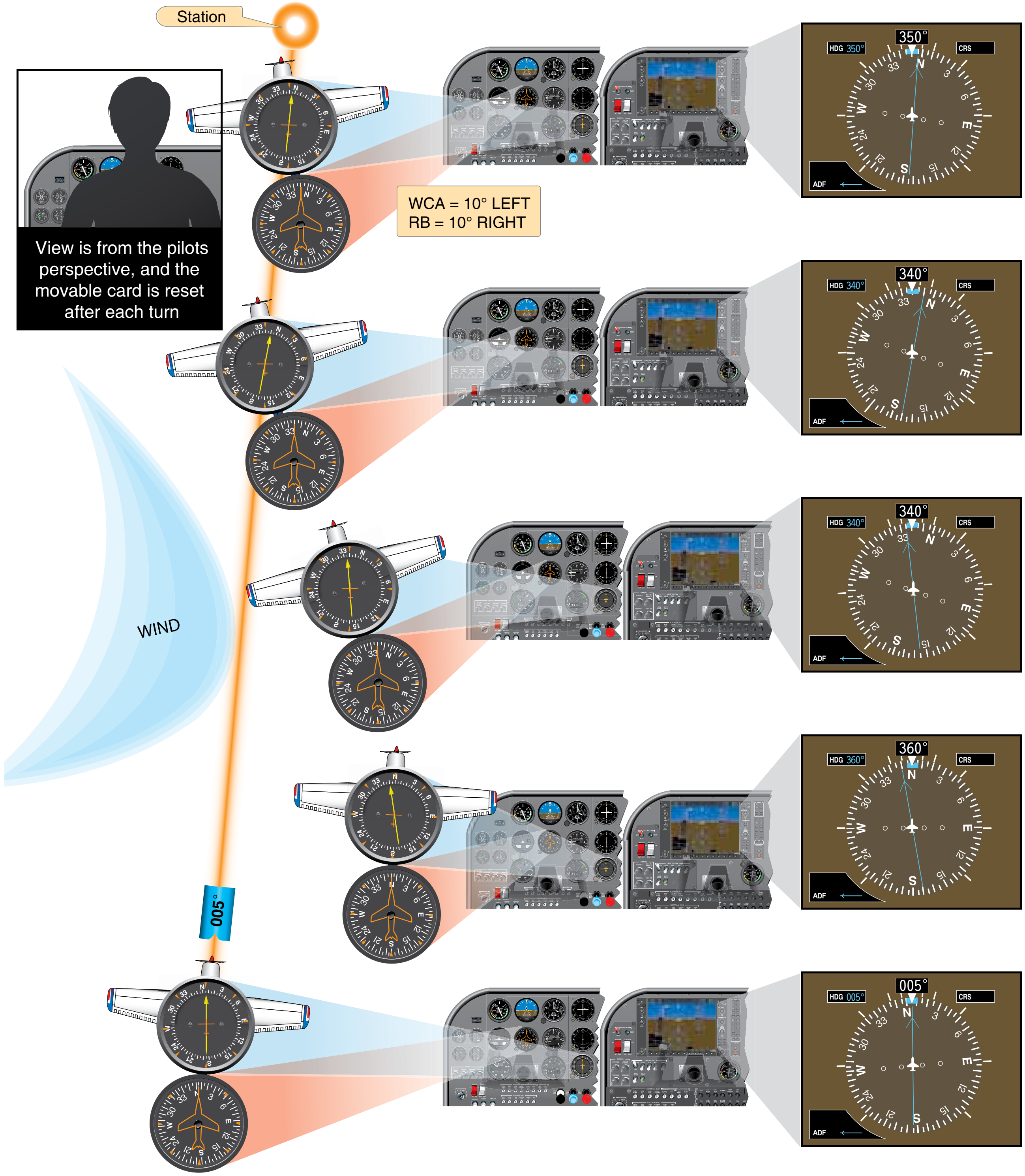


Figure 7-7. *ADF Tracking Inbound.*

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.

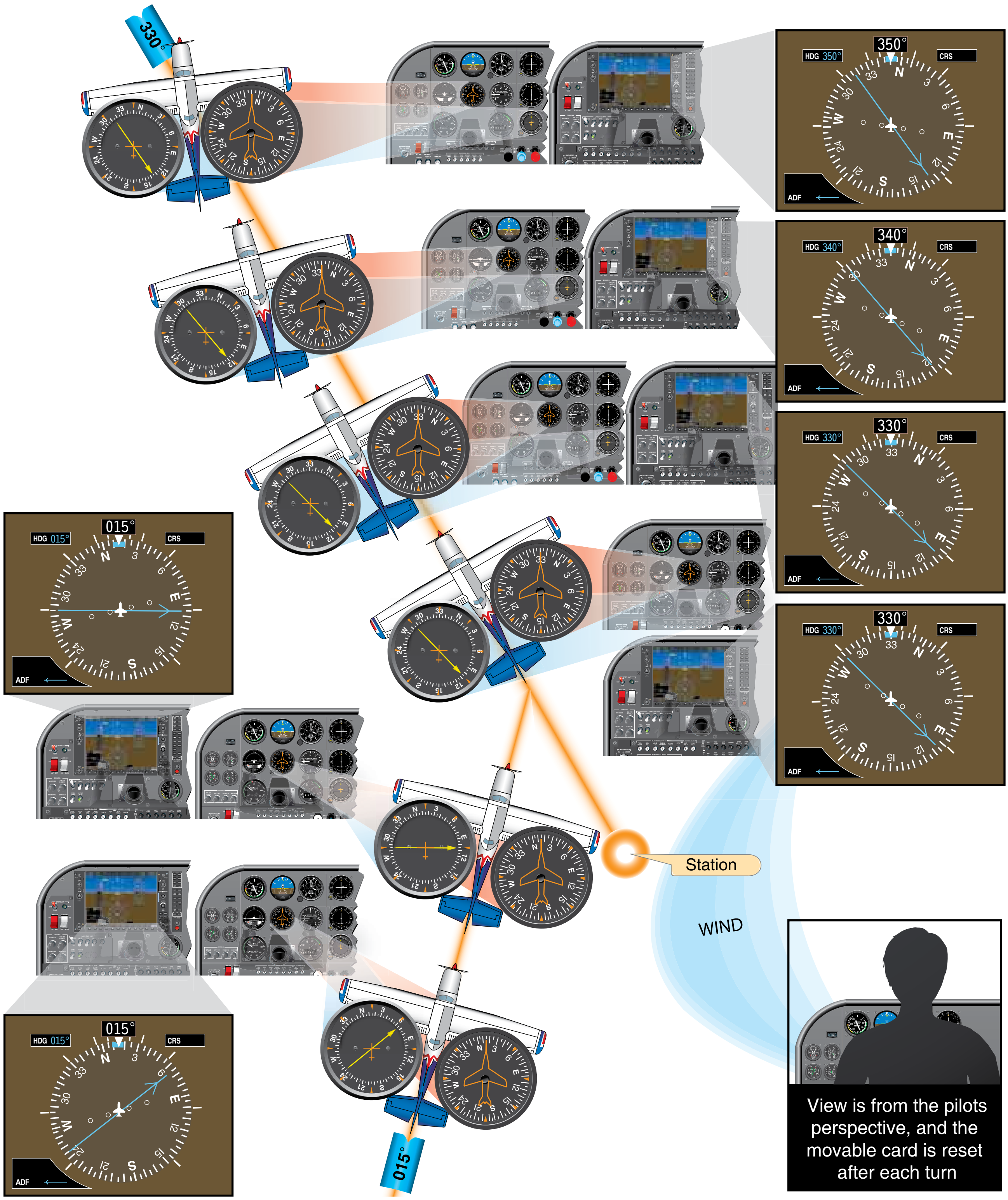


Figure 7-8. *ADF Interception and Tracking Outbound.*

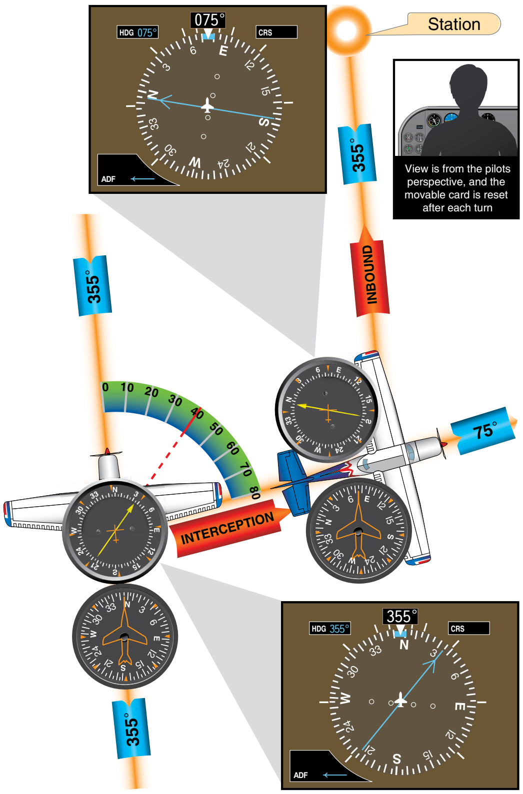


Figure 7-9. *Interception of Bearing.*

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

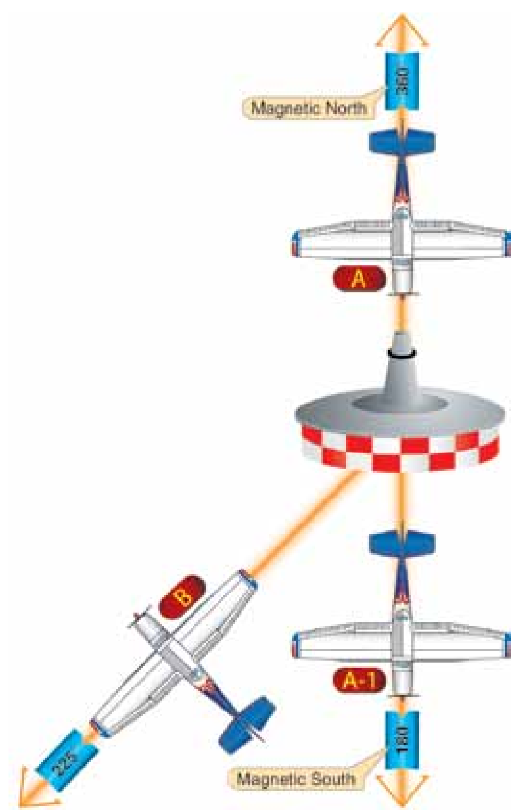


Figure 7-10. *VOR Radials.*

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.*

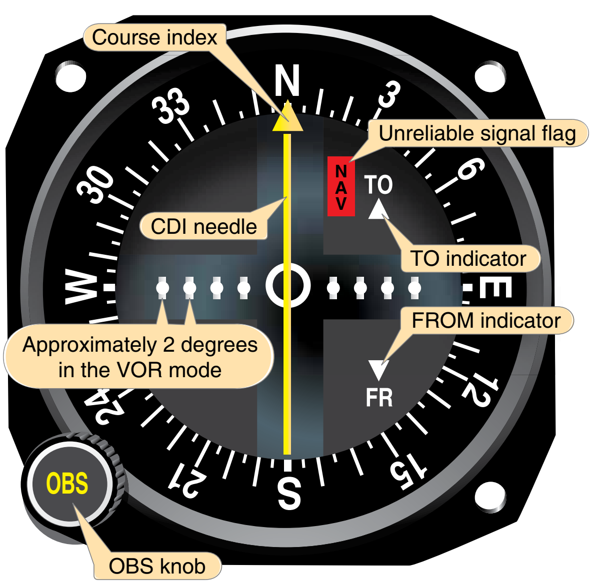


Figure 7-12. *The VOR Indicator Instrument.*

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 if intercepted and flown 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 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.

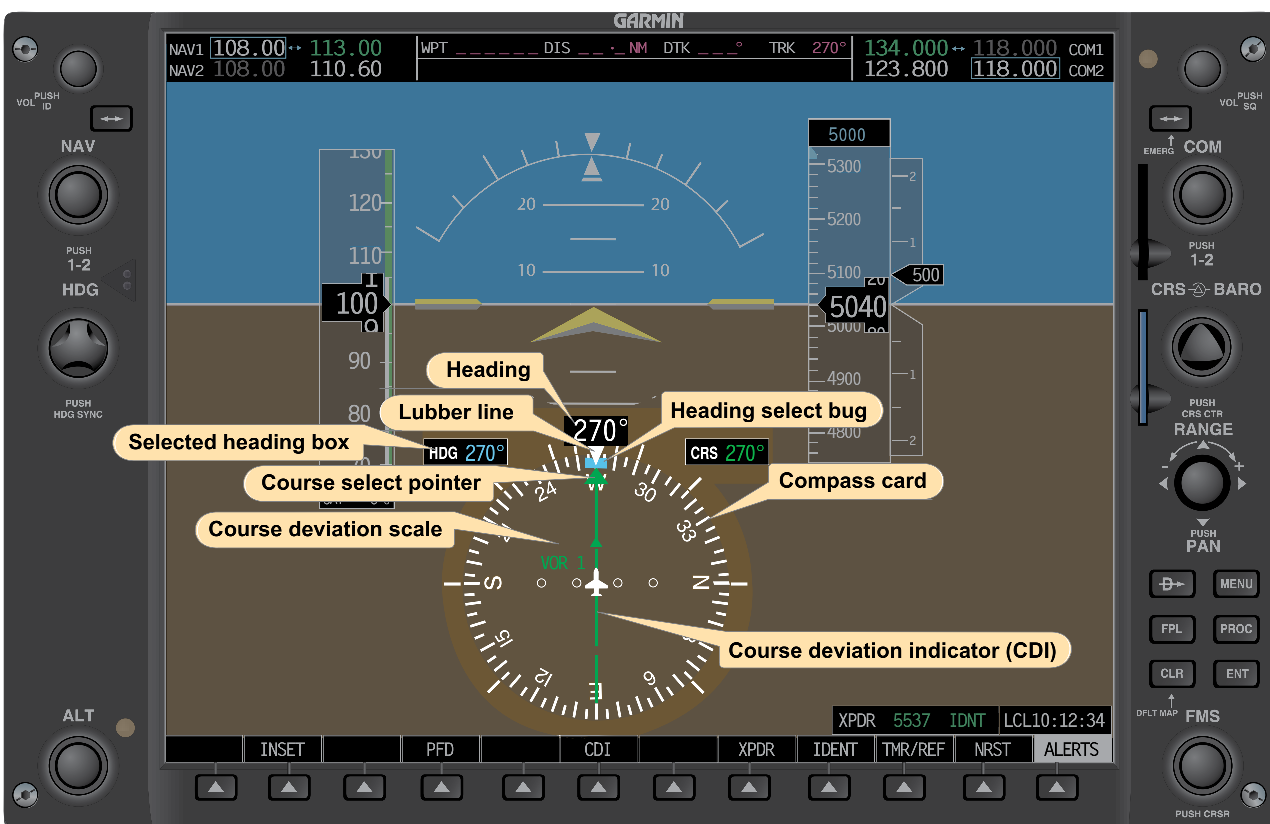


Figure 7-14. *An HSI display as seen on the pilot's primary flight display (PFD) on an electronic flight instrument. Note that only attributes related to the HSI are labeled.*

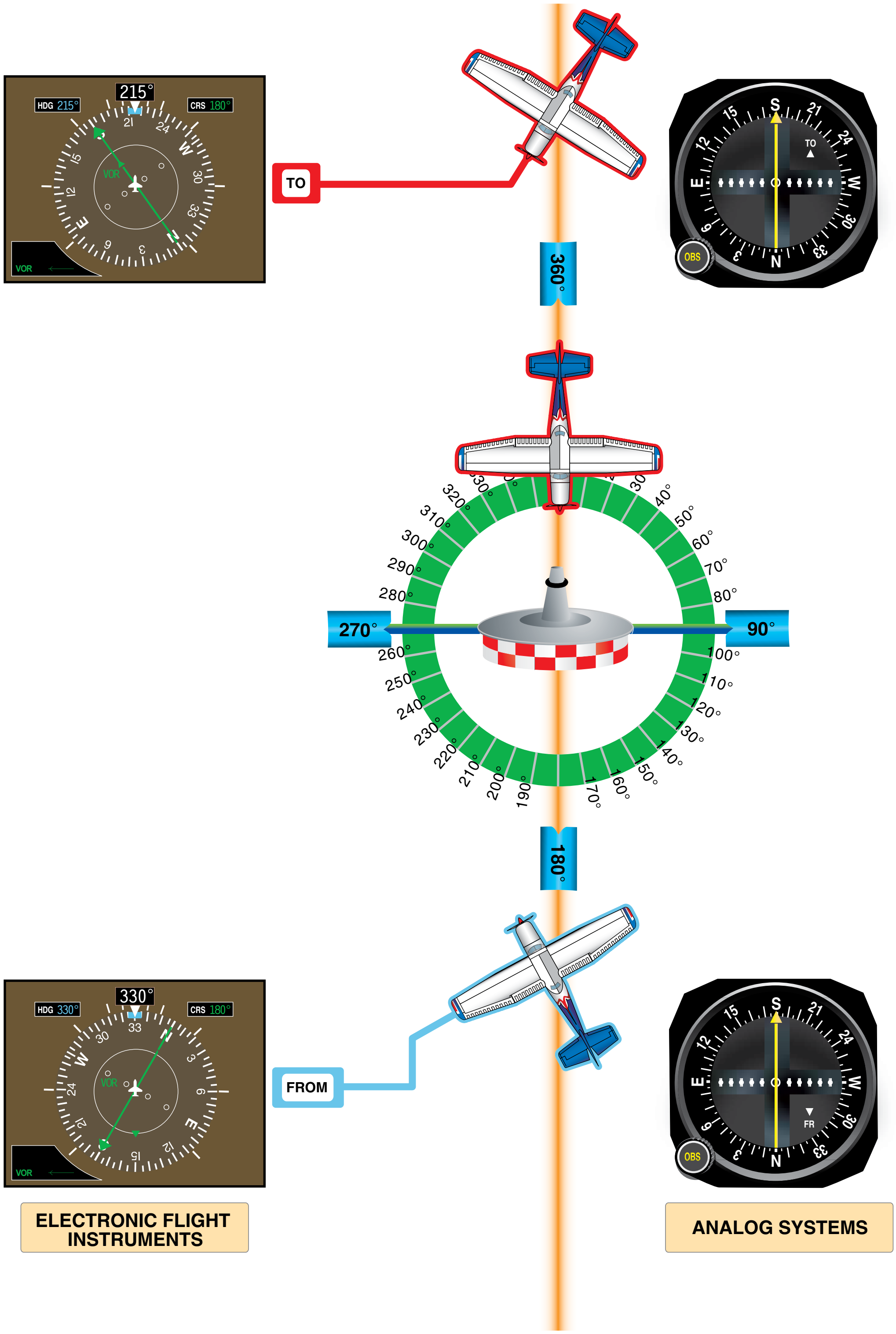


Figure 7-15. *CDI Interpretation. The CDI as typically found on analog systems (right) and as found on electronic flight instruments (left).*

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. Determine the difference between the radial to be intercepted and the radial on which the aircraft is located (205° – 160° = 045°).
2. 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)
3. Rotate the OBS to the desired radial or inbound course.
4. Turn to the interception heading.
5. 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.)
6. 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.

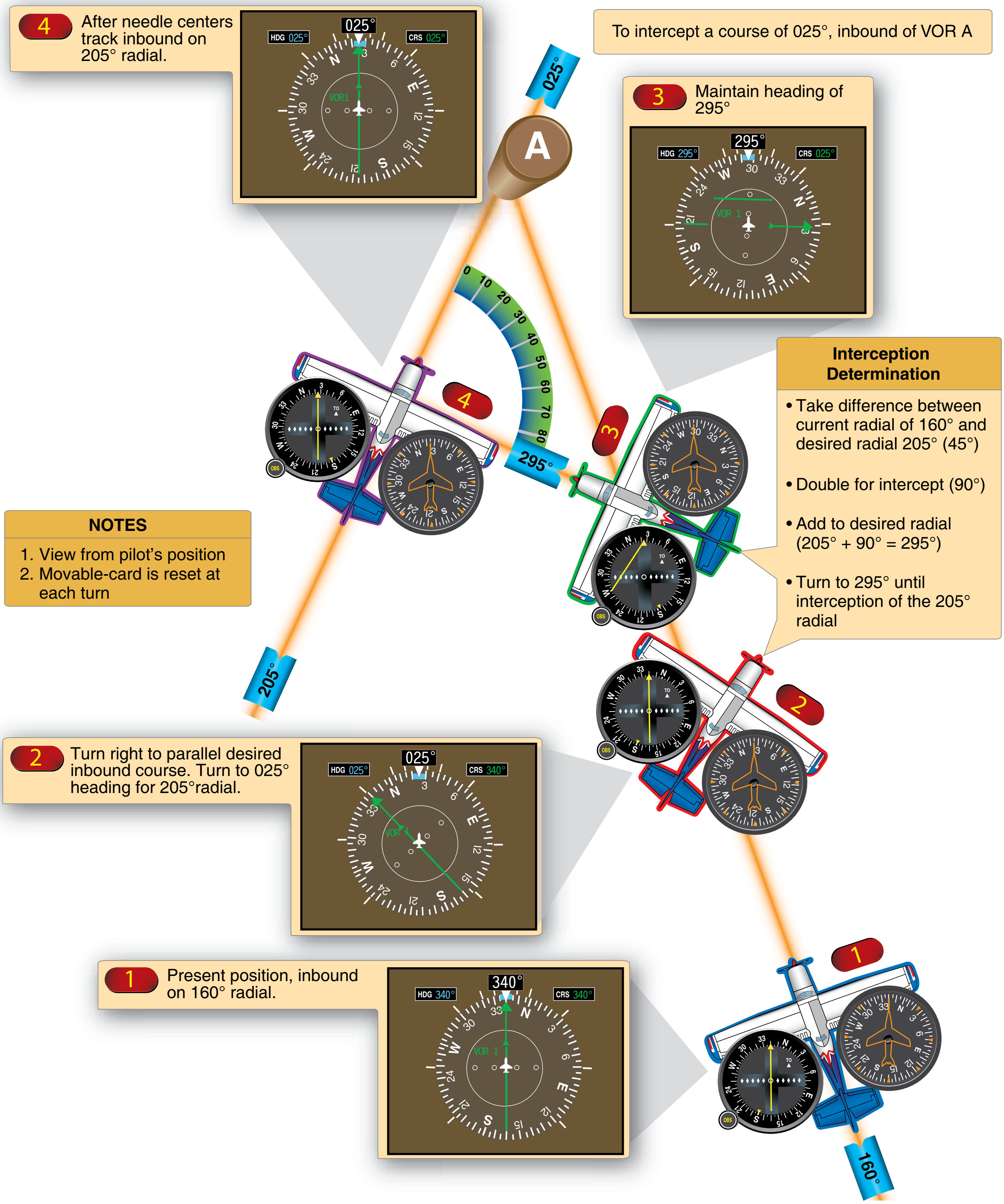


Figure 7-16. *Course Interception (VOR).*

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.

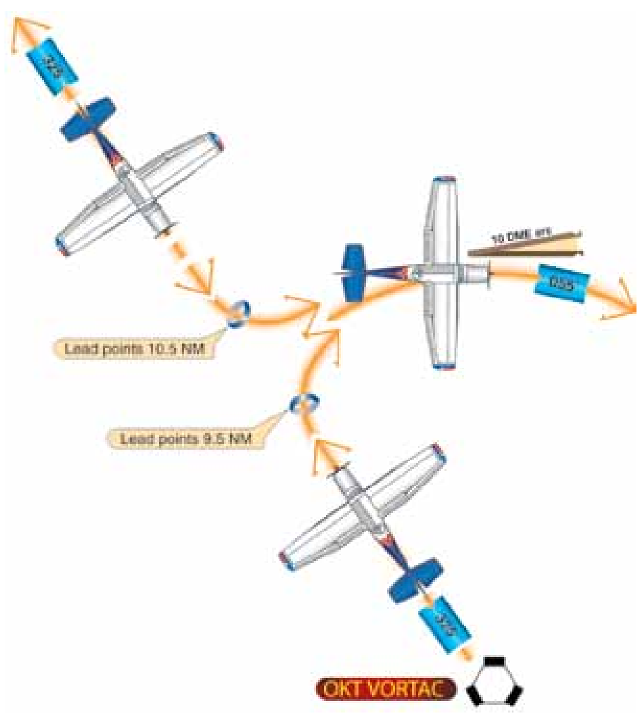


Figure 7-17. *DME Arc Interception.*

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

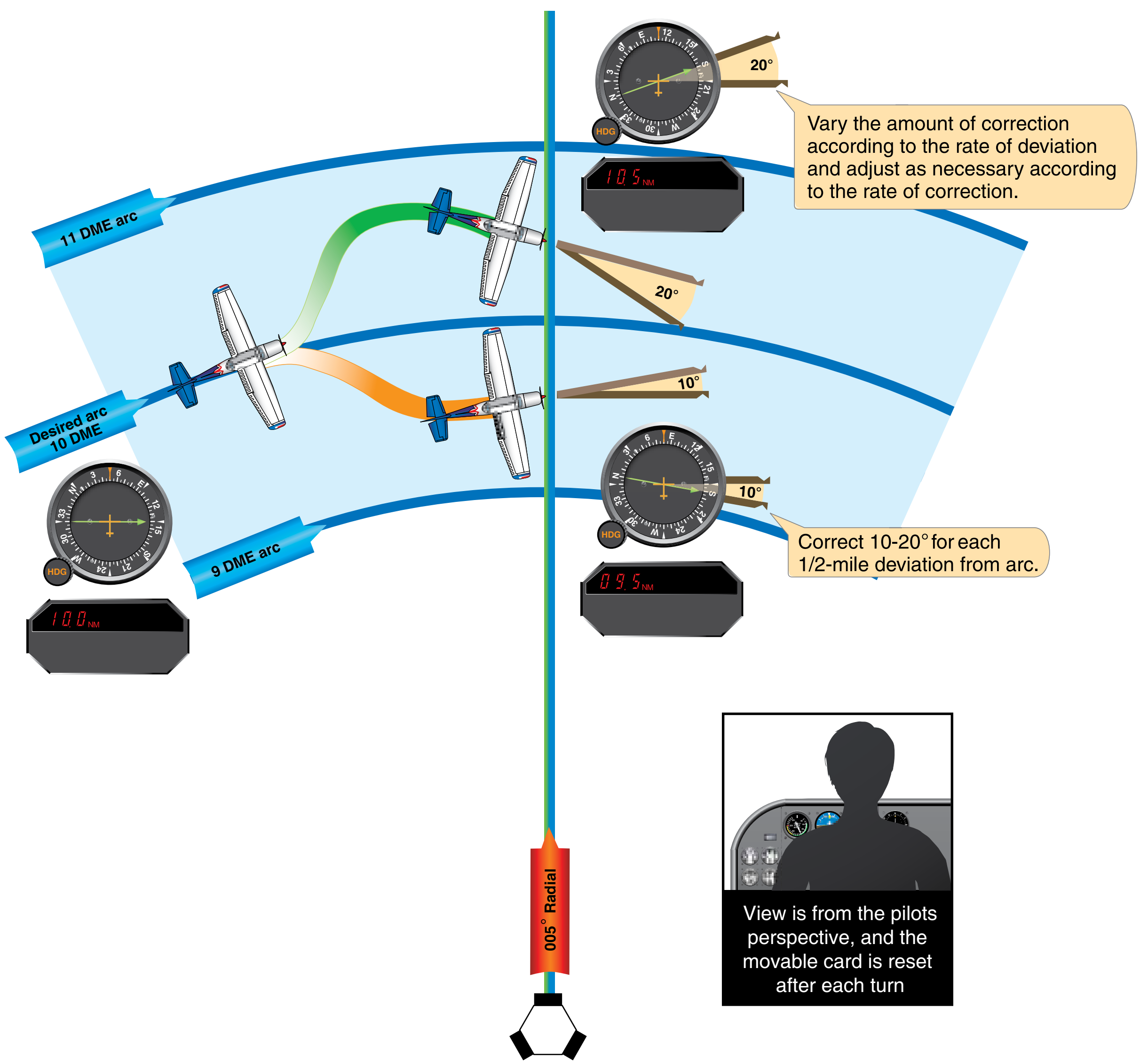


Figure 7-18. *Using DME and RMI To Maintain an Arc.*

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 223 or LR 212 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.

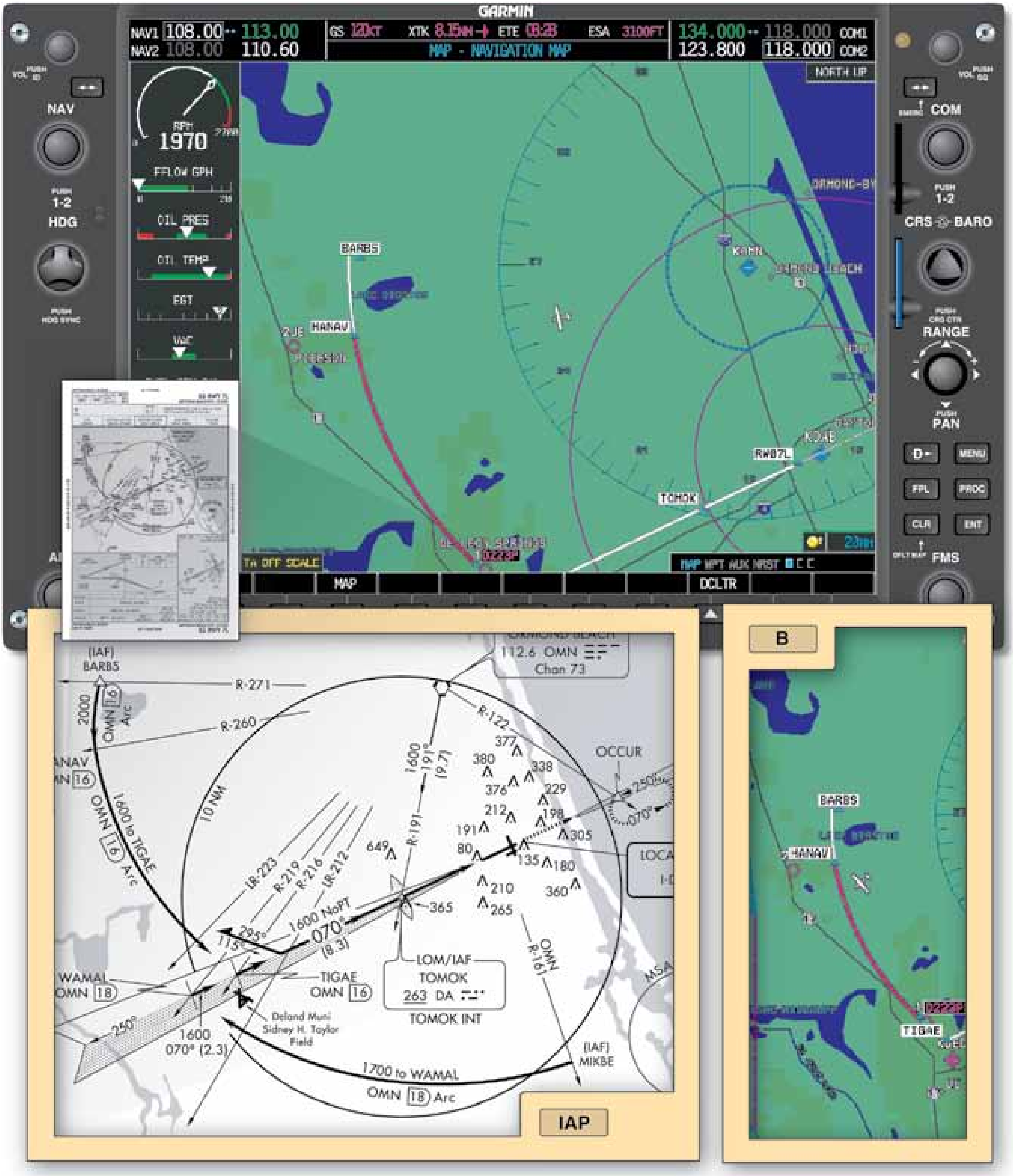


Figure 7-19. *An aircraft is displayed heading southwest to intercept the localizer approach, using the 16 NM DME Arc off of ORM.*

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.*

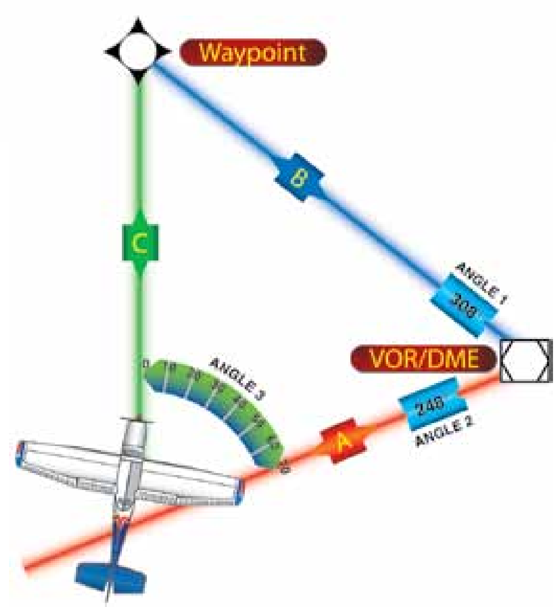


Figure 7-22. *RNAV Computation.*

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.

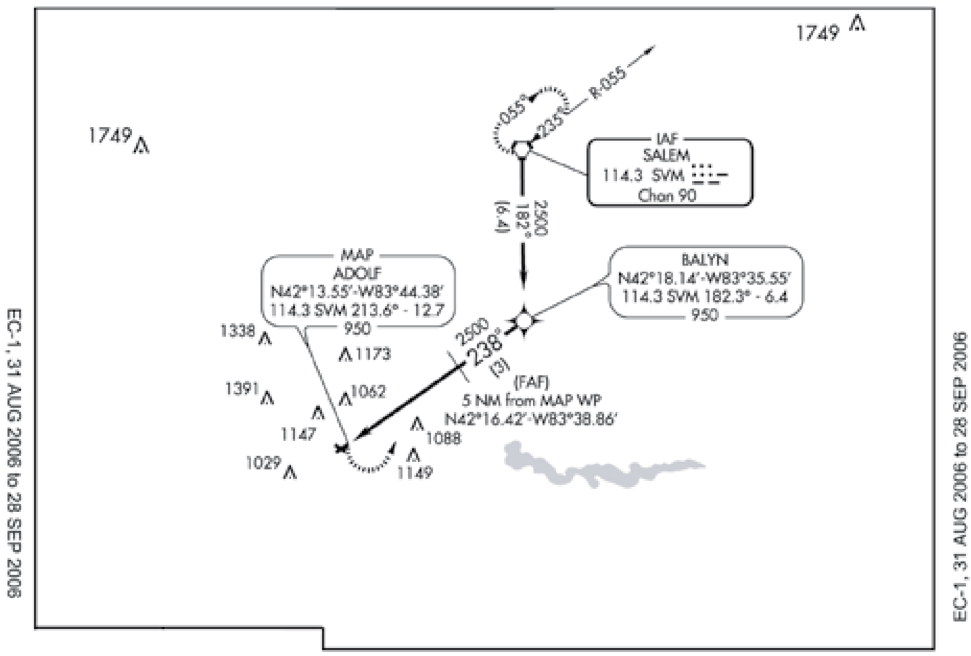


Figure 7-24. *VOR/DME RNAV Rwy 25 Approach (Excerpt).*

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.

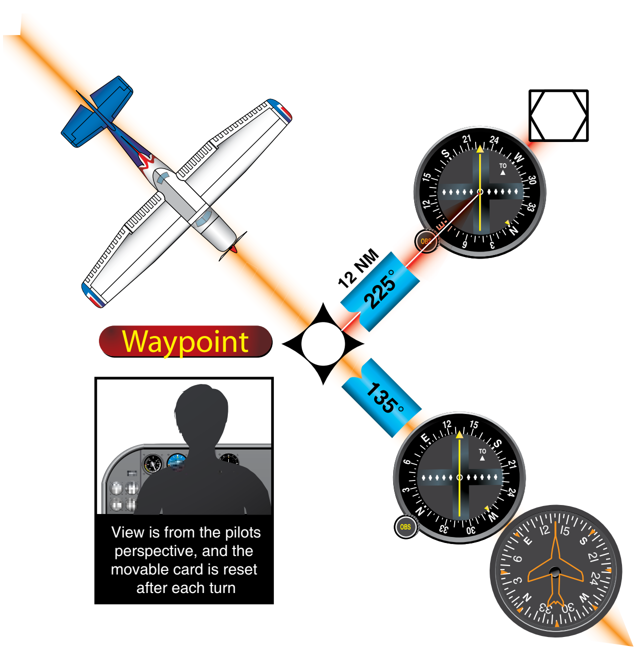


Figure 7-25. *Aircraft/DME/Waypoint Relationship.*

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 planned to be 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 2013.
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]*

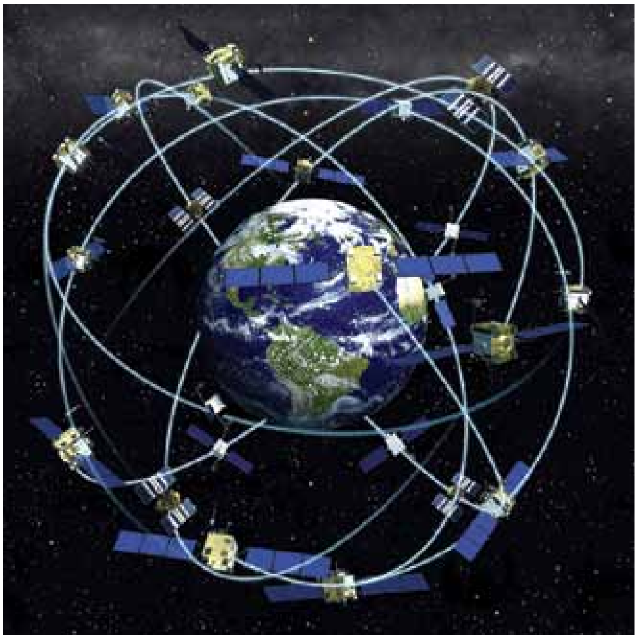


Figure 7-28. *Typical GPS Satellite Array.*

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 space element consists of 24 Navigation System using Timing and Ranging (NAVSTAR) satellites in 6 orbital planes. The satellites in each plane are spaced 60° apart for complete coverage and are located (nominally) at about 11,000 miles above the Earth. The planes are arranged so that there are always five satellites in view at any time on the Earth. Presently, there are at least 31 Block II/IIA/IIR and IIR-M satellites in orbit with the additional satellites representing replacement satellites (upgraded systems) and spares. Recently, the Air Force received funding for procurement of 31 Block IIF satellites. 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.

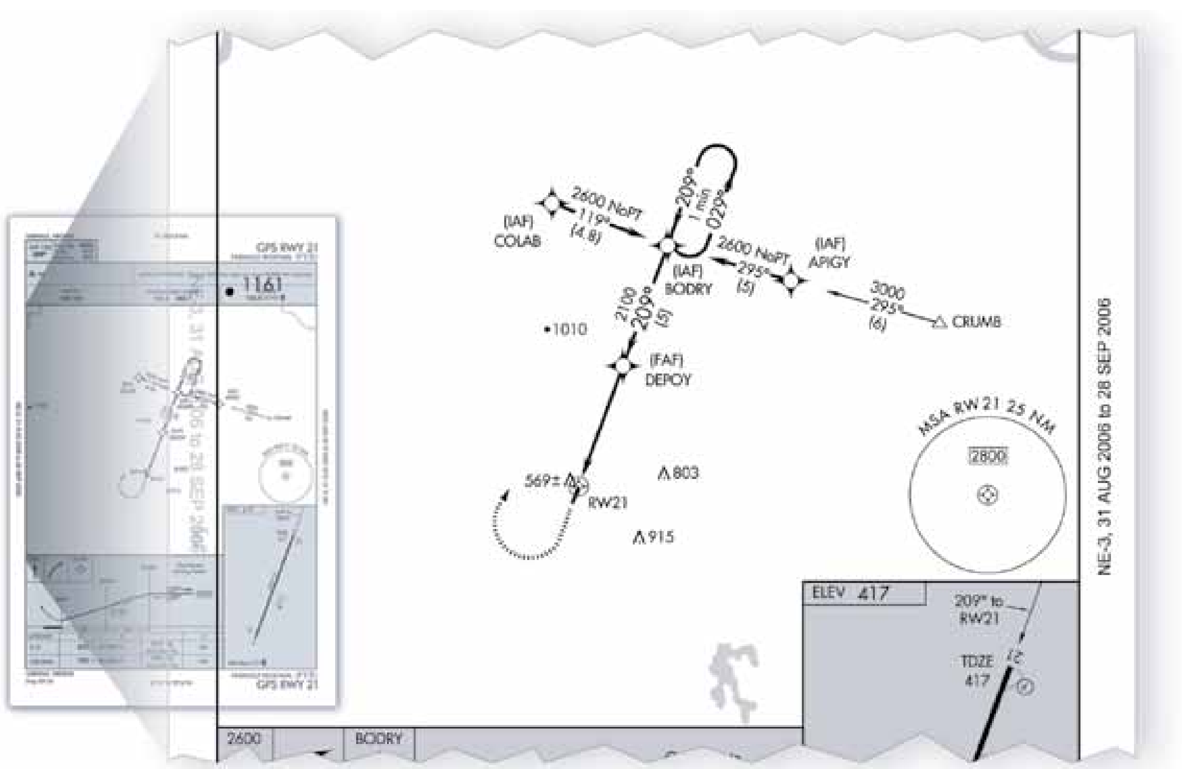


Figure 7-29. *A GPS Stand-Alone Approach.*

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.

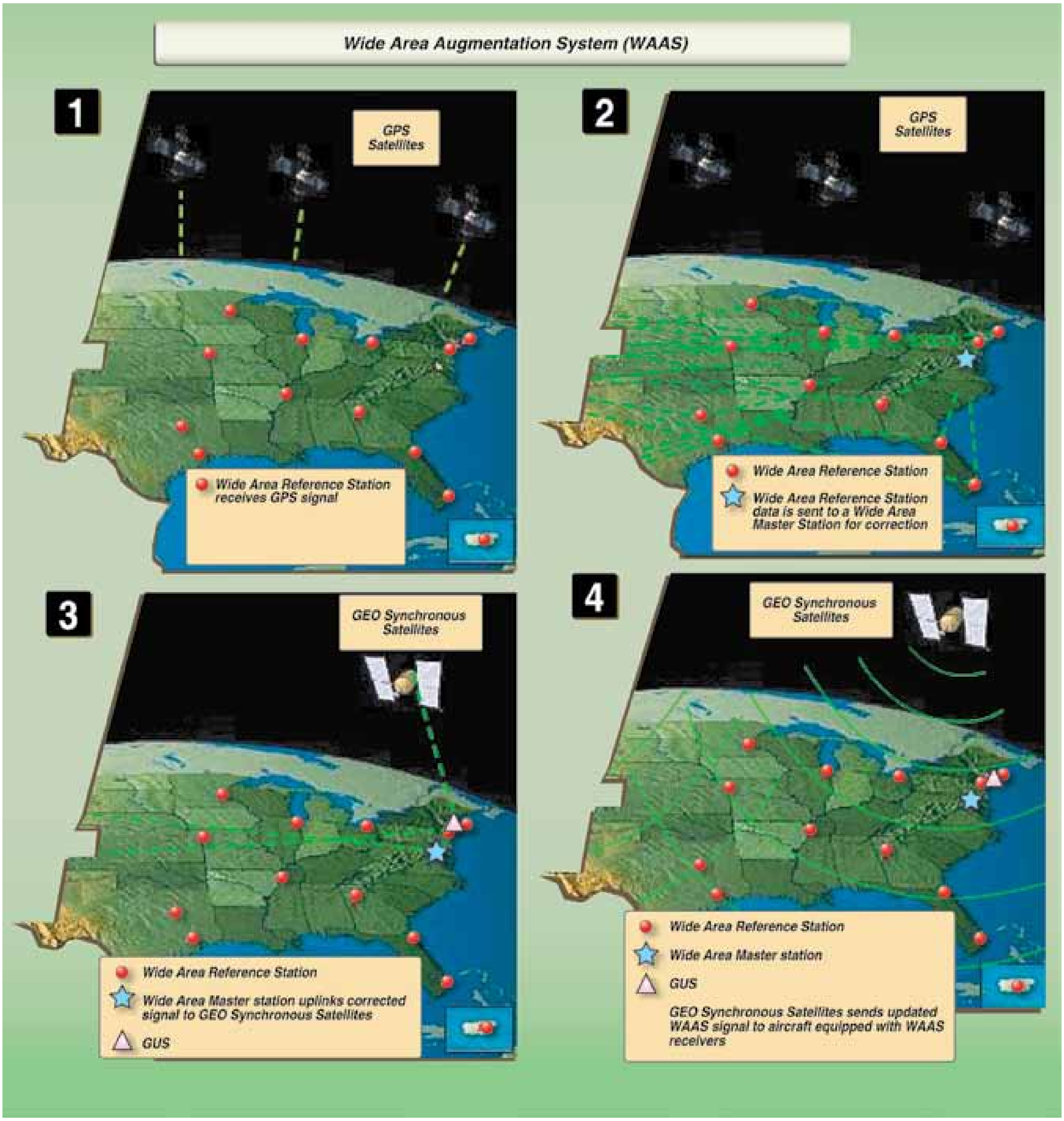


Figure 7-30. *WAAS Satellite Representation.*

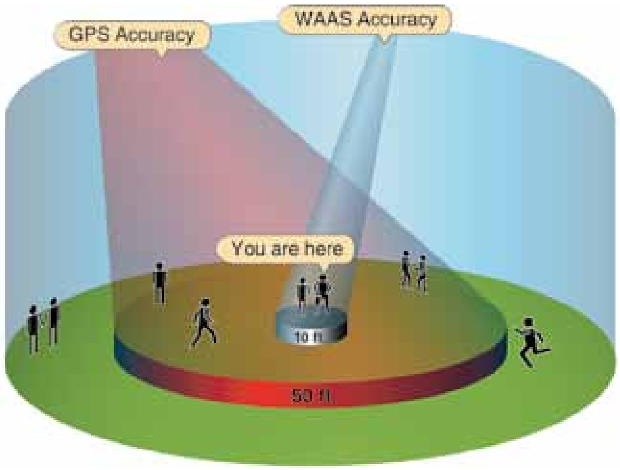


Figure 7-31. *WAAS Satellite Representation.*

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.

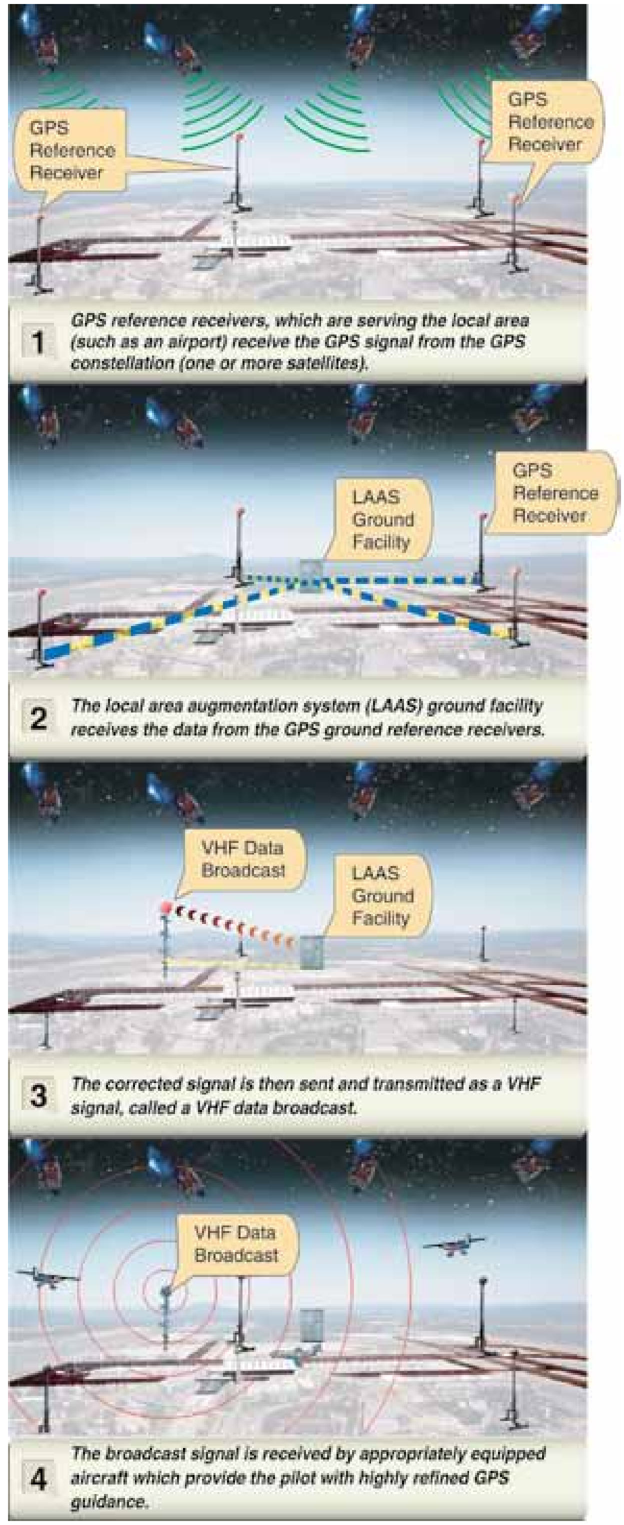


Figure 7-32. *LAAS Representation.*

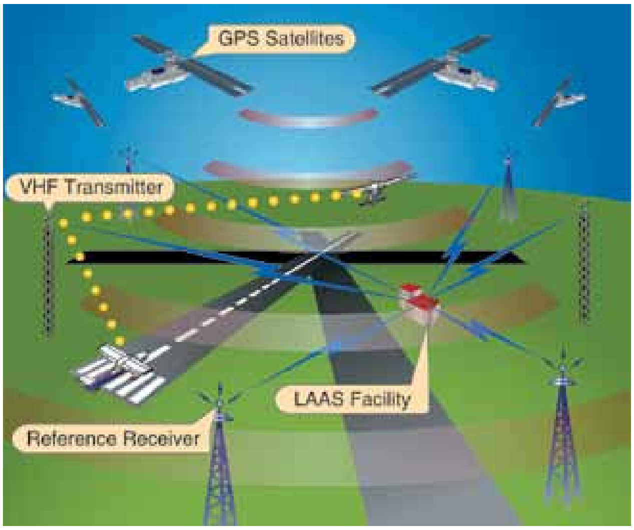


Figure 7-33. *LAAS Representation.*

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)

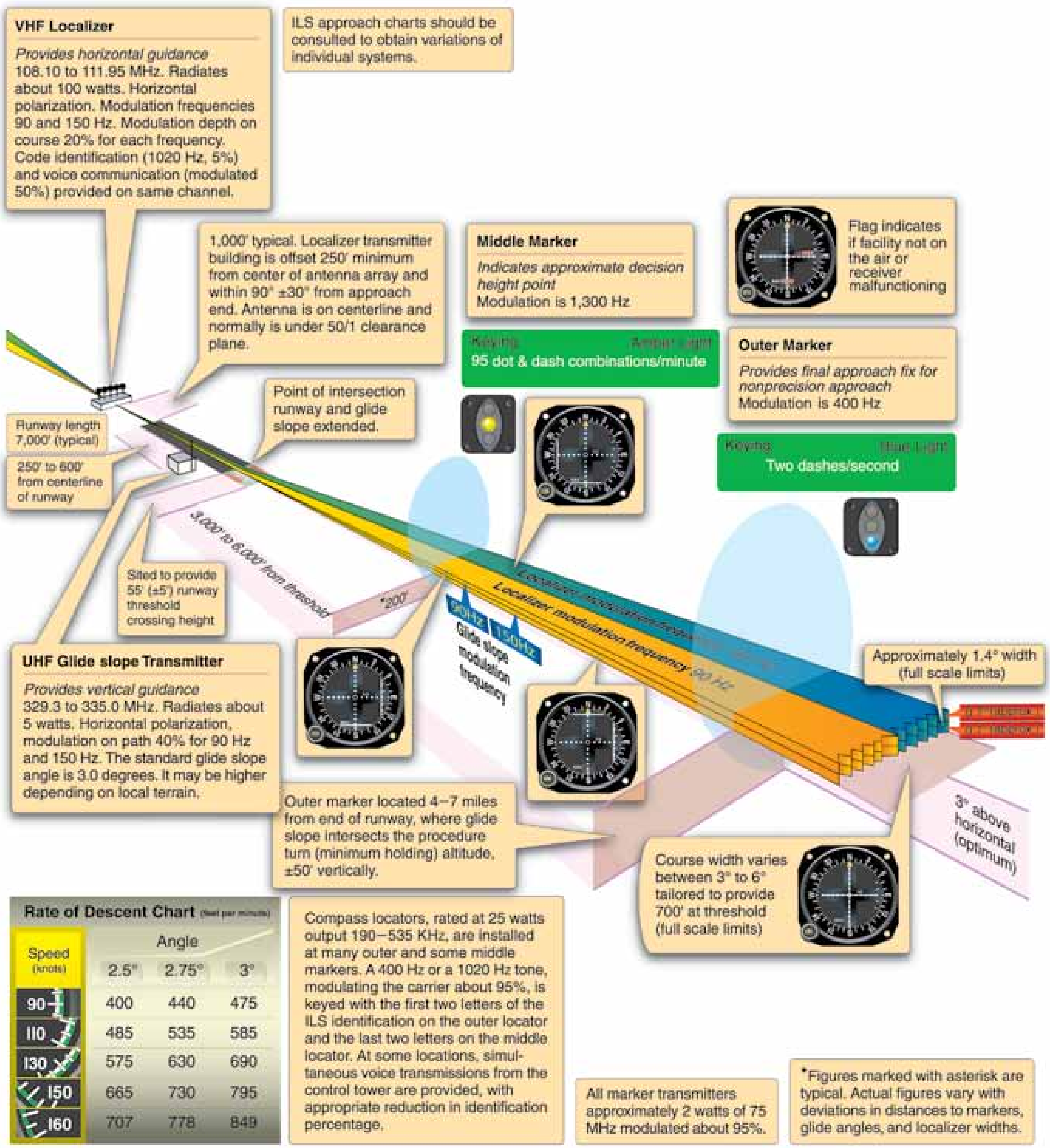
The ILS system provides both course and altitude guidance to a specific runway. The ILS system is used to execute a precision instrument approach procedure or precision approach. *[Figure 7-34]* The system consists of the following components:

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



Speed (knots)	Angle 2.5°	Angle 2.75°	Angle 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.

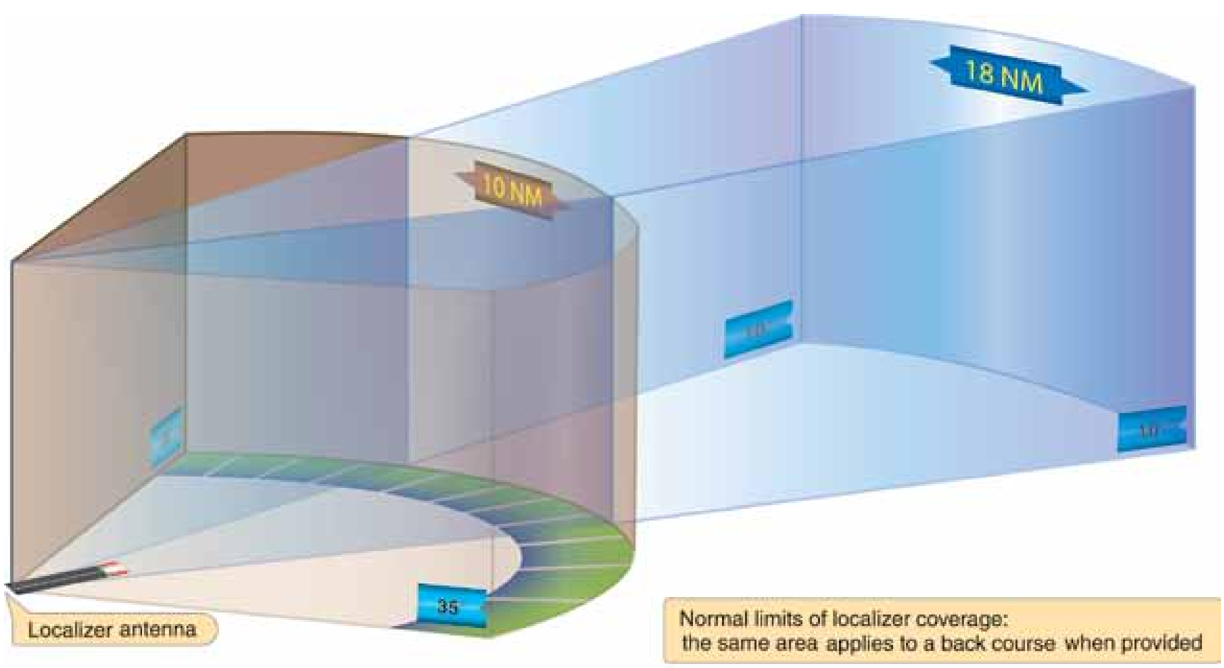


Figure 7-35. *Localizer Coverage Limits.*

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.

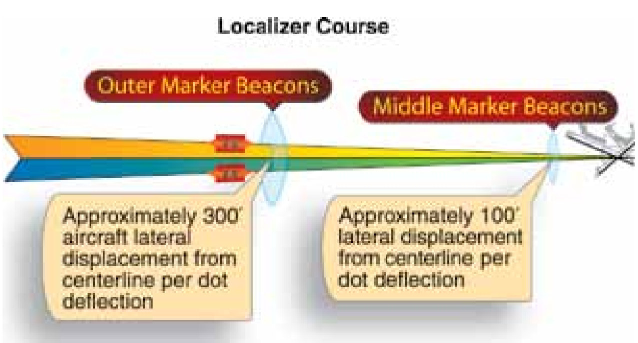


Figure 7-36. *Localizer receiver indications and aircraft displacement.*

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.

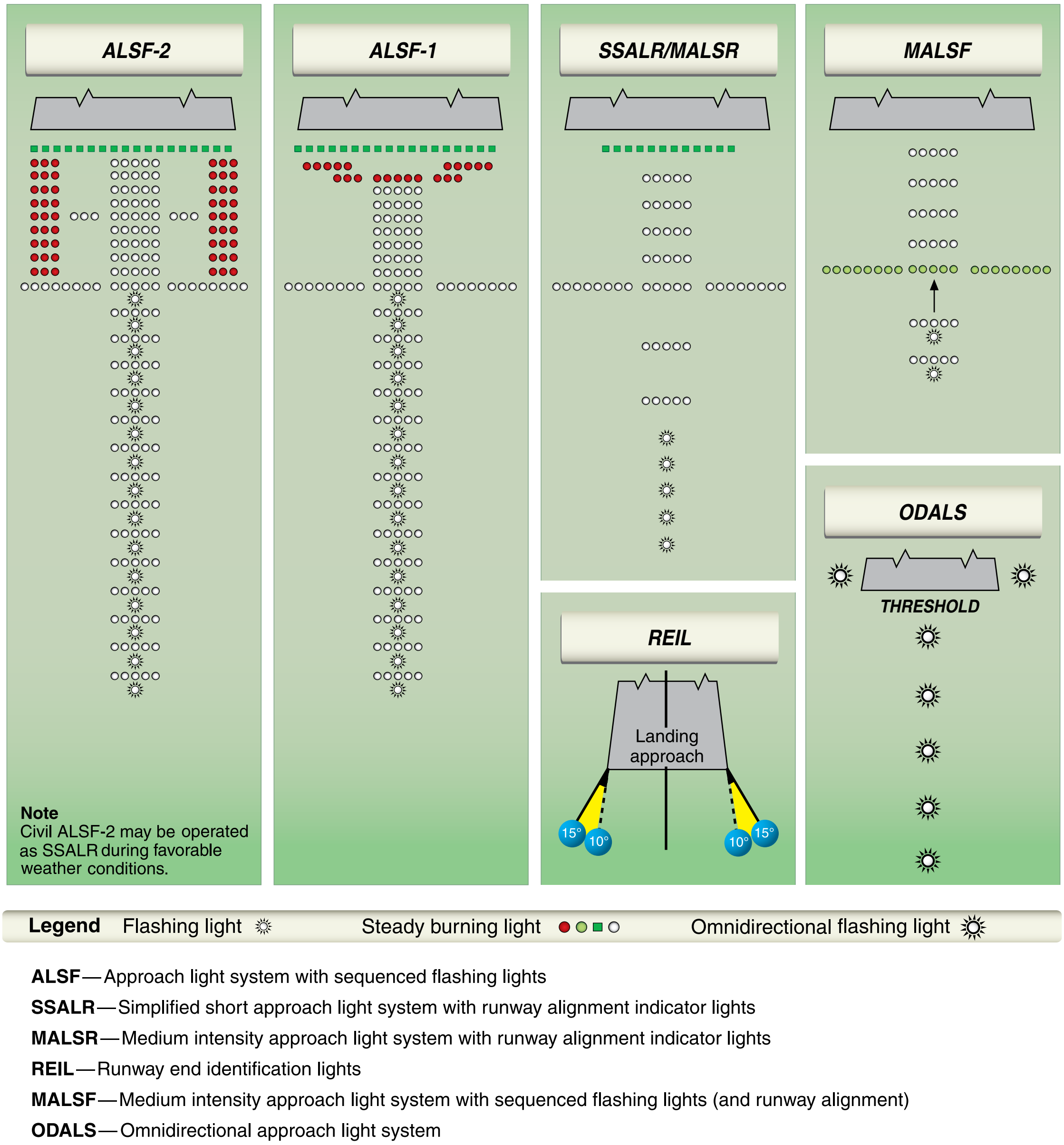


Figure 7-37. *Precision and Nonprecision ALS Configuration.*

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

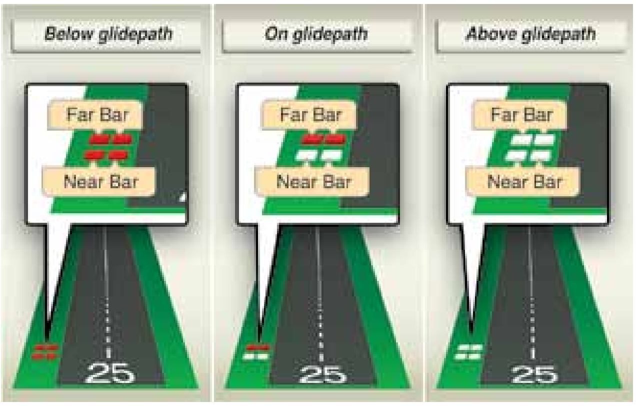


Figure 7-38. *Standard two-bar VASI.*

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

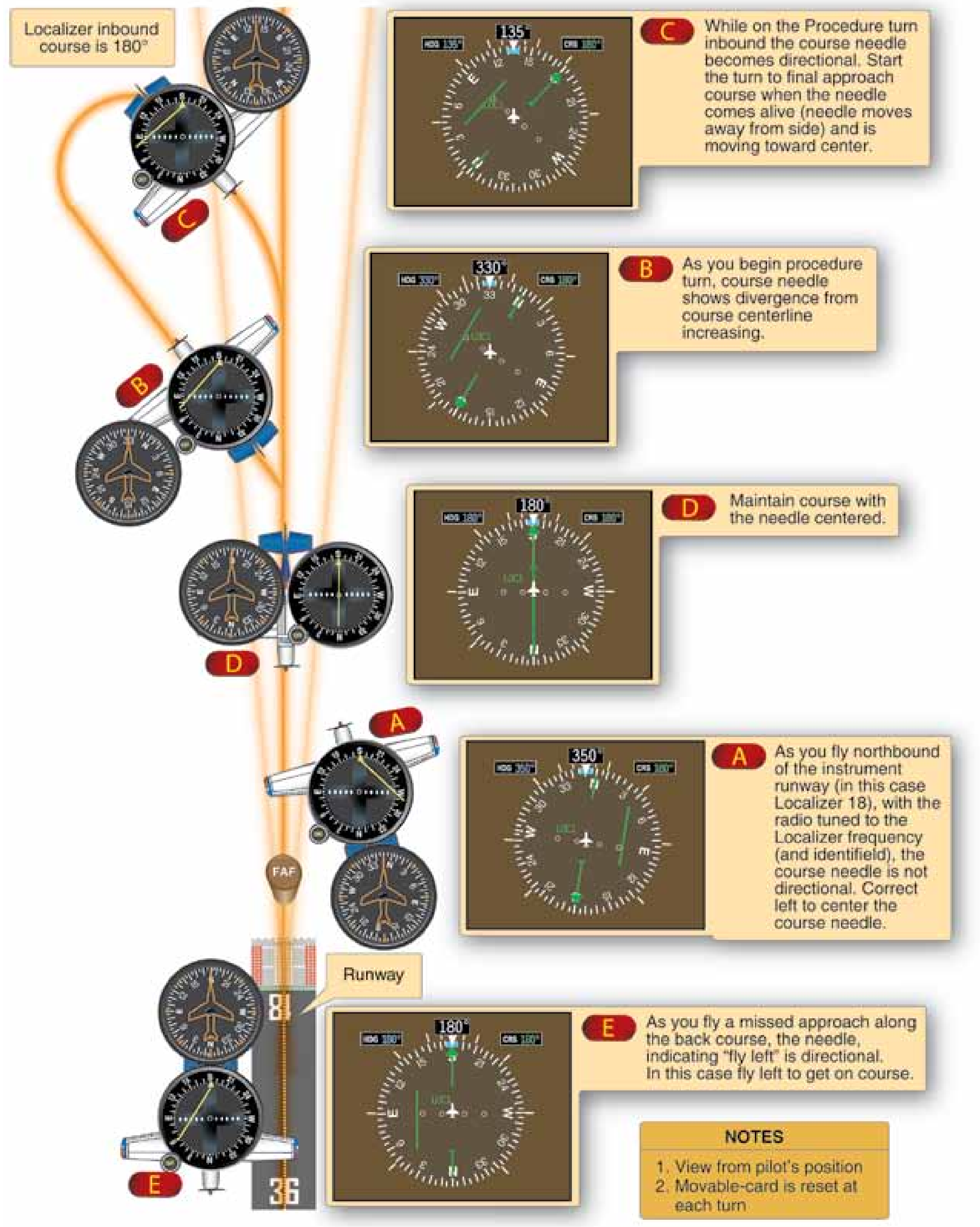


Figure 7-39. *Localizer Course Indications. To follow indications displayed in the aircraft, start from A and proceed through E.*

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

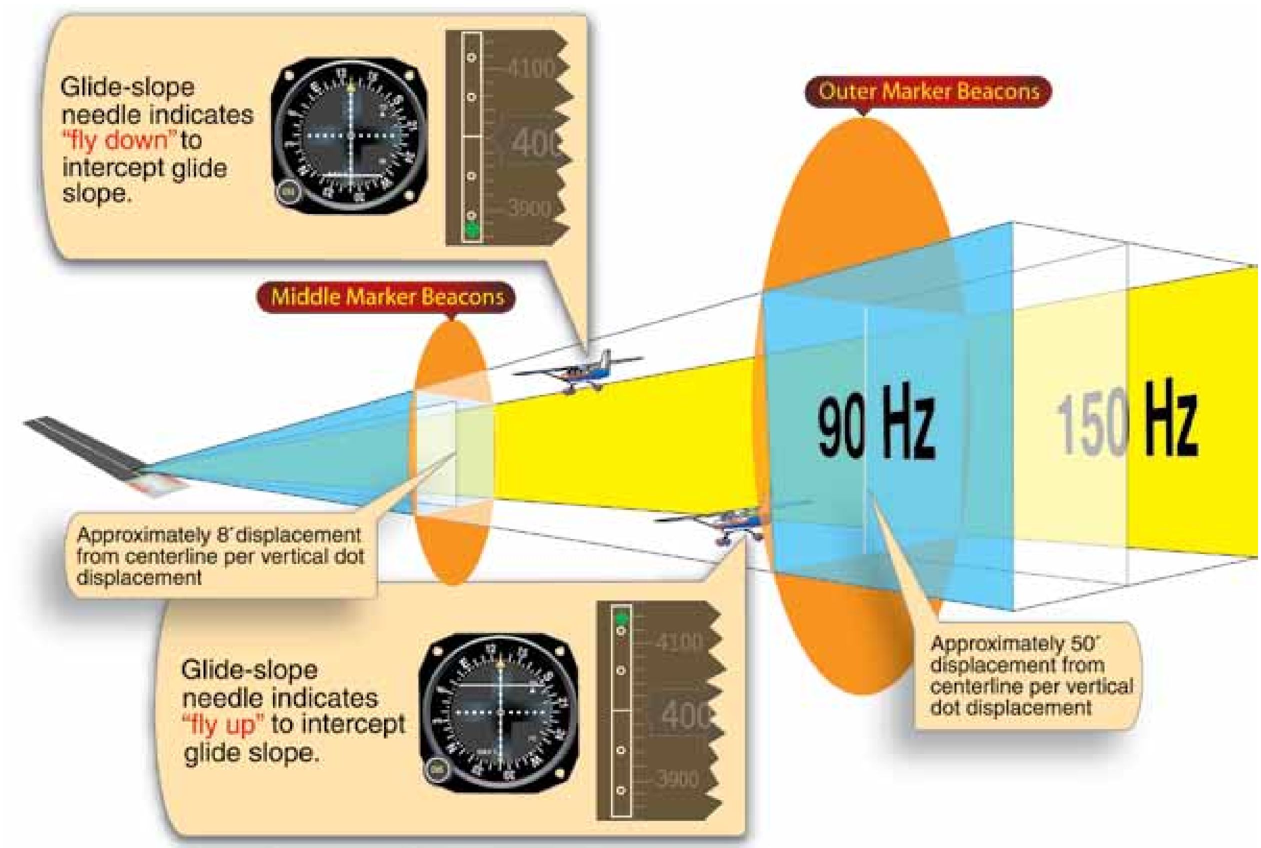


Figure 7-40. *Illustrates a GS receiver indication and aircraft displacement. An analog system is on the left and the same indication on the Garmin PFD on the right.*

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

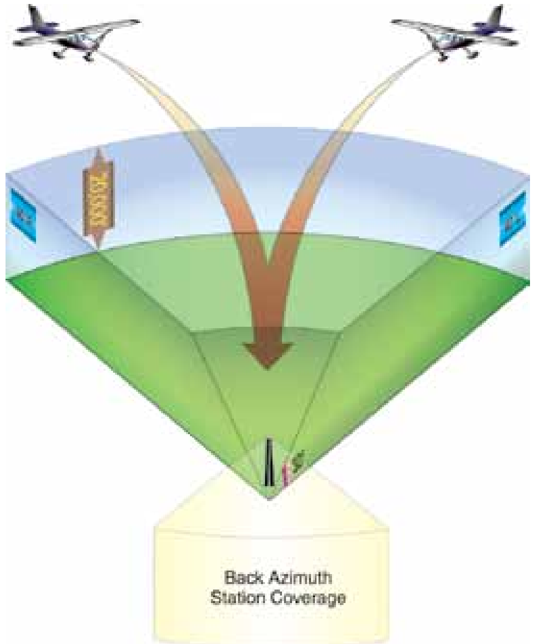


Figure 7-41. *MLS Coverage Volumes, 3-D Representation.*

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

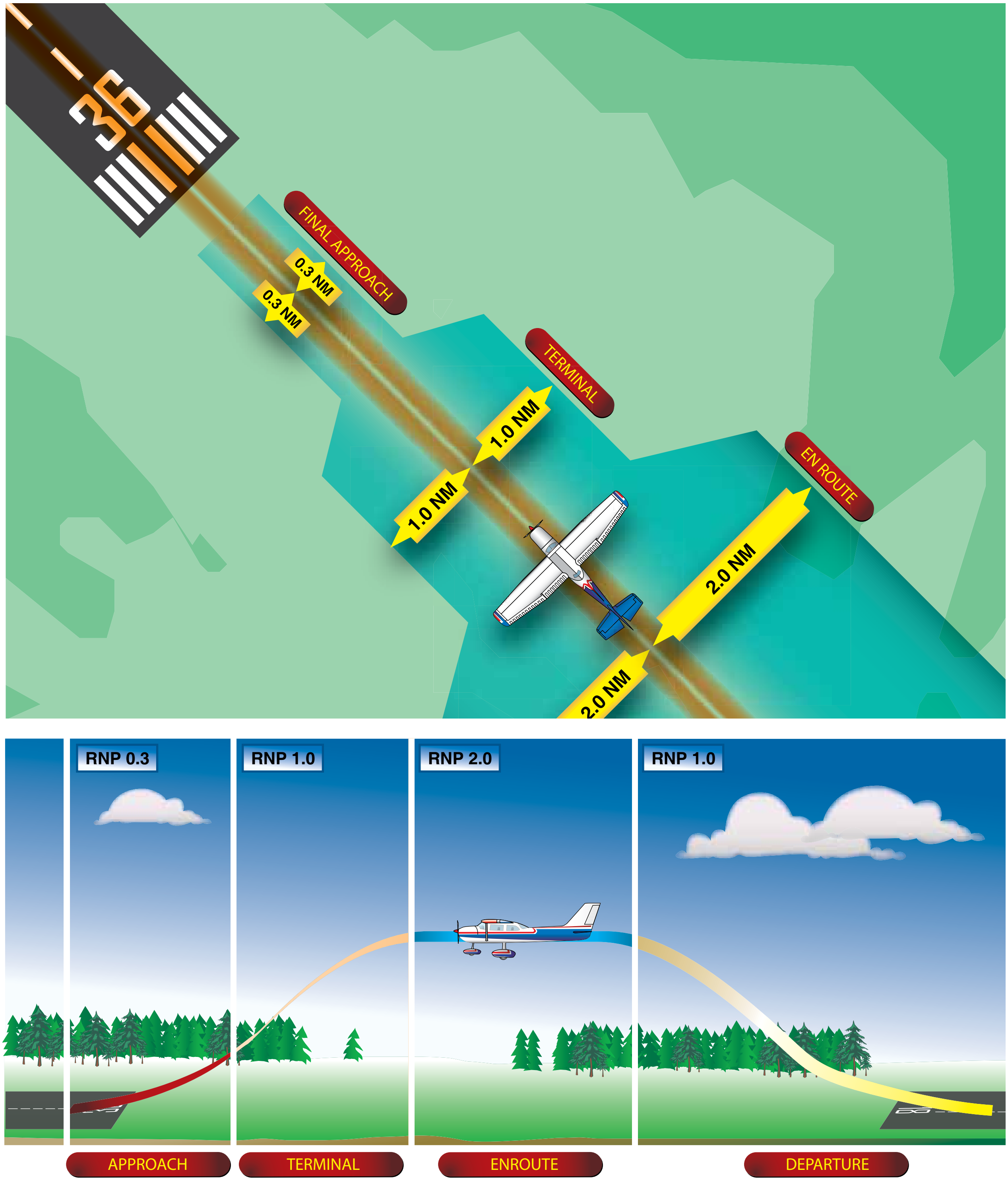


Figure 7-42. *Required Navigation Performance.*

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.