

pilot with an effective safeguard against disorientation in the event of radio malfunction.

There are four radio navigation systems available for use for VFR navigation. These are:

- VHF Omnidirectional Range (VOR)
- Nondirectional Radio Beacon (NDB)
- Long Range Navigation (LORAN-C)
- Global Positioning System (GPS)

Very High Frequency (VHF) Omnidirectional Range (VOR)

The VOR system is present in three slightly different navigation aids (NAVAIDs): VOR, VOR/DME, and VORTAC. By itself it is known as a VOR, and it provides magnetic bearing information to and from the station. When DME is also installed with a VOR, the NAVAID is referred to as a VOR/DME. When military tactical air navigation (TACAN) equipment is installed with a VOR, the NAVAID is known as a VORTAC. DME is always an integral part of a VORTAC. Regardless of the type of NAVAID utilized (VOR, VOR/DME or VORTAC), the VOR indicator behaves the same. Unless otherwise noted, in this section, VOR, VOR/DME and VORTAC NAVAIDs are all referred to hereafter as VORs.

The prefix “omni-” means all, and an omnidirectional range is a VHF radio transmitting ground station that projects straight line courses (radials) from the station in all directions. From a top view, it can be visualized as being similar to the spokes from the hub of a wheel. The distance VOR radials are projected depends upon the power output of the transmitter.

The course or radials projected from the station are referenced to magnetic north. Therefore, a radial is defined as a line of magnetic bearing extending outward from the VOR station. Radials are identified by numbers beginning with 001, which is 1° east of magnetic north, and progress in sequence through all the degrees of a circle until reaching 360. To aid in orientation, a compass rose reference to magnetic north is superimposed on aeronautical charts at the station location.

VOR ground stations transmit within a VHF frequency band of 108.0–117.95 MHz. Because the equipment is VHF, the signals transmitted are subject to line-of-sight restrictions. Therefore, its range varies in direct proportion to the altitude of receiving equipment. Generally, the reception range of the signals at an altitude of 1,000 feet above ground level (AGL) is about 40 to 45 miles. This distance increases with altitude. [Figure 15-28]

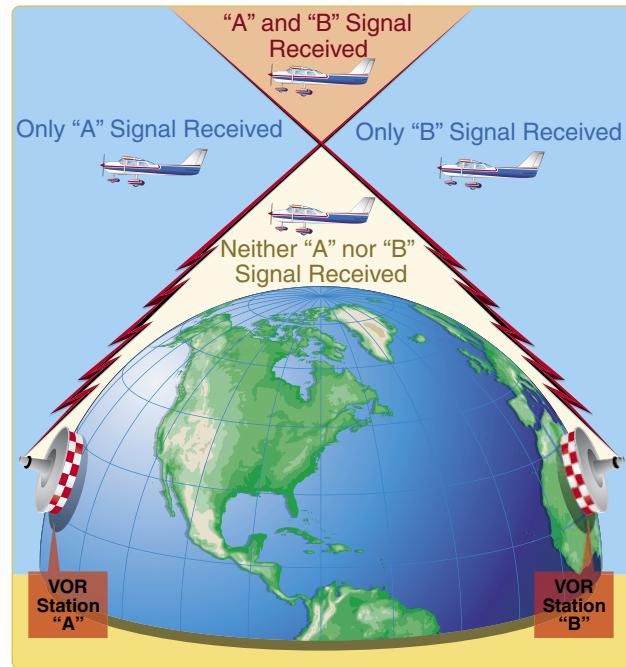


Figure 15-28. VHF transmissions follow a line-of-sight course.

VORs and VORTACs are classed according to operational use. There are three classes:

- T (Terminal)
- L (Low altitude)
- H (High altitude)

The normal useful range for the various classes is shown in the following table:

VOR/VORTAC NAVAIDS
Normal Usable Altitudes and Radius Distances

Class	Altitudes	Distance (Miles)
T	12,000' and below	25
L	Below 18,000'	40
H	Below 14,500'	40
H	Within the conterminous 48 states only, between 14,500 and 17,999'	100
H	18,000'—FL 450	130
H	60,000'—FL 450	100

The useful range of certain facilities may be less than 50 miles. For further information concerning these restrictions, refer to the Communication/NAVAID Remarks in the A/FD.

The accuracy of course alignment of VOR radials is considered to be excellent. It is generally within plus or minus 1°. However, certain parts of the VOR receiver equipment deteriorate, and this affects its accuracy. This is particularly true at great distances from the VOR station. The best assurance of maintaining an accurate VOR receiver is periodic checks and calibrations. VOR accuracy checks are not a regulatory requirement for VFR flight. However, to assure accuracy of the equipment, these checks should be accomplished quite frequently and a complete calibration each year. The following means are provided for pilots to check VOR accuracy:

- FAA VOR test facility (VOT)
- Certified airborne checkpoints
- Certified ground checkpoints located on airport surfaces

If an aircraft has two VOR receivers installed, a dual VOR receiver check can be made. To accomplish the dual receiver check, a pilot tunes both VOR receivers to the same VOR ground facility. The maximum permissible variation between the two indicated bearings is 4 degrees. A list of the airborne and ground checkpoints is published in the A/FD.

Basically, these checks consist of verifying that the VOR radials the aircraft equipment receives are aligned with the radials the station transmits. There are not specific tolerances in VOR checks required for VFR flight. But as a guide to assure acceptable accuracy, the required IFR tolerances can be used— $\pm 4^\circ$ for ground checks and $\pm 6^\circ$ for airborne checks. These checks can be performed by the pilot.

The VOR transmitting station can be positively identified by its Morse code identification or by a recorded voice identification which states the name of the station followed by "VOR." Many FSS transmit voice messages on the same frequency that the VOR operates. Voice transmissions should not be relied upon to identify stations, because many FSS remotely transmit over several omniranges, which have names different from that of the transmitting FSS. If the VOR is out of service for maintenance, the coded identification is removed and not transmitted. This serves to alert pilots that this station should not be used for navigation. VOR receivers are designed with an alarm flag to indicate when signal strength is inadequate to operate the navigational equipment. This happens if the aircraft is too far from the VOR or the aircraft is too low and, therefore, is out of the line of sight of the transmitting signals.

Using the VOR

In review, for VOR radio navigation, there are two components required: ground transmitter and aircraft

receiving equipment. The ground transmitter is located at a specific position on the ground and transmits on an assigned frequency. The aircraft equipment includes a receiver with a tuning device and a VOR or omnirange instrument. The navigation instrument could be a course deviation indicator (CDI), horizontal situation indicator (HSI), or a radio magnetic indicator (RMI). Each of these instruments indicates the course to the tuned VOR.

Course Deviation Indicator (CDI)

The CDI is found in most training aircraft. It consists of (1) omnibearing selector (OBS) sometimes referred to as the course selector, (2) a CDI needle (Left-Right Needle), and (3) a TO/FROM indicator.

The course selector is an azimuth dial that can be rotated to select a desired radial or to determine the radial over which the aircraft is flying. In addition, the magnetic course "TO" or "FROM" the station can be determined.

When the course selector is rotated, it moves the CDI or needle to indicate the position of the radial relative to the aircraft. If the course selector is rotated until the deviation needle is centered, the radial (magnetic course "FROM" the station) or its reciprocal (magnetic course "TO" the station) can be determined. The course deviation needle also moves to the right or left if the aircraft is flown or drifting away from the radial which is set in the course selector.

By centering the needle, the course selector indicates either the course "FROM" the station or the course "TO" the station. If the flag displays a "TO," the course shown on the course selector must be flown to the station. [Figure 15-29] If

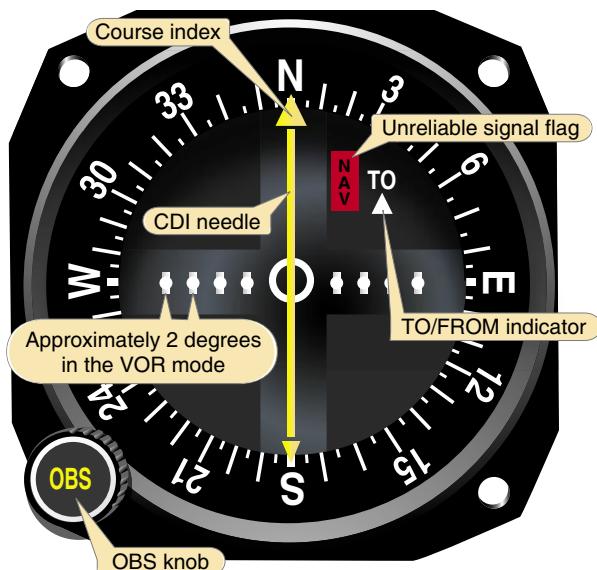


Figure 15-29. VOR indicator.

"FROM" is displayed and the course shown is followed, the aircraft is flown away from the station.

Horizontal Situation Indicator

The HSI is a direction indicator that uses the output from a flux valve to drive the compass card. The HSI [Figure 15-30] combines the magnetic compass with navigation signals and a glideslope. The HSI gives the pilot an indication of the location of the aircraft with relationship to the chosen course or radial.

In Figure 15-30, the aircraft magnetic heading displayed on the compass card under the lubber line is 184°. The course select pointer shown is set to 295°; the tail of the pointer indicates the reciprocal, 115°. The course deviation bar operates with a VOR/Localizer (VOR/LOC) or GPS navigation receiver to indicate left or right deviations from the course selected with the course select pointer; operating

in the same manner, the angular movement of a conventional VOR/LOC needle indicates deviation from course.

The desired course is selected by rotating the course select pointer, in relation to the compass card, by means of the course select knob. The HSI has a fixed aircraft symbol and the course deviation bar displays the aircraft's position relative to the selected course. The TO/FROM indicator is a triangular pointer. When the indicator points to the head of the course select pointer, the arrow shows the course selected. If properly intercepted and flown, the course will take the aircraft to the chosen facility. When the indicator points to the tail of the course, the arrow shows that the course selected, if properly intercepted and flown, will take the aircraft directly away from the chosen facility.

When the NAV warning flag appears it indicates no reliable signal is being received. The appearance of the HDG flag indicates the compass card is not functioning properly.

The glideslope pointer indicates the relation of the aircraft to the glideslope. When the pointer is below the center position, the aircraft is above the glideslope and an increased rate of descent is required. In some installations, the azimuth card is a remote indicating compass; however, in others the heading must be checked occasionally against the magnetic compass and reset.

Radio Magnetic Indicator (RMI)

The RMI [Figure 15-31] is a navigational aid providing aircraft magnetic or directional gyro heading and very high frequency omnidirectional range (VOR), GPS, and automatic direction finder (ADF) bearing information. Remote indicating

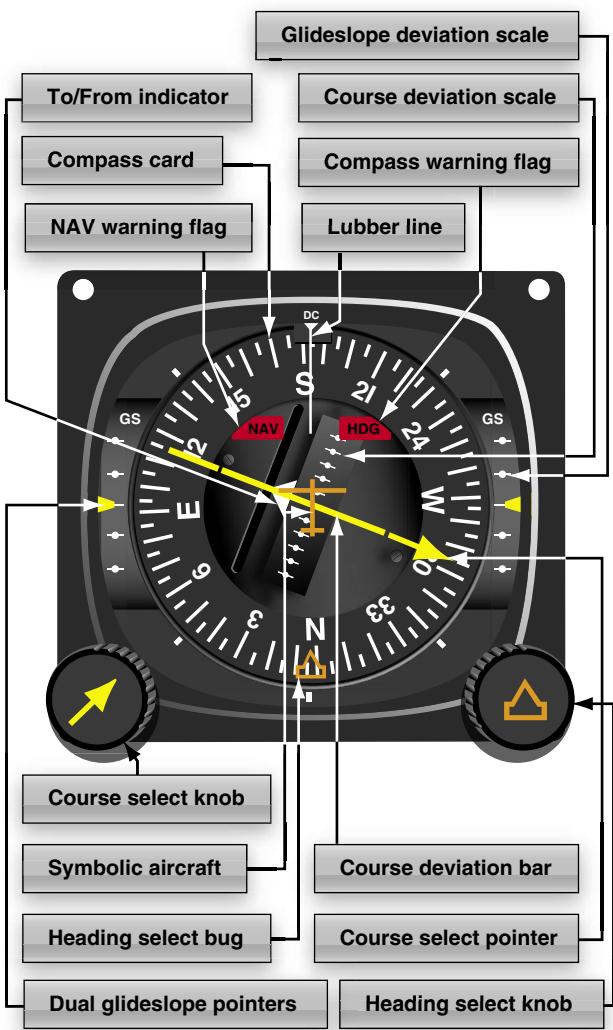


Figure 15-30. Horizontal situation indicator.



Figure 15-31. Radio magnetic indicator.

compasses were developed to compensate for errors in and limitations of older types of heading indicators.

The remote compass transmitter is a separate unit usually mounted in a wingtip to eliminate the possibility of magnetic interference. The RMI consists of a compass card, a heading index, two bearing pointers, and pointer function switches. The two pointers are driven by any two combinations of a GPS, an ADF, and/or a VOR. The pilot has the ability to select the navigation aid to be indicated. The pointer indicates course to selected NAVAID or waypoint. In *Figure 15-31* the green pointer is indicating the station tuned on the ADF. The yellow pointer is indicating the course to a VOR or GPS waypoint. Note that there is no requirement for a pilot to select course with the RMI, but only the NAVAID is to be indicated.

Tracking With VOR

The following describes a step-by-step procedure to use when tracking to and from a VOR station using a CDI. *Figure 15-32* illustrates the procedure.

First, tune the VOR receiver to the frequency of the selected VOR station. For example, 115.0 to receive Bravo VOR. Next, check the identifiers to verify that the desired VOR is being received. As soon as the VOR is properly tuned, the course deviation needle deflects either left or right. Then, rotate the azimuth dial to the course selector until the course deviation needle centers and the TO-FROM indicator indicates “TO.” If the needle centers with a “FROM” indication, the azimuth should be rotated 180° because, in this case, it is desired to fly “TO” the station. Now, turn the aircraft to the heading indicated on the VOR azimuth dial or course selector, 350° in this example.

If a heading of 350° is maintained with a wind from the right as shown, the aircraft drifts to the left of the intended track. As the aircraft drifts off course, the VOR course deviation needle gradually moves to the right of center or indicates the direction of the desired radial or track.

To return to the desired radial, the aircraft heading must be altered to the right. As the aircraft returns to the desired track, the deviation needle slowly returns to center. When centered, the aircraft is on the desired radial and a left turn must be made toward, but not to the original heading of 350° because a wind drift correction must be established. The amount of correction depends upon the strength of the wind. If the wind velocity is unknown, a trial-and-error method can be used to find the correct heading. Assume, for this example, a 10° correction for a heading of 360° is maintained.

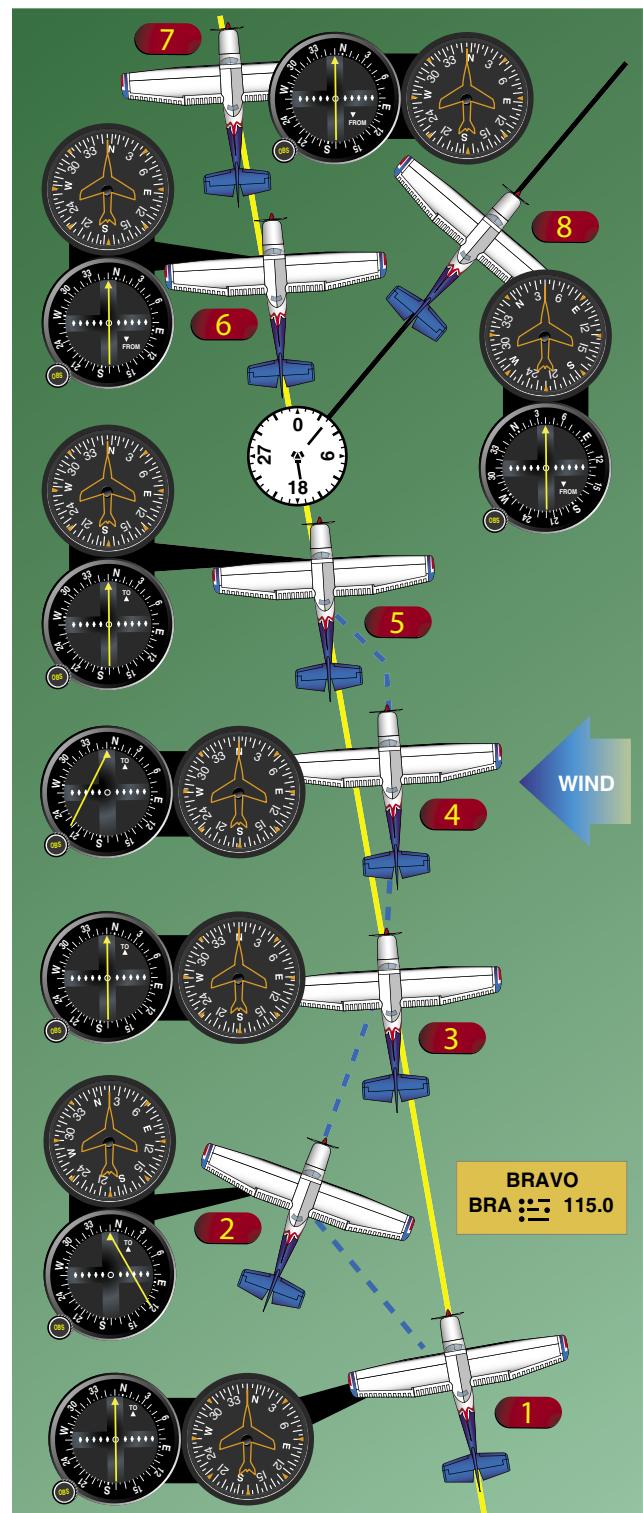


Figure 15-32. Tracking a radial in a crosswind.

While maintaining a heading of 360°, assume that the course deviation begins to move to the left. This means that the wind correction of 10° is too great and the aircraft is flying to the right of course. A slight turn to the left should be made to permit the aircraft to return to the desired radial.

When the deviation needle centers, a small wind drift correction of 5° or a heading correction of 355° should be flown. If this correction is adequate, the aircraft remains on the radial. If not, small variations in heading should be made to keep the needle centered, and consequently keep the aircraft on the radial.

As the VOR station is passed, the course deviation needle fluctuates, then settles down, and the “TO” indication changes to “FROM.” If the aircraft passes to one side of the station, the needle deflects in the direction of the station as the indicator changes to “FROM.”

Generally, the same techniques apply when tracking outbound as those used for tracking inbound. If the intent is to fly over the station and track outbound on the reciprocal of the inbound radial, the course selector should not be changed. Corrections are made in the same manner to keep the needle centered. The only difference is that the omnidirectional range indicator indicates “FROM.”

If tracking outbound on a course other than the reciprocal of the inbound radial, this new course or radial must be set in the course selector and a turn made to intercept this course. After this course is reached, tracking procedures are the same as previously discussed.

Tips on Using the VOR

- Positively identify the station by its code or voice identification.
- Keep in mind that VOR signals are “line-of-sight.” A weak signal or no signal at all is received if the aircraft is too low or too far from the station.
- When navigating to a station, determine the inbound radial and use this radial. Fly a heading that will maintain the course. If the aircraft drifts, fly a heading to re-intercept the course then apply a correction to compensate for wind drift.
- If minor needle fluctuations occur, avoid changing headings immediately. Wait momentarily to see if the needle recenters; if it does not, then correct.
- When flying “TO” a station, always fly the selected course with a “TO” indication. When flying “FROM” a station, always fly the selected course with a “FROM” indication. If this is not done, the action of the course

deviation needle is reversed. To further explain this reverse action, if the aircraft is flown toward a station with a “FROM” indication or away from a station with a “TO” indication, the course deviation needle indicates in a direction opposite to that which it should indicate. For example, if the aircraft drifts to the right of a radial being flown, the needle moves to the right or points away from the radial. If the aircraft drifts to the left of the radial being flown, the needle moves left or in the direction opposite to the radial.

- When navigating using the VOR it is important to fly headings that maintain or re-intercept the course. Just turning toward the needle will cause overshooting the radial and flying an S turn to the left and right of course.

Time and Distance Check From a Station

To compute time and distance from a station, first turn the aircraft to place the bearing pointer on the nearest 90° index. Note time and maintain heading. When the bearing pointer has moved 10°, note the elapsed time in seconds and apply the formulas in the following example to determine time and distance. [Figure 15-33]

Time-Distance Check Example	
Time in seconds between bearings	
Degrees of bearing change	= Minutes to station
For example, if 2 minutes (120 seconds) is required to fly a bearing change of 10 degrees, the aircraft is—	
$\frac{120}{10} = 12 \text{ minutes to the station}$	

Figure 15-33. Time-distance check example.

The time from station may also be calculated by using a short method based on the above formula, if a 10° bearing change is flown. If the elapsed time for the bearing change is noted in seconds and a 10° bearing change is made, the time from the station in minutes is determined by counting off one decimal point. Thus, if 75 seconds are required to fly a 10° bearing change, the aircraft is 7.5 minutes from the station. When the bearing pointer is moving rapidly or when several corrections are required to place the pointer on the wingtip position, the aircraft is at station passage.

The distance from the station is computed by multiplying TAS or GS (in miles per minute) by the previously determined time in minutes. For example, if the aircraft is 7.5 minutes from station, flying at a TAS of 120 knots or 2 NM per minute, the distance from station is 15 NM ($7.5 \times 2 = 15$).

The preceding are methods of computing approximate time and distance. The accuracy of time and distance checks is governed by existing wind, degree of bearing change, and accuracy of timing. The number of variables involved causes the result to be only an approximation. However, by flying an accurate heading and checking the time and bearing closely, the pilot can make a reasonable estimate of time and distance from the station.

Course Intercept

Course interceptions are performed in most phases of instrument navigation. The equipment used varies, but an intercept heading must be flown that results in an angle or rate of intercept sufficient to solve a particular problem.

Rate of Intercept

Rate of intercept, seen by the aviator as bearing pointer or HSI movement, is a result of the following factors:

- The angle at which the aircraft is flown toward a desired course (angle of intercept)
- True airspeed and wind (GS)
- Distance from the station

Angle of Intercept

The angle of intercept is the angle between the heading of the aircraft (intercept heading) and desired course. Controlling this angle by selection/adjustment of the intercept heading is the easiest and most effective way to control course interceptions. Angle of intercept must be greater than the degrees from course, but should not exceed 90°. Within this limit, adjust to achieve the most desirable rate of intercept.

When selecting an intercept heading, the key factor is the relationship between distance from the station and degrees from the course. Each degree, or radial, is 1 NM wide at a distance of 60 NM from the station. Width increases or decreases in proportion to the 60 NM distance. For example, 1 degree is 2 NM wide at 120 NM—and $\frac{1}{2}$ NM wide at 30 NM. For a given GS and angle of intercept, the resultant rate of intercept varies according to the distance from the station. When selecting an intercept heading to form an angle of intercept, consider the following factors:

- Degrees from course
- Distance from the station
- True airspeed and wind (GS)

Distance Measuring Equipment (DME)

Distance measuring equipment (DME) consists of an ultra high frequency (UHF) navigational aid with VOR/DMEs and VORTACs. It measures, in NM, the slant range distance of an aircraft from a VOR/DME or VORTAC (both hereafter

referred to as a VORTAC). Although DME equipment is very popular, not all aircraft are DME equipped.

To utilize DME, the pilot should select, tune, and identify a VORTAC, as previously described. The DME receiver, utilizing what is called a “paired frequency” concept, automatically selects and tunes the UHF DME frequency associated with the VHF VORTAC frequency selected by the pilot. This process is entirely transparent to the pilot. After a brief pause, the DME display shows the slant range distance to or from the VORTAC. Slant range distance is the direct distance between the aircraft and the VORTAC, and is therefore affected by aircraft altitude. (Station passage directly over a VORTAC from an altitude of 6,076 feet above ground level (AGL) would show approximately 1.0 NM on the DME.) DME is a very useful adjunct to VOR navigation. A VOR radial alone merely gives line of position information. With DME, a pilot may precisely locate the aircraft on that line (radial).

Most DME receivers also provide GS and time-to-station modes of operation. The GS is displayed in knots (NMPH). The time-to-station mode displays the minutes remaining to VORTAC station passage, predicated upon the present GS. GS and time-to-station information is only accurate when tracking directly to or from a VORTAC. DME receivers typically need a minute or two of stabilized flight directly to or from a VORTAC before displaying accurate GS or time-to-station information.

Some DME installations have a hold feature that permits a DME signal to be retained from one VORTAC while the course indicator displays course deviation information from an ILS or another VORTAC.

VOR/DME RNAV

Area navigation (RNAV) permits electronic course guidance on any direct route between points established by the pilot. While RNAV is a generic term that applies to a variety of navigational aids, such as LORAN-C, GPS, and others, this section deals with VOR/DME-based RNAV. VOR/DME RNAV is not a separate ground-based NAVAID, but a method of navigation using VOR/DME and VORTAC signals specially processed by the aircraft’s RNAV computer. [Figure 15-34]

NOTE: In this section, the term “VORTAC” also includes VOR/DME NAVAIDs.

In its simplest form, VOR/DME RNAV allows the pilot to electronically move VORTACs around to more convenient locations. Once electronically relocated, they are referred to as waypoints. These waypoints are described as a

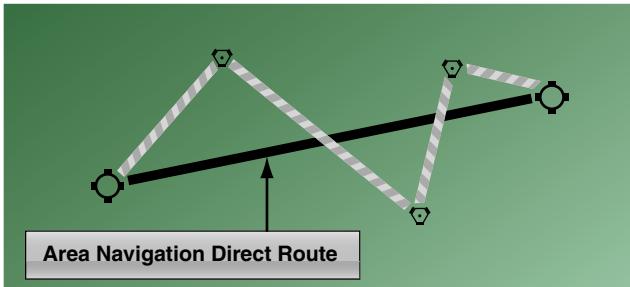


Figure 15-34. Flying an RNAV course.

combination of a selected radial and distance within the service volume of the VORTAC to be used. These waypoints allow a straight course to be flown between almost any origin and destination, without regard to the orientation of VORTACs or the existence of airways.

While the capabilities and methods of operation of VOR/DME RNAV units differ, there are basic principles of operation that are common to all. Pilots are urged to study the manufacturer's operating guide and receive instruction prior to the use of VOR/DME RNAV or any unfamiliar navigational system. Operational information and limitations should also be sought from placards and the supplement section of the AFM/POH.

VOR/DME-based RNAV units operate in at least three modes: VOR, en route, and approach. A fourth mode, VOR Parallel, may also be found on some models. The units need both VOR and DME signals to operate in any RNAV mode. If the NAVAID selected is a VOR without DME, RNAV mode will not function.

In the VOR (or non-RNAV) mode, the unit simply functions as a VOR receiver with DME capability. [Figure 15-35] The unit's display on the VOR indicator is conventional in all respects. For operation on established airways or any other ordinary VOR navigation, the VOR mode is used.

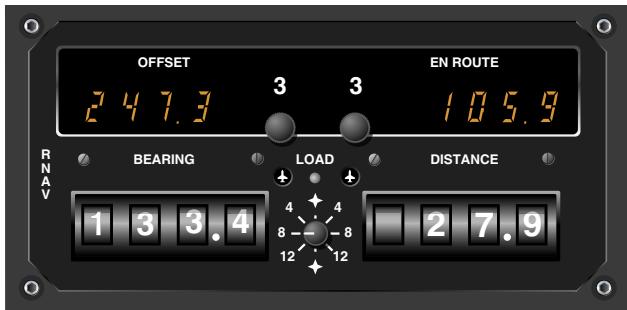


Figure 15-35. RNAV controls.

To utilize the unit's RNAV capability, the pilot selects and establishes a waypoint or a series of waypoints to define

a course. To operate in any RNAV mode, the unit needs both radial and distance signals; therefore, a VORTAC (or VOR/DME) needs to be selected as a NAVAID. To establish a waypoint, a point somewhere within the service range of a VORTAC is defined on the basis of radial and distance. Once the waypoint is entered into the unit and the RNAV en route mode is selected, the CDI displays course guidance to the waypoint, not the original VORTAC. DME also displays distance to the waypoint. Many units have the capability to store several waypoints, allowing them to be programmed prior to flight, if desired, and called up in flight.

RNAV waypoints are entered into the unit in magnetic bearings (radials) of degrees and tenths (i.e., 275.5°) and distances in NM and tenths (i.e., 25.2 NM). When plotting RNAV waypoints on an aeronautical chart, pilots find it difficult to measure to that level of accuracy, and in practical application, it is rarely necessary. A number of flight planning publications publish airport coordinates and waypoints with this precision and the unit accepts those figures. There is a subtle, but important difference in CDI operation and display in the RNAV modes.

In the RNAV modes, course deviation is displayed in terms of linear deviation. In the RNAV en route mode, maximum deflection of the CDI typically represents 5 NM on either side of the selected course, without regard to distance from the waypoint. In the RNAV approach mode, maximum deflection of the CDI typically represents 1¼ NM on either side of the selected course. There is no increase in CDI sensitivity as the aircraft approaches a waypoint in RNAV mode.

The RNAV approach mode is used for instrument approaches. Its narrow scale width (¼ of the en route mode) permits very precise tracking to or from the selected waypoint. In visual flight rules (VFR) cross-country navigation, tracking a course in the approach mode is not desirable because it requires a great deal of attention and soon becomes tedious.

A fourth, lesser-used mode on some units is the VOR Parallel mode. This permits the CDI to display linear (not angular) deviation as the aircraft tracks to and from VORTACs. It derives its name from permitting the pilot to offset (or parallel) a selected course or airway at a fixed distance of the pilot's choosing, if desired. The VOR parallel mode has the same effect as placing a waypoint directly over an existing VORTAC. Some pilots select the VOR parallel mode when utilizing the navigation (NAV) tracking function of their autopilot for smoother course following near the VORTAC.

Confusion is possible when navigating an aircraft with VOR/DME-based RNAV, and it is essential that the pilot become

familiar with the equipment installed. It is not unknown for pilots to operate inadvertently in one of the RNAV modes when the operation was not intended by overlooking switch positions or annunciators. The reverse has also occurred with a pilot neglecting to place the unit into one of the RNAV modes by overlooking switch positions or annunciators. As always, the prudent pilot is not only familiar with the equipment used, but never places complete reliance in just one method of navigation when others are available for cross-check.

Automatic Direction Finder (ADF)

Many general aviation-type aircraft are equipped with ADF radio receiving equipment. To navigate using the ADF, the pilot tunes the receiving equipment to a ground station known as a nondirectional radio beacon (NDB). The NDB stations normally operate in a low or medium frequency band of 200 to 415 kHz. The frequencies are readily available on aeronautical charts or in the A/FD.

All radio beacons except compass locators transmit a continuous three-letter identification in code except during voice transmissions. A compass locator, which is associated with an instrument landing system, transmits a two-letter identification.

Standard broadcast stations can also be used in conjunction with ADF. Positive identification of all radio stations is extremely important and this is particularly true when using standard broadcast stations for navigation.

NDBs have one advantage over the VOR. This advantage is that low or medium frequencies are not affected by line-of-sight. The signals follow the curvature of the Earth; therefore, if the aircraft is within the range of the station, the signals can be received regardless of altitude.

The following table gives the class of NDB stations, their power, and usable range:

NONDIRECTIONAL RADIOBEACON (NDB)

(Usable Radius Distances for All Altitudes)

Class	Power (Watts)	Distance (Miles)
Compass Locator	Under 25	15
MH	Under 50	25
H	50–1999	*50
HH	2000 or more	75

*Service range of individual facilities may be less than 50 miles.

One of the disadvantages that should be considered when using low frequency (LF) for navigation is that low frequency signals are very susceptible to electrical disturbances, such as lightning. These disturbances create excessive static, needle deviations, and signal fades. There may be interference from distant stations. Pilots should know the conditions under which these disturbances can occur so they can be more alert to possible interference when using the ADF.

Basically, the ADF aircraft equipment consists of a tuner, which is used to set the desired station frequency, and the navigational display.

The navigational display consists of a dial upon which the azimuth is printed, and a needle which rotates around the dial and points to the station to which the receiver is tuned.

Some of the ADF dials can be rotated to align the azimuth with the aircraft heading; others are fixed with 0° representing the nose of the aircraft, and 180° representing the tail. Only the fixed azimuth dial is discussed in this handbook. [Figure 15-36]



Figure 15-36. ADF with fixed azimuth and magnetic compass.

Figure 15-37 illustrates terms that are used with the ADF and should be understood by the pilot.

To determine the magnetic bearing “FROM” the station, 180° is added to or subtracted from the magnetic bearing to the station. This is the reciprocal bearing and is used when plotting position fixes.

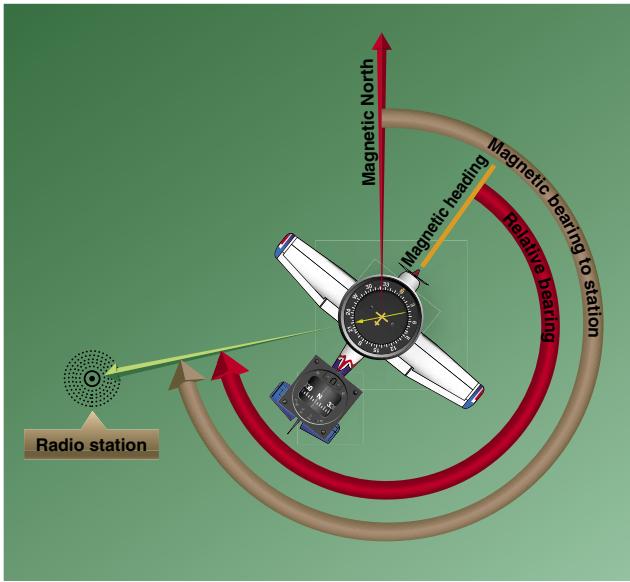


Figure 15-37. ADF terms.

Keep in mind that the needle of fixed azimuth points to the station in relation to the nose of the aircraft. If the needle is deflected 30° to the left for a relative bearing of 330° , this means that the station is located 30° left. If the aircraft is turned left 30° , the needle moves to the right 30° and indicates a relative bearing of 0° , or the aircraft is pointing toward the station. If the pilot continues flight toward the station keeping the needle on 0° , the procedure is called homing to the station. If a crosswind exists, the ADF needle continues to drift away from zero. To keep the needle on zero, the aircraft must be turned slightly resulting in a curved flightpath to the station. Homing to the station is a common procedure, but results in drifting downwind, thus lengthening the distance to the station.

Tracking to the station requires correcting for wind drift and results in maintaining flight along a straight track or bearing to the station. When the wind drift correction is established, the ADF needle indicates the amount of correction to the right or left. For instance, if the magnetic bearing to the station is 340° , a correction for a left crosswind would result in a magnetic heading of 330° , and the ADF needle would indicate 10° to the right or a relative bearing of 010° . [Figure 15-38]

When tracking away from the station, wind corrections are made similar to tracking to the station, but the ADF needle points toward the tail of the aircraft or the 180° position on the azimuth dial. Attempting to keep the ADF needle on the 180° position during winds results in the aircraft flying a curved flight leading further and further from the desired track. To correct for wind when tracking outbound, correction should be made in the direction opposite of that in which the needle is pointing.

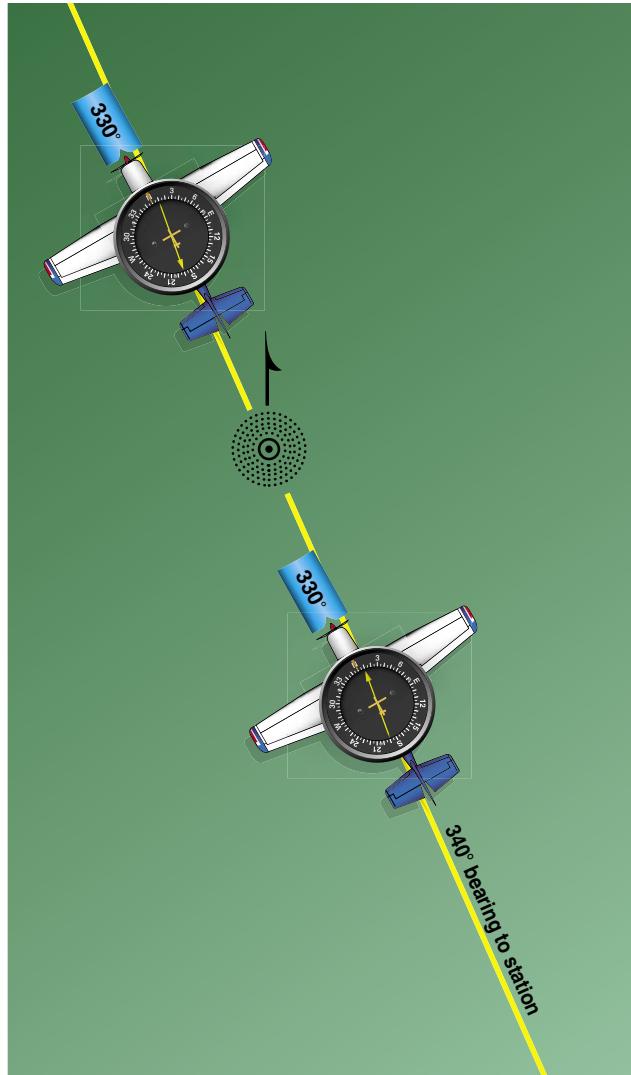


Figure 15-38. ADF tracking.

Although the ADF is not as popular as the VOR for radio navigation, with proper precautions and intelligent use, the ADF can be a valuable aid to navigation.

Loran-C Navigation

Long range navigation, version C (LORAN-C) is another form of RNAV, but one that operates from chains of transmitters broadcasting signals in the LF spectrum. World Aeronautical Chart (WAC), sectional charts, and VFR terminal area charts do not show the presence of LORAN-C transmitters. Selection of a transmitter chain is either made automatically by the unit, or manually by the pilot using guidance information provided by the manufacturer. LORAN-C is a highly accurate, supplemental form of navigation typically installed as an adjunct to VOR and ADF equipment. Databases of airports, NAVAIDS, and ATC facilities are frequently features of LORAN-C receivers.

LORAN-C is an outgrowth of the original LORAN-A developed for navigation during World War II. The LORAN-C system is used extensively in maritime applications. It experienced a dramatic growth in popularity with pilots with the advent of the small, panel-mounted LORAN-C receivers available at relatively low cost. These units are frequently very sophisticated and capable, with a wide variety of navigational functions.

With high levels of LORAN-C sophistication and capability, a certain complexity in operation is an unfortunate necessity. Pilots are urged to read the operating handbooks and to consult the supplements section of the AFM/POH prior to utilizing LORAN-C for navigation. Many units offer so many features that the manufacturers often publish two different sets of instructions: (1) a brief operating guide and (2) in-depth operating manual.

While coverage is not global, LORAN-C signals are suitable for navigation in all of the conterminous United States, and parts of Canada and Alaska. Several foreign countries also operate their own LORAN-C systems. In the United States, the U.S. Coast Guard operates the LORAN-C system. LORAN-C system status is available from: USCG Navigation Center, Alexandria, Virginia at (703) 313-5900.

LORAN-C absolute accuracy is excellent—position errors are typically less than .25 NM. Repeatable accuracy, or the ability to return to a waypoint previously visited, is even better. While LORAN-C is a form of RNAV, it differs significantly from VOR/DME-based RNAV. It operates in a 90–110 kHz frequency range and is based upon measurement of the difference in arrival times of pulses of radio frequency (RF) energy emitted by a chain of transmitters hundreds of miles apart.

Within any given chain of transmitters, there is a master station, and from three to five secondary stations. LORAN-C units must be able to receive at least a master and two secondary stations to provide navigational information. Unlike VOR/DME-based RNAV, where the pilot must select the appropriate VOR/DME or VORTAC frequency, there is not a frequency selection in LORAN-C. The most advanced units automatically select the optimum chain for navigation. Other units rely upon the pilot to select the appropriate chain with a manual entry.

After the LORAN-C receiver has been turned on, the unit must be initialized before it can be used for navigation. While this can be accomplished in flight, it is preferable to perform this task, which can take several minutes, on the ground. The methods for initialization are as varied as the number of different models of receivers. Some require pilot input

during the process, such as verification or acknowledgment of the information displayed.

Most units contain databases of navigational information. Frequently, such databases contain not only airport and NAVAID locations, but also extensive airport, airspace, and ATC information. While the unit can operate with an expired database, the information should be current or verified to be correct prior to use. The pilot can update some databases, while others require removal from the aircraft and the services of an avionics technician.

VFR navigation with LORAN-C can be as simple as telling the unit where the pilot wishes to go. The course guidance provided is a great circle (shortest distance) route to the destination. Older units may need a destination entered in terms of latitude and longitude, but recent designs need only the identifier of the airport or NAVAID. The unit also permits database storage and retrieval of pilot defined waypoints. LORAN-C signals follow the curvature of the Earth and are generally usable hundreds of miles from their transmitters.

The LORAN-C signal is subject to degradation from a variety of atmospheric disturbances. It is also susceptible to interference from static electricity buildup on the airframe and electrically “noisy” airframe equipment. Flight in precipitation or even dust clouds can cause occasional interference with navigational guidance from LORAN-C signals. To minimize these effects, static wicks and bonding straps should be installed and properly maintained.

LORAN-C navigation information is presented to the pilot in a variety of ways. All units have self-contained displays, and some elaborate units feature built-in moving map displays. Some installations can also drive an external moving map display, a conventional VOR indicator, or a horizontal situation indicator (HSI). Course deviation information is presented as a linear deviation from course—there is no increase in tracking sensitivity as the aircraft approaches the waypoint or destination. Pilots must carefully observe placards, selector switch positions, and annunciator indications when utilizing LORAN-C because aircraft installations can vary widely. The pilot’s familiarity with unit operation through AFM/POH supplements and operating guides cannot be overemphasized.

LORAN-C Notices to Airmen (NOTAMs) should be reviewed prior to relying on LORAN-C for navigation. LORAN-C NOTAMs are issued to announce outages for specific chains and transmitters. Pilots may obtain LORAN-C NOTAMs from FSS briefers only upon request.

The prudent pilot never relies solely on one means of navigation when others are available for backup and cross-check. Pilots should never become so dependent upon the extensive capabilities of LORAN-C that other methods of navigation are neglected.

Global Positioning System

The GPS is a satellite-based radio navigation system. Its RNAV guidance is worldwide in scope. There are no symbols for GPS on aeronautical charts as it is a space-based system with global coverage. Development of the system is underway so that GPS is capable of providing the primary means of electronic navigation. Portable and yoke mounted units are proving to be very popular in addition to those permanently installed in the aircraft. Extensive navigation databases are common features in aircraft GPS receivers.

The GPS is a satellite radio navigation and time dissemination system developed and operated by the U.S. Department of Defense (DOD). Civilian interface and GPS system status is available from the U.S. Coast Guard.

It is not necessary to understand the technical aspects of GPS operation to use it in VFR/instrument flight rules (IFR) navigation. It does differ significantly from conventional, ground-based electronic navigation, and awareness of those differences is important. Awareness of equipment approvals and limitations is critical to the safety of flight.

The GPS navigation system broadcasts a signal that is used by receivers to determine precise position anywhere in the world. The receiver tracks multiple satellites and determines a pseudorange measurement to determine the user location. A minimum of four satellites is necessary to establish an accurate three-dimensional position. The Department of Defense (DOD) is responsible for operating the GPS satellite constellation and monitors the GPS satellites to ensure proper operation.

The status of a GPS satellite is broadcast as part of the data message transmitted by the satellite. GPS status information is also available by means of the U.S. Coast Guard navigation information service at (703) 313-5907 or online 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. Baro-aiding is a method of augmenting the GPS integrity solution by using a nonsatellite input source. GPS derived altitude should not be relied upon to determine aircraft altitude since the vertical error can be quite large and no integrity is provided. To ensure that baro-aiding is available, the current altimeter setting must be entered into the receiver as described in the operating manual.

RAIM messages vary somewhat between receivers; however, generally there are two 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.

The GPS constellation of 24 satellites is designed so that a minimum of five satellites are always observable by a user anywhere on earth. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which a receiver can use a satellite).

VFR Use of GPS

GPS navigation has become a great asset to VFR pilots, providing increased navigation capability and enhanced situational awareness, while reducing operating costs due to greater ease in flying direct routes. While GPS has many benefits to the VFR pilot, care must be exercised to ensure that system capabilities are not exceeded.

Types of receivers used for GPS navigation under VFR are varied, from a full IFR installation being used to support a VFR flight, to a VFR only installation (in either a VFR or IFR capable aircraft) to a hand-held receiver. The limitations of each type of receiver installation or use must be understood by the pilot to avoid misusing navigation information. In all cases, VFR pilots should never rely solely on one system of navigation. GPS navigation must be integrated with other forms of electronic navigation as well as pilotage and dead reckoning. Only through the integration of these techniques can the VFR pilot ensure accuracy in navigation.

Some critical concerns in VFR use of GPS include RAIM capability, database currency and antenna location.

RAIM Capability

Many VFR GPS receivers and all hand-held units have no RAIM alerting capability. Loss of the required number of satellites in view, or the detection of a position error, cannot be displayed to the pilot by such receivers. In receivers with no RAIM capability, no alert would be provided to the pilot that the navigation solution had deteriorated, and an undetected navigation error could occur. A systematic cross-check with other navigation techniques would identify this failure, and prevent a serious deviation.

In many receivers, an updatable database is used for navigation fixes, airports, and instrument procedures. These databases must be maintained to the current update for IFR operation, but no such requirement exists for VFR use. However, in many cases, the database drives a moving map display which indicates Special Use Airspace and the various classes of airspace, in addition to other operational information. Without a current database the moving map display may be outdated and offer erroneous information to VFR pilots wishing to fly around critical airspace areas, such as a Restricted Area or a Class B airspace segment. Numerous pilots have ventured into airspace they were trying to avoid by using an outdated database. If there is not a current database in the receiver, disregard the moving map display when making critical navigation decisions.

In addition, waypoints are added, removed, relocated, or renamed as required to meet operational needs. When using GPS to navigate relative to a named fix, a current database must be used to properly locate a named waypoint. Without the update, it is the pilot's responsibility to verify the waypoint location referencing to an official current source, such as the A/FD, sectional chart, or en route chart.

In many VFR installations of GPS receivers, antenna location is more a matter of convenience than performance. In IFR installations, care is exercised to ensure that an adequate clear view is provided for the antenna to see satellites. If an alternate location is used, some portion of the aircraft may block the view of the antenna, causing a greater opportunity to lose navigation signal.

This is especially true in the case of hand-helds. The use of hand-held receivers for VFR operations is a growing trend, especially among rental pilots. Typically, suction cups are used to place the GPS antennas on the inside of aircraft windows. While this method has great utility, the antenna location is limited by aircraft structure for optimal reception of available satellites. Consequently, signal losses may occur

in certain situations of aircraft-satellite geometry, causing a loss of navigation signal. These losses, coupled with a lack of RAIM capability, could present erroneous position and navigation information with no warning to the pilot.

While the use of a hand-held GPS for VFR operations is not limited by regulation, modification of the aircraft, such as installing a panel- or yoke-mounted holder, is governed by 14 CFR part 43. Pilots should consult with a mechanic to ensure compliance with the regulation and a safe installation.

Tips for Using GPS for VFR Operations

Always check to see if the unit has RAIM capability. If no RAIM capability exists, be suspicious of a GPS displayed position when any disagreement exists with the position derived from other radio navigation systems, pilotage, or dead reckoning.

Check the currency of the database, if any. If expired, update the database using the current revision. If an update of an expired database is not possible, disregard any moving map display of airspace for critical navigation decisions. Be aware that named waypoints may no longer exist or may have been relocated since the database expired. At a minimum, the waypoints planned to be used should be checked against a current official source, such as the A/FD, or a Sectional Aeronautical Chart.

While a hand-held GPS receiver can provide excellent navigation capability to VFR pilots, be prepared for intermittent loss of navigation signal, possibly with no RAIM warning to the pilot. If mounting the receiver in the aircraft, be sure to comply with 14 CFR part 43.

Plan flights carefully before taking off. If navigating to user-defined waypoints, enter them before flight, not on the fly. Verify the planned flight against a current source, such as a current sectional chart. There have been cases in which one pilot used waypoints created by another pilot that were not where the pilot flying was expecting. This generally resulted in a navigation error. Minimize head-down time in the aircraft and keep a sharp lookout for traffic, terrain, and obstacles. Just a few minutes of preparation and planning on the ground makes a great difference in the air.

Another way to minimize head-down time is to become very familiar with the receiver's operation. Most receivers are not intuitive. The pilot must take the time to learn the various keystrokes, knob functions, and displays that are used in the operation of the receiver. Some manufacturers provide computer-based tutorials or simulations of their receivers. Take the time to learn about the particular unit before using it in flight.

In summary, be careful not to rely on GPS to solve all VFR navigational problems. Unless an IFR receiver is installed in accordance with IFR requirements, no standard of accuracy or integrity has been assured. While the practicality of GPS is compelling, the fact remains that only the pilot can navigate the aircraft, and GPS is just one of the pilot's tools to do the job.

VFR Waypoints

VFR waypoints provide VFR pilots with a supplementary tool to assist with position awareness while navigating visually in aircraft equipped with area navigation receivers. VFR waypoints should be used as a tool to supplement current navigation procedures. The uses of VFR waypoints include providing navigational aids for pilots unfamiliar with an area, waypoint definition of existing reporting points, enhanced navigation in and around Class B and Class C airspace, and enhanced navigation around Special Use Airspace. VFR pilots should rely on appropriate and current aeronautical charts published specifically for visual navigation. If operating in a terminal area, pilots should take advantage of the Terminal Area Chart available for that area, if published. The use of VFR waypoints does not relieve the pilot of any responsibility to comply with the operational requirements of 14 CFR part 91.

VFR waypoint names (for computer entry and flight plans) consist of five letters beginning with the letters "VP" and are retrievable from navigation databases. The VFR waypoint names are not intended to be pronounceable, and they are not for use in ATC communications. On VFR charts, a stand-alone VFR waypoint is portrayed using the same four-point star symbol used for IFR waypoints. VFR waypoint collocated with a visual checkpoint on the chart is identified by a small magenta flag symbol. A VFR waypoint collocated with a visual checkpoint is pronounceable based on the name of the visual checkpoint and may be used for ATC communications. Each VFR waypoint name appears in parentheses adjacent to the geographic location on the chart. Latitude/longitude data for all established VFR waypoints may be found in the appropriate regional A/FD.

When filing VFR flight plans, use the five-letter identifier as a waypoint in the route of flight section if there is an intended course change at that point or if used to describe the planned route of flight. This VFR filing would be similar to VOR use in a route of flight. Pilots must use the VFR waypoints only when operating under VFR conditions.

Any VFR waypoints intended for use during a flight should be loaded into the receiver while on the ground and prior to departure. Once airborne, pilots should avoid programming routes or VFR waypoint chains into their receivers.

Pilots should be especially vigilant for other traffic while operating near VFR waypoints. The same effort to see and avoid other aircraft near VFR waypoints is necessary, as is the case when operating near VORs and NDBs. In fact, the increased accuracy of navigation through the use of GPS demands even greater vigilance, as off-course deviations among different pilots and receivers is less. When operating near a VFR waypoint, use whatever ATC services are available, even if outside a class of airspace where communications are required. Regardless of the class of airspace, monitor the available ATC frequency closely for information on other aircraft operating in the vicinity. It is also a good idea to turn on landing light(s) when operating near a VFR waypoint to make the aircraft more conspicuous to other pilots, especially when visibility is reduced.

Lost Procedures

Getting lost in an aircraft is a potentially dangerous situation especially when low on fuel. If a pilot becomes lost, there are some good common sense procedures to follow. If a town or city cannot be seen, the first thing to do is climb, being mindful of traffic and weather conditions. An increase in altitude increases radio and navigation reception range, and also increases radar coverage. If flying near a town or city, it might be possible to read the name of the town on a water tower.

If the aircraft has a navigational radio, such as a VOR or ADF receiver, it can be possible to determine position by plotting an azimuth from two or more navigational facilities. If GPS is installed, or a pilot has a portable aviation GPS on board, it can be used to determine the position and the location of the nearest airport.

Communicate with any available facility using frequencies shown on the sectional chart. If contact is made with a controller, radar vectors may be offered. Other facilities may offer direction finding (DF) assistance. To use this procedure, the controller requests the pilot to hold down the transmit button for a few seconds and then release it. The controller may ask the pilot to change directions a few times and repeat the transmit procedure. This gives the controller enough information to plot the aircraft position and then give vectors to a suitable landing site. If the situation becomes threatening, transmit the situation on the emergency frequency 121.5 MHz and set the transponder to 7700. Most facilities, and even airliners, monitor the emergency frequency.

Flight Diversion

There probably comes a time when a pilot is not able to make it to the planned destination. This can be the result of unpredicted weather conditions, a system malfunction, or

poor preflight planning. In any case, the pilot needs to be able to safely and efficiently divert to an alternate destination. Before any cross-country flight, check the charts for airports or suitable landing areas along or near the route of flight. Also, check for navigational aids that can be used during a diversion.

Computing course, time, speed, and distance information in flight requires the same computations used during preflight planning. However, because of the limited flight deck space, and because attention must be divided between flying the aircraft, making calculations, and scanning for other aircraft, take advantage of all possible shortcuts and rule-of-thumb computations.

When in flight, it is rarely practical to actually plot a course on a sectional chart and mark checkpoints and distances. Furthermore, because an alternate airport is usually not very far from your original course, actual plotting is seldom necessary.

A course to an alternate can be measured accurately with a protractor or plotter, but can also be measured with reasonable accuracy using a straightedge and the compass rose depicted around VOR stations. This approximation can be made on the basis of a radial from a nearby VOR or an airway that closely parallels the course to your alternate. However, remember that the magnetic heading associated with a VOR radial or printed airway is outbound from the station. To find the course TO the station, it may be necessary to determine the reciprocal of that heading. It is typically easier to navigate to an alternate airport that has a VOR or NDB facility on the field.

After selecting the most appropriate alternate, approximate the magnetic course to the alternate using a compass rose or airway on the sectional chart. If time permits, try to start the diversion over a prominent ground feature. However, in an emergency, divert promptly toward your alternate. Attempting to complete all plotting, measuring, and computations involved before diverting to the alternate may only aggravate an actual emergency.

Once established on course, note the time, and then use the winds aloft nearest to your diversion point to calculate a heading and GS. Once a GS has been calculated, determine a new arrival time and fuel consumption. Give priority to flying the aircraft while dividing attention between navigation and planning. When determining an altitude to use while diverting, consider cloud heights, winds, terrain, and radio reception.

Chapter Summary

This chapter has discussed the fundamentals of VFR navigation. Beginning with an introduction to the charts that can be used for navigation to the more technically advanced concept of GPS, there is one aspect of navigation that remains the same. The pilot is responsible for proper planning and the execution of that planning to ensure a safe flight.