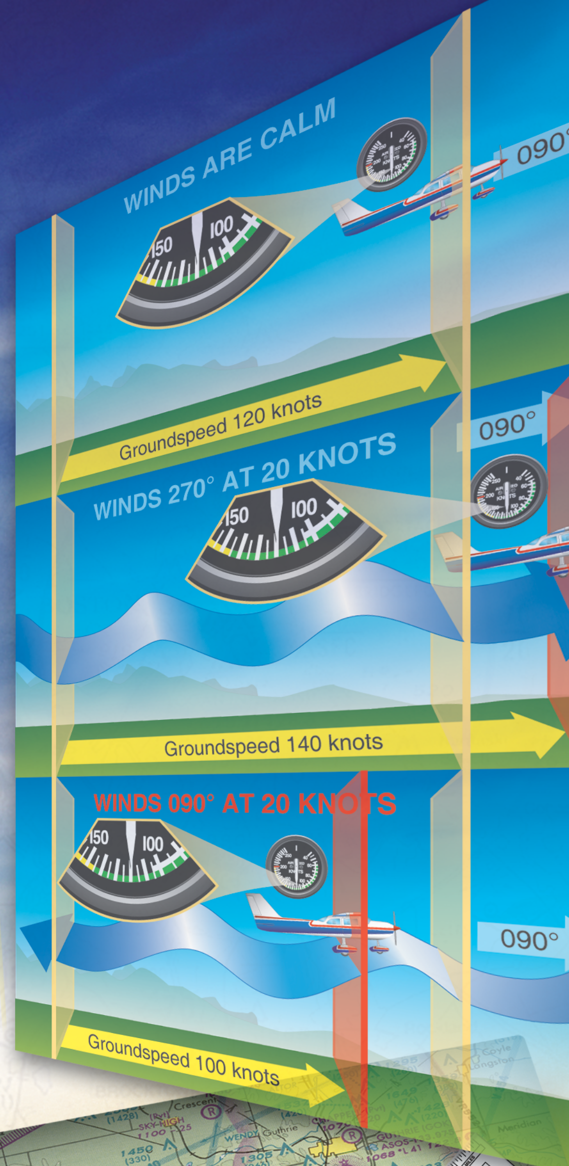
Chapter 16

Navigation

Introduction

This chapter provides an introduction to cross-country flying under visual flight rules (VFR). It contains practical information for planning and executing cross-country flights for the beginning pilot.

Air navigation is the process of piloting an aircraft from one geographic position to another while monitoring one's position as the flight progresses. It introduces the need for planning, which includes plotting the course on an aeronautical chart, selecting checkpoints, measuring distances, obtaining pertinent weather information, and computing flight time, headings, and fuel requirements. The methods used in this chapter include pilotage—navigating by reference to visible landmarks, dead reckoning—computations of direction and distance from a known position, and radio navigation—by use of radio aids.



Aeronautical Charts

An aeronautical chart is the road map for a pilot flying under VFR. The chart provides information that allows pilots to track their position and provides available information that enhances safety. The three aeronautical charts used by VFR pilots are:

- Sectional
- VFR Terminal Area
- World Aeronautical

Sectional Charts

Sectional charts are the most common charts used by pilots today. The charts have a scale of 1:500,000 (1 inch = 6.86 nautical miles (NM) or approximately 8 statute miles (SM)), which allows for more detailed information to be included on the chart.

The charts provide an abundance of information, including airport data, navigational aids, airspace, and topography. *Figure 16-1* is an excerpt from the legend of a sectional chart. By referring to the chart legend, a pilot can interpret most of the information on the chart. A pilot should also check the chart for other legend information, which includes air traffic control (ATC) frequencies and information on airspace. These charts are revised semiannually except for some areas outside the conterminous United States where they are revised annually.

VFR Terminal Area Charts

VFR terminal area charts are helpful when flying in or near Class B airspace. They have a scale of 1:250,000 (1 inch = 3.43 NM or approximately 4 SM). These charts provide a more detailed display of topographical information and are revised semiannually, except for several Alaskan and Caribbean charts. *[Figure 16-2]*

World Aeronautical Charts

World aeronautical charts are designed to provide a standard series of aeronautical charts, covering land areas of the world, at a size and scale convenient for navigation by moderate speed aircraft. They are produced at a scale of 1:1,000,000 (1 inch = 13.7 NM or approximately 16 SM). These charts are similar to sectional charts, and the symbols are the same except there is less detail due to the smaller scale. *[Figure 16-3]* These charts are revised annually except several Alaskan charts and the Mexican/Caribbean charts, which are revised every 2 years.

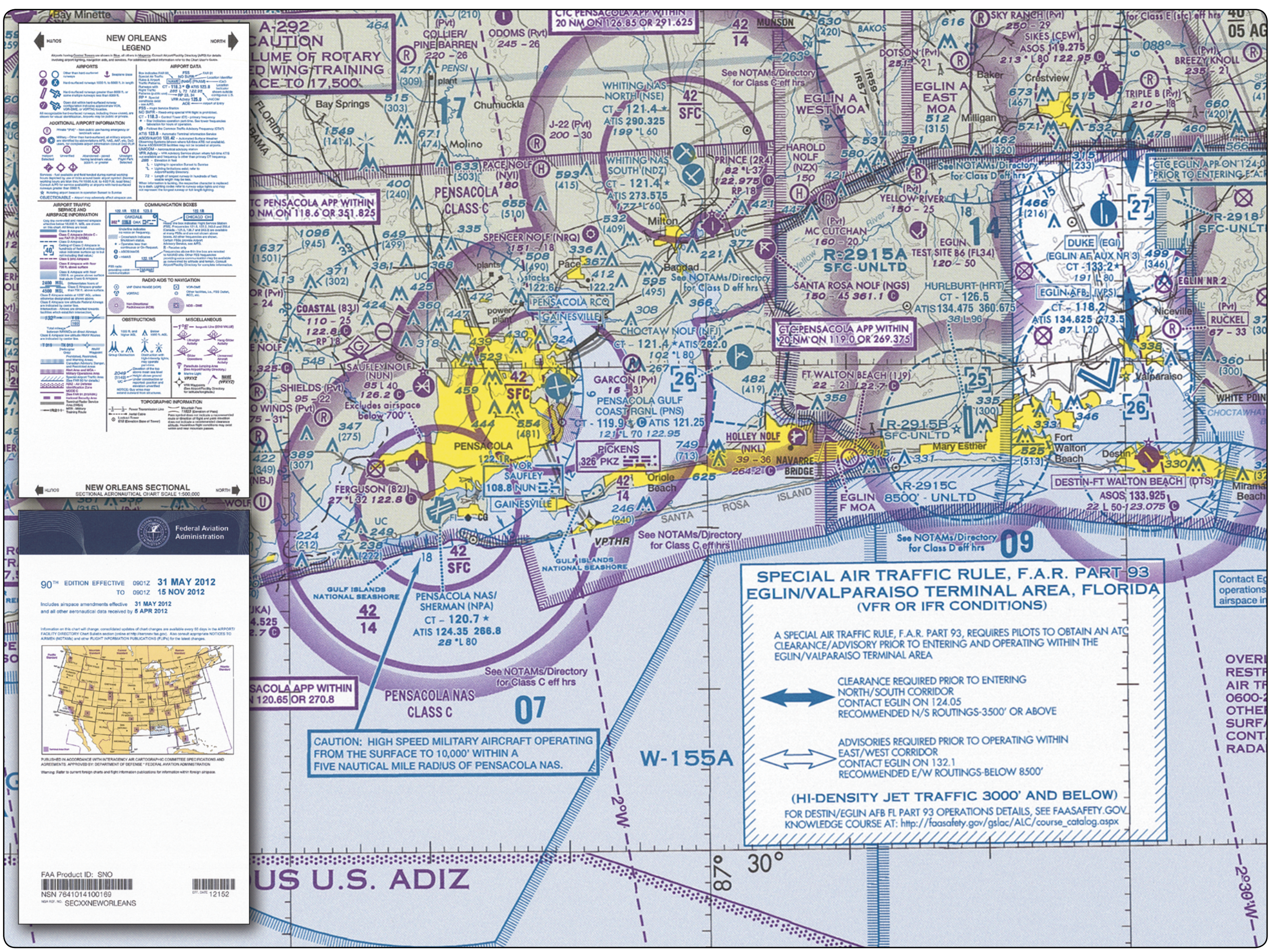


Figure 16-1. *Sectional chart and legend.*

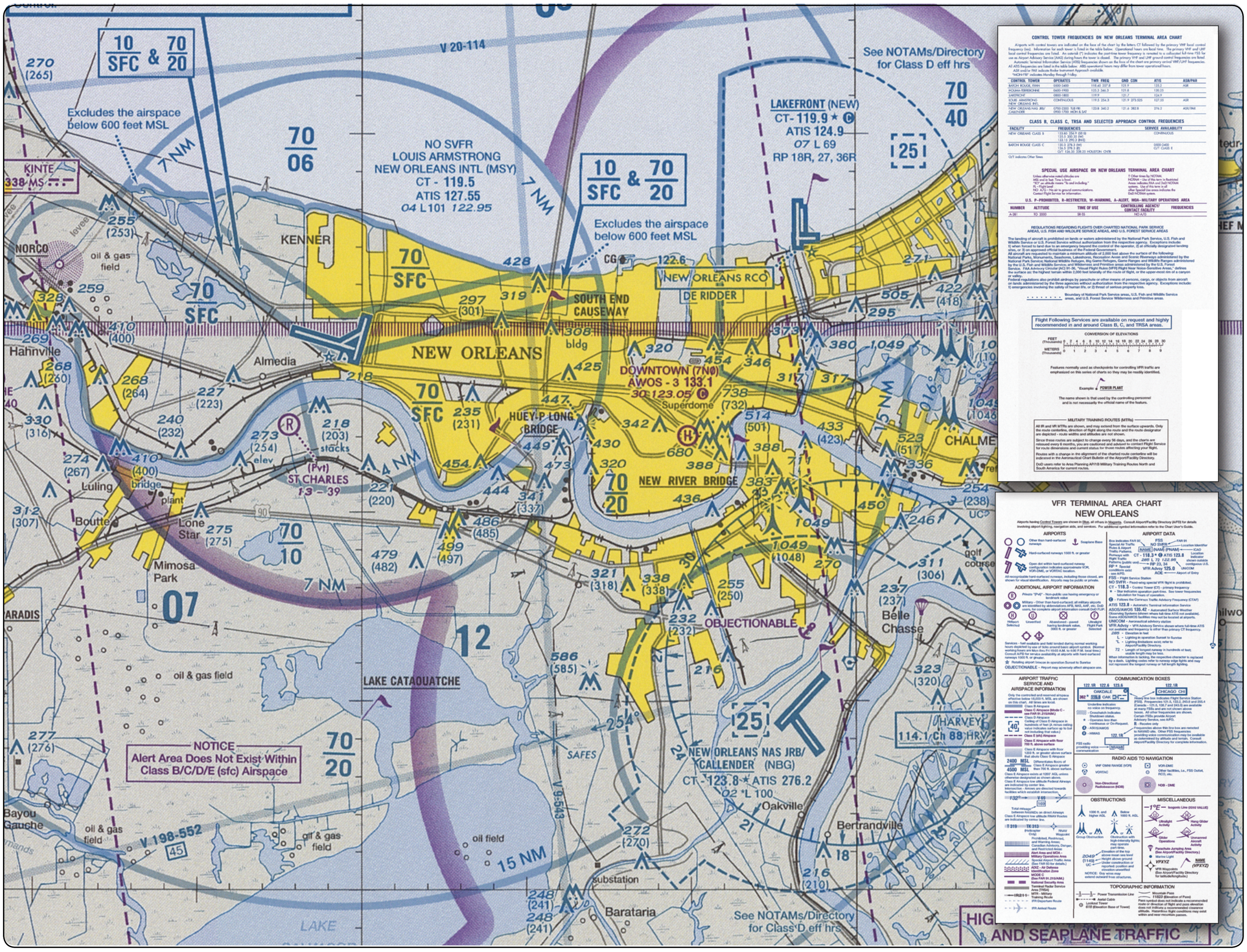


Figure 16-2. *VFR Terminal Area Chart and legend.*

Latitude and Longitude (Meridians and Parallels)

The equator is an imaginary circle equidistant from the poles of the Earth. Circles parallel to the equator (lines running east and west) are parallels of latitude. They are used to measure degrees of latitude north (N) or south (S) of the equator. The angular distance from the equator to the pole is one-fourth of a circle or 90°. The 48 conterminous states of the United States are located between 25° and 49° N latitude. The arrows in *Figure 16-4* labeled "Latitude" point to lines of latitude. Meridians of longitude are drawn from the North Pole to the South Pole and are at right angles to the Equator. The "Prime Meridian," which passes through Greenwich, England, is used as the zero line from which measurements are made in degrees east (E) and west (W) to 180°. The 48 conterminous states of the United States are between 67° and 125° W longitude. The arrows in *Figure 16-4* labeled "Longitude" point to lines of longitude.

Any specific geographical point can be located by reference to its longitude and latitude. Washington, D.C., for example, is approximately 39° N latitude, 77° W longitude. Chicago is approximately 42° N latitude, 88° W longitude.

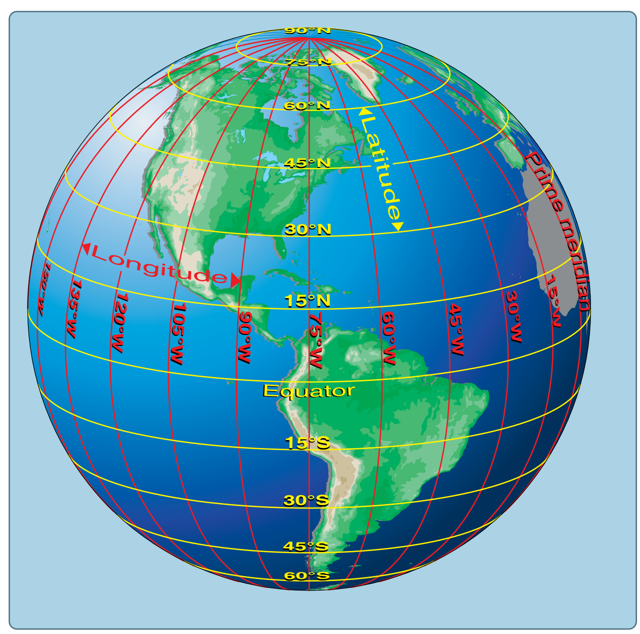


Figure 16-4. *Meridians and parallels—the basis of measuring time, distance, and direction.*

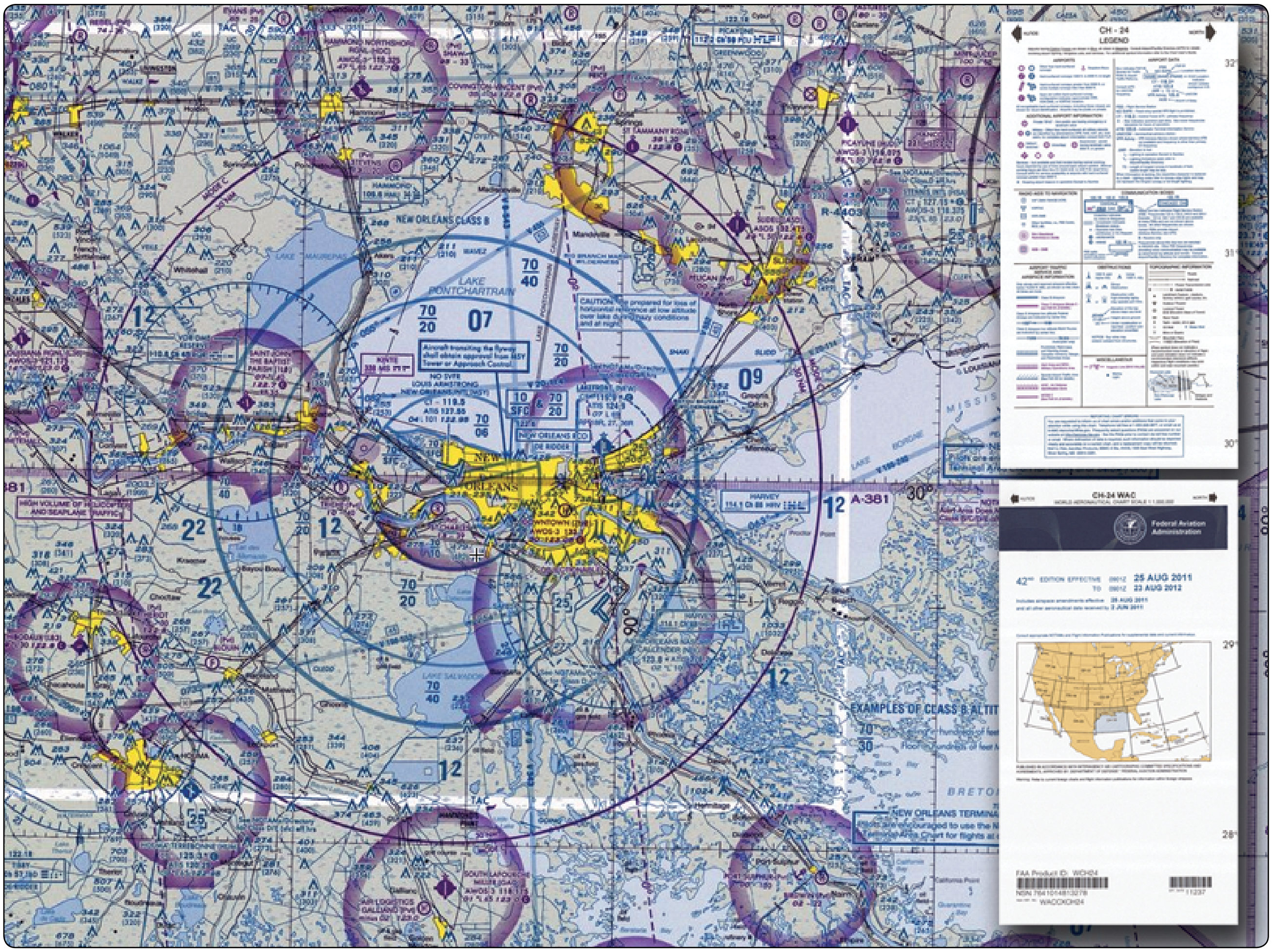


Figure 16-3. *World aeronautical chart.*

Time Zones

The meridians are also useful for designating time zones. A day is defined as the time required for the Earth to make one complete rotation of 360°. Since the day is divided into 24 hours, the Earth revolves at the rate of 15° an hour. Noon is the time when the sun is directly above a meridian; to the west of that meridian is morning, to the east is afternoon.

The standard practice is to establish a time zone for each 15° of longitude. This makes a difference of exactly 1 hour between each zone. In the conterminous United States, there are four time zones. The time zones are Eastern (75°), Central (90°), Mountain (105°), and Pacific (120°). The dividing lines are somewhat irregular because communities near the boundaries often find it more convenient to use time designations of neighboring communities or trade centers.

These time zone differences must be taken into account during long flights eastward—especially if the flight must be completed before dark. Remember, an hour is lost when flying eastward from one time zone to another, or perhaps even when flying from the western edge to the eastern edge of the same time zone. Determine the time of sunset at the destination by consulting the flight service station (FSS) and take this into account when planning an eastbound flight.

In most aviation operations, time is expressed in terms of the 24-hour clock. ATC instructions, weather reports and broadcasts, and estimated times of arrival are all based on this system. For example: 9 a.m. is expressed as 0900, 1 p.m. is 1300, and 10 p.m. is 2200.

Because a pilot may cross several time zones during a flight, a standard time system has been adopted. It is called Universal Coordinated Time (UTC) and is often referred to as Zulu time. UTC is the time at the 0° line of longitude which passes through Greenwich, England. All of the time zones around the world are based on this reference. To convert to this time, a pilot should do the following:

Eastern Standard Time..........Add 5 hours

Central Standard Time..........Add 6 hours

Mountain Standard Time.......Add 7 hours

Pacific Standard Time...........Add 8 hours

For Daylight Saving Time, 1 hour should be subtracted from the calculated times.

Measurement of Direction

By using the meridians, direction from one point to another can be measured in degrees, in a clockwise direction from true north. To indicate a course to be followed in flight, draw a line on the chart from the point of departure to the destination and measure the angle that this line forms with a meridian. Direction is expressed in degrees, as shown by the compass rose in *Figure 16-6.*

Because meridians converge toward the poles, course measurement should be taken at a meridian near the midpoint of the course rather than at the point of departure. The course measured on the chart is known as the true course (TC). This is the direction measured by reference to a meridian or true north (TN). It is the direction of intended flight as measured in degrees clockwise from TN.

As shown in *Figure 16-7,* the direction from A to B would be a TC of 065°, whereas the return trip (called the reciprocal) would be a TC of 245°.

The true heading (TH) is the direction in which the nose of the aircraft points during a flight when measured in degrees clockwise from TN. Usually, it is necessary to head the aircraft in a direction slightly different from the TC to offset the effect of wind. Consequently, numerical value of the TH may not correspond with that of the TC. This is discussed more fully in subsequent sections in this chapter. For the purpose of this discussion, assume a no-wind condition exists under which heading and course would coincide. Thus, for a TC of 065°, the TH would be 065°. To use the compass accurately, however, corrections must be made for magnetic variation and compass deviation.

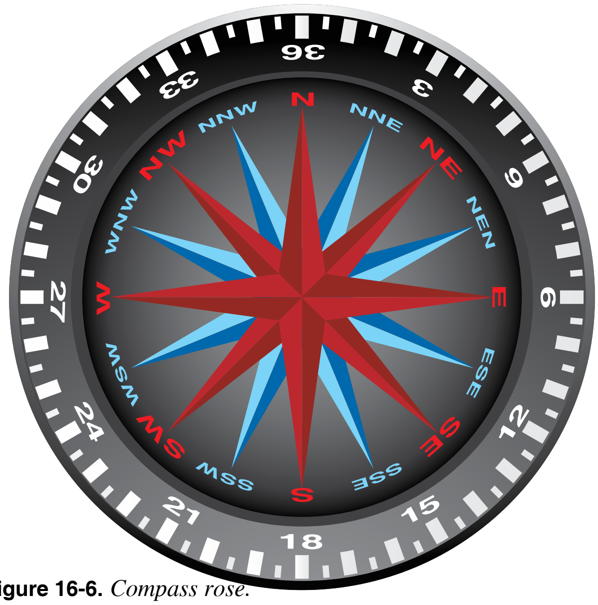


Figure 16-6. *Compass rose.*

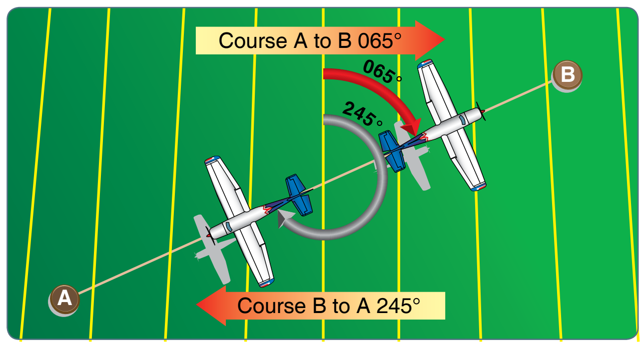


Figure 16-7. *Courses are determined by reference to meridians on aeronautical charts.*

Variation

Variation is the angle between TN and magnetic north (MN). It is expressed as east variation or west variation depending upon whether MN is to the east or west of TN.

The north magnetic pole is located close to 71° N latitude, 96° W longitude and is about 1,300 miles from the geographic or true north pole, as indicated in

were uniformly magnetized, the compass needle would point toward the magnetic pole, in which case the variation between TN (as shown by the geographical meridians) and MN (as shown by the magnetic meridians) could be measured at any intersection of the meridians.

Actually, the Earth is not uniformly magnetized. In the United States, the needle usually points in the general direction of the magnetic pole, but it may vary in certain geographical localities by many degrees. Consequently, the exact amount of variation at thousands of selected locations in the United States has been carefully determined. The amount and the direction of variation, which change slightly from time to time, are shown on most aeronautical charts as broken magenta lines called isogonic lines that connect points of equal magnetic variation. (The line connecting points at which there is no variation between TN and MN is the agonic line.) An isogonic chart is shown in

bends and turns in the isogonic and agonic lines are caused by unusual geological conditions affecting magnetic forces in these areas.

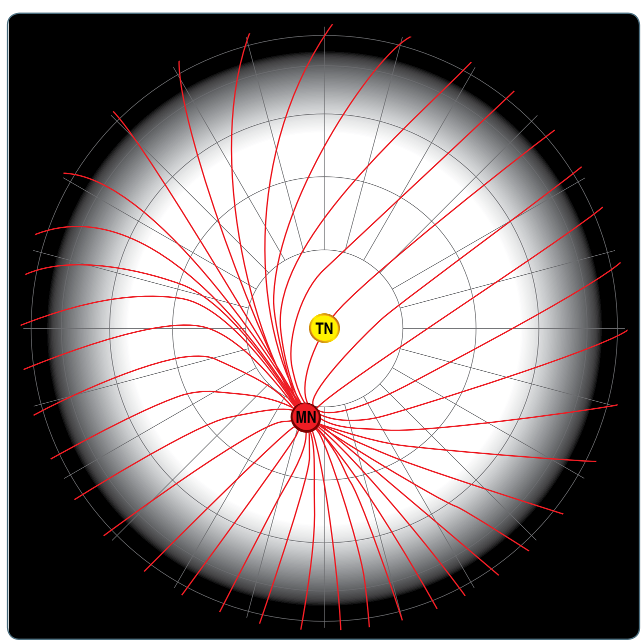


Figure 16-8. *Magnetic meridians are in red while the lines of longitude and latitude are in blue. From these lines of variation (magnetic meridians), one can determine the effect of local magnetic variations on a magnetic compass.*

Magnetic Variation

As mentioned in the paragraph discussing variation, the appropriate variation for the geographical location of the flight must be considered and added or subtracted as appropriate. If flying across an area where the variation changes, then the values must be applied along the route of flight appropriately. Once applied, this new course is called the magnetic course.

Magnetic Deviation

Because each aircraft has its own internal effect upon the onboard compass systems from its own localized magnetic influencers, the pilot must add or subtract these influencers based upon the direction he or she is flying. The application of deviation (taken from a compass deviation card) compensates the magnetic course unique to that aircraft's compass system (as affected by localized magnetic influencers) and it now becomes the compass course. Therefore, the compass course, when followed (in a no wind condition), takes the aircraft from point A to point B even though the aircraft heading may not match the original course line drawn on the chart.

If the variation is shown as "9° E," this means that MN is 9° east of TN. If a TC of 360° is to be flown, 9° must be subtracted from 360°, which results in a magnetic heading of 351°. To fly east, a magnetic course of 081° (090° – 9°) would be flown. To fly south, the magnetic course would be 171° (180° – 9°). To fly west, it would be 261° (270° – 9°). To fly a TH of 060°, a magnetic course of 051° (060° – 9°) would be flown.

Remember, if variation is west, add; if east, subtract. One method for remembering whether to add or subtract variation is the phrase "east is least (subtract) and west is best (add)."

Deviation

Determining the magnetic heading is an intermediate step necessary to obtain the correct compass heading for the flight. To determine compass heading, a correction for deviation must be made. Because of magnetic influences within an aircraft, such as electrical circuits, radio, lights, tools, engine, and magnetized metal parts, the compass needle is frequently deflected from its normal reading. This deflection is called deviation. The deviation is different for each aircraft, and it also may vary for different headings in the same aircraft. For instance, if magnetism in the engine attracts the north end of the compass, there would be no effect when the plane is on a heading of MN. On easterly or westerly headings, however, the compass indications would be in error, as shown in *Figure 16-11*. Magnetic attraction can come from many other parts of the aircraft; the assumption of attraction in the engine is merely used for the purpose of illustration.

For (Magnetic)	N	30	60	E	120	150
Steer (Compass)	0	28	57	86	117	148
For (Magnetic	S	210	240	W	300	330
Steer (Compass)	180	212	243	274	303	332

Figure 16-12. *Compass deviation card.*

Some adjustment of the compass, referred to as compensation, can be made to reduce this error, but the remaining correction must be applied by the pilot.

Proper compensation of the compass is best performed by a competent technician. Since the magnetic forces within the aircraft change because of landing shocks, vibration, mechanical work, or changes in equipment, the pilot should occasionally have the deviation of the compass checked. The procedure used to check the deviation is called "swinging the compass" and is briefly outlined as follows.

The aircraft is placed on a magnetic compass rose, the engine started, and electrical devices normally used (such as radio) are turned on. Tailwheel-type aircraft should be jacked up into flying position. The aircraft is aligned with MN indicated on the compass rose and the reading shown on the compass is recorded on a deviation card. The aircraft is then aligned at 30° intervals and each reading is recorded. If the aircraft is to be flown at night, the lights are turned on and any significant changes in the readings are noted. If so, additional entries are made for use at night. The accuracy of the compass can also be checked by comparing the compass reading with the known runway headings.

A deviation card, similar to *Figure 16-12,* is mounted near the compass showing the addition or subtraction required to correct for deviation on various headings, usually at intervals of 30°. For intermediate readings, the pilot should be able to interpolate mentally with sufficient accuracy. For example, if the pilot needed the correction for 195° and noted the correction for 180° to be 0° and for 210° to be +2°, it could be assumed that the correction for 195° would be +1°. The magnetic heading, when corrected for deviation, is known as compass heading.

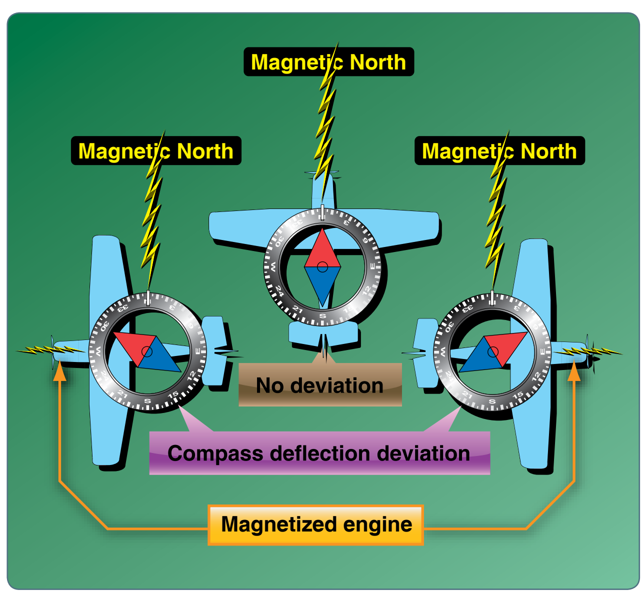


Figure 16-11. *Magnetized portions of the airplane cause the compass to deviate from its normal indications.*

Effect of Wind

The preceding discussion explained how to measure a TC on the aeronautical chart and how to make corrections for variation and deviation, but one important factor has not been considered—wind. As discussed in the study of the atmosphere, wind is a mass of air moving over the surface of the Earth in a definite direction. When the wind is blowing from the north at 25 knots, it simply means that air is moving southward over the Earth's surface at the rate of 25 NM in 1 hour.

Under these conditions, any inert object free from contact with the Earth is carried 25 NM southward in 1 hour. This effect becomes apparent when such things as clouds, dust, and toy balloons are observed being blown along by the wind. Obviously, an aircraft flying within the moving mass of air is similarly affected. Even though the aircraft does not float freely with the wind, it moves through the air at the same time the air is moving over the ground, and thus is affected by wind. Consequently, at the end of 1 hour of flight, the aircraft is in a position that results from a combination of the following two motions:

- Movement of the air mass in reference to the ground
- Forward movement of the aircraft through the air mass

Actually, these two motions are independent. It makes no difference whether the mass of air through which the aircraft is flying is moving or is stationary. A pilot flying in a 70-knot gale would be totally unaware of any wind (except for possible turbulence) unless the ground were observed. In reference to the ground, however, the aircraft would appear to fly faster with a tailwind or slower with a headwind, or to drift right or left with a crosswind.

As shown in *Figure 16-13,* an aircraft flying eastward at an airspeed of 120 knots in still air has a groundspeed (GS) exactly the same—120 knots. If the mass of air is moving eastward at 20 knots, the airspeed of the aircraft is not affected, but the progress of the aircraft over the ground is 120 plus 20 or a GS of 140 knots. On the other hand, if the mass of air is moving westward at 20 knots, the airspeed of the aircraft remains the same, but GS becomes 120 minus 20 or 100 knots.

Assuming no correction is made for wind effect, if an aircraft is heading eastward at 120 knots and the air mass moving southward at 20 knots, the aircraft at the end of 1 hour is almost 120 miles east of its point of departure because of its progress through the air. It is 20 miles south because of the motion of the air. Under these circumstances, the airspeed remains 120 knots, but the GS is determined by combining the movement of the aircraft with that of the air mass. GS can be measured as the distance from the point of departure to the position of the aircraft at the end of 1 hour. The GS can be computed by the time required to fly between two points a known distance apart. It also can be determined before flight by constructing a wind triangle, which is explained later in this chapter. *[Figure 16-14]*

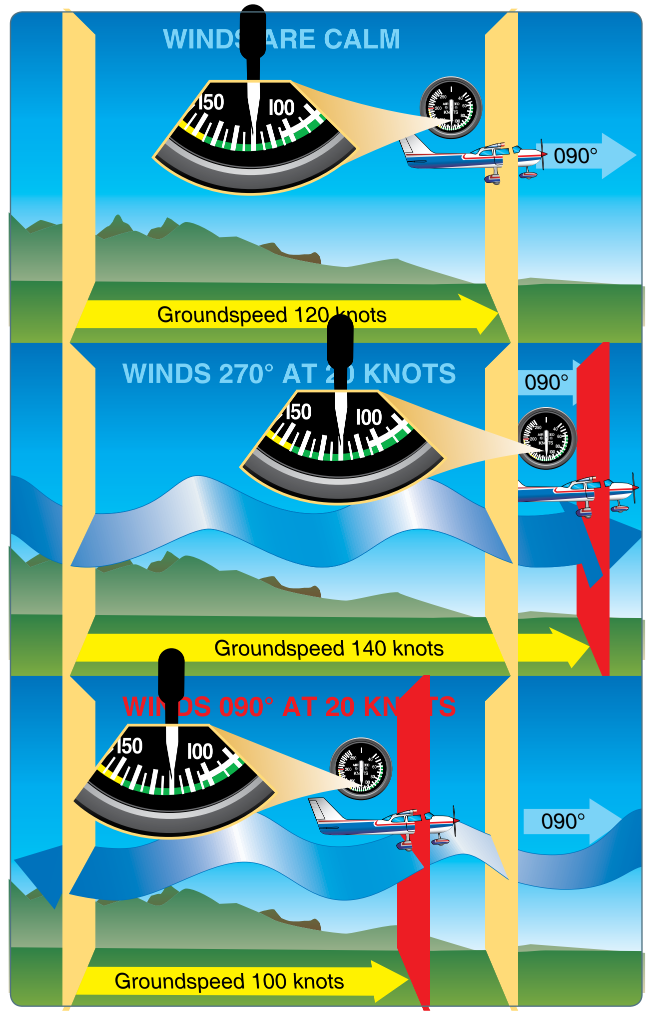


Figure 16-13. *Motion of the air affects the speed with which aircraft move over the Earth's surface. Airspeed, the rate at which an aircraft moves through the air, is not affected by air motion.*

The direction in which the aircraft is pointing as it flies is called heading. Its actual path over the ground, which is a combination of the motion of the aircraft and the motion of the air, is called track. The angle between the heading and the track is called drift angle. If the aircraft heading coincides with the TC and the wind is blowing from the left, the track does not coincide with the TC. The wind causes the aircraft to drift to the right, so the track falls to the right of the desired course or TC. *[Figure 16-15]*

The following method is used by many pilots to determine compass heading: after the TC is measured, and wind correction applied resulting in a TH, the sequence TH ± variation (V) = magnetic heading (MH) ± deviation (D) = compass heading (CH) is followed to arrive at compass heading. *[Figure 16-16]*

By determining the amount of drift, the pilot can counteract the effect of the wind and make the track of the aircraft coincide with the desired course. If the mass of air is moving across the course from the left, the aircraft drifts to the right, and a correction must be made by heading the aircraft sufficiently to the left to offset this drift. In other words, if the wind is from the left, the correction is made by pointing the aircraft to the left a certain number of degrees, therefore correcting for wind drift. This is the wind correction angle (WCA) and is expressed in terms of degrees right or left of the TC. *[Figure 16-17]*

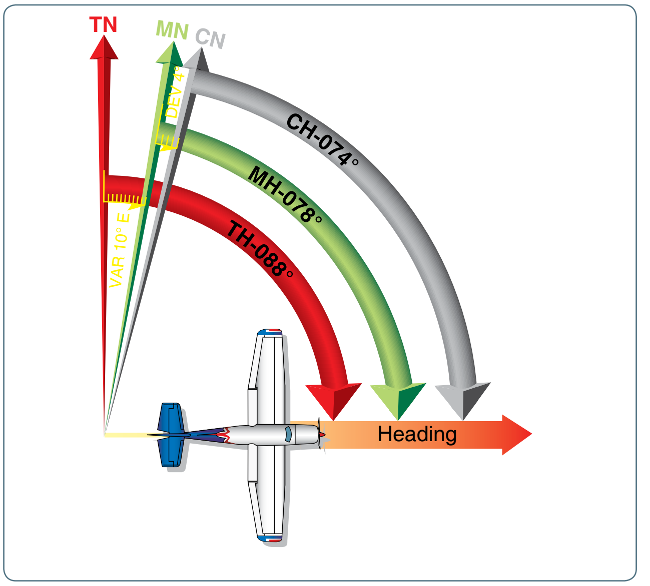


Figure 16-16. *Relationship between true, magnetic, and compass headings for a particular instance.*

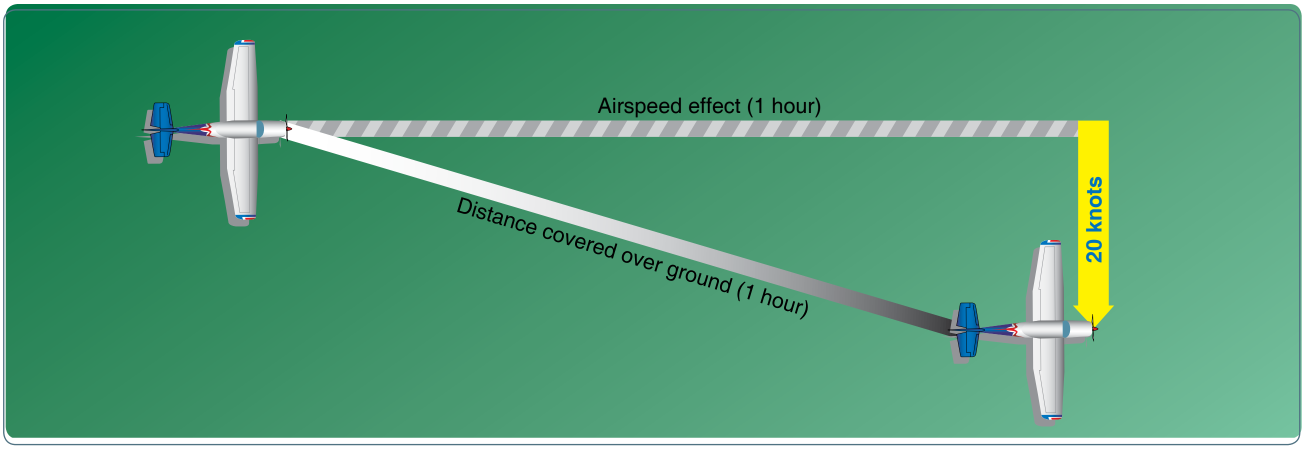


Figure 16-14. *Aircraft flight path resulting from its airspeed and direction and the wind speed and direction.*

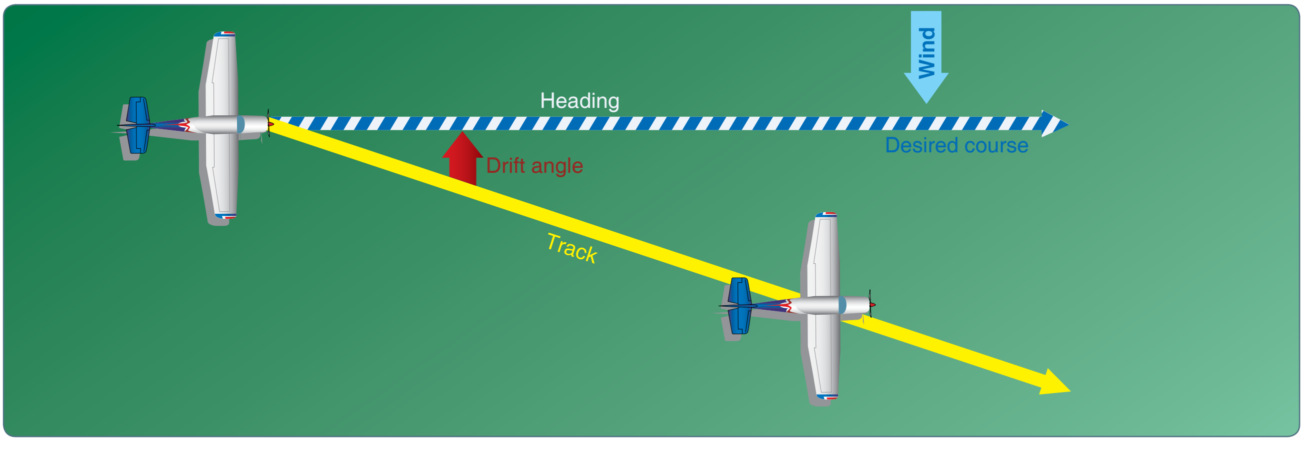


Figure 16-15. *Effects of wind drift on maintaining desired course.*

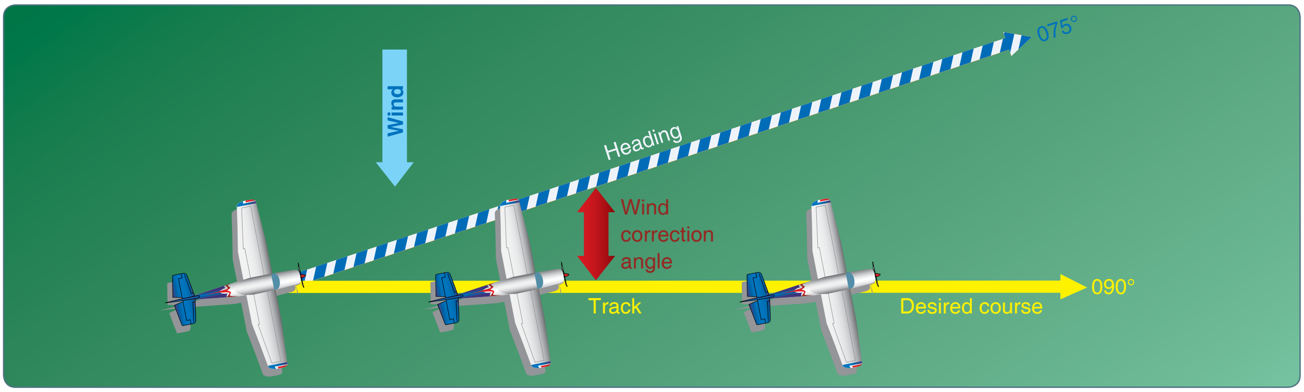


Figure 16-17. *Establishing a wind correction angle that counteracts wind drift and maintains the desired course.*

To summarize:

- Course—intended path of an aircraft over the ground or the direction of a line drawn on a chart representing the intended aircraft path, expressed as the angle measured from a specific reference datum clockwise from 0° through 360° to the line.
- Heading—direction in which the nose of the aircraft points during flight.
- Track—actual path made over the ground in flight. (If proper correction has been made for the wind, track and course are identical.)
- Drift angle—angle between heading and track.
- WCA—correction applied to the course to establish a heading so that track coincides with course.
- Airspeed—rate of the aircraft's progress through the air.
- GS—rate of the aircraft's inflight progress over the ground.

Basic Calculations

Before a cross-country flight, a pilot should make common calculations for time, speed, and distance, and the amount of fuel required.

Converting Minutes to Equivalent Hours

Frequently, it is necessary to convert minutes into equivalent hours when solving speed, time, and distance problems. To convert minutes to hours, divide by 60 (60 minutes = 1 hour). Thus, 30 minutes is 30/60 = 0.5 hour. To convert hours to minutes, multiply by 60. Thus, 0.75 hour equals 0.75× 60 = 45 minutes.

Time T = D/GS

To find the time (T) in flight, divide the distance (D) by the GS. The time to fly 210 NM at a GS of 140 knots is 210 ÷ 140 or 1.5 hours. (The 0.5 hour multiplied by 60 minutes equals 30 minutes.) Answer: 1:30.

Distance D = GS X T

To find the distance flown in a given time, multiply GS by time. The distance flown in 1 hour 45 minutes at a GS of 120 knots is 120 × 1.75 or 210 NM.

GS GS = D/T

To find the GS, divide the distance flown by the time required. If an aircraft flies 270 NM in 3 hours, the GS is 270 ÷ 3 = 90 knots.

Converting Knots to Miles Per Hour

Another conversion is that of changing knots to miles per hour (mph). The aviation industry is using knots more frequently than mph, but is important to understand the conversion for those that use mph when working with speed problems. The NWS reports both surface winds and winds aloft in knots. However, airspeed indicators in some aircraft are calibrated in mph (although many are now calibrated in both mph and knots). Pilots, therefore, should learn to convert wind speeds that are reported in knots to mph.

A knot is 1 nautical mile per hour (NMPH). Because there are 6,076.1 feet in 1 NM and 5,280 feet in 1 SM, the conversion factor is 1.15. To convert knots to mph, multiply speed in knots by 1.15. For example: a wind speed of 20 knots is equivalent to 23 mph.

Most flight computers or electronic calculators have a means of making this conversion. Another quick method of conversion is to use the scales of NM and SM at the bottom of aeronautical charts.

Fuel Consumption

To ensure that sufficient fuel is available for your intended flight, you must be able to accurately compute aircraft fuel consumption during preflight planning. Typically, fuel consumption in gasoline-fueled aircraft is measured in gallons per hour. Since turbine engines consume much more fuel than reciprocating engines, turbine-powered aircraft require much more fuel, and thus much larger fuel tanks. When determining these large fuel quantities, using a volume measurement such as gallons presents a problem because the volume of fuel varies greatly in relation to temperature. In contrast, density (weight) is less affected by temperature and therefore, provides a more uniform and repeatable measurement. For this reason, jet fuel is generally quantified by its density and volume.

This standard industry convention yields a pounds-of-fuel-per-hour value which, when divided into the nautical miles (NM) per hour of travel (TAS ± winds) value, results in a specific range value. The typical label for specific range is NM per pound of fuel, or often NM per 1,000 pounds of fuel. Preflight planning should be supported by proper monitoring of past fuel consumption as well as use of specified fuel management and mixture adjustment procedures in flight.

For simple aircraft with reciprocating engines, the Aircraft Flight Manual/Pilot's Operating Handbook (AFM/POH) supplied by the aircraft manufacturer provides gallons-per-hour values to assist with preflight planning.

When planning a flight, you must determine how much fuel is needed to reach your destination by calculating the distance the aircraft can travel (with winds considered) at a known rate of fuel consumption (gal/hr or lbs/hr) for the expected groundspeed (GS) and ensure this amount, plus an adequate reserve, is available on board. GS determines the time the flight will take. The amount of fuel needed for a given flight can be calculated by multiplying the estimated flight time by the rate of consumption. For example, a flight of 400 NM at 100 knots GS takes 4 hours to complete. If an aircraft consumes 5 gallons of fuel per hour, the total fuel consumption is 20 gallons (4 hours times 5 gallons). In this example, there is no wind; therefore, true airspeed (TAS) is also 100 knots, the same as GS. Since the rate of fuel consumption remains relatively constant at a given TAS, you must use GS to calculate fuel consumption when wind is present. Specific range (NM/lb or NM/gal) is also useful in calculating fuel consumption when wind is a factor.

You should always plan to be on the surface before any of the following occur:

- Your flight time exceeds the amount of flight time you calculated for the consumption of your preflight fuel amount
- Your fuel gauge indicates low fuel level

The rate of fuel consumption depends on many factors: condition of the engine, propeller/rotor pitch, propeller/rotor revolutions per minute (rpm), richness of the mixture, and the percentage of horsepower used for flight at cruising speed. The pilot should know the approximate consumption rate from cruise performance charts or from experience. In addition to the amount of fuel required for the flight, there should be sufficient fuel for reserve. When estimating consumption you must plan for cruise flight as well as startup and taxi, and higher fuel burn during climb. Remember that ground speed during climb is less than during cruise flight at the same airspeed. Additional fuel for adequate reserve should also be added as a safety measure.

Flight Computers

Up to this point, only mathematical formulas have been used to determine such items as time, distance, speed, and fuel consumption. In reality, most pilots use a mechanical flight computer called an E6B or electronic flight calculator. These devices can compute numerous problems associated with flight planning and navigation. The mechanical or electronic computer has an instruction book that probably includes sample problems so the pilot can become familiar with its functions and operation. *[Figure 16-18]*

Plotter

Another aid in flight planning is a plotter, which is a protractor and ruler. The pilot can use this when determining TC and measuring distance. Most plotters have a ruler that measures in both NM and SM and has a scale for a sectional chart on one side and a world aeronautical chart on the other. *[Figure 16-18]*

Pilotage

Pilotage is navigation by reference to landmarks or checkpoints. It is a method of navigation that can be used on any course that has adequate checkpoints, but it is more commonly used in conjunction with dead reckoning and VFR radio navigation.

The checkpoints selected should be prominent features common to the area of the flight. Choose checkpoints that can be readily identified by other features, such as roads, rivers, railroad tracks, lakes, and power lines. If possible, select features that make useful boundaries or brackets on each side of the course, such as highways, rivers, railroads, and mountains. A pilot can keep from drifting too far off course by referring to and not crossing the selected brackets. Never place complete reliance on any single checkpoint. Choose ample checkpoints. If one is missed, look for the next one while maintaining the heading. When determining position from checkpoints, remember that the scale of a sectional chart is 1 inch = 8 SM or 6.86 NM. For example, if a checkpoint selected was approximately one-half inch from the course line on the chart, it is 4 SM or 3.43 NM from the course on the ground. In the more congested areas, some of the smaller features are not included on the chart. If confused, hold the heading. If a turn is made away from the heading, it is easy to become lost.

Roads shown on the chart are primarily the well-traveled roads or those most apparent when viewed from the air. New roads and structures are constantly being built and may not be shown on the chart until the next chart is issued. Some structures, such as antennas, may be difficult to see. Sometimes TV antennas are grouped together in an area near a town. They are supported by almost invisible guy wires. Never approach an area of antennas less than 500 feet above the tallest one. Most of the taller structures are marked with strobe lights to make them more visible to pilots. However, some weather conditions or background lighting may make them difficult to see. Aeronautical charts display the best information available at the time of printing, but a pilot should be cautious for new structures or changes that have occurred since the chart was printed.

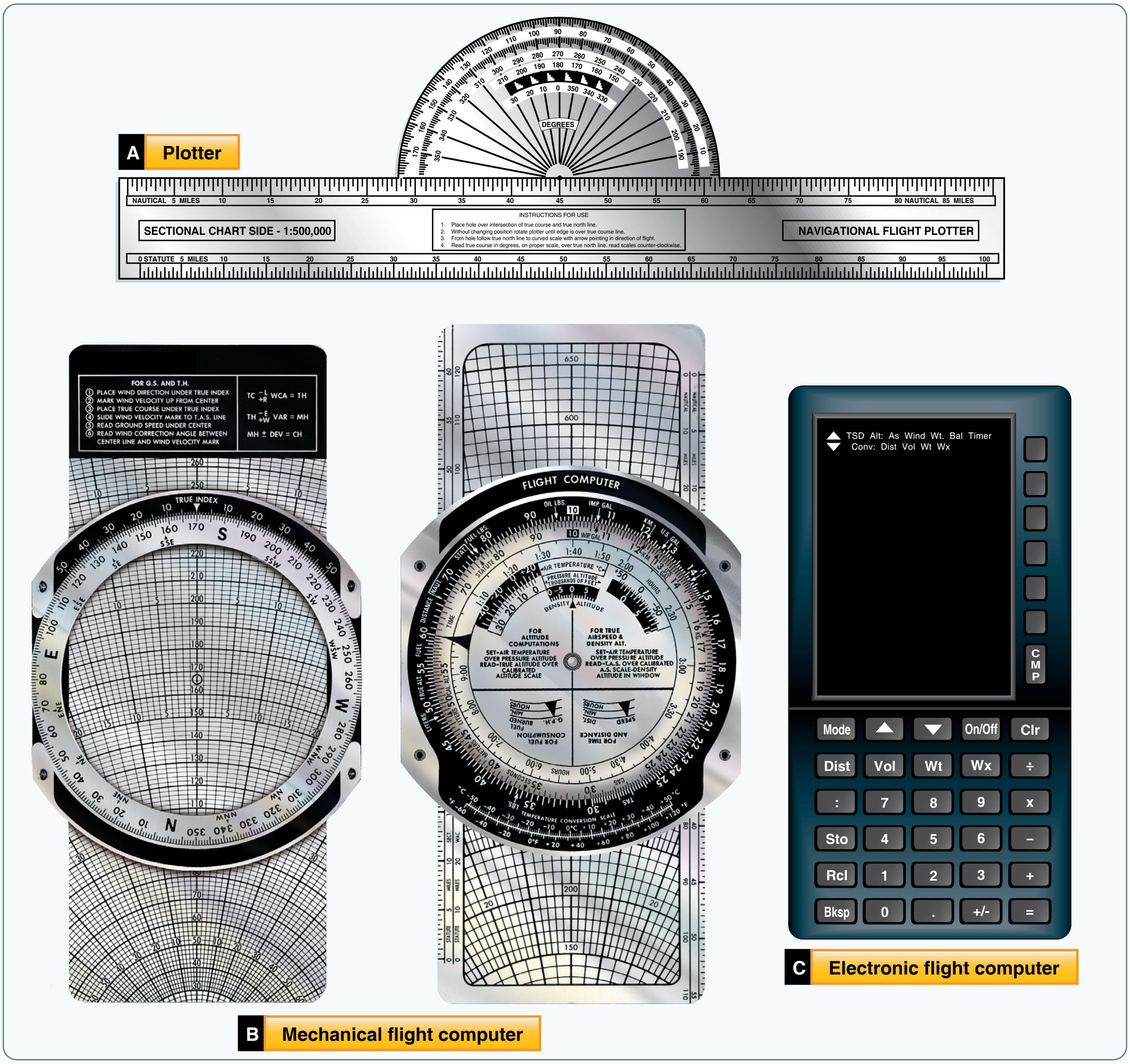


Figure 16-18. *A plotter (A), the computational and wind side of a mechanical flight computer (E6B) (B), and an electronic flight computer (C).*

Dead Reckoning

Dead reckoning is navigation solely by means of computations based on time, airspeed, distance, and direction. The products derived from these variables, when adjusted by wind speed and velocity, are heading and GS. The predicted heading takes the aircraft along the intended path and the GS establishes the time to arrive at each checkpoint and the destination. Except for flights over water, dead reckoning is usually used with pilotage for cross-country flying. The heading and GS, as calculated, is constantly monitored and corrected by pilotage as observed from checkpoints.

Wind Triangle or Vector Analysis

If there is no wind, the aircraft's ground track is the same as the heading and the GS is the same as the true airspeed. This condition rarely exists. A wind triangle, the pilot's version of vector analysis, is the basis of dead reckoning.

The wind triangle is a graphic explanation of the effect of wind upon flight. GS, heading, and time for any flight can be determined by using the wind triangle. It can be applied to the simplest kind of cross-country flight, as well as the most complicated instrument flight. The experienced pilot becomes so familiar with the fundamental principles that estimates can be made that are adequate for visual flight without actually drawing the diagrams. The beginning student, however, needs to develop skill in constructing these diagrams as an aid to the complete understanding of wind effect. Either consciously or unconsciously, every good pilot thinks of the flight in terms of wind triangle.

If flight is to be made on a course to the east, with a wind blowing from the northeast, the aircraft must be headed somewhat to the north of east to counteract drift. This can be represented by a diagram as shown in *Figure 16-19.* Each line represents direction and speed. The long blue and white hashed line shows the direction the aircraft is heading, and its length represents the distance traveled at the indicated airspeed for 1 hour. The short blue arrow at the right shows the wind direction, and its length represents the wind velocity for 1 hour. The solid yellow line shows the direction of the track or the path of the aircraft as measured over the earth, and its length represents the distance traveled in 1 hour or the GS.

In actual practice, the triangle illustrated in *Figure 16-19* is not drawn; instead, construct a similar triangle as shown by the blue, yellow, and black lines in *Figure 16-20,* which is explained in the following example.

Suppose a flight is to be flown from E to P. Draw a line on the aeronautical chart connecting these two points; measure its direction with a protractor, or plotter, in reference to a meridian. This is the TC, which in this example is assumed to be 090° (east). From the NWS, it is learned that the wind at the altitude of the intended flight is 40 knots from the northeast (045°). Since the NWS reports the wind speed in knots, if the true airspeed of the aircraft is 120 knots, there is no need to convert speeds from knots to mph or vice versa.

Now, on a plain sheet of paper draw a vertical line representing north to south. (The various steps are shown in *Figure 16-21.*)

Step 1

Place the protractor with the base resting on the vertical line and the curved edge facing east. At the center point of the base, make a dot labeled "E" (point of departure) and at the curved edge, make a dot at 90° (indicating the direction of the true course) and another at 45° (indicating wind direction).

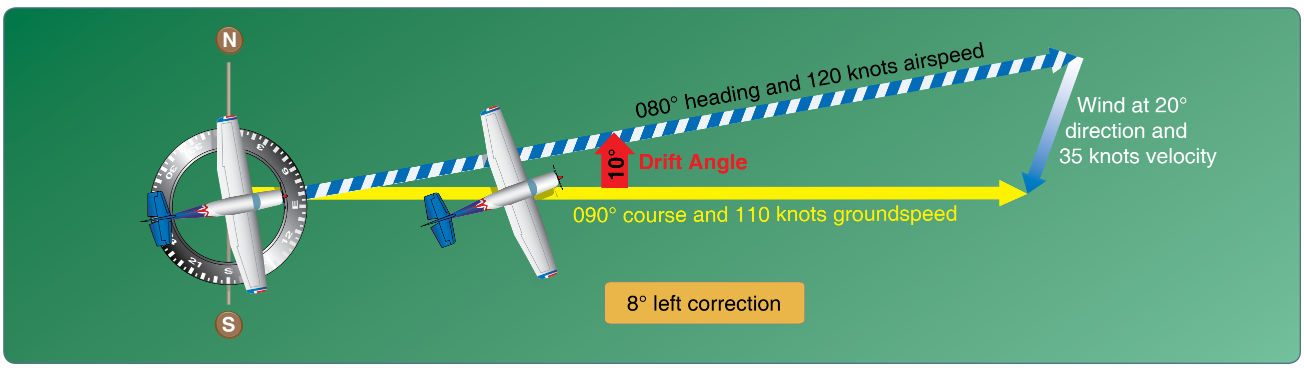


Figure 16-19. *Principle of the wind triangle.*

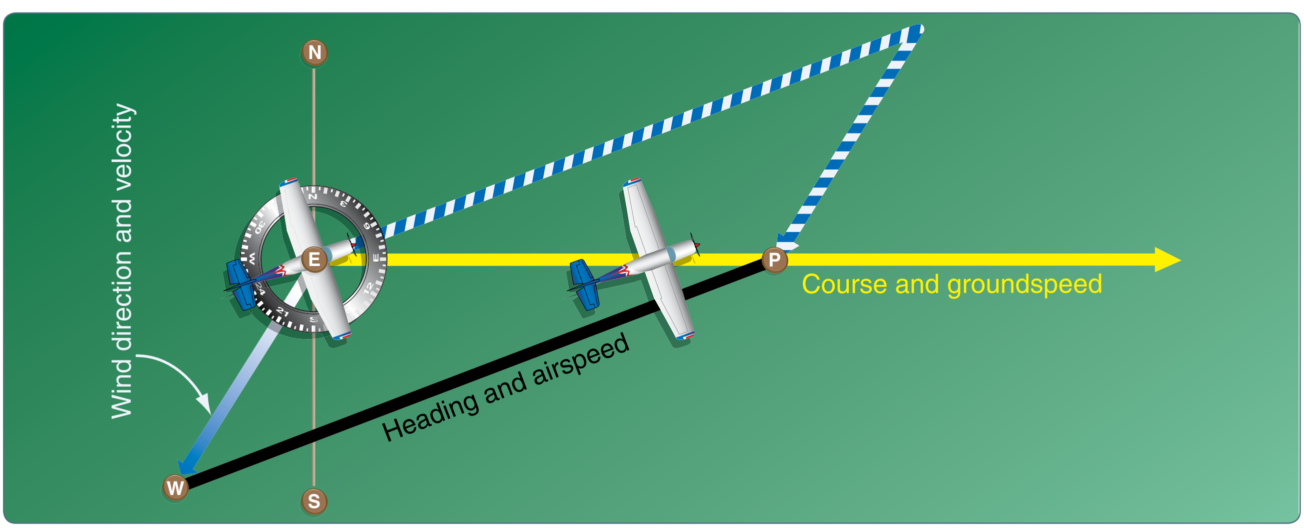


Figure 16-20. *The wind triangle as is drawn in navigation practice.*

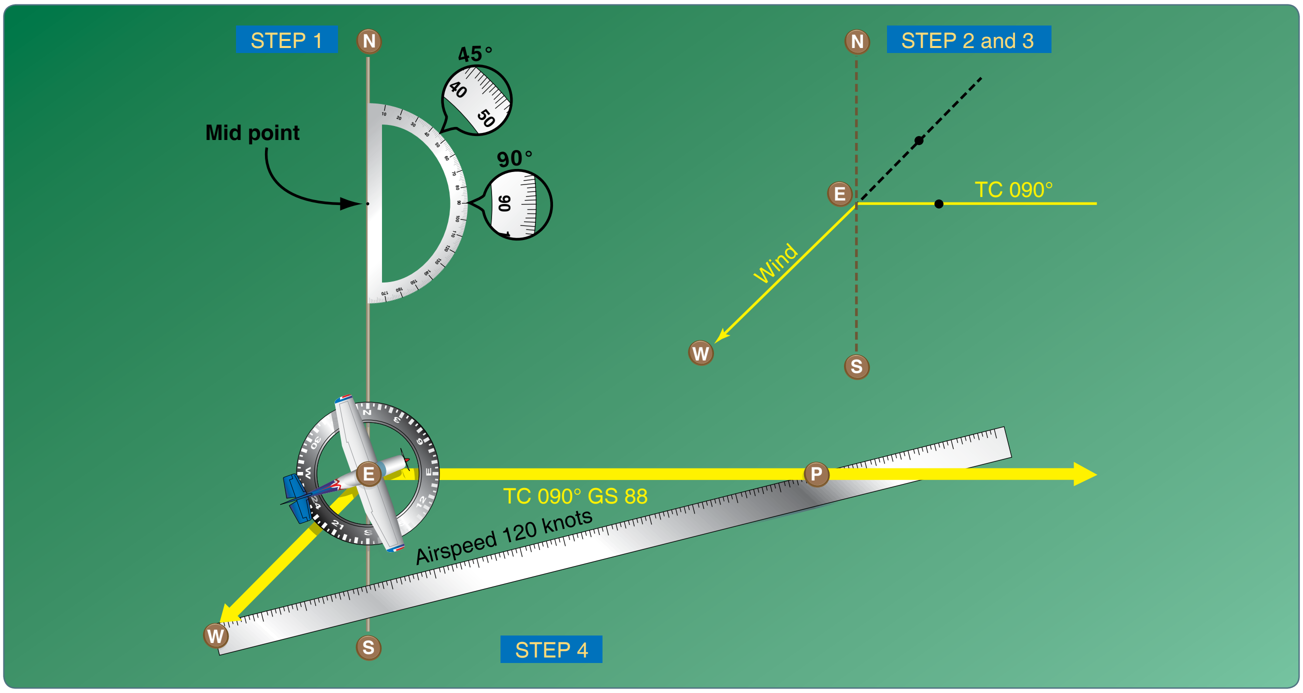


Figure 16-21. *Steps in drawing the wind triangle.*

Step 2

With the ruler, draw the true course line from E, extending it somewhat beyond the dot by 90°, and labeling it "TC 090°."

Step 3

Next, align the ruler with E and the dot at 45°, and draw the wind arrow from E, not toward 045°, but downwind in the direction the wind is blowing making it 40 units long to correspond with the wind velocity of 40 knots. Identify this line as the wind line by placing the letter "W" at the end to show the wind direction.

Step 4

Finally, measure 120 units on the ruler to represent the airspeed, making a dot on the ruler at this point. The units used may be of any convenient scale or value (such as ¼ inch = 10 knots), but once selected, the same scale must be used for each of the linear movements involved. Then place the ruler so that the end is on the arrowhead (W) and the 120-knot dot intercepts the TC line. Draw the line and label it "AS 120." The point "P" placed at the intersection represents the position of the aircraft at the end of 1 hour. The diagram is now complete.

The distance flown in 1 hour (GS) is measured as the numbers of units on the TC line (88 NMPH or 88 knots). The TH necessary to offset drift is indicated by the direction of the airspeed line, which can be determined in one of two ways:

- By placing the straight side of the protractor along the north-south line, with its center point at the intersection of the airspeed line and north-south line, read the TH directly in degrees (076°). *[Figure 16-22]*
- By placing the straight side of the protractor along the TC line, with its center at P, read the angle between the TC and the airspeed line. This is the WCA, which must be applied to the TC to obtain the TH. If the wind blows from the right of TC, the angle is added; if from the left, it is subtracted. In the example given, the WCA is 14° and the wind is from the left; therefore, subtract 14° from TC of 090°, making the TH 076°. *[Figure 16-23]*

After obtaining the TH, apply the correction for magnetic variation to obtain magnetic heading and the correction for compass deviation to obtain a compass heading. The compass heading can be used to fly to the destination by dead reckoning.

To determine the time and fuel required for the flight, first find the distance to your destination by measuring the length of the course line drawn on the aeronautical chart (using the appropriate scale at the bottom of the chart). If the distance measures 220 NM, divide by the GS of 88 knots, which gives 2.5 hours, or 2:30, as the time required. If fuel consumption is 8 gallons an hour, 8 × 2.5 or about 20 gallons is used.

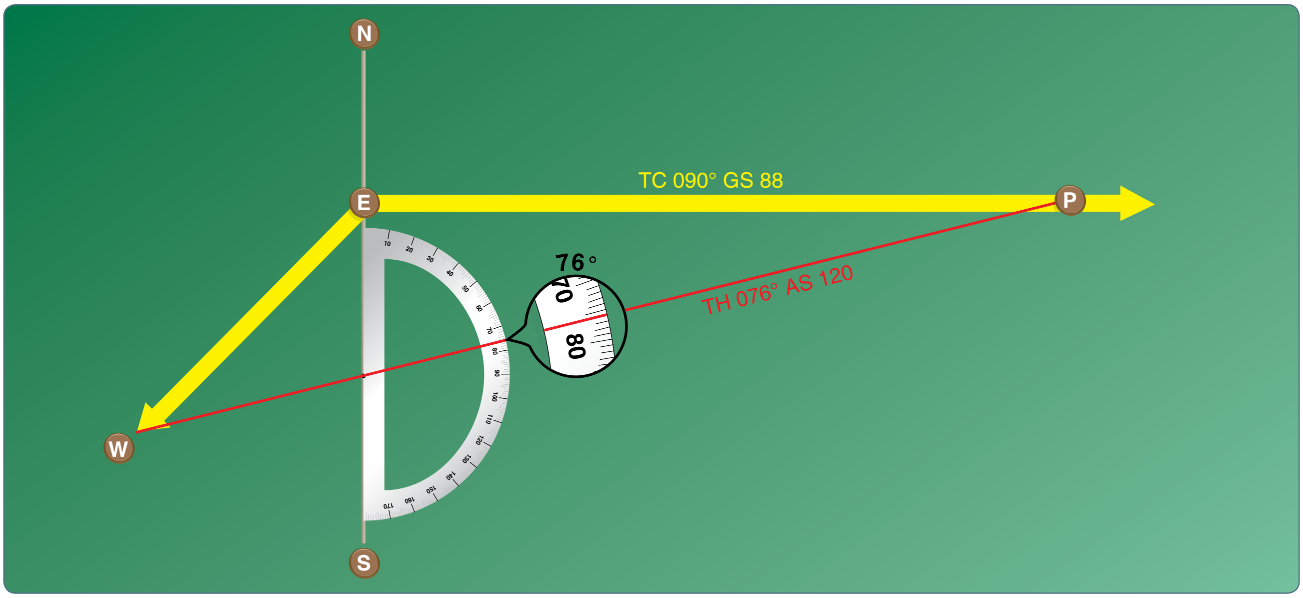


Figure 16-22. *Finding true heading by the wind correction angle.*

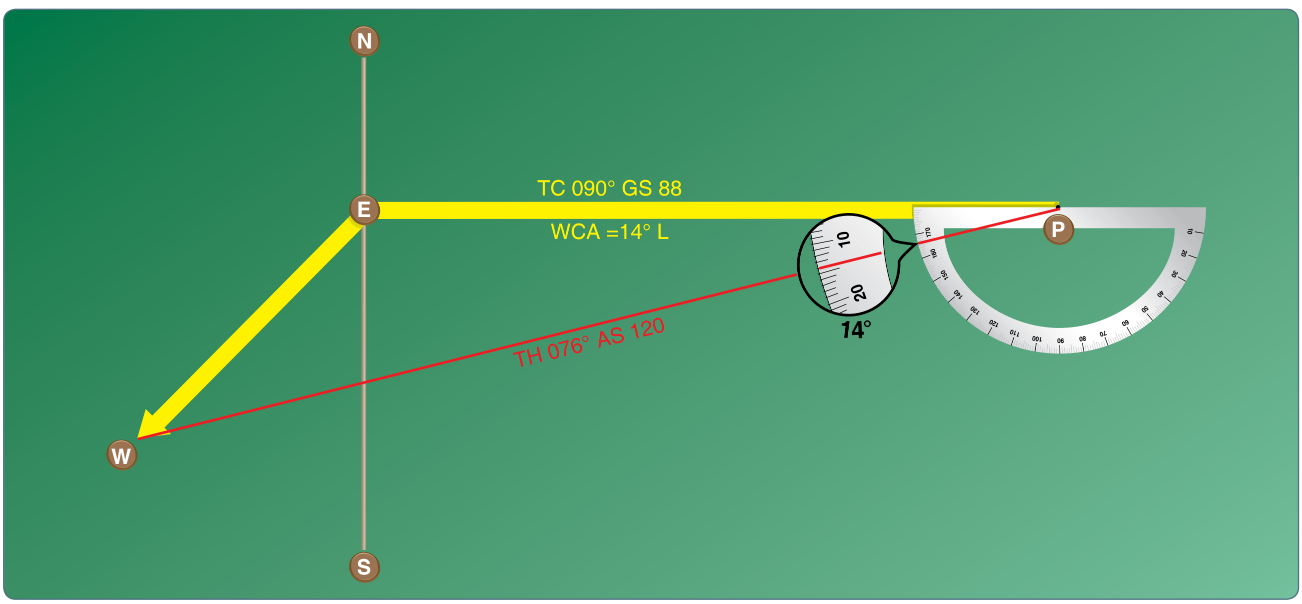


Figure 16-23. *Finding true heading by direct measurement.*

Briefly summarized, the steps in obtaining flight information are as follows:

- TC—direction of the line connecting two desired points, drawn on the chart and measured clockwise in degrees from TN on the mid-meridian
- WCA—determined from the wind triangle. (Added to TC if the wind is from the right; subtracted if wind is from the left)
- TH—direction measured in degrees clockwise from TN, in which the nose of the plane should point to remain on the desired course
- Variation—obtained from the isogonic line on the chart (added to TH if west; subtracted if east)
- MH—an intermediate step in the conversion (obtained by applying variation to TH)
- Deviation—obtained from the deviation card on the aircraft (added to or subtracted from MH, as indicated)
- Compass heading—reading on the compass (found by applying deviation to MH) that is followed to remain on the desired course

- Total distance—obtained by measuring the length of the TC line on the chart (using the scale at the bottom of the chart)
- GS—obtained by measuring the length of the TC line on the wind triangle (using the scale employed for drawing the diagram)
- Estimated time en route (ETE)—total distance divided by GS
- Fuel rate—predetermined gallons per hour used at cruising speed

NOTE: Additional fuel for adequate reserve should be added as a safety measure.

Flight Planning

Title 14 of the Code of Federal Regulations (14 CFR) part 91 states, in part, that before beginning a flight, the pilot in command (PIC) of an aircraft shall become familiar with all available information concerning that flight. For flights not in the vicinity of an airport, this must include information on available current weather reports and forecasts, fuel requirements, alternatives available if the planned flight cannot be completed, and any known traffic delays of which the PIC has been advised by ATC.

Assembling Necessary Material

The pilot should collect the necessary material well before beginning the flight. An appropriate current sectional chart and charts for areas adjoining the flight route should be among this material if the route of flight is near the border of a chart.

Additional equipment should include a flight computer or electronic calculator, plotter, and any other item appropriate to the particular flight. For example, if a night flight is to be undertaken, carry a flashlight; if a flight is over desert country, carry a supply of water and other necessities.

Weather Check

It is wise to check the weather before continuing with other aspects of flight planning to see, first of all, if the flight is feasible and, if it is, which route is best. Chapter 12, "Aviation Weather Services," discusses obtaining a weather briefing.

Airplane Flight Manual or Pilot's Operating Handbook (AFM/POH)

The Aircraft Flight Manual or Pilot's Operating Handbook (AFM/POH) should be checked to determine the proper loading of the aircraft (weight and balance data). The weight of the usable fuel and drainable oil aboard must be known. Also, check the weight of the passengers, the weight of all baggage to be carried, and the empty weight of the aircraft to be sure that the total weight does not exceed the maximum allowable weight. The distribution of the load must be known to tell if the resulting center of gravity (CG) is within limits. Be sure to use the latest weight and balance information in the FAA-approved AFM or other permanent aircraft records, as appropriate, to obtain empty weight and empty weight CG information.

Determine the takeoff and landing distances from the appropriate charts, based on the calculated load, elevation of the airport, and temperature; then compare these distances with the amount of runway available. Remember, the heavier the load and the higher the elevation, temperature, or humidity, the longer the takeoff roll and landing roll and the lower the rate of climb.

Check the fuel consumption charts to determine the rate of fuel consumption at the estimated flight altitude and power settings. Calculate the rate of fuel consumption, and compare it with the estimated time for the flight so that refueling points along the route can be included in the plan.

PILOT'S PLANNING SHEET

PLANE IDENTIFICATION N123DB **DATE**

COURSE	TC	WIND Knots	WIND From	ALTITUDE	WCA R+ L-	TH	MAG VAR W+ E-	MH	DEV	CH	TOTAL MILES	GS	TOTAL TIME	FUEL RATE	TOTAL FUEL
From Chickasha To Guthrie	031°	10	360°	8000	3° L	28	7° E	21°	+2°	23	53	106 kts	35 min	8 GPH	38 gal
From To															

VISUAL FLIGHT LOG

TIME OF DEPARTURE	NAVIGATION AIDS	COURSE	ALTITUDE	DISTANCE	ELAPSED TIME	GS	CH	REMARKS
POINT OF DEPARTURE Chickasha Airport	NAVAID IDENT. FREQ.	TO / FROM	TO / FROM	POINT TO POINT / CUMULATIVE	ESTIMATED / ACTUAL	ESTIMATED / ACTUAL	ESTIMATED / ACTUAL	WEATHER AIRSPACE ETC.
CHECKPOINT #1			8000 / 10000	11 NM	6 min / +5	106 kts	023°	
CHECKPOINT #2			8000 / 10000	10 NM / 21 NM	6 min	106 kts	023°	
CHECKPOINT #3			8000 / 10000	10.5 NM / 31.5 NM	6 min	106 kts	023°	
CHECKPOINT #4			8000 / 10000	13 NM / 44.5 NM	7 min	106 kts	023°	
DESTINATION Guthrie Airport				8.5 NM / 53 NM	5 min			

Figure 16-26. *Pilot's planning sheet and visual flight log.*

Ground-Based Navigation

Advances in navigational radio receivers installed in aircraft, the development of aeronautical charts that show the exact location of ground transmitting stations and their frequencies, along with refined flight deck instrumentation make it possible for pilots to navigate with precision to almost any point desired. Although precision in navigation is obtainable through the proper use of this equipment, beginning pilots should use this equipment to supplement navigation by visual reference to the ground (pilotage). This method provides the pilot with an effective safeguard against disorientation in the event of radio malfunction.

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

- VHF Omnidirectional Range (VOR)
- Nondirectional Radio Beacon (NDB)
- 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/distance measuring equipment (DME)(discussed in a later section), 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 MN. 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 MN 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 16-28]*

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, affecting 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 should be performed each year.

The VOR transmitting station can be positively identified by its Morse code identification or by a recorded voice identification that states the name of the station followed by "VOR." Many FSSs transmit voice messages on the same frequency that the VOR operates. Voice transmissions should not be relied upon to identify stations because many FSSs remotely transmit over several omniranges that 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.

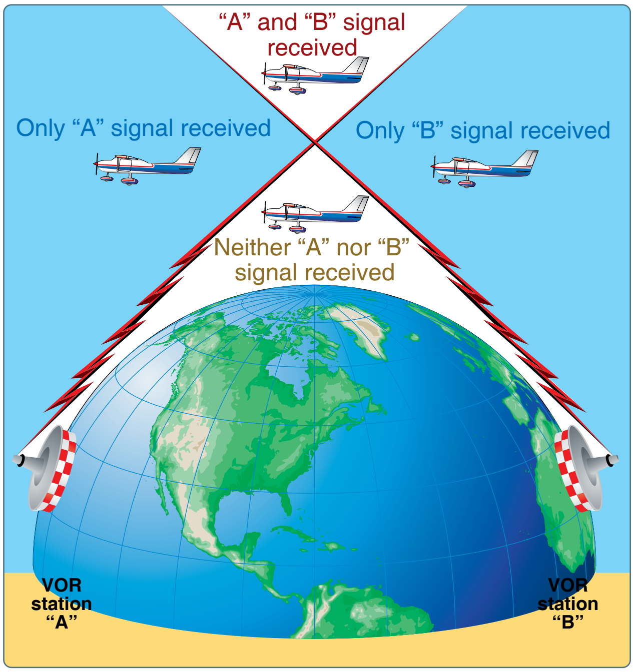


Figure 16-28. *VHF transmissions follow a line-of-sight course.*

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 omninavigation 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 an omnibearing selector (OBS) sometimes referred to as the course selector, a CDI needle (left-right needle), and 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 16-29]* If "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 16-30]* combines the magnetic compass with navigation signals and a glideslope. The HSI gives the pilot an indication of the location of the aircraft in relation to the chosen course or radial.

In *Figure 16-30,* 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 takes 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, takes 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.

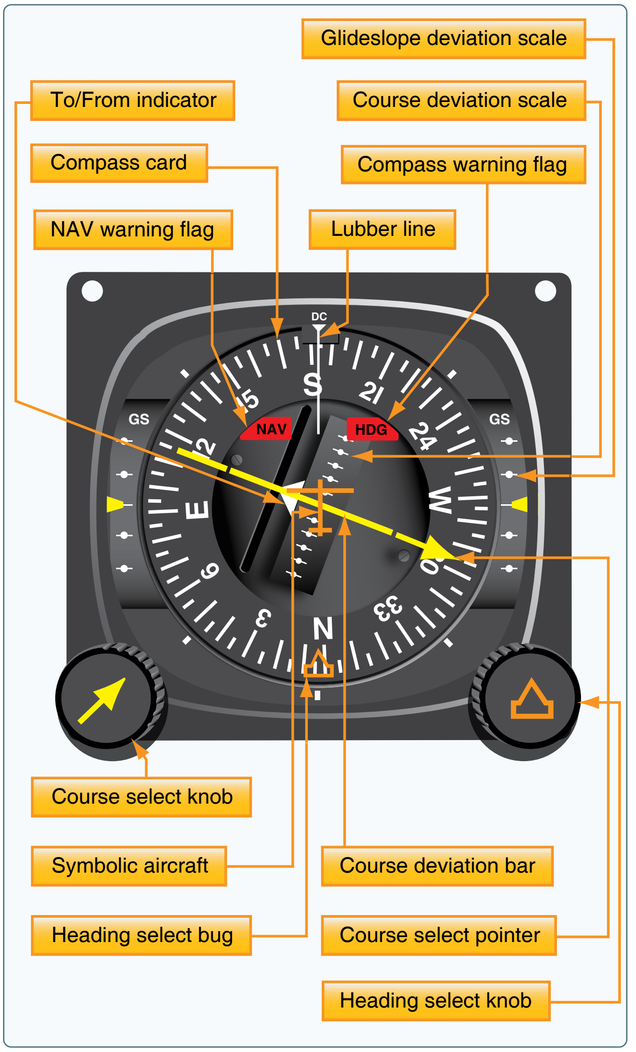


Figure 16-30. *Horizontal situation indicator.*

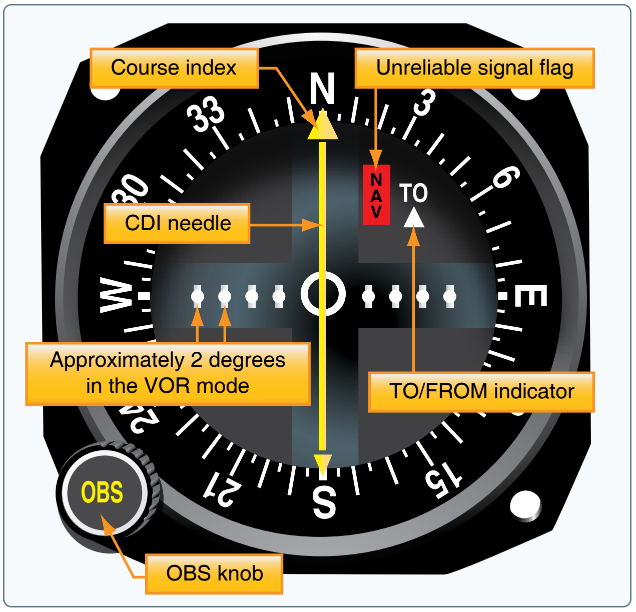


Figure 16-29. *VOR indicator.*

Tracking With VOR

The following describes a step-by-step procedure for tracking to and from a VOR station using a CDI. *Figure 16-32* 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.

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."

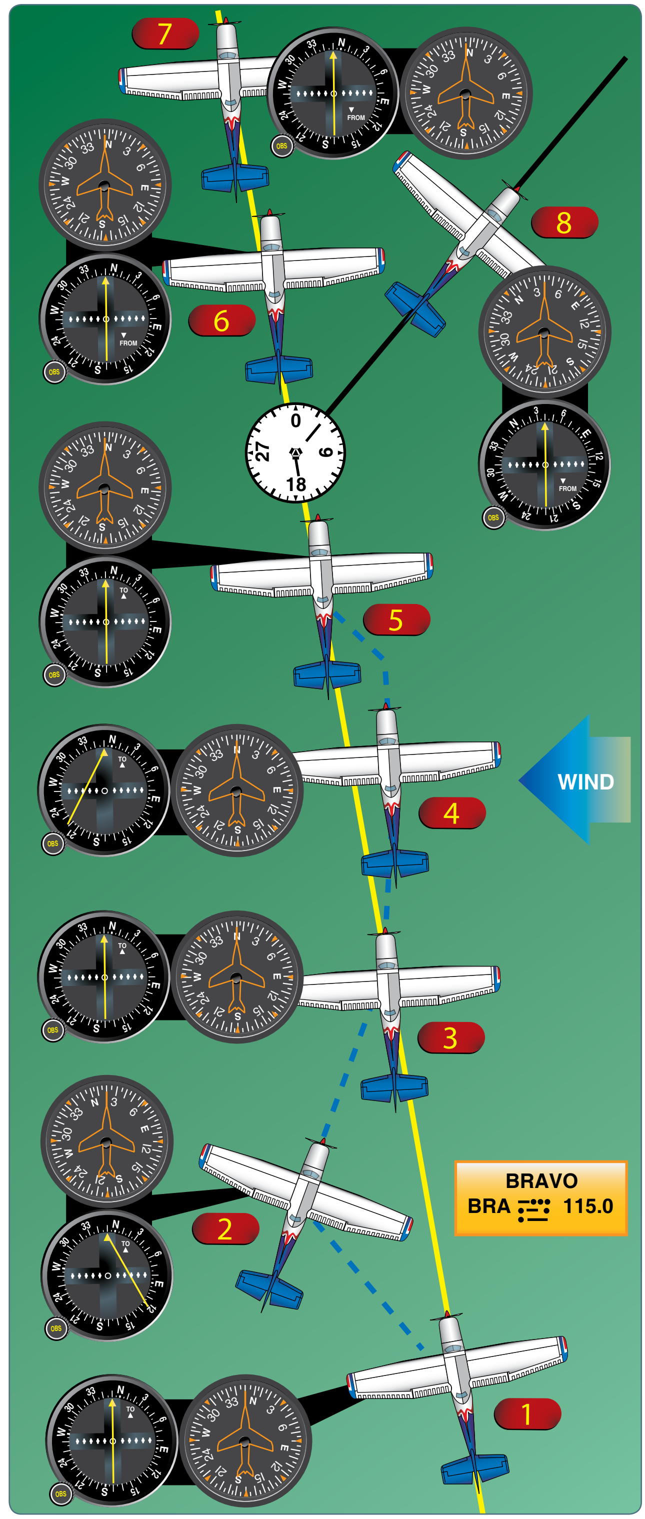


Figure 16-32. *Tracking a radial in a crosswind.*

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.
- Remember 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 a moment to see if the needle recenters; if it does not, then you must correctly recenter the course to the needle.
- 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 of 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 Using a RMI

To compute time and distance from a station, first turn the aircraft to place the RMI bearing pointer on the nearest 90° index. Note the time and maintain the heading. When the RMI bearing pointer has moved 10°, note the elapsed time in seconds and apply the formulas in the following example to determine the approximate time and distance from a given station. *[Figure 16-33]*

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

Time-Distance Check Example

$$\frac{\textbf{Time in seconds between bearings}}{\textbf{Degrees of bearing change}} = \textbf{Minutes to station}$$

For example, if 2 minutes (120 seconds) is required to fly a bearing change of 10 degrees, the aircraft is—

$$\frac{120}{10} = \textbf{12 minutes to the station}$$

Figure 16-33. *Time-distance check example.*

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 RMI 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 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.

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 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 a given 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.

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.

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 in 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.

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 16-37]*

Figure 16-38 illustrates terms that are used with the ADF and should be understood by the pilot.

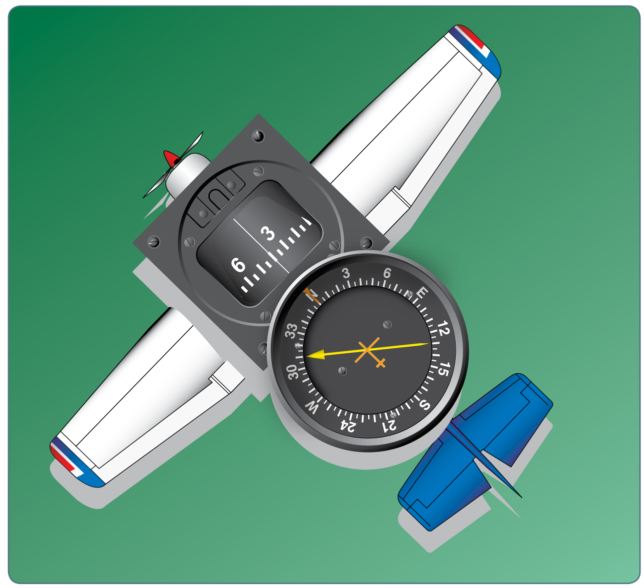


Figure 16-37. *ADF with fixed azimuth and magnetic compass.*

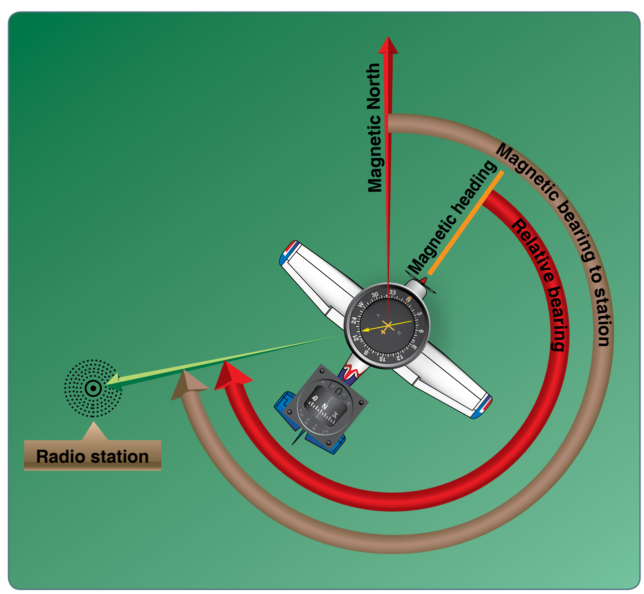


Figure 16-38. *ADF terms.*

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.

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.

It is not necessary to understand the technical aspects of GPS operation to use it in VFR/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 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 baseline GPS satellite constellation consists of 24 satellites positioned in six earth-centered orbital planes with four operation satellites and a spare satellite slot in each orbital plane. The system can support a constellation of up to thirty satellites in orbit. The orbital period of a GPS satellite is one-half of a sidereal day or 11 hours 58 minutes. The orbits are nearly circular and equally spaced about the equator at a 60-degree separation with an inclination of 55 degrees relative to the equator. The orbital radius (i.e. distance from the center of mass of the earth to the satellite) is approximately 26,600 km.

With the baseline satellite constellation, users with a clear view of the sky have a minimum of four satellites in view. It is more likely that a user would see six to eight satellites. The satellites broadcast ranging signals and navigation data allowing users to measure their pseudoranges in order to estimate their position, velocity and time, in a passive, listen-only mode. 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). The exact number of satellites operating at any one particular time varies depending on the number of satellite outages and operational spares in orbit. For current status of the GPS constellation, please visit http://tycho.usno.navy.mil/gpscurr.html. *[Figure 16-40]*

Figure 16-40. *Satellite constellation.*

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.

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.

Plan flights carefully before taking off. If navigating to user-defined waypoints, enter them prior to 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 maintain 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 can be 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.

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 there are fewer off-course deviations among different pilots and receivers. When operating near a VFR waypoint, use all available ATC services, 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 flight 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 may 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 may come 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. Risk management procedures become a priority during any type of flight diversion and should be used the pilot. For example, the hazards of inadvertent VFR into IMC involve a risk that the pilot can identify and assess and then mitigate through a pre-planned or in-flight diversion around hazardous weather. 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. Risk management is explained in greater detail in Chapter 2, Aeronautical Decision-making.

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.

The course to an alternate destination 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 destination. 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 destination, 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 destination. Attempting to complete all plotting, measuring, and computations involved before diverting to the alternate destination 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.