

## 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

A free catalog listing aeronautical charts and related publications including prices and instructions for ordering is available at the Aeronautical Navigation Products website: [www.aeronav.faa.gov](http://www.aeronav.faa.gov).

## 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,

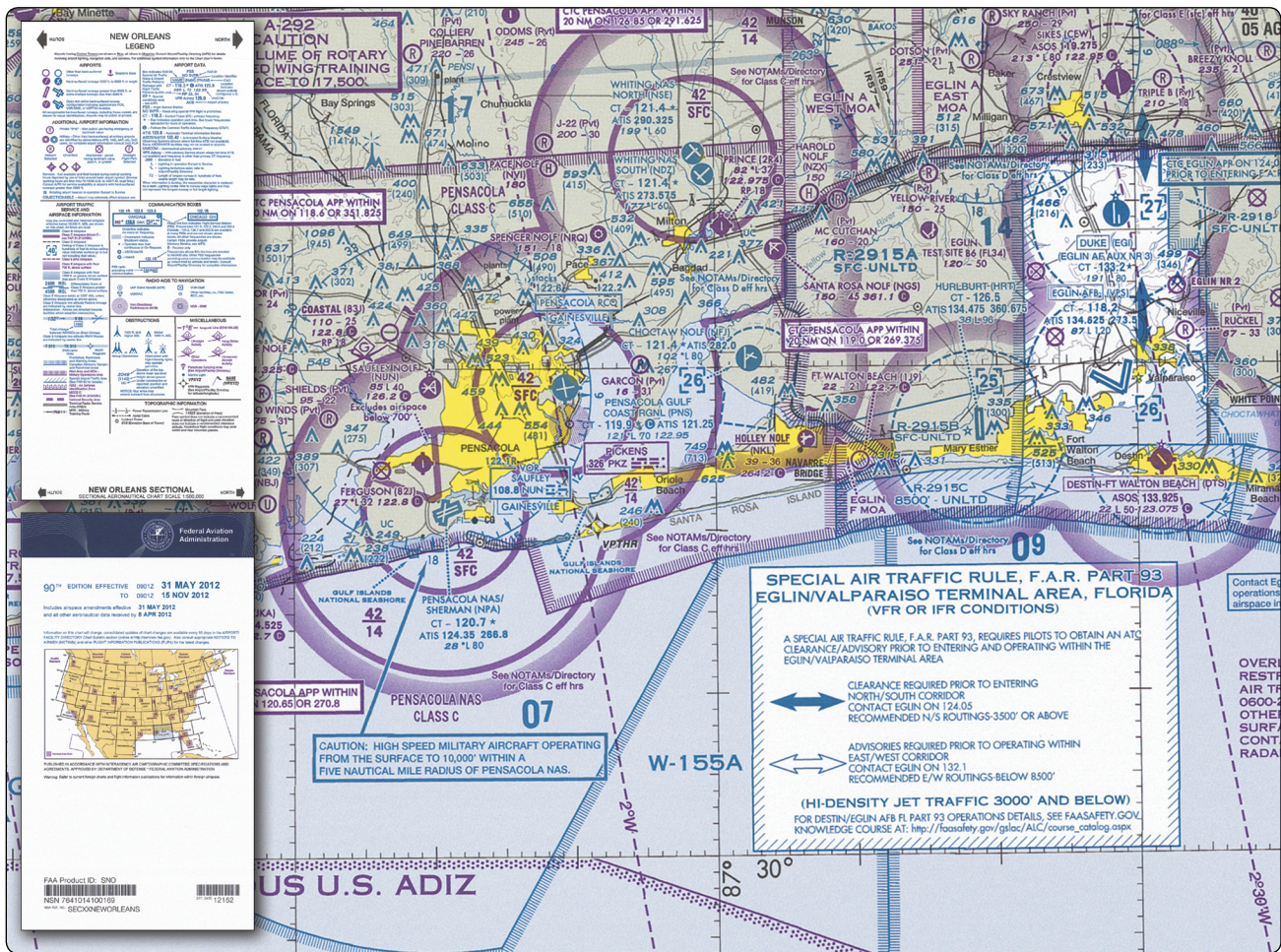


Figure 16-1. Sectional chart and legend.

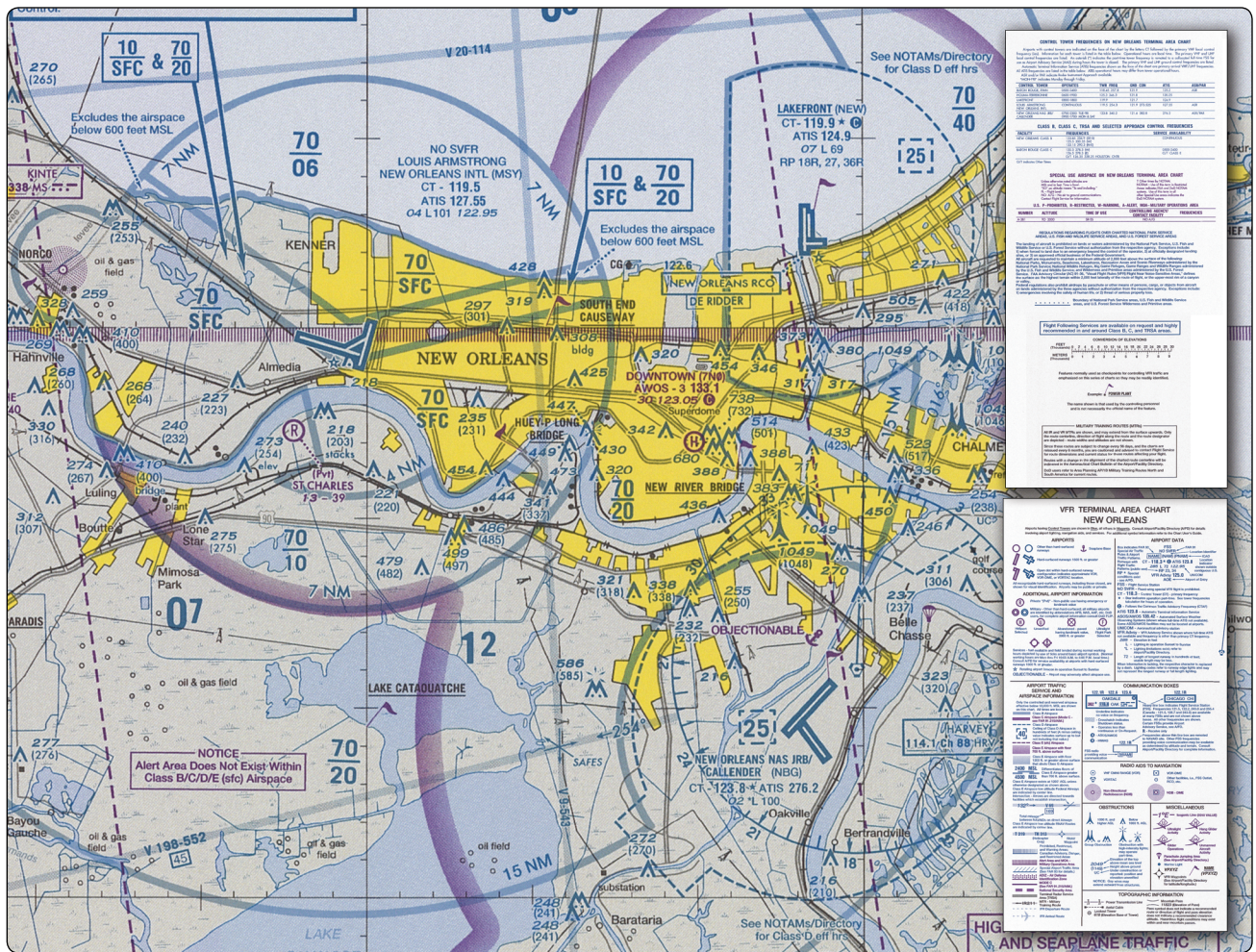


Figure 16-2. VFR Terminal Area Chart and legend.

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.

### 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.

### 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.

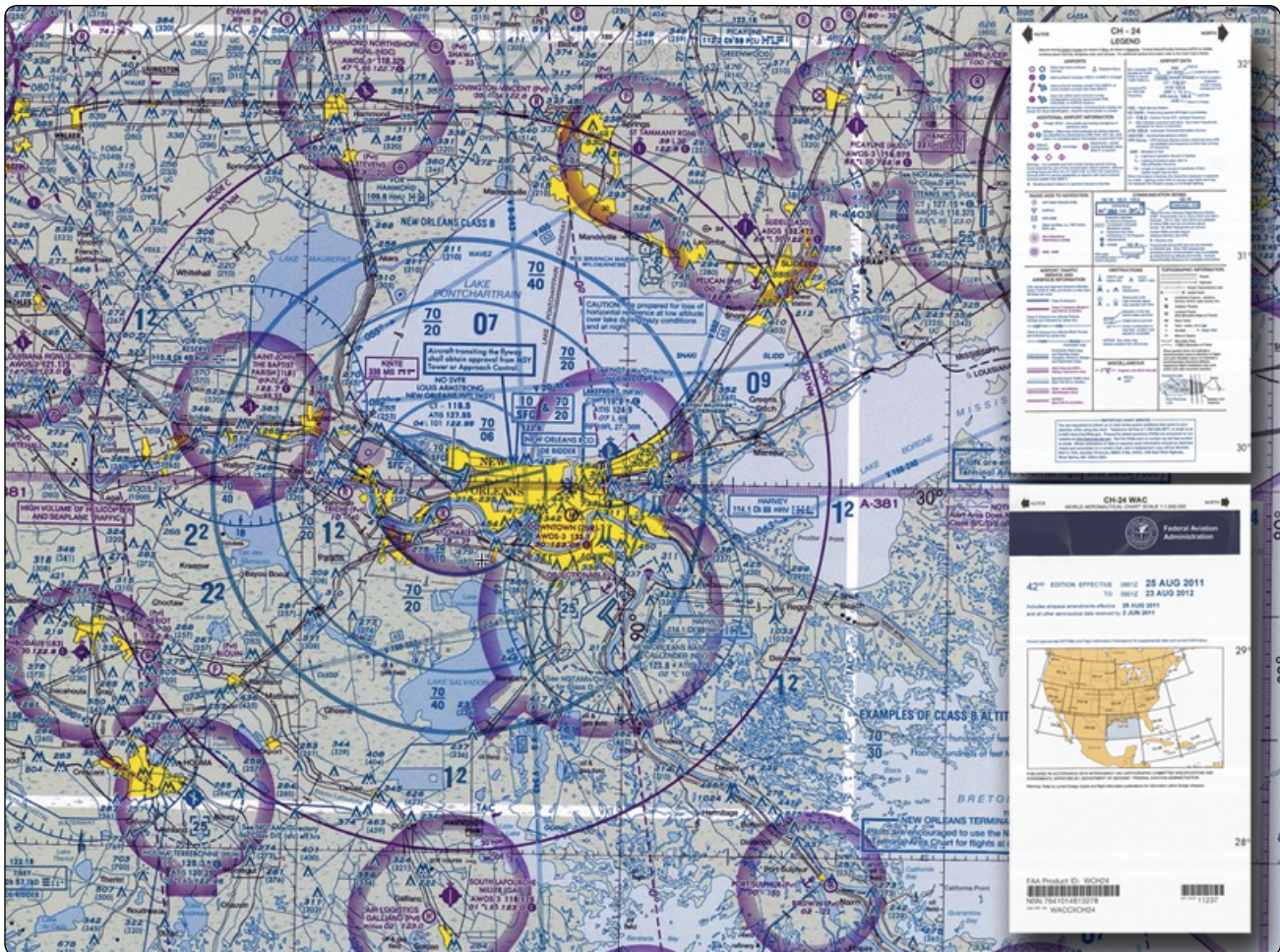


Figure 16-3. World aeronautical chart.

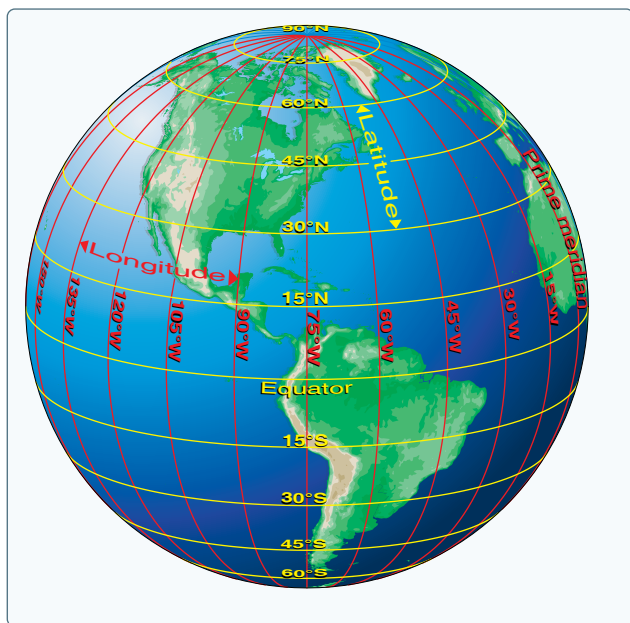


Figure 16-4. Meridians and parallels—the basis of measuring time, distance, and direction.

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.

Figure 16-5 shows the time zones in the conterminous United States. When the sun is directly above the 90th meridian, it is noon Central Standard Time. At the same time, it is 1 p.m. Eastern Standard Time, 11 a.m. Mountain Standard Time, and 10 a.m. Pacific Standard Time. When Daylight Saving Time is in effect, generally between the second Sunday in March and the first Sunday in November, the sun is directly above the 75th meridian at noon, Central Daylight Time.

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

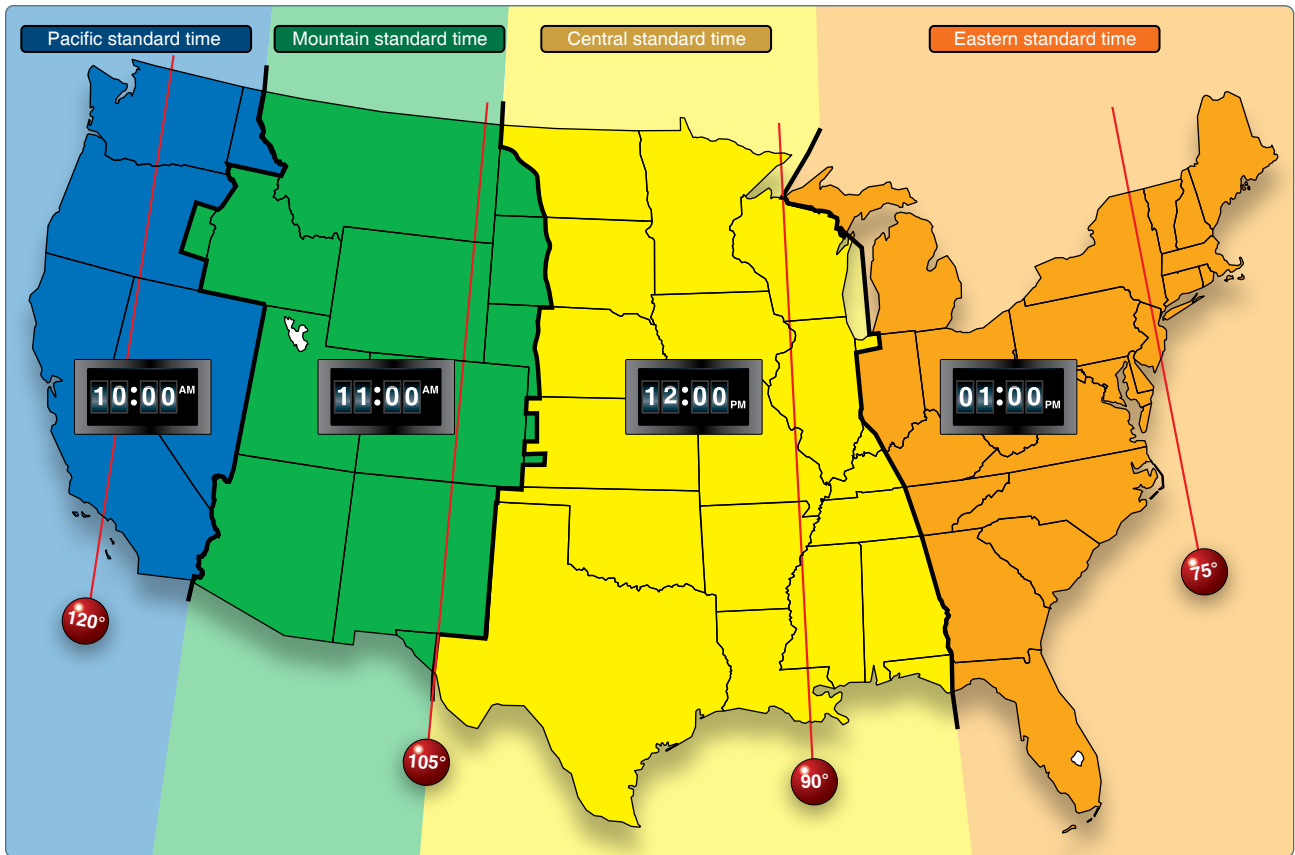


Figure 16-5. Time zones in the conterminous United States.

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°.



Figure 16-6. Compass rose.

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.

### 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.

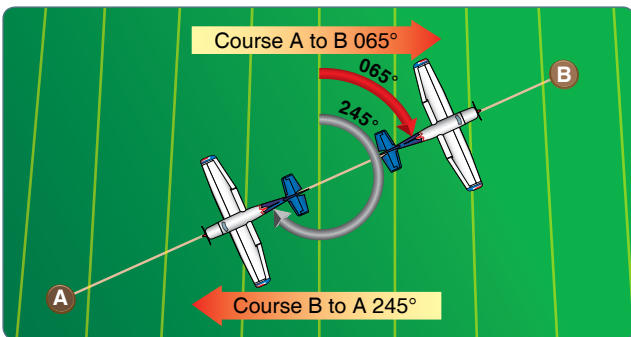


Figure 16-7. Courses are determined by reference to meridians on aeronautical charts.

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 Figure 16-8. If the Earth 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 Figure 16-9. Minor bends and turns in the isogonic and agonic lines are caused by unusual geological conditions affecting magnetic forces in these areas.

On the west coast of the United States, the compass needle points to the east of TN; on the east coast, the compass needle points to the west of TN.

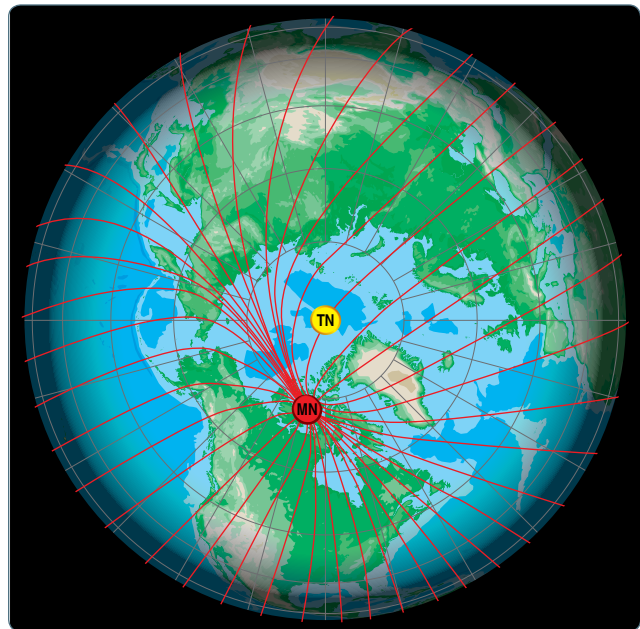


Figure 16-8. Magnetic meridians are in red while the lines of longitude and latitude are in blue. From these lines of variation (magnetic meridians), one can determine the effect of local magnetic variations on a magnetic compass.

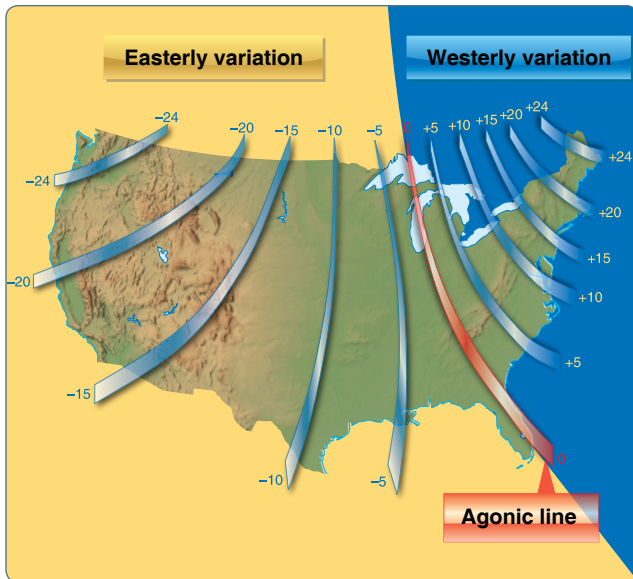


Figure 16-9. Note the agonic line where magnetic variation is zero.

Zero degree variation exists on the agonic line where MN and TN coincide. This line runs roughly west of the Great Lakes, south through Wisconsin, Illinois, western Tennessee, and along the border of Mississippi and Alabama. Compare Figures 16-9 and 16-10.

Because courses are measured in reference to geographical meridians that point toward TN, and these courses are maintained by reference to the compass that points along a magnetic meridian in the general direction of MN, the true direction must be converted into magnetic direction for the purpose of flight. This conversion is made by adding or subtracting the variation indicated by the nearest isogonic line on the chart.

For example, a line drawn between two points on a chart is called a TC as it is measured from TN. However, flying

this course off the magnetic compass would not provide an accurate course between the two points due to three elements that must be considered. The first is magnetic variation, the second is compass deviation, and the third is wind correction. All three must be considered for accurate navigation.

### 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.

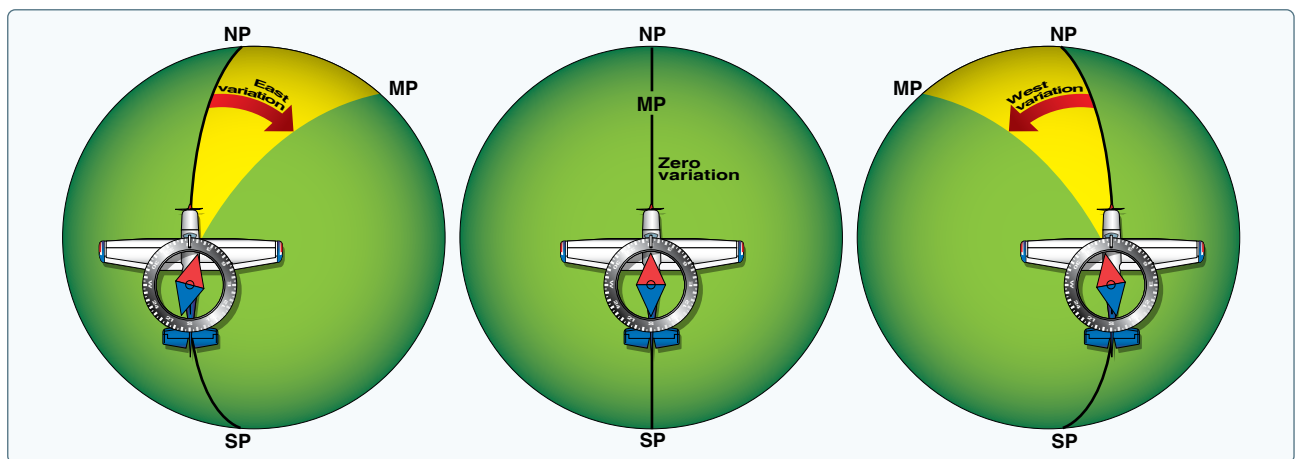


Figure 16-10. Effect of variation on the compass.

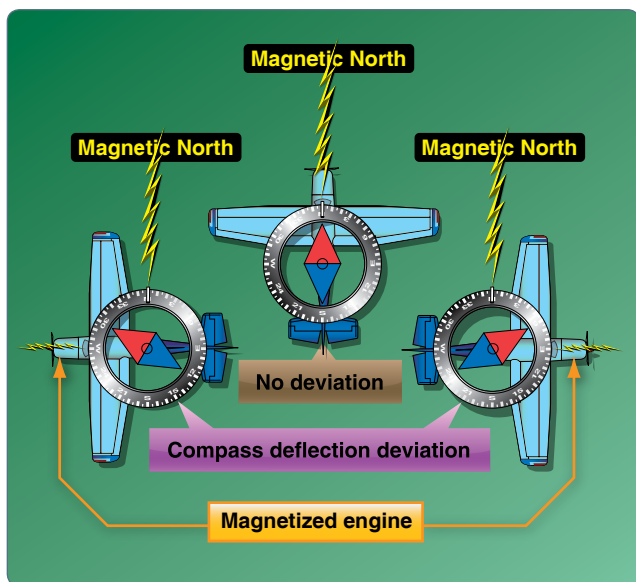
Remember, if variation is west, add; if east, subtract. One method for remembering whether to add or subtract variation is the phrase “east is least (subtract) and west is best (add).”

### 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.

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.



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

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.

### 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:

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.



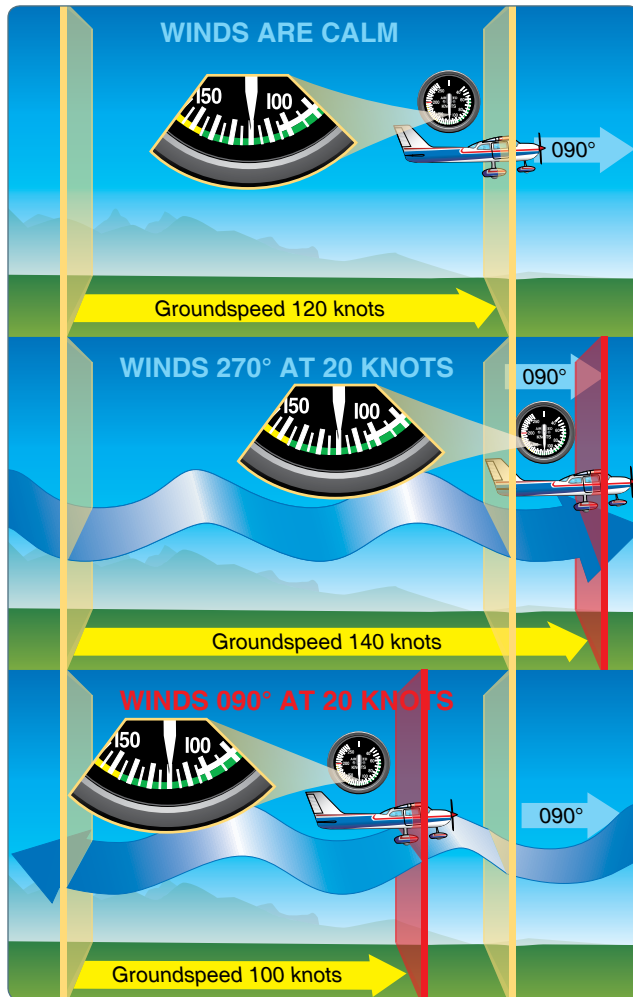
- Movement of the air mass in reference to the ground
- Forward movement of the aircraft through the air mass

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  $TH \pm \text{variation (V)} = \text{magnetic heading (MH)} \pm \text{deviation (D)} = \text{compass heading (CH)}$  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*]

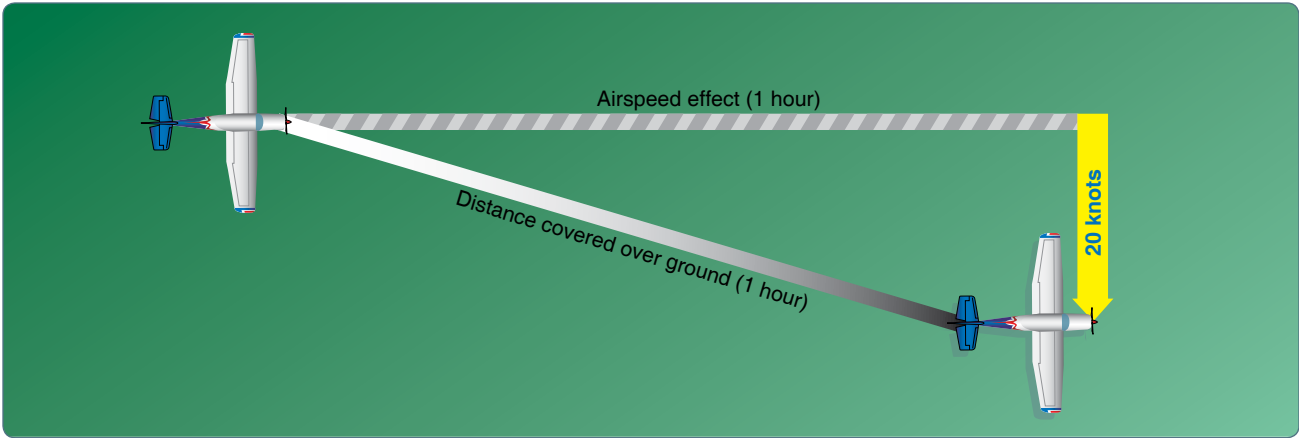


Figure 16-14. Aircraft flight path resulting from its airspeed and direction and the wind speed and direction.

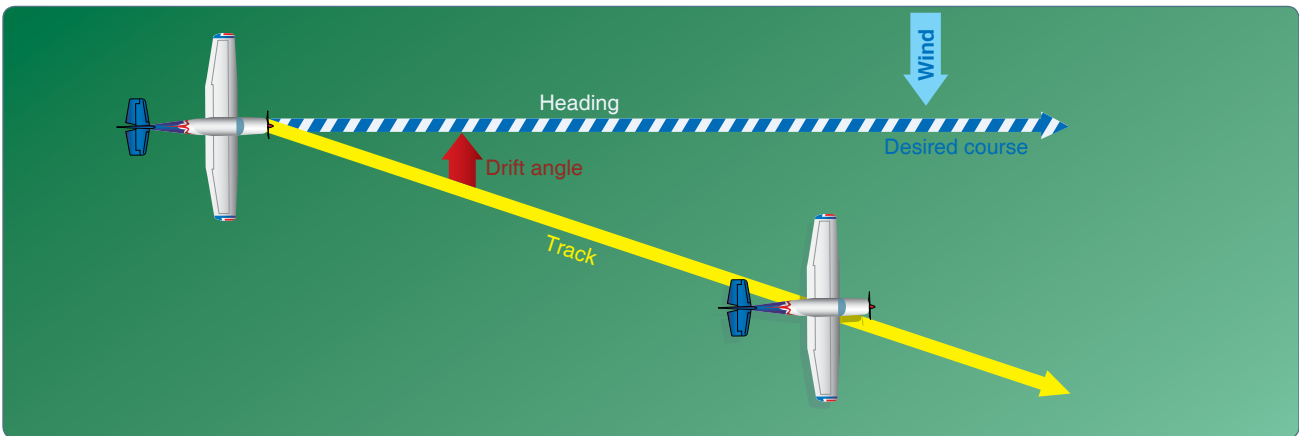


Figure 16-15. Effects of wind drift on maintaining desired course.

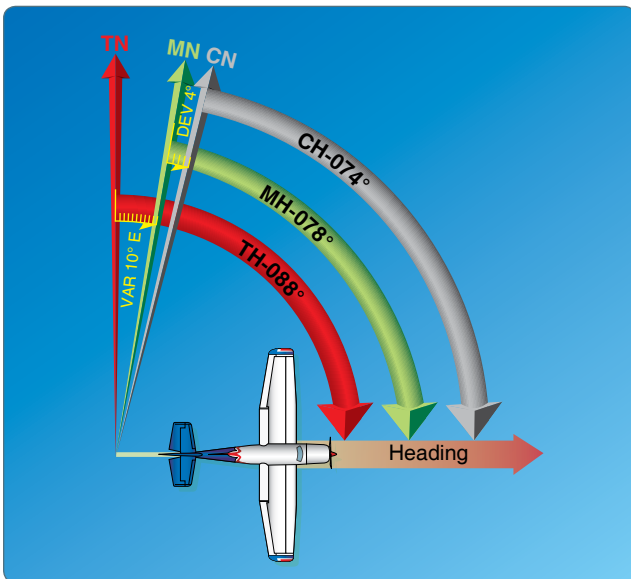
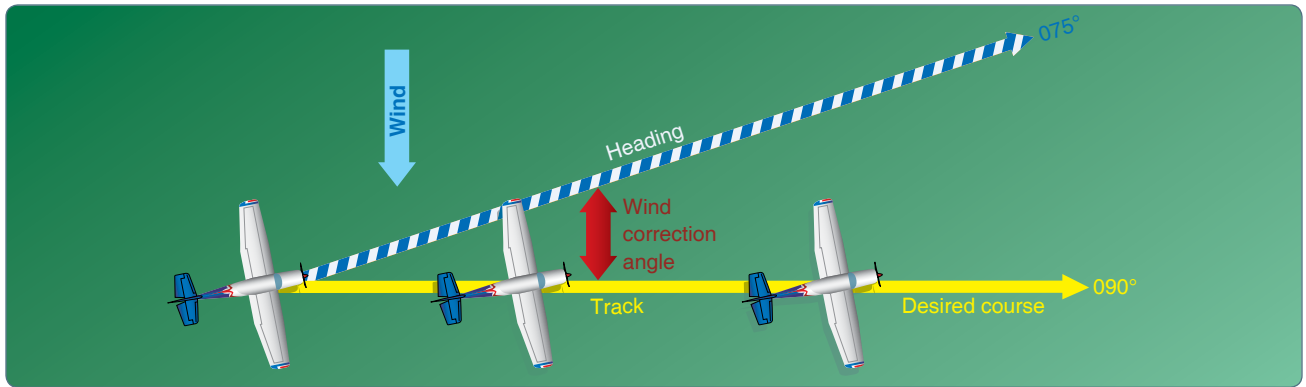


Figure 16-16. Relationship between true, magnetic, and compass headings for a particular instance.

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.



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

## 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  $0.75 \times 60 = 45$  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  $210 \div 140$  or 1.5 hours. (The 0.5 hour multiplied by 60 minutes equals 30 minutes.) Answer: 1:30.

### Distance $D = GS \times T$

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  $120 \times 1.75$  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  $270 \div 3 = 90$  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  $\pm$  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.

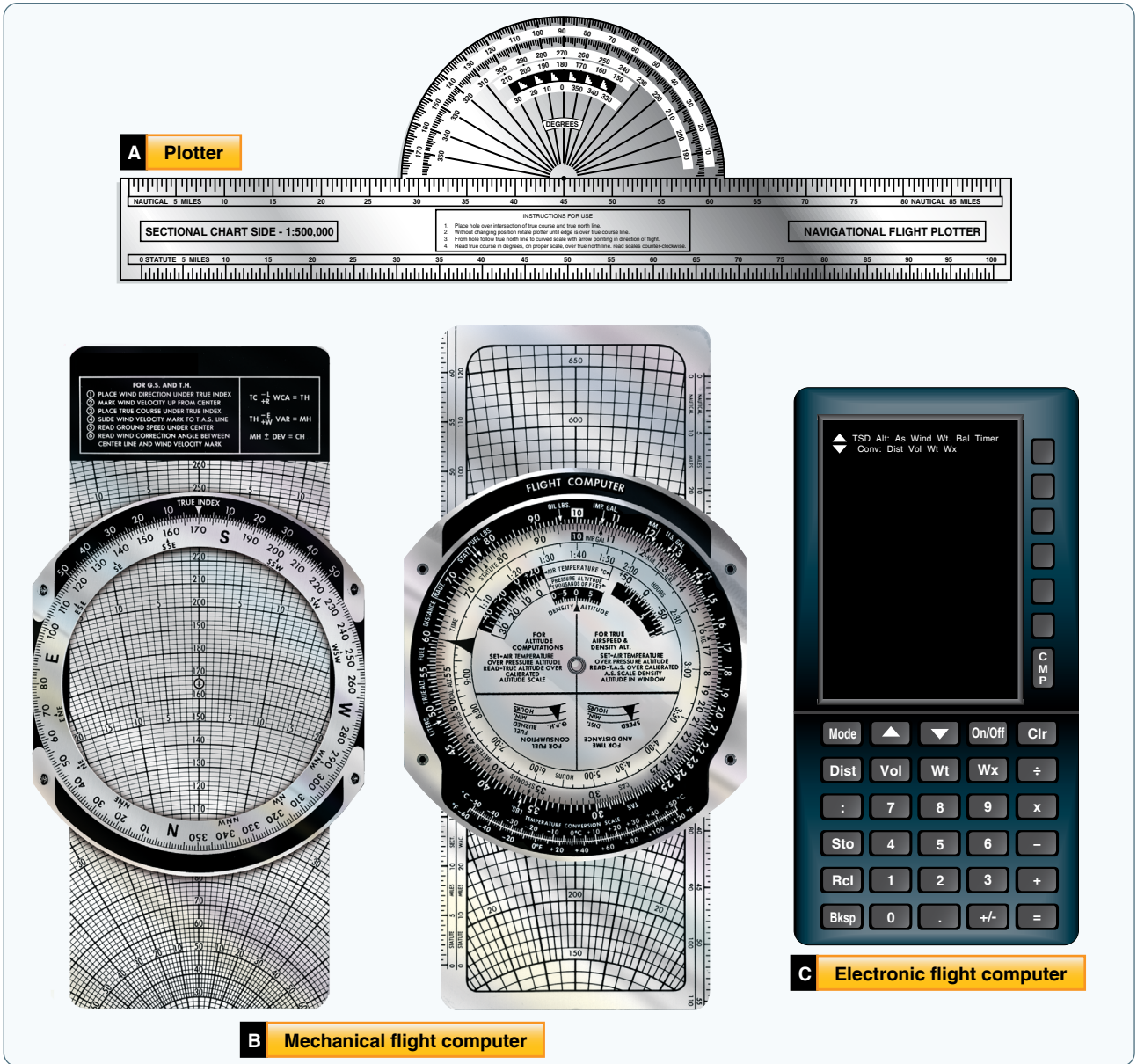


Figure 16-18. A plotter (A), the computational and wind side of a mechanical flight computer (E6B) (B), and an electronic flight computer (C).

## 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  $090^\circ$  (east). From the NWS, it is learned that the wind at the altitude of the intended flight is 40 knots from the northeast ( $045^\circ$ ). 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  $90^\circ$  (indicating the direction of the true course) and another at  $45^\circ$  (indicating wind direction).

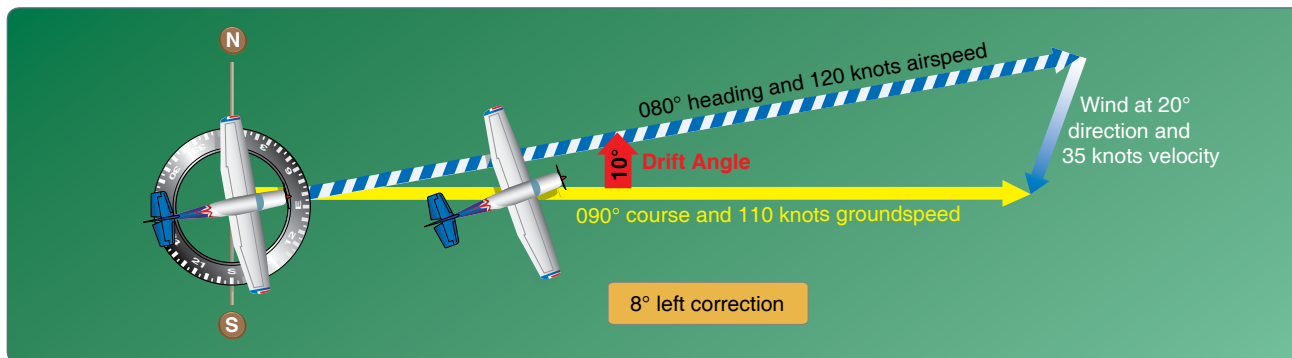


Figure 16-19. Principle of the wind triangle.

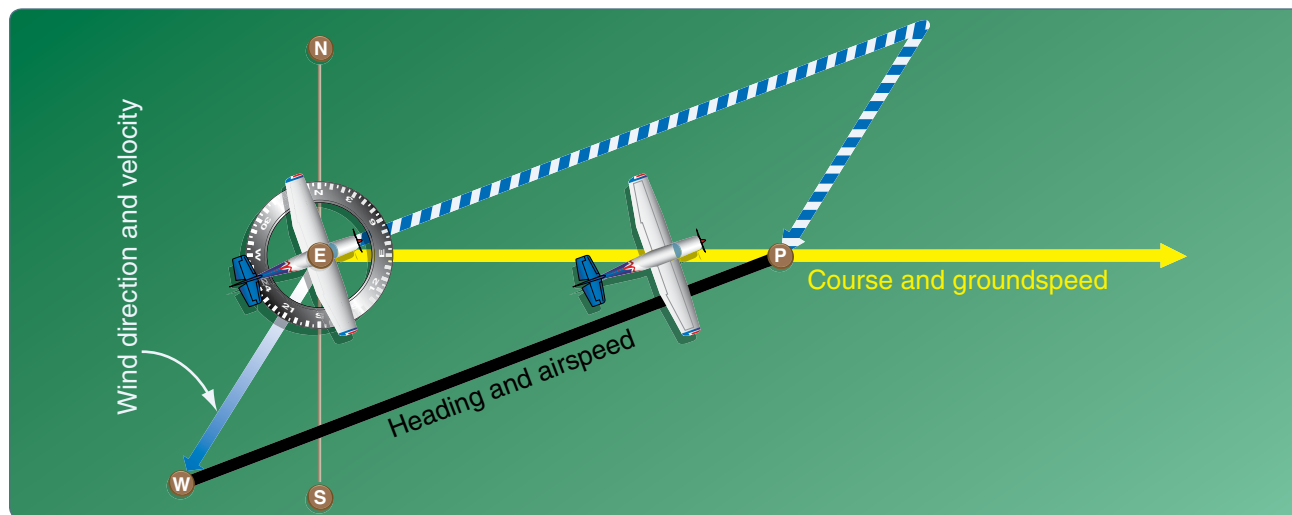


Figure 16-20. The wind triangle as is drawn in navigation practice.

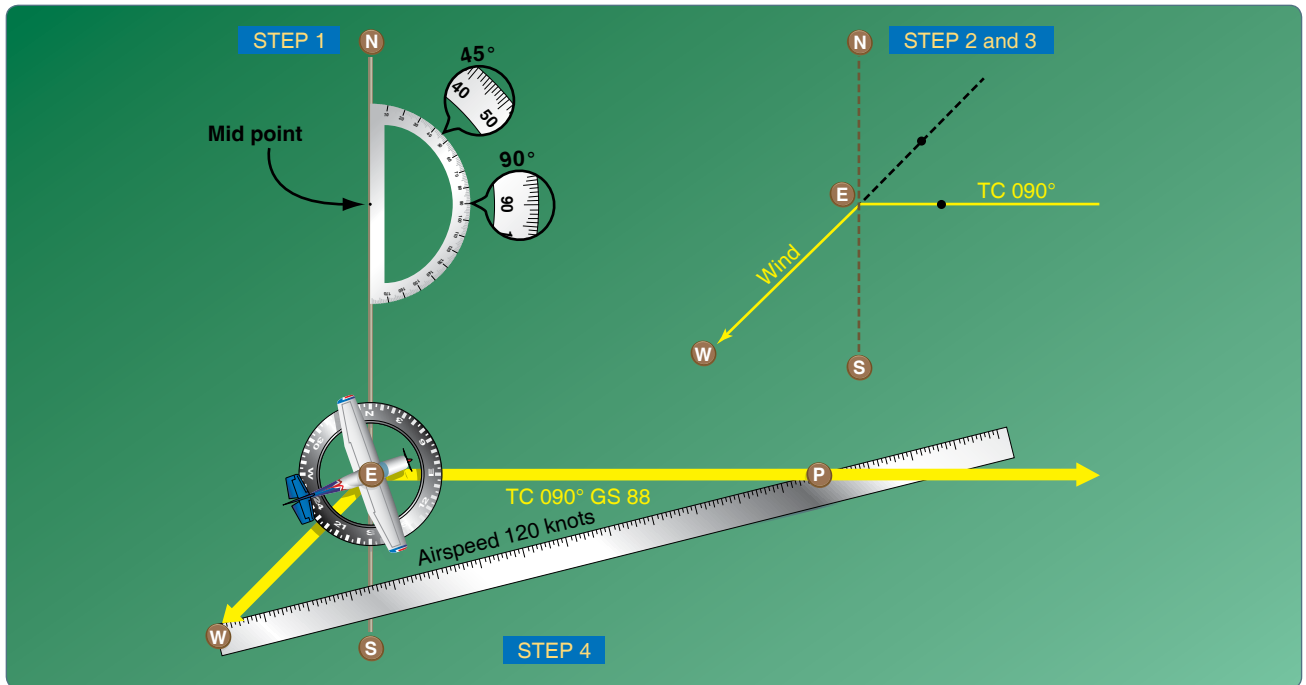


Figure 16-21. Steps in drawing the wind triangle.

### 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,  $8 \times 2.5$  or about 20 gallons is used.

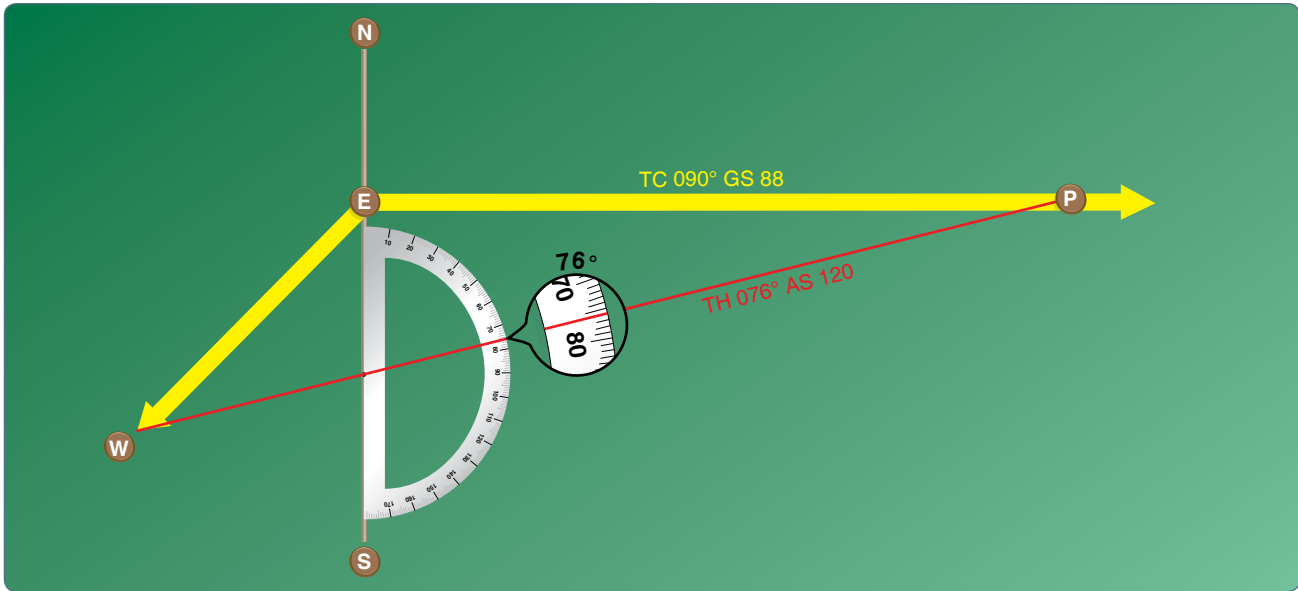


Figure 16-22. Finding true heading by the wind correction angle.

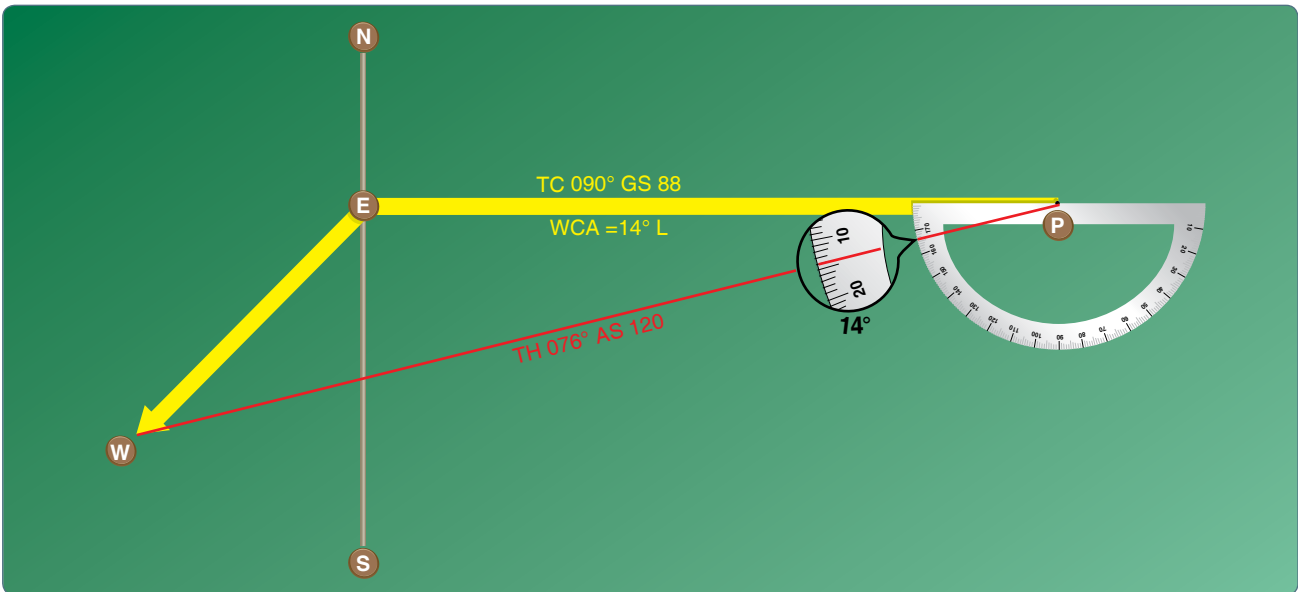


Figure 16-23. Finding true heading by direct measurement.

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.

### Use of Chart Supplement U.S. (formerly Airport/Facility Directory)

Study available information about each airport at which a landing is intended. This should include a study of the Notices to Airmen (NOTAMs) and the Chart Supplement U.S. (formerly Airport/Facility Directory). [Figure 16-24] This includes location, elevation, runway and lighting facilities, available services, availability of aeronautical advisory station frequency (UNICOM), types of fuel available (use to

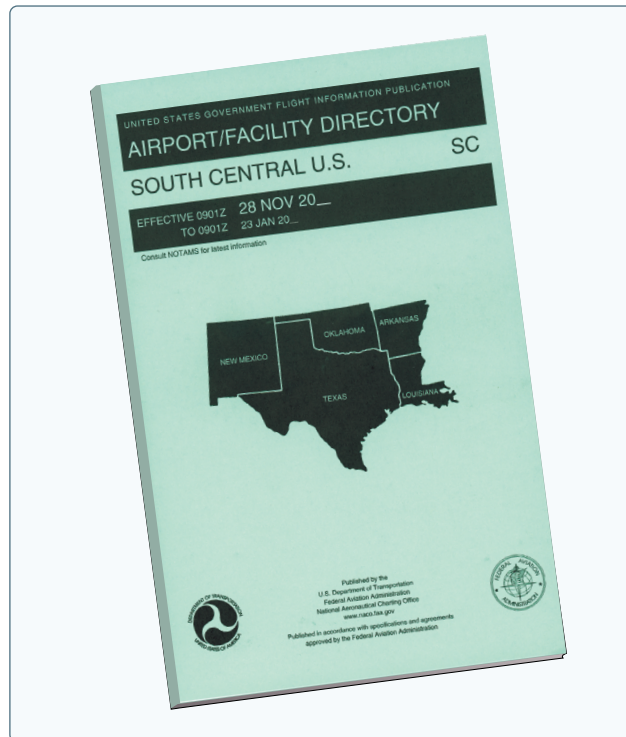


Figure 16-24. Chart Supplement U.S. (formerly Airport/Facility Directory).

decide on refueling stops), FSS located on the airport, control tower and ground control frequencies, traffic information, remarks, and other pertinent information. The NOTAMs, issued every 28 days, should be checked for additional information on hazardous conditions or changes that have been made since issuance of the Chart Supplement U.S.

The sectional chart bulletin subsection should be checked for major changes that have occurred since the last publication date of each sectional chart being used. Remember, the chart may be up to 6 months old. The effective date of the chart appears at the top of the front of the chart. The Chart Supplement U.S. generally has the latest information pertaining to such matters and should be used in preference to the information on the back of the chart, if there are differences.

### 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.