CHAPTER 8 - 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 simply the process of piloting an airplane 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 which allows pilots to track their position and provides available information which enhances safety. The three aeronautical charts used by VFR pilots are:

- VFR Navigation Charts (VNC)
- VFR Terminal Area Charts (VTA)
- World Aeronautical Charts (WAC)

A free catalog listing all Canadian and US aeronautical charts and related publications including prices and instructions for orderingc

VFR Navigation Charts

VFR Navigation Charts are the most common charts used by pilots today. The charts have a scale of 1:500,000 which allows for more detailed information to be included on the chart. A distance of 1cm on the chart equals 500,000 cm, or 5km, on the ground.

The charts provide an abundance of information, including airport data, navigational aids, airspace, and topography etc. Figure 8-1 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 frequencies and information on airspace. These charts are revised on a schedule of 1 to 5 years. Generally, charts near major urban centres are revised annually, rural areas every two years, and remote northern and arctic areas every 5 years. areas

VFR Terminal Area Charts (VTA)

VTA charts are helpful when flying in Class C or D terminal airspace. They have a scale of 1:250,000. These charts provide a more detailed display of topographical information and are revised annually.

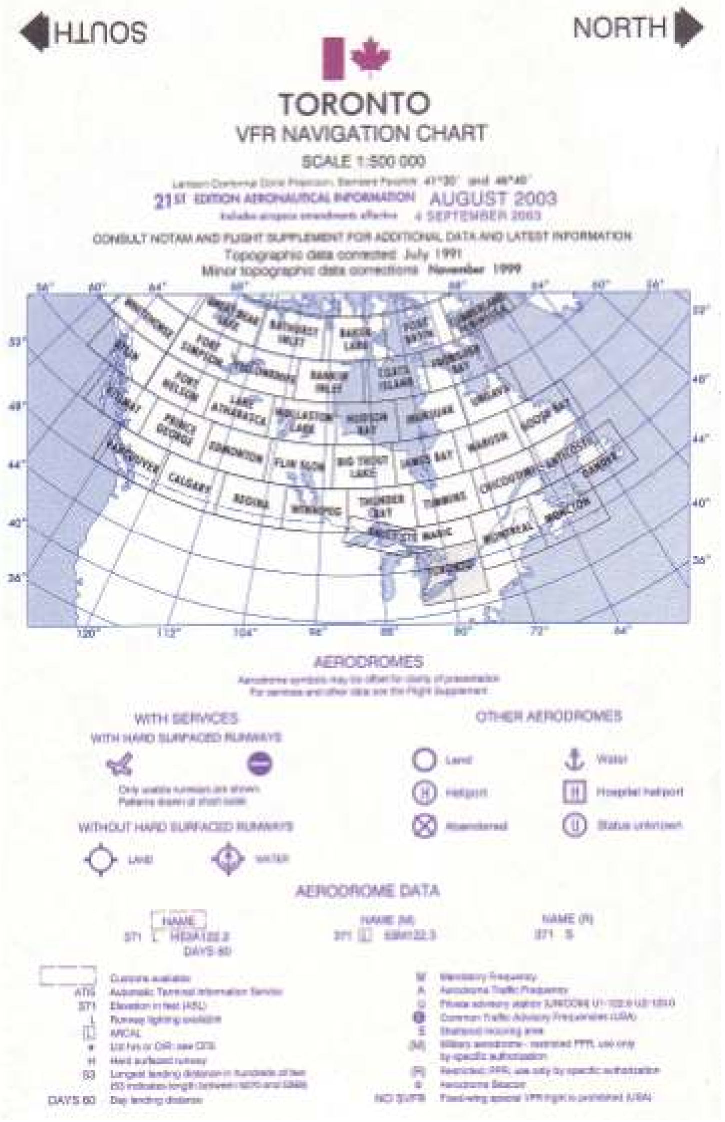
World Aeronautical Charts

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 nautical miles (NM) or 16 statute miles). These charts are similar to sectional charts and the symbols are the same except there is less detail due to the smaller scale. These charts are revised approximately every 5 years.

A list of current charts available for all areas of North America is available on the internet from:

http://www.aerotraining.com

VFR charts contain all the necessary information for *visual navigation.* Roads, cities, rivers, lakes, power lines and railways are all key elements of the visual landscape, and they are all shown on VFR charts. Airports, of course, are hi-lighted so that they are easy to find on the chart, as well as radio navigation aids and compass directions. The symbol of a compass on a chart is called an *azimuth.*



SOUTH

NORTH

TORONTO

VFR NAVIGATION CHART

SCALE 1:500 000

21ST EDITION AERONAUTICAL INFORMATION AUGUST 2003

4 SEPTEMBER 2003

CONSULT NOTAM AND FLIGHT SUPPLEMENT FOR ADDITIONAL DATA AND LATEST INFORMATION

Topographic data corrected July 1991

Minor topographic data corrections November 1999

AERODROMES

WITH SERVICES

WITH HARD SURFACED RUNWAYS

WITHOUT HARD SURFACED RUNWAYS

OTHER AERODROMES

AERODROME DATA

ATIS	Automatic Terminal Information Service
371	Elevation in feet (ASL)
L	Runway lighting available
H	Hard surfaced runway
DAYS 60	Day landing distance

Figure 8-1— VFR Navigation Chart

Fig 8.1b VFR Chart Legend, Part 1

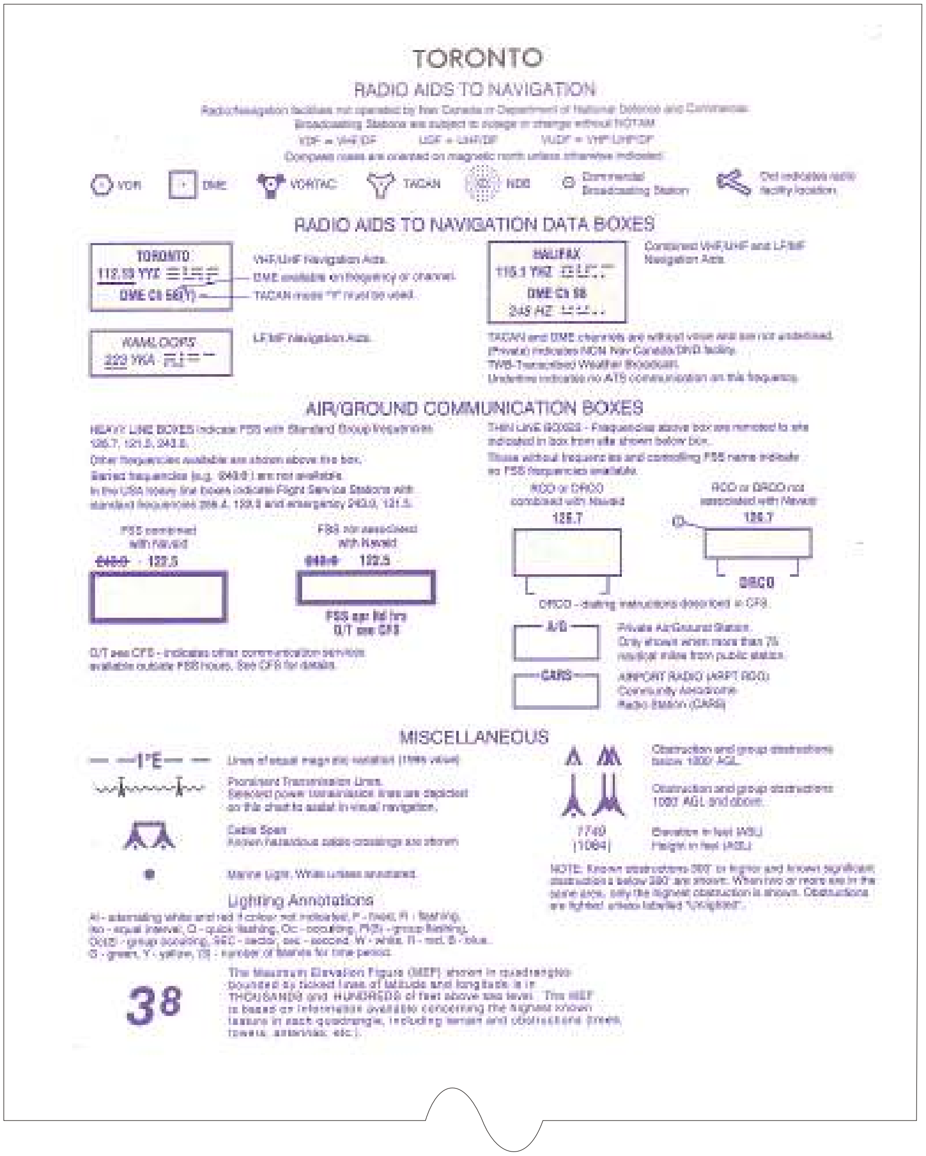


Fig 8.1c VFR Chart Legend Part 2

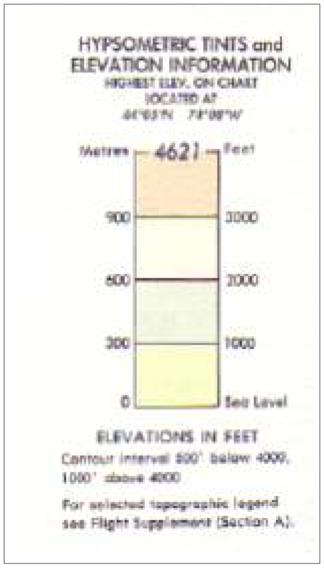


Fig 8.1c VFR Chart Legend Part 3: Hypsometric tints used to distinguish ground elevations

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 or south 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 8-2 labeled “LATITUDE” point to lines of latitude.

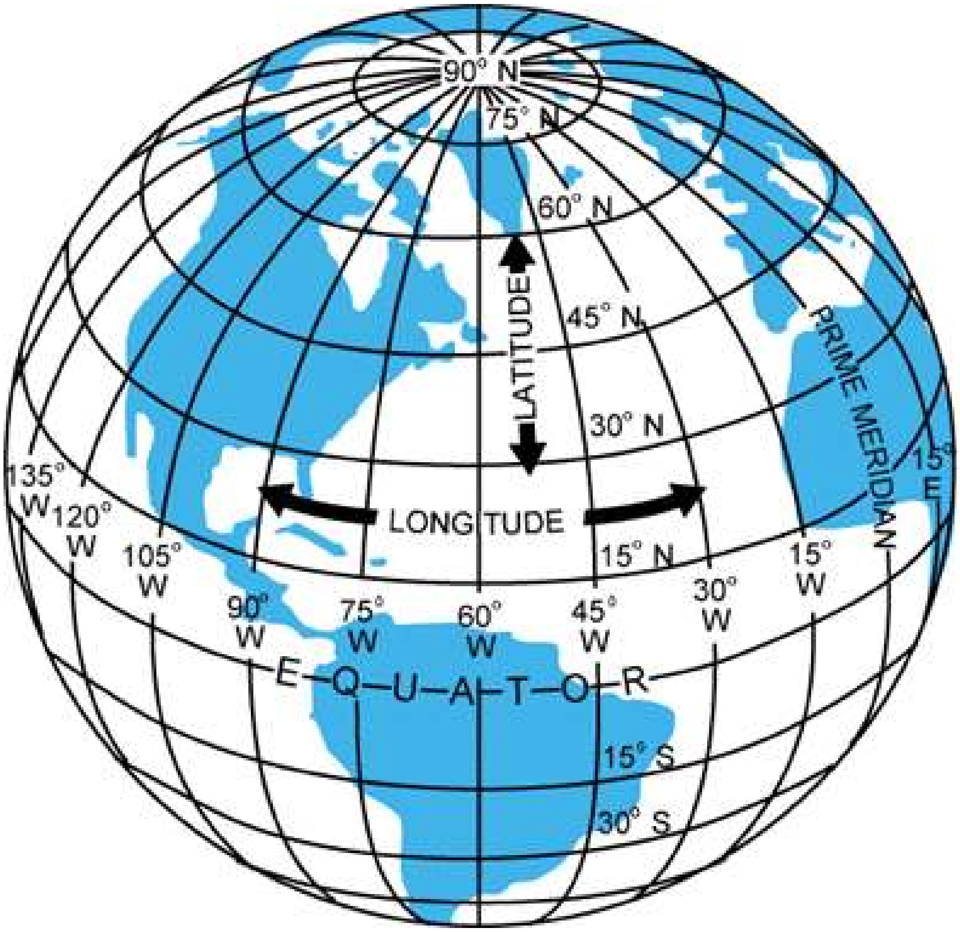


Figure 8-2.—Meridians and parallels—the basis of measuring time, distance, and direction.

Vertical 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 and west to 180°. The Prime Meridian is located at Greenwich because that is the location of the British Naval Academy that invented longitude and latitude for navigation. The arrows in figure 8-2 labeled “LONGITUDE” point to parallel lines of longitude.

Any specific geographical point can thus be located by reference to its longitude and latitude. Toronto, for example, is approximately 44° N. latitude, 79° W. longitude. Winnipeg, is approximately 50° N. latitude, 97° 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 revolution 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 forenoon, 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 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 8-3 shows the time zones of North America. When the Sun is directly above the 90th meridian, it is noon Central Standard Time. At the same time, it will be 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 last Sunday in April and the last Sunday in October, 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 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 stations (FSS) and take this into account when planning an eastbound flight. Certain types of aircraft (for example, seaplanes and balloons) are not permitted to fly at night.

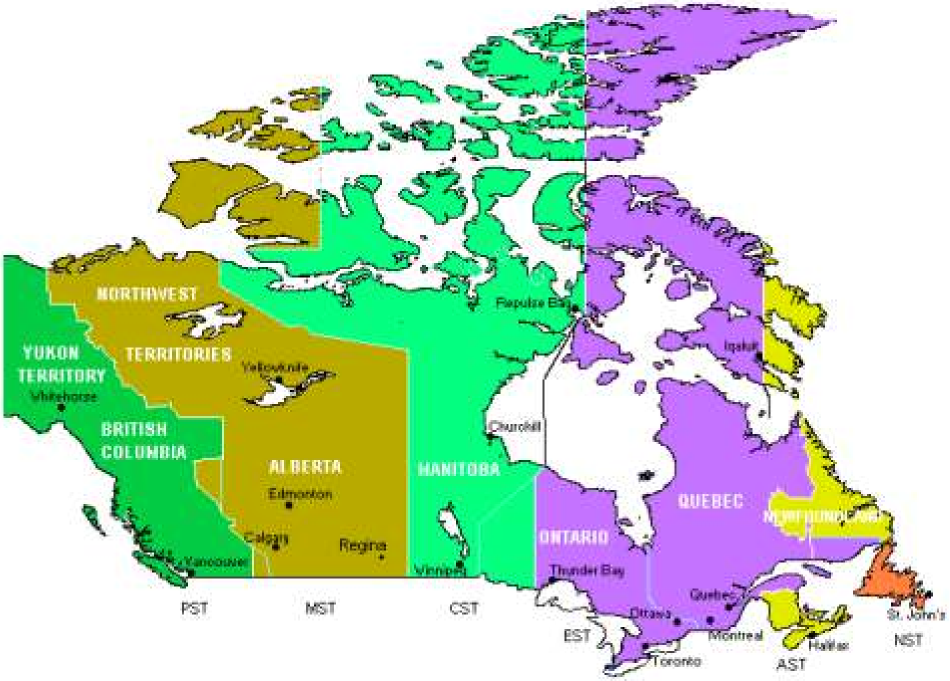


Figure 8-3.— Canadian Time zones.

In most aviation operations, time is expressed in terms of the 24-hour clock. Air traffic control 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; 10 p.m. is 2200 etc.

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:

•Newfoundland Standard Time	Add 3.5 hours
•Atlantic Standard Time	Add 4 hours
•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 which this line forms with a meridian. Direction is expressed in degrees, as shown by the compass rose in figure 8-4.

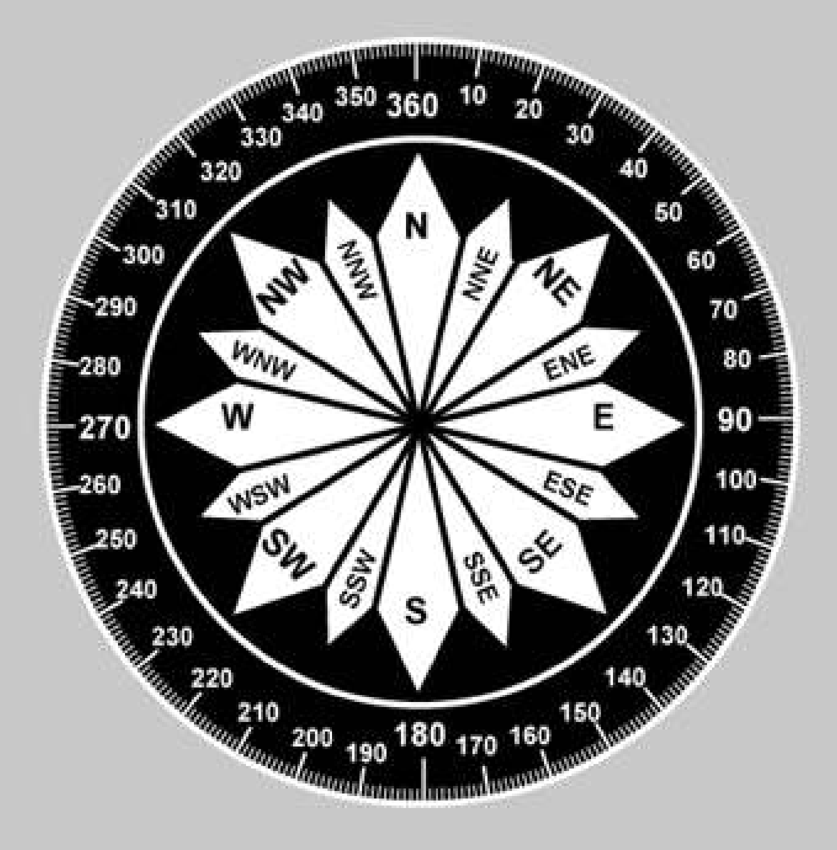
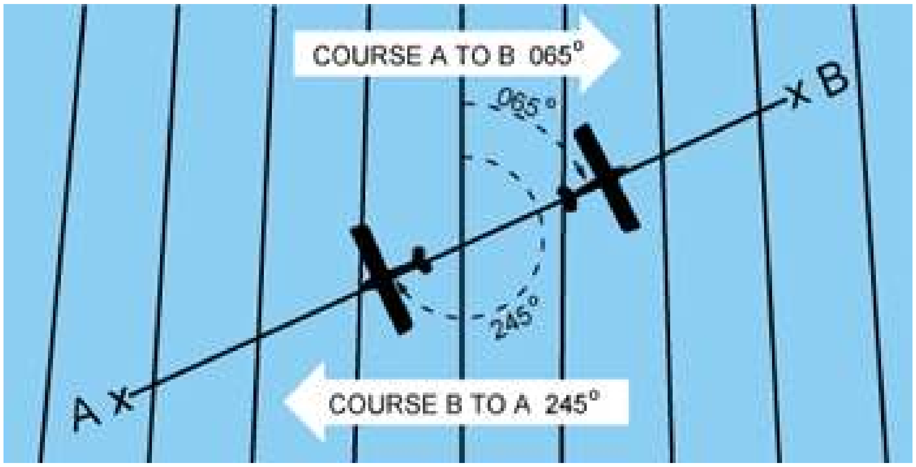


Figure 8-4.—Compass rose.

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. This is the direction measured by reference to a meridian or true north. It is the direction of intended flight as measured in degrees clockwise from true north. As shown in figure 8-5, the direction from A to B would be a true course of 065°, whereas the return trip (called the reciprocal) would be a true course of 245°.

Fig 8-5. Measuring Direction



The true heading is the direction in which the nose of the airplane points during a flight when measured in degrees clockwise from true north. Usually, it is necessary to head the airplane in a direction slightly different from the true course to offset the effect of wind. Consequently, numerical value of the true heading may not correspond with that of the true course. This will be 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 true course of 065°, the true heading 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 true north and magnetic north. It is expressed as east variation or west variation depending upon whether magnetic north (MN) is to the east or west of true north (TN), respectively.

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 8-6. If the Earth were uniformly magnetized, the compass needle would point toward the magnetic pole, in which case the variation between true north (as shown by the geographical meridians) and magnetic north (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, which connects points of equal magnetic variation. (The line connecting points at which there is no variation between true north and magnetic north is the agonic line.) An isogonic chart is shown in figure 8-6. Minor bends and turns in the isogonic and agonic lines are caused by unusual geological conditions affecting magnetic forces in these areas.

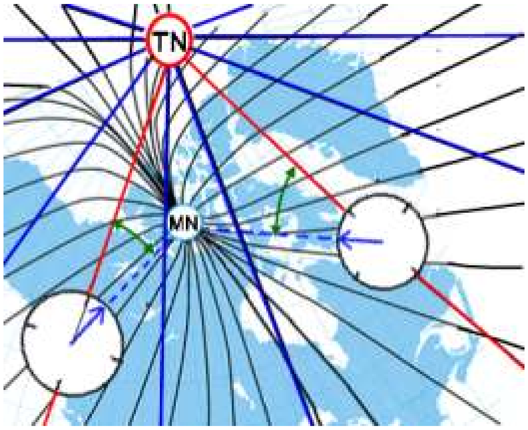


Figure 8-6.—Isogonic chart. Magnetic meridians are in black, geographic meridians and parallels Are in blue. Variation is the angle between a magnetic and geographic meridian (green).

On the west coast of Canada, the compass needle points to the east of true north; on the east coast, the compass needle points to the west of true north. Zero degree variation exists on the agonic line which runs roughly through Lake Michigan, the Appalachian Mountains, and off the coast of Florida, where magnetic north and true north coincide. [Compare figures 8-7 and 8-8]

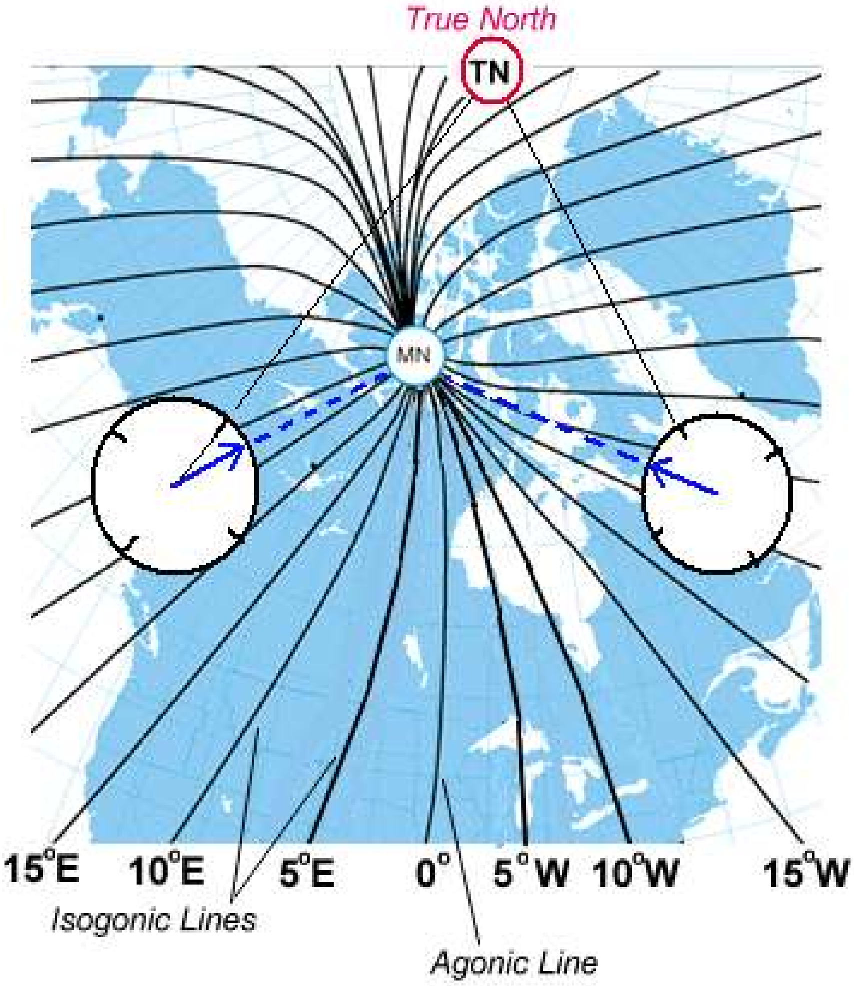


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Figure 8-7.—A typical isogonic chart. The black lines are isogonic lines which connect geographic points with identical magnetic variation.

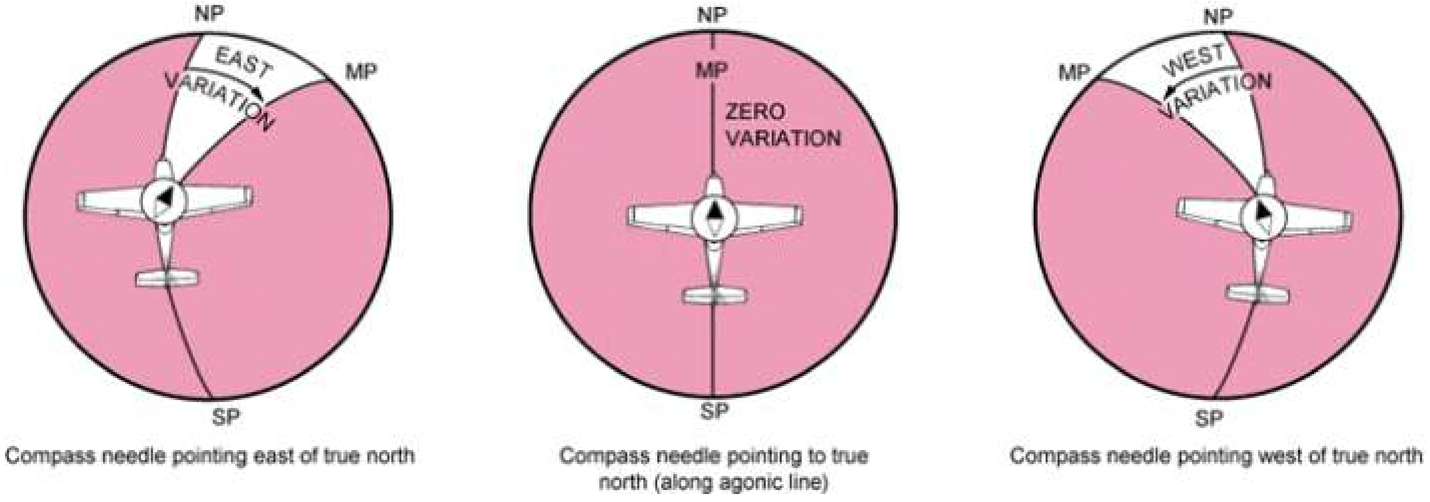
Because courses are measured in reference to geographical meridians which point toward true north, and these courses are maintained by reference to the compass which points along a magnetic meridian in the general direction of magnetic north, the true direction must be converted into magnetic direction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

If the variation is shown as “9° E,” this means that magnetic north is 9° east of true north. If a true heading 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 heading of 081° (090° - 9°) would be flown. To fly south, the magnetic heading would be 171° (180° - 9°). To fly west, it would be 261° (270° - 9°). To fly a true heading of 060°, a magnetic heading of 051° (060° - 9°) would be flown.

Remember, to convert true course or heading to magnetic course or heading, note the variation shown by the nearest isogonic line. 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 reading for the flight. To determine compass heading, a correction for deviation must be made. Because of magnetic influences within the airplane such as electrical circuits, radio, lights, tools, engine, magnetized metal parts, etc., the compass needle is frequently deflected from its normal reading. This deflection is deviation. The deviation is different for each airplane, and it also may vary for different headings in the same airplane. 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 magnetic north. On easterly or westerly headings, however, the compass indications would be in error, as shown in figure 8-9. Magnetic attraction can come from many other parts of the airplane; the assumption of attraction in the engine is merely used for the purpose of illustration.



Compass needle pointing east of true north

Compass needle pointing to true north (along agonic line)

Compass needle pointing west of true north

Figure 8-8.—Effect of variation on the compass.

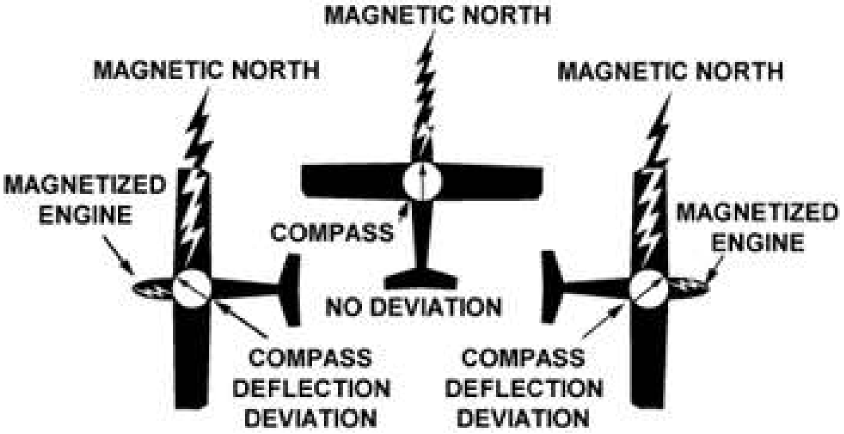


Figure 8-9.—Magnetized portions of the airplane cause the compass to deviate from its normal indications.

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 airplane 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 (called “swinging the compass”) is briefly outlined.

The airplane is placed on a magnetic compass rose, the engine started, and electrical devices normally used (such as radio) are turned on. Tailwheel-type airplanes should be jacked up into flying position. The airplane is aligned with magnetic north indicated on the compass rose and the reading shown on the compass is recorded on a deviation card. The airplane is then aligned at 30° intervals and each reading is recorded. If the airplane 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.

On the compass card, the letters, N, E, S, and W, are used for north, east, south, and west. The final zero is omitted from the degree markings so that figures will be larger and more easily seen.

A deviation card, similar to figure 8-10, 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.

FOR (MAGNETIC)	N	30	60	E	120	150	S	210	240W	300	330
STEER (COMPASS)	0	28	57	86	117	148	180	212	243274	303	332

Figure 8-10.—Compass deviation card.

The following method is used by many pilots to determine compass heading:

After the true course (TC) is measured, and wind correction applied resulting in a true heading (TH), the sequence TH ± V = MH ± D = CH is followed to arrive at compass heading. [Figure 8-11]

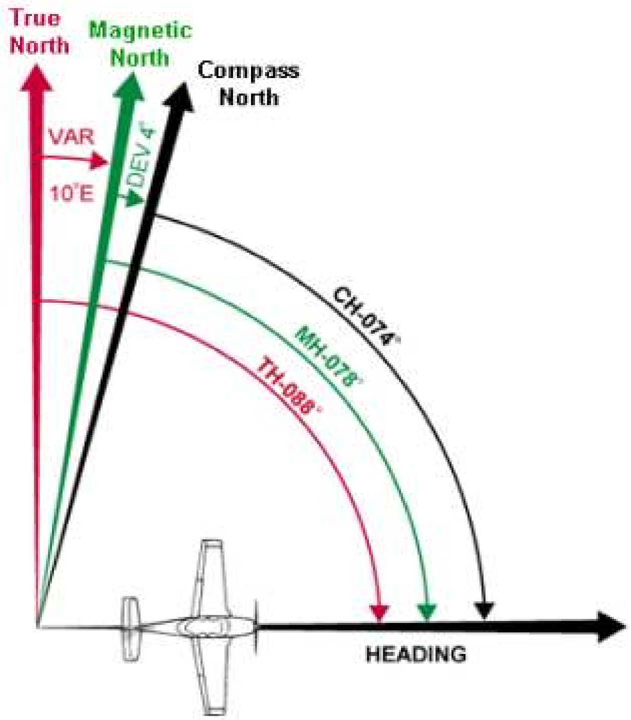


Figure 8-11.—Relationship between true, magnetic, and compass headings for a particular instance.

EFFECT OF WIND

The preceding discussion explained how to measure a true course 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 will be carried 25 NM southward in 1 hour. This effect becomes apparent when clouds, dust, toy balloons, etc., are observed being blown along by the wind. Obviously, an airplane flying within the moving mass of air will be similarly affected. Even though the airplane does not float freely with the wind, it moves through the air at the same time the air is moving over the ground, thus is affected by wind. Consequently, at the end of 1 hour of flight, the airplane will be in a position which results from a combination of these two motions:

- the movement of the air mass in reference to the ground, and
- the forward movement of the airplane through the air mass.

Actually, these two motions are independent. So far as the airplane's flight through the air is concerned, it makes no difference whether the mass of air though which the airplane 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 airplane 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 8-12, an airplane flying eastward at an airspeed of 120 knots in calm wind, will have a groundspeed exactly the same—120 knots. If the mass of air is moving eastward at 20 knots, the airspeed of the airplane will not be affected, but the progress of the airplane over the ground will be 120 plus 20, or a groundspeed of 140 knots. On the other hand, if the mass of air is moving westward at 20 knots, the airspeed of the airplane still remains the same, but groundspeed becomes 120 minus 20 or 100 knots.

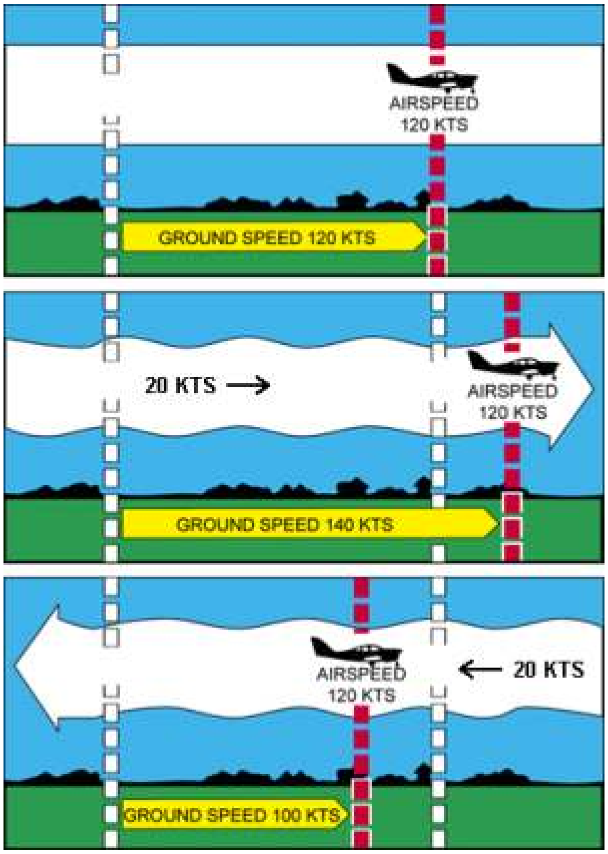


Figure 8-12.—Motion of the air affects the speed with which airplanes move over the Earth's surface. Airspeed, the rate at

which an airplane moves through the air, is not affected by air motion.

Assuming no correction is made for wind effect, if the airplane is heading eastward at 120 knots, and the air mass moving southward at 20 knots, the airplane at the end of 1 hour will be 120 miles east of its point of departure because of its progress through the air. It will be 20 miles south because of the motion of the air. Under these circumstances, the airspeed remains 120 knots, but the groundspeed is determined by combining the movement of the airplane with that of the air mass. Groundspeed can be measured as the distance from the point of departure to the position of the airplane at the end of 1 hour. The groundspeed 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 will be explained later in this chapter. [See Figure 8-13]

Figure 8-13.—Airplane flightpath resulting from its airspeed and direction, and the windspeed and direction.

The direction in which the plane is pointing as it flies is heading. Its actual path over the ground, which is a combination of the motion of the airplane and the motion of the air, is track. The angle between the heading and the track is drift angle. If the airplane's heading coincides with the true course and the wind is blowing from the left, the track will not coincide with the true course. The wind will drift the airplane to the right, so the track will fall to the right of the desired course or true course. [Figure 8-14]

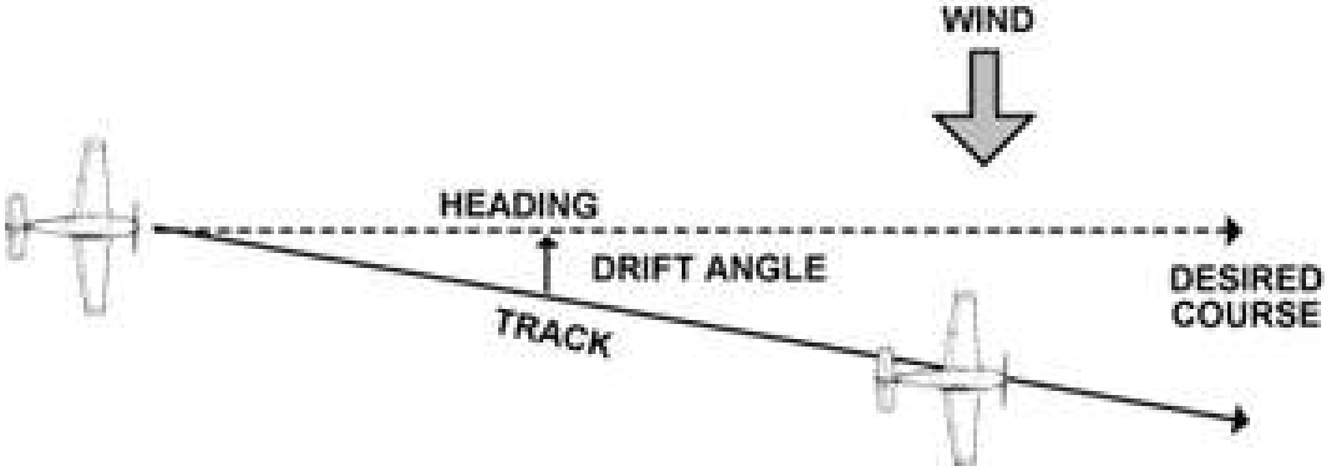


Figure 8-14.—Effects of wind drift on maintaining desired course.

By determining the amount of drift, the pilot can counteract the effect of the wind and make the track of the airplane coincide with the desired course. If the mass of air is moving across the course from the left, the airplane will drift to the right, and a correction must be made by heading the airplane sufficiently to the left to offset this drift. To state in another way, if the wind is from the left, the correction will be made by pointing the airplane to the left a certain number of degrees, therefore correcting for wind drift. This is wind correction angle and is expressed in terms of degrees right or left of the true course. [Figure 8-15]

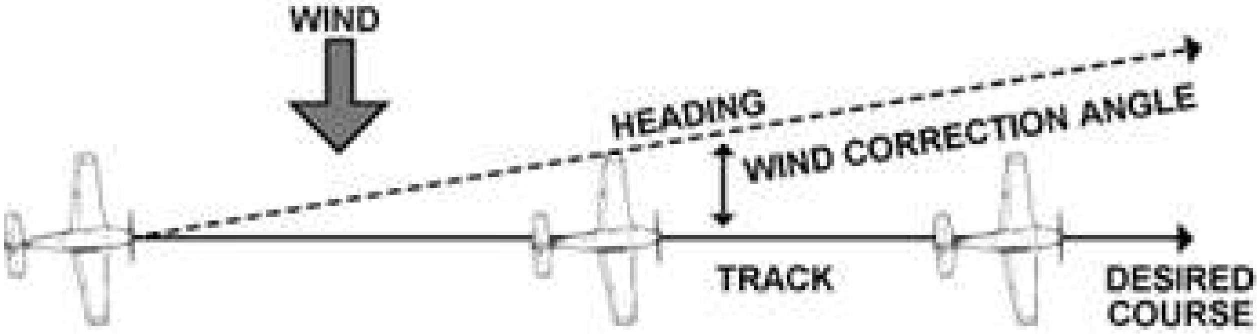


Figure 8-15.—Establishing a wind correction angle that will counteract wind drift and maintain the desired course.

To summarize:

- **COURSE**— is the intended path of an aircraft over the Earth; 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**— is the direction in which the nose of the airplane points during flight.
- **TRACK**—is the actual path made over the ground in flight. (If proper correction has been made for the wind, track and course will be identical.)
- **DRIFT ANGLE**—is the angle between heading and track.
- **WIND CORRECTION ANGLE**—is correction applied to the course to establish a heading so that track will coincide with course.
- **AIRSPEED**—is the rate of the airplane’s progress through the air.
- **GROUNDSPEED**—is the rate of the airplane’s in-flight 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. These calculations should present no difficulty.

Converting Minutes to Equivalent Hours

It frequently 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 30/60 = 0.5 hour. To convert hours to minutes, multiply by 60. Thus, 0.75 hour equals 0.75 x 60 = 45 minutes. Time T = D/GS

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

Distance D = GS * T

To find the distance flown in a given time, multiply ***groundspeed (not airspeed)*** by time. The distance flown in 1 hour 45 minutes at a groundspeed of 120 knots is 120 x 1.75, or 210 nautical miles.

Groundspeed GS = D/T

To find the groundspeed, divide the distance flown by the time required. If an airplane flies 270 NM in 3 hours, the groundspeed is 270 divided by 3 = 90 knots.

Converting Knots to Miles Per Hour

Another conversion is that of changing knots to miles per hour. The aviation industry uses knots for all speed measurements, but some very old airplanes have speed indicators in the “mph” units. It might be useful to discuss the conversion for those antique flyers who do use miles per hour when working with speed problems.

A knot is 1 nautical mile per hour. Because there are 1852 metres (1.8km) in a nautical mile and 1609 metres (1.6km) in a statute mile, the conversion factor is 1.15. To convert knots to miles per hour, multiply knots by 1.15. For example: a windspeed of 20 knots is equivalent to 23 MPH. *This information is provided for antique operators only, and is not required for exam purposes.*

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

Fuel Consumption

Airplane fuel consumption rate in middle-aged airplanes is computed in gallons per hour. Fuel is sold in litres, and some newer types such as the Katana use litres in all measurements. Consequently, to determine the fuel required for a given flight, the time required for the flight must be known. Time in flight multiplied by rate of consumption gives the quantity of fuel required. For example, a flight of 400 NM at a groundspeed of 100 knots requires 4 hours. If the plane consumes 5 gallons an hour, the total consumption will be 4 x 5, or 20 gallons. One US gallon is approximately 3.9 litres; 1 litre is approximately 1 US quart. Accurate units are listed in the ***AIP Canada.***

The rate of fuel consumption depends on many factors: condition of the engine, propeller pitch, propeller RPM, richness of the mixture, and particularly 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.

Flight Computers

Up to this point, only mathematical formulas have been used to determine time, distance, speed, fuel consumption, etc. In reality, most pilots will use a mechanical or electronic flight computer. These devices can compute numerous problems associated with flight planning and navigation. The mechanical or electronic computer will have an instruction book and most likely sample problems so the pilot can become familiar with its functions and operation. [Figure 8-16]

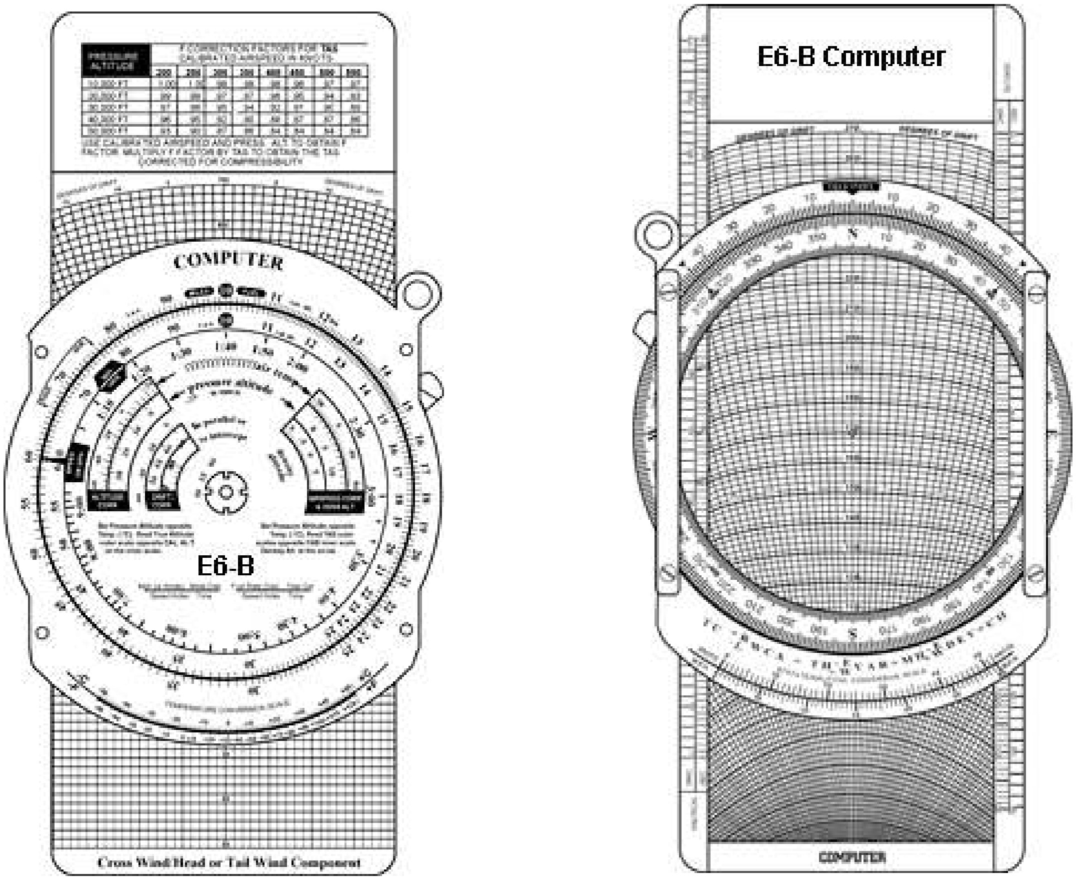


Fig 8-16: The E6-B flight computer

Plotters

Another aid in flight planning is a plotter, which is a protractor and ruler. The pilot can use this when determining true course and measuring distance. Most plotters have a ruler which measures in both nautical and statute miles and has a scale for a sectional chart on one side and a world aeronautical chart on the other. [Figure 8-16]

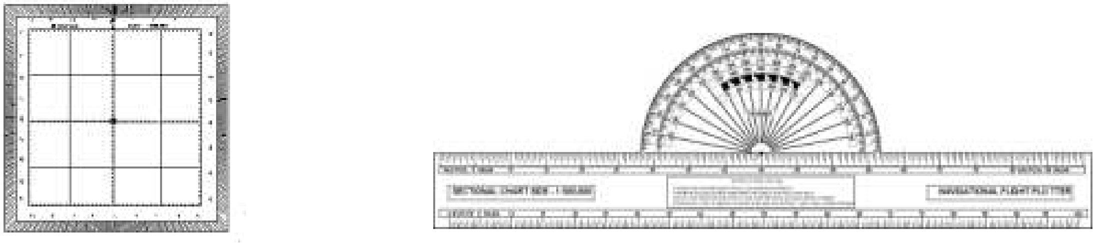


Fig 8-16: The Douglas Protractor (left) is used for plotting tracks In northern latitudes such as Canada where the meridians are converging more sharply than in southern latitudes. The combined plotter (right) can be used with reasonable accuracy in lower latitudes where the problem of converging meridians is not so severe.

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, power lines, etc. If possible, select features that will make useful boundaries or brackets on each side of the course, such as highways, rivers, railroads, mountains, etc. 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. If confused, hold the heading. If a turn is made away from the heading, it will be 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 a pilot. 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.

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 windspeed and velocity, are heading and groundspeed. The predicted heading will guide the airplane along the intended path and the groundspeed will establish the time to arrive at each checkpoint and the destination. The word “dead” in dead reckoning is actually derived from “ded,” or deduced reckoning. Except for flights over water, dead reckoning is usually used with pilotage for cross-country flying. The heading and groundspeed as calculated is constantly monitored and corrected by pilotage as observed from checkpoints.

The Wind Triangle or Vector Analysis

If there is no wind, the airplane’s ground track will be the same as the heading and the groundspeed will be the same as the true airspeed. Only on rare occasions does this condition exist. A wind triangle, the pilot’s version of vector analysis, is the backbone of dead reckoning.

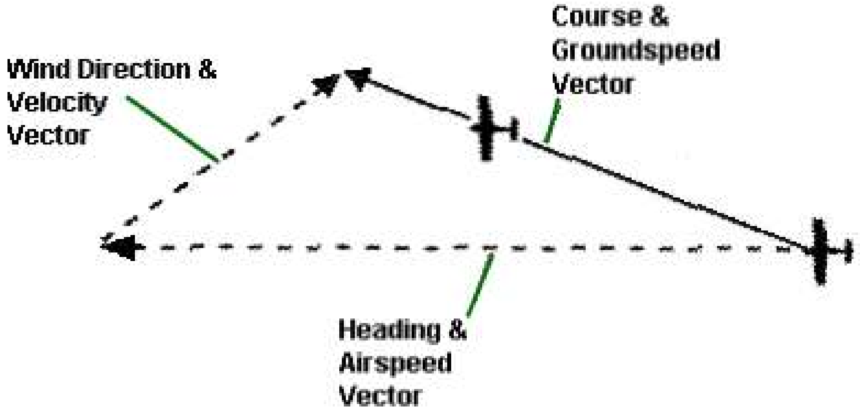


Fig 8-17: The Wind Triangle, or the Triangle of Vectors
This is a fundamental navigation principle.

The wind triangle is a graphic explanation of the effect of wind upon flight. Groundspeed, 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 which 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 a flight is to be made on a course to the east, with a wind blowing from northeast, the airplane must be headed somewhat to the north of east to counteract drift. This can be represented by a diagram as shown in figure 8-17. Each line represents direction and speed. The long dotted line shows the direction the plane is heading, and its length represents the airspeed for 1 hour. The short dotted line at the right shows the wind direction, and its length represents the wind velocity for 1 hour. The solid line shows the direction of the track, or the path of the airplane as measured over the Earth, and its length represents the distance traveled in 1 hour, or the groundspeed.

In actual practice, the triangle illustrated in figure 8-17 is not drawn; instead, construct a similar triangle as shown by the black lines in figure 8-18, 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 true course which in this example is assumed to be 090° (east). From the National Weather Service, it is learned that the wind at the altitude of the intended flight is 40 knots from the northeast (045°). Since the National Weather Service reports the windspeed in knots, if the true airspeed of the airplane 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 and south. (The various steps are shown in figure 8-19.)

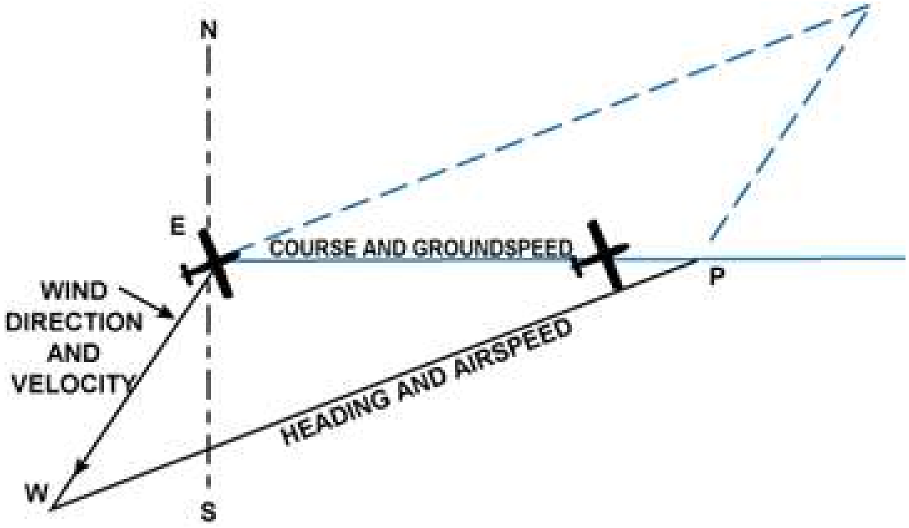
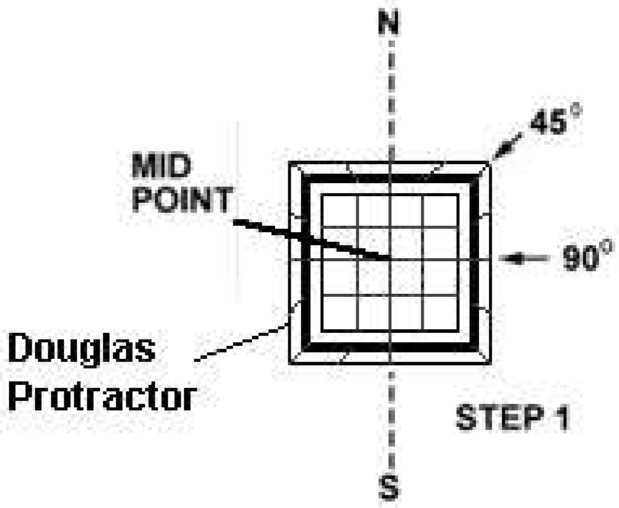
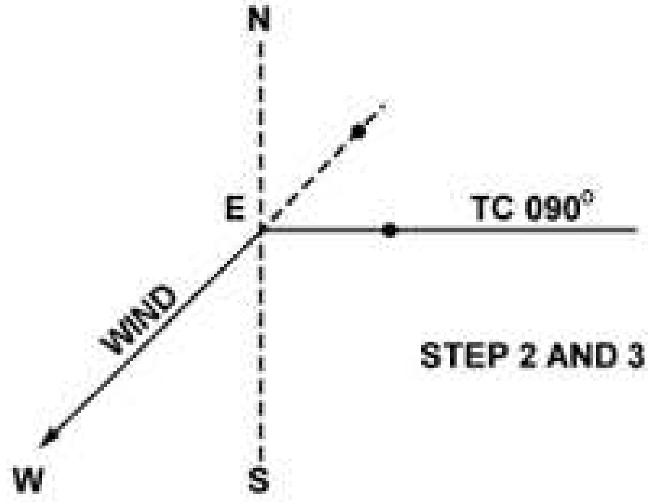
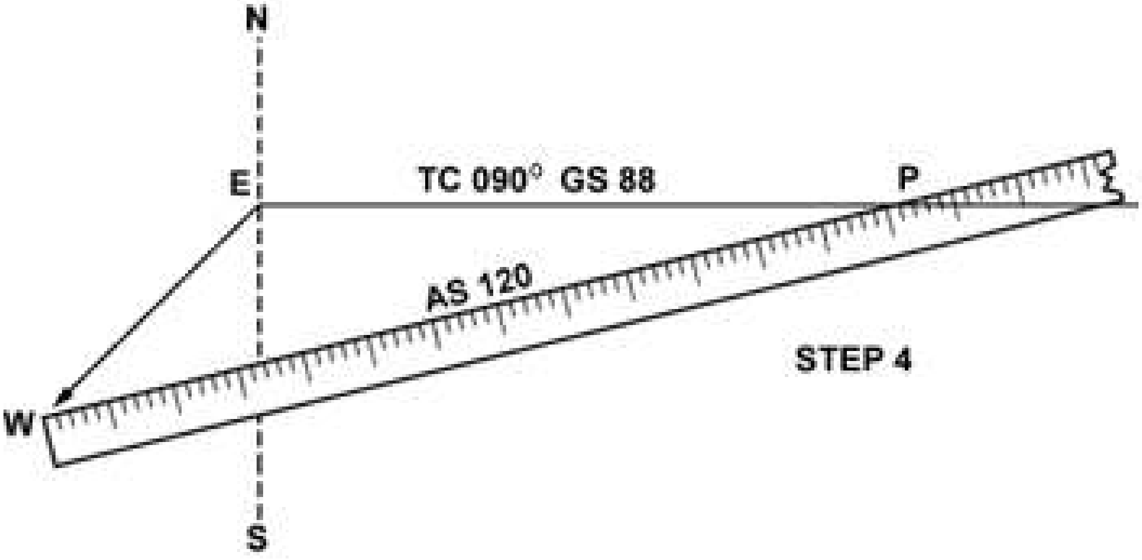


Figure 8-18.—The wind triangle as drawn in navigation practice. Blue lines show the triangle as drawn in figure 8-17.







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).

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

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. 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 1cm = 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 true course line. Draw the line and label it "AS 120." The point "P" placed at the intersection, represents the position of the airplane at the end of 1 hour. The diagram is now complete.

The distance flown in 1 hour (groundspeed) is measured as the numbers of units on the true course line (88 nautical miles per hour or 88 knots).

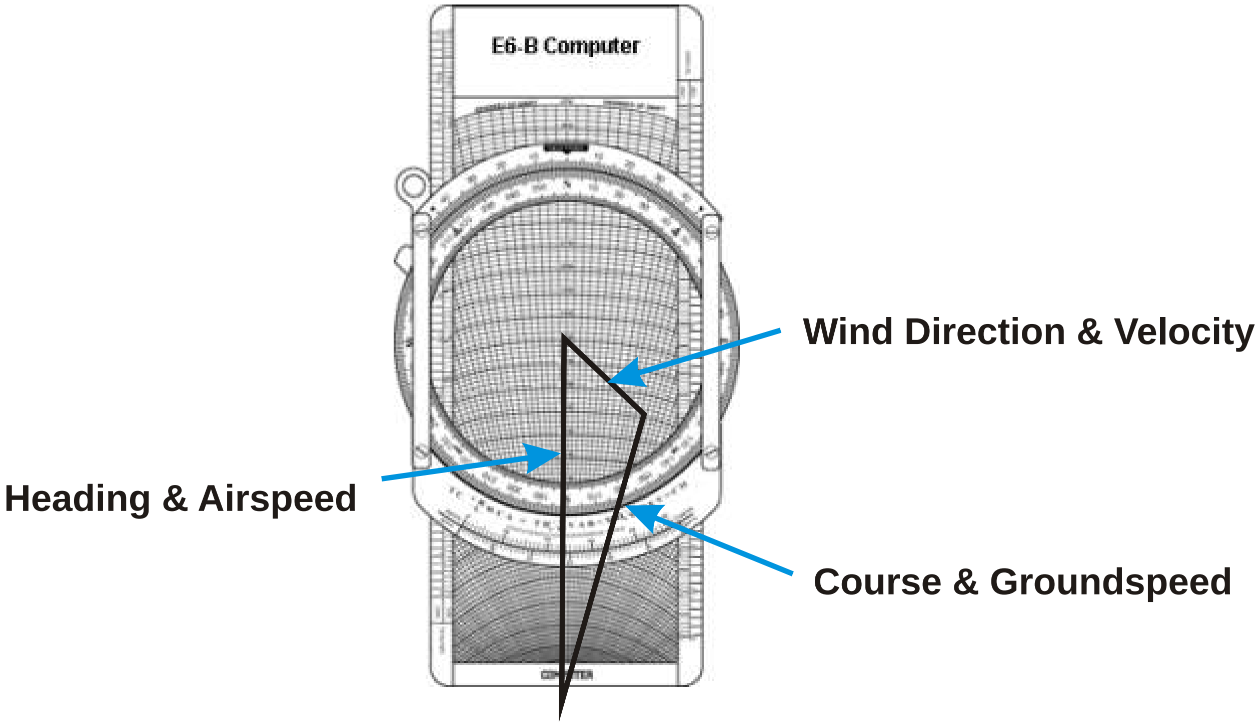


Fig 19b. The Triangle of Velocities as visualized using the wind side of the E6-B flight computer

The true heading 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 true heading directly in degrees (076°). [Figure 8-20]

- By placing the straight side of the protractor along the true course line, with its center at P, read the angle between the true course and the airspeed line. This is the wind correction angle (WCA) which must be applied to the true course to obtain the true heading. If the wind blows from the right of true course, the angle will be added; if from the left, it will be subtracted. In the example given, the WCA is 14° and the wind is from the left; therefore, subtract 14° from true course of 090°, making the true heading 076°. [Figure 8-21]

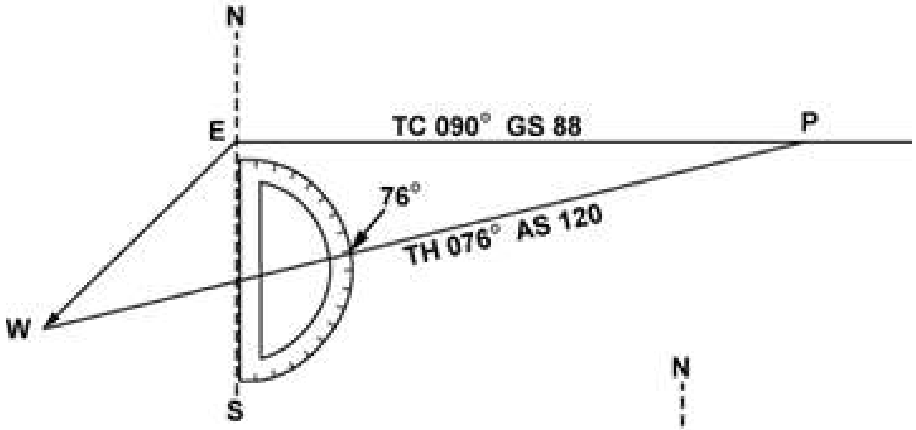
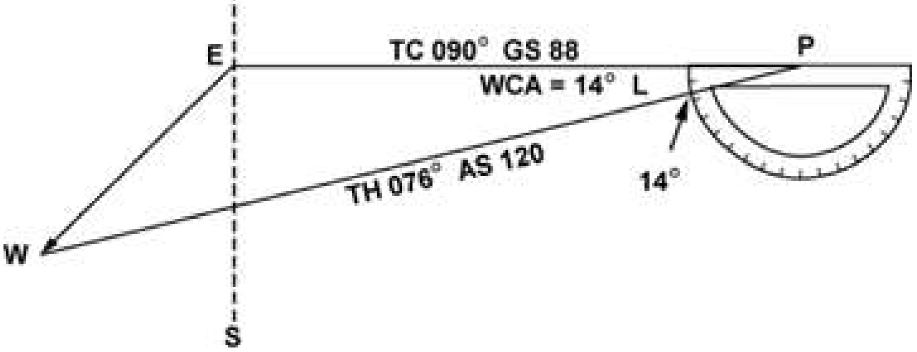


Figure 8-20.—Finding true heading by direct measurement.



After obtaining the true heading, 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 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 groundspeed of 88 knots, which gives 2.5 hours or (2:30) as the time required. If fuel consumption is 8 gallons an hour, 8 x 2.5 or about 20 gallons will be used. Briefly summarized, the steps in obtaining flight information are as follows:

- TRUE COURSE—Direction of the line connecting two desired points, drawn on the chart and measured clockwise in degrees from true north on the mid-meridian.
- WIND CORRECTION ANGLE—Determined from the wind triangle. (Added to TC if the wind is from the right; subtract if wind is from the left.)
- TRUE HEADING—The direction measured in degrees clockwise from true north, in which the nose of the plane should point to make good the desired course.
- VARIATION—Obtained from the isogonic line on the chart. (Added to TH if west; subtract if east.)
- MAGNETIC HEADING—An intermediate step in the conversion. (Obtained by applying variation to true heading.)
- DEVIATION—Obtained from the deviation card on the airplane. (Added to MH or subtracted from, as indicated.)
- COMPASS HEADING—The reading on the compass (found by applying deviation to MH) which will be followed to make good 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).
- GROUNDSPEED—Obtained by measuring the length of the TC line on the wind triangle (using the scale employed for drawing the diagram).
- TIME FOR FLIGHT— Total distance divided by groundspeed.
- FUEL RATE—Predetermined gallons per hour used at cruising speed.

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

Most *Flight Planning Log Sheets*, such as the downloadable one included in the On-line Exams on this website, are laid out in this ame sequence in order to simplify the record-keeping involved in planning a flight.

FLIGHT PLANNING

The Canadian Aviation Regulations state, in part, that before beginning a flight, the pilot in command 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 reported by air traffic control (ATC).

Careful preflight planning is extremely important. With adequate planning, the pilot can complete the flight with greater confidence, ease, and safety. Statistics show inadequate preflight planning is a significant cause of fatal accidents.

Assembling Necessary Material

The pilot should collect the necessary material well before the flight to be sure nothing is missing. 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.

A GPS unit is useful to double-check dead-reckoning calculations. Note that on your flight test, you will likely be asked to perform all navigation without the assistance of a GPS unit.

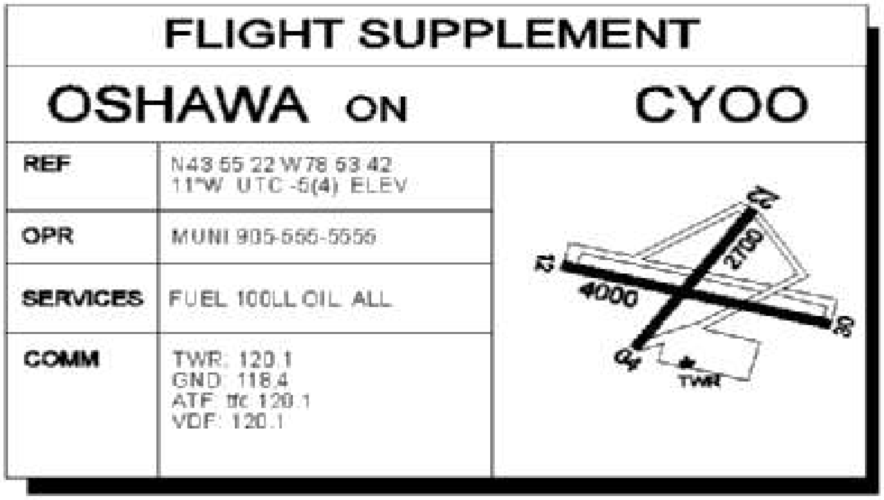
Weather Check

It may be 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 5 (Weather) discusses obtaining a weather briefing.

Figure 8-22.—Toronto VNC chart excerpt.

Use of the Canada Flight Supplement

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 **Canada Flight Supplement.** This includes location, elevation, runway and lighting facilities, available services, availability of aeronautical advisory station frequency (UNICOM), types of fuel available (use to decide on refueling stops), AFSS/FSS located on the airport, control tower and ground control frequencies, traffic information, remarks, and other pertinent information. The NOTAMs, issued every 14 days, should be checked for additional information on hazardous conditions or changes that have been made since issuance of the **Canada Flight Supplement.**



FLIGHT SUPPLEMENT

OSHAWA ON CYOO

REF	N43 55 22 W78 53 42 11°W UTC -5(4) ELEV
OPR	MUNI 905-555-5555
SERVICES	FUEL 100LL OIL ALL
COMM	TWR: 120.1 GND: 118.4 ATF: tfc 120.1 VDF: 120.1

Remember, the VNC chart may be up to 5 years old. The effective date of the chart appears at the top of the front of the chart. The **Canada Flight Supplement** will generally have 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. Chart issue dates are also available on this website.

Airplane Flight Manual or Pilot's Operating Handbook

The Airplane Flight Manual or Pilot's Operating Handbook should be checked to determine the proper loading of the airplane (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 airplane to be sure that the total weight does not exceed the maximum allowable. The distribution of the load must be known to tell if the resulting center of gravity is within limits. Be sure to use the latest weight and balance information in the FAA-approved Airplane Flight Manual or other permanent aircraft records, as appropriate, to obtain empty weight and empty weight center-of-gravity 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, then compare it with the estimated time for the flight so that refueling points along the route can be included in the plan.

CHARTING THE COURSE

Once the weather has been checked and some preliminary planning done, it is time to chart the course and determine the data needed to accomplish the flight. The following sections will provide a logical sequence to follow in charting the course, filling out a flight log, and filing a flight plan. In the following example, a trip is planned based on the following data and the sectional chart excerpt in figure 8-22.

Route of flight: OshawaAirport direct to Orillia Airport

True Airspeed (TAS)	115 knots
Winds Aloft	360° at 10 knots
Usable fuel	38 US gallons
Fuel Rate	8 GPH
Deviation	+2°

Steps in Charting the Course

The following is a suggested sequence for arriving at the pertinent information for the trip. As information is determined, it may be noted as illustrated in the example of a flight log in figure 8-23. Where calculations are required, the pilot may use a mathematical formula or a manual or electronic flight computer. If unfamiliar with how to use a manual or electronic computer competently, it would be advantageous to read the operation manual and work several practice problems at this point.

First draw a line from Oshawa Airport directly to Orillia Airport . The course line should begin at the center of the airport of departure and end at the center of the destination airport (track shown by red line). If the route is direct, the course line will consist of a single straight line. If the route is not direct, it will consist of two or more straight line segments—for example, a VOR station which is off the direct route, but which will make navigating easier, may be chosen (radio navigation is discussed later in this chapter).

Appropriate checkpoints should be selected along the route and noted in some way. These should be easy-to-locate points such as large towns, large lakes and rivers, or combinations of recognizable points such as towns with an airport, towns with a network of highways and railroads entering and departing, etc. Normally, choose only towns indicated by splashes of yellow on the chart. Do not choose towns represented by a small circle—these may turn out to be only a half-dozen houses. (In isolated areas, however, towns represented by a small circle can be prominent checkpoints.) For this trip, three checkpoints have been selected. Checkpoint 1 consists of the western tip of Lake Scugog located east of the course followed by Checkpoint 2, the town of Greenbank. Checkpoint 3 is the southeast shore of Lake Simcoe.

The course and areas on either side of the planned route should be checked to determine if there is any type of airspace with which the pilot should be concerned or which has special operational requirements. For this trip, it should be noted that the course will pass through a segment of Class F training airspace. You should check with FSS for the current status and activity of this airspace.

Study the terrain and obstructions along the route. This is necessary to determine the highest and lowest elevations as well as the highest obstruction to be encountered so that an appropriate altitude which will conform to Crusing Altitude regulations can be selected. If the flight is to be flown at an altitude more than 3,000 feet above the terrain, conformance to the cruising altitude appropriate to the direction of flight is required. Check the route for particularly rugged terrain so it can be avoided. Areas where a takeoff or landing will be made should be carefully checked for tall obstructions. TV and communications towers may extend to altitudes over 1,500 feet above the surrounding terrain. It is essential that pilots be aware of their presence and location.

Since the wind is no factor and it is desirable and within the airplane's capability to fly above any training activities north of Oshawa, an altitude of 4,500 feet MSL will be chosen. This altitude also gives adequate clearance of all obstructions as well as conforms to the CARs requirement to fly at an altitude of odd thousand plus 500 feet when on a magnetic course between 0 and 179°.

Next, the pilot may want to measure the total distance of the course as well as the distance between checkpoints. The total distance is 48 NM and the distance between checkpoints is as noted on the flight log in figure 8-23.

After determining the distance, the true course should be measured. If using a plotter, follow the directions on the plotter. The true course is 335°. Once the true heading is established, the pilot can determine the compass heading. This is done by following the formula given earlier in this chapter. The formula is:

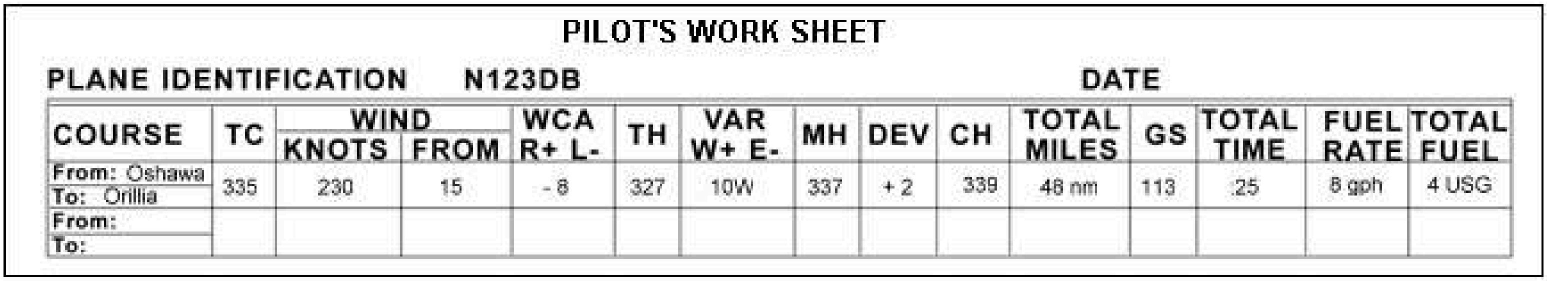
$$TC \pm WCA = TH \pm VAR = MH \pm DEV = CH$$

The wind correction angle can be determined by using a manual or electronic flight computer. Using a wind of 230° at 15 knots, it is determined the WCA is 8° left. This is subtracted from the TC making the TH 327°. Next, the pilot should locate the isogonic line closest to the route of the flight to determine variation. Figure 8-22 shows two isogonic lines, and the variation to be 10° W which means it should be added to the TH giving an MH of 337°. Next, add 2° to the MH for the deviation correction (See Fig 8-10). This gives the pilot the compass heading which is 339°.

Next, the groundspeed should be determined. This can be done using a manual or electronic calculator. It is determined the GS is 113 knots. Based on this information, the total trip time, as well as time between checkpoints, and the fuel burned can be determined. These calculations can be done mathematically or by using a manual or electronic calculator.

For this trip, the GS is 113 knots and the total time is 30 minutes (25 minutes enroute, plus 5 minutes for climb to altitude). Refer to the flight log in figure 8-23 for the time between checkpoints. For 30 minutes of flight at 8gph, the fule consumed will be approximately 4 US gallons.

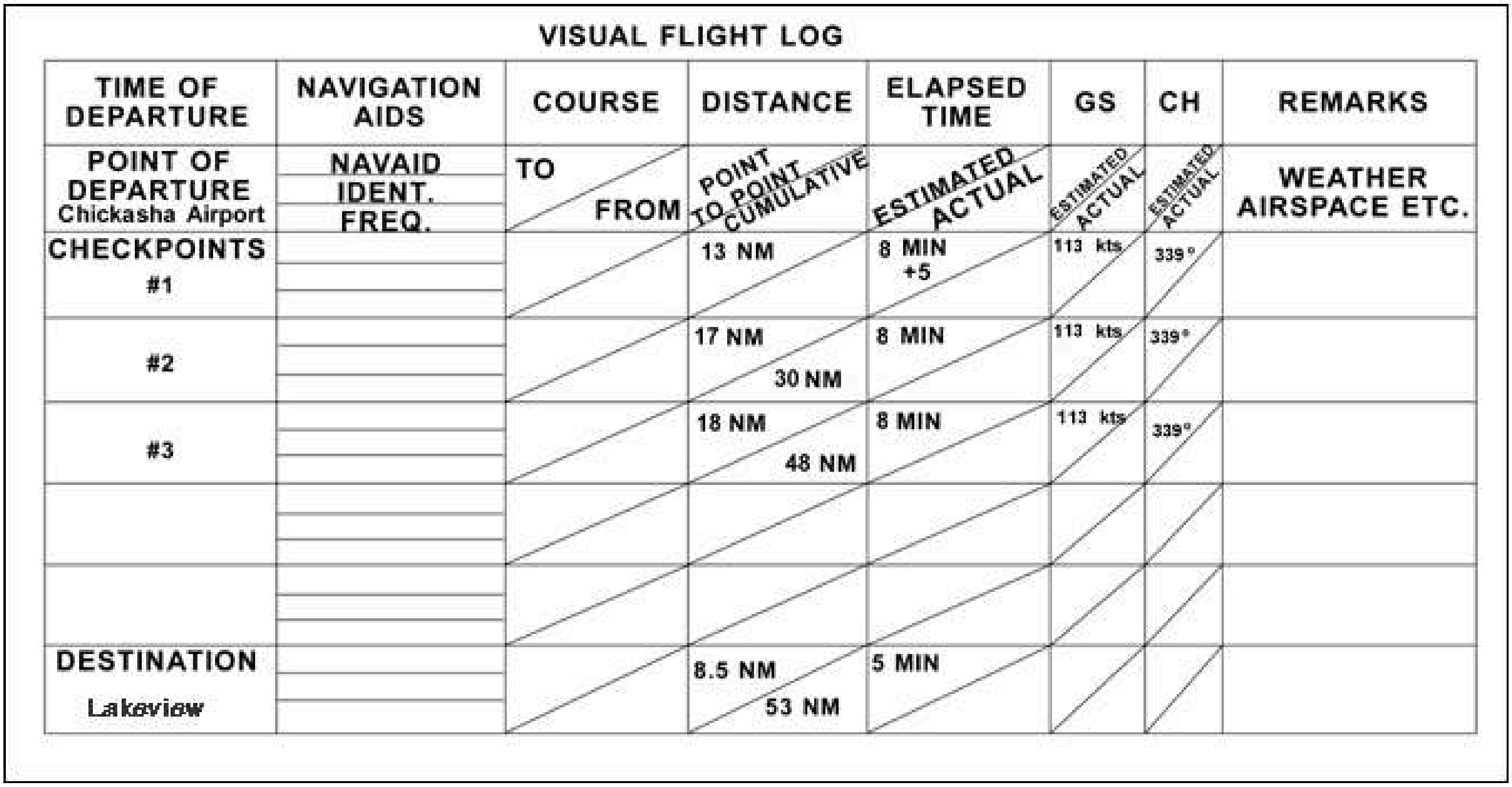
As the trip progresses, the pilot can note headings and time and make adjustments in heading, groundspeed, and time.



PILOT'S WORK SHEET

PLANE IDENTIFICATION N123DB DATE

COURSE	TC	WIND		WCA R+ L-	TH	VAR W+ E-	MH	DEV	CH	TOTAL MILES	GS	TOTAL TIME	FUEL RATE	TOTAL FUEL
		KNOTS	FROM											
From: Oshawa To: Orillia	335	230	15	- 8	327	10W	337	+ 2	339	48 nm	113	:25	8 gph	4 USG
From: To:														



VISUAL FLIGHT LOG

TIME OF DEPARTURE	NAVIGATION AIDS	COURSE	DISTANCE	ELAPSED TIME	GS	CH	REMARKS
POINT OF DEPARTURE Chickasha Airport	NAVAID IDENT. FREQ.	TO FROM	POINT TO POINT CUMULATIVE	ESTIMATED ACTUAL	ESTIMATED ACTUAL	ESTIMATED ACTUAL	WEATHER AIRSPACE ETC.
CHECKPOINTS #1			13 NM	8 MIN +5	113 kts	339°	
#2			17 NM 30 NM	8 MIN	113 kts	339°	
#3			18 NM 48 NM	8 MIN	113 kts	339°	
DESTINATION Lakeview			8.5 NM 53 NM	5 MIN			

Figure 8-23.—Pilot’s planning sheet and visual flight log (Free copies can be printed from Private Pilot Navigation Exams in AeroTransport's Exam Tutor™)

FILING A VFR FLIGHT PLAN

Filing a flight plan is required by regulations for flights beyond 25nm; however, it is a good operating practice regardless of the distance since the information contained in the flight plan can be used in search and rescue in the event of an emergency.

Flight plans can be filed in the air by radio, but it is best to file a flight plan either in person at the FSS or by phone just before departing. After takeoff, contact the FSS by radio and give them the takeoff time so the flight plan can be activated.

When a VFR flight plan is filed, it will be held by the FSS until 1 hour after the proposed departure time and then canceled unless: the actual departure time is received; or a revised proposed departure time is received; or at the time of filing, the FSS is informed that the proposed departure time will be met, but actual time cannot be given because of inadequate communication. The FSS specialist who accepts the flight plan will not inform the pilot of this procedure, however.

Figure 8-24 shows the flight plan form a pilot files with the Nav Canada Flight Service. **When filing a flight plan by telephone or radio**, give the information in the order of the numbered spaces. This enables the FSS specialist to copy the information more efficiently. Most of the spaces are either self-explanatory or nonapplicable to the VFR flight plan (such as item 13). However, some spaces may need explanation. Flight Service normally discourages filing Flight Plans by radio in order to reduce radio congestion.

Item 3 asks for the aircraft type and special equipment. An example would be C-150/X which means the aircraft has no transponder. A listing of special equipment codes is listed in the Aeronautical Information Manual.

Item 6 asks for the proposed departure time in Universal Coordinated Time (indicated by the “Z”).

Item 7 asks for the cruising altitude. Normally “VFR” can be entered in this block, since the pilot will choose a cruising altitude to conform to FAA regulations.

Item 8 asks for the route of flight. If the flight is to be direct, enter the word “direct;” if not, enter the actual route to be followed such as via certain towns or navigation aids.

Flight Plan / Itineraire de Vol

1 TYPE: ☒ VFR ☐ IFR ☐ DVFR
2 AIRCRAFT IDENTIFICATION: C-FABC
3 AIRCRAFT TYPE/ SPECIAL EQUIPMENT: C172 / X
4 TRUE AIRSPEED: 110 KTS
5 DEPARTURE POINT: Oshawa,ON
6 DEPARTURE TIME PROPOSED (Z): 1400Z ACTUAL (Z):
7 CRUISING ALTITUDE: 4500
8 ROUTE OF FLIGHT: Oshawa direct Orillia
9 DESTINATION (Name of airport and city):
10 EST. TIME ENROUTE HOURS: MINUTES:
11 REMARKS:
12 FUEL ON BOARD HOURS: 4 MINUTES: 45
13 ALTERNATE AIRPORT(S):
14 PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE: Joe Biggs
123 Main St, Oshawa
905-123-4567
15 NUMBER ABOARD: 1
16 COLOR OF AIRCRAFT: Red & White
CLOSE VFR FLIGHT PLAN WITH Oshawa FSS ON ARRIVAL

Figure 8-24.—Flight plan form.

Item 10 asks for the estimated time en route. In the sample flight plan, 5 minutes was added to the total time to allow for the climb.
Item 12 asks for the fuel on board in hours and minutes. This is determined by dividing the total usable fuel aboard in gallons by the estimated rate of fuel consumption in gallons.

A Flight Plan is required for any flight over 25nm from the point of departure. Do not forget to close the flight plan on arrival since “non-arrival” of your aircraft triggers mandatory ***Search & Rescue*** operations (SAR). Do this by telephone with the nearest FSS, if possible, to avoid radio congestion. Ground Control at a controlled airport will close your Flight Plan automatically, but confirm with Ground that they will do so. If there is no FSS near the point of landing, the flight plan may be closed by radio with the nearest FSS upon arrival at the destination airport.

RADIO NAVIGATION

Most airplanes flown in today’s environment are equipped with radios that provide a means of navigation and communication with ground stations.

Advances in navigational radio receivers installed in airplanes, the development of aeronautical charts which show the exact location of ground transmitting stations and their frequencies, along with refined cockpit 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). If this is done, it provides the pilot with an effective safeguard against disorientation in the event of radio malfunction.

There are three radio navigation systems normally available for use for VFR navigation in light aircraft. These are:

- VHF Omnidirectional Range (VOR)
- Non-Directional Radiobeacon (NDB)
- Global Positioning System (GPS)

Very High Frequency (VHF) Omnidirectional Range (VOR)

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

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

VOR ground stations transmit within a VHF frequency band of 108.0 - 117.95 MHz. Because the equipment is VHF, the signals transmitted are subjected 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 is about 40 to 45 miles. This distance increases with altitude. [Figure 8-25]

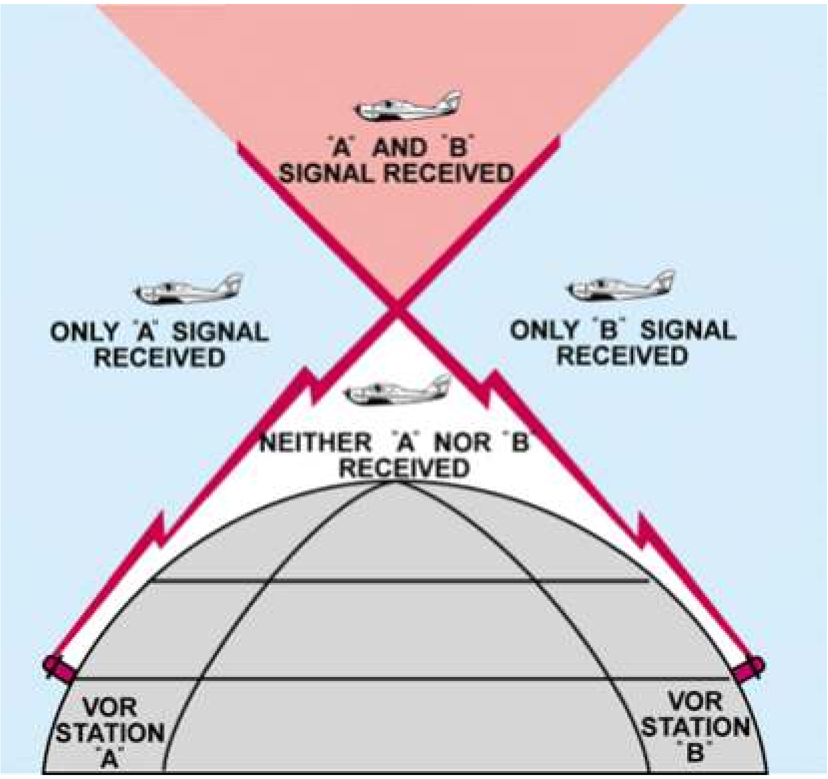


Figure 8-25.—VHF transmissions follow a line-of-sight course.

For the purpose of this discussion, the term “VOR” will be used to include both VOR and VORTAC. Briefly, a VORTAC station provides, in addition to azimuth information, range information. If the airplane is equipped with distance measuring equipment (DME), the distance from the station in nautical miles is displayed on the instrument.

The useful range of certain facilities may be less than 50 miles. For further information concerning these restrictions, refer to the Comm/NAVAID Remarks in the Canada Flight Supplement.

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

- Transport Canada VOR test facility (VOT);
- certified airborne checkpoints; and
- certified ground checkpoints located on airport surfaces.

A list of these checkpoints is published in the **Canada Flight Supplement.** Basically, these checks consist of verifying that the VOR radials the airplane equipment receives are aligned with the radials the station transmits. There are not specific tolerances in VOR checks required for VFR flight. But as a guide to assure acceptable accuracy, the required IFR tolerances can be used which are ±4° for ground checks and ±6° for airborne checks. These checks can be performed by the pilot.

The VOR transmitting station can be positively identified by its Morse code identification or by a recorded voice identification which states the name of the station followed by the word “VOR.” Many Flight Service Stations transmit voice messages on the same frequency that the VOR operates. Voice transmissions should not be relied upon to identify stations, because many FSS’s remotely transmit over several omniranges which have different names than 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 airplane is too far from the VOR or the airplane is too low and therefore, is out of the line-of-sight of the transmitting signals.

Using the VOR

Using the VOR is quite simple once the basic concept is understood. The following information, coupled with practice in actually using this equipment, should erase all the mysteries and also provide a real sense of security in navigating with the VOR.

In review, for VOR radio navigation, there are two components required: the ground transmitter and the aircraft receiving equipment. The ground transmitter is located at specific positions 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 consists of (1) an omnibearing selector (OBS) sometimes referred to as the course selector, (2) a course deviation indicator needle (Left-Right Needle), and (3) a TO-FROM indicator.

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

When the course selector is rotated, it moves the course deviation indicator 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 will also move 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 will indicate 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. If “FROM” is displayed and the course shown if followed, the aircraft will be flown away from the station. [Figure 8-26]

Figure 8-26.—VOR indicator.

Tracking with the VHF Omni Receiver (VOR)

The following describes a step-by-step procedure to use when tracking to and from a VOR station. Figure 8-27 illustrates the discussion:

- 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 will deflect either left or right; then rotate the azimuth dial to the course selector until the course deviation needle centers and the TO-FROM 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 omni azimuth dial or course selector. In this example 350°.

- If a heading of 350° is maintained with a wind from the right as shown, the airplane will drift to the left of the intended track. As the airplane drifts off course, the VOR course deviation needle will gradually move to the right of center or indicate the direction of the desired radial or track.

- To return to the desired radial, the aircraft heading must be altered approximately 30° to the right. As the aircraft returns to the desired track, the deviation needle will slowly return to center. When centered, the aircraft will be 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 or 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 airplane is flying to the right of course. A slight turn to the left should be made to permit the airplane 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 airplane will remain on the radial. If not, small variation in heading should be made to keep the needle centered, and consequently keep the airplane on the radial.

•As the VOR station is passed, the course deviation needle will fluctuate then settle down, and the “TO” indication will change to “FROM.” If the aircraft passes to one side of the station, the needle will deflect 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 omni will indicate “FROM.”

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

Tips on Using the VOR

•Positively identify the station by its code or voice identification.

•Keep in mind that VOR signals are “line-of-sight.” A weak signal or no signal at all will be received if the aircraft is too low or too far from the station.

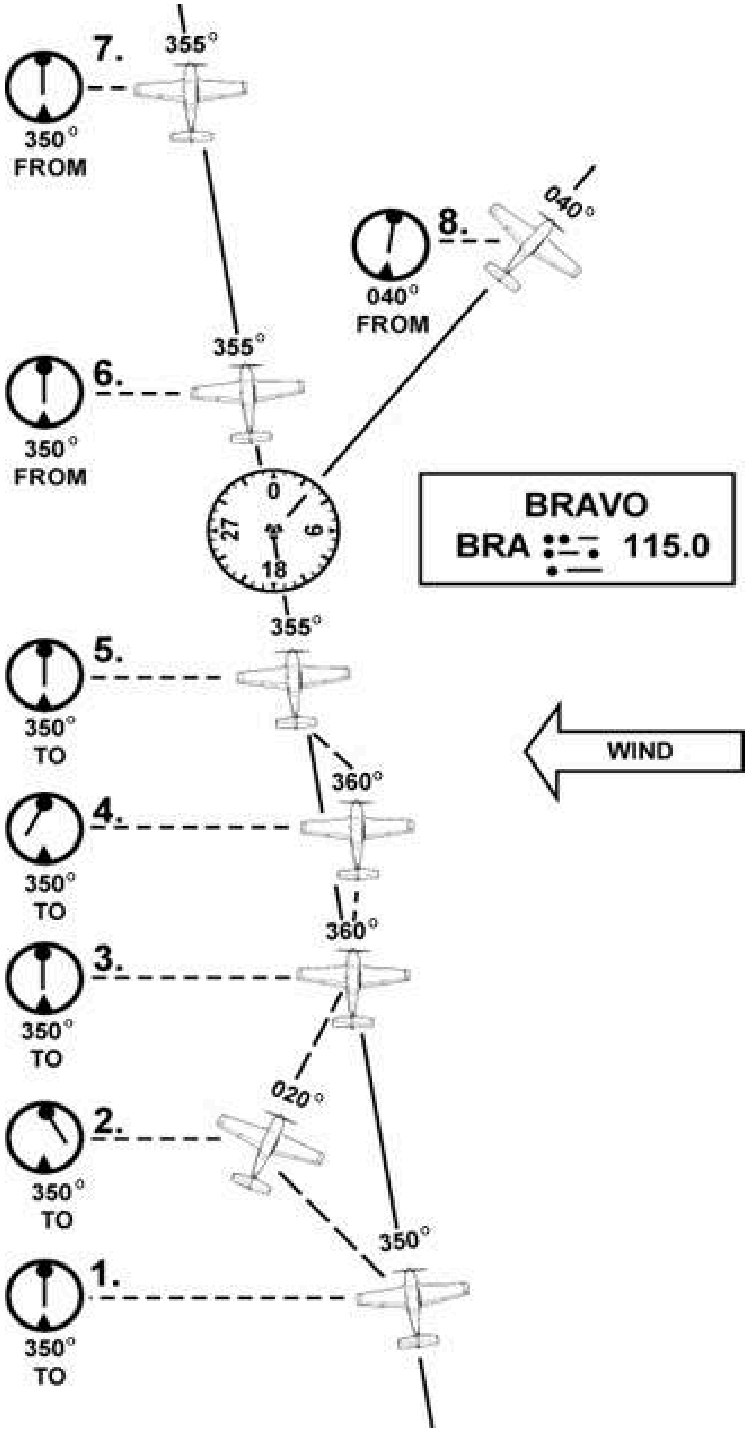


Figure 8-27.—Tracking a radial in a crosswind.

•When navigating to a station, determine the inbound radial and use this radial. If the aircraft drifts, do not reset the course selector, but correct for drift and fly a heading that will compensate for wind drift.

•If minor needle fluctuations occur, avoid changing headings immediately. Wait momentarily to see if the needle recenters; if it doesn’t, then correct.

•When flying “TO” a station, always fly the selected course with a “TO” indication. When flying “FROM” a station, always fly the selected course with a “FROM” indication. If this is not done, the action of the course deviation needle will be 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 will indicate in an opposite direction to that which it should. For example, if the aircraft drifts to the right of a radial being flown, the needle will move to the right or point away from the radial. If the aircraft drifts to the left of the radial being flown, the needle will move left or in the opposite direction of the radial.

Automatic Direction Finder

Many general aviation-type airplanes are equipped with automatic direction finder (ADF) radio receiving equipment. To navigate using the ADF, the pilot tunes the receiving equipment to a ground station known as a NONDIRECTIONAL RADIOBEACON (NDB). The NDB stations normally operate in a low or medium frequency band of 200 to 415 kHz. The frequencies are readily available on aeronautical charts or in the Canada Flight Supplement

All radiobeacons 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 AM 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.

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

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

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

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

Some of the ADF dials can be rotated so as 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 will be discussed in this handbook. [Figure 8-28]

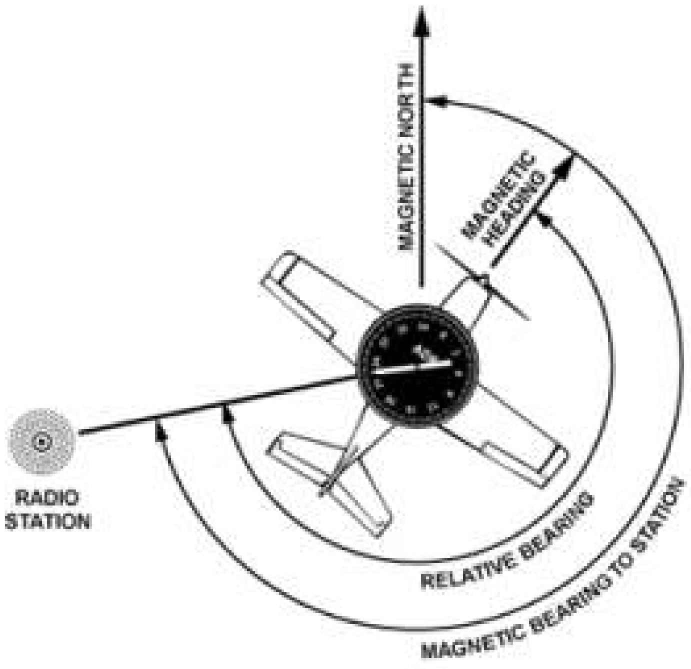


Figure 8-28.—ADF with fixed azimuth and magnetic compass.

Figure 8-29 illustrates the following terms that are used with the ADF and should be understood by the pilot.

•**Relative Bearing**—is the value to which the indicator (needle) points on the azimuth dial. When using a fixed dial, this number is relative to the nose of the aircraft and is the angle measured clockwise from the nose of the aircraft to a line drawn from the aircraft to the station.

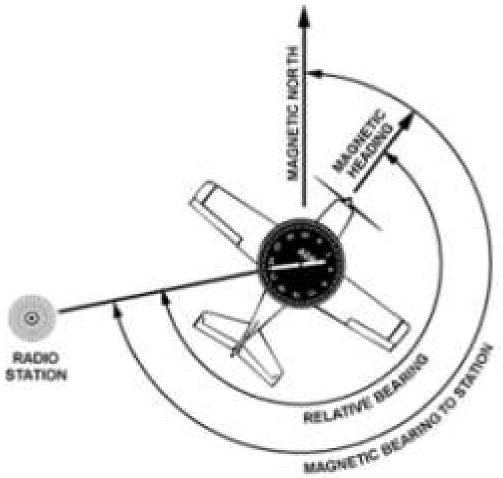


Figure 8-29.—ADF terms.

•**Magnetic Bearing** —“TO” the station is the angle formed by a line drawn from the aircraft to the station and a line drawn from the aircraft to magnetic north. The magnetic bearing to the station can be determined by adding the relative bearing to the magnetic heading of the aircraft. For example, if the relative bearing is 060° and the magnetic heading is 130°, the magnetic bearing to the station is 060° plus 130° or 190°. This means that in still air a magnetic heading of approximately 190° would be flown to the station. If the total is greater than 360°, subtract 360° from the total to obtain the magnetic bearing to the station. For example, if the relative bearing is 270° and magnetic heading is 300°, 360° is subtracted from the total, or 570° – 360° = 210°, which is the magnetic bearing to the station.

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

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

Tracking to the station requires correcting for wind drift and results in maintaining flight along a straight track or bearing to the station. When the wind drift correction is established, the ADF needle will indicate the amount of correction to the right or left. For instance, if the magnetic bearing to the station is 340°, a correction for a left crosswind would result in a magnetic heading of 330°, and the ADF needle would indicate 10° to the right or a relative bearing of 010°. [Figure 8-30]

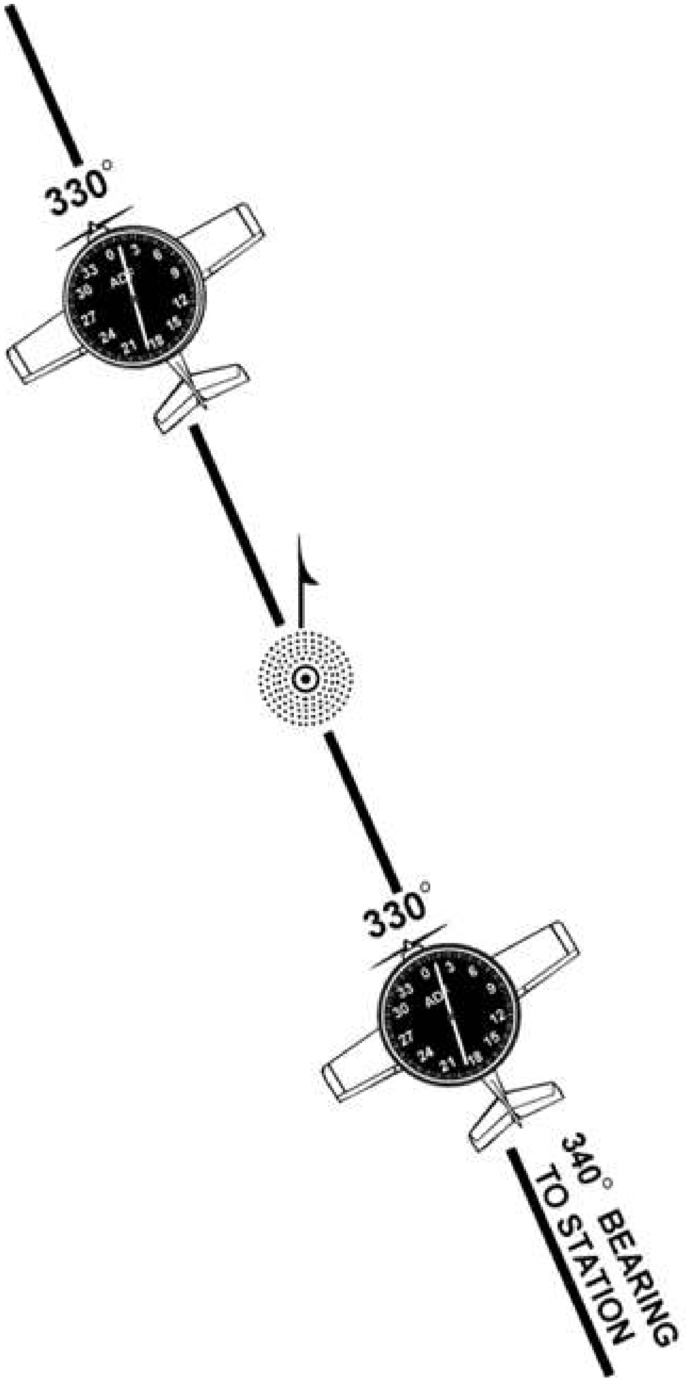


Figure 8-30.—ADF tracking.

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

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 low-tech aid to navigation, especially since (unlike any other navigation device) the ADF can be tuned to AM radio stations

Other Navigational Systems

There are other navigational systems which are more advanced such as long range navigation (**LORAN-C**) and global positioning system (GPS).

The LORAN system was originally designed for submarine navigation. It uses a network of land-based radio transmitters developed to provide an accurate system for long range, underwater navigation. Pilots quickly figured out that it was equally useful for air navigation except for the fact that it was designed for use near oceans. For years, there was a “mid-continent gap” that made the system inadequate for use from Saskatchewan through Ontario. The LORAN system is based upon the measurement of the difference in time of arrival of pulses of radio-frequency energy radiated by a group or chain of transmitters which are separated by hundreds of miles. The LORAN system is still available for use, but it has been largely superceded by GPS in General Aviation.

The Global Positioning System (GPS)

The global positioning system (GPS) is a satellite-based radio positioning, navigation, and time-transfer system developed by the U.S. Department of Defense. The concept of GPS is based on accurate and continuous knowledge of the spatial position of each satellite in the system. GPS provides accurate information 24 hours a day and is unaffected by the weather. Because of the geometry of the system, it is able to provide accurate altitude information as well as position. Intelligent GPS units will incorporate digital maps, trsansponders, and VHF radios. Canadian pilots need to be aware that GPS may not have the expected accuracy in northern latitudes.

Electronic charts for GPS and tablets are available for a fee. Pilots must always be using the latest charts, whether paper or electronic to avoid being stranded by a closed airport or other similar inconvenience.

There are two other global systems similar to the US GPS system: the Russian **GLONASS** system, which uses fewer satellites and different orbits. GLONASS participates in the world-wide ELT signal relays. The European **Galileo** system has a planned completion date of 2019. Galileo will be free for civilian use, but a fee will be charged for more accurate commercial applications.

The future

In spite of the many advantages of satellite navigation tools, Canadian & US pilots will still be required to know how to navigate by Dead Reckoning (paper charts, pencil, & plotter) without using GPS and how to find the latest navigation aids and frequencies enroute.

Fig 8.31 Garmin ™ Handheld GPS unit with moving map display and nav data

If more detailed information on these systems is desired, the pilot may reference the Aeronautical Information Publication (AIP Canada). Since satellite nav units have various presentations, a pilot should refer to the Aircraft Flight Manual for the individual make and model for proper usage.