Chapter 3

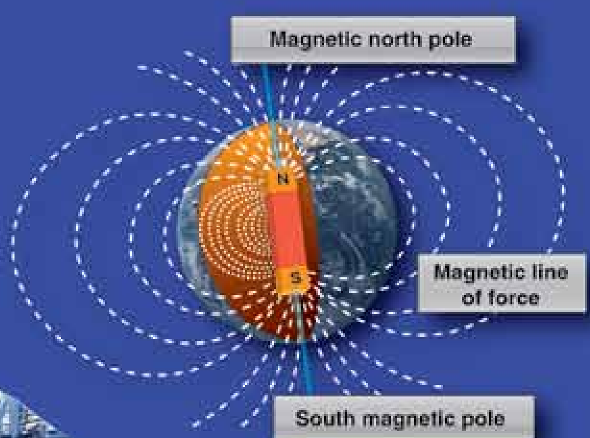
Basic Instruments

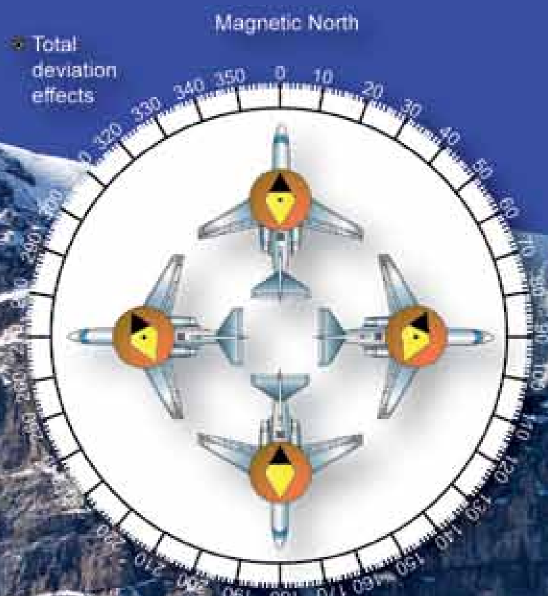
Compass: Magnetic			
Swung: 12 APR, 95		By: TTD	
To Fly	Steer	To Fly	Steer
N	001	180	179
15	016	195	194
30	131	210	209
45	046	225	224
60	062	240	238
75	077	255	253
90	092	270	268
105	107	285	283
120	122	300	298
135	135	315	314
150	149	330	330
165	164	345	346

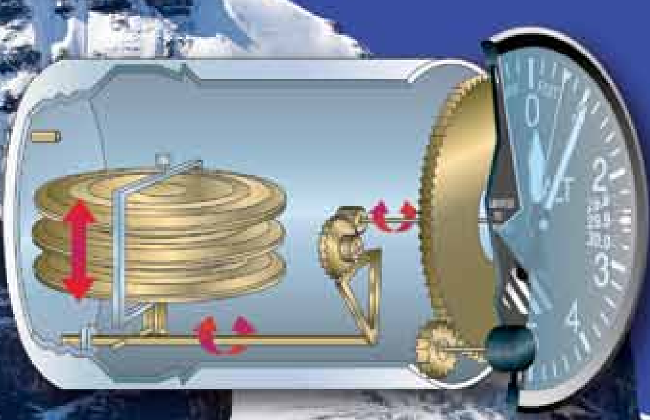
Introduction

Instruments mechanically measure physical quantities or properties with varying degrees of accuracy. Much of a navigator's work consists of applying corrections to the indications of various instruments and interpreting the results. Therefore, navigators must be familiar with the capabilities and limitations of the instruments available to them.

A navigator obtains the following flight information from basic instruments: direction, altitude, temperature, airspeed, drift, and groundspeed (GS). Some of the basic instruments are discussed in this chapter. The more complex instruments that make accurate and long distance navigation possible are discussed in later chapters.







Direction

Basic Instruments

The navigator must have a fundamental background in navigation to ensure accurate positioning of the aircraft. Dead reckoning (DR) procedures aided by basic instruments give the navigator the tools to solve the three basic problems of navigation: position of the aircraft, direction to destination, and time of arrival. Using only a basic instrument, such as the compass and drift information, you can navigate directly to any place in the world. Various fixing aids, such as celestial and radar, can greatly improve the accuracy of basic DR procedures. This chapter discusses the basic instruments used for DR and then reviews the mechanics of DR, plotting, wind effect, and computer solutions.

Directional information needed to navigate is obtained by use of the earth's magnetic lines of force. A compass system uses a device that detects and converts the energy from these lines of force to an indicator reading. The magnetic compass operates independently of the aircraft electrical systems. Later developed compass systems require electrical power to convert these lines of force to an aircraft heading.

Earth's Magnetic Field

The earth has some of the properties of a bar magnet; however, its magnetic poles are not located at the geographic poles, nor are the two magnetic poles located exactly opposite each other as on a straight bar. The north magnetic pole is located approximately at 73° N latitude and 100° W longitude on Prince of Wales Island. The south magnetic pole is located at 68° S latitude and 144° E longitude on Antarctica.

The earth's magnetic poles, like those of any magnet, can be considered to be connected by a number of lines of force. These lines result from the magnetic field that envelops the earth. They are considered to be emanating from the south magnetic pole and terminating at the north magnetic pole. *[Figure 3-1]*

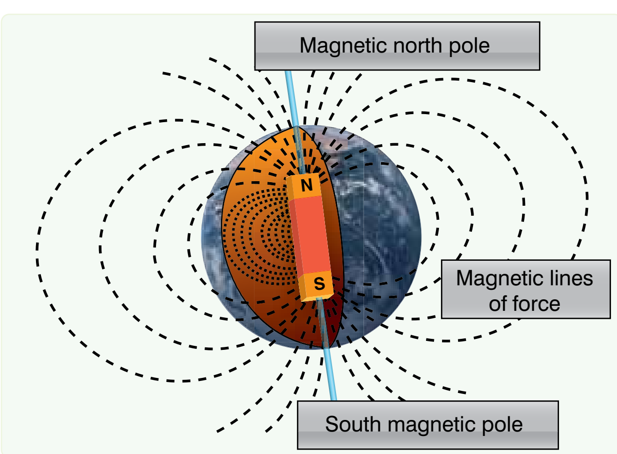


Figure 3-1. *Earth's magnetic field.*

The force of the magnetic field of the earth can be divided into two components: the vertical and the horizontal. The relative intensity of these two components varies over the earth so that, at the magnetic poles, the vertical component is at maximum strength and the horizontal component is minimum strength. At approximately the midpoint between the poles, the horizontal component is at maximum strength and the vertical component is at minimum strength. Only the horizontal component is used as a directive force for a magnetic compass. Therefore, a magnetic compass loses its usefulness in an area of weak horizontal force, such as the area around the magnetic poles. The vertical component causes the end of the needle nearer to the magnetic pole to tip as the pole is approached. *[Figure 3-1]* This departure from the horizontal is called magnetic dip.

Compasses

A compass may be defined as an instrument that indicates direction over the earth's surface with reference to a known datum. Various types of compasses have been developed, each of which is distinguished by the particular datum used as the reference from which direction is measured. Two basic types of compasses are in current use: the magnetic and gyrocompass.

The magnetic compass uses the lines of force of the earth's magnetic field as a primary reference. Even though the earth's field is usually distorted by the pressure of other local magnetic fields, it is the most widely used directional reference. The gyrocompass uses as its datum an arbitrary fixed point in space determined by the initial alignment of the gyroscope axis. Compasses of this type are widely used today and may eventually replace the magnetic compass entirely.

Magnetic Compass

The magnetic compass indicates direction in the horizontal plane with reference to the horizontal component of the earth's magnetic field. This field is made up of the earth's field in combination with other magnetic fields in the vicinity of the compass. These secondary fields are caused by the presence of ferromagnetic objects.

Magnetic compasses may be divided into two classes:

1. The direct-indicating magnetic compass in which the measurement of direction is made by a direct observation of the position of a pivoted magnetic needle; and
2. The remote-indicating gyro-stabilized magnetic compass.

Magnetic direction is sensed by an element located at positions where local magnetic fields are at a minimum, such as the vertical stabilizer and wing tips. The direction is then transmitted electrically to repeater indicators on the instrument panels.

Direct-Indicating Magnetic Compass

Basically, the magnetic compass is a magnetized rod pivoted at its middle, with several features incorporated to improve its performance. One type of direct-indicating magnetic compass, the B-16 compass (often called the whiskey compass), is illustrated in *Figure 3-2*. It is used as a standby compass in case of failure of the electrical system that operates the remote compasses. It is a reliable compass and gives good navigational results if used carefully.

Magnetic Variation and Compass Errors

The earth's magnetic poles are joined by irregular curves called magnetic meridians. The angle between the magnetic meridian and the geographic meridian is called the magnetic variation. Variation is listed on charts as east or west. When variation is east, magnetic north (MN) is east of true north (TN). Similarly, when variation is west, MN is west of TN. *[Figure 3-3]* Lines connecting points having the same magnetic variation are called isogonic lines. *[Figure 3-4]* Compensate for magnetic variation to convert a compass direction to true direction.

Compass error is caused by nearby magnetic influences, such as magnetic material in the structure of the aircraft and its electrical systems. These magnetic forces deflect a compass needle from its normal alignment. The amount of such deflection is called deviation which, like variation, is labeled "east" or "west" as the north-seeking end of the compass is deflected east or west of MN, respectively.

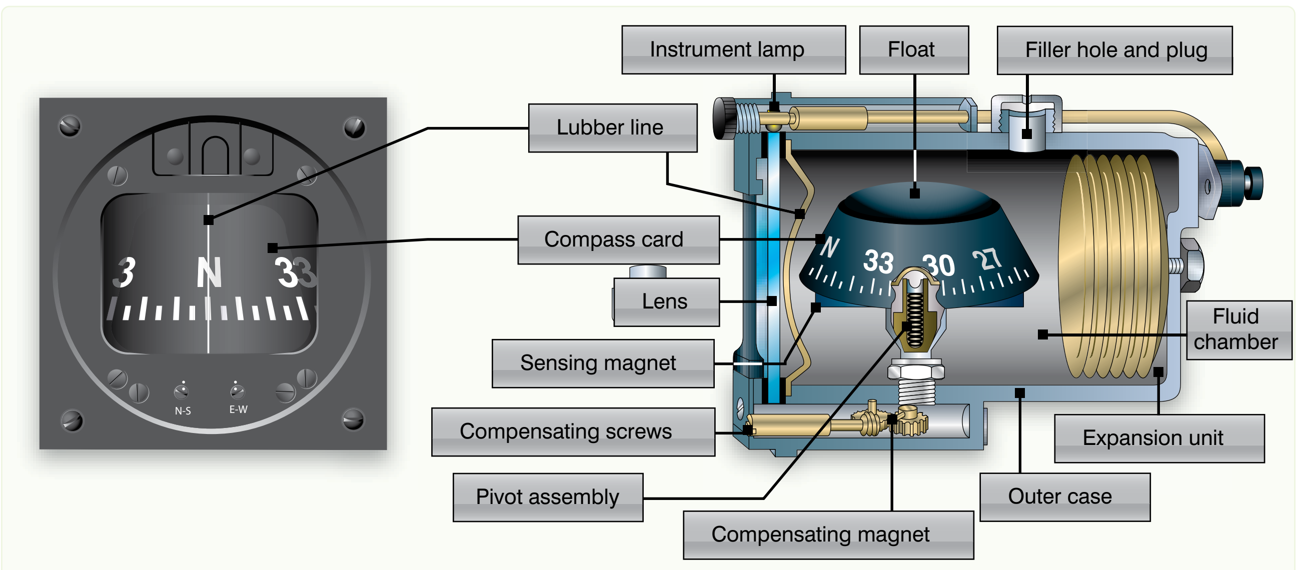


Figure 3-2. *Magnetic compass.*

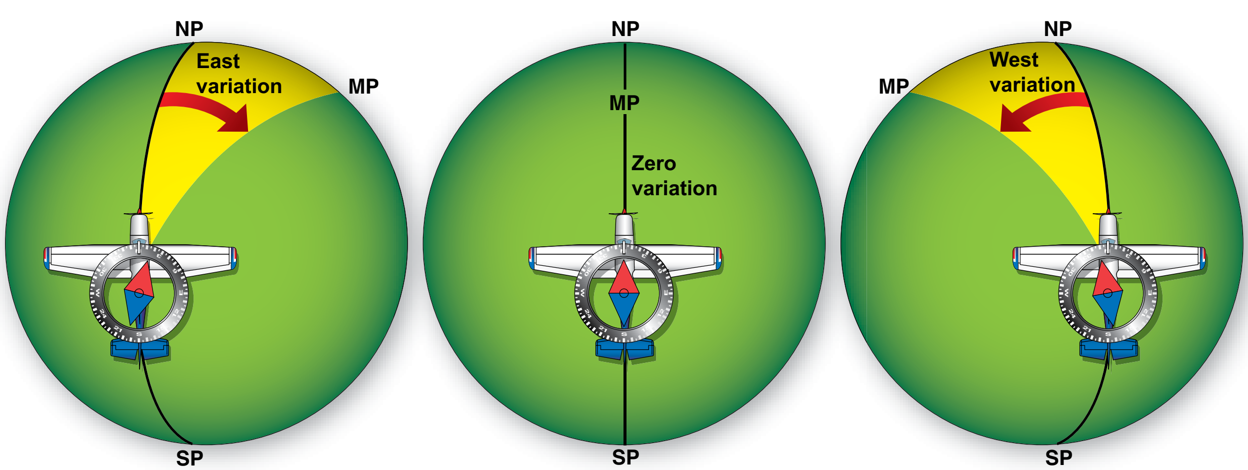


Figure 3-3. *Effects of variation.*

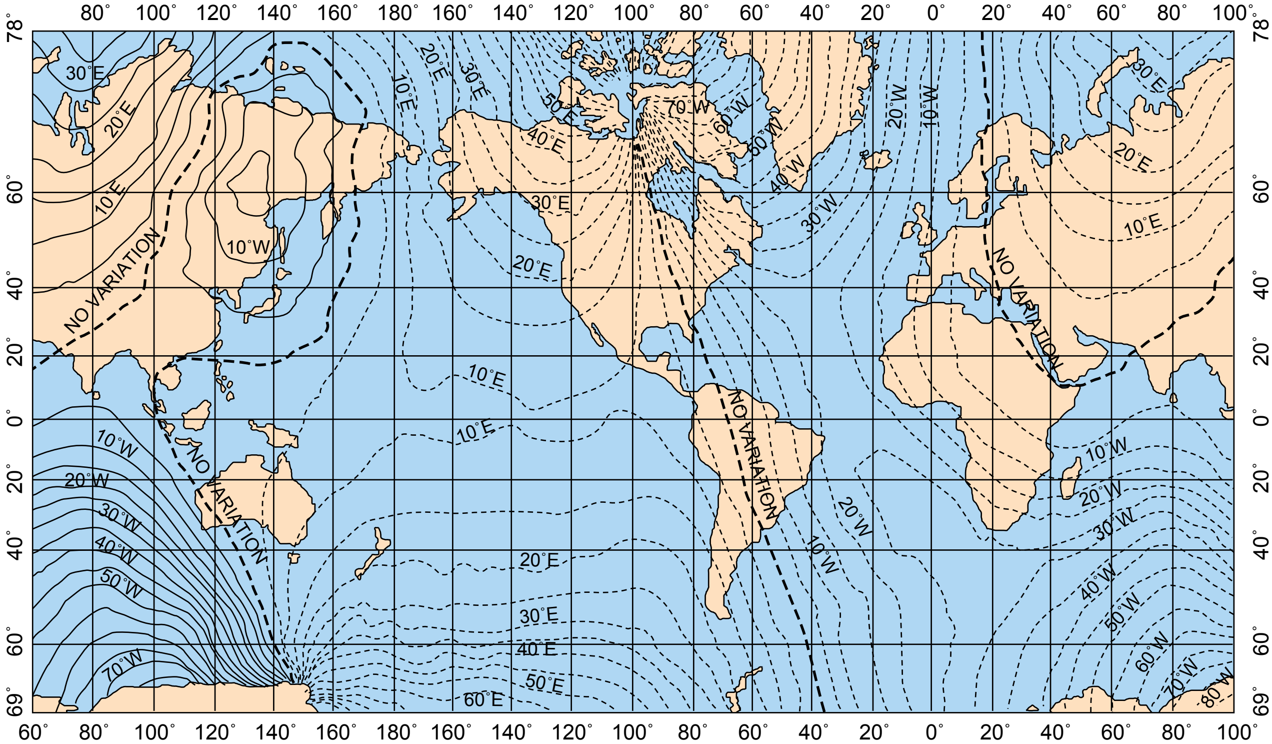


Figure 3-4. *Isogonic lines show same magnetic variation.*

The correction for variation and deviation is usually expressed as a plus or minus value and is computed as a correction to true heading (TH). If variation or deviation is east, the sign of the correction is minus; if west, the sign is plus. A rule of thumb for this correction is easily remembered as east is least and west is best.

Aircraft headings are expressed as TH or magnetic headings (MH). If the heading is measured in relation to geographical north, it is a TH. If the heading is in reference to MN, it is a MH; if it is in reference to the compass lubber line, it is a compass heading (CH). CH corrected for variation and deviation is TH. MH corrected for variation is TH.

This relationship is best expressed by reference to the navigator's log, where the various headings and corrections are listed as TH, variation (var), MH, deviation (dev), and CH. *[Figure 3-5]* Thus, if an aircraft is flying in an area where the variation is 10° E and the compass has a deviation of 3° E, the relationship would be expressed as follows, assuming a CH of 125°:

TH var MH dev CH
138 – 10 = 128 – 3 = 125

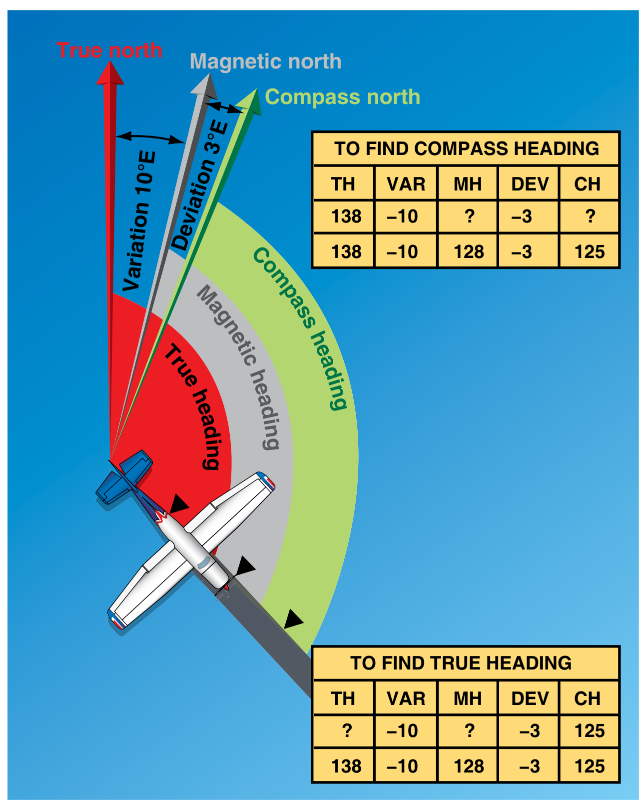


Figure 3-5. *Find true heading by working backwards.*

Variation

Variation has been measured throughout the world and the values found have been plotted on charts. Isogonic lines are printed on most charts used in aerial navigation so that, if the aircraft's approximate position is known, the amount of variation can be determined by visual interpolation between the printed lines. At high altitudes, these values can be considered quite realistic. Conversely, at low altitudes, these magnetic values are less reliable because of local anomalies.

Variation changes slowly over a period of years and the yearly amount of such change is printed on most charts. Variation is also subject to small diurnal (daily) changes that may generally be neglected in air navigation.

Deviation

Because deviation depends upon the distribution of magnetic forces in the aircraft itself, it must be obtained individually for each magnetic compass on each aircraft. The process of determining deviation, known as compass swinging, should be discussed in the technical order for each compass.

Deviation changes with heading are shown in *Figure 3-6.* The net result of all magnetic forces of the aircraft (those forces excluding the earth's field) is represented by a dot located just behind the wings of the aircraft. If the aircraft is headed toward MN, the dot attracts one pole of the magnetic compass (in this case, the South Pole) but, on this heading, does not change its direction. The only effect is to amplify the directive force of the earth's field. If the aircraft heads toward magnetic east, the dot is now west of the compass, and attracts the South Pole of the compass, causing easterly deviation. *Figure 3-6* also shows that the deviation is zero on a south heading, and westerly when the aircraft is heading west.

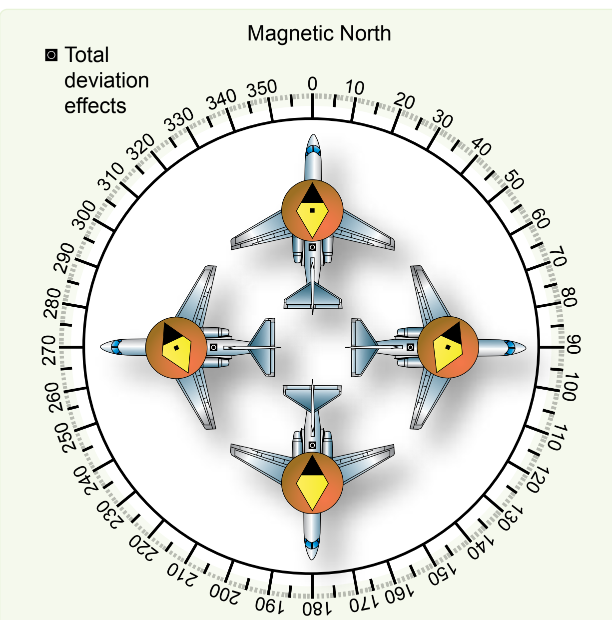


Figure 3-6. *Deviation changes with heading.*

Deviation can be reduced (but not eliminated) in some direct-indicating magnetic compasses by adjusting the small compensating magnets in the compass case. Remaining deviation is referred to as residual deviation and can be determined by comparison with true values. This residual deviation is recorded on a compass correction card showing actual deviation on various headings or the compass headings. From the compass correction card illustrated in *Figure 3-7,* the navigator knows that to fly a magnetic heading (MH) of 270°, the pilot must steer a CH of 268°.

Compass: Magnetic			
Swung: 12 APR 95		By: TTD	
To Fly	**Steer**	**To Fly**	**Steer**
N	001	180	179
15	016	195	194
30	131	210	209
45	046	225	224
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75	077	255	253
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Figure 3-7. *Compass correction card.*

Errors in Flight

Unfortunately, deviation is not the only error of a magnetic compass. Additional errors are introduced by the motion of the aircraft itself. These errors have minimal effect on the use of magnetic compasses and come into play normally during turns or changes in speed. They are mentioned only to bring awareness of the limitations of the basic compass. Although a basic magnetic compass has some shortcomings, it is simple and reliable. The compass is very useful to both the pilot and navigator and is carried on all aircraft as an auxiliary compass. Because compass systems are dependent upon the electrical system of the aircraft, a loss of power means a loss of the compass system. For this reason, an occasional check on the standby compass provides an excellent backup to the main systems.

Remote-Indicating Gyro-Stabilized Magnetic Compass System

A chief disadvantage of the simple magnetic compass is its susceptibility to deviation. In remote-indicating gyro-stabilized compass systems, this difficulty is overcome by locating the compass direction-sensing device outside magnetic fields created by electrical circuits in the aircraft. This is done by installing the direction-sensing device in a remote part of the aircraft, such as the outer extremity of a wing or vertical stabilizer. Indicators of the compass system can then be located throughout the aircraft without regard to magnetic disturbances.

Several kinds of compass system are used in aircraft systems. All include the following five basic components: remote compass transmitter, directional gyro (DG), amplifier, heading indicators, and slaving control. Though the names of these components vary among systems, the principle of operation is identical for each. Thus, the N-1 compass system shown in *Figure 3-8* can be considered typical of all such systems.

The N-1 compass system is designed for airborne use at all latitudes. It can be used either as a magnetic-slaved compass or as a DG. In addition, the N-1 generates an electric signal that is used as an azimuth reference by the autopilot, the radar system, the navigation and bombing computers, and various compass cards.

Remote Compass Transmitter

The remote compass transmitter is the magnetic-direction sensing component of the compass system when the system is in operation as a magnetic-slaved compass. The transmitter is located as far from magnetic disturbances of the aircraft as possible, usually in a wing tip or the vertical stabilizer. The transmitter senses the horizontal component of the earth's magnetic field and electrically transmits it to the master indicator. The compensator, an auxiliary unit of the remote compass transmitter, is used to eliminate most of the magnetic deviation caused by the aircraft electrical equipment and ferrous metal when a deviation-free location for the remote compass transmitter is not available.

Directional Gyro (DG)

The DG is the stabilizing component of the compass system when the system is in magnetic-slaved operation. When the compass system is in DG operation, the gyro acts as the directional reference component of the system.

Amplifier

The amplifier is the receiving and distributing center of the compass system. Azimuth correction and leveling signals originating in the components of the system are each received, amplified, and transmitted by separate channels in the amplifier. Primary power to operate the compass is fed to the amplifier and distributed to the systems components.

Master Indicator

The master indicator is the heading-indicating component of the compass system. The mechanism in the master indicator integrates all data received from the directional gyro and the remote compass transmitter, corrects the master indicator heading pointer for azimuth drift of the DG due to the earth's rotation, and provides takeoff signals for operating remote indicators, radar, navigation computers, and directional control of the autopilot.

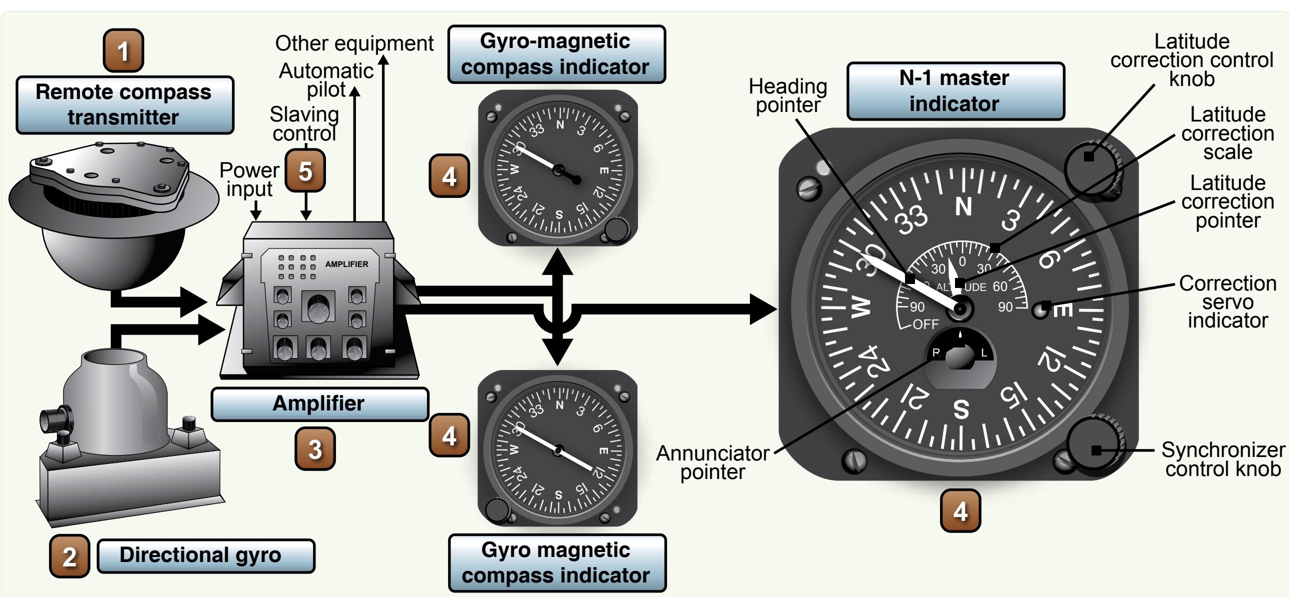

Figure 3-8. *N-1 compass system components.*

The latitude correction control provides a means for selecting either magnetic-slaved operation or DG operation of the compass system, as well as the proper latitude correction rate. The latitude correction pointer is mechanically connected to the latitude correction control knob and indicates the latitude setting on the latitude correction scale at the center of the master indicator dial face.

The synchronizer control knob at the lower right-hand corner of the master indicator face provides a means of synchronizing the master indicator heading pointer with the correct MH when the system is in magnetic-slaved operation. It also provides a means of setting the master indicator heading pointer on the desired gyro heading reference when the system is in DG operation. The annunciator pointer indicates the direction in which to rotate the synchronizer control knob to align the heading pointer with the correct MH.

Gyro-Magnetic Compass Indicators

The gyro-magnetic compass indicators are remote-reading, movable dial compass indicators. They are intended for supplementary use as directional compass indicators when used with the compass system. The indicators duplicate the azimuth heading of the master indicator heading pointer. A setting knob is provided at the front of each indicator for rotating the dial 360° in either direction without changing the physical alignment of the pointer.

Slaving Control

The slaving control is a gyro control rate switch that reduces errors in the compass system during turns. When the aircraft turns at a rate of 23° or more per minute, the slaving control prevents the remote compass transmitter signal from being transmitted to the compass system during magnetic-slaved operation. It also interrupts leveling action in the DG when the system is in magnetic-slaved or DG operation.

Gyro Basics

Any spinning body exhibits gyroscopic properties. A wheel designed and mounted to use these properties is called a gyroscope or gyro. Basically, a gyro is a rapidly rotating mass that is free to move about one or both axes perpendicular to the axis of rotation and to each other. The three axes of a gyro (spin, drift, and topple) shown in *Figure 3-9* are defined as follows:

1. In a DG, the spin axis or axis of rotation is mounted horizontally;
2. The topple axis is that axis in the horizontal plane that is 90° from the spin axis;
3. The drift axis is that axis 90° vertically from the spin axis.

Gyroscopic drift is the horizontal rotation of the spin axis about the drift axis. Topple is the vertical rotating of the spin axis about the topple axis. These two component drifts result in motion of the gyro called precession.

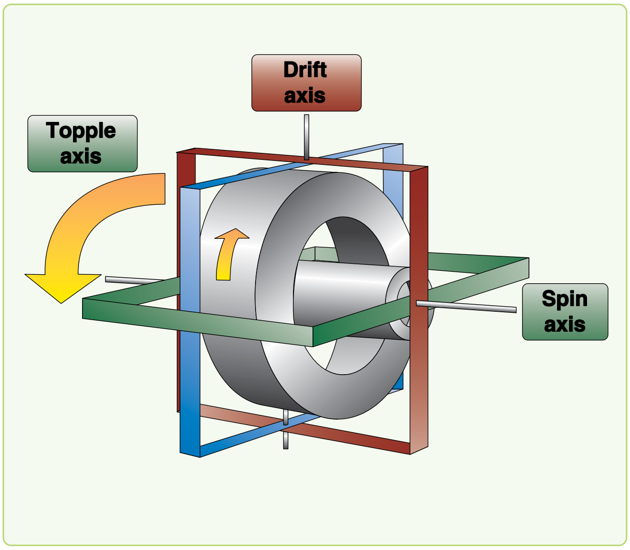

Figure 3-9. *Gyroscope axes.*

A freely spinning gyro tends to maintain its axis in a constant direction in space, a property known as rigidity in space or gyroscopic inertia. Thus, if the spin axis of a gyro were pointed toward a star, it would keep pointing at the star. Actually, the gyro does not move, but the earth moving beneath it gives it an apparent motion. This apparent motion is called apparent precession. *[Figure 3-10]* The magnitude of apparent precession is dependent upon latitude. The horizontal component, drift, is equal to 15° per hour times the sine of the latitude, and the vertical component, topple, is equal to 15° per hour times the cosine of the latitude.

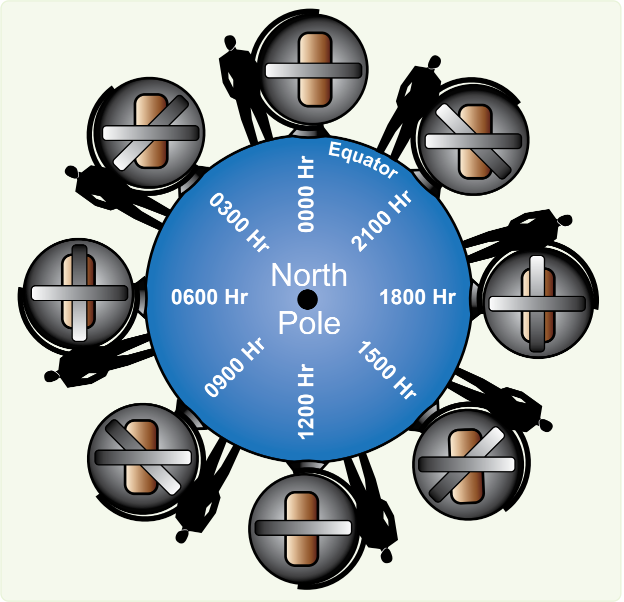

Figure 3-10. *Apparent precession.*