

Flight Navigator Handbook

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Chapter I

Maps and Charts

Introduction

Aviators use air navigation to determine where they are going and how to get there. This book serves as a reference for techniques and methods used in air navigation. In addition to this book, several other sources provide excellent references to methods and techniques of navigation:

- The Journal of the Institute of Navigation—published quarterly by The Institute of Navigation, 1800 Diagonal Road, Alexandria, Virginia, 22314, and covers the latest in navigation technology.
- The United States Observatory and United States Navy Oceanographic Office—publications include the Air Almanac, Nautical Almanac, NV Publication 9 (Volumes 1 and 2).
- The American Practical Navigator, SR Publication 249, Volumes 1 through 3, Sight Reduction Tables for Air Navigation and Catalog, and the NGA Public Sale Aeronautical Charts and Products—published by the National Geo-Spatial Intelligence Agency (NGA) (formally known as the National Imagery and Mapping Agency (NIMA)).
- Dutton's Navigation and Piloting—published by the Naval Institute Press, Annapolis, Maryland.

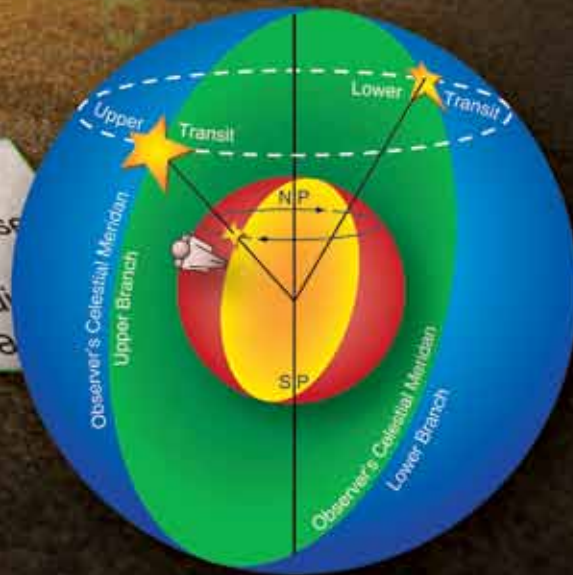
The equator and poles divide meridians into four equal parts.

The plane of a parallel is parallel to the equator.



The equator is a great circle whose plane is perpendicular to the axis.

Great circles through the poles from meridians.



International date line

Basic Terms

Basic to the study of navigation is an understanding of certain terms that could be called the dimensions of navigation. The navigator uses these dimensions of position, direction, distance, altitude, and time as basic references. A clear understanding of these dimensions as they relate to navigation is necessary to provide the navigator with a means of expressing and accomplishing the practical aspects of air navigation. These terms are defined as follows:

- **Position**—a point defined by stated or implied coordinates. Though frequently qualified by such adjectives as estimated, dead reckoning (DR), no wind, and so forth, the word position always refers to some place that can be identified. It is obvious that a navigator must know the aircraft's current position before being able to direct the aircraft to another position or in another direction.
- **Direction**—the position of one point in space relative to another without reference to the distance between them. Direction is not in itself an angle, but it is often measured in terms of its angular distance from a referenced direction.
- **Distance**—the spatial separation between two points, measured by the length of a line joining them. On a plane surface, this is a simple problem. However, consider distance on a sphere, where the separation between points may be expressed as a variety of curves. It is essential that the navigator decide exactly how the distance is to be measured. The length of the line can be expressed in various units (e.g., nautical miles (NM) or yards).
- **Altitude**—the height of an aircraft above a reference plane. Altitude can be measured as absolute or pressure. Absolute altitude is measured by a radar altimeter, and pressure altitude is measured from various datum planes. Compare with elevation, which is the height of a point or feature on the earth above a reference plane.
- **Time**—defined in many ways, but definitions used in navigation consist mainly of:
 1. Hour of the day.
 2. Elapsed interval.
- **Methods of expression**—the methods of expressing position, direction, distance, altitude, and time are covered fully in appropriate chapters. These terms, and others similar to them, represent definite quantities or conditions that may be measured in several different ways. For example, the position of an aircraft may be expressed in coordinates, such as a certain latitude and longitude. The position may also

be expressed as 10 miles south of a certain city. The study of navigation demands the navigator learn how to measure quantities, such as those just defined and how to apply the units by which they are expressed.

The Earth

Shape and Size

For most navigational purposes, the earth is assumed to be a perfect sphere, although in reality it is not. Inspection of the earth's crust reveals there is a height variation of approximately 12 miles from the top of the tallest mountain to the bottom of the deepest point in the ocean. A more significant deviation from round is caused by a combination of the earth's rotation and its structural flexibility. When taking the ellipsoidal shape of the planet into account, mountains seem rather insignificant. The peaks of the Andes are much farther from the center of the earth than Mount Everest.

Measured at the equator, the earth is approximately 6,378,137 meters in diameter, while the polar diameter is approximately 6,356,752.3142 meters. The difference in these diameters is 21,384.6858 meters, and this difference may be used to express the ellipticity of the earth. The ratio between this difference and the equatorial diameter is:

$$\text{Ellipticity} = \frac{21,384.6858}{6,378,137} = \frac{1}{298.257223}$$

Since the equatorial diameter exceeds the polar diameter by only 1 part in 298, the earth is nearly spherical. A symmetrical body having the same dimensions as the earth, but with a smooth surface, is called an ellipsoid. The ellipsoid is sometimes described as a spheroid, or an oblate spheroid.

In *Figure 1-1*, polar north (Pn), east (E), polar south (Ps), and west (W) represent the surface of the earth. Pn and Ps represent the axis of rotation. The earth rotates from west to east. All points in the hemisphere Pn, W, Ps approach the reader, while those in the opposite hemisphere recede from the reader. The circumference W-E is called the equator, which is defined as that imaginary circle on the surface of the earth whose plane passes through the center of the earth and is perpendicular to the axis of rotation.

Great Circles and Small Circles

A great circle is defined as a circle on the surface of a sphere whose center and radius are those of the sphere itself. It is the largest circle that can be drawn on the sphere; it is the intersection with the surface of the earth of any plane passing through the earth's center. The arc of a great circle is the shortest distance between two points on a sphere, just as a straight line is the shortest distance between two points on a plane. On any sphere, an indefinitely large number of great

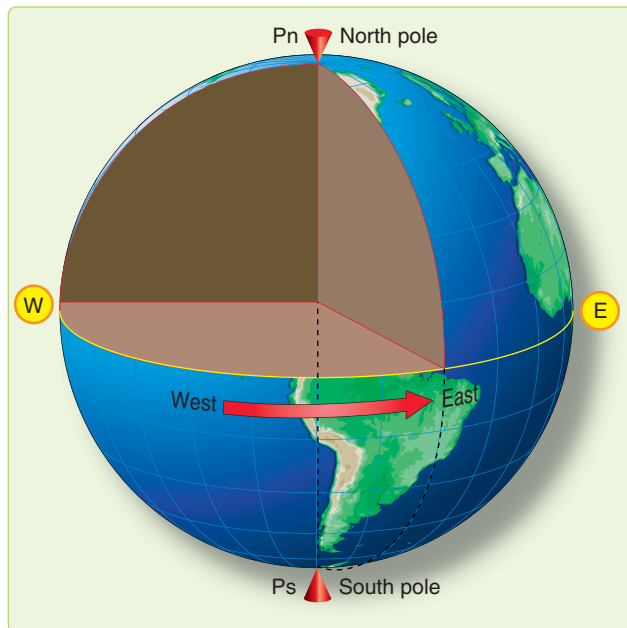


Figure 1-1. Schematic representation of the earth showing its axis of rotation and equator.

circles may be drawn through any point, though only one great circle may be drawn through any two points not diametrically opposite. Several great circles are shown in Figure 1-2.

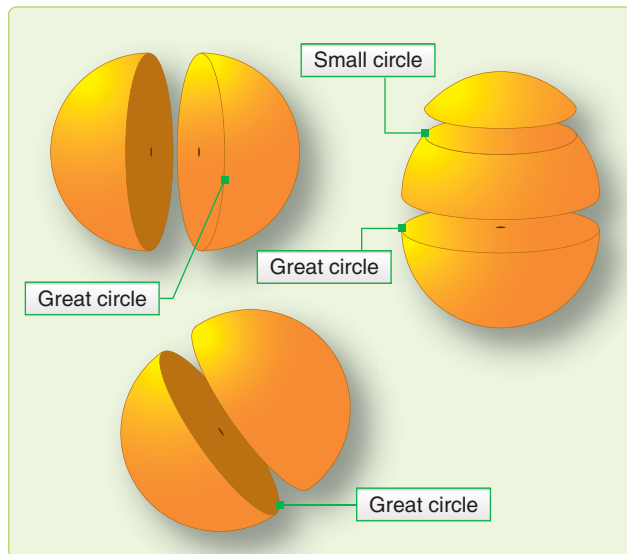


Figure 1-2. A great circle is the largest circle in a sphere.

Circles on the surface of the sphere, other than great circles, may be defined as small circles. A small circle is a circle on the surface of the earth whose center and/or radius are not that of the sphere. A set of small circles, called latitude, is discussed later. In summary, the intersection of a sphere and a plane is a great circle if the plane passes through the center of the sphere and a small circle if it does not.

Latitude and Longitude

The nature of a sphere is such that any point on it is exactly like any other point. There is neither beginning nor ending as far as differentiation of points is concerned. In order that points may be located on the earth, some points or lines of reference are necessary so that other points may be located with regard to them. The location of New York City with reference to Washington, D.C. can be stated as a number of miles in a certain direction from Washington. Any point on the earth can be located in this manner.

Imaginary Reference Lines

Such a system, however, does not lend itself readily to navigation, because it would be difficult to locate a point precisely in mid-ocean without any nearby geographic features to use for reference. We use a system of coordinates to locate positions on the earth by means of imaginary reference lines. These lines are known as parallels of latitude and meridians of longitude.

Latitude

Once a day, the earth rotates on its north-south axis, which is terminated by the two poles. The equatorial plane is constructed at the midpoint of this axis at right angles to it. [Figure 1-3] A great circle drawn through the poles is called a meridian, and an infinite number of great circles may be constructed in this manner. Each meridian is divided into four quadrants by the equator and the poles. The circle is arbitrarily divided into 360° , and each of these quadrants contains 90° .

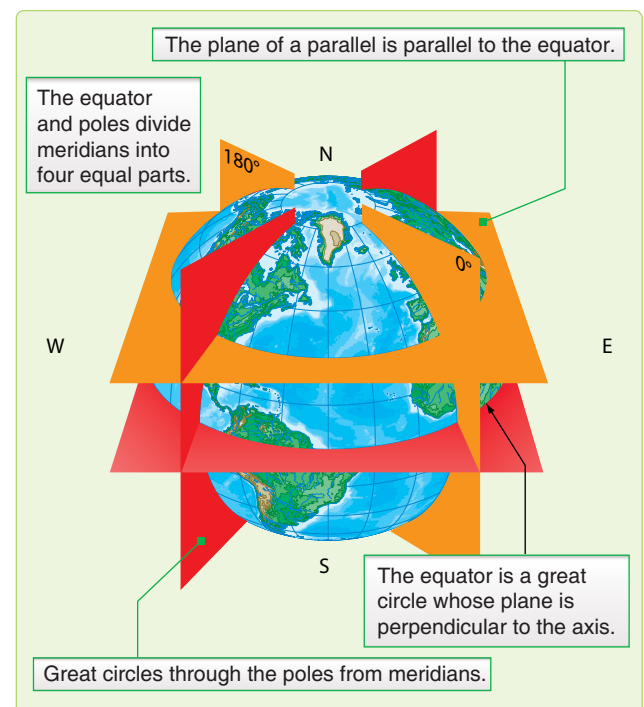


Figure 1-3. Planes of the earth.

Take a point on one of these meridians 30° N of the equator. Through this point passes a plane perpendicular to the north-south axis of rotation. This plane is parallel to the plane of the equator as shown in *Figure 1-3* and intersects the earth in a small circle called a parallel or parallel of latitude. The particular parallel of latitude chosen as 30° N, and every point on this parallel is at 30° N. In the same way, other parallels can be constructed at any desired latitude, such as 10° , 40° , etc.

Bear in mind that the equator is drawn as the great circle; midway between the poles and parallels of latitude are small circles constructed with reference to the equator. The angular distance measured on a meridian north or south of the equator is known as latitude [*Figure 1-4*] and forms one component of the coordinate system.

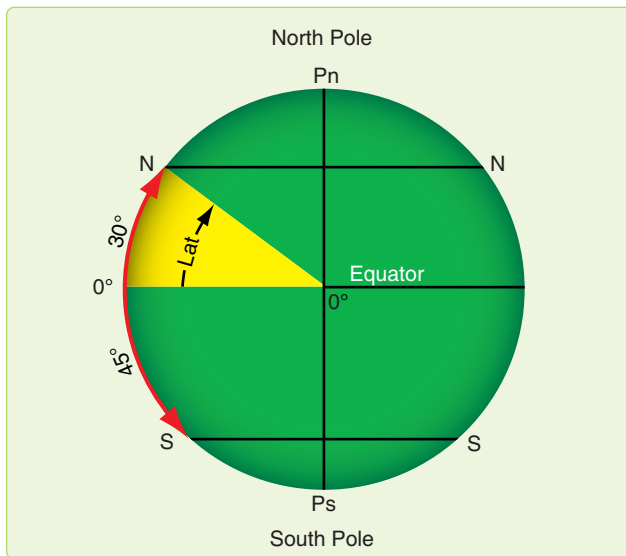


Figure 1-4. Latitude as an angular measurement.

Longitude

The latitude of a point can be shown as 20° N or 20° S of the equator, but there is no way of knowing whether one point is east or west of another. This difficulty is resolved by use of the other component of the coordinate system, longitude, which is the measurement of this east-west distance. Longitude, unlike latitude, has no natural starting point for numbering. The solution has been to select an arbitrary starting point. A great many places have been used, but when the English-speaking people began to make charts, they chose the meridian through their principal observatory in Greenwich, England, as the origin for counting longitude. This Greenwich meridian is sometimes called the prime meridian, though actually it is the zero meridian. Longitude is counted east and west from this meridian through 180° . [*Figure 1-5*] Thus, the Greenwich meridian is the 0° longitude on one side of the earth and, after crossing the poles, it becomes the 180th meridian (180° east or west of the 0° meridian).

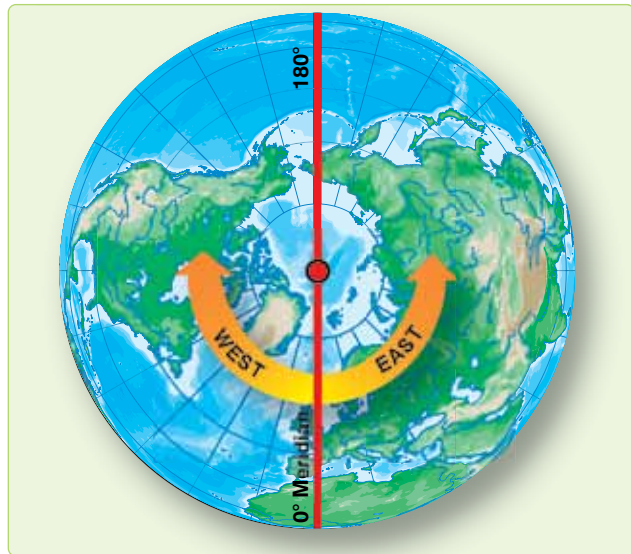


Figure 1-5. Longitude is measured east and west of the Greenwich Meridian.

In summary, if a globe has the circles of latitude and longitude drawn upon it according to the principles described, any point can be located on the globe using these measurements. [*Figure 1-6*]

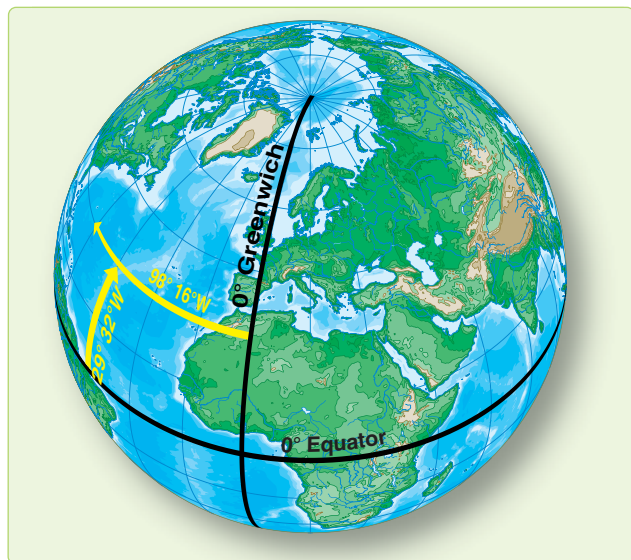


Figure 1-6. Latitude is measured from the equator; longitude from the prime meridian.

It is beneficial to point out here some of the measurements used in the coordinate system. Latitude is measured in degrees up to 90, and longitude is expressed in degrees up to 180. The total number of degrees in any one circle is always 360. A degree ($^\circ$) of arc may be subdivided into smaller units by dividing each degree into 60 minutes ($'$) of arc. Each minute may be further subdivided into 60 seconds ($''$) of arc.

Measurement may also be expressed in degrees, minutes, and tenths of minutes.

A position on the surface of the earth is expressed in terms of latitude and longitude. Latitude is expressed as being either north or south of the equator, and longitude as either east or west of the prime meridian.

In actual practice, map production requires surveyors to measure the latitude and longitude of geographic objects in their area of interest. Local variation in the earth's gravity field can cause these measurements to be inconsistent. All coordinates from maps, charts, traditional surveys, and satellite positioning systems are tied to an individual mathematical model of the earth called a datum. Coordinates for a given point may differ between datums by hundreds of yards. In other words, latitude and longitude measured directly from observation of stars (called an astronomic coordinate) is consistent, but it may not match maps, charts, or surveyed points. The theoretical consistency of latitude and longitude is therefore not achievable in reality. Without knowledge of the datum used to establish a particular map or surveyed coordinate, the coordinate is suspect at best.

Distance

Distance, as previously defined, is measured by the length of a line joining two points. The standard unit of distance for navigation is the nautical mile (NM). The NM can be defined as either 6,076 feet or 1 minute of latitude. Sometimes it is necessary to convert statute miles (SM) to NM and vice versa. This conversion is easily done with the following ratio:

$$\frac{\text{Number of statute miles}}{\text{Number of nautical miles}} = \frac{76}{66}$$

Closely related to the concept of distance is speed, which determines the rate of change of position. Speed is usually expressed in miles per hour (mph), this being either SM per hour or NM per hour. If the measure of distance is NM, it is customary to speak of speed in terms of knots. Thus, a speed of 200 knots and a speed of 200 NM per hour are the same thing. It is incorrect to say 200 knots per hour unless referring to acceleration.

Direction

Remember, direction is the position of one point in space relative to another without reference to the distance between them. The time honored point system for specifying a direction as north, north-northwest, northwest, west-northwest, west, etc., is not adequate for modern navigation. It has been replaced for most purposes by a numerical system. [Figure 1-7] The numerical system divides the horizon into 360°, starting with north as 000° and continuing clockwise through east 090°, south 180°, west 270°, and back to north.

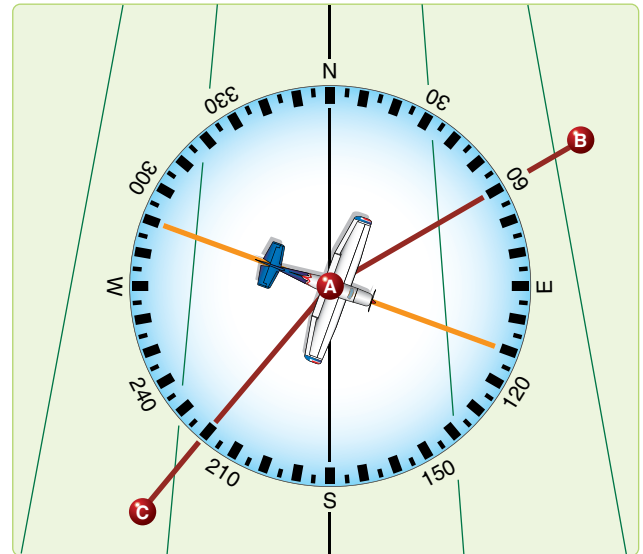


Figure 1-7. Numerical system is used in air navigation.

The circle, called a compass rose, represents the horizon divided into 360°. The nearly vertical lines in *Figure 1-7* are meridians drawn as straight lines with the meridian of position A passing through 000° and 180° of the compass rose. Position B lies at a true direction of 062° from A, and position C is at a true direction of 220° from A.

Since determination of direction is one of the most important parts of the navigator's work, the various terms involved should be clearly understood. Generally, in navigation, unless otherwise stated, directions are called true directions.

Course

Course is the intended horizontal direction of travel. Heading is the horizontal direction in which an aircraft is pointed. Heading is the actual orientation of the longitudinal axis of the aircraft at any instant, while course is the direction intended to be made good. Track is the actual horizontal direction made by the aircraft over the earth.

Bearing

Bearing is the horizontal direction of one terrestrial point from another. As illustrated in *Figure 1-8*, the direction of the island from the aircraft is marked by a visual bearing called the line of sight (LOS). Bearings are usually expressed in terms of one of two reference directions: true north (TN) or the direction in which the aircraft is pointed. If TN is the reference direction, the bearing is called a true bearing (TB). If the reference direction is the heading of the aircraft, the bearing is called a relative bearing (RB). [Figure 1-9]