AFM 51-40

NAVAIR 00-80V-49

FLYING TRAINING

AIR NAVIGATION

15 MARCH 1983

(Reprinted 1 December 1989 with Changes 1 and 2 included)

DEPARTMENTS OF THE AIR FORCE AND THE NAVY

DEPARTMENT OF THE AIR FORCE
Headquarters US Air Force
Washington DC 20330

AF MANUAL 51-40
NAVAIR 00-80V-49
15 March 1983

DEPARTMENT OF THE NAVY
Chief of Naval Operations
Washington, DC 20350

Flying Training
AIR NAVIGATION

This manual provides information on all phases of air navigation for navigators. It is written as a source of reference for a recent graduate from navigator training. This manual develops the art of navigation to include the most advanced procedures and techniques. The text contains explanations on how to measure, map, chart the Earth, and use basic instruments to solve basic navigation problems by dead reckoning. Many special techniques used to navigate are covered in detail. There is information on flight publications, weather services, mission planning, in-flight procedures, and low level navigation. The final chapters cover advanced navigation systems, aerial delivery, and air refueling.

Supersedes AFM 51-40/NAVAIR 00-80V-49, 1 July 1973. (See signature page for summary of changes.)
No of Printed Pages: 359
USAF OPR: HQ ATC/DON (by delegation) (Capt M. Maloney)
USN OPR: NAVAIRTU/Mather AFB, CA (Capt Floyd W. Carter, Jr., USN)
Approved by: Brig Gen E. N. Giddings
Editor: J. Comeaux
Distribution:
Air Force: F;
Navy: X

Published by Air Training Command in accordance with AFR 5-6

For sale by the Superintendent of Documents, U.S. Government Printing Office Washington, D.C. 20402

Chapter 1

INTRODUCTION

DEFINING AIR NAVIGATION

The word navigator comes from two Latin words, ''navis,'' meaning ship, and ''agere,'' meaning to direct or move. Navigation is defined as the process of directing the movement of a craft from one place to another. The craft may be, in its broadest sense, any object requiring direction or capable of being directed. Unlike sea or naval navigation, air navigation involves movement above the surface of the Earth, within or beyond the atmosphere. Air navigation, then, can be defined as the ''process of determining the geographical position and of maintaining the desired direction of an aircraft relative to the surface of the Earth.'' Other terms, ''avigation'' and ''aerial navigation'' have fallen into disuse in favor of the term, ''air navigation.'' Certain unique conditions are encountered in air navigation that have a special impact on the navigator.

- *Need for continued motion*. A ship or land vehicle can stop and resolve any uncertainty of motion or await more favorable conditions if necessary. Except to a limited extent, most aircraft must keep going.
- *Limited endurance*. Most aircraft can remain aloft for only a relatively short time, usually a matter of hours.
- *Greater speed*. Navigation of high-speed aircraft requires detailed flight planning, and navigation methods and procedures that can be accomplished quickly and accurately.
- *Effect of weather*. Visibility affects the availability of landmarks. The wind has a more direct effect upon the position of aircraft than upon that of ships or land vehicles. Changes of atmospheric pressure and temperature affect the height measurement of aircraft using barometric altimeters.

Some form of navigation has been used ever since humans have ventured from their immediate surroundings with definite destinations in mind. Exactly how the earliest navigators found their way must remain, to some extent, a matter of conjecture but some of their methods are known. For example, the Phoenicians and Greeks were the first to navigate far from land and to sail at night. They made primitive charts and used a crude form of dead reckoning. They used observations of the Sun and the North Star, or pole star, to determine direction. Early explorers were aided by the invention of the astrolabe (figure 1-1), but it was not until the 1700s that an accurate chronometer (timepiece) and the sextant were invented making it possible for navigators to know exactly where they were, even when far from land.

Navigation is considered both an art and a science. Science is involved in the development of instruments and methods of navigation as well as in the computations involved. The skillful use of navigational instruments and the interpretation of available data may be considered an art. This combination has led some to refer to navigation as a ''scientific art.''

As instruments and other navigational aids have become more complicated, an increasing proportion of the development has been shifted from practicing navigators to navigational scientists who aid in drawing together the applications of principles from such sciences as astronomy, cartography, electronics, geodesy, mathematics, meteorology, oceanography, and physics. Such applications aid in explaining navigational phenomena and in developing improvements in speed, accuracy, or routine actions in perfecting the ''scientific art'' of navigation.

The beginning navigators largely practiced the science of navigation; that is, they gathered data and used it to solve the navigation problem in a more or less mechanical manner. It is not until after many hours of flying that navigators begin to realize that their total role involves an integration based on judgment. Navigators build accuracy and reliability into their performance by applying judgment based upon experience. Military navigators must be able to plan missions covering every eventuality; in flight, they must be able to evaluate the progress of the aircraft and plan for the remainder of the mission. High-speed navigation demands that they have the ability to anticipate changes in flight conditions—to think ahead of the aircraft—and to make the correct decision immediately on the basis of anticipated changes.

AIR NAVIGATION PROBLEM

The problem of air navigation is, primarily, to determine the direction necessary to accomplish the intended flight, to locate positions, and to measure distance and time as means to that end.

When navigation is performed without ''aids,'' that is, without obtaining or deducing position information from special equipment specifically designed to provide only momentary knowledge of position, the basic method of navigation, ''dead reckoning,'' is used.

Dead reckoning is the determination of position by advancing a previous position, using only direction and speed data. Navigators do this by applying, to the last well-established position, a vector or a series of consecutive vectors representing the magnitude and direction of movement that has been made since the previous position. The new position obtained is for a specific time and is essentially a predicted or theoretical position. The navigators assume that they can use direction and speed data

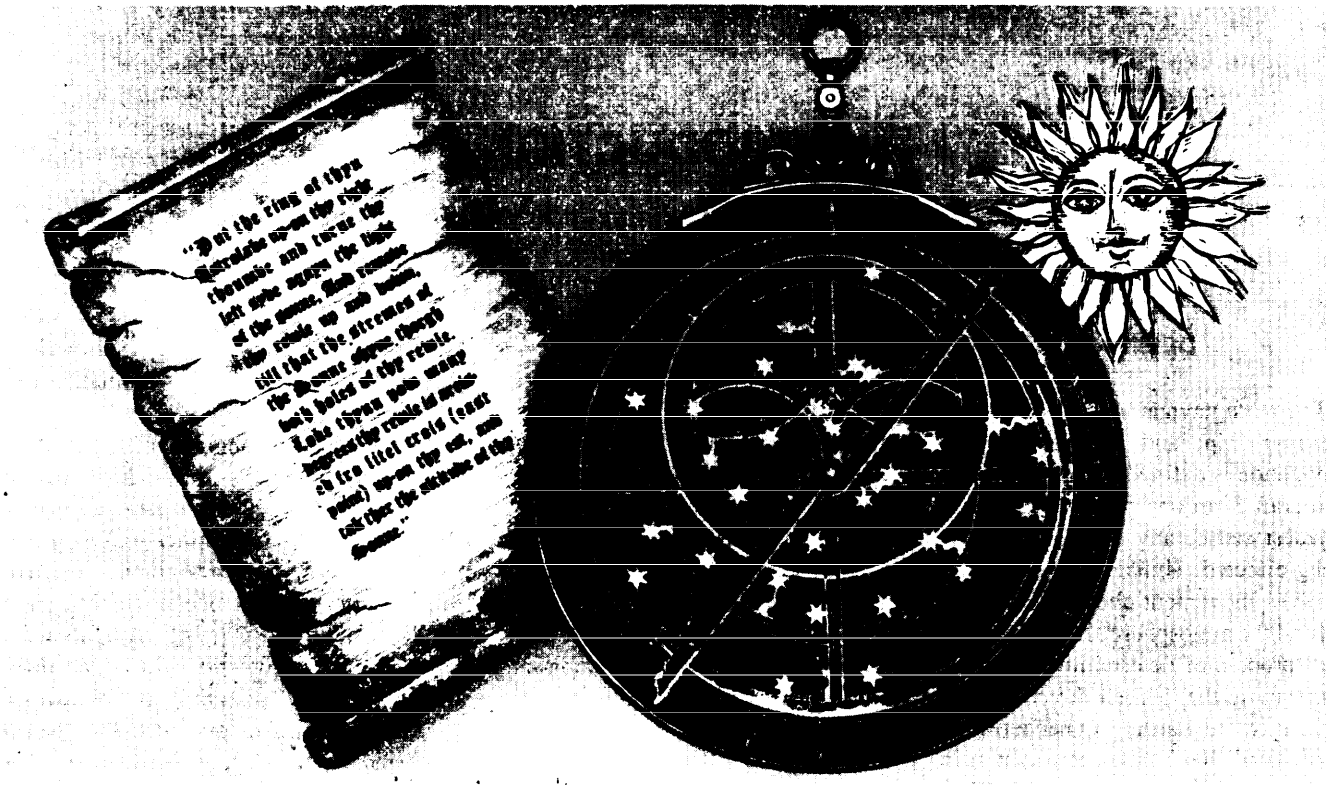


Figure 1-1. The Ancient Astrolabe.

previously determined with reasonable accuracy to obtain a future position.

The most important elements in the plotting of a dead reckoning position are elapsed time, direction, distance, and speed. Knowing these and the precise starting point, a navigator can plot the approximate position, which in turn, can serve as a base for a subsequent course change.

When the function of air navigation is performed with aids to navigation, the navigator can provide a new and separate base or starting point from which to use dead reckoning procedures. When an aid to navigation provides the navigator with a position or fix, any cumulative errors in previous dead reckoning elements are cancelled. In effect, the navigator can restart the mission, as far as the future is concerned, from each new fix or accurate position determined by the use of aids.

An adjective is often used with the word "navigation" to indicate the type or primary method being used, such as dead reckoning navigation, celestial navigation, radar navigation, pressure pattern navigation, Doppler navigation, grid navigation, inertial navigation, and others.

SOURCES OF NAVIGATIONAL INFORMATION

In addition to this manual, several other sources provide complete or partial references to all methods and techniques of navigation. Some of these are:

- US Navy Oceanographic Office, Air Navigation, HO Pub 216. This is a general reference book for air navigators.
- US Navy Oceanographic Office, American Practical Navigator, Bowditch, HO Pub 9. An epitome of navigation, this text provides a compendium of navigational material. Although designed primarily for the marine navigator, it has valuable application for the air navigator.
- United States Naval Institute, Navigation and Piloting, Dutton. This is a teaching text for the elements of marine navigation.
- Air Training Command, Navigation for Pilot Training, ATCP 51-16. This manual explains the basic principles and procedures of air navigation used by pilots.
- USAF, Air Training Command, The Navigator, USAFRP 50-3, published three times per year by ATC. This magazine contains a variety of articles from worldwide sources that relate to navigation and which advance new and different means for accomplishing techniques of navigation.

The following United States Observatory and U.S. Navy Oceanographic Office publications are also prescribed for Air Force use:

- Air Almanac
- American Ephemeris and Nautical Almanac
- HO Pub 9 (Part II), Useful Tables for the American Practical Navigator
- HO Pub 211, Dead Reckoning Altitude and Azimuth Tables
- HO Pub 249, Sight Reduction Tables for Air Navigation

The Department of Defense (DOD) Catalog of Aeronautical Charts and Flight Publications, published by the Defense Mapping Agency (DMA), contains information on the basis of issue and procedures for requisitioning these publications. The use of the Air Almanac and HO 249 tables is discussed in detail later in this manual.

SUMMARY

Some form of navigation has been accomplished since the ancient Greeks and Phoenicians began sailing far from land. The problems of air navigation and the navigator today are far different from those experienced by these ancient mariners. With the advent of newer, high-speed aircraft, the navigator must be able to quickly and accurately make decisions which directly affect the safety of the aircraft and the crew. Using proven techniques and modern aids, the navigator practices a scientific art.

Chapter 2

MAPS AND CHARTS (EARTH'S COORDINATES)

INTRODUCTION

Basic to the study of navigation is an understanding of certain terms which could be called the dimensions of navigation. These so-called dimensions of position, direction, distance, and time are basic references used by the air navigator. 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 is a point defined by stated or implied coordinates. Though frequently qualified by such adjectives as "estimated," "dead reckoning," "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 immediate position before being able to direct the aircraft to another position or in another direction.
- Direction is 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 reference direction.
- Distance is the spatial separation between two points and is 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, once the path or direction of the line has been determined, can be expressed in various units; for example, miles, yards, and so forth.
- Time is defined in many ways, but those definitions used in navigation consist mainly of: (1) the hour of the day and (2) an elapsed interval.

The methods of expressing position, direction, distance, and time are covered fully in appropriate chapters. It is desirable at this time to emphasize that these terms, and others similar to them, represent definite quantities or conditions which 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 being 10 miles south of a certain city. The study of navigation demands that the navigator learn how to measure quantities such as those just defined and how to apply the units by which they are expressed.

EARTH'S SIZE AND SHAPE

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. Smaller variations in the surface (valleys, mountains, oceans, etc) cause an irregular appearance.

Measured at the equator, the Earth is approximately 6,887.91 nautical miles in diameter, while the polar diameter is approximately 6,864.57 nautical miles. The difference in these diameters is 23.34 nautical miles, and this difference may be used to express the ellipticity of the Earth. It is sometimes expressed as a ratio between the difference and the equatorial diameter:

$$\text{Ellipticity} = \frac{23.34}{6{,}887.91} = \frac{1}{295}$$

Since the equatorial diameter exceeds the polar diameter by only 1 part in 295, the Earth is very nearly spherical. A symmetrical body having the same dimensions as the Earth, but with a smooth surface, is called an oblate spheriod.

In figure 2-1, Pn, E, Ps, and W represent the surface of the Earth, and Pn-Ps represents the axis of rotation. The Earth

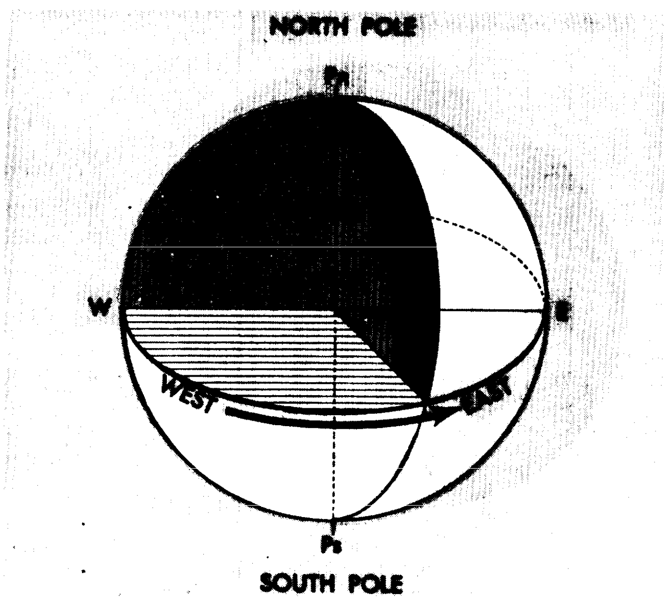


Figure 2-1. Schematic Representation of the Earth Showing Axis of Rotation and Equator.

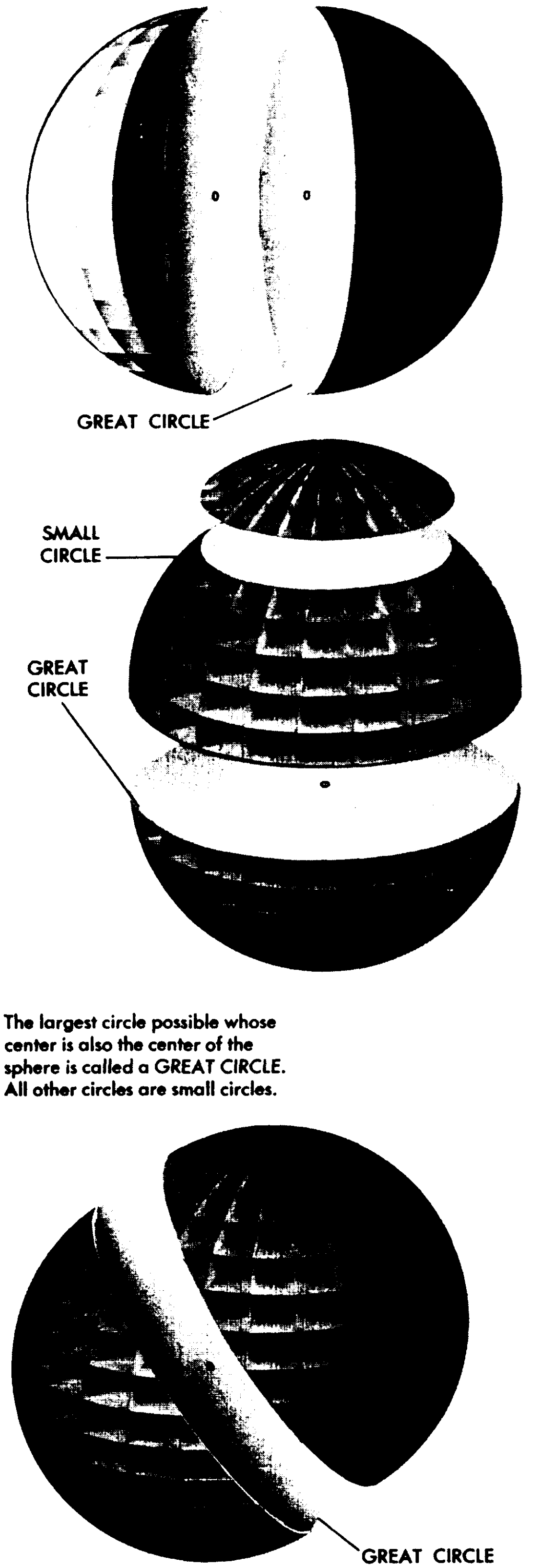


Figure 2-2. A Great Circle is the Largest Circle in a Sphere.

rotates from W to E. 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 circles may be drawn through any point, though only one great circle may be drawn through any two points that are not diametrically opposite. Several great circles are shown in figure 2-2.

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 special set of small circles, called latitude, is discussed later.

In summary, the intersection of a sphere and a plane is a circle—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. Thus, the location of New York City with reference to Washington DC, is stated as a number of miles in a certain direction from Washington. Any point on the Earth can be located in this manner.

Such a system, however, does not lend itself readily to navigation, for it would be difficult to locate a point precisely in mid-Pacific without any nearby known geographic features to use for reference. A system of coordinates has been developed 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 equator is constructed at the midpoint of this axis at right angles to it (figure 2-3). 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. Since a circle is arbitrarily divided into 360 degrees, each of these quadrants therefore contains 90 degrees.

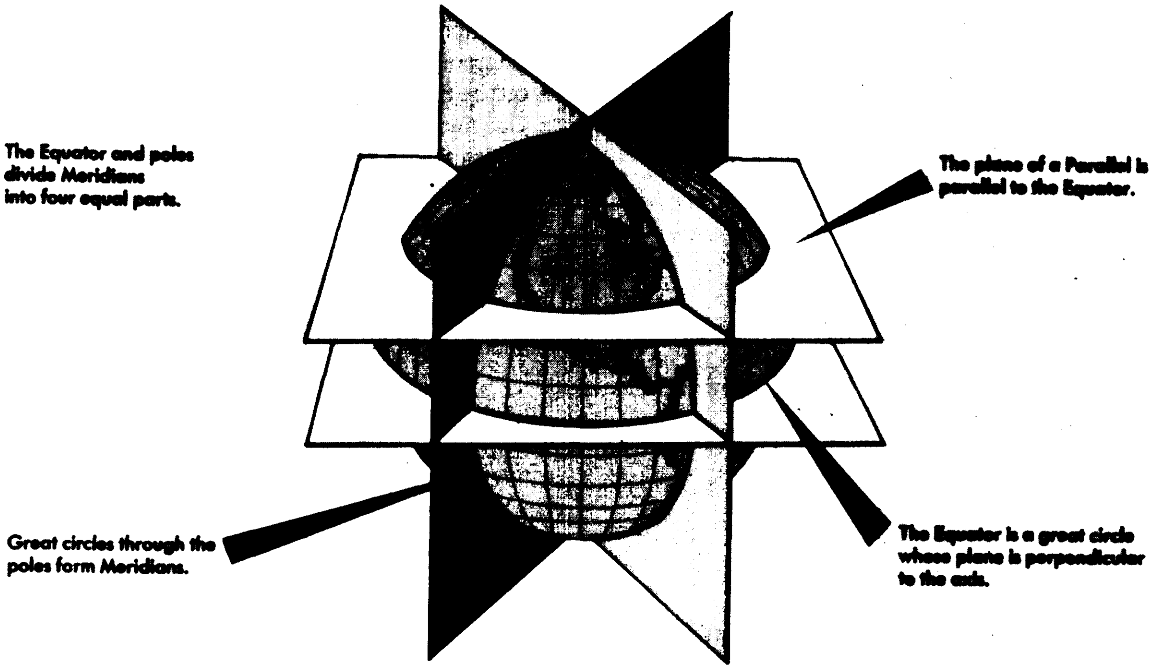


Figure 2-3. Planes of the Earth.

Take a point on one of these meridians 30 degrees north of the equator. Through this point passes a plane perpendicular to the north-south axis of rotation. This plane will be parallel to the plane of the equator as shown in figure 2-3 and will intersect 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 will be at 30° N. In the same way, other parallels can be constructed at any desired latitude, such as 10 degrees, 40 degrees, etc.

Bear in mind that the equator is drawn as the great circle midway between the poles and that the 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 2-4) and forms one component of the coordinate system.

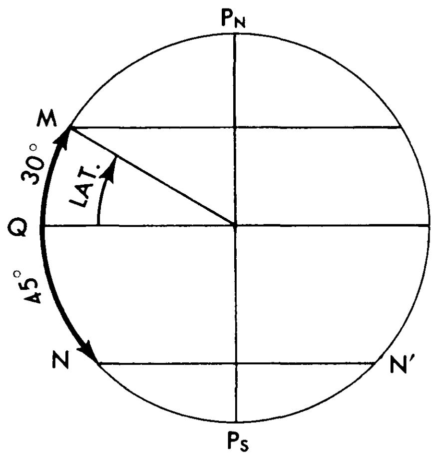


Figure 2-4. Latitude of M is Angle QOM or ARC QM.

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.

There is not, as with latitude, a natural starting point for numbering, such as the equator. 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

Figure 2-5. Longitude is Measured East and West of Greenwich Meridian.

Figure 2-6. Latitude is Measured from the Equator; Longitude from the Prime Meridian.

Greenwich, England, as the origin for counting longitude, and this point has now been adopted by most other countries of the world. This Greenwich meridian is sometimes called the prime or first meridian, though actually it is the zero meridian. Longitude is counted east and west from this meridian through 180 degrees, as shown in figure 2-5. Thus, the Greenwich meridian is the 0 degree longitude on one side of the Earth and, after crossing the poles, it becomes the 180th meridian (180 degrees east or west of the 0-degree meridian).

Summary. If a globe has the circles of latitude and longitude drawn upon it according to the principles described, and the latitude and longitude of a certain place have been determined by observation, this point can be located on the globe in its proper position (figure 2-6). In this way, a globe can be formed that resembles a small-scale copy of the spherical Earth.

It may be well 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 cannot exceed 360. A degree (°) 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 (") or arc. Measurement may also be made, if desired, 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.

Distance

Distance as previously defined is measured by the length of a line joining two points. In navigation, the most common unit for measuring distances is the nautical mile. For most practical navigational purposes, all of the following units are used interchangeably as the equivalent of one nautical mile:

- 6,076.10 feet (nautical mile).
- One minute of arc of a great circle on a sphere having an area equal to that of the Earth.
- 6,087.08 feet. One minute of arc on the Earth's equator (geographic mile).
- One minute of arc on a meridian (one minute of latitude).
- Two thousand yards (for short distances).

Navigation is done in terms of nautical miles. However, it is sometimes necessary to interconvert statute and nautical miles. This conversion is easily made with the following ratio:

In a given distance:

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

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, this being either statute miles per hour or nautical miles per hour. If the measure of distance is nautical miles, it is customary to speak of speed in terms of knots. Thus, a speed of 200 knots and a speed of 200 nautical miles per hour are the same thing. It is incorrect to say 200 knots per hour unless referring to acceleration.

Direction

Remember that 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.

The numerical system (figure 2-7) divides the horizon into 360 degrees starting with north as 000 degrees, and continuing clockwise through east 090 degrees, south 180 degrees, west 270 degrees, and back to north.

The circle, called a compass rose, represents the horizon divided into 360 degrees. The nearly vertical lines in the illustra-

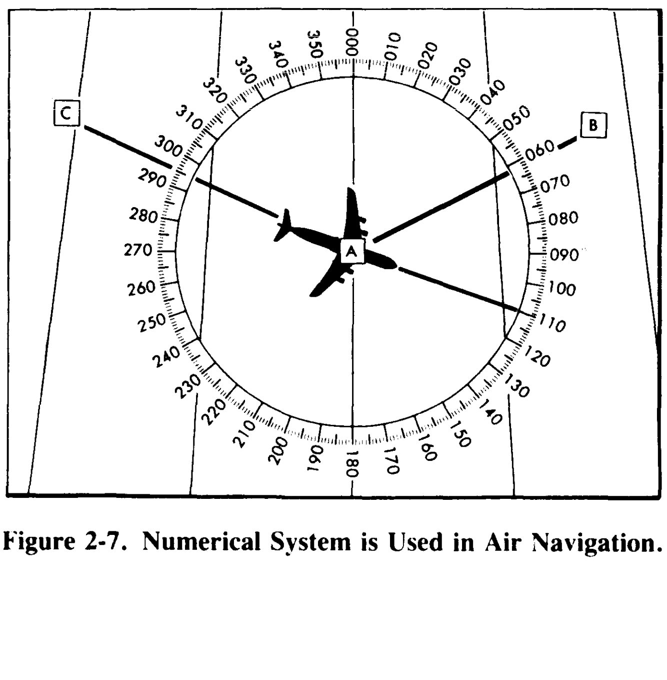


Figure 2-7. Numerical System is Used in Air Navigation.

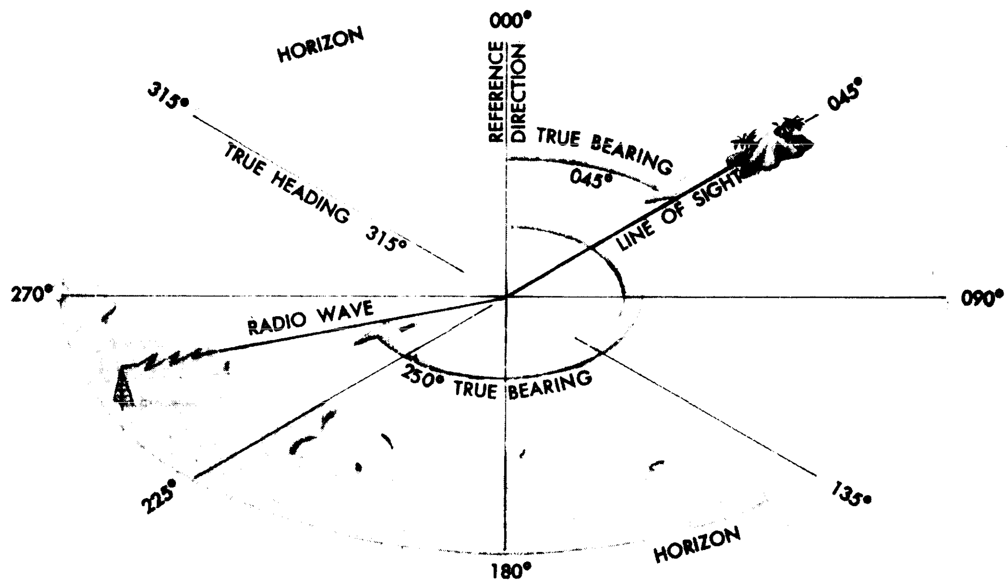


Figure 2-8. Measuring True Bearing from True North.

tion are meridians drawn as straight lines with the meridian of position "A" passing through 000 degrees and 180 degrees of the compass rose. Position "B" lies at a true direction of 062 degrees from "A", and position "C" is at a true direction of 295 degrees 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, all directions are called true (T) directions.

- 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 is the horizontal direction of one terrestrial point from another. As illustrated in figure 2-8, the direction of the island from the aircraft is marked by the line of sight (a visual bearing). Bearings are usually expressed in terms of one of two reference directions: (1) true north, or (2) the direction in which the aircraft is pointed. If true north is the reference direction, the bearing is called a true bearing. If the reference direction is the heading of the aircraft, the bearing is called a relative bearing as shown in figure 2-9. (A complete explanation of these terms and their use in navigation is given in attachment 3.)

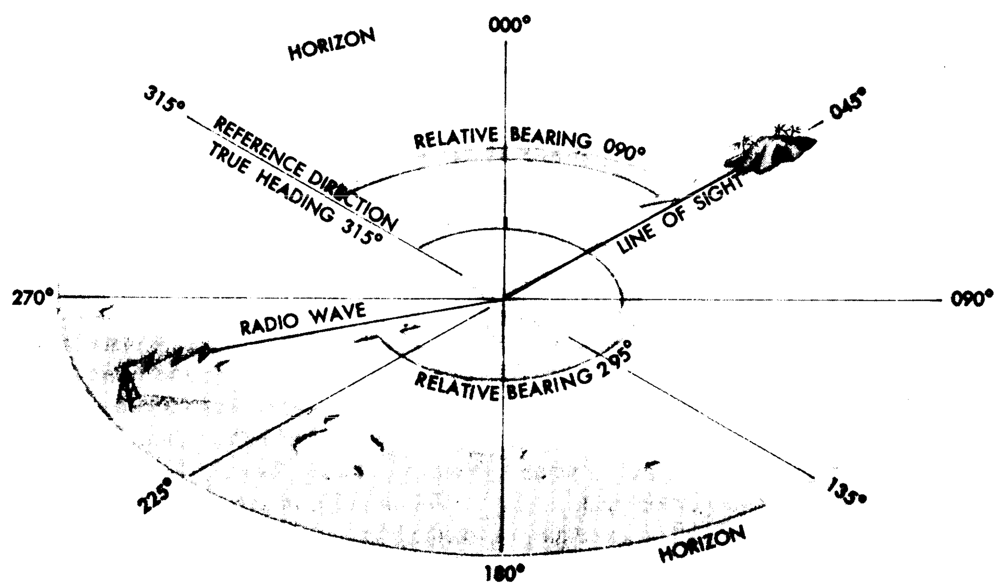


Figure 2-9. Measure Relative Bearing from Aircraft Heading.

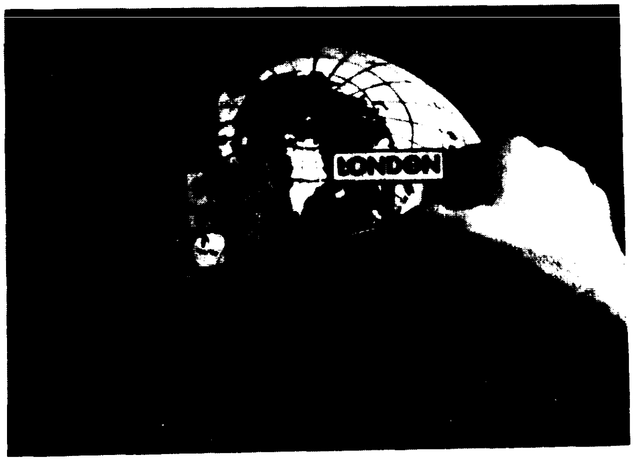


Figure 2-10. Great Circle and Rhumb Line.

Great Circle and Rhumb Line Direction

The direction of the great circle, shown in figure 2-10, makes an angle of about 50 degrees with the meridian of New York, about 90 degrees with the meridian of Iceland, and a still greater angle with the meridian of London. In other words, the direction of the great circle is constantly changing as progress is made along the route, and is different at every point along the great circle. Flying such a route requires constant change of direction and would be difficult to fly under ordinary conditions. Still, it is the most desirable route, since it is the shortest distance between any two points.

A line which makes the same angle with each meridian is called a rhumb line. An aircraft holding a constant true heading would be flying a rhumb line. Flying this sort of path results in a greater distance traveled, but it is easier to steer. If continued, a rhumb line spirals toward the poles in a constant true direction but never reaches them. The spiral formed is called a loxodrome or loxodromic curve as shown in figure 2-11.

Between two points on the Earth, the great circle is shorter than the rhumb line, but the difference is negligible for short distances (except in high latitudes) or if the line approximates a meridian or the equator.

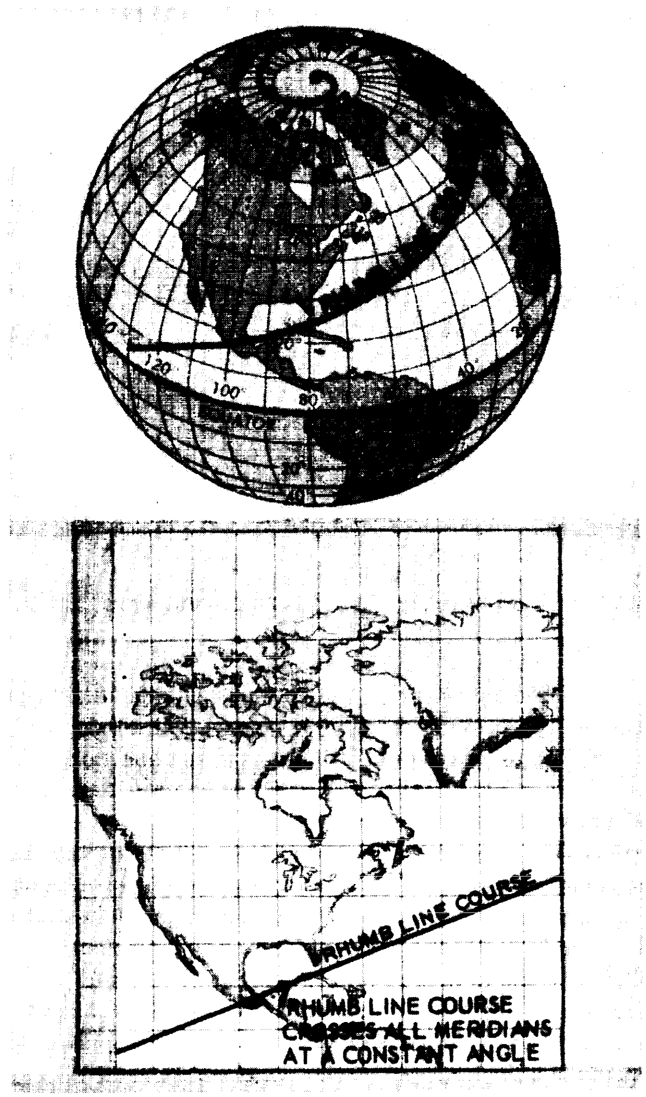


Figure 2-11. A Rhumb Line or Loxodrome.

CHARTS AND PROJECTIONS

Basic Information

There are several basic terms and ideas, relative to charts and projections, that the reader should be familiar with prior to discussing the various projections used in the creation of aeronautical charts.

- A map or chart is a small scale representation on a plane surface of the surface of the Earth or some portion of it.
- A chart projection is a method for systematically representing the meridians and parallels of the Earth on a plane surface.
- The chart projection forms the basic structure on which a chart is built and determines the fundamental characteristics of the finished chart.
- There are many difficulties which must be resolved when representing a portion of the surface of a sphere upon a plane. Two of these are distortion and perspective.

Distortion cannot be entirely avoided, but it can be controlled and systematized to some extent in the drawing of a chart. If a chart is drawn for a particular purpose, it can be drawn in such a way as to minimize the type of distortion which is most detrimental to the purpose. Surfaces that can be spread out in a plane without stretching or tearing such as a cone or cylinder are called developable surfaces, and those like the sphere or spheroid that cannot be formed into a plane without distortion are called nondevelopable. (figure 2-12.)

The problem of creating a projection lies in developing a method for transferring the meridians and parallels to the chart in a manner that will preserve certain desired characteristics as nearly as possible. The methods of projection are either mathematical or perspective.

The perspective or geometric projection consists of projecting

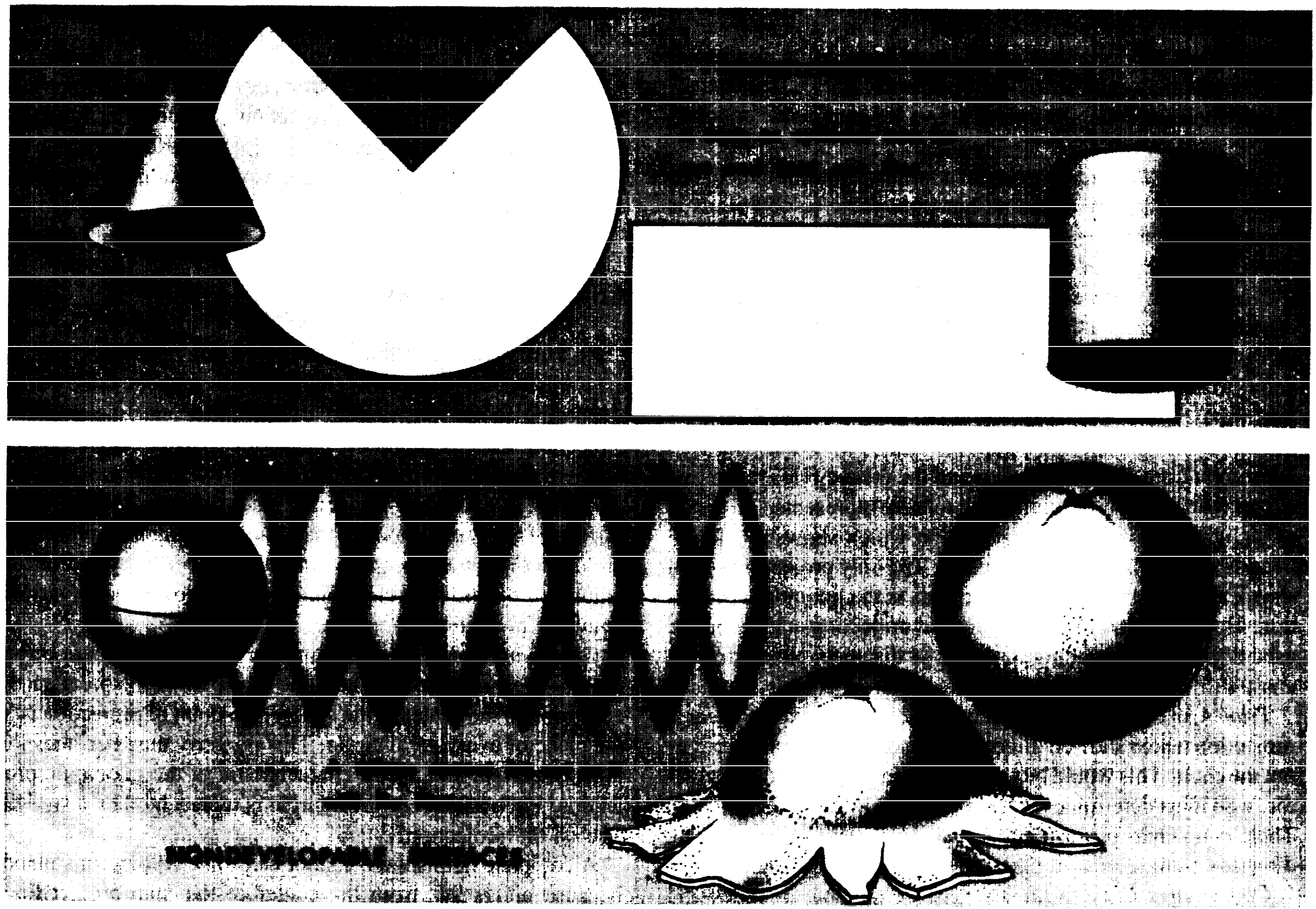


Figure 2-12. Developable and Nondevelopable Surfaces.

a coordinate system based on the Earth-sphere from a given point directly onto a developable surface. The properties and appearance of the resultant map will depend upon two factors; the type of developable surface and the position of the point of projection.

The mathematical projection is derived analytically to provide certain properties or characteristics which cannot be arrived at geometrically. Let us now consider some of the choices we have for selecting projections which best accommodate these properties and characteristics.

Choice of Projection

The ideal chart projection would portray the features of the Earth in their true relationship to each other; that is, directions would be true and distances would be represented at a constant scale over the entire chart. This would result in equality of area and true shape throughout the chart.

Such a relationship can only be represented on a globe. It is impossible to preserve, on a flat chart, constant scale and true direction in all directions at all points, nor can both relative size and shape of the geographic features be accurately portrayed throughout the chart. The characteristics most commonly desired in a chart projection are:

- Conformality
- Constant Scale
- Equal area
- Great circles as straight lines
- Rhumb lines as straight lines
- True azimuth
- Geographic position easily located

Conformality. Of the many projection characteristics, conformality is the most important for air navigation charts. The limitations imposed by selection of this characteristic, with the resulting loss of other desirable but inharmonious qualities, are offset by the advantages of conformality. For any projection to be conformal, three conditions must be satisfied:

First, the scale at any point on the projection must be independent of azimuth. This does not imply, however, that the scale about two points at different latitudes will be equal. It means, simply, that the scale at any given point will, for a short distance, be equal in all directions.

Second, the outline of areas on the chart must conform in shape to the feature being portrayed. This condition applies only to small and relatively small areas; large land masses must necessarily reflect any distortion inherent in the projection.

Finally, since the meridians and parallels of Earth intersect at right angles, the longitude and latitude lines on all conformal projections must exhibit this same perpendicularly. This characteristic facilitates the plotting of points by geographic coordinates.

Constant Scale. The property of constant scale throughout the entire chart is highly desirable but impossible to obtain, as it would require that the scale be the same at all points and in all directions throughout the chart.

Equal Area. These charts are so designed to maintain a constant ratio of area throughout, although original shapes may be distorted beyond recognition. Equal area charts are of little value to the navigator, since an equal area chart cannot be conformal. They are, however, often used for statistical purposes.

Straight Line. The rhumb line and the great circle are the two curves that a navigator might wish to have represented on a map as straight lines. The only projection which shows all rhumb lines as straight lines is the Mercator. The only projection which shows all great circles as straight lines is the gnomonic projection. However, this is not a conformal projection and cannot be used directly for obtaining direction or distance. No conformal chart will represent all great circles as straight lines.

True Azimuth. It would be extremely desirable to have a projection which showed directions or azimuths as true throughout the chart. This would be particularly important to the navigator, who must determine from the chart the heading to be flown. There is no chart projection that will represent true great circle direction along a straight line from all points to all other points.

Coordinates Easy to Locate. The geographic latitudes and longitudes of places should be easily found or plotted on the map when the latitudes and longitudes are known.

CLASSIFICATION OF PROJECTIONS

Chart projections may, of course, be classified in many ways. In this manual, the various projections are divided into three classes according to the type of developable surface to which the projections are related. These classes are azimuthal, cylindrical, and conical.

Azimuthal Projections

An azimuthal or zenithal projection is one in which points on the Earth are transferred directly to a plane tangent to the Earth. According to the positioning of the plane and the point of projection, various geometric projections may be derived. If the origin of the projecting rays (point of projection) is the center of the sphere, a gnomonic projection results. If it is located on the surface of the Earth opposite the point of the tangent plane, the projection is a stereographic, and if it is at infinity, an orthographic projection results. Figure 2-13 shows these various points of projection.

Gnomonic Projection. All gnomonic projections are direct perspective projections. Since the plane of every great circle cuts through the center of the sphere, the point of projection is in the plane of every great circle. This property then becomes the most important and useful characteristic of the gnomonic projection. Each and every great circle is represented by a straight line on the projection.

A complete hemisphere cannot be projected onto this plane, because points 90° from the center of the map project lines parallel to the plane of projection.

Because the gnomonic is nonconformal, shapes or land mas-

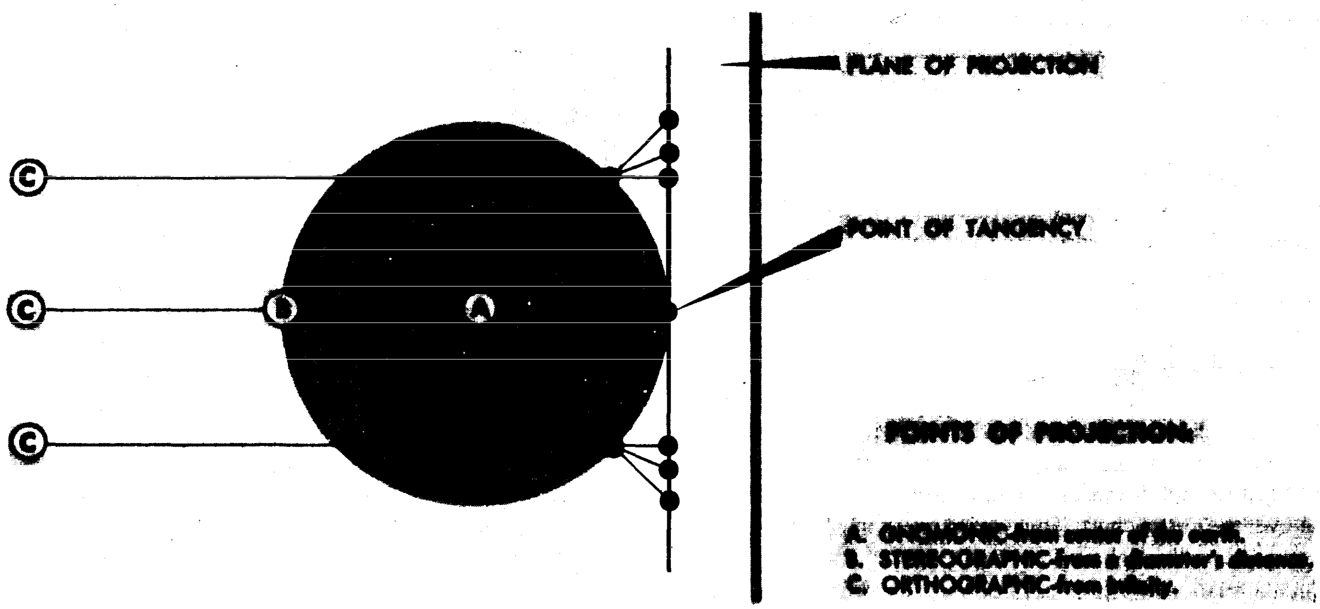


Figure 2-13. Azimuthal Projections.

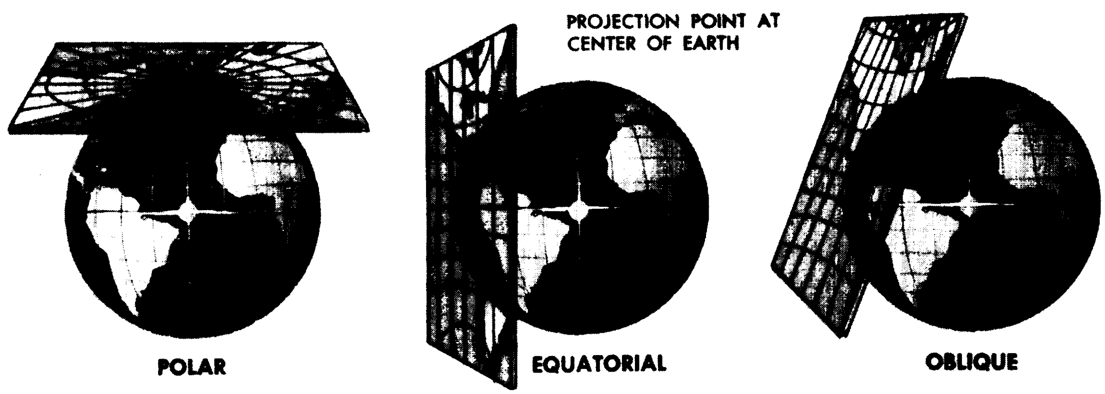


Figure 2-14. Gnomonic Projections.

ses are distorted, and measured angles are not true. At only one point, the center of the projection, are the azimuths of lines true. At this point, the projection is said to be azimuthal.

Gnomonic projections are classified according to the point of tangency of the plane of projection. A gnomonic projection is polar gnomonic when the point of tangency is one of the poles, equatorial gnomonic when the point of tangency is at the equator and any selected meridian, and oblique gnomonic when the point of tangency is at any point other than one of the poles or the equator (figure 2-14).

Stereographic Projection. The stereographic projection is a perspective conformal projection of the sphere.

The term horizon stereographic is applied to any stereographic projection where the center of the projection is positioned at any point other than the geographic poles or the equator. If the center is coincident with one of the poles of the reference surface the projection is called polar stereographic. If the center lies on the equator, the primitive circle is a meridian, which gives the name meridian stereographic or equatorial stereographic. The illustration in figure 2-15 shows the three stereographic projections.

Horizon and Meridian Stereographic. Since the horizon stereographic and the meridian stereographic are not used in navigation, they are not discussed in this manual.

Orthographic Projection. If the plane is tangent to the Earth at the equator, the parallels appear as straight lines and the meridians as elliptical curves, except the meridian through the point of tangency, which is a straight line.

The illustration in figure 2-16 shows an equatorial orthographic projection. Its principal use in navigation is in the field of navigational astronomy, where it is useful for illustrating celestial coordinates, since the view of the Moon, the Sun, and other celestial bodies from the Earth is essentially orthographic.

Azimuthal Equidistant Projection. This projection is neither perspective, equal area, nor conformal. It is called azimuthal equidistant because straight lines radiating from the center represent great circles as true azimuths, and distances along these lines are true to scale.

The entire surface of the sphere is mapped in a circle, the diameter being equal to the circumference of the Earth at reduced scale. With respect to the entire Earth, the perimeter of the circle represents the points diametrically opposite the center of the projection. The appearance of the curves representing the parallels and meridians depends upon the point selected as the center of the projection and may be described in terms of three general classifications.

1. If the center is one of the poles, the meridians are represented as straight lines radiating from it, with convergence equal

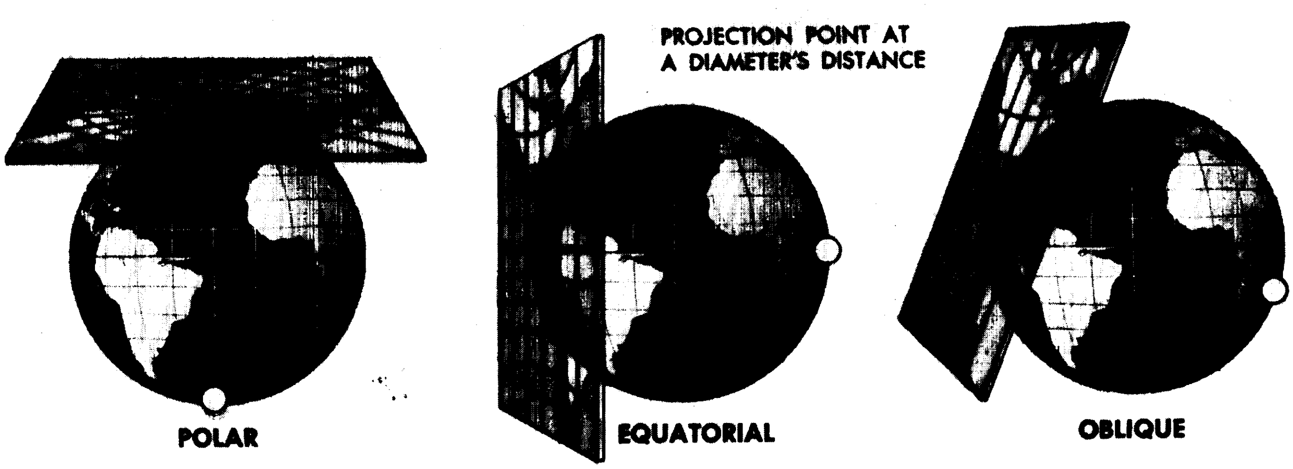


Figure 2-15. Stereographic Projections.

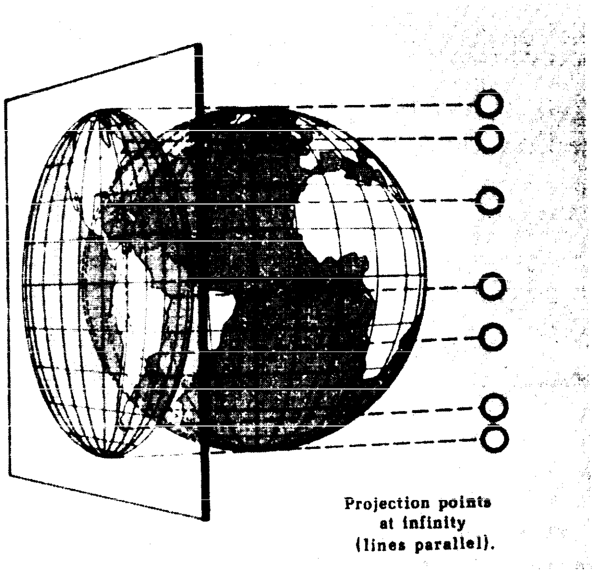


Figure 2-16. Equatorial Orthographic Projection.

to unity, and the parallels are represented as equally spaced concentric circles.

2. If the center is on the equator, the meridian of the center point and its antimeridian form a diameter of the circle (shown as a vertical line) and the equator is also a diameter perpendicular to it. One-fourth of the Earth's surface is mapped in each of the quadrants of the circle determined by these two lines.

3. If the center is any other point, only the central meridian (and its antimeridian) form a straight line diameter. All other lines are curved. For an example of the projection see figure 2-17.

Figure 2-17. Azimuthal Equidistant Projection with Point of Tangency Lat 40°N, Long 100°W.

The property of true distance and azimuth from the central point makes the projection useful in aeronautics and radio engineering. For example, if an important airport is selected for the point of tangency, the great circle distance and course from that point to any other position on the Earth are quickly and accurately determined. Similarly, for communications work at a fixed point (point of tangency), the path of an incoming signal whose direction of arrival has been determined is at once apparent, as is the direction in which to train a directional antenna for desired results.

Cylindrical Projections

The only cylindrical projection used for navigation is the Mercator, named after its originator, Gerhard Mercator (Kramer), who first devised this type of chart in the year 1569. The Mercator is the only projection ever constructed that is conformal and at the same time displays the rhumb line as a straight line. It is used for navigation, for nearly all atlases (a word coined by Mercator), and for many wall maps.

Imagine a cylinder tangent to the equator, with the source of projection at the center of the Earth. It would appear much like the illustration in figure 2-18, with the meridians being straight

Figure 2-18. Cylindrical Projection.

lines and the parallels being unequally spaced circles around the cylinder. It is obvious from the illustration that those parts of the terrestrial surface close to the poles could not be projected unless the cylinder was tremendously long, and the poles could not be projected at all.

On the Earth, the parallels of latitude are perpendicular to the meridians, forming circles of progressively smaller diameters as the latitude increases. On the cylinder, the parallels of latitude are shown perpendicular to the projected meridians but, since the diameter of a cylinder is the same at any point along the longitudinal axis, the projected parallels are all the same length. If the cylinder is cut along a vertical line—a meridian—and spread flat, the meridians appear as equal-spaced, vertical lines, and the parallels as horizontal lines.

The cylinder may be tangent at some great circle other than the equator, forming other types of cylindrical projections. If the cylinder is tangent at some meridian, it is a transverse cylindrical projection and, if it is tangent at any point other than the equator or a meridian, it is called an oblique cylindrical projection. The patterns of latitude and longitude appear quite different on these projections, since the line of tangency and the equator no longer coincide.

Mercator Projection. The Mercator projection is a conformal, nonperspective projection; it is constructed by means of a mathematical transformation and cannot be obtained directly by graphical means. The distinguishing feature of the Mercator projection among cylindrical projections is that at any latitude the ratio of expansion of both meridians and parallels is the same, thus preserving the relationship existing on the Earth. This expansion is equal to the secant of the latitude, with a small correction for the ellipticity of the Earth. Since expansion is the same in all directions and since all directions and all angles are correctly represented, the projection is conformal. Rhumb lines appear as straight lines, and their directions can be measured directly on the chart. Distance can also be measured directly, but not by a single distance scale on the entire chart, unless the spread of latitude is small. Great circles appear as curved lines, concave to the equator, or convex to the nearest pole. The shapes of small areas are very nearly correct, but are of increased size unless they are near the equator as shown in figure 2-19.

The Mercator projection has the following disadvantages:

- Difficulty of measuring large distances accurately.
- Conversion angle must be applied to great circle bearing before plotting.
- The chart is useless in polar regions above 80° N or below 80° S since the poles cannot be shown.

Transverse Mercator. The transverse or inverse Mercator is a conformal map designed for areas not covered by the equatorial Mercator. With the transverse Mercator, the property of straight meridians and parallels is lost, and the rhumb line is no longer represented by a straight line. The parallels and meridians become complex curves and, with geographic reference, the transverse Mercator is difficult to use as a plotting chart. The transverse Mercator, though often considered analogous to a projection onto a cylinder, is in reality a nonperspective projection that is constructed mathematically. This analogy (illustrated in figure 2-20) however, does permit the reader to visualize that the transverse Mercator will show scale correctly along the central meridian which forms the great circle of tangency. In effect, the cylinder has been turned 90 degrees from its position for the ordinary Mercator, and some meridian, called the central meridian, becomes the tangential great circle. One series of USAF charts using this type of projection places the cylinder tangent to

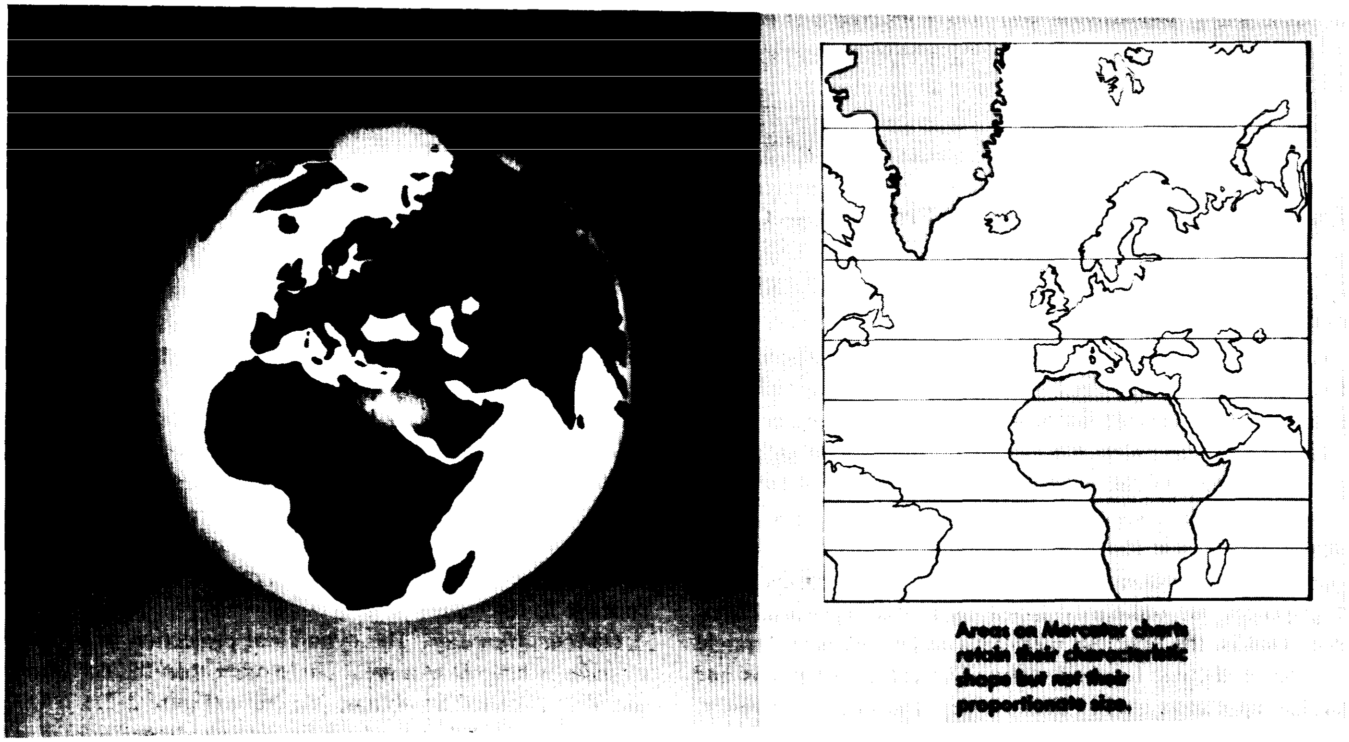


Figure 2-19. Mercator is Conformal but not Equal Area.

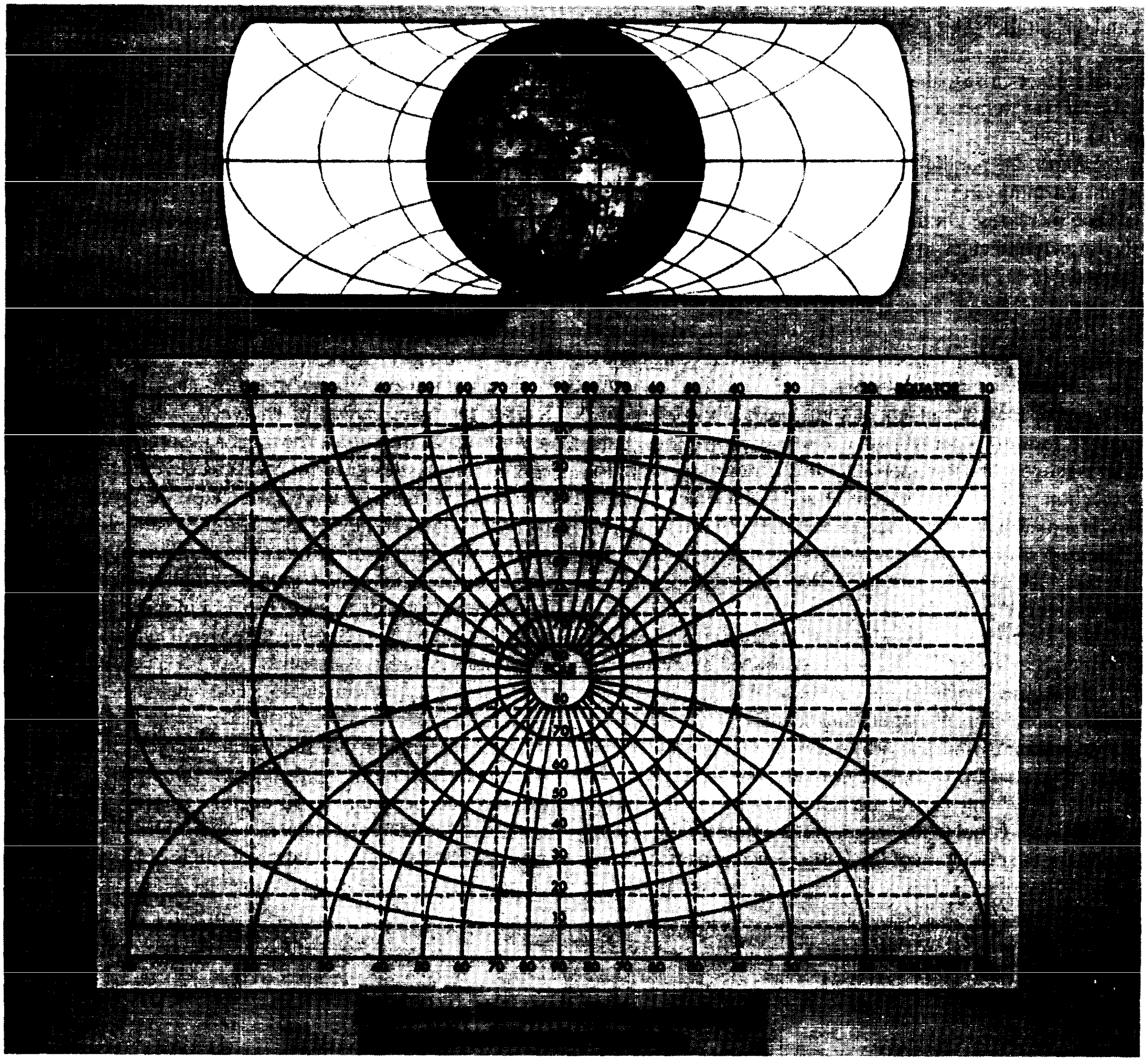


Figure 2-20. Transverse Cylindrical Projection — Cylinder Tangent at the Poles.

the 90°E-90°W longitude.

These projections use a fictitious graticule similar to, but offset from, the familiar network of meridians and parallels. The tangent great circle is the fictitious equator. Ninety degrees from it are two fictitious poles. A group of great circles through these poles and perpendicular to the tangent constitutes the fictitious meridians, while a series of lines parallel to the plane of the tangent great circle forms the fictitious parallels.

On these projections, the fictitious graticule appears as the geographical one ordinarily appearing on the equatorial Mercator. That is, the fictitious meridians and parallels are straight lines perpendicular to each other. The actual meridians and parallels appear as curved lines, except the line of tangency. Geographical coordinates are usually expressed in terms of the conventional graticule. A striaght line on the transverse Mercator projection makes the same angle with all fictitious meridians, but not with the terrestrial meridians. It is, therefore, a fictitious rhumb line.

The appearance of a transverse Mercator using the 90°E-90°W meridian as a reference or fictitious equator is shown in figure 2-20. The dotted lines are the lines of the fictitious projection. The N-S meridian through the center is the fictitious equator, and all other original meridians are now curves concave to the N-S meridian with the original parallels now being curves concave to the nearer pole.

Oblique Mercator. The cylindrical projection in which the cylinder is tangent at a great circle other than the equator or a meridian is called an oblique Mercator (figure 2-21).

You can see that as a sphere fits into a cylinder, it makes no difference how it is turned. The fit, or line of tangency, can be

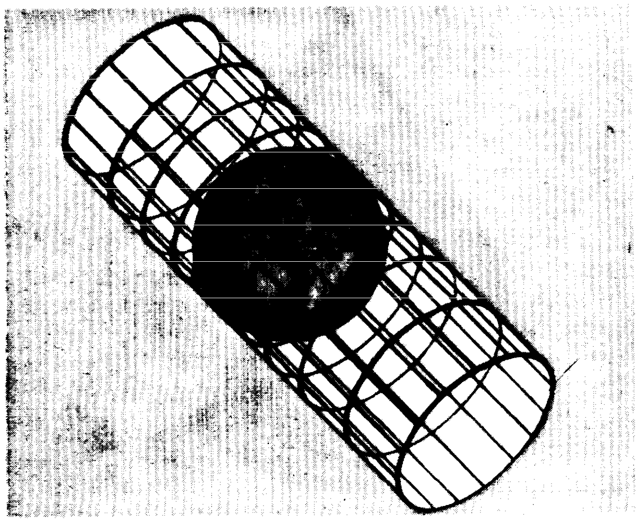


Figure 2-21. Oblique Mercator Projection.

any great circle. Thus, the oblique Mercator projection is unique in that it is prepared and used for special purposes. This projection is used principally to depict an area in the near vicinity of an oblique great circle, as, for instance, along the great circle route between two important centers a relatively great distance apart (figure 2-22).

Consider a flight between Seattle and Tokyo. The shortest distance is naturally the great circle distance and is, therefore, the route to fly. Plotting the great circle on a Mercator, you find that it takes the form of a high arching curve as shown. Since the scale on a Mercator changes with latitude, there will be a considerable scale change when you consider the latitude band that this great circle route covers.

If you were only concerned with the great circle route and a small band of latitude (say 5°) on either side, the answer to your problem would be the oblique Mercator. With the cylinder made tangential along the great circle joining Seattle and Tokyo, the resultant graticule would enjoy most of the good properties found near the equator on a conventional Mercator.

Advantages. The oblique Mercator projection has several desirable properties. The projection is conformal. The x axis is a great circle course at true scale. The projection can be constructed using any desired great circle as the x axis. The scale is equal to the secant of the angular distance from the x axis. Therefore, near the x axis, the scale change is slight. This makes the projection almost ideal for strip charts of great circle flights.

Limitations. The projection also has many disadvantages. Rhumb lines are curved lines; therefore, the chart is of little use to the navigator. Scale expansion and area distortion in the region of the oblique pole are the same as that of the standard Mercator in the region of the pole. Radio bearings cannot be plotted directly on the chart. All meridians and parallels are curved lines. A separate projection must be computed and constructed for each required great circle course.

Conic Projections

There are two classes of conic projections. The first is a simple conic projection constructed by placing the apex of the cone over some part of the Earth (usually the pole) with the cone tangent to a parallel called the standard parallel and projecting the graticule of the reduced Earth onto the cone as shown in figure 2-23. The chart is obtained by cutting the cone along some meridian and unrolling it to form a flat surface. Notice, in

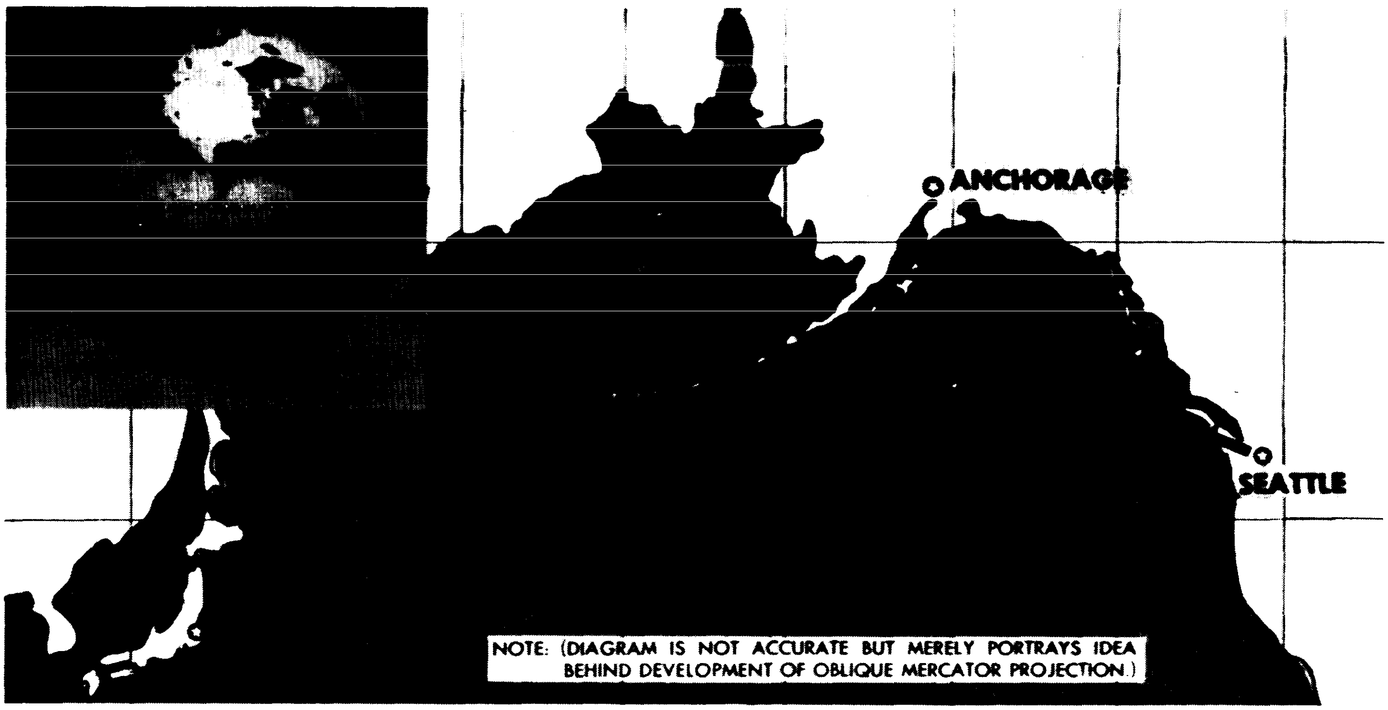


Figure 2-22. Great Circle Route from Seattle to Tokyo on Mercator Projection.

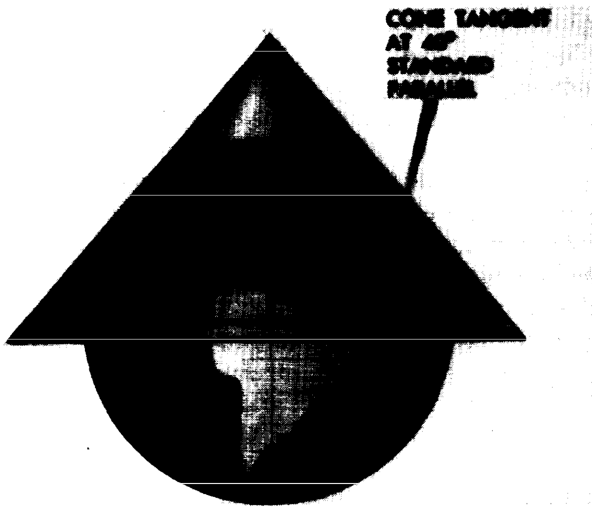


Figure 2-23. Simple Conic Projection.

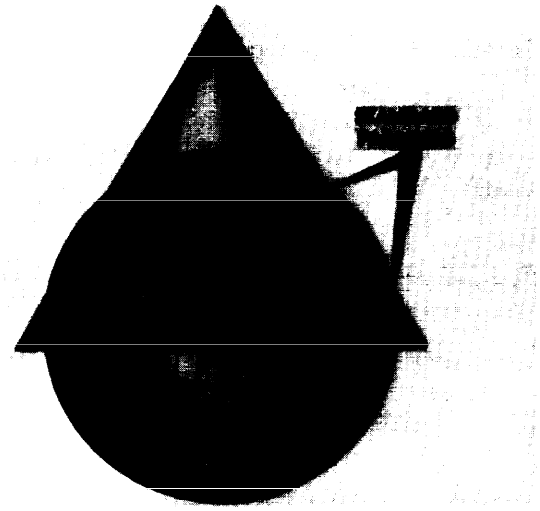


Figure 2-25. Conic Projection Using Secant Cone.

figure 2-24, the characteristic gap that appears when the cone is unrolled. The second is a secant cone, cutting through the Earth and actually contacting the surface at two standard parallels as shown in figure 2-25.

Lambert Conformal (Secant Cone). The Lambert conformal conic projection is of the conical type in which the meridians are straight lines which meet at a common point beyond the limits of the chart and parallels are concentric circles, the center of each being the point of intersection of the meridians. Meridians and parallels intersect at right angles. Angles formed by any two lines or curves on the Earth's surface are correctly represented.

The projection may be developed by either the graphic or mathematical method. It employs a secant cone intersecting the spheroid at two parallels of latitude, called the standard parallels, of the area to be represented. The standard parallels are represented at exact scale. Between these parallels, the scale

Figure 2-24. Simple Conic Projection of Northern Hemisphere.

factor is less than unit and, beyond them, greater than unity. For equal distribution of scale error (within and beyond the standard parallels), the standard parallels are selected at one-sixth and five-sixths of the total length of the segment of the central meridian represented. The development of the Lambert conformal conic projection is shown by figure 2-26.

The great elliptic is a curve closely approximating a straight line.

The geodesic is a curved line always concave toward the midparallel, except in the case of a meridian where, by definition, it is a straight line.

The loxodrome, with the exception of meridians, is a curved line concave toward the pole.

Uses. The chief use of the Lambert conformal conic projection is in mapping areas of small latitudinal width but great longitudinal extent. No projection can be both conformal and equal area but, by limiting latitudinal width, scale error is decreased to the extent that the projection gives very nearly an equal area representation in addition to the inherent quality of conformality. This makes the projection very useful for aeronautical charts.

Advantages. Some of the chief advantages of the Lambert conformal conic projection are:

- Conformality
- Great circles are approximated by straight lines (actually concave toward the midparallel).
- For areas of small latitudinal width, scale is nearly constant. For example, the US may be mapped with standard parallels at 33°N and 45°N with a scale error of only 2½% for southern Florida. The maximum scale error between 30°30'N and 47°30'N is only one-half of 1%.
- Positions are easily plotted and read in terms of latitude and longitude.
- Construction is relatively simple.
- Its two standard parallels give it two "lines of strength" (lines along which elements are represented true to shape and scale).
- Distance may be measured quite accurately. For example, the

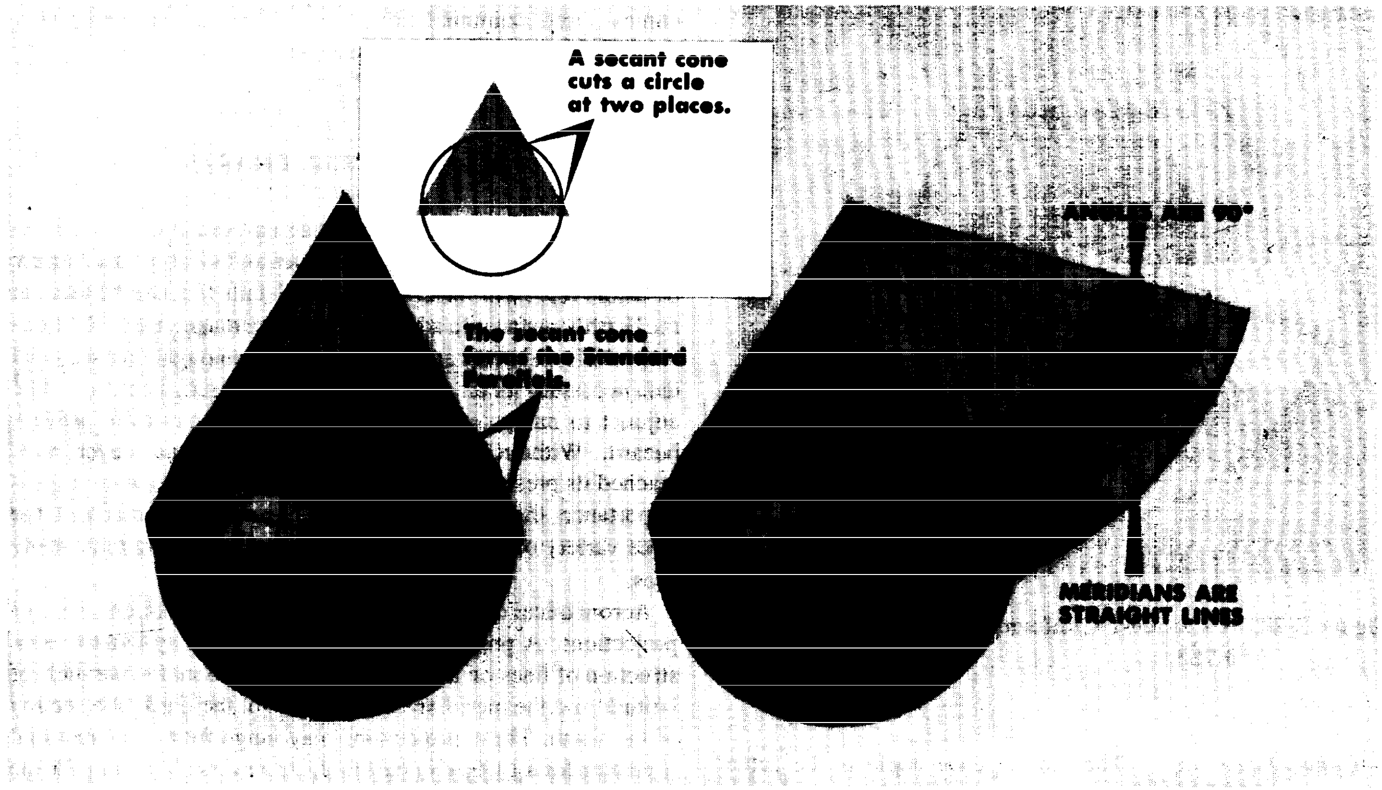


Figure 2-26. Lambert Conformal Conic Projection.

distance from Pittsburgh to Istanbul is 5,277 nautical miles; distance as measured by the graphic scale on a Lambert projection (standard parallels 36°N and 54°N) without application of the scale factor is 5,258 nautical miles; an error of less than four-tenths of 1%.

Limitations. Some of the chief limitations of the Lambert Conformal conic projection are:

- Rhumb lines are curved lines which cannot be plotted accurately.
- Great circles are curved lines concave toward the midparallel.
- Maximum scale increases as latitudinal width increases.
- Parallels are curved lines (arcs of concentric circles).
- Continuity of conformality ceases at the junction of two bands, even though each is conformal. If both have the same scale along their standard parallels, the common parallel (junction) will have a different radius for each band; therefore, they will not join perfectly.

Constant of the Cone. Most conic charts have the constant of the cone (convergence factor) computed and listed on the chart as shown in figure 2-27.

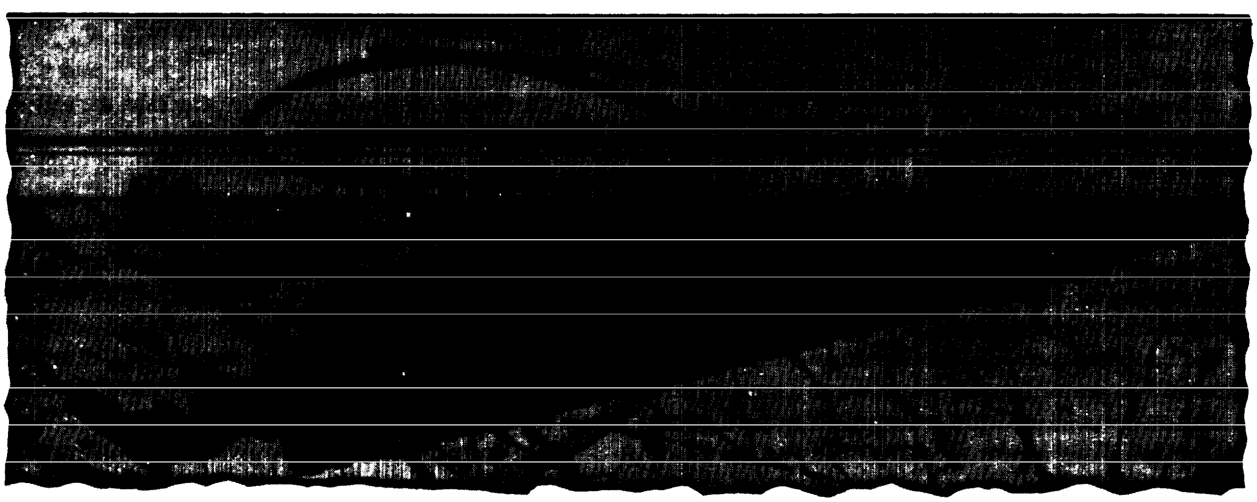


Figure 2-27. Convergence Factor on JN Chart.

Figure 2-28. A Lambert Conformal, Covergence Factor 0.785.

Convergence Angle. The convergence angle is the actual angle on a chart formed by the intersection of the Greenwich meridian and some other meridian; the pole serves as the vertex of the angle. Convergence angles, like longitudes, are measured east and west from the Greenwich meridian.

Convergence Factor. A chart's convergence factor is a decimal number which expresses the ratio between meridional convergence as it actually exists on the Earth and as it is portrayed on the chart. When the convergence angle equals the number of the selected meridian, the chart convergence factor is 1.0. When the convergence angle is less than the number of the selected meridian, the chart convergency factor is proportionately less than 1.0.

The subpolar projection illustrated in figure 2-28 portrays the standard parallels, 37°N and 65°N. It presents 360 degrees of the Earth's surface on 283 degrees of paper. Therefore, the chart has a convergence factor (CF) of 0.785 (283 degrees divided by 360 degrees equals 0.785). Meridian 90°W forms a west convergence angle (CA) of 71° with the Greenwich meridian. Expressed as a formula:

$CF \times longitude = CA$

$0.785 \times 90°W = 71°$ west CA

A chart's convergence factor is easily approximated on subpolar charts by:

1. Drawing a straight line which covers 10 lines of longitude.
2. Measuring the true course at each end of the line, noting the difference between them, and dividing the difference by 10.
3. The quotient represents the chart's convergence factor.

Because of its projection, the meridians on a transverse Mercator chart do not coincide with the meridians on the Earth. As a result, the meridians appear as curved lines on the chart. A correction factor is obtained through the use of a graph (figure 2-29) to mathematically straighten the longitudes.

Figures 2-30, 2-31, and 2-32 list characteristics of cylindrical, conical, and azimuthal projections. They are presented as a review of the material, concerning projections, covered this far.

AERONAUTICAL CHARTS

An aeronautical chart is a pictorial representation of a portion of the Earth's surface upon which lines and symbols in a variety of colors represent features and (or) details that can be seen on the Earth's surface. In addition to ground image, many additional symbols and notes are added to indicate navigational aids and data necessary for air navigation. Properly used, a chart is a vital adjunct to navigation; improperly used, it may even prove a hazard. Without it, modern navigation would never have reached its present state of development. Because of their great importance, the navigator must be thoroughly familiar with the wide variety of aeronautical charts and understand their many uses.

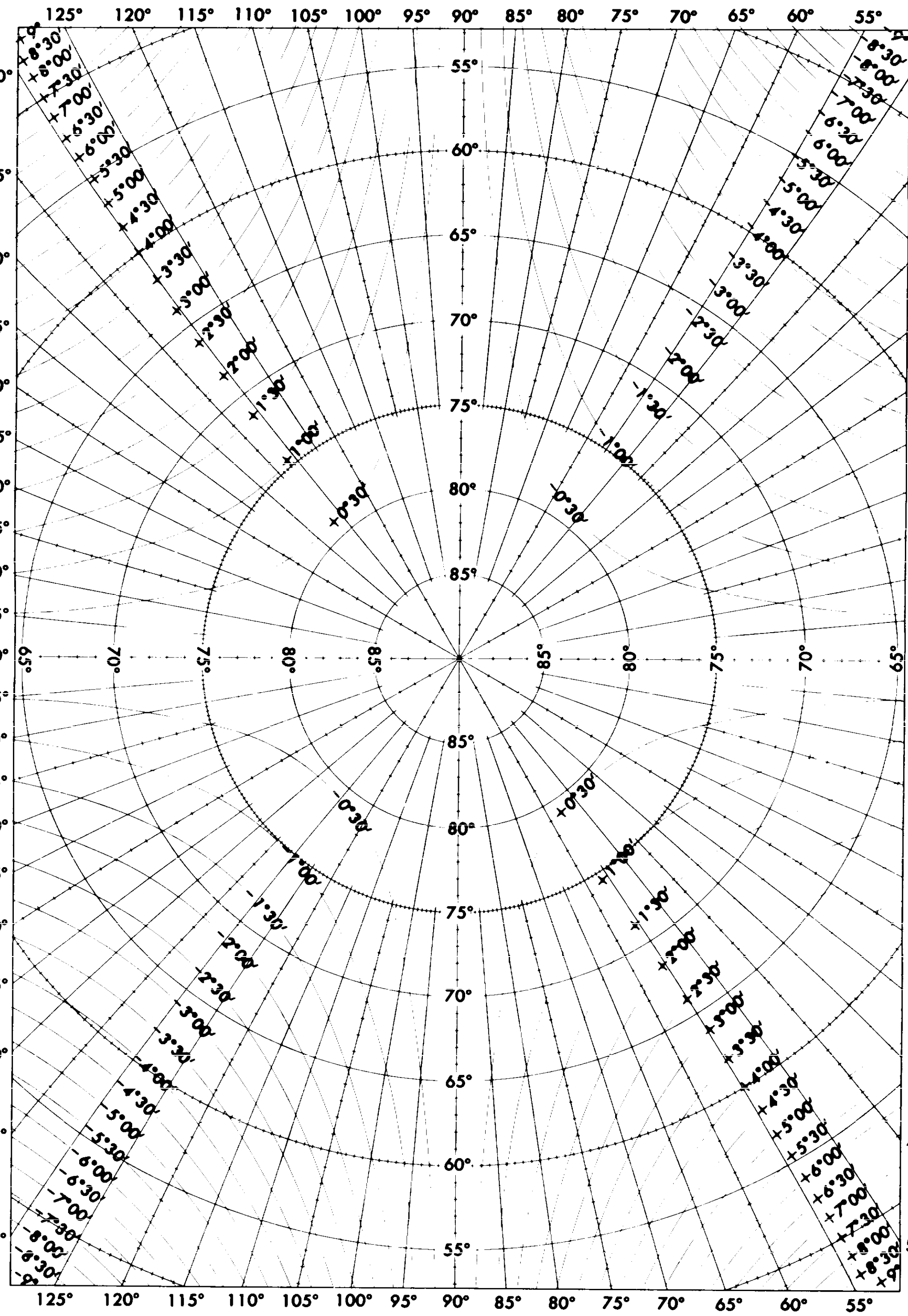
Aeronautical charts are produced on many different types of projections. A projection can be defined as a systematic construction of lines on a plane surface to represent the parallels of latitude and the meridians of longitude of the Earth or a section of the Earth. These projections may range from the equatorial Mercator for a LORAN chart to the transverse Mercator for the polar region. Since the demand for variety in charts is so great and since the properties of the projections vary greatly, there is no one projection that will satisfy all the needs of contemporary navigation. The projection that most nearly answers all the navigator's problems is the Lambert conformal, and this projection is the one most widely used for aeronautical charts.

Aeronautical charts, in their full range of projections, give worldwide coverage. Some single projections used for a single series of charts will cover nearly all the Earth. An aeronautical chart of some projection and scale can be obtained for any portion of the Earth. The accuracy of the information displayed on these charts will vary but, generally speaking, worldwide aeronautical charts in use today are very accurate representations of the Earth's surface.

Scale

Obviously, charts are much smaller than the area which they represent. The ratio between any given unit of length on a chart and the true distance it represents on the Earth is the scale of the chart. The scale may be relatively uniform over the whole chart, or it may vary greatly from one part of the chart to another. Charts are made to various scales for different purposes. If a chart is to show the whole world and yet not be too large, it must be drawn to small scale. If a chart is to show much detail, it must be drawn to a large scale; then it shows a smaller area than does a chart of the same size drawn to a small scale. Remember: large area, small scale; small area, large scale.

The scale of a chart may be given by a simple statement, such as, "1 inch equals 10 miles." This, of course, means that a distance of 10 miles on the Earth's surface is shown 1 inch long on the chart. On aeronautical charts, the scale is indicated in one



★ Use the graph to obtain the convergence factor as follows:

A. Locate geographic location of heading determination on graph (use 68N 120E for example. True Heading (TH) = 240).

B. Find appropriate correction factor from graph to closest degree (correction factor lines are on graph in red to nearest degree). (68N 120E gives + 2-00' correction factor).

C. Determine Convergence Angle (CA) using the following formula: CA = +W Long or -E Long + correction factor. (CA = -120E Long + 2-00' = 118)

D. Given the above information, determine Grid Heading (GH) using the following formula: GH = TH + WCA OR -ECA. (GH = 240-118 = 122 degrees)

★ Figure 2-29. Transverse Mercator Convergence Graph.

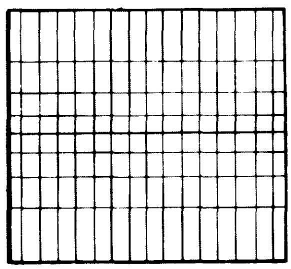
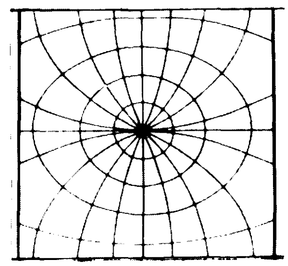
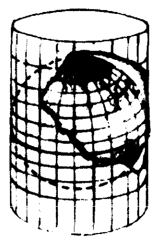
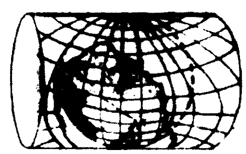
		MERCATOR	TRANSVERSE MERCATOR
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	CONFORMAL
	DISTANCE SCALE	VARIABLE (Measure at Mid-Latitude)	NEARLY CONSTANT (Near Meridian of true scale)
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM EQUATOR	INCREASES AWAY FROM TANGENT MERIDIAN
	ANGLE BETWEEN PARALLELS AND MERIDIANS	90° ANGLE	90° ANGLE
	APPEARANCE OF PARALLELS	PARALLEL STRAIGHT LINES UNEQUALLY SPACED	CURVES CONCAVE TOWARD NEAREST POLE
	APPEARANCE OF MERIDIANS	PARALLEL STRAIGHT LINES EQUALLY SPACED	COMPLEX CURVES CONCAVE TOWARD CENTRAL MERIDIAN
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM CENTER OF SPHERE (For illustration only)	FROM CENTER OF SPHERE (For illustration only)
	POINT OF TANGENCY	EQUATOR	GREAT CIRCLE THROUGH THE POLES
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	CONSTANT ANGLE (Rhumb line)	VARIABLE ANGLE (Approximates Great Circle)
	GREAT CIRCLE	CURVED LINE (Except Equator and Meridians)	APPROXIMATED BY STRAIGHT LINE
	RHUMB LINE	STRAIGHT LINE	CURVED LINE
	NAVIGATIONAL USES	DEAD RECKONING AND CELESTIAL (Suitable for all types)	GRID NAVIGATION IN POLAR AREAS

Figure 2-30. Cylindrical Projections.

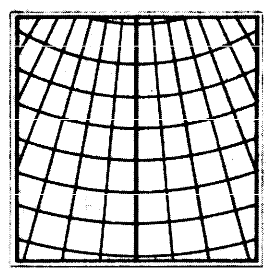
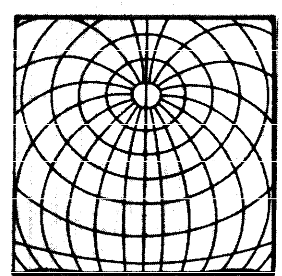
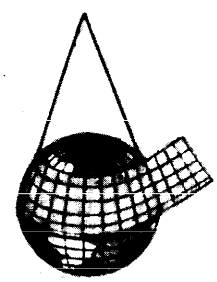
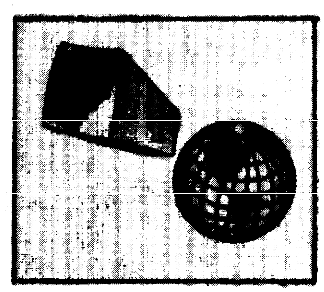
		LAMBERT CONFORMAL	AZIMUTHAL EQUIDISTANT
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	NOT CONFORMAL
	DISTANCE SCALE	NEARLY CONSTANT	CORRECT SCALE AT ALL AZIMUTHS FROM CENTER ONLY
	DISTORTION OF SHAPES & AREAS	VERY LITTLE	INCREASES AWAY FROM CENTER
	ANGLE BETWEEN PARALLELS AND MERIDIANS	90° ANGLE	VARIABLE ANGLE
	APPEARANCE OF PARALLELS	ARCS OF CONCENTRIC CIRCLES NEARLY EQUALLY SPACED	CURVED LINES UNEQUALLY SPACED
	APPEARANCE OF MERIDIANS	STRAIGHT LINES CONVERGING AT THE POLE	CURVED LINES CONVERGING AT THE POLE
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM CENTER OF SPHERE (For illustration only)	NOT PROJECTED
	POINT OF TANGENCY	TWO STANDARD PARALLELS	NONE
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (Approximates Great Circle)	VARIABLE ANGLE
	GREAT CIRCLE	APPROXIMATED BY STRAIGHT LINE	ANY STRAIGHT LINE RADIATING FROM CENTER OF PROJECTION
	RHUMB LINE	CURVED LINE	CURVED LINE
	NAVIGATIONAL USES	PILOTAGE AND RADIO (Suitable for all types)	AERONAUTICS/RADIO ENGINEERING & CELESTIAL MAP

Figure 2-31. Conic Projection.

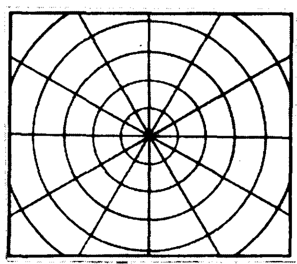
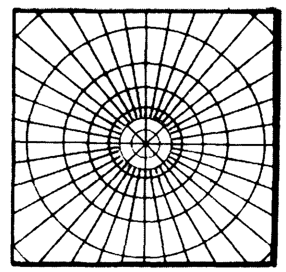
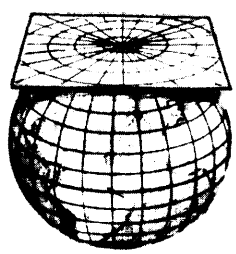
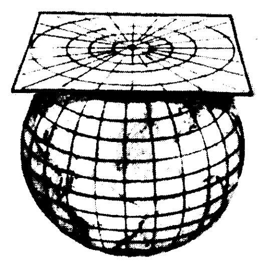
		POLAR STEREOGRAPHIC	POLAR GNOMONIC
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	NOT CONFORMAL
	DISTANCE SCALE	NEARLY CONSTANT EXCEPT ON SMALL SCALE CHARTS	VARIABLE
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM POLE	INCREASES AWAY FROM POLE
	ANGLE BETWEEN PARALLELS AND MERIDIANS	90° ANGLE	90° ANGLE
	APPEARANCE OF PARALLELS	CONCENTRIC CIRCLES UNEQUALLY SPACED	CONCENTRIC CIRCLES UNEQUALLY SPACED
	APPEARANCE OF MERIDIANS	STRAIGHT LINES RADIATING FROM THE POLE	STRAIGHT LINES RADIATING FROM THE POLE
	APPEARANCE OF PROJECTION		
	GRAPHIC ILLUSTRATION		
PRODUCTION	METHOD OF PRODUCTION	GRAPHIC OR MATHEMATICAL	GRAPHIC OR MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM OPPOSITE POLE	FROM CENTER OF SPHERE
	POINT OF TANGENCY	POLE	POLE
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (Approximates Great Circle)	VARIABLE ANGLE (Great Circle)
	GREAT CIRCLE	APPROXIMATED BY STRAIGHT LINE	STRAIGHT LINE
	RHUMB LINE	CURVED LINE	CURVED LINE
	NAVIGATIONAL USES	ALL TYPES OF POLAR NAVIGATION	GREAT CIRCLE NAVIGATION AND PLANNING

Figure 2-32. Azimuth Projections.

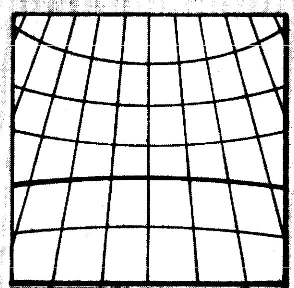
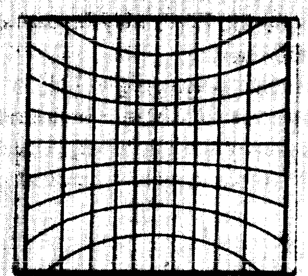
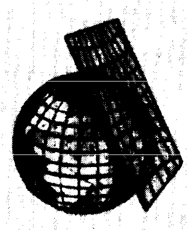
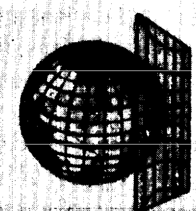
		OBLIQUE GNOMONIC	EQUATORIAL GNOMONIC
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	NOT CONFORMAL	NOT CONFORMAL
	[illegible] SCALE	VARIABLE	VARIABLE
	[illegible]	INCREASES AWAY FROM POINT OF TANGENCY	INCREASES AWAY FROM CENTER OF PROJECTION
	[illegible]	VARIABLE ANGLE	VARIABLE ANGLE
	[illegible]	CURVED LINES UNEQUALLY SPACED	CURVED LINES UNEQUALLY SPACED
	[illegible]	STRAIGHT LINES CONVERGING AT THE POLE	STRAIGHT PARALLEL LINES UNEQUALLY SPACED
	APPEARANCE OF PROJECTION		
	[illegible]		
PRODUCTION	[illegible]	GRAPHIC OR MATHEMATICAL	GRAPHIC OR MATHEMATICAL
	[illegible]	FROM CENTER OF SPHERE	FROM CENTER OF SPHERE
	[illegible]	VARIABLE	EQUATOR (Meridian variable)
APPEARANCE OF LINES ON CHARTS	[illegible]	VARIABLE ANGLE (Great Circle)	CONSTANT ANGLE (Great Circle)
	GREAT CIRCLE	STRAIGHT LINE	STRAIGHT LINE
	RHUMB LINE	CURVED LINE	CURVED LINE
	NAVIGATIONAL USES	GREAT CIRCLE NAVIGATION AND PLANNING	GREAT CIRCLE NAVIGATION AND PLANNING

Figure 2-32 (continued)

of two ways—representative fraction or graphic scale.

Representative Fraction. The scale may be given as a representative fraction, such as 1:500,000 or 1/500,000. This means that one of any unit on the chart represents 500,000 of the same unit on the Earth. For example, 1 inch on the chart represents 500,000 of the same unit on the Earth.

A representative fraction can be converted into a statement of miles to the inch. Thus, if the scale is 1:1,000,000, 1 inch on the chart stands for 1,000,000 inches or 1,000,000 divided by (6080 × 12) equaling about 13.7 NM. Similarly, if the scale is 1:500,000, 1 inch on the chart represents about 6.85 NM. Thus, the larger the denominator of the representative fraction, the smaller the scale.

Graphic Scale. The graphic scale may be shown by a graduated line. It usually is found printed along the border of a chart. Take a measurement on the chart and compare it with the graphic scale of miles. The number of miles that the measurement represents on the Earth may be read directly from the graphic scale on the chart.

The distance between parallels of latitude also provides a convenient scale for distance measurement. As shown in figure 2-33, 1 degree of latitude always equals 60 nautical miles and 1 minute of latitude equals 1 nautical mile.

DOD Aeronautical Charts and Flight Information Publications

The following publications are available to pilots and navigators in base operations offices, flight planning rooms, and other locations where aeronautical charts are issued or where flight planning takes place.

DOD Catalog of Aeronautical Charts and Flight Information Publications. This catalog provides information on the latest

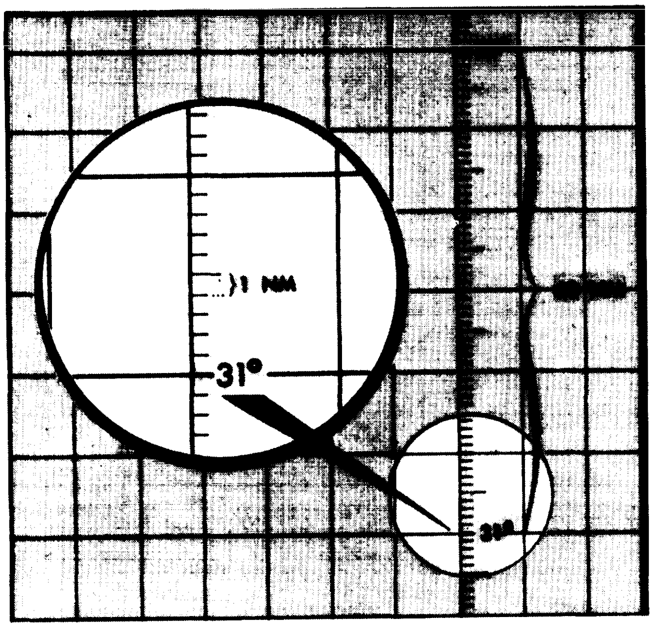


Figure 2-33. Latitude Provides a Convenient Graphic Scale.

aeronautical cartographic products produced and distributed by the Defense Mapping Agency Aerospace Center (DMAAC) and the Defense Mapping Agency Hydrographic Center (DMAHC). A brief description of each series or type of chart listed in this catalog is presented with the appropriate index or listing. Chart samples are given for each series indexed in sections IV, V, and VI. The DOD Catalog is divided into the following sections:

Section I. General Information. The overall purpose of this section is to acquaint users with information within the catalog. It also provides basic information on projections and a variety of other basic cartographic data.

Section II. Requisitioning and Distribution Procedures.

- General Procedures. A detailed description of procedures to follow in normal requisitioning of charts and publications by USAF activities and other authorized agencies. This section contains samples of requisitioning forms and charts depicting areas of distribution and defines responsibilities for issuance and procurement of charts and publications.
- Uniform Material Movement and Issue Priority System (UMMIPS). A detailed description of the priority system to follow when requisitioning charts and publications.

Section III. Flight Information Publications (FLIP). These publications consist of that textual and graphic information required to plan and conduct an IFR flight. The FLIP is separated into three basic categories corresponding to phases of flight as follows:

- Planning. Complete description of (1) Flight Information Publication Planning Document which includes Planning Data and Procedures; Military Training Routes, United States; International Rules and Procedures and Regulations, (2) FLIP Planning Charts, and (3) Foreign Clearance Guide.
- En route. A complete listing of DOD En route charts and supplements covering United States, Alaska, Canada, and North Atlantic, Caribbean and South America, Europe and North Africa, Africa and Southwest Asia, Australia, New Zealand, Antarctica, the Pacific and Southeast Asia; TACAN facility chart coverage of Alaska also included.
- Terminal. Describes the DOD publications which contain approved low and high altitude instrument approach procedures and aerodrome sketches.

Section IV. Navigational Charts. This section contains a general description of the scale, code, projection, size, purpose, cartographic style, and information shown on navigational charts. They are grouped in three categories: general purpose, special purpose, and plotting charts.

Section V. General Planning. This section contains a general description of the scale, code, projection, size, purpose, style, and information shown on all charts used for planning references and wall displays.

Section VI. Special Purpose. This section outlines all requistioning procedures for the special purpose charts along with a brief description of their purpose.

Aeronautical Chart Currency and Updating Information

DOD Bulletin Digest. This document is published semiannually in both classified and unclassified versions. It provides a complete cumulative listing of current chart editions available for distributions of users. Information available in these documents (within each chart series) is the chart number, current edition, and date of edition.

DOD Bulletin. This document is published monthly in both classified and unclassified versions. It provides a listing of the availability of new aeronautical charts, new editions of previously published charts, discontinued charts, miscellaneous ICAO and FAA publications and amendments, requisitioning information, and charts scheduled for completion. This document supplements the Bulletin Digest.

DOD Chart Updating Manual (CHUM). This document is published monthly in both classified and unclassified versions. It lists, for each current chart edition, corrections and additions which could affect flying safety. The unclassified CHUM should be found in all flight planning rooms. The additions and corrections listed for the appropriate charts should be checked and the applicable ones annotated on the charts.

Types of Charts. Aeronautical charts are differentiated on a functional basis by the type of information they contain. Navigation charts are grouped into three major types: general purpose, special purpose, and plotting. The name of the chart is a reasonable indication of its intended use. Thus, a Consol Chart has information needed by the navigator to use Consol as a navigation aid; a Minimal Flight Planning Chart is primarily used in minimal flight planning techniques; and a Jet Navigation Chart has properties that make it adaptable to the speed, altitude, and instrumentation of jet aircraft. In addition to the specific type of information contained, charts vary according to the amount of information displayed. Charts designed to facilitate the planning of long distance flight carry less detail than those required for navigation en route. Local charts present great detail.

Chart Symbols

Standard Symbols. Symbols are used for easy identification

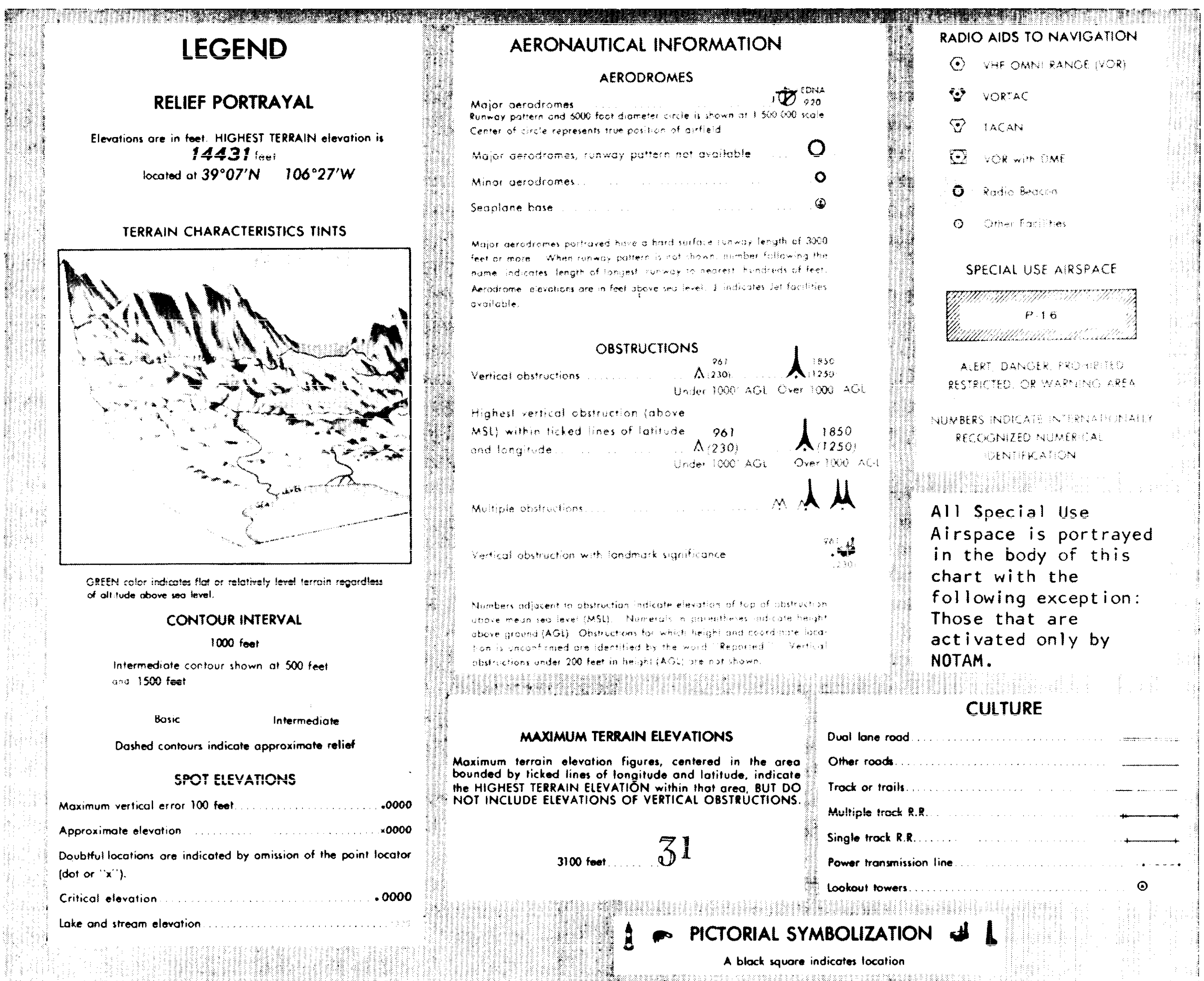


Figure 2-34. Sample Chart Legend.

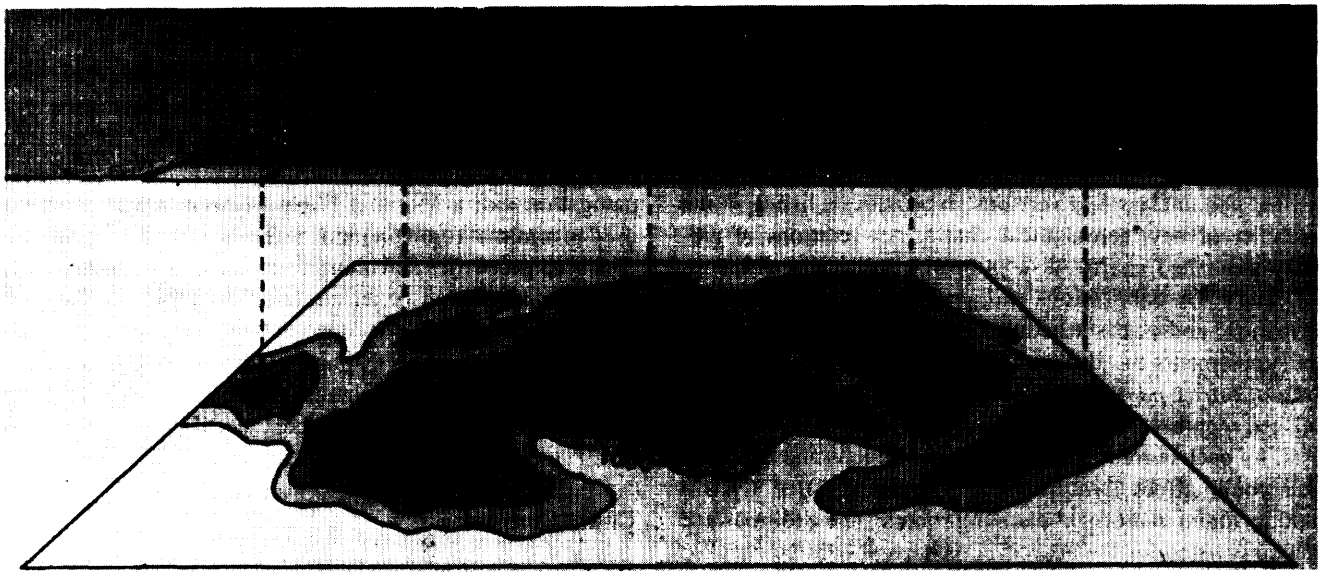


Figure 2-35. Contour Lines.

of information portrayed on aeronautical charts. While these symbols may vary slightly between various projections, the amount of variance is slight and once the basic symbol is understood, variations of it are easy to identify. A chart legend is the key which explains the meaning of the relief, culture, hydrography, vegetation, and aeronautical symbols, as shown in figure 2-34.

Relief (Hypsography). Chart relief shows the physical features related to the differences in elevation of land surface. These include features such as mountains, hills, plateaus, plains, depressions, etc. Standard symbols and shading techniques are used in relief portrayal on charts; these include contours, spot elevations, variations in tint, and shading to represent shadows.

Contour Lines. A contour is a line connecting points of equal elevation. Figure 2-35 shows the relationship between contour lines and terrain. Notice that on steep slopes the contours are close together and on gentle slopes they are farther apart. The interval of the contour lines usually depends upon the scale of the chart and the terrain depicted. In the illustration, the contour interval is 1,000 feet. Depression contours are regular contour lines with spurs or ticks added on the downslope side.

Spot Elevations. Spot elevations are the height of a particular point of terrain above an established datum, usually sea level.

Gradient Tints. The relief indicating by contours is further emphasized on charts by a system of gradient tints. They are used to designate areas within certain elevation ranges by different color tints.

Shading. Perhaps the most obvious portrayal of relief is supplied by graduated shading applied to the "southeastern" side of elevated terrain and the "northwestern" side of depressions. This shading simulates the shadows cast by elevated features, lending a sharply defined, three-dimensional effect.

Cultural Features. All structural developments appearing on the terrain are known as cultural features. Three main factors govern the amount of detail given to cultural features: (1) the scale of the chart, (2) the use of the chart, and (3) the geographical area covered. Populated places, roads, railroads, installations, dams, bridges, and mines are some of the many kinds of cultural features portrayed on aeronautical charts. The true representative size and shape of larger cities and towns are shown. Standardized coded symbols and type sizes are used to represent the smaller population center. Some symbols denoting cultural features are usually keyed in a chart legend. However, some charts use pictorial symbols which are self-explanatory. These require no explanations in the legend.

Hydrography. In this category, aeronautical charts portray oceans, coast lines, lakes, rivers, streams, swamps, reefs, and numerous other hydrographic features. Open water may be portrayed by tinting, by vignetting, or may be left blank.

Vegetation. Vegetation is not shown on most small scale charts. Forests and wooded areas in certain parts of the world are portrayed on some medium scale charts. On some large scale charts, park areas, orchards, hedgerows, and vinyards are shown. Portrayal may be by solid tint, vignette, or supplemented vignette.

Aeronautical Information. In the aeronautical category, coded chart symbols denote airfields, radio aids to navigation, commercial broadcasting stations. Air Defense Identification Zones (ADIZ), compulsory corridors, restricted airspace, warning notes, lines of magnetic variation, and special navigational grids. Some aeronautical information is subject to frequent change. For economy of production, charts are retained in stock for various periods of time. So as not to provide the chart user with aeronautical information that is rapidly out of date, only the more "stable" type information is printed on navigation charts. Aeronautical type data subject to frequent change is provided the user by the DOD Flight Information Publications (FLIP) documents. Consult the DOD Flight Information Publications, Chart Updating Manual (CHUM), and Notices to Airmen

Name and Code	Projection	Scale and Coverage	Description	Purpose
USAF Jet Navigation Charts JN	Charts 4, 5, 6 & 7 transverse Mercator. All other Lambert	1:2,000,000 Northern Hemisphere	Charts show all pertinent hydrographic and cultural features. Complete transportation network in areas surrounding cities. A maximum of radar-significant detail as required for long range navigation and a suitable aeronautical information overprint including runway pattern.	For preflight planning and enroute navigation by long range, high speed aircraft; for radar, celestial, and grid navigation. This series can also be used for navigation at medium speeds and altitudes.
Operational Navigation Charts ONC	0°-80° Lambert conformal conic 80°-90° polar stereographic	1:1,000,000 World-wide	Charts show all types hydrographic and cultural features. All important navigation aids and air facilities are included.	Standard series of aeronautical charts designed for military low altitude navigation. Also used for planning intelligence briefings, plotting, and wall displays. (Replaces WAC.)
Tactical Pilotage Charts TPC	0°-80° Lambert conformal conic 80°-90° polar stereographic	1:500,000 World-wide	Charts show all types hydrographic and cultural features. All important navigation aids and air facilities are included.	To provide charts with detailed ground features significant to visual and radar low level navigation for immediate ground/chart orientation at predetermined checkpoints.
Joint Operations Graphic Air Series 1501AIR Formerly JOG (A)	Latitude 84° N to 80° S, Transverse Mercator Latitude 84° to 90° N and 80° to 90° S, Polar-Stereographic	1:250,000 World-wide	Charts show all types hydrographic and cultural features. All important navigation aids and air facilities are included.	To provide Army, Navy, Air Force with a common large-scale graphic. Used for tactical air operations, close air support, interdiction by all aircraft at low and very low altitudes. Used for preflight planning and inflight navigation for short range flights using DR and visual pilotage. Also used for operational planning and intelligence briefing.
Consol-Loran Navigation Charts CJC LJC	Transverse Mercator and Lambert conformal conic	1:2,000,000 Northern Europe and Arctic	Show land areas in subdued tone. Consol, Loran and radio aids are emphasized.	Long range flight planning and electronic navigation.
Air Navigation Charts V 30	Mercator, except Antarctic-Polar Stereographic	1:2,188,800 World-wide with relating Arctic coverage	Charts contain essential topographical, hydrographical, and aeronautical information. Primary roads and railroads are shown.	Basic long range air navigation plotting series designed primarily for use in larger aircraft.
Air/Surface Loran Navigation Charts VL 30 VLC 30	Mercator	1:2,188,800 World-wide with relating Arctic coverage	Contain essential topographical, hydrographical, and aeronautical information. Roads and railroads not shown. Land areas are tinted.	Basic long range Loran air navigation, designed primarily for over water.
Special Navigation Charts VS	Mercator	1:750,000 to 1:4,000,000 Special areas	Charts show essential hydrographic and cultural features. Roads and major railroads are shown. Important air facilities included.	Designed for general air navigation.
Gnomonic Tracking Charts GT	Gnomonic	Various scales From North Pole to approximately 40° South Latitude	Majority are 2-color outline charts with blue for graticule and buff for all land areas. Majority of charts are overprinted with special airways and air communication services.	Series of plotting charts suitable for accurate tracking of aircraft by electronic devices and small scale plotting charts for accurate great circle courses.

Figure 2-36. Summary of Typical Charts.

Name and Code	Projection	Scale and Coverage	Description	Purpose
Continental Entry Charts CEC	Lambert conformal conic	1:2,000,000 East and West Coasts of U.S.	Show principal cities and hydrography. Show major aeronautical facilities and spot evaluations.	For Consolan and Loran navigation where a high degree of accuracy is required for entry into the U.S. Also suitable as a basic DR sheet and celestial navigation.
USAF Loran-C Navigation Charts LCC	Transverse	1:3,000,000 North Polar areas	Relief not shown. Show major cities and stable aeronautical information. Polar Grid overprint.	For preflight and inflight long range navigation where Loran-C is the basic aid.
USAF Global Loran Navigation Charts GLC	Polar Chart—Transverse Mercator Lower Latitudes—Lambert conformal conic	1:5,000,000 World-wide	Major cities and stable aeronautical information shown. No relief shown.	For inflight long range navigation using Loran and Consol.
USN/USAF Plotting Sheets VP 30	Mercator	1:2,187,400 70° North to 70° South Latitude	Projection graticule only.	To provide uncluttered universal plotting sheets of suitable scope for long range Dead Reckoning and Celestial navigation for selected bands of latitudes.
USAF Global Navigation and Planning Charts GNC	Polar Chart—Transverse Mercator Lower Latitudes—Lambert conformal conic	1:5,000,000 World-wide	Show spot evalautions, major cities, roads, principal hydrography, and stable aeronautical information.	Long distance operational planning. Also suitable for long range inflight navigation at high altitudes and speeds.

Figure 2-36 (continued)

(NOTAMS) for the most current air information and (or) chart information.

Requisitioning of Charts and Flight Information Publications

All aeronautical charts and flight information publications produced and distributed by the Defense Mapping Agency Aerospace Center (DMAAC) or any of its overseas flight information offices are requisitioned in accordance with procedures outlined in section II of the DOD Catalogue of Aeronautical Charts and Flight Information Publications. A summary of the typical charts is found in figure 2-36. Requisitions should indicate item identification and terminology for each item requested as listed in the catalog. List aeronautical charts by series in numerical and (or) alphabetical sequence and Flight Information Publications by type (En route, Planning, Terminal), title, and geographic area of coverage.

When requisitioning, refer to the sample requisition shown in the DOD Catalog to expedite processing and prompt shipment of chart and flight information needs.

The Air Force Intelligence Service is responsible for all Air Force Mapping, Charting, and Geodesy (MC&G) matters. Many times in the tactical operation of the Air Force, pilots and navigators need new or additional cartographic support in performing their navigational duties. The following information tells them how to submit requirements for developing or modifying MC&G products.

Air Force organizations, except those designated as specified commands or components of unified commands, submit their MC&G product requirements through command channels to Air Force Intelligence Service (AFIS/INTB), Washington DC 20330, in accordance with AFR 96-9.

Air Force Commands designated as specified commands or components of unified commands submit MC&G product requirements according to DMA directives and unified or specified command instructions. Forward an information copy of the requirements to Air Force Intelligence Service (AFIS/INTB), Washington DC 20330.

All Air Force organizations may contact the Defense Mapping Agency Aerospace Center (DMAAC) or its squadrons and detachments for technical assistance in preparing statements of requirements. Addresses are listed in the DOD Catalog of Aeronautical Charts and Flight Information Publications.

POSITION REFERENCING SYSTEMS

The spherical coordinate system of latitude and longitude sometimes proves difficult to use because its units of degrees, minutes, and seconds are not comparable to the normal units of surface measurement. Further, the geographic graticule is not printed in its entirety on most topographic maps.

Consideration for the above factors led to the development of military grid systems in an effort to simplify and increase the accuracy of position referencing. As early as World War I, the French superimposed a military grid on maps of small areas in order to control artillery fire. After World War I, a number of nations followed the example of the French-devised military grid system for the use of their own military forces.

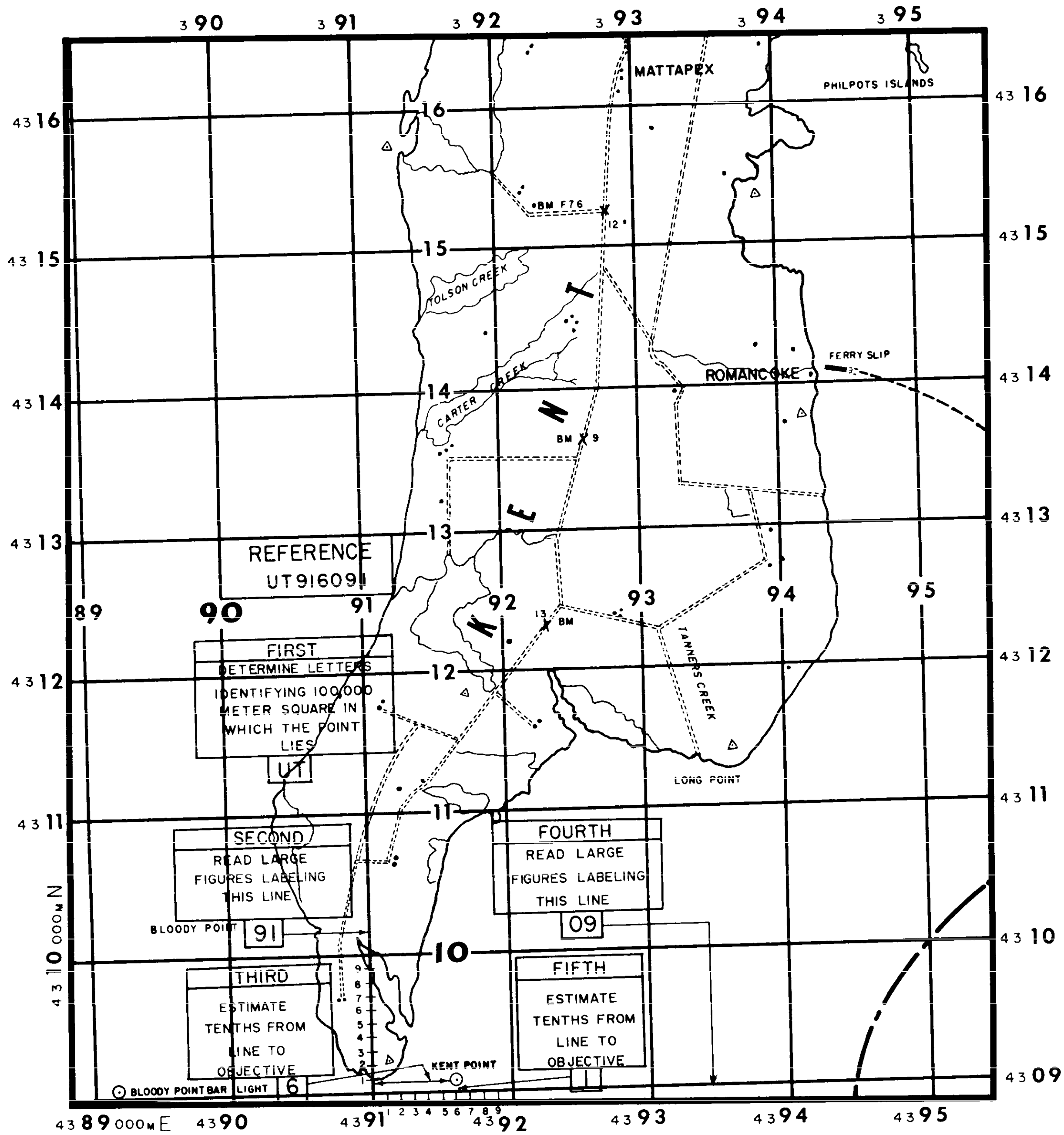


Figure 2-37. Military Grid.

Explanation of Terms

Military Grid. A military grid (figure 2-37) is composed of two series of equally spaced parallel lines perpendicular to each other. The grid is constructed by first establishing an origin. Next, perpendicular axes are drawn through the origin with one of them pointing to true north. North-south grid lines (eastings) and east-west grid lines (northings) are then drawn parallel and perpendicular, respectively, to the north-south axis. On military maps of scale 1:75,000 and larger, the distance between successive grid lines (grid interval) represents 1,000 meters (or yards) at the scale of the map. The military grid is superimposed on charts and maps to permit accurate identification of ground positions and to allow the computing or measuring of correct distances and directions from one point to another. The origin is assigned false values to avoid coordinates of negative value. Grid lines are identified by grid line values printed in two sizes of type in the margin at each end of the grid line. For referencing purposes, only the grid line values printed in the larger type size (principal digits), increased by any digits needed to express the reference to the desired degree of accuracy, are used. Grid line values increase from west to east and from south to north.

Position Referencing System. A position referencing system is any system which permits the designation of a point or an area on the Earth's surface, usually in terms of numbers or letters, or a combination thereof.

World Position Referencing System. References for points taken from charts or maps not gridded with a military grid are expressed as geographic coordinates in terms of latitude and longitude.

Military Grid Reference System (MGRS). This is a position referencing system developed for use with the Universal Transverse Mercator (UTM) and Universal Polar Stereographic (UPS) grids.

World Geographic Reference System (GEOREF). This is a referencing system sometimes employed by the Air Force in the control and direction of air forces engaged in operations not involving other military forces.

General Information

DOD Policy for Position Referencing. It is possible for the practicing navigator to encounter any or all of the basic reference systems discussed in this manual. The Department of Defense policy for position referencing procedures for joint use by all the US military services establishes two position referencing systems for all joint operations as follows:

1. The system of geographic coordinates expressed in latitude and longitude.
2. The Military Grid Reference System (MGRS) as developed for use with the UTM and UPS grids.

Relationship of Military Grids to Map Projections. Because military grids are designed to permit accurate identification of ground locations and the computation of distance and direction from one point to another, and because all map projections have inherent distortion of scale and angles, it is essential that military grids be superimposed upon projections having the least distortion. Conformal projections selected by the Department of Defense as having the least distortion of scale and angles for large and medium scale mapping are the transverse Mercator and the polar stereographic. The military grid systems are applied to aeronautical charts primarily for use in Air Force sup-

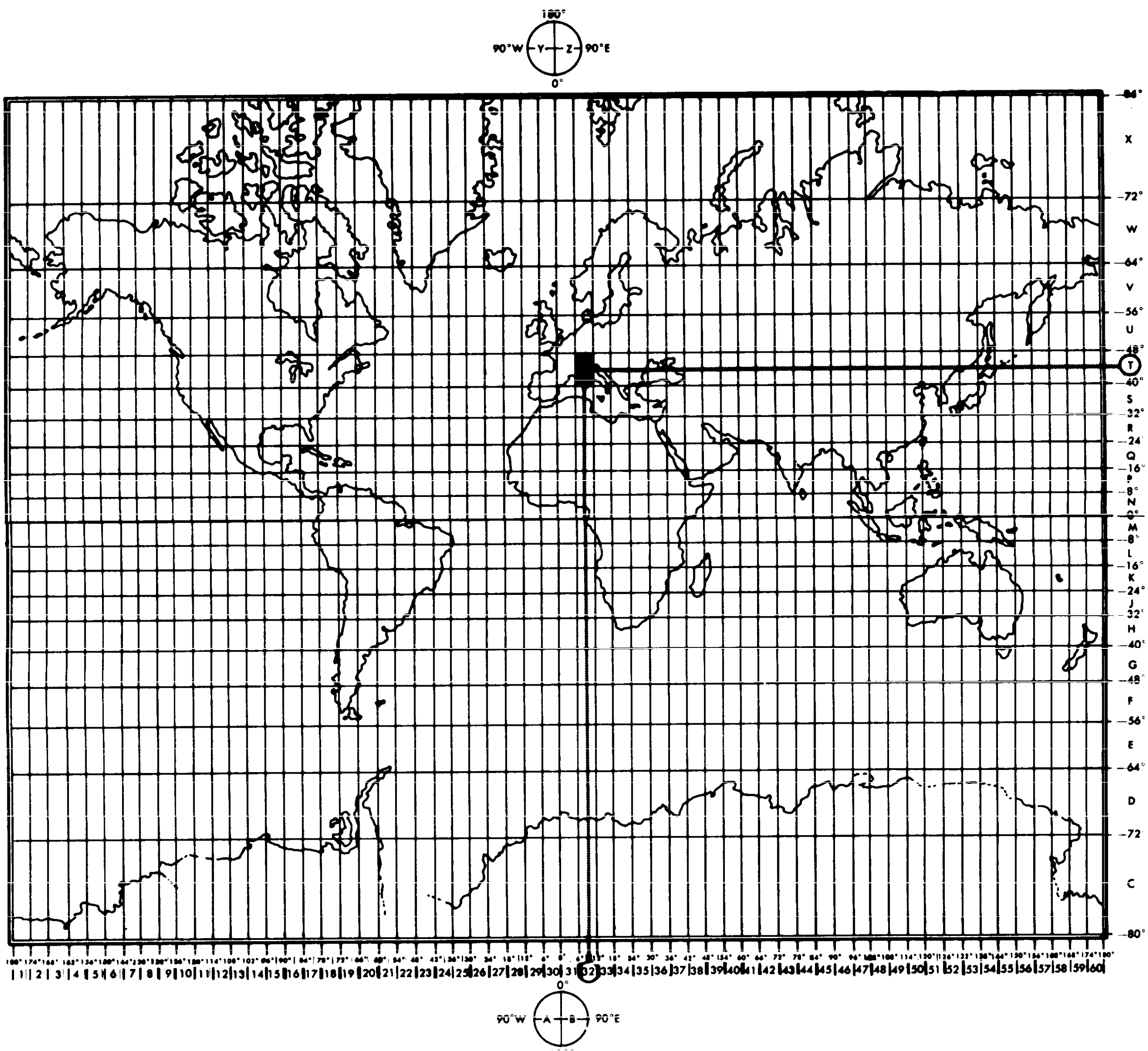


Figure 2-38. Designation of UTM Grid Zones.

port of ground operations. The Air Force uses the Universal Transverse Mercator (UTM) from latitude 80°S to 84°N and the Universal Polar Stereographic (UPS) from latitudes 84°N and 80°S to the respective poles. The standard unit of measure used with UTM and UPS grids is the meter.

Military Grid Reference System

General Description. The Military Grid Reference System is designed for use with the UTM and UPS grids.

The world is divided into large, regularly shaped geographic areas, each of which is given a unique identification, called the Grid Zone Designation (GZD). These areas are subdivided into 100,000-meter squares, based on the grid covering the area. Each square is identified by two letters called the 100,000-meter square identification. This identification is unique within the area covered by the GZD. Numerical references within the 100,000-meter square are given to the desired accuracy in terms of the east (E) and north (N) grid coordinates for the point.

Ordinarily, a reference keyed to a gridded map of any scale is made by giving the 100,000-meter square identification together with the numerical term. The GZD usually is prefixed to the identification when references are made in more than one grid zone.

Grid Zone Designation for UTM Grids. Between 72° north and 72° south, the globe is divided into areas 6° east-west by 8° north-south. Between 72° north and 84°N (72° south and 80° south) the bands are not always 6° wide. The columns (6° side) are identified by the Universal Transverse Mercator (UTM) Zone numbers; i.e., starting at the 180° meridian and proceeding easterly, the columns are numbered 1 through 60, consecutively (figure 2-38). The rows (8° high, except for the last which is 12° high) are identified by letters; starting at 80° south and proceeding northerly to 84° north, the rows are lettered alphabetically C through X with the letters I and O omitted. The grid zone designation is determined by reading to the right the column designation (as 32), then up the row designation (as T), to obtain 32T (figure 2-38).

100,000-Meter Square Identification for UTM Grids. Between 84° north and 80° south, grid zone areas are divided into 100,000-meter squares based on the UTM grid for the zone. Each column of squares is identified by a letter and each row of squares is identified by a letter (figure 2-39). Starting at 180° meridian and proceeding easterly along the equator for 18°, the 100,000-meter column, including partial columns along grid junctions, are lettered alphabetically A through Z (with I and O omitted). This alphabet is repeated at 18° intervals. The 100,000-meter rows are lettered alphabetically A through V (I and O omitted) reading from south to north, with this partial alphabet being repeated every 2,000,000 meters. Normally, every odd-numbered UTM zone has the alphabet of the 100,000-meter row letters beginning at the equator; the even-numbered UTM zones normally have the alphabet of the 100,000-meter row letters beginning at the northing grid line 500,000 meters south of the equator. This staggering lengthens the distance between 100,000-meter squares of the same identification. Below the equator, 100,000 row letters also read alphabetically from south to north, tying into the letters above in the same zone. These principles are illustrated in figure 2-39.

The identification of any 100,000-meter square is determined by reading (to the right) first its column letter (as N) and (then up) to its row letter (as L) giving NL 25 in figure 2-40.

Under this system, a 100,000-meter square identification usually is not repeated within 18° in any direction. This normally eliminates the necessity within such distance for preceding grid references with the Grid Zone Designation even though the report is being made from as many as two grid zones away.

To prevent ambiguity of identifications along spheroid junctions, changes in the order of the row letters are necessary. The row alphabet is shifted 10 letters. Thus, the maximum distance between the same combination of letter identifiers is increased.

Locating A Military Grid Reference

A Miltary grid reference consists of a group of letters and numbers which indicate (1) the Grid Zone Designation, (2) the

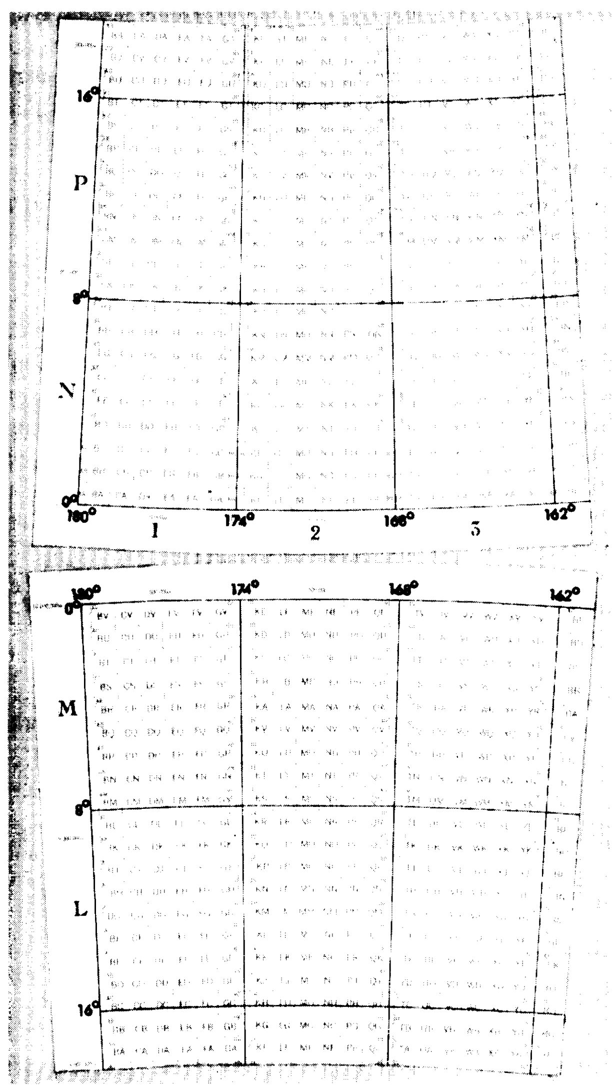


Figure 2-39. Designation of 100,000-Meter Squares, UTM Grid.

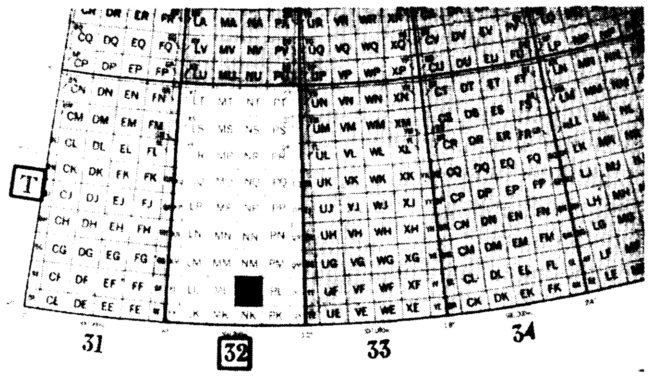


Figure 2-40. Identification of 100,000-Meter Square (NL) within UTM Zone 32T.

100,000-meter square identification, and (3) the grid coordinates—the numerical references—of the point expressed to the desired accuracy. A reference is written as a continuous number without spaces, parentheses, dashes, or decimal points. Examples:

- 32TNL—Locating a point within a 100,000-meter square
- 32TNL73—Locating a point within a 10,000-meter square
- 32TNL7438—Locating a point within 1000 meters
- 32TNL743385—Locating a point within 100 meters

To satisfy special needs, a reference can be given to the nearest 10 meters and the nearest 1 meter.

Examples:

- 32TNL74343856—Locating a point within 10 meters
- 32TNL7434238565—Locating a point within 1 meter

Normally, all elements of a grid reference are not used. Those to be omitted depend upon the size of the area of activities, the proximity of a spheroid junction, and the scale of the map to which the reference is keyed (interval of grid lines). To give the position of a point, first give the grid zone designation, then the 100,000-meter square, such as 32TNL. The designation 32TNL describes the 100,000-meter square (NL) that is located in the 6° by 8° grid zone, 32T. The origin of every 100,000-meter square is 0,0. To reference a point within a 100,000-meter square, give

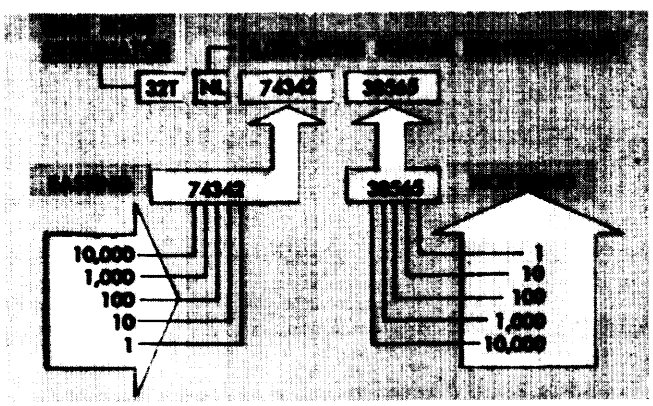


Figure 2-41. Grid Coordinates 32TNL7434238565 Identify a 1-Meter Square.

the grid coordinates of the point. The grid coordinates are designated by an even number of digits. The first half of this number, no matter how small or large, is the easting; the second half, the northing. The reference 32TNL7434238565 locates an object within a 1-meter square. The number 74342 is the easting (read to the right) coordinate, while 38565 is the northing (read up) coordinate which locates a point within a 1-meter square of the 100,000 meter square designated as NL and in grid zone 32T (figure 2-41).

Sample Reference of UTM Grid. To illustrate the procedure for locating a point by the UTM grid system, a fictitious example point identified within a reference box accompanies each grid overprint as shown in figure 2-42. Using the sample reference, the following procedure illustrates how to locate the point whose standard reference is: 32TNL7438.

- 32T—identifies the 6° by 8° grid zone in which the point is located.
- NL—identifies the 100,000-meter square in which the point is located.
- 74—The numbers 7 and 4 are both right reading, or easting figures. The first of these two digits (7) identifies the interval easting beyond which the point falls. The second digit (4) is estimated; it represents the value of the imaginary 1,000-meter easting column which includes the point.
- 38—The numbers 3 and 8 are both up reading, or northing figures. The 3 identifies the interval northing beyond which the point falls. Finally, the 8 defines the 1,000-meter estimated northing required to complete the area dimensions of the sample reference point.

Grid Zone Designation for UPS Grid. In the Universal Polar Stereographic (UPS) grid zone, the North Polar Area is divided into two parts by the 180° and 0° meridians. The half containing the west longitudes is given the grid zone designation Y; the half containing the east longitudes is given the grid zone designation Z. No numbers are used in conjunction with the letter to give a grid zone designation.

Similarly, the South Polar Area is divided into two parts by the 0° and 180° meridians. The half containing the west longitude is identified as A; the half containing the east longitude is identified as B. No numbers are used in conjunction with the letter to give a grid zone designation. These divisions are illustrated in figure 2-43.

100,000-Meter Square Identification for UPS Grids. In the North Polar Area, the 180°—0° meridians coincide with an even 100,000-meter vertical grid line and the 90°—90° meridians coincide with an even 100,000-meter horizontal grid line. Grid north is coincident with the 180° meridian from the Pole. In the half of the area identified by the Grid Zone Designation Y, the 100,000-meter columns (these are at right angles to the 90°—90° meridians) are labeled R through Z alphabetically from left to right. In the half identified by the Grid Zone Designation Z, the 100,000-meter columns are labeled A through J alphabetically from left to right; in this case, the letter I is omitted, and to avoid confusion with 100,000-meter squares in adjoining UTM zones, the letters, D, E, V and W are omitted. Starting at the 84° parallel and reading toward grid north, the 100,000-meter rows at right angles to the 180°—0° meridians are alphabetically

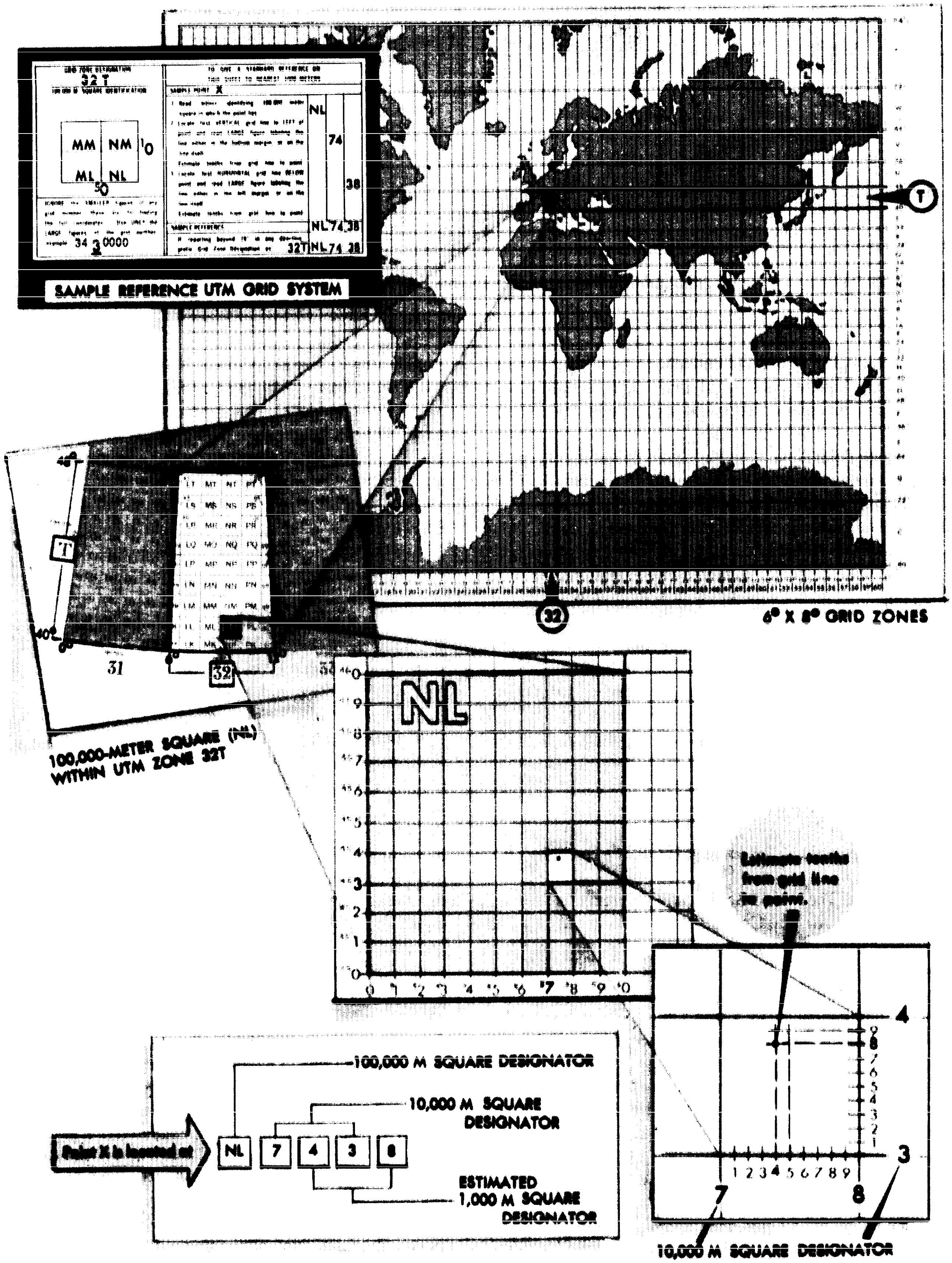


Figure 2-42. Using UTM Grid System to locate a Point.

Figure 2-43. Designation of Universal Polar Stereographic (UPS) Grid Zone.

labeled A through P (I and O omitted). The identification of a 100,000-meter square consists of two letters determined by reading (right) its column letter and (up) its row letter (figure 2-44).

In the South Polar Area, a similar plan is followed, except that grid north is coincident with the 0° meridian from the pole. In the half of the area identified by the Grid Zone Designation A, the 100,000-meter columns (these are at right angles to the 90°—90° meridians) are labeled J through Z alphabetically from left to right. In the half identified by the Grid Zone Designation B, the 100,000-meter columns are labeled A through R alphabetically from left to right. In both cases, the letters I and O are omitted and, to avoid confusion with 100,000-meter squares in adjoining UTM zones, the letters D, E, M, N, V, and W are also omitted. Starting at the 80° parallel and reading toward grid north, the 100,000-meter rows at right angles to the 180°—0° meridians are alphabetically labeled A through Z (I and O omitted). The identification of a 100,000-meter square consists of two letters determined by reading (right) its column letter and (up) to its row letter (figure 2-45).

World Geographic Reference (GEOREF) System

Development. The World Geographic Reference System was developed by the Air War College, Air University, as a worldwide geographic referencing system and is generally known by its short title "GEOREF." It makes use of the simplified system of always reading from left to right and up, using a group of letters and numbers to locate a point, thus making the referencing of a point much easier than using the geographic coordinates of latitude and longitude which require the giving of latitude in degrees, minutes, and seconds (north or south) and the longitude in degrees, minutes, and seconds (east or west). For example, to call in a reference to the nearest minute using geo-coordinates, it would be necessary to say, "60 degrees, 12 minutes north, but 119 degrees 57 minutes east" as compared to a reference to the same point using the GEOREF system "VLAQ5712." The possibility of error in communicating a reference is greatly reduced by the relatively simple GEOREF system.

Composition. The GEOREF system is based on the normal longitude and latitude values that appear on all maps and charts. Instead of using a grid system of its own, as does the UTM grid and other military grids, the GEOREF system make use of the meridians and parallels that appear on the chart. Basically, this system defines the unit geographic area in which a specific point lies. It may be applied to any map or chart regardless of the type of projection. The GEOREF is read to the right and up in all cases. The point of origin is the 180th meridian and the South Pole. It extends to the right or eastward from the 180th meridian around the globe, 360° to the 180th meridian again. It extends upward or northward from the South Pole, 180° to the North Pole.

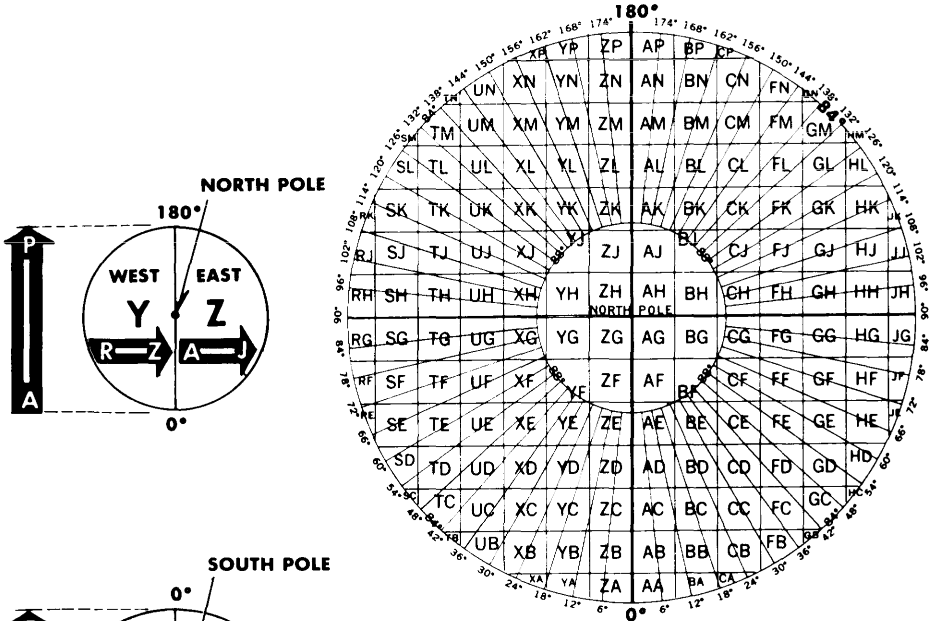
Referencing. The GEOREF divides the Earth's surface into quadrangles of longitude and latitude with a simple, brief, systematic code that gives positive identification to each quadrangle. The system and identification codes include:

Twenty-four longitudinal zones of 15° each, which are lettered from A through Z (omitting I and O) eastward from the 180th meridian. Twelve bands of latitude, each 15° wide, are lettered from A through M (omitting I) northward from the South Pole. This combination divides the Earth's surface into 288 basic 15° quadrangles, each identified by two letters. In local operations confined to a single chart or to a single 15° quadrangle, these letters may be dropped. On small scale charts, the letter designators are shown in large letters in the southwest corner of each 15° quadrangle. On larger scale charts, the 15° quadrangle designators are shown along the border. When the southwest corner of a 15° quadrangle falls in the chart area, the designators also are shown in the southwest corner of the quadrangle. The worldwide breakdown is illustrated by figure 2-46.

Each basic 15° quadrangle is divided into 15 lettered 1-degree units eastward and 15 lettered 1-degree units northward from A through Q (omitting I and O). Thus, two additional letters (four in all) identify any 1-degree quadrangle in the world. Figure 2-47 illustrates the alphabetical breakdown of a 15° quadrangle.

Each 1-degree quadrangle is divided into 60 numbered "minute" units eastward and northward. Thus, four letters and four figures identify a 1-minute quadrangle anywhere in the world. This breakdown permits location of a point within approximately 1 nautical mile. This manner of numbering is used whenever the 1-degree quadrangle is located; it does not vary even though the location may be west of the Greenwich meridian or south of

Figure 2-44. North Polar Area UPS Grid.



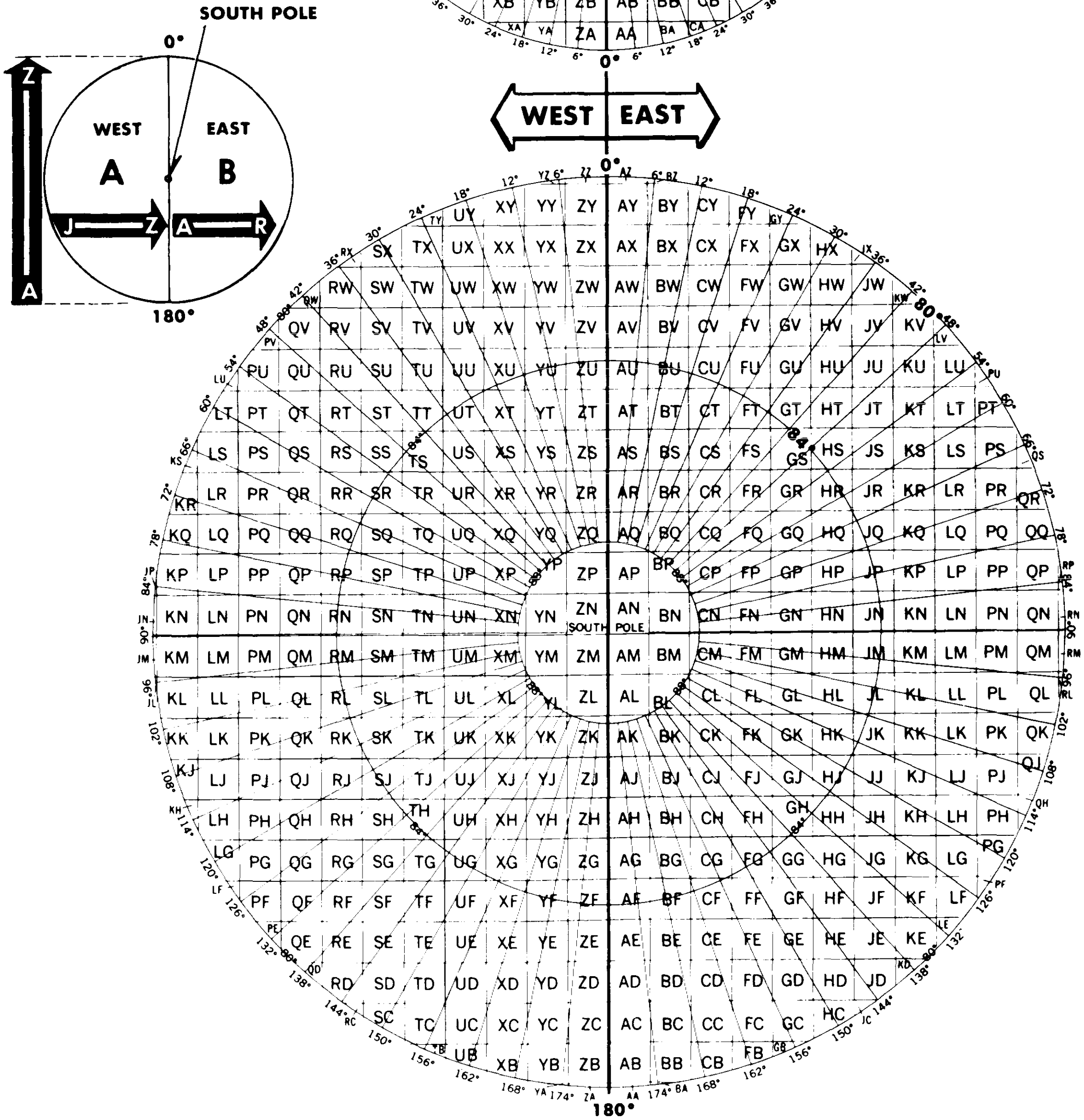


Figure 2-45. South Polar Area UPS Grid.

WORLD GEOGRAPHIC REFERENCE SYSTEM (GEOREF) INDEX

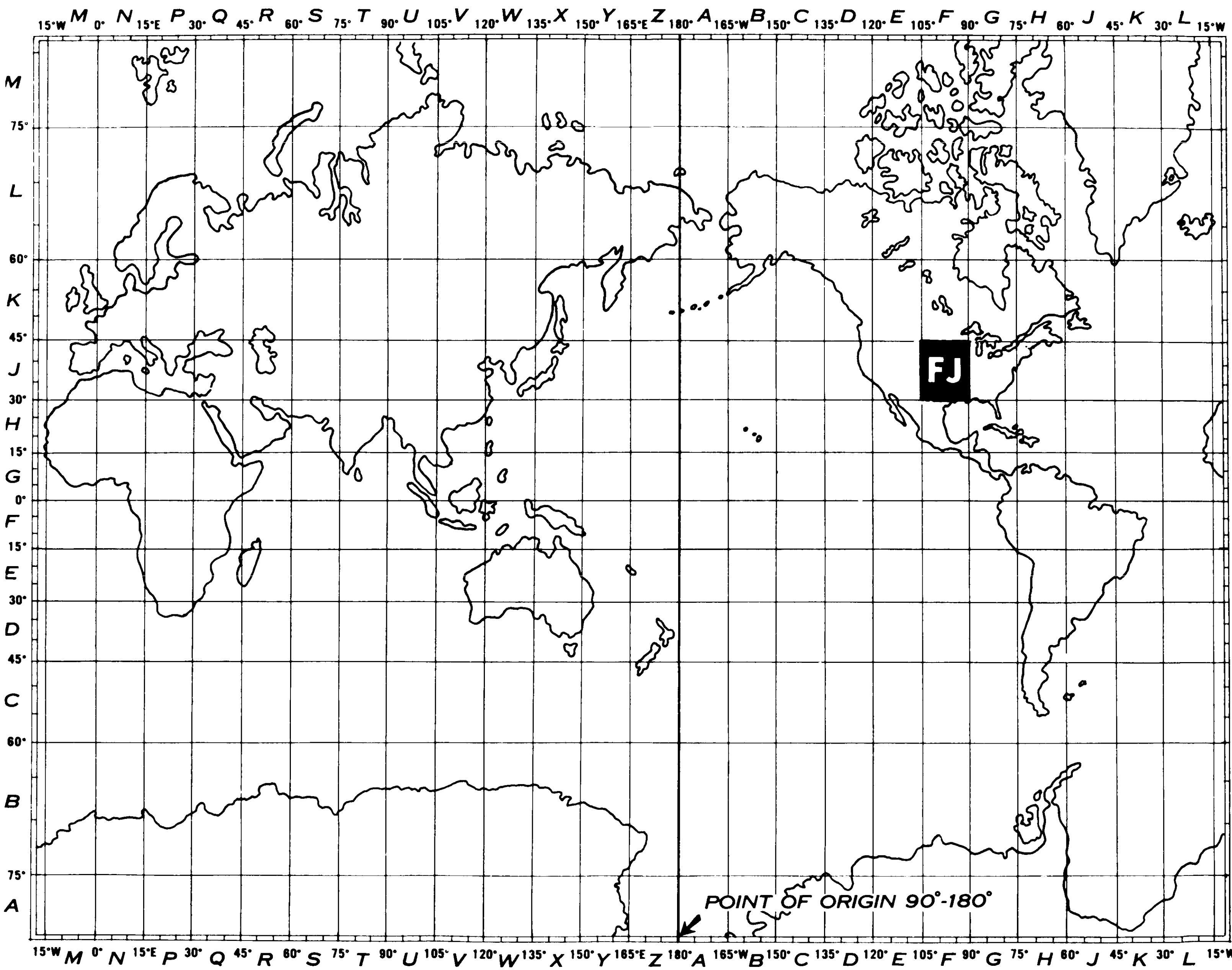


Figure 2-46. Location of 15° Quadrangle FJ, GEOREF Index.

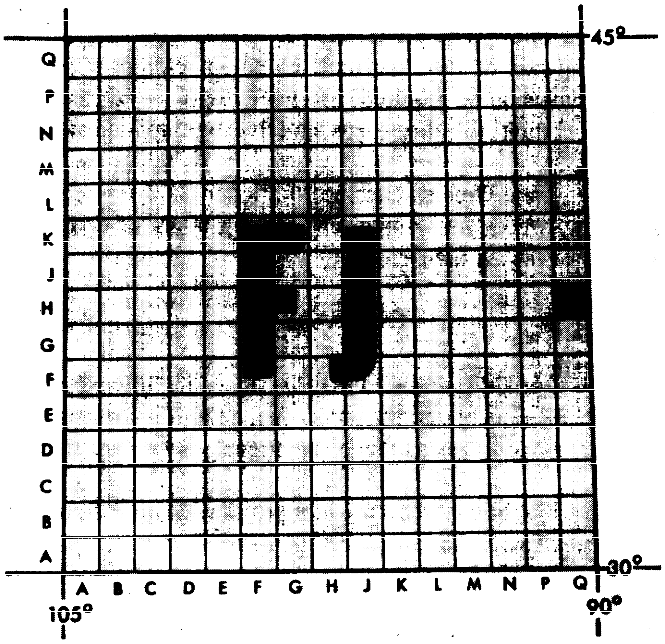


Figure 2-47. GEOREF 15° Quadrangle FJ Breakdown into 1° Units.

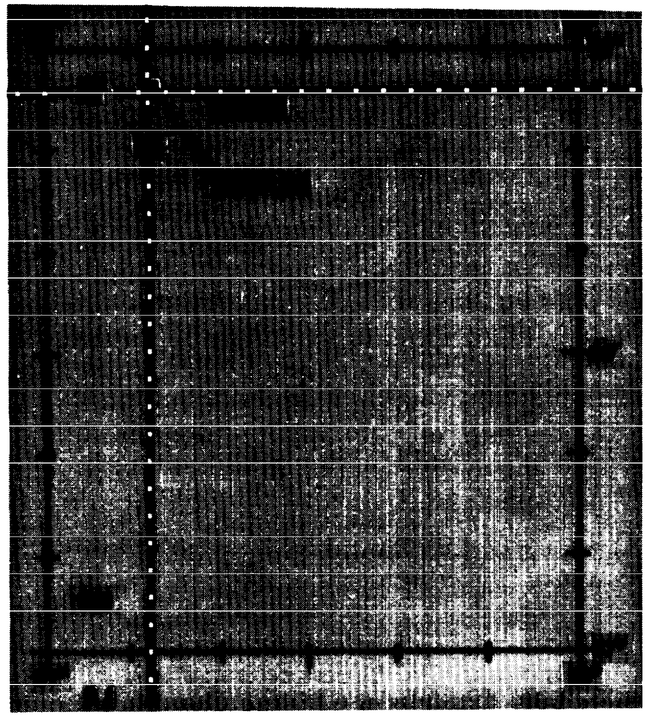


Figure 2-49. To locate FJQH 1256, Interpolate for 12 and 56.

the equator. The GEOREF minutes of longitude always increase from west to east, and the GEOREF minutes of latitude always increases from south to north. This is contrary to the geographic minutes of latitude in the Southern Hemisphere and the geographic minutes of longitude in the Western Hemisphere.

If references of greater accuracy than 1 minute are required, each 1-minute quadrangle may be further subdivided into decimal parts eastward and northward. Four letters and six figures define a location of 1/10th part of a minute; four letters and eight figures to 1/100th part of a minute, etc.

A reference box is required on all charts overprinted by GEOREF. This box illustrates the standard reference procedures by a fictitious example (figure 2-48).

Sample Reference. A GEOREF reference consists of all letters and number characters arranged in right and up reading order and in largest to smallest area sequence. References are written and read as a continuous series of characters without spaces or punctuation. For example, FJQH1256 is the standard reference that identifies the southwest corner of the town of Potosi, Missouri. The procedure for locating this point, shown

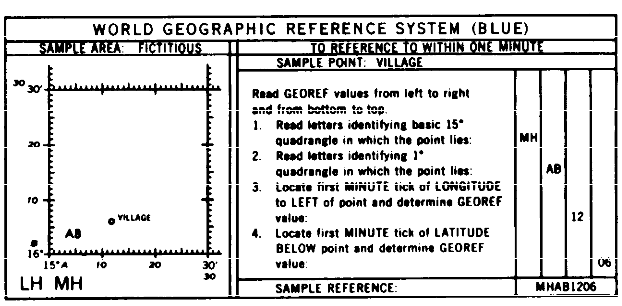


Figure 2-48. GEOREF Simple Reference.

in figure 2-49, is as follows:

- FJ—identifies the basic 15° quadrangle in which the point lies.
- QH—identifies the 1° quadrangle in which the point lies.
- 12—identifies the first minute of longitude to left of the point. (This value is read from left to right.)
- 56—identifies the first minute of latitude below the point. (this value is read from bottom to top.)

Special Referencing Problems. In addition to making basic area references, it is often necessary in air operations to indicate large area and altitude. Adaptations of the World Geographic Reference System with respect to these requirements follow.

To designate a rectangular or square area other than the basic area referred to in the World Geographic Reference System, the following procedure is used:

1. Read the GEOREF coordinates of the southwest corner of the area.
2. Immediately following the GEOREF coordinates, add the letter "S" denoting "side."
3. Add digits defining the west to east extent of the area in nautical miles.
4. Add the letter "X" denoting "multiplied by."
5. Add digits defining the south to north extent of the area in nautical miles.
6. The designation of the rectangular area in figure 2-50 is EJQK2015S10X12.

To designate a circular area, reference its center by normal GEOREF coordinates, add the letter "R" denoting "radius" and digits defining the radius in nautical miles. Thus, the designation of the circular area in figure 2-50 is EJQK4550R12.

An altitude reference is designated by the letter "H" denoting

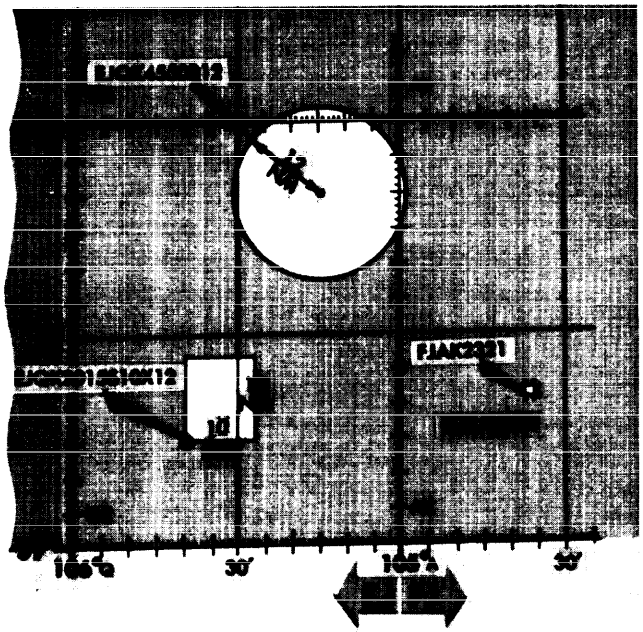


Figure 2-50. Examples of GEOREF Coordinates.

"height" followed by digits, such as "H10." Two digits indicate thousands of feet, the most common reference. Should greater precision be required, use three digits to indicate hundreds, four digits to indicate tens, and five digits to indicate units of feet.

To designate Greenwich time, the letter "Z" is used, followed by two or four digits representing hours or hours and minutes of the 24-hour clock.

SUMMARY

The UTM, UPS, and GEOREF systems are all designed to facilitate location of definite points on the Earth's surface. They are used primarily when other conventional systems are difficult to use.

The various grid systems used for position location should not be confused with the grid directional system. Grid directional overlays are used in polar navigation. The primary purpose of a grid directional system is to establish a reference direction with regard to some point other than the North Pole. A full explanation of the construction and use of the grid directional overlay is given in the chapter on Grid Navigation.

Chapter 3

MISSION PLANNING

Prior to boarding an aircraft, a navigator must thoroughly plan the mission. A well-planned mission will provide a professional atmosphere in which safety and accomplishment of mission objectives are enhanced. This chapter is devoted to the navigator's mission planning. It begins with a discussion of air traffic control systems, followed by a brief description of publications which a professional navigator should be familiar with. US military publications used for flight planning and in-flight purposes follow specific service publications; that is, Air Force and Navy. The bulk of this chapter is devoted to general mission planning considerations. All phases of ground planning are discussed, from chart selection to arrival study. Adequate mission planning prior to flight can avoid unnecessary in-flight problems.

AIR TRAFFIC CONTROL SYSTEMS

General

Most nations of the world today have established airspace, air traffic units, and air traffic services to promote a safe, orderly, and expeditious flow of traffic. Furthermore, in the interest of standardization, many nations are establishing systems in accordance with the standards and recommended practices adopted by the International Civil Aviation Organization (ICAO). Navigators must understand what these air traffic services are and how they can be used because military operations are directly affected by these services.

Air Traffic Service

Air traffic service is a general term used to mean any of the following services.

Air Traffic Control. This is a service provided to aircraft by ground agencies to prevent collisions and to expedite and maintain an orderly flow of traffic. Air traffic control includes such services as area and en route control, approach control, and tower control. It is used primarily under instrument flight rules (IFR).

Advisory Service. This service is provided to give air information useful for the safe and effective conduct of flight. This service is usually associated with the visual flight rules (VFR) environment and includes such services as weather conditions, location of known traffic, status of navigational aids, status of aerodromes and facilities, etc.

Alerting Service. This is a service provided to notify appropriate organizations regarding aircraft in need of search and rescue aid and to assist such organizations as required.

Airspace

When it has been determined that air traffic services are to be provided, portions of the airspace are designed in relation to the air traffic services that are required. Some of the more important divisions of the airspace follow.

Controlled Airspace. This is airspace of defined dimensions within which air traffic control service is provided.

Airway. This is controlled airspace established in the form of a corridor defined by radio navigation aids.

Advisory Route. This is uncontrolled airspace similar to an airway along which air traffic advisory service is available. Advisory service provides separation or control from other known traffic.

Control Zone. This is controlled airspace extending upward from the surface of the Earth. Normally, these zones are circular areas surrounding one or more aerodromes.

Flight Information Regions (FIR). This is an airspace of defined dimensions within which Advisory Service and Alerting Service are available. The FIR is the basic breakdown of the ICAO Regions. Also, portions of the FIR may contain controlled airspace. Some countries have established Upper Information Regions (UIR) for their high altitude airway systems. When the UIR is implemented, it exists above the FIR.

Positive Control Area (PCA.) This includes all airspace in the United States, from 18,000 feet MSL to FL600. Only IFR flights are conducted in this area. All VFR activities, including climbs, descents, and VFR-on-top operations on IFR flight plans are prohibited within a PCA. All aircraft operating within a PCA must have radio equipment capable of maintaining pilot-controller contact, applicable navigation aids, and have a coded transponder with a mode-3 capability.

Terminal Control Area (TCA). This is the airspace designed in the vicinity of certain major terminal areas. All aircraft operating within a TCA are subject to air traffic control.

Air Traffic Service Units

These are the units which provide the air traffic service within defined airspace.

Air Route Traffic Control Centers (ARTCC). This facility provides air traffic control to IFR flights within controlled airspace.

Approach Control. This facility provides air traffic control to aircraft arriving at or departing from one or more aerodromes.

Aerodrome Control Tower. This facility provides air traffic control service for aerodrome traffic.

Flight Service Station (FSS). This facility is operated by the FAA to provide flight assistance service.

International Civil Aviation Organization (ICAO)

In order to establish international rules for air traffic control, the International Civil Aviation Organization was formed in April 1947. ICAO is affiliated with the United Nations as a specialized international body dealing with aviation matters.

The member states (refer to FLIP General Planning) of the International Civil Aviation Organization subscribe to ICAO rules and procedures. These rules and procedures are used except for national deviations which are usually filed with ICAO. Since standardization in ICAO is based upon the same technical principles and policies which are in actual effect in the continental US, American airmen can fly all major routes following the same general rules of the air, using the same navigation equipment and communications practices and procedures, and being governed by the same traffic control service with which they are familiar at home.

The policy of the Department of Defense is to support activities of the International Civil Aviation Organization in an attempt to standardize air facilities, services, procedures, and practices. This standardization involves rules of the air, air traffic control, search and rescue, communications and navigational aids, maps and charts, flight information publications, meteorology, aerodromes, and visual aids. Nations may adopt the ICAO standards, change them slightly, or not adopt them at all. What each nation does about ICAO standards consitutes that nation's rules of the air. US military crews must comply with the national rules of the foreign state being overflown. Therefore, when the provisions of AFR 60-16 (Air Force) or OPNAVINST 3710.7 (Navy) conflict with the national rules of a foreign nation, the national rules apply. However, when the provisions of these regulations do not conflict with, but are more restrictive than the national rules, AFR 60-16 (Air Force) or OPNAVINST 3710.7 (Navy) will apply. As a general policy, in international airspace over the high seas, Air Force and Naval air operations are conducted in accordance with ICAO standards and recommended practices—military mission permitting.

US military aircraft flying over a foreign country which is not a contracting state of ICAO must comply with the national practices of that country and any special provisions of the bilateral agreements the US may have with that country. In the absence of any national practice or bilateral agreements governing rules of the air, the ICAO rules and procedures are followed.

Federal Aviation Administration (FAA)

The United States is a member of ICAO and follows ICAO standards. Deviations from ICAO standards are filed with ICAO. The Federal Aviation Administation is responsible for air traffic services in the United States and its possessions in accordance with the Federal Aviation Act of 1958 which consolidated all air traffic regulatory agencies under the control of the FAA. Following are some of the responsibilities of the FAA.

- Operates the air traffic control system within the US airspace.
- Establishes and assures compliance with the Federal Aviation Regulations (FARs) which are binding on the entire aviation community.
- Issues licenses to aircrew members, maintenance personnel, and control tower operators.
- Investigates aircraft accidents.
- Maintains communication stations and navigational aids.
- Flight checks navigational aids.

AIR FORCE PUBLICATIONS

The Air Force uses many publications to give direction, offer guidance, explain policy, etc., to Air Force personnel. The publications include Air Force letters, manuals, pamphlets, regulations, and visual aids. Among the publications which are of primary interest to Air Force navigators are the following:

- Flying Training—51 Series. These include such subjects as air navigation, instrument flying, etc.
- Operations—55 Series. These include such subjects as airfield management and base operations, NOTAMs, overdue aircraft, etc.
- Flying—60 Series. All subjects in this series directly concern rated personnel. They include general flight rules, air traffic control procedures, etc.
- Safety—127 Series. These include such subjects as investigating and reporting US Air Force mishaps, etc.

Air Force navigators should become thoroughly familiar with all flying publications provided by the Air Force. AFR 96-9 is of special interest to navigators. This regulation provides guidance on the submission of mapping, charting, and geodetic (MC&G) product requirements, and explains that the Defense Mapping Agency Aerospace Center (DMAAC) is available for technical assistance in defining cartographic requirements.

NAVY PUBLICATIONS

The United States Navy has many publications, regulations, and manuals that govern aviation to promote safety and an optimum readiness. The following publications are the primary references for naval flight operations.

- NATOPS (Naval Air Training and Operating Procedures Standardization Program) Manuals. These manuals, specific for each aircraft in the naval inventory and specific for each crew position, denote emergency and safety procedures, specific mission mechanics and responsibilities, as well as detailed aircraft hardware and software descriptions.
- OPNAVINST 3710.7 (series). This manual is the "general" NATOPS manual and includes such subjects as aviation operating policies, flight rules, safety, annual flight performance requirements, and classification and qualification of flight personnel.
- OPORDER 201 (series). These manuals, generally classified, are published by the various Navy commanders. They describe specific operational activities, procedures, and objectives. Search and rescue, communications, and mission procedures are contained in these publications.

US MILITARY PUBLICATIONS

Foreign Clearance Guide (FCG).

The Foreign Clearance Guide, published by the US Air Force, is used by all US military personnel traveling abroad. The FCG provides information on all foreign nations, US possessions, and US-controlled or administered areas outside CONUS. This information covers:

- Aircraft diplomatic clearances and advance notice requirements
- Personnel clearance and entrance requirements
- Special restrictions and precautions
- General briefing information
- Material clearance requirements. Additionally the FCG covers requirements of international agencies, unified and specified commands, command activities exercising command prerogatives, joint missions, and advisory groups.

Flight Information Publications (FLIP)

Complete aeronautical information concerning air traffic systems is published in the Flight Information Publications (FLIP). The Department of Defense, the primary user, has directed that FLIPs be published covering the entire free world area. Published by the Defense Mapping Agency Aerospace Center, the FLIP program is divided into three separate phases of flight—flight planning, en route operations, and terminal operations. The en route and terminal phase publications have been divided into seven separate areas. These areas are:

1. United States
2. Alaska
3. Canada and the North Atlantic
4. Caribbean and South America
5. Europe, North Africa, and the Middle East
6. Africa
7. Pacific, Australasia, and Antarctica

Flight Planning

General Planning Document (GP). Published every 24 weeks, the General Planning Document contains information on terms, NOTAM code, airspace divisions, DD Forms 175 and 1801, United States and ICAO procedures, ICAO organization, time signals, meteorological data, conversion tables, LORAN chart coverage, and the FLIP program. The GP is used for planning purposes only and is seldom carried aboard aircraft. The first section of the FLIP Planning Document will contain the GP.

★ *Area Planning Documents (AP/1, 2, and 3).* Area Planning Documents, located behind the General Planning Document in the FLIP Planning Document binder, contain planning and procedure information for a specific geographical area. Area Planning Documents 1, 2, and 3 are respectively North and South America, Europe-Africa — Middle East, and Pacific-Australia-Antarctica.

Area Planning Documents (AP/1A, 2A, and 3A). Located behind their respective Area Planning Documents, these publications contain a tabulation of all prohibited, restricted, danger, warning, and alert areas. In addition it contains intensive student jet training areas, military training areas, and known parachute jumping areas within their specific geographical area.

Area Planning (AP/1B). Located behind AP/1A in the FLIP Planning Document, it contains information relative to military training routes in North and South America, including IFR and VFR Military Training routes.

Planning Change Notices (PCNs). These are in textual form and are used to update the FLIP Planning Document.

En Route Operations

FLIP En Route Charts. Charts portray airway systems, radio aids to navigation, aerodromes, airspace divisions, and other aeronautical data for IFR operations. FLIP EnRouteCharts are divided into high altitude (18,000 ft MSL through FL450) for use in the jet route system, and low altitude (1,200 ft above the surface up to but not including 18,000 ft MSL) for use in the airway systems. Packets of low and high altitude charts are available for the seven geographic areas; such as, USA, Alaska, Canada and North Atlantic; Caribbean and South America; Europe, North Africa and the Middle East; Africa; and Pacific, Australasia and Antarctica.

FLIP En Route Supplements. One is published for each of the seven geographical areas. Each supplement contains an aerodrome/facility directory, en route procedures, special notices, and other textual data required to support en route charts. In the United States, there are two supplements. One supplement is designed for IFR operations and contains IFR aerodrome and facility directory, special notices, and procedures required to support the en route and area charts. The other supplement is designed for VFR operations and contains a listing of selected VFR aerodromes with sketches and an IFR/VFR city and aerodrome cross-reference listing.

In all other FLIP areas, aerodrome sketches are published for a limited number of selected aerodromes and are provided with a separate section of the En Route Supplement. Aerodrome sketch details include aerodrome identification, city name, distance and direction, and elevation as well as a diagram of each aerodrome.

Area and Terminal Area Charts. These charts are large-scale graphics of selected terminal areas. In the United States, area charts are provided primarily as area enlargements; in foreign areas, the terminal area charts are published primarily to provide arrival and departure routings. The area and terminal charts are printed on the same size sheet as the en route charts (that is, the terminal or area sheet contains several terminal or area charts) and are distributed with the En Route FLIPs.

Terminal

FLIP Terminal-Instrument Approach Procedure Plates. Divided into low altitude approaches (approaches initiated below 18,000 ft MSL) and high altitude approaches (approaches initiated normally at or above 18,000 ft MSL; such as high performance aircraft) they contain the approved instrument approach procedures for which a DOD requirement has been established. Each instrument approach procedure shows an aerodrome sketch with additional data as deemed necessary for an approach under IFR conditions.

The Caribbean and South America volumes contain departure procedures as well as approach procedures. The number of volumes vary in each area depending on the number of required approach procedures. The booklets are divided into low and high altitude booklets in all areas except Pacific, Australasia, Antarctica, Africa, and Alaska where high and low altitude approaches are contained in one volume.

MANs (Military Aviation Notices). MANs contain revisions to approach procedures and are published normally at the midpoint of the FLIP Terminal booklets. The changes may be in textual form or graphic. In the US area, MANs revise only the low altitude approaches; however, in the Europe, North Africa, Middle East area and Pacific, Australasia and Antarctica areas MANs revise both low and high altitude approaches. In the other four FLIP areas, MANs are not published and NOTAMs must be consulted for changes to approach procedures.

SIDs (Standard Instrument Departure). Published as looseleaf booklets for individual bases, they depict standard IFR departures. In the Alaska area and Pacific, Australasia and Antartica area, the FLIP Terminal booklets may contain the applicable SID.

STARs (Standard Terminal Arrival Routes). Containing preplanned IFR air traffic control arrival routes, STARs are published for pilots use in graphic and (or) textual form. STARs provide transition from the en route structure to a fix or point from which an approach can be made.

In Alaska area and Pacific, Australasia and Antarctica area, STARs information is contained in the FLIP Terminal booklets. In the US, STARs are published in a bound booklet.

NOTAMs (Notice to Airman). A NOTAM is a message requiring expeditious and wide dissemination by telecommunication means. NOTAMs provide information which is essential to all personnel concerned with flight operations. NOTAM information is normally in the form of abbreviations or a "NOTAM Code." The General Planning Document contains an alphabetical list of these abbreviations.

FLIGHT PLANNING

In the air, there is little time for lengthy processes of reasoning. Decisions must be made quickly and accurately; therefore, careful planning is essential to any flight. A smooth, successful flight requires a careful step-by-step plan which can be followed from takeoff to landing.

Route Determination

When planning a route to be flown, many factors enter into consideration. The route may be dictated by operational requirements of the mission; it may be a preplanned route; or the navigator may have the prerogative of selecting the route to be flown. In any case, definite factors affect route selection and the navigator must be aware of them.

In most cases, a direct route is usually best, since it conserves both time and fuel. This, however, can be affected by such things as airways routing, high terrain, and bad weather. The direction of prevailing winds can affect route selection since the proper use of a jet stream often decreases total flying time, even though a direct route is not flown.

Chart Selection

Once a route is established, navigation charts appropriate to the intended flightpath should be selected. Correct selection depends mainly on distance to be flown, airspeeds, methods of navigation, and chart accuracy.

Total Distance to Fly. A great circle is the shortest distance between two points. It is possible to save considerable distance by flying a great circle course, particularly on long-range missions in polar latitudes.

A straight line on a gnomonic chart represents a great circle course. One convenient method of flight planning a great circle course is to plot the entire route on a gnomonic chart, and then transfer coordinates to charts more appropriate for navigation as shown in figure 3-1. Select coordinates at intervals of approximately 300 nautical miles. Once the route is plotted on the navigation chart, record true courses and distances for each leg of the mission on the flight plan.

Chart and Methods of Navigation. The method of navigation is determined by mission requirements and the area over which

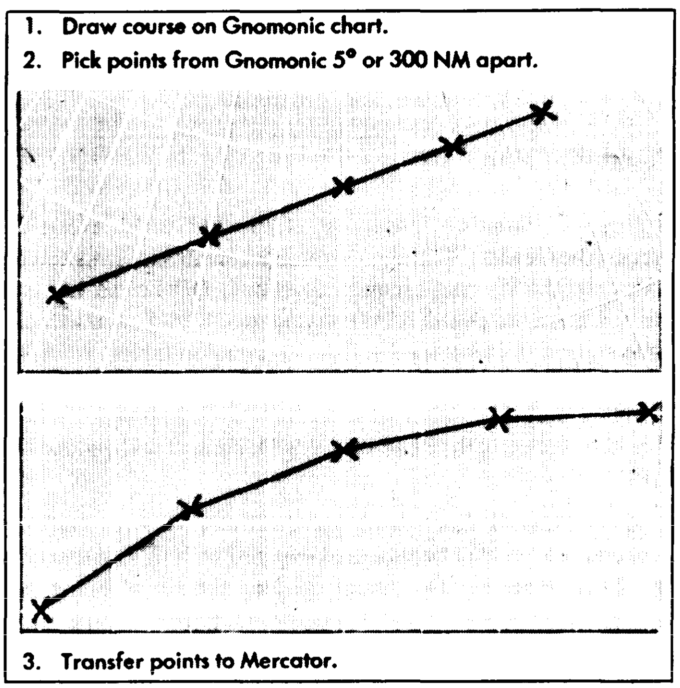


Figure 3-1. Plotting Great Circle Course.

CHARTS PRODUCED BY THE DEFENSE MAPPING AGENCY

1501 AIR	Joint Operations Graphics	1:250,000
	Sectional Aeronautical Charts	1:500,000
PC	Pilotage Charts (Small size)	1:500,000
TPC	Tactical Pilotage Charts	1:500,000
ONC	Operational Navigational Charts	1:1,000,000
WAC	World Aeronautical Charts	1:1,000,000
ASWPC	Anti-Submarine Warfare Plotting Charts	1:1,166,612
JNC	Jet Navigation Charts	1:2,000,000
JNU	Universal Jet Navigation Charts	1:2,000,000
CEC	Continental Entry Charts	1:2,000,000
JNCA	Jet Navigation Charts	1:3,000,000
LCC	Loran C Navigation Charts	1:3,000,000
GLC	Global Loran Navigation Charts (Loran A)	1:5,000,000
GLCC	Global Loran Navigation Charts (Loran C)	1:5,000,000
GNC	Global Navigation Planning Charts	1:5,000,000
NASC	Antarctic Strip Charts	Various

Figure 3-2. Available Charts.

the mission will progress. Select charts for the mission which are best-suited to the navigational techniques chosen. For example, radar missions require charts with representative returns for precision fixing; grid missions require charts with a grid overlay; and LORAN charts are needed for overwater missions.

When several navigation techniques are planned, it may be convenient to use separate charts for different navigation legs. The entire route might be plotted on a JN chart for premission briefing, reference, etc; the radar navigation legs plotted on an ONC chart to aid in precision fixing; and the target area plotted on a TPC chart for accurate target identification.

Airspeed. The scale of charts used for navigation varies inversely with the speed of the aircraft. For example, JN charts have a small scale and contain features appropriate for high-speed navigation. Navigation at slower speeds requires large scale charts providing more detailed coverage.

Chart Currency. The navigator should always insure that the chart to be used is the latest edition. The following listed documents, published by the Defense Mapping Agency (DMA), provide this information.

• DOD Bulletin Digest. The digest is published semiannually and contains a listing of the current chart editions.

• DOD Bulletin. The bulletin is published monthly to update the Bulletin Digest and to inform Air Force and Navy activities of the availability of new aeronautical charts and new editions of previously published charts.

• DMA Aeronautical Chart Updating Manual (CHUM). The CHUM provides the latest chart correction information. The CHUM is published semiannually with monthly supplements and contains a cumulative listing of significant changes and additions to navigation and planning charts. A copy of the CHUM is maintained in each base operations.

• NOTAMs. Interim aeronautical flight information changes are disseminated by Notices to Airmen (NOTAMs), which are posted in each base operations until the change is provided in all pertinent Flight Information Publications (FLIPs). NOTAMs also provide the most current information on restrictions to flight, reliability of aerodrome facilities and services, en route hazards, radio aids, etc.

AIRWAYS

General

Airways are corridors established by a national government within its airspace to facilitate the navigation and control of air traffic under IFR conditions. Usually, an airway is 10-statute miles wide and follows a route over the ground defined by radio navigational aids.

Generally, there are many different airways within a country as evidenced by those established in the US. (Note that in the US as well as in other countries, there are two sets of airways; one for low altitudes and one for high altitudes.) To distinguish one airway from another, each has its own designator; such as V (low altitude), J (high altitude). These designators simplify the preparation of a flight plan and improve the communication between aircrews and air traffic controllers.

Military aircrews are encouraged to use airways to simplify traffic control if the mission will permit. The most current and complete information on airways is contained in the DOD Flight Information Publications. There is much information included in these documents which has significant interest to navigators, such as magnetic courses, distances, compulsory reporting points, frequencies, and call signs of radio aids to navigation.

Alternate Aerodrome

This is an aerodrome where an aircraft intends to land if weather conditions prevent landing at scheduled destination. Occasionally, an aerodrome may also be identified as an alternate for takeoff purposes. This is at the direction of a major command which authorizes the use of lower minimums for takeoff than for landing. The conditions under which an alternate aerodrome must be selected and when it will be used are established by the Air Force in AFR 60-16 and by the Navy in OPNAV 3710.7 (series) instructions.

Emergency Aerodromes

During flight planning, select certain aerodromes along the planned flight route as possible emergency landing areas; then annotate these aerodromes on the charts for quick reference. Consider the following factors when selecting an emergency aerodrome: type of aircraft, weather conditions, runway length, runway weight-bearing capacity, runway lighting, and radio navigational aids. The NOTAMs for these aerodromes should be checked prior to flight.

Highest Obstruction

After the route has been determined, the navigator should then study the area surrounding the planned route and annotate the highest obstruction (terrain or cultural). The distance within which the highest obstruction will be annotated will be in accordance with governing or local directives. The highest obstruction will be taken into consideration when determining the minimum en route altitude (MEA) and in emergency procedures discussion.

Special Use Airspace

In determining the route, the locations of special use airspace will have to be considered. The best place to find the locations of the areas is by checking an en route chart. After the route is determined, any special use airspace that may be close enough to the route of flight to cause concern (as per governing directives) should be annotated on the chart with pertinent information such as time and days of operation, effective altitudes, and any restriction applicable to that area. These areas, when annotated on the chart, will assist the navigator with in-flight mission changes and prevent planning a route of flight that cannot be flown.

MISSION PREFLIGHT LOG	NAVIGATOR:	TRAINING MISSION COMMANDER:	AIRCRAFT COMMANDER:	MISSION:	OPERATING WT:	CLIMB TEMP DEV:	ACFT CALL SIGN:
	Lt Luhrman	Capt McNeely	Maj Neveng	51-40	66,400	+5	Gator79

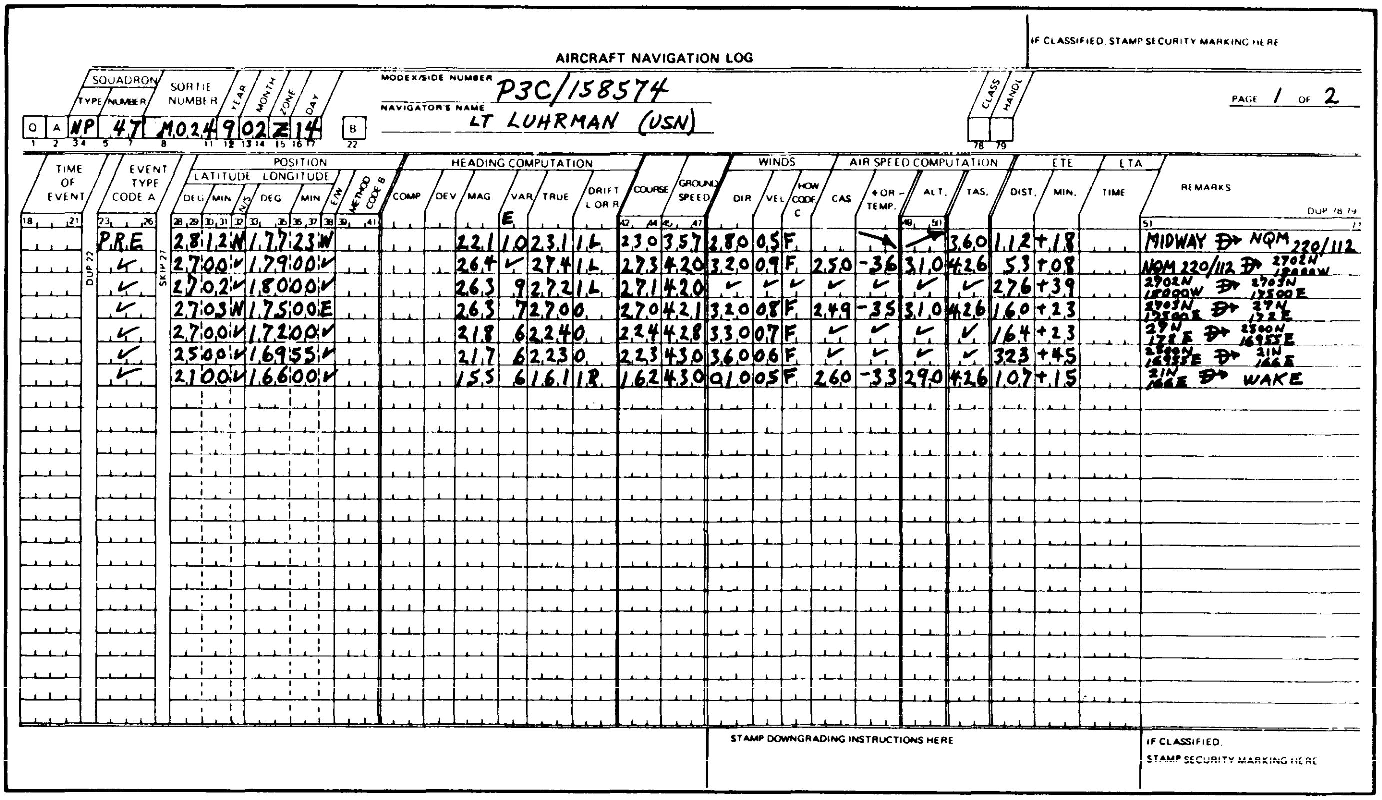
DESTINATION:	ROUTE:	SQUADRON:	CLASS:	CREW:	SCHEDULE/ACTUAL TAKEOFF:	DATE OF TAKEOFF: (Z)	CARGO/PAX WT:	CRUISE TEMP DEV:	ACFT SERIAL NO:
Wake Is AFB N19-17.0 E166-380	MDWAKATC	452FTS		N01	1900 Z/ Z	2Jul79	4,600	+1	1404

ROUTE IDENT	FROM / ROUTE	T.C. OR G.C.	W/V / DC	T.H. OR G.H.	VAR OR GRIV	M.H.	(M.C.)	TEMP / ALT	TAS / TRUE MACH	GS	GRD DIS / ACC. GRD DIS	TIME / ACC. TIME	PROP ETA	RETA / ATA	A OR B	REMARKS
	FROM Midway NS N28-12.0 W177-23.0															
A	NQM 220/112 N27-00.0 W179-07.0	230	300/10 / +1	231	-10	221	220	↗ M	360	357	112 / 112	+18 / +18				
	L/O	273	300/10 / +1	274	-10	264	263	↗ M	360	357	6 / 118	+01 / +19				AD116
B	N27-02.0 W180-00.0	273	320/10 / +1	274	-10	264	263	-45 / 31.0 M	426 / 172	420	~~(53)~~ 47 / 165	+07 / +26				Dept
C	N27-03.0 E175-00.0	271	320/10 / +1	272	-9	263	262	✓ / ✓ M	✓ / ✓	420	267 / 432	+39 / 1+05				
D	N27-00.0 E172-00.0	270	320/10 / 0	270	-7	263	263	✓ / ✓ M	✓ / ✓	421	160 / 592	+23 / 1+28				TP
E	N25-00.0 E169-55.0	224	330/10 / 0	224	-6	218	218	✓ / ✓ M	✓ / ✓	428	164 / 756	+23 / 1+51				
F	N21-00.0 E166-00.0	223	360/05 / 0	223	-6	217	217	✓ / ✓ M	✓ / ✓	430	323 / 1079	+45 / 2+36				Term
G	AWK N19-18.0 E166-36.0	162	010/05 / -1	161	-6	155	156	✓ / ✓ M	✓ / ✓	430	107 / 1186	+15 / 2+51				
	TERMINAL ALTERNATE: NR		/					M								A.D. =

RAMP FUEL WT:	TAKEOFF WT:	ACFT TYPE:
37,000	107,000	T43A

RAMP GROSS WT: 108,000	PG: 4-6	TIME	FUEL
1. ENROUTE		2+51	16.7
2. RESERVE		+20	4.0
3. ENROUTE PLUS RESERVE		3+11	20.7
4. ALTERNATE (AND MISSED APPROACH)		NR	NR
5. HOLDING		—	—
6. APPROACH/LANDING		+15	1.0
7. IDENTIFIED EXTRA			—
8. TOTAL (3+4+5+6+7) TAKEOFF/FLAPS UP		3+26	21.7
9. TAXI AND RUN UP (Acceleration)			1.0
10. REQUIRED RAMP			22.7
11. ACTUAL RAMP			
12. UNIDENTIFIED EXTRA			
13. REQUIRED OVER DEST (4+5+6)			1.0
ENDURANCE HRS		BURN OFF (1+6+7)	17.7 LBS
HIGHEST ACCEPTABLE FL		LOWEST ACCEPT. FL	
WIND FACTOR:	TOTAL -2	1ST HALF -5	2ND HALF +3
TOTAL DISTANCE( ) ÷ (WF₂ - WF₁) ÷ 2 (TAS)( ) = T( ) MIN			
TOTAL TIME - T = TIME TO ETP			

Figure 3-3. Typical Air Force Flight Plan.



IF CLASSIFIED, STAMP SECURITY MARKING HERE

AIRCRAFT NAVIGATION LOG

Q A | SQUADRON TYPE: NP | NUMBER: 47 | SORTIE NUMBER: M024 | YEAR: 9 | MONTH: 02 | ZONE: Z | DAY: 14 | B

MODEX/SIDE NUMBER: P3C/158574

NAVIGATOR'S NAME: LT LUHRMAN (USN)

CLASS | HANDL

PAGE 1 OF 2

TIME OF EVENT	EVENT TYPE CODE A	LAT DEG	LAT MIN	N/S	LONG DEG	LONG MIN	E/W	METHOD CODE B	COMP	DEV	MAG	VAR (E)	TRUE	DRIFT L OR R	COURSE	GROUND SPEED	WINDS DIR	WINDS VEL	HOW CODE C	CAS	+ OR − TEMP.	ALT.	TAS.	DIST.	ETE MIN.	ETA TIME	REMARKS
	PRE	28	12	W	177	23	W				221	10	231	1L	230	357	280	05	F		↘	↗	360	112	+18		MIDWAY → NQM 220/112
	✓	27	00	✓	179	00	✓				264	✓	274	1L	273	420	320	09	F	250	−36	310	426	53	+08		NQM 220/112 → 2702N 18000W
	✓	27	02	✓	180	00	✓				263	9	272	1L	271	420	✓	✓	✓	✓	✓	✓	✓	276	+39		2702N 18000W → 2703N 17500E
	✓	27	03	W	175	00	E				263	7	270	0	270	421	320	08	F	249	−35	310	426	160	+23		2703N 17500E → 27N 172E
	✓	27	00	✓	172	00	✓				218	6	224	0	224	428	330	07	F	✓	✓	✓	✓	164	+23		27N 172E → 2500N 16955E
	✓	25	00	✓	169	55	✓				217	6	223	0	223	430	360	06	F	✓	✓	✓	✓	323	+45		2500N 16955E → 21N 166E
	✓	21	00	✓	166	00	✓				155	6	161	1R	162	430	010	05	F	260	−33	290	426	107	+15		21N 166E → WAKE

STAMP DOWNGRADING INSTRUCTIONS HERE

IF CLASSIFIED, STAMP SECURITY MARKING HERE

Figure 3-4. Typical Navy Flight Plan.

FLIGHT PLAN

To meet specialized operational requirements, each command prescribes and issues its own navigator's logs.

The complete flight plan forms shown in figures 3-3 and 3-4 are typical flight plans. There are only slight differences in the flight plan columns; the main differences are in the "Time and Fuel Analysis" sections. The headings and columns on the forms are self-explanatory.

Computer flight plans are available, time permitting. Weather and route data are inserted into a computer and the flight plan is automatically completed as shown in figure 3-5. The navigator then computes only the additional information needed, such as fuel analysis, equal time point (ETP), and any other information required by local procedures.

Fuel Analysis

The following example of computation of fuel requirements for the flight plan is shown in figure 3-3.

En Route Fuel. En route fuel is determined with a fuel graph such as the one depicted in figure 3-6. Each type of aircraft has a series of fuel graphs based on: (1) aircraft gross weight, (2) pressure or density altitude, (3) true airspeed or Mach number, and (4) on some aircraft, the aerodynamic drag of external stores.

En route fuel is computed in a manner that will take into account the worst fuel consumption situation, such as the lowest cruise altitude and highest airspeed. Also, most fuel graphs will be designed for a standard day, so a temperature deviation will have to be considered. An example of en route fuel computation is shown in figure 3-6.

Fuel Reserve. This is a quantity of useable fuel to be carried aboard all aircraft which is in excess of mission requirements if the flight is completed as planned. MAJCOMs are authorized to establish fuel requirements for aircraft of their respective command. In the absence of command-established reserves, enough useable fuel is carried on each flight to increase the total planned flight time between refueling points by 10 percent or 20 minutes, whichever is greater. Refer to AFR 60-16 for additional information.

En Route Plus Reserve. En route time and reserve time are added together to obtain the en route plus reserve time. (NOTE: In certain commands, the fuel for this time is extracted from the fuel graph in the same manner as the en route fuel.)

Alternate Fuel. The fuel to the alternate is based on the fuel flow for the gross weight of the aircraft at destination, the true airspeed, and altitude to the alternate. Some flight manuals include graphs designed for computing fuel to the alternate, but the fuel can also be computed by adding en route time and the time to the alternate. This time is then used to extract the total fuel required from takeoff to alternate. The en route fuel is then subtracted from this to obtain the fuel to the alternate. A stan-

```
COMPUTER FLT PLAN FOR MIDWAY TO WAKE

OATUFGBC RHWWAAA3304 2821457-UUUU--RUWMDTA
ZNR UUUU
O 021557Z JUL 76
FM AFGWC OFFUTT AFB NE
TO RUHPLVA/FLT OPS/MIDWAY ISLAND
BT
UNCLAS AFGWC/WP

    ROUTE FORECAST  MIDWAY TO WAKE

FOR 323FTW SIMULATOR TRAINING MISSIONS
AFGWC TIME PHASED ROUTE FORECAST      MDWAKATC    CFPI-2821457.0
DEPARTURE POINT PMDY
LAT 2812N  LONG 17723W DEPT ALT  1000FT  ETD 76 JUL 02 1900Z
ACCUMULATED TIMES ADJUSTED FOR 1 PCT ROUTE DEVIATIONS
  LAT    LONG ALT DDVVV  TAS   GS ZD  ZT  ATIM TDIS TCS THD MHD
LOCATION          TTR TTT
2700N 17900W  294 28005  360  357 112 018 0018  112 230 231 221
NQM 220/112       233 -04
2700N 17907W  310 32008  360  354 006 001 0019  118 270 271 261
LEVEL OFF         232 -34
2702N 18000W  310 32009  426  420 047 007 0026  165 273 274 264
                  225 -36
2703N 17500E  310 32004  426  420 267 039 0105  432 271 272 263
                  146 -36
2700N 17200E  310 32008  426  421 160 023 0128  592 270 270 263
                  123 -35
2500N 16955E  310 33007  426  428 164 023 0151  756 224 224 218
                  100 -35
2100N 16600E  310 36006  426  430 323 045 0236 1079 223 223 217
                   15 -35
1918N 16636E  290 01005  426  430 107 015 0251 1186 162 161 155
AWK                 0 -33
EPT SUMMARY       FWF  -1, WF1  -5, WF2   3, TIME 0128, DIST  594

AFGWC TIME PHASED ALTERNATE ROUTE FORECAST
DEPARTURE POINT
LAT 1918N  LONG 16636E DEPT ALT  33000FT  ETD 76 JUL 02 2151Z
  LAT   LONG ALT DDVVV  TAS   GS ZD  ZT  ATIM TDIS TCS THD MHD
LOCATION         TTR TTT
0843N 16744E 330 30005  426  429 638 090 0421 1824 174 174 168
BUCHOLZ AAF        0 -39
```

Figure 3-5. Typical Computer Flight Plan.

dard weight may be added to allow for a missed approach at the original destination.

Holding Fuel. Adverse weather, air traffic, or aircraft malfunction in the terminal area may force the aircraft to "hold" in the local area for a period of time before landing. The amount of holding fuel is based on any planned delays in accordance with applicable directives.

Approach and Landing Fuel. Approach and landing fuel is the fuel required from the terminal fix to the runway. This is computed for a prescribed amount of time (usually 15 minutes). The amount of fuel needed for approach and landing varies with the aircraft.

Identified Extra Fuel. Any additional fuel needed for special reasons dictated by mission requirements.

Total Takeoff or Flaps Up. This is total fuel from takeoff or flaps up that is required for en route, reserve, alternate, holding, and approach and landing. It is a cumulative total of blocks 3, 4, 5, 6, and 7. (Figure 3-3).

Taxi and Runup. The fuel needed for taxiing, engine runup, and acceleration to takeoff speed. It is usually a predetermined value for each type of aircraft.

Required Ramp Fuel. The amount of fuel required at engine start to complete the mission.

Actual Ramp Fuel. The fuel on board prior to engine start.

Unidentified Extra Fuel. Additional fuel over and above that required by the flight plan. It is the difference between planned ramp fuel and actual ramp fuel.

Burnoff Fuel. Burnoff is the planned amount of fuel to be used after takeoff. This value subtracted from takeoff gross weight produces the predicted gross weight of the aircraft on landing.

Range Control Graph. A range control graph shown in figure 3-7 may be prepared by the navigator. It portrays planned, minimum, and actual fuel consumption. It is used to flight plan fuel consumption and serves as an in-flight work sheet for comparing actual and planned fuel consumption.

This range control graph is constructed with information taken from the completed flight plan (figure 3-3) and the applicable fuel planning graph (figure 3-6). As shown in figure 3-7, fuel remaining (vertical) is plotted against time remaining (horizontal).

The planned fuel consumption is then plotted on the graph along with the minimum required fuel line. In-flight fuel readings are taken periodically and plotted on the graph to determine the fuel consumption in relation to that planned.

The planned line is determined by calculating the fuel remaining and time remaining at predetermined points in the mission and then plotting these points on the graph and connecting them with a line. The minimum line is determined by adding up all fuel required as a minimum at the destination (reserve, alternate, approach, etc.) and plotting it on the zero time remaining line. The difference between the minimum fuel required and the planned on the zero time remaining line is then plotted below each of the predetermined fuel remaining points on the planned line. The points are then connected with a line which represents the minimum required fuel line. This line is used to determine whether or not to continue the mission.

In-flight, fuel readings are obtained and plotted against time remaining to determine fuel status. These plotted points are then connected with a dotted line which represents the actual fuel consumption. The trend of the in-flight fuel readings indicates actual fuel consumption and is used to make mission decisions with regard to fuel.

★Equal Time Point (ETP)

The ETP is that point along the route (normally one with an extended overwater leg) from which it takes the same amount of time to return to departure (usually the last suitable airfield prior to beginning the overwater leg of the mission) as it would to continue to destination (normally the first airfield suitable for landing).

The ETP is not necessarily the midpoint in time from departure to destination. Its location is somewhere near the midpoint of the route (between suitable airfields), and it is dependent upon the wind factors.

A wind factor (WF) is a headwind or tailwind component which is computed at planned altitude and between suitable airfields by comparing the average groundspeed (GS) to the average true airspeed (TAS). To do this, algebraically subtract the TAS from the GS. When the wind factor is a minus value, it is called a *headwind factor;* when it is a plus value, it is a *tailwind factor*. When computing ETP, obtain a wind factor for each half of the route.

An ETP may be computed using the following formula:

$$\frac{\text{Total Distance}}{(WF_2 - WF_1) + (2 \times TAS)} = \frac{T}{(60 \text{ min})}$$

Total distance is the number of nautical miles from last suitable airfield to the first suitable airfield. WF2 and WF1 are wind

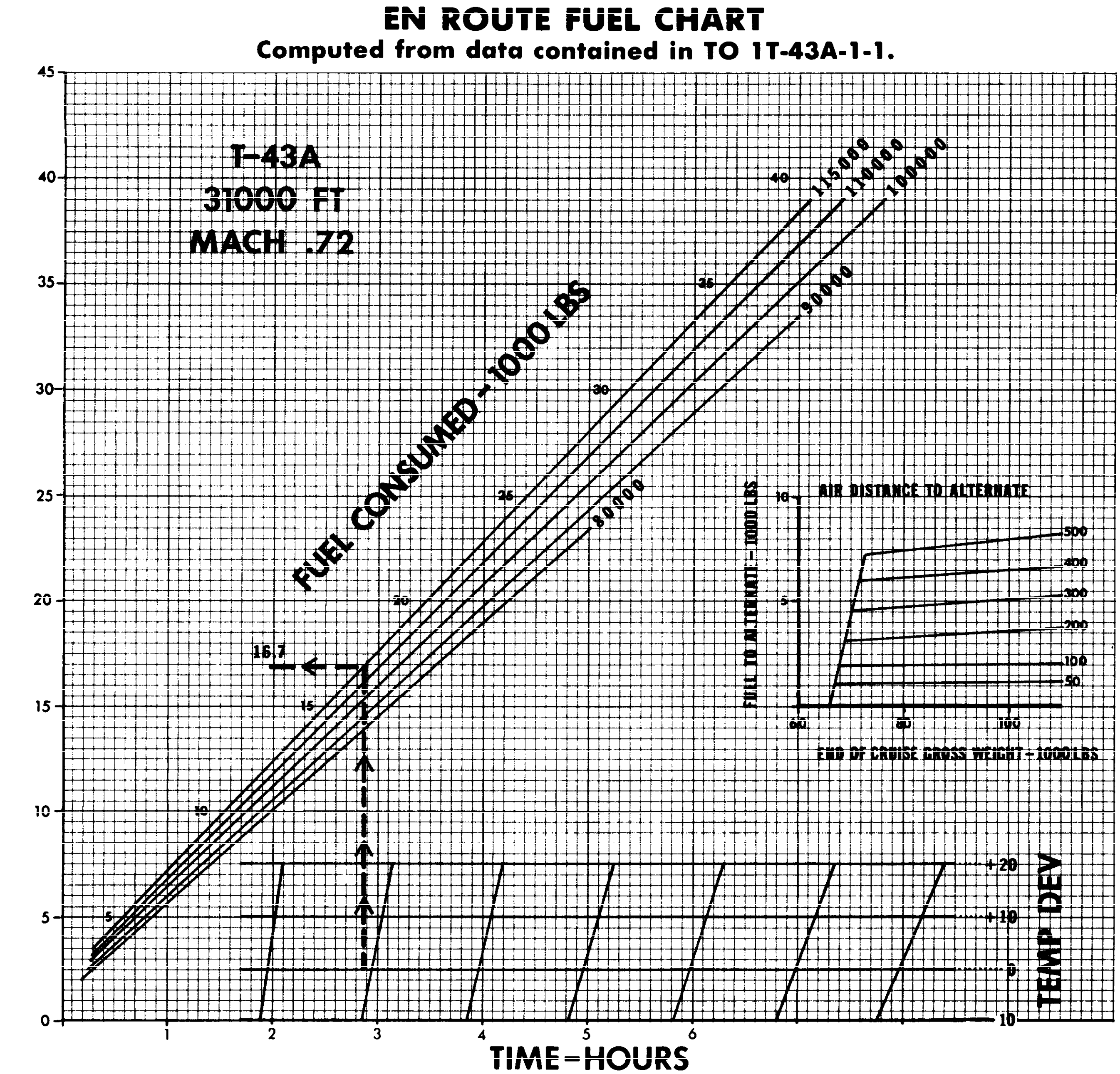


Figure 3-6. Typical Fuel Graph.

factors for the second and first halves of the route segment, respectively. T is the time remaining in minutes from the ETP to the first suitable airfield. This time can be converted to distance by applying the groundspeed for the second half of the route segment. The distance can then be measured uptrack and the ETP plotted on the chart. The time should be plotted on the range control graph with a vertical line that crosses both the planned and minimum lines. If the first suitable airfield is not the planned landing airfield, then we should add the time between the first suitable airfield and the landing airfield to determine the ETP.

Endurance

Endurance is the time an aircraft can remain airborne, not including minimum required fuel. In the fuel graph shown in figure 3-7, endurance can be computed by taking the last plotted fuel reading and following a line parallel to the fuel remaining lines in the direction of increasing time remaining until intercepting the minimum line. This point and its corresponding time remaining represent the endurance at the time of the fuel reading that is being used. This time would be especially important in making in-flight diversion decisions.

ROUTE STUDY

General

During mission planning, a route study should be performed by all crewmembers. For the navigator, a route study encom-

FUEL PLANNING					
FLIGHT PHASE	TIME ACCUM TIME	TIME REMAINING	36.0 FUEL WEIGHT A	FUEL CONSUMED B	FUEL REMAINING A-B
TAXI AND RUN UP		2+51			
CLIMB	+19 / +19	2+32	36.0	3.5	32.5
CRUISE 1	+38 / +57	1+54	36.0	6.5	29.5
CRUISE 2	+38 / 1+35	1+16	36.0	10.1	26.9
CRUISE 3	+38 / 2+13	+38	36.0	13.4	22.6
CRUISE 4	+38 / 2+51		36.0	16.7	19.3
LONG RANGE ALTERNATE					

OPERATING WT: 66,400	CLIMB TEMP DEV: +5	ACFT CALL SIGN: [illegible]
CARGO/PAX WT: 4,600	CRUISE TEMP DEV: +1	ACFT SERIAL NO: 1404
RAMP FUEL WT: 37,000	TAKEOFF WT: 107,000	ZULU DATE: 2[illegible]79
RAMP GROSS WT: 108,000	FG: 4-6	

	TIME	FUEL
1. ENROUTE	2+51	16.7
2. RESERVE	+20	4.0
3. ENROUTE PLUS RESERVE	3+11	20.7
4. ALTERNATE (AND MISSED APPROACH)	NR	NR
5. HOLDING	—	—
6. APPROACH/ LANDING	+15	1.0
7. IDENTIFIED EXTRA		—
8. TOTAL (3+4+5+6+7) TAKEOFF/FLAPS UP	3+26	21.7
9. TAXI AND RUNUP (ACCELERATION)		1.0
10. REQUIRED RAMP		22.7
11. ACTUAL RAMP		
12. UNIDENTIFIED EXTRA		
13. DEST PLUS RESERVE (2+4+6)		5.0

ETP SUMMARY

WIND FACTOR	TOTAL:	1ST HALF:	2ND HALF:
	-2	-5	+3

TOTAL DISTANCE (1186) / $(WF_2 - WF_1) + 2$ (TAS) (860) = T (83) MIN

(+3-(-5))+(2×426)

8 + 852

860

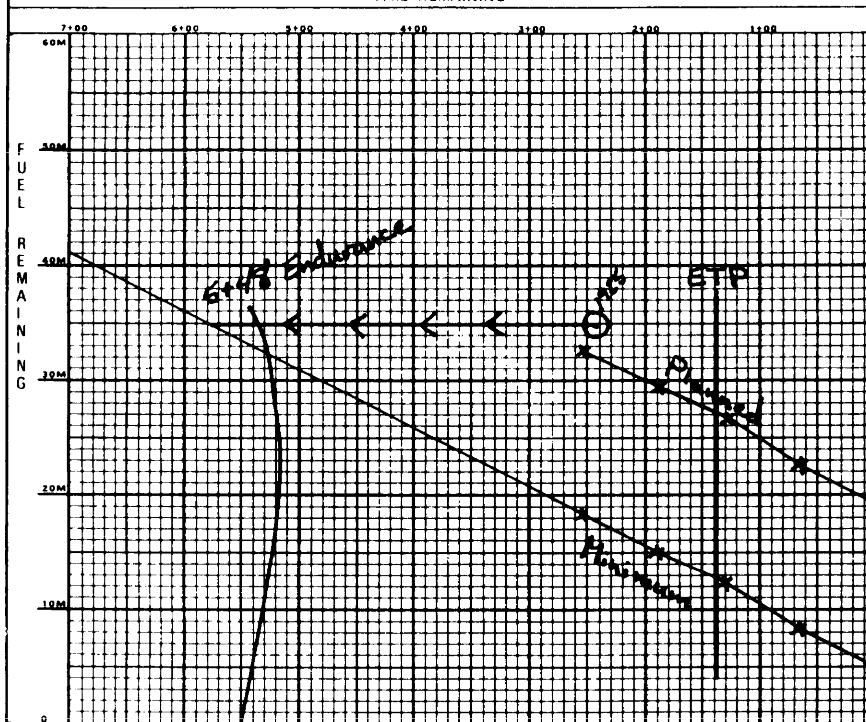
CLEARANCES
ATC CLEARANCE
DEPARTURE CLEARANCES
ENROUTE CLEARANCES
ARRIVAL CLEARANCES

POSITION REPORTING					
PRESENT					
POSITION					
TIME					
ALTITUDE					
NEXT					
POSITION					
TIME					

RANGE CONTROL GRAPH

NAVIGATOR	DEPARTURE:	DESTINATION	MACH NO	AVG TAS:
Lt Luhrman	Midway NS	Wake Is AFB	.72	426

TIME REMAINING



FLIGHT PROGRESS DATA										
CURRENT ETA DEST	2151									
TIME	L/O 1925									
ETR	2+26									
FUEL REMAINING	34.9									
ENDURANCE	5+48									

Figure 3-7. Range Control Computations.

passes three phases of flight—takeoff and climb, cruise, and approach and landing. The following paragraphs discuss these three areas in general terms as specific weapon systems and missions will most often differ in their objectives and parameters.

Takeoff and Climb

Prior to boarding the aircraft and copying the clearance, a study of the SID (Standard Instrument Departure) to be flown should be accomplished. This study includes a study of NAVAIDs; such as TACAN, VOR, and ADF to be used on the SID. Magnetic headings, radials or bearings, and altitude restrictions should be noted. AFM 51-37, Instrument Flying, discusses how to accurately monitor instrument departures.

During takeoff and climb, the navigator's duties include monitoring the SID, copying clearances, and insuring applicable altitude restrictions and terrain clearance are maintained.

Frequently during climb out, estimated time of arrivals (ETAs) will be required by the pilot to communicate to controlling authorities and, generally, it is the navigator's duty to compute these required ETAs. Groundspeeds for computing ETAs can be obtained from an inertial navigation system, Doppler radar, flight-planned groundspeed, or even by observing a TACAN DME increase or decrease rate (NM or min).

When a controlled time of arrival is required, the navigator must also compute an indicated airspeed (IAS) for the pilot to maintain when approaching cruise altitude.

CRUISE

General

The duties of the navigator in flight are many and varied. While the primary duty is to monitor and direct the progress of the aircraft, the navigator must meet many associated requirements such as completing the log, filling out forms, working controlled ETAs, and analyzing the information received from the navigation equipment.

Navigator's Log

The navigator's log is usually the only record of the aircraft's actual position at any given time during the flight. For this reason, it must be accurate and complete.

Log procedures vary between organizations; however, the basic log requirements and purpose remain the same—to keep an accurate record of data for the navigator's reference and debriefing purposes, and to perform the function of a worksheet for the navigator. Generally, required items for log entry are items and computations necessary to direct the aircraft.

Navigator's Celestial Precomps

Like navigator logs, celestial precomp forms also vary between organizations. Like the log, the computational format may vary; however, the celestial computations themselves are essentially the same.

Airborne Report (AIREP)

When flying over water, the navigator will be required to fill out an AIREP and, in some commands (for example, Navy P3C), the navigator must transmit the report over the radio circuits. The AIREP is used for reporting position information (generally over water), and in-flight weather conditions from observations taken as the flight progresses. The AIREP log varies from organization; however, the format (located on the back of any IFR Supplement) remains the same. Remember the letters PTAPT as they describe the required items. The first item is your present poisition (P) and time (T) at that position, present altitude (A), next position (P), and time (T) to that position; weather observation data will follow, as noted in figure 3-8.

APPROACH AND LANDING

Standard Approaches

The descent portion of the flight is similar to the climb portion. Instrument approach plates are established for almost all airfields of any significance in the world. These are similar to the SID that is used for departure. The published approaches are normally flightchecked for safety of flight; if not, they are appropriately annotated. The navigator must make certain that the route affords adequate terrain clearance given by the approach control. Because of congested air traffic, approaches must be followed precisely. The navigator should monitor the aircraft position and altitude during descent and advise the pilot of any deviations. AFM 51-37 discusses how to accurately monitor instrument approaches.

Airborne Radar Approach (ARA)

An additional means of approach to the terminal airfield available to the aircrew is the airborne radar approach. The ARA is an emergency procedure used when the other approaches are not available. When using this means, the pilot receives all directions and altitudes from the navigator. ARA letdown plates are published for some airfields. A typical ARA approach is shown in figure 3-9. Where an ARA letdown plate has not been published, one may be planned by the individual concerned. The navigator computes the absolute altitude above field elevation for each 1-mile increment from touchdown point on final approach. To do this, the navigator uses the rate of descent and the final approach speed for the aircraft being flown. A typical glide slope computed by the navigator is shown in figure 3-9. The field elevation must be added to each of the altitudes to produce the correct altitude for the pilot to fly. This will be the true altitude read on the pressure altimeter (the local altimeter setting in the Kollsman window).

The navigator may be directed by ground control to the point from which the ARA is planned to begin or the aircraft may be flown directly to this point without ground guidance. In either

AIREP

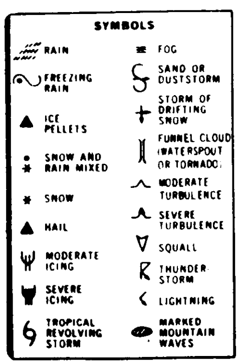
	RECORD AND TRANSMIT IN TELEGRAPHY (including teletypwriting) * as appropriate	TRANSMIT IN TELEPHONY * as appropriate
	† ARP or ARS	† AIREP or AIREP SPECIAL
1	(aircraft identification)	(aircraft identification)
2	(latitude) N or S (longitude) E or W (significant point) ABM (significant point) (significant point) (bearing) (distance)	POSITION (latitude and longitude) OVER (significant point) ABEAM (significant point) (significant point) (bearing) (distance)
3	(time)	AT (time)
4	F (flight level number) (number) M or FT ASC F (flight level number) or (number) M or FT DES F (flight level number) or (number) M or FT	FLIGHT LEVEL (number) (number) METRES or FEET CLIMBING TO FLIGHT LEVEL (number) or (number) METRES or FEET DESCENDING TO FLIGHT LEVEL (number) or (number) METRES or FEET
5	(next position)(time)	NEXT POSITION (position) AT (time)
6	ETA(aerodrome)(time)	ESTIMATING ARRIVAL (aerodrome) AT (time)
7	FUEL (hours and minutes)	ENDURANCE (hours and minutes)
8	PS (degrees) MS (degrees)	TEMPERATURE PLUS (degrees) TEMPERATURE MINUS (degrees)
9	(degrees)/(knots) (MEAN) LV (MEAN) VRB/(knots) (MEAN) (latitude) N or S (longitude) E or W	WIND (degrees) OBLIQUE (knots) (MEAN) WIND LIGHT AND VARIABLE (MEAN) WIND VARIABLE OBLIQUE (knots) (MEAN) POSITION (latitude and longitude)
10	TURB MOD TURB SEV (INC)	TURBULENCE MODERATE TURBULENCE SEVERE (IN CLOUD)
11	ICE MOD ICE SEV	ICING MODERATE ICING SEVERE
12	RA SN FZRA FC TS FRONT SCT BKN CNS CB BASE F (flight level number) or (number) M or FT TOP F (flight level number) or (number) M or FT TURB MOD } If observed prior to ICE MOD } last 10 minutes D-VALUE PS (number) M or FT D-VALUE MS (number) M or FT (Significant radar echoes) (Differences between observed and forecast weather) AT (position of phenomenon reported under Item 12 if different from that reported under Item 2)	RAIN SNOW FREEZING RAIN FUNNEL CLOUD THUNDERSTORM FRONT SCATTERED BROKEN CONTINUOUS CUMULONIMBUS BASE FLIGHT LEVEL (number) or (number) METRES or FEET TOP FLIGHT LEVEL (number) or (number) METRES or FEET TURBULENCE MODERATE ICING MODERATE D-VALUE PLUS (number) METRES or FEET D-VALUE MINUS (number) METRES or FEET ... ... AT ... ...

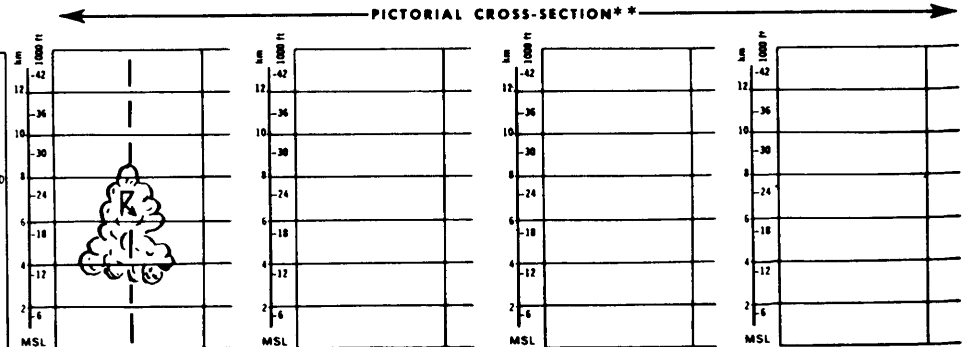
* Increasing use of air-reports in automated systems makes it essential that the elements of such reports be transmitted in the order and form prescribed.

† Only when Section 3 is included.

Section			I	II	III	IV
		Company	BOAC			
		Flight No.	568	441	101	1634
		Addressee	GANDER	REYKJAVIK	SHANWICK	PORT MORESBY
		† Message type designator	ARP	ARP	ARS	ARS
Section 1	1	Aircraft identification	BAGABCD	JL441	PA101	PN1634
	2	Position	49N050W	70N 01420W	5045N 02015W	MD
	3	Time	1317	0930	1536	0846
	4	Flight level or altitude	F310	F350	F310 ASC F350	19000FT
	5	Next position and time over	50N040W 55	65N 00950W 07	51N030W 21	LA 13
Section 2	6	Estimated time of arrival				
	7	Endurance	FUEL 0830		FUEL 0900	
Section 3	8	Air temperature	MS47	MS53		
	9	Spot wind or mean wind and position thereof	255/65	310/60 MEAN 74N020W		
	10	Turbulence	TURB MOD			TURB SEV
	11	Aircraft icing			ICE SEV	
	12	Supplementary information	SCT CB TOP F280			
		Time transmitted	1320	0932	1539	0847

PICTORIAL CROSS-SECTION**





50W

** Information entered on this pictorial cross-section is intended to supplement the observations recorded on this form when, in the opinion of the pilot-in-command, a graphical representation will usefully amplify or assist in clarifying the observations recorded elsewhere on this form.

Figure 3-8. AIREP Form.

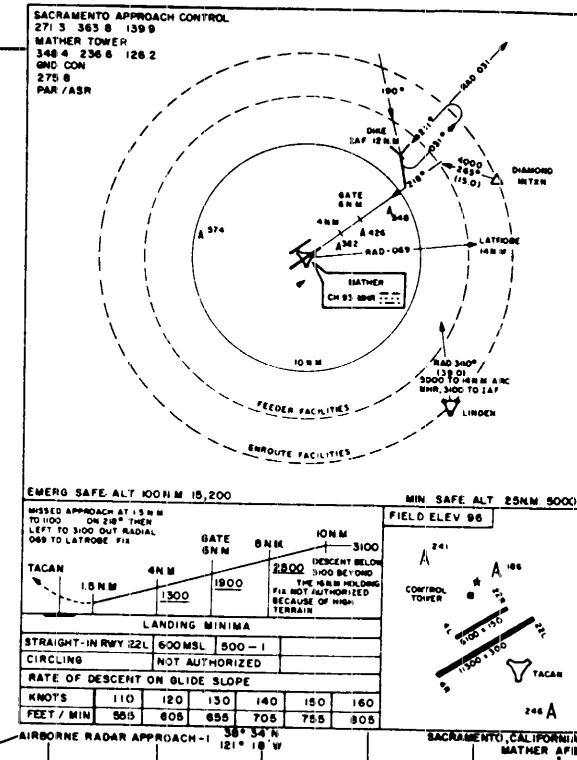
ARA CONSTRUCTION GRAPH

FOR RUNWAY 22L AT MATHER AFB

NAME MAJOR NERENG

BRIEFING GUIDE:

RUNWAY MAGNETIC COURSE	216°
INITIAL APPROACH ALTITUDE	3300'
DESCENT POINT	10 NM
RATE OF DESCENT	600 FT/MIN
IAS	120
MDA	600'
MISSED APPROACH POINT	1.5 NM TACAN



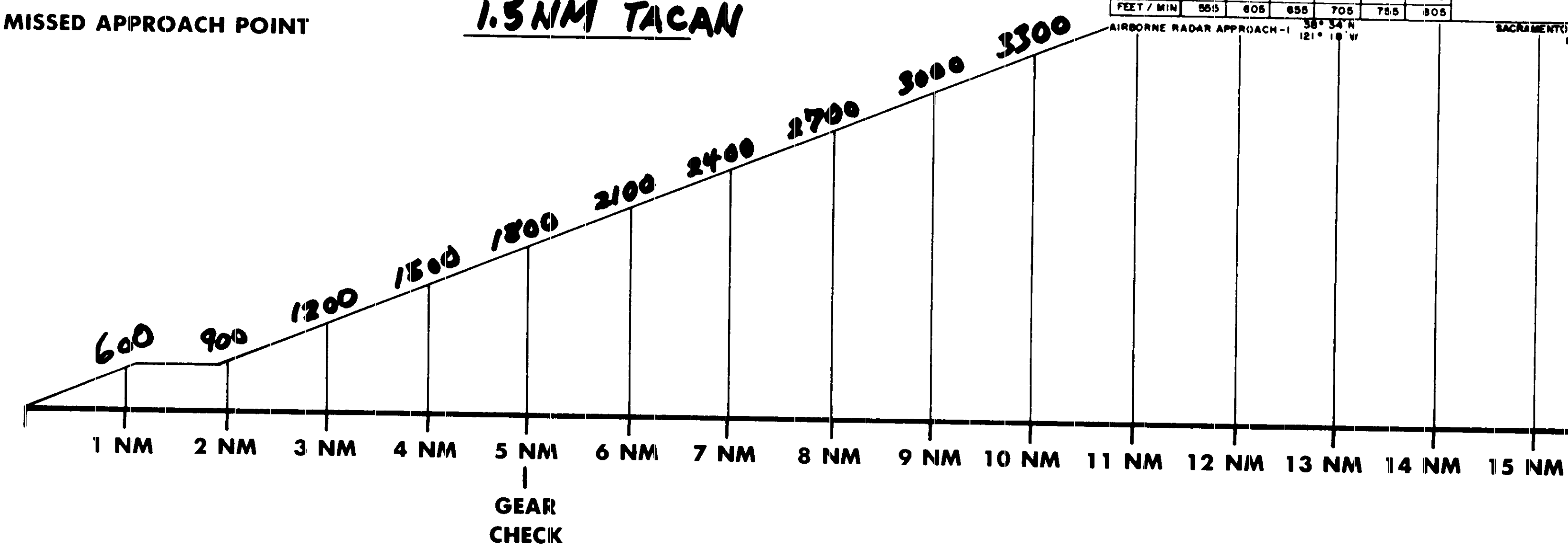


Figure 3-9. ARA Construction Graph.

case, once on the final approach, the navigator is directing the aircraft. To do this, the navigator must keep the pilot informed of the altitudes and headings to the runway. After the aircraft has landed, the navigator's duties terminate except for completing the navigation checklists and required reports.

Range Control

The navigator also monitors the fuel to destination, to insure a safe, prescribed amount of fuel upon landing. All commands that fly over water have a form, usually a graph, where spot fuel readings taken at least hourly are plotted against time remaining to destination or time accumulated since level off; these readings are compared by the navigator against fuel computations for normal flight progress. The navigator uses these comparisons for decisions on whether or not to continue the flight, or whether an in-flight diversion can be accomplished safely.

SUMMARY

In-flight duties for the navigator are many and diverse. As it is true that the "pilot makes money on takeoffs and landings," "the navigator makes money during the cruise portion," but is also responsible for monitoring the departure and approach. These responsibilities are indeed great in that crew safety and success of any mission will rely almost entirely on the navigator's competence.

Indeed, considerations of the in-flight duties by the navigator while mission planning can avoid embarrassing and dangerous situations for the entire crew.

Chapter 4

DEAD RECKONING WITH BASIC INSTRUMENTS

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.

An air navigator obtains the following flight information from basic instruments.

- Direction
- Altitude
- Temperature
- Airspeed
- Drift
- Groundspeed

In this section, some of the basic instruments are discussed. The more complex instruments which make accurate, long distance navigation possible are discussed in later chapters or in specific aircraft technical orders.

DIRECTION

Basic Instruments

The navigator must have a fundamental background in navigation to insure accurate positioning of the aircraft. Dead reckoning procedures aided by basic instruments give the navigator a foundation which can help solve the three basic problems of navigation: position of the aircraft, direction to destination, and time of arrival. It is possible, using only basic instruments such as the compass, airspeed meter, and Doppler, to navigate directly to any place in the world. As we will discuss in later chapters, various fixing aids such as celestial, radar, LORAN, etc, can greatly improve the accuracy of basic DR procedures. This chapter will discuss the basic instruments used for DR and then review 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 which 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 latitude 73°N and longitude 100°W, on Prince of Wales Island. The south magnetic pole is located at latitude 68°S and longitude 144°E, on Antartica.

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 which envelops the Earth. They are considered to be emanating from the south magnetic pole and terminating at the north magnetic pole as illustrated in figure 4-1.

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. At approximately the midpoint between the poles, the horizontal component is at maximum strength and the vertical component is minimum. 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 4-1). This departure from the horizontal is called "magnetic dip."

COMPASSES

A compass may be defined as an instrument which 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 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 intial 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

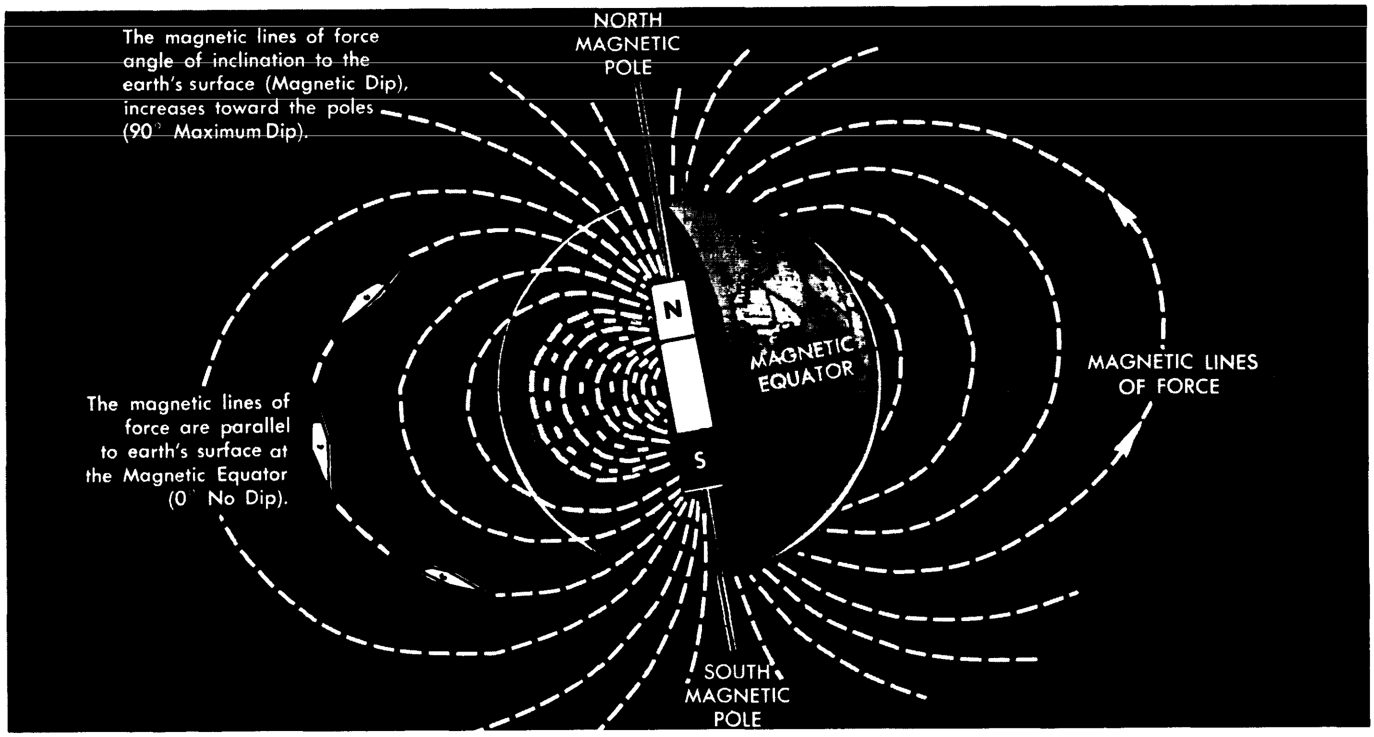


Figure 4-1. Earth's Magnetic Field Compared to a Bar Magnet.

magnetic field. This field is made up of the Earth's magnetic field in combination with other magnetic fields in the vicinity of the compass. These secondary magnetic fields are caused by the presence of ferromagnetic objects, etc. Magnetic compasses may be divided into two classes. These are:

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.
2. The remote-indicating gyro-stabilized magnetic compass in which the magnetic direction is sensed by an element located at positions where local magnetic fields are at a minimum, such as the 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, but several features have been incorporated in design to improve its performance. One type of direct-indicating magnetic compass, the B-16 compass, often called the pilot's compass, is illustrated in

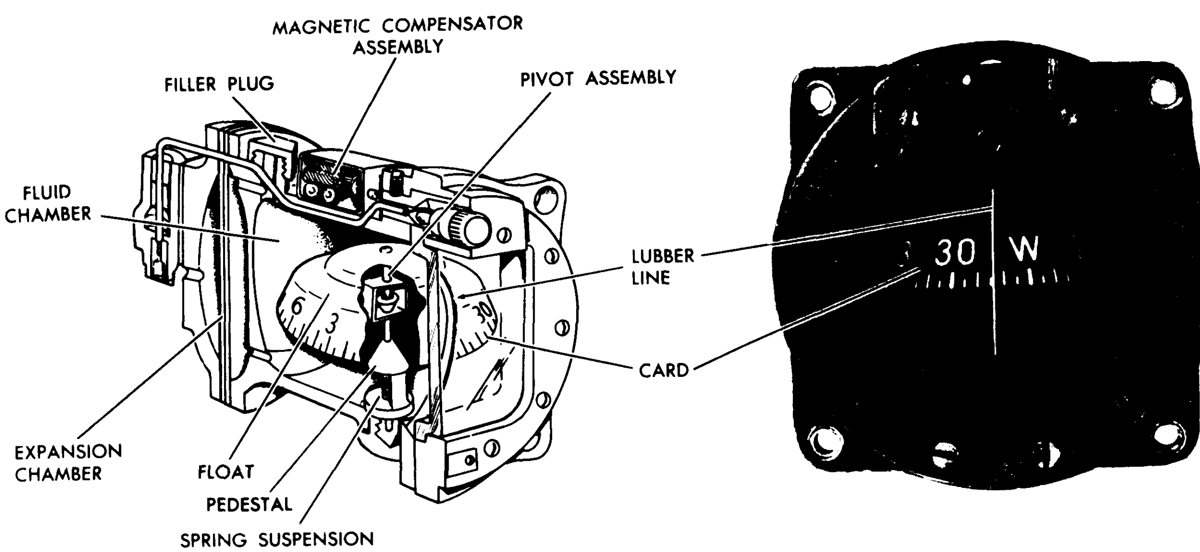


Figure 4-2. Magnetic Compass.

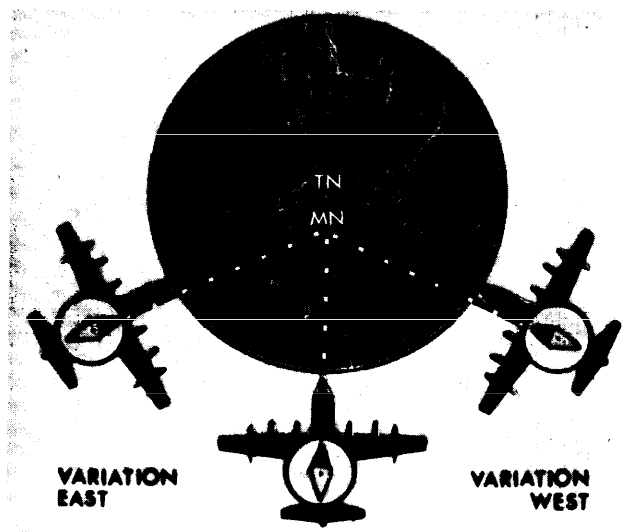


Figure 4-3. Variation is Angle Between True North and Magnetic North.

figure 4-2. 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 will give good navigational results if used carefully.

Magnetic Compass Errors. It has been stated that the Earth's magnetic poles are joined by irregular curves called magnetic meridians. The angle formed at any point between the magnetic meridian and the geographic meridian is called the magnetic variation. Variation is listed on the charts as east or west. When variation is east, magnetic north is east of true north. Similarly, when variation is west, magnetic north is west of true north (figure 4-3). Lines connecting points having the same magnetic variation are called isogonic lines, as shown in figure 4-4. Magnetic variation is an error which must be corrected if a compass indication is to be converted to true direction.

Another error which the navigator is concerned with is caused by nearby magnetic influences, such as those related to 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 magnetic north, respectively.

The correction for variation and deviation is usually expressed as a plus or minus value and is computed as a correction to true heading. If variation or deviation is east, the sign of the correction is minus and, 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 in various ways, according to the basic reference for the heading. If the heading is measured in relation to geographical north, it is a true heading. If the heading is in reference to magnetic north, it is a magnetic heading and, if it is in reference to the compass lubber line, it is a compass heading. Compass heading differs from true heading by the amount of variaton and deviation encountered. Magnetic heading varies from true heading by the amount of variation.

This relationship is best expressed by reference to the naviga-

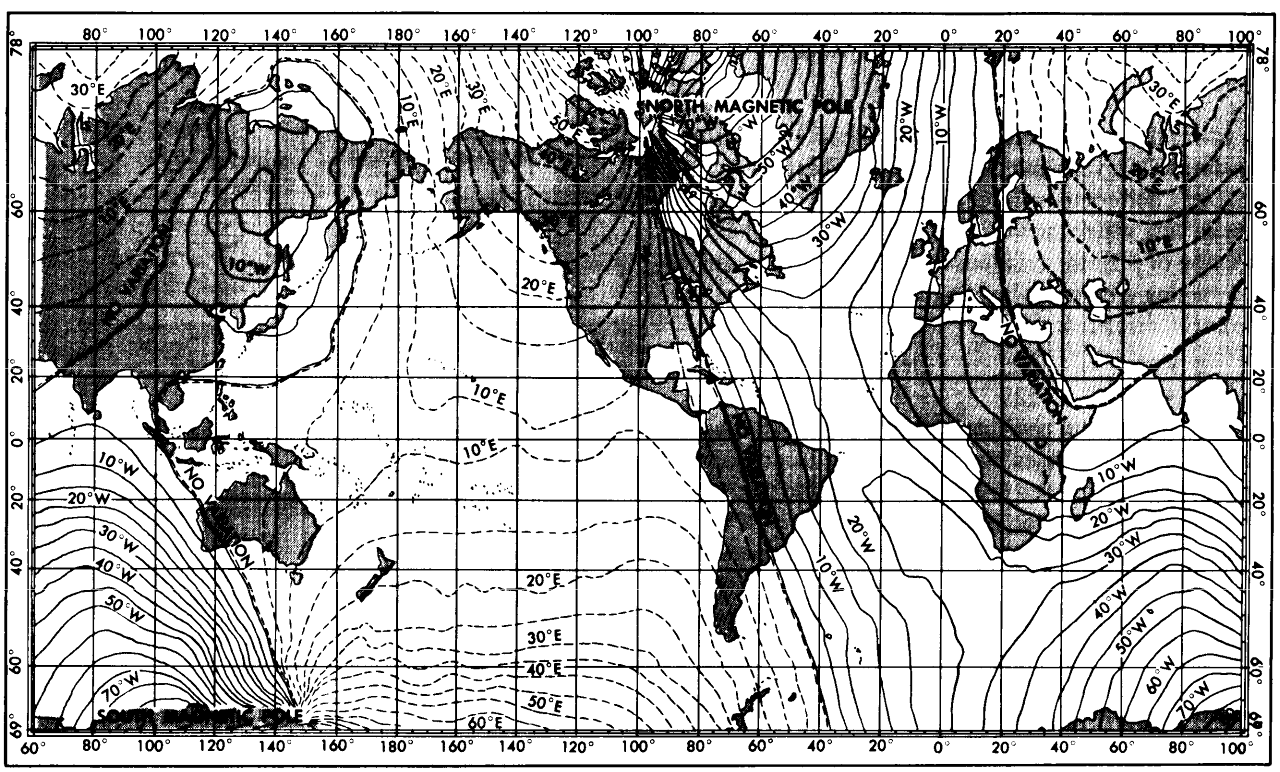


Figure 4-4. Isogonic Lines show same Magnetic Variation.

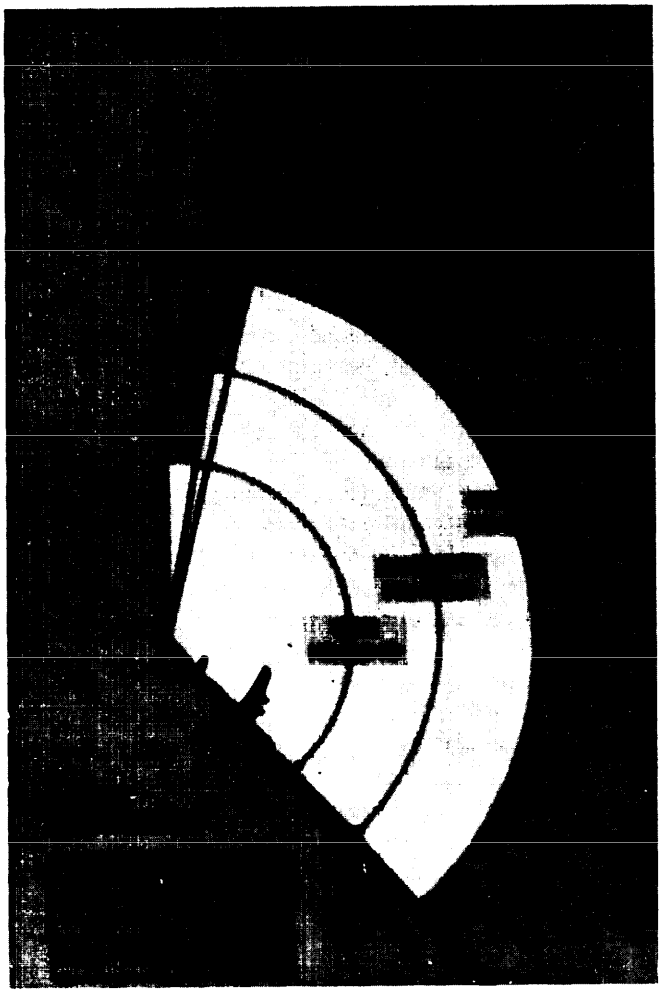


Figure 4-5. To Find True Heading, Work Backwards.

tor's log, where the various headings and corrections are listed as true heading (TH), variation (Var), magnetic heading (MH), deviation (Dev), and compass heading (CH). 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 compass heading of 125 degrees (refer to figure 4-5):

TH	Var		MH	Dev		Ch
138	− 10	=	128	− 3	=	125

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 which may generally be neglected in air navigation.

Deviation. Since deviation depends upon the distribution of

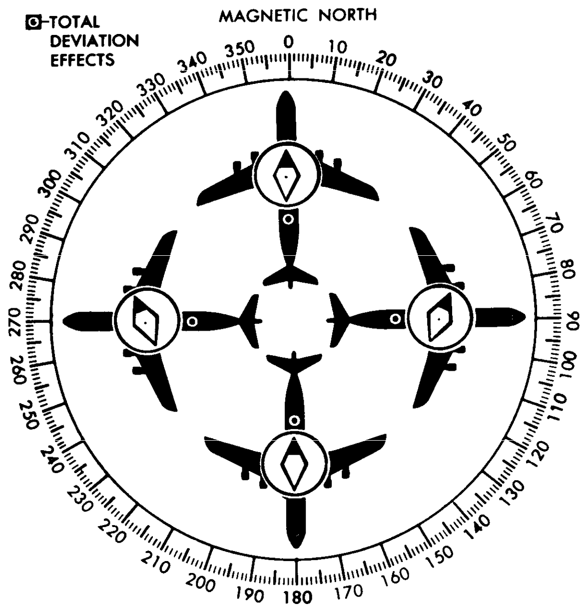
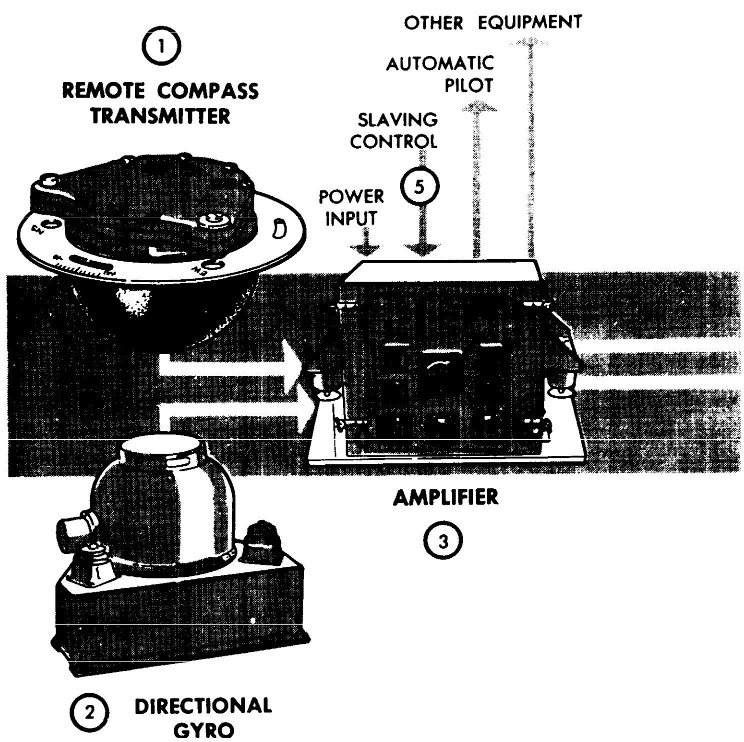
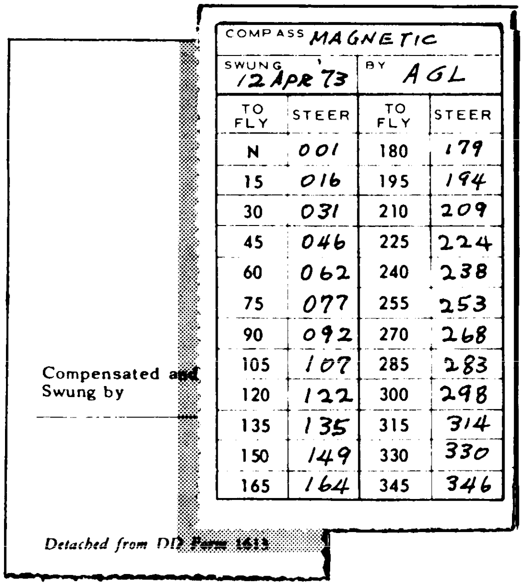


Figure 4-6. Deviation Changes with Heading.

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, is fully discussed in the technical order for each compass.

Deviation changes with heading as shown in figure 4-6. Suppose the net result of all inherent magnetic forces of the aircraft (those forces excluding the Earth's field) is represented by a dot on the longitudinal axis located just behind the wings of





COMPASS MAGNETIC

SWUNG 12 APR 73 BY AGL

TO FLY	STEER	TO FLY	STEER
N	001	180	179
15	016	195	194
30	031	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

Compensated and Swung by

Detached from DD Form 1613

Figure 4-7. Compass Correction Card.

the aircraft. If the aircraft is headed toward magnetic north, 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. Suppose now that the aircraft heads toward magnetic east. The illustration in figure 4-6 shows that the dot is now west of the compass, in which position it attracts the south pole of the compass and repels the north pole, causing easterly deviation. The illustration in figure 4-6 also shows that the deviation is zero on a south heading, and westerly when the aircraft is heading west. Deviation can be reduced in some of the more basic compasses, such as the direct-indicating magnetic compass, by changing the position of the small compensating magnets in the compass case; however, it is usually not possible to remove all of the deviation on all the headings. The deviation that remains is referred to as residual deviation and can be determined by comparison with true values. After such deviation has been determined, it is recorded on a compass correction card which shows the actual deviation on various headings or, more frequently, the compass headings as illustrated in figure 4-7.

From the compass correction card illustrated in figure 4-7, the navigator knows that to fly a magnetic heading of 270 degrees, the pilot must steer a compass heading of 268 degrees.

Errors in Flight. Unfortunately, variation and deviation are not the only errors of a magnetic compass. Additional errors are introduced by the motion of the aircraft itself. These errors may be classified as:

- Northerly turning error.
- Speed error.
- Heeling error.
- Swirl error.
- Yaw error

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 make you aware 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. Since most modern compass systems are dependent

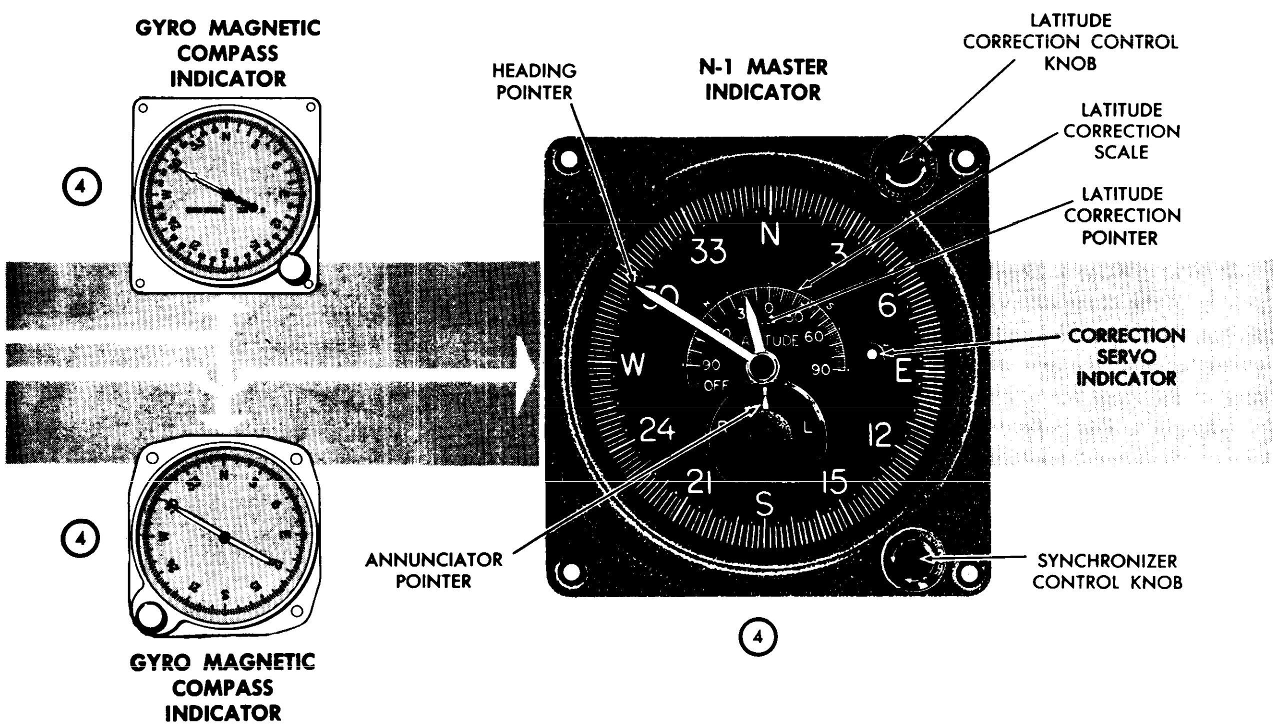


Figure 4-8. N-1 Compass System Components.

upon the electrical system of the aircraft, a loss of power means a loss of the compass system. For this reason, a constant check on the standby compass provides a good check on the electrical systems of the aircraft.

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. Indicators of the compass system can then be located throughout the aircraft without regard to magnetic disturbances.

Several kinds of compass systems are used in Air Force aircraft. All include the following five basic components: (1) remote compass transmitter, (2) directional gyro, (3) amplifier, (4) heading indicators, and (5) 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 4-8 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 directional gyro. In addition, the N-1 generates an electric signal which 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. The directional gyro is the stabilizing component of the compass system when the system is in magnetic-slaved operation. When the compass system is in directional-gyro 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 system's 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 directional gyro due to the Earth's rotation, and provides takeoff signals for operating remote indicators, radar, navigation computers, and directional control of the autopilot.

The latitude correction control provides a means for selecting either magnetic-slaved operation or directional gyro 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 magnetic heading 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 directional gyro operation.

The annunciator pointer indicates the direction in which to rotate the synchronizer control knob to align the heading pointer with the correct magnetic heading.

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 which 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-

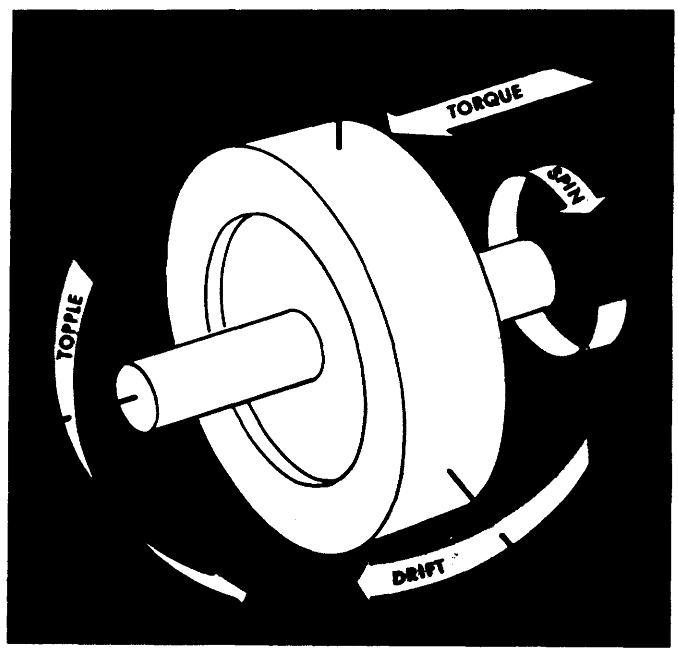


Figure 4-9. Gyroscope Axes.

slaved operation. It also interrupts leveling action in the directional gyro when the system is in magnetic-slaved or directional gyro operation.

The Gyro

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 which 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, namely, spin axis, drift axis, and topple axis shown in figure 4-9 are defined as follows:

- In a directional gyro, the spin axis or axis of rotation is mounted horizontally.
- The topple axis is that axis in the horizontal plane that is 90 degrees from the spin axis.
- The drift axis is that axis 90 degrees 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.

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

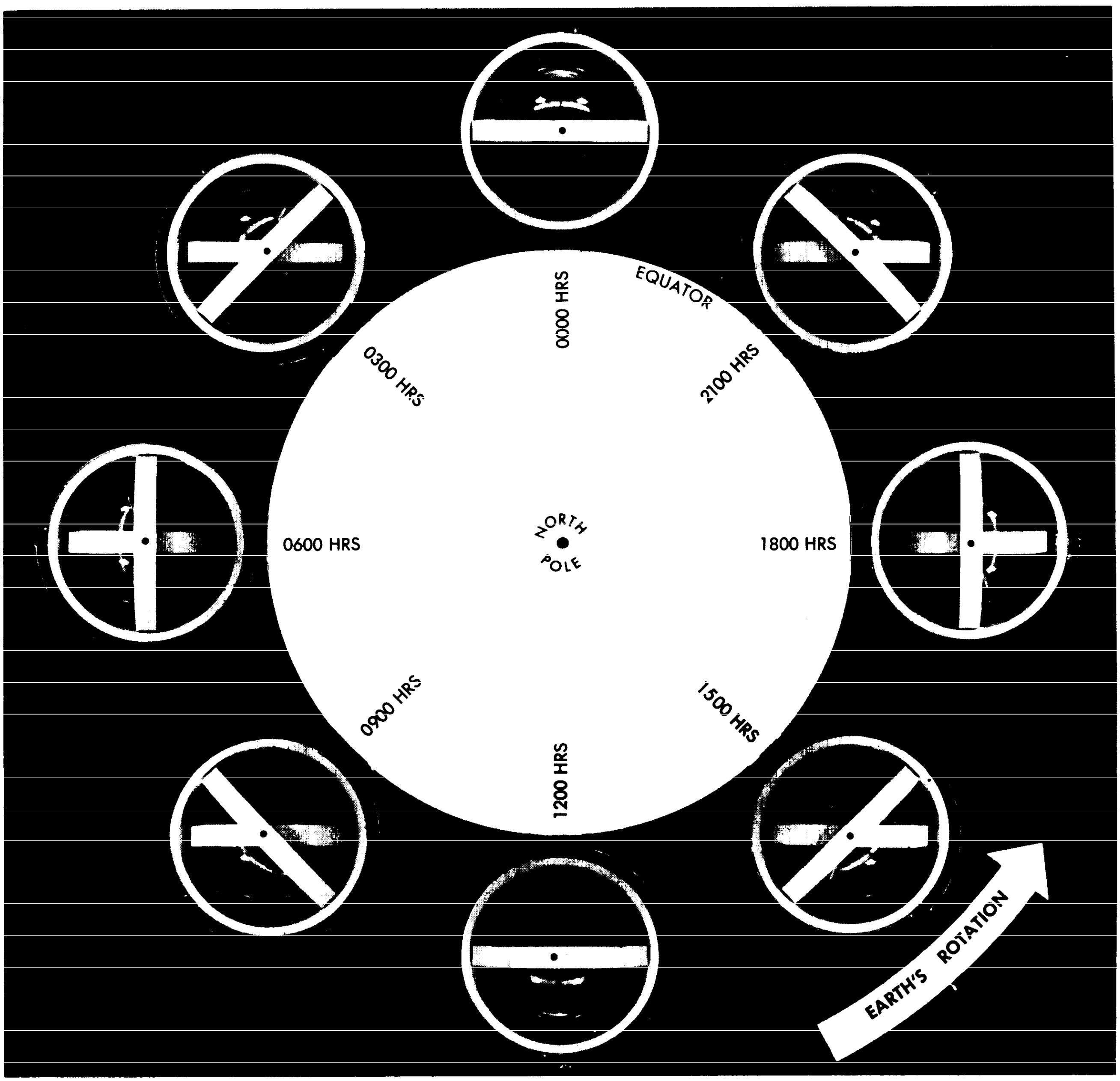


Figure 4-10. Apparent Precession.

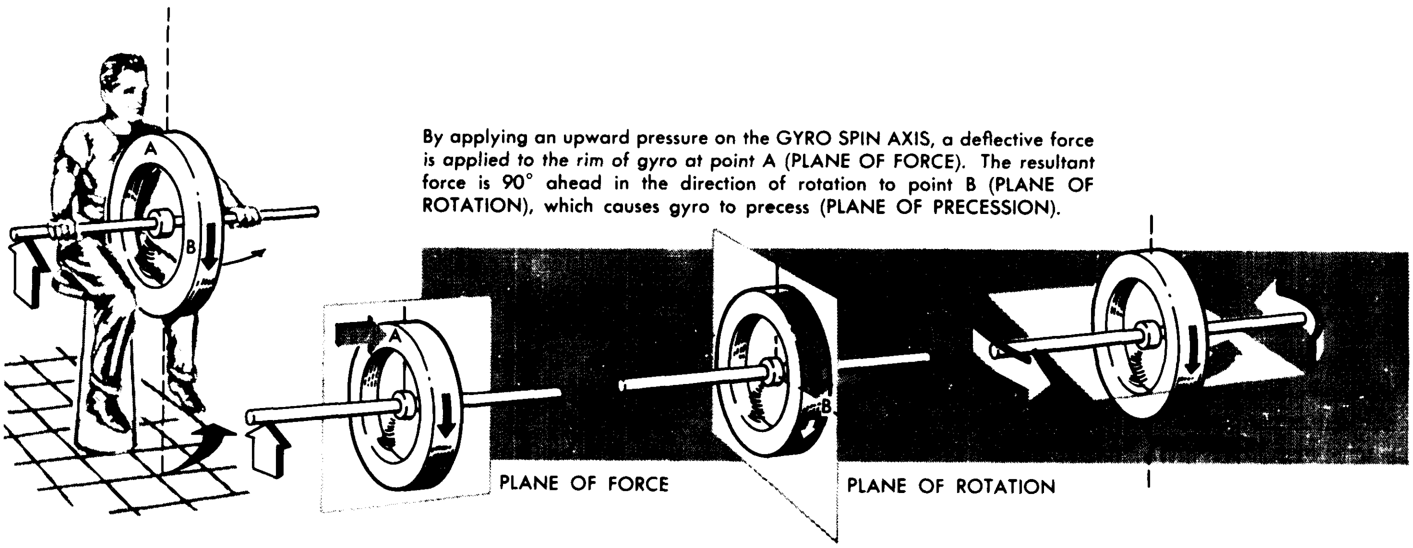


Figure 4-11. Precession of Gyroscope Resulting from Applied Deflective Force.

apparent motion. This apparent motion, shown in figure 4-10, is called apparent precession. The magnitude of apparent precession is dependent upon latitude. The horizontal component, drift, is equal to 15 degrees per hour times the sine of the latitude, and the vertical component, topple, is equal to 15 degrees per hour times the cosine of the latitude.

These computations assume the gyro is stationary with respect to the Earth. However, if the gyro is to be used in a high-speed aircraft, it is readily apparent that its speed with respect to a point in space may be more or less than the speed of rotation of the Earth. If the aircraft in which the gyro is mounted is moving in the same direction as the Earth, the speed of the gyro with respect to space will be greater than the Earth's speed. The opposite is true if the aircraft is flying in a direction opposite to that of the Earth's rotation. This difference in the magnitude of apparent precession caused by transporting the gyro over the Earth is called transport precession.

A gyro may precess because of factors other than the Earth's rotation. When this occurs, the precession is labeled real precession. When a force is applied to the plane of rotation of a gyro, the plane tends to rotate, not in the direction of the applied force, but 90 degrees around the spin axis from it. This torquing action, shown in figure 4-11, may be used to control the gyro by bringing about a desired reorientation of the spin axis, and most directional gyros are equipped with some sort of device to introduce this force.

However, friction within the bearings of a gyro may have the same effect and cause a certain amount of unwanted precession. Great care is taken in the manufacture and maintenance of gyroscopes to eliminate this factor as much as possible, but, as yet, it has not been possible to eliminate it entirely. Precession caused by the mechanical limitations of the gyro is called real or induced precession. The combined effects of apparent precession, transport precession, and real precession produce the total precession of the gyro.

The properties of the gyro that most concern the navigators are rigidity and precession. By understanding these two properties, the navigator is well-equipped to use the gyro as a reliable steering guide.

Directional Gyro. The discussion thus far has been of a universally mounted gyro, free to turn in the horizontal or vertical, or any component of these two. This type of gyro is seldom, if ever, used as a directional gyro. When the gyro is used as a steering instrument, it is restricted so that the spin axis remains parallel to the surface of the Earth. Thus, the spin axis is free to turn only in the horizontal plane (assuming the aircraft normally flies in a near-level attitude), and only the horizontal component (drift) will affect a steering gyro. In the terminology of gyro steering, precession always means the horizontal component of precession.

The operation of the instrument depends upon the principle of rigidity in space of the gyroscope. Fixed to the plane of the spin axis is a circular compass card, shown in figure 4-12, similar to that of the magnetic compass. Since the spin axis remains rigid in space, the points on the card hold the same position in space relative to the horizontal plane. The case, to which the lubber line is attached, simply revolves about the card.

It is important at this point to understand that the numbers on the compass card have no meaning within themselves, as on the magnetic compass. The fact that the gyro may indicate 100 degrees under the lubber line is not an indication that the instrument is actually oriented to magnetic north, or any other known point. To steer by the gyro, the navigator must first set it to a known direction or point. Usually, this is magnetic north or geographic north, though it can be at any known point. If, for example, magnetic north is set as the reference, all headings on the gyro read relative to the position of the magnetic poles.

The actual setting of the initial reference heading is done by using the principle discussed earlier of torque application to the spinning gyro. By artificially introducing precession, the navigator can set the gyro to whatever heading is desired and can reset it at any time using the same technique.

Gyro-Compass Errors. The major error affecting the gyro and its use as a steering instrument is precession. Apparent

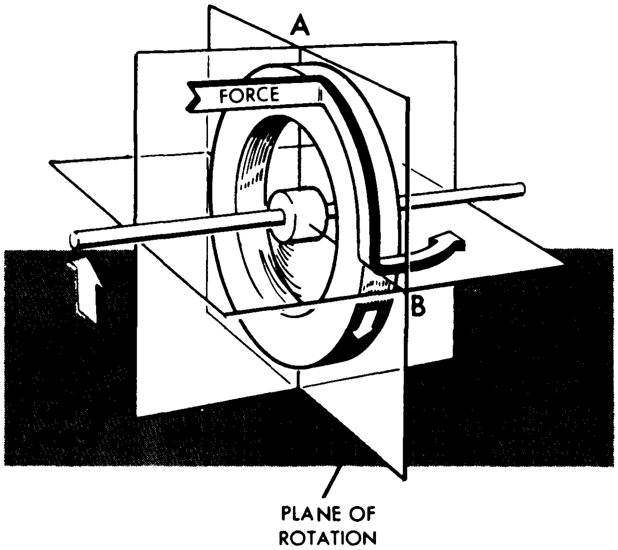


Figure 4-11. (Cont).

precession will cause an apparent change of heading equal to 15 degrees per hour times the sine of the latitude. Real precession, caused by defects in the gyro, may occur at any rate. This type of precession has been greatly reduced by the high precision of modern manufacturing methods. Apparent precession is a known value depending upon location and can be compensated for. In some of the more complex gyro systems, apparent precession is compensated for by setting in a constant correction equal to and in the opposite direction to the precession caused by the Earth's rotation.

ALTITUDE AND ALTIMETERS

Altitude may be defined as the vertical distance of a level, a point, or an object considered as a point, measured from a given surface. Knowledge of the aircraft altitude is imperative for terrain clearance, aircraft separation, and a multitude of operational reasons.

Altitude may be defined as a vertical distance above some point or plane used as a reference. There are as many kinds of altitude as there are reference planes from which to measure them. Only six concern the navigator: indicated altitude, calibrated altitude, pressure altitude, density altitude, true altitude, and absolute altitude. There are two main types of altimeters; the pressure altimeter which is installed in every aircraft, and the absolute or radar altimeter. To understand the pressure altimeter's principle of operation, a knowledge of the standard datum plane is essential.

Standard Datum Plane

The standard datum plane is a theoretical plane where the atmospheric pressure is 29.92 inches of mercury (Hg) and the temperature is + 15°C. The standard datum plane is the zero elevation level of an imaginary atmosphere known as the standard atmosphere. In the standard atmosphere, pressure is 29.92" Hg at 0 feet and decreases upward at the standard pressure lapse rate. The temperature is + 15°C at 0 feet and decreases at the standard temperature lapse rate. Both the pressure and temperature lapse rates are given in the table in figure 4-13.

The standard atmosphere is theoretical. It was derived by

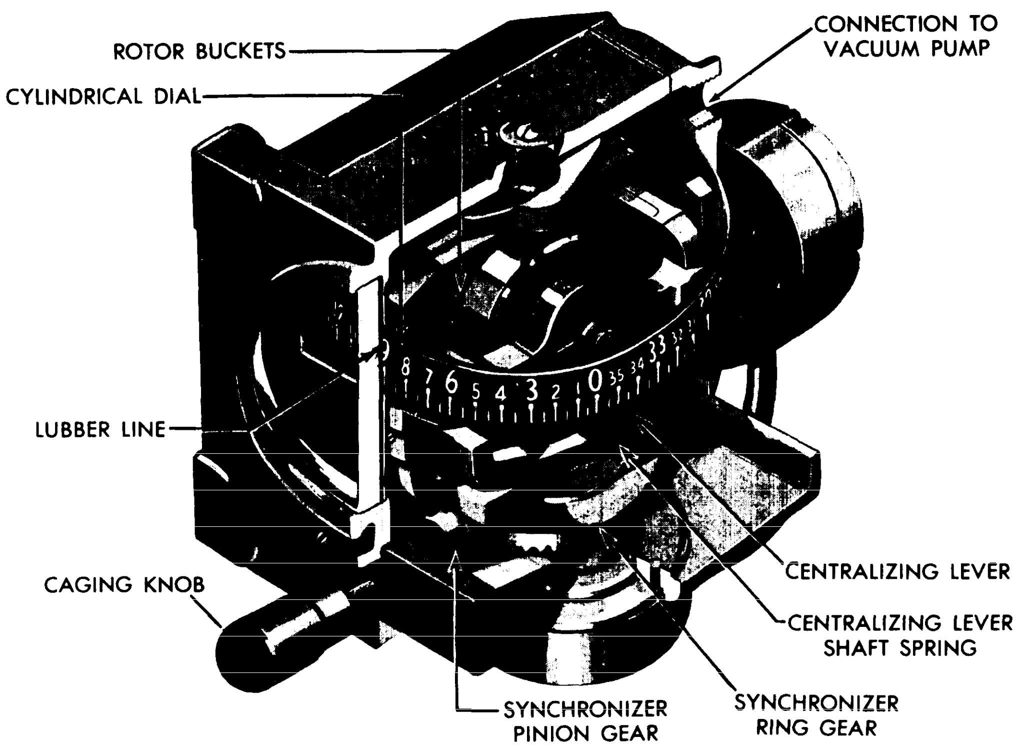


Figure 4-12. Cutaway View of a Directional Gyro.

Altitude (feet)	Standard pressure (millibars)	Standard pressure (inches of mercury)	Standard temperature (°C)	Standard temperature (°F)
60,000	71.7	2.12	−56.5	−69.7
59,000	75.2	2.22	−56.5	−69.7
58,000	79.0	2.33	−56.5	−69.7
57,000	82.8	2.45	−56.5	−69.7
56,000	86.9	2.57	−56.5	−69.7
55,000	91.2	2.69	−56.5	−69.7
54,000	95.7	2.83	−56.5	−69.7
53,000	100.4	2.96	−56.5	−69.7
52,000	105.3	3.11	−56.5	−69.7
51,000	110.5	3.26	−56.5	−69.7
50,000	116.0	3.42	−56.5	−69.7
49,000	121.7	3.59	−56.5	−69.7
48,000	127.7	3.77	−56.5	−69.7
47,000	134.0	3.96	−56.5	−69.7
46,000	140.6	4.15	−56.5	−69.7
45,000	147.5	4.35	−56.5	−69.7
44,000	154.7	4.57	−56.5	−69.7
43,000	162.4	4.79	−56.5	−69.7
42,000	170.4	5.04	−56.5	−69.7
41,000	178.7	5.28	−56.5	−69.7
40,000	187.5	5.54	−56.5	−69.7
39,000	196.8	5.81	−56.5	−69.7
38,000	206.5	6.10	−56.5	−69.7
37,000	216.6	6.40	−56.5	−69.7
36,000	227.3	6.71	−56.3	−69.4
35,000	238.4	7.04	−54.3	−65.8
34,000	250.0	7.38	−52.4	−62.2
33,000	262.0	7.74	−50.4	−58.7
32,000	274.5	8.11	−48.4	−55.1
31,000	287.4	8.49	−46.4	−51.6
30,000	300.9	8.89	−44.4	−48.0
29,000	314.8	9.30	−42.5	−44.4
28,000	329.3	9.72	−40.5	−40.9
27,000	344.3	10.17	−38.5	−37.3
26,000	359.9	10.63	−36.5	−33.7
25,000	376.0	11.10	−34.5	−30.2
24,000	392.7	11.60	−32.5	−26.6
23,000	410.0	12.11	−30.6	−23.0
22,000	427.9	12.64	−28.6	−19.5
21,000	446.4	13.18	−26.6	−15.9
20,000	465.6	13.75	−24.6	−12.3
19,000	485.5	14.34	−22.6	−8.8
18,000	506.0	14.94	−20.7	−5.2
17,000	527.2	15.57	−18.7	−1.6
16,000	549.2	16.22	−16.7	1.9
15,000	571.8	16.89	−14.7	5.5
14,000	595.2	17.58	−12.7	9.1
13,000	619.4	18.29	−10.8	12.6
12,000	644.4	19.03	− 8.8	16.2
11,000	670.2	19.79	− 6.8	19.8
10,000	696.8	20.58	− 4.8	23.3
9,000	724.3	21.39	− 2.8	26.9
8,000	752.6	22.22	− 0.8	30.5
7,000	781.8	23.09	1.1	34.0
6,000	812.0	23.98	3.1	37.6
5,000	843.1	24.90	5.1	41.2
4,000	875.1	25.84	7.1	44.7
3,000	908.1	26.82	9.1	48.3
2,000	942.1	27.82	11.0	51.9
1,000	977.2	28.86	13.0	55.4
Sea level	1013.2	29.92	15.0	59.0

Figure 4-13. Standard Lapse Rate Table.

averaging the readings taken over a period of many years. The list of altitudes and their corresponding values of temperature and pressure given in the table were determined by these averages. The height of the aircraft above the standard datum plane (29.92" Hg and + 15°C) is called pressure altitude as illustrated in figure 4-14.

Pressure Altimeter Principles of Operation

The pressure altimeter is an aneroid barometer calibrated to indicate feet of altitude instead of pressure. As shown in figure 4-15, the pointers are connected by a mechanical linkage to a set of aneroid cells. These aneroid cells expand or contract with changes in barometric pressure. In this manner, the cells assume a particular thickness at a given pressure level and thereby position the altitude pointers accordingly. On the face of the altimeter is a barometric scale which indicates the barometric pressure (expressed in inches of mercury) of the point or plane from which the instrument is measuring altitude. Turning the barometric pressure set knob on the altimeter manually changes this altimeter setting on the barometric scale and results in simultaneous movement of the altitude pointers to the corresponding altitude reading.

Like all measurements, an altitude reading is meaningless if the point from which it starts is unknown. The face of the pressure altimeter supplies both values. The position of the pointers indicates the altitude in feet, and the barometric pressure appearing on the barometric scale is that of the reference plane above which the measurement is made.

Altimeter Displays

Counter-Pointer Altimeter. The counter-pointer altimeter has a two-counter digital display unit located in the nine o'clock position of the dial. The counter indicates altitude in 1,000-foot increments from zero to 80,000 feet (figure 4-16). A single conventional pointer indicates 100s of feet on the fixed circular scale. It makes one complete revolution per 1,000 feet of altitude change and, as it passes through the 900- to 1,000-foot area of the dial, the 1,000-foot counter is actuated. The shaft of the 1,000-foot counter in turn actuates the 10,000-foot counter at each 10,000 feet of altitude change. To determine the indicated altitude, first read the 1,000-foot counter and then add the 100-foot pointer indication.

CAUTION

It is possible to misinterpret the counter-pointer altimeter by 1,000 feet immediately before or after the 1,000-foot counter moves. This error is possible because the 1,000-foot counter changes when the 100-foot pointer is between the 900- and 1,000-foot position.

Counter-Drum-Pointer Altimeter. Aside from the familiar circular scale and 100-foot pointer, the counter-drum-pointer presentation differs somewhat in appearance from the present three-pointer altimeter. Starting at the left of the instrument illustrated in figure 4-17 and reading from left to right, there are

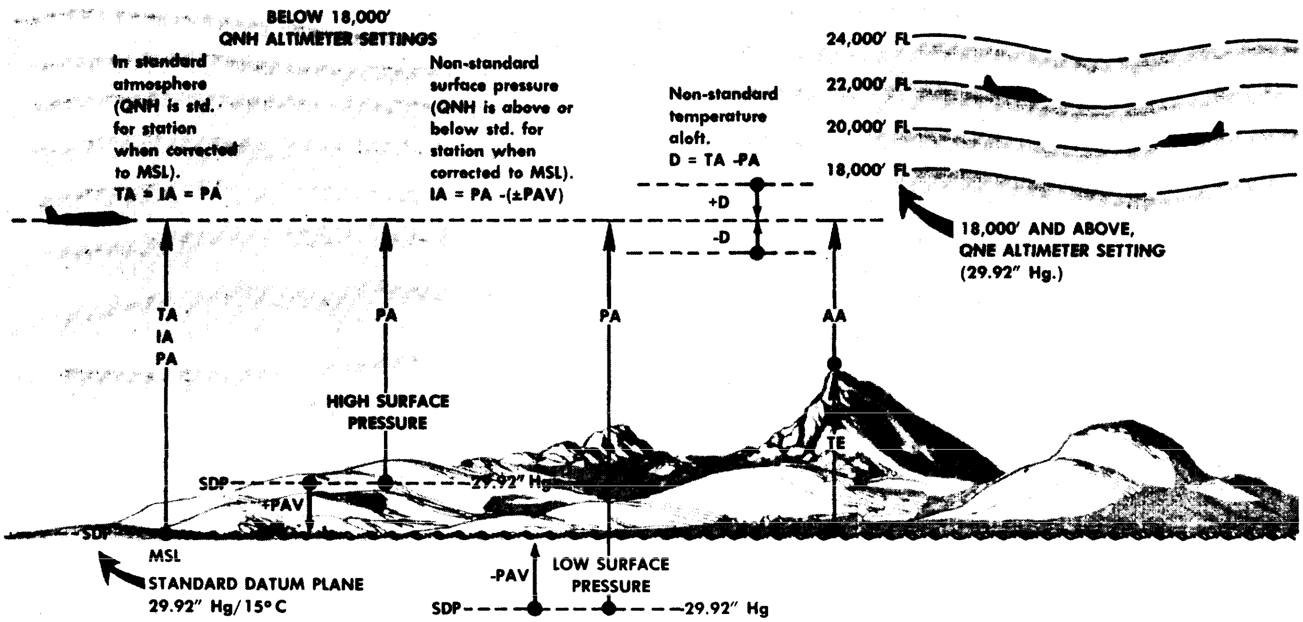


Figure 4-14. Depiction of Altimetry Terms.

two counter windows and one drum window (white). The numerals presented in the counter windows indicate 10,000s and 1,000s of feet respectively. The drum window numbers always follow the pointer number, thereby indicating 100s of feet.

Two methods may be used to read indicated pressure altitude on the counter-drum-pointer altimeter: (1) read the counter-drum window, without referring to the 100-foot pointer, as a direct digital readout of both thousands and hundreds of feet; (2) read the two counter indications, without referring to the drum, and then add the 100-foot pointer indication. The 100-foot pointer serves as a precise readout of values less than 100 feet.

The differential air pressure which is used to operate the counter-drum-pointer altimeter is processed by an altitude transducer where it is converted to electrical signals that drive the indicator. The transducer is also used to send digital signals to a transponder for purposes of automatic altitude reporting to Air Route Traffic Control Centers. A standby system is available for use should an electrical malfunction occur. In the standby system, the altimeter receives static air pressure directly from the pitot-static system. When the instrument is operating in the standby system, the word STANDBY appears on the instrument face. A switch in the upper right-hand corner of the instrument is provided to return the instrument to its normal mode of operation. This switch may also be used to manually place the instrument in the STANDBY mode.

Altimeter Errors

The pressure altimeter is subject to certain errors which fall in five general categories.

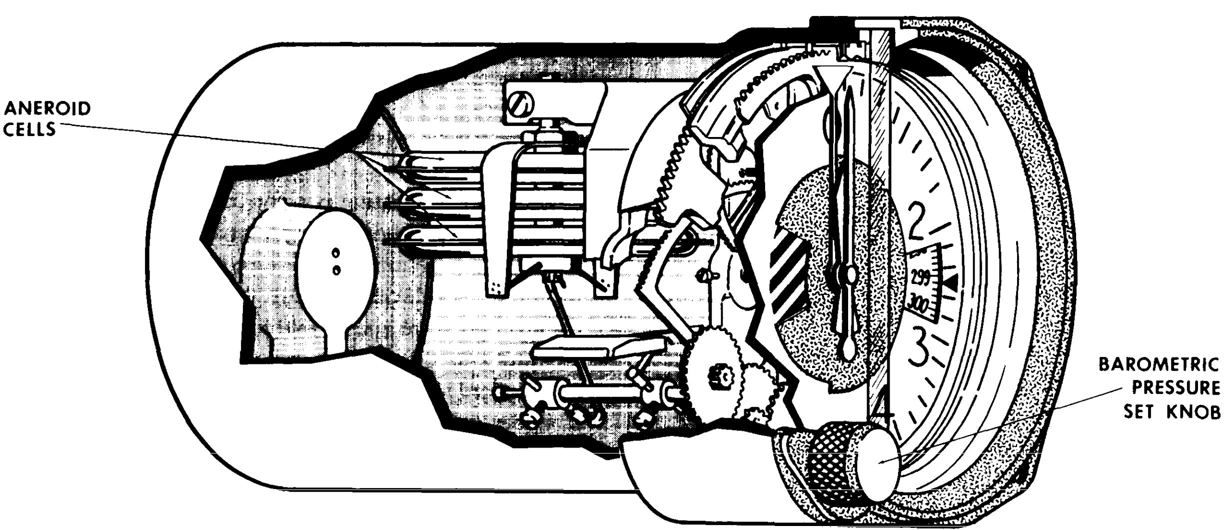


Figure 4-15. Altimeter Mechanical Linkage.

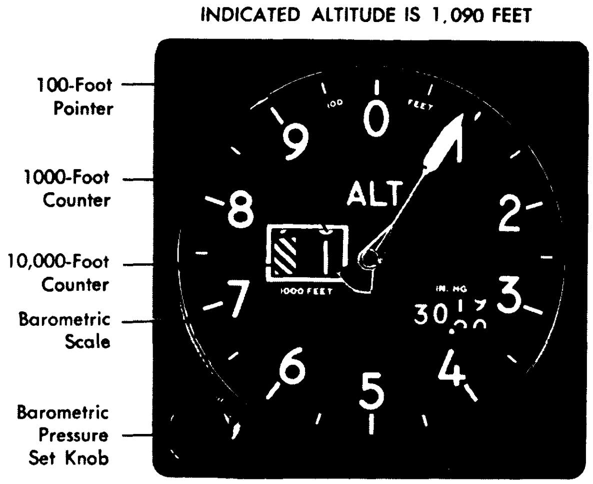


Figure 4-16. Counter-Pointer Altimeter.

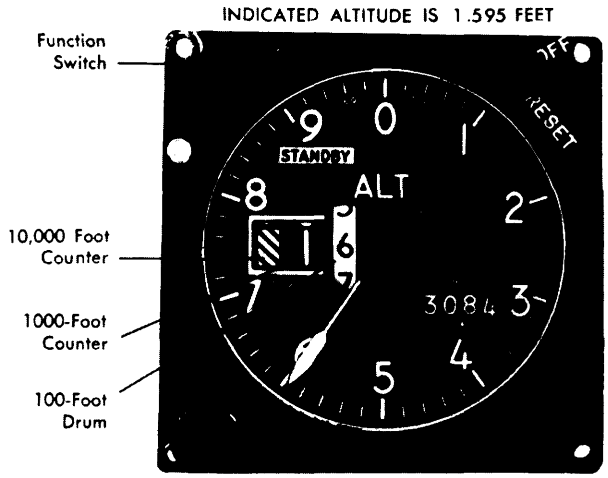


Figure 4-17. Counter-Drum-Pointer Altimeter.

Mechanical Error. Mechanical error is caused by misalignments in gears and levers which transmit the aneroid cell expansion and contraction to the pointers of the altimeter. This error is not constant and must be checked before each flight by the setting procedure.

Scale Error. Scale error is caused by irregular expansion of the aneroid cells and is recorded on a scale correction card maintained for each altimeter in the instrument maintenance shop.

Installation/Position Error. Installation/position error is caused by the airflow around the static ports. This error varies with the type of aircraft, airspeed, and altitude. The magnitude and direction of this error can be determined by referring to the performance data section in the aircraft technical order.

An altimeter correction card is installed in some aircraft which combines the installation/position and scale errors. The card indicates the amount of correction required at different altitudes and airspeeds.

WARNING

Installation/position error may be considerable at high speeds and altitudes. Apply the corrections as outlined in the technical order or on the altimeter correction card.

Reversal Error. Reversal error is caused by inducing false static pressure in the static system. It normally occurs during abrupt or large pitch changes. This error appears on the altimeter as a momentary indication in the opposite direction.

Hysteresis Error. Hysteresis error is a lag in altitude indication caused by the elastic properties of the material within the altimeter. This occurs after an aircraft has maintained a constant altitude for an extended period of time and then makes a large, rapid altitude change. After a rapid descent, altimeter indications are higher than actual. This error is negligible during climbs and descents at slow rate or after maintaining a new altitude for a short period of time.

Setting the Altimeter

The barometric scale is used to set a reference plane into the altimeter. Rotating the barometric pressure set knob increases or decreases the scale reading and the indicated altitude. Each .01 change on the barometric scale is equal to 10 feet of altitude.

The majority of altimeters have mechanical stops at or just beyond the barometric scale limits (28.10 to 31.00).

NOTE: Those altimeters not equipped with mechanical stops near the barometric scale limits can be set with a 10,000-foot error. Therefore, when setting the altimeter, insure that the 10,000-foot pointer is reading correctly.

The altimeter must be checked for accuracy before every flight. To check and set the altimeter:

1. Set the current altimeter setting on the barometric scale. It may be necessary to tap the altimeter gently.
2. Check altimeter at a known elevation and note the error in feet.
3. If the error exceeds 75 feet, do not use the altimeter for IFR flights.

Nonstandard Atmosphere Effects

The altimeter setting is a correction for nonstandard surface pressure only. Atmospheric pressure is measured at each station and the value obtained is corrected to sea level according to the surveyed field elevation. Thus, the altimeter setting is computed sea level pressure and should be considered valid only in close proximity to the station and the surface. It does not reflect nonstandard temperature nor distortion of atmospheric pressure at higher altitudes.

Types of Altitude

Indicated Altitude. The term, indicated altitude, means simply the value of altitude that is displayed on the pressure altimeter.

Calibrated Altitude. Calibrated altitude is indicated altitude corrected for installation/position error.

Pressure Altitude. The height above the standard datum plane (29.92" Hg and + 15°C) is pressure altitude (refer to figure 4-14).

Density Altitude. Density is mass per unit volume. The density of the air varies with temperature and with height. Warm air expands, and is less dense than cold air. Normally, the higher the pressure altitude, the less dense the air becomes. The density of the air can be expressed in terms of the standard atmosphere. Density altitude is the pressure altitude corrected for temperature in the "Density Altitude" window of the DR computer. This calculation converts the density of the air to the standard atmospheric altitude having the same density. Density altitude is used in performance data and true airspeed calculations.

True Altitude. True altitude is the actual vertical distance above mean sea level, measured in feet. It can be determined by two methods: (1) Set the local altimeter setting on the barometric scale of the pressure altimeter to obtain the indicated true altitude. The indicated true altitude can then be resolved to true altitude by use of the DR computer (refer to figure 4-14). (2) Measure altitude over water with an absolute altimeter.

Absolute Altitude. The height above the terrain is called absolute altitude. It is computed by subtracting terrain elevation from true altitude, or it can be read directly from an absolute altimeter.

Computer Altitude Solutions

The two altitudes most commonly accomplished on the computer are true altitude and density altitude. Nearly all DR computers have a window by which density altitude can be determined; however, be certain that the window is labeled "Density Altitude."

True Altitude Determination. In the space marked "For Altitude Computations" are two scales: (1) a centigrade scale in the window and (2) a pressure altitude scale on the upper disk. When a pressure altitude is placed opposite the temperature at that height, all values on the outer (miles) scale are equal to the corresponding values on the inner (minutes) scale increased or decreased by two percent for each 5.5°C that the actual temperature differs from the standard temperature at that pressure altitude, as set in the window.

Although the pressure altitude is set in the window, the indicated true altitude is used on the inner (minutes) scale for finding the true altitude, corrected for difference in temperature lapse rate.

Example:

Given: Pressure altitude 8,500 feet

Indicated true altitude 8,000 feet

Air Temperature (°C) − 16

To Find: True altitude

Procedure: Place PA (8,500 feet) opposite the temperature (− 16) on the FOR ALTITUDE COMPUTATIONS scale. Opposite the indicated true altitude (8,000 feet) on the inner scale, read the true altitude (7,600 feet) on the outer scale. The solution is illustrated in figure 4-18.

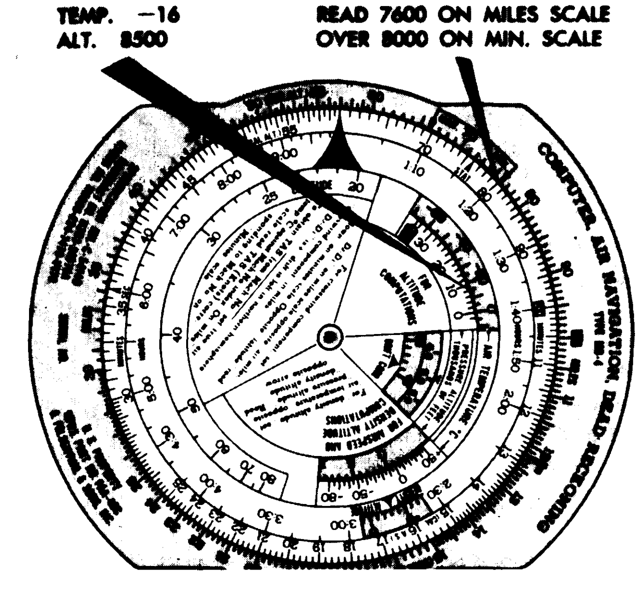


Figure 4-18. Finding True Altitude.

Density Altitude Determination. Density altitude determination on the computer is accomplished by using the window just above FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS and the small window just above that marked DENSITY ALTITUDE.

Example:

Given: Pressure altitude 9,000 feet

Air temperature (°C) + 10

To Find: Density altitude

Procedure: Place pressure altitude (9,000 feet) opposite air temperature (+ 10) in window marked FOR AIRSPEED AND DENSITY ALTITUDE, read density altitude (10,400 feet). The

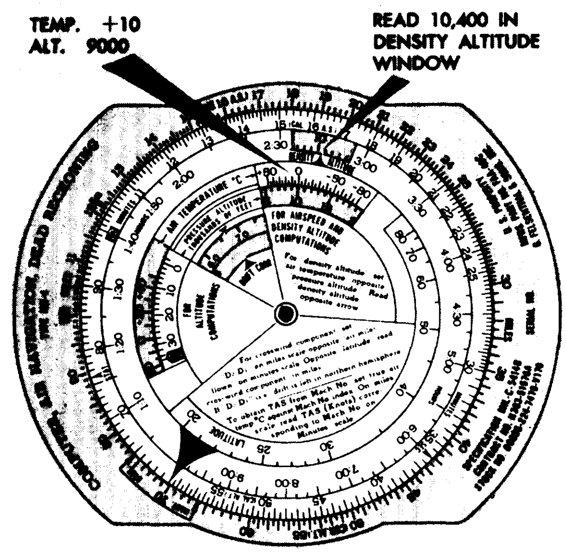


Figure 4-19. Finding Density Altitude.

solution is illustrated in figure 4-19.

ABSOLUTE ALTIMETER

Accurate absolute altitude is an important requisite for navigation, photography, and bombing as well as for safe piloting. It is particularly important in pressure pattern navigation. Absolute altitude may be computed from the pressure altimeter readings if the position of the aircraft is known, but the results are often inaccurate. Under changing atmospheric conditions, corrections applied to pressure altimeter readings to obtain true altitudes are only approximate. In addition, any error made in determining the terrain elevations results in a corresponding error in the absolute altitude.

Radar Altimeter (High Level)

A typical high-level radar altimeter is designed to indicate absolute altitude of the aircraft up to 50,000 feet above the terrain, land or water. This altimeter does not warn of approaching obstructions such as mountains because it measures altitude only to a point directly below the aircraft. Refer to figure 4-20.

A typical set consists of the radar receiver-transmitter, height indicator, and antenna. The transmitter section of the receiver-transmitter unit develops recurring pulses of radio frequency (RF) energy which are delivered to the transmitter antenna located either flush-mounted or on the underside of the aircraft. The transmitter antenna radiates the pulsed energy downward to reflect off the Earth and return to the receiver antenna on the aircraft. The time consumed between transmission and reception of the RF pulse is determined only by the aboslute altitude of the aircraft above the terrain since the radio wave velocity is constant. The receiver antenna delivers the returned pulse to the receiver section of the receiver-transmitter unit where it is amplified and detected for presentation on the indicator unit. The radar altimeter indicator displays absolute altitude which is used in pressure pattern navigation, terrain clearance, or as a backup for the pressure altimeter.

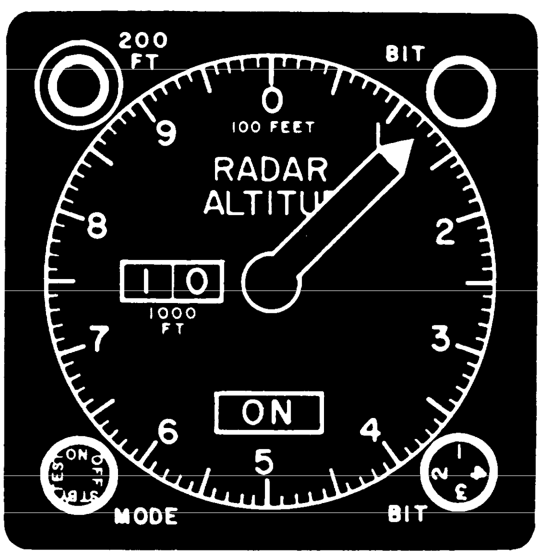


Figure 4-20. Typical High Level Radar Altimeter.

Radar Altimeter (Low Level)

This type altimeter provides a dial indication of the altitude of the aircraft above the terrain. It is designed to eliminate the necessity of adding antennas or any other equipment external to the surface of the aircraft. This equipment may also be used in conjunction with automatic pilot or other devices requiring altitude limit data.

The components of a typical system include the receiver-transmitter, the height indicator, and the electronic control amplifier. The height indicator contains the only operating control on the equipment. This instrument gives altitude readings of the aircraft up to 10,000 feet over land and up to 20,000 feet over water. The scale is logarithmic and is graduated in 10s of feet for the first 200 feet. From 200 feet to 20,000 feet, the graduations are gradually compressed. A limit indicator system is included to provide an indication of flight below a preset altitude.

To operate the equipment, turn the ON-LIMIT control to ON. After warmup, the terrain clearance of the aircraft within the range of 0-20,000 is read directly from the single pointer on the indicator as shown in figure 4-21. This pointer can be preset to any desired altitude by the ON-LIMIT control and is used as a reference for flying at fixed altitudes. The altitude can be maintained by observing the position of the pointer with respect to the small triangular marker instead of the actual altitude scale. In addition, a red light on the front of the indicator lights up when the aircraft is at or below the preset altitude. To turn off the equipment, it is only necessary to turn off the ON-LIMIT control on the indicator.

TEMPERATURE

Determination of correct temperature is neccessary for accurate computation of airspeed and altitude. Temperature, airspeed, and altitude are all closely interrelated, and the practicing

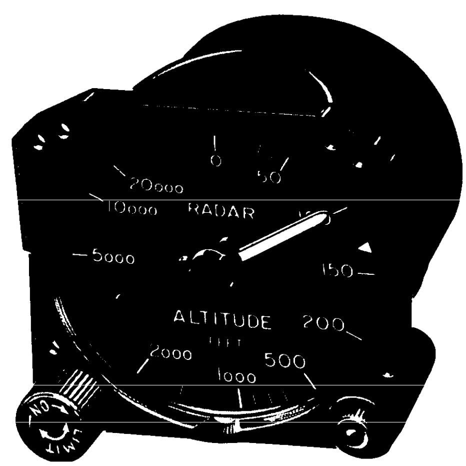


Figure 4-21. Radar Height Indicator.

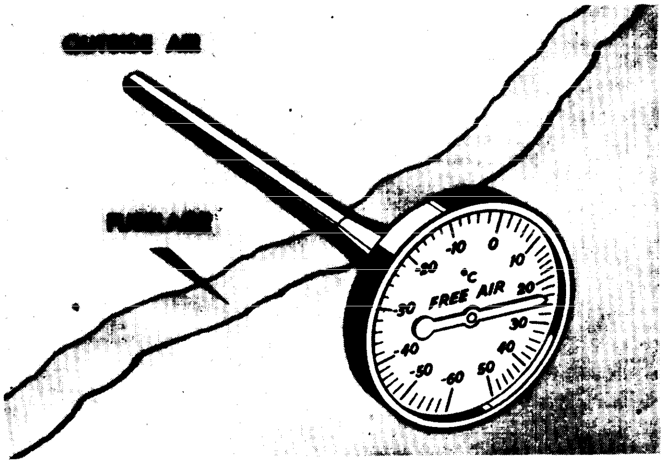


Figure 4-22. Free Air Temperature Gage.

navigator must be familiar with each in order to work effectively and accurately.

Temperature Gages

The temperature gage most commonly used in the Air Force employs a bimetallic element. The instrument, illustrated in figure 4-22, is a single unit consisting of a stainless steel stem which projects into the airstream and a head which contains the pointer and scale. The sensitive element in the end of the stem—projected outside the aircraft—is covered by a radiation shield of brightly polished metal to cut down the amount of heat that the element might absorb by direct radiation from the Sun.

The bimetallic element (called the sensitive element) is so named because it consists of two strips of different metal alloys welded together. When the element is heated, one alloy expands more rapidly than the other causing this element, which is shaped like a coil spring, to turn. This, in turn, causes the indicator needle to move on the pointer dial. Temperatures between $-60°C$ and $+50°C$ can be measured on this type of thermometer.

Temperature Scales

In the United States, temperature is usually expressed in terms of the Fahrenheit scale (°F). In aviation, temperature is customarily measured on the centigrade, or Celsius, (°C) scale.

Although aircraft thermometers are usually calibrated in °C, it is sometimes necessary to interconvert Fahrenheit and centigrade temperatures. The following formulas may be used:

$$°F = (1.8 \times °C) + 32°$$
$$°C = \frac{°F - 32°}{1.8}$$

Temperature error is the total effect of scale error and heat of compression error. Scale error is simply an erroneous reading of the pointer under standard conditions. It is difficult for a crewmember to evaluate this error without sensitive testing equipment. With this in mind, the reading of the indicator is considered correct and is called indicated air temperature (IAT).

The second error, heat of compression error, causes the instrument to read too warm. Heating occurs at high speeds from friction and the compression of air on the forward edge of the temperature probe. Thus, the IAT is always corrected by a minus correction factor to produce true air temperature (TAT). Heat of compression increases with true airspeed. The TAT can be obtained from the aircraft flight manual.

AIRSPEED

Airspeed is the speed of the aircraft with relation to the air mass surrounding that aircraft.

Pitot-Static System

Accurate airspeed measurement is obtained by means of a pitot-static system. The system consists of: (1) a tube mounted parallel to the longitudinal axis of the aircraft in an area that is free of turbulent air generated by the aircraft, and (2) a static source that provides still, or undisturbed, air pressure.

Ram and static pressures may be taken from a single pitot-static tube or from completely separate sources. A pitot-static tube usually has a baffle plate, as shown in figure 4-23, to reduce turbulence and to prevent rain, ice, and dirt from entering the tube. There may be one or more drain holes in the bottom of the tube to dispose of condensed moisture. A built-in electrical heating element, controlled by a switch inside the aircraft, prevents the formation of ice in the tube.

Reasonable care should be taken with the pitot-static system to insure continuous, reliable service. The drain holes should be checked periodically to insure they are not clogged. At the completion of each flight, a cover is placed over the intake end of the tube to prevent dirt and moisture from collecting in the tube.

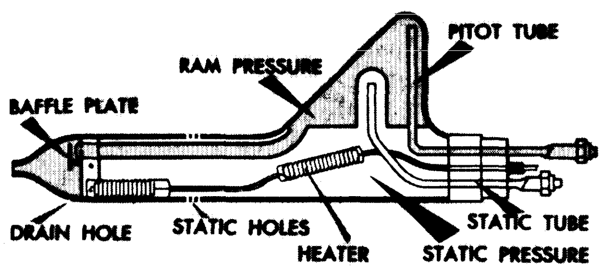


Figure 4-23. Structure of the Pitot Tube.

Principles of Operation of Airspeed Indicator

The heart of the airspeed indicator is a diaphragm which is sensitive to pressure changes. Figure 4-24 shows it located inside the indicator case and connected to the ram air source in the pitot tube. The indicator case is sealed airtight and connected to the static pressure source. The differential pressure created by

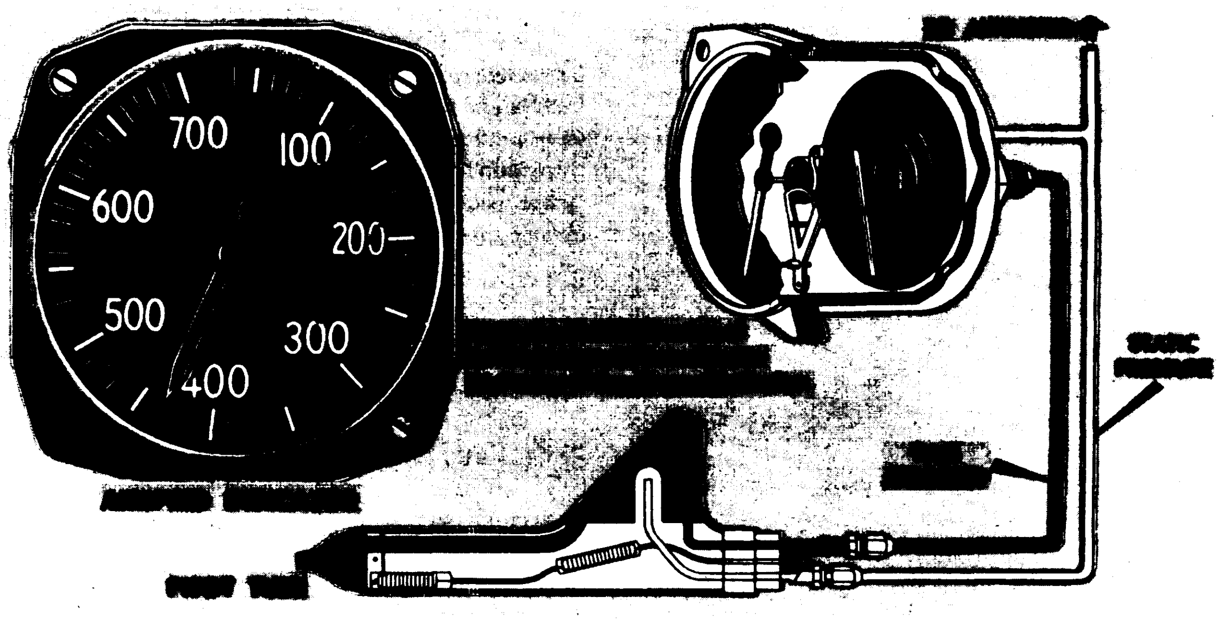


Figure 4-24. Operating Principle of the Airspeed Indicator.

the relative effects of the impact and static pressures on the diaphragm causes it to expand or contract. As the speed of the aircraft increases, the impact pressure increases, causing the diaphragm to expand. Through mechanical linkage, the expansion is displayed as an increase in airspeed. This principle is used in the indicated airspeed meter, the true airspeed meter, and the machmeter.

Airspeed Definitions

There are many reasons for the difference between indicated airspeed and true airspeed. Some of the reasons are the error in the mechanical makeup of the instrument, the error caused by incorrect installation, and the fact that density and pressure of the atmosphere vary from standard conditions.

Indicated Airspeed (IAS). Indicated airspeed is the uncorrected reading taken from the face of the indicator. It is the airspeed that the instrument shows on the dial.

Basic Airspeed (BAS). Basic airspeed is the indicated airspeed corrected for instrument error. Each airspeed indicator has its own characteristics which cause it to differ from any other airspeed indicator. These differences may be caused by slightly different hairspring tensions, flexibility of the diaphragm, accuracy of the scale markings, or even the effect of temperature on the different metals in the indicator mechanism. The effect of temperature introduces an instrument error due to the variance in the coefficient of expansion of the different metals comprising the working mechanisms. This error can be removed by the installation of a bimetallic compensator within the mechanical linkage. This bimetallic compensator is installed and properly set at the factory, thereby eliminating the temperature error within the instrument. The accuracy of the airspeed indicator is also affected by the length and curvature of the pressure line from the pitot tube. These installation errors must be corrected mathematically. Installation, scale, and instrument errors are all combined under one title called instrument error. Instrument error is factory-determined to be within specified tolerances for various airspeeds. It is considered negligible or is accounted for in TO tables and graphs.

Calibrated Airspeed (CAS). Calibrated airspeed is basic airspeed corrected for pitot-static error and (or) attitude of the aircraft. The pitot-static system of a moving aircraft will have some error. Minor errors will be found in the pitot section of the system. The major difficulty is encountered in the static pressure section. As the flight attitude of the aircraft changes, the pressure at the static inlets changes. This is caused by the aistream striking the inlet at an angle. Different types and locations of installations cause different errors. It is immaterial whether the status source is located in the pitot-static head or at some flush mounting on the aircraft. This error will be essentially the same for all aircraft of the same model, and a correction can be computed by referring to tables found in the appendix of the appropriate flight manual.

Equivalent Airspeed (EAS). Equivalent airspeed is calibrated airspeed corrected for compressibility. Compressibility becomes noticeable when the airspeed is great enough to create an impact pressure which causes the air molecules to be compressed within the impact chamber of the pitot tube. The amount of the compression is directly proportionate to the impact pressure. As the air is compressed, it causes the dynamic pressure to be greater than it should be. Therefore, the correction is a negative value. The correction for compressibility error can be determined by referring to the performance data section of the aircraft flight manual or by using the "F" correction factor on the DR computer.

Density Airspeed (DAS). Density airspeed is calibrated airspeed corrected for pressure altitude and true air temperature. Pitot pressure varies not only with airspeed but also with air

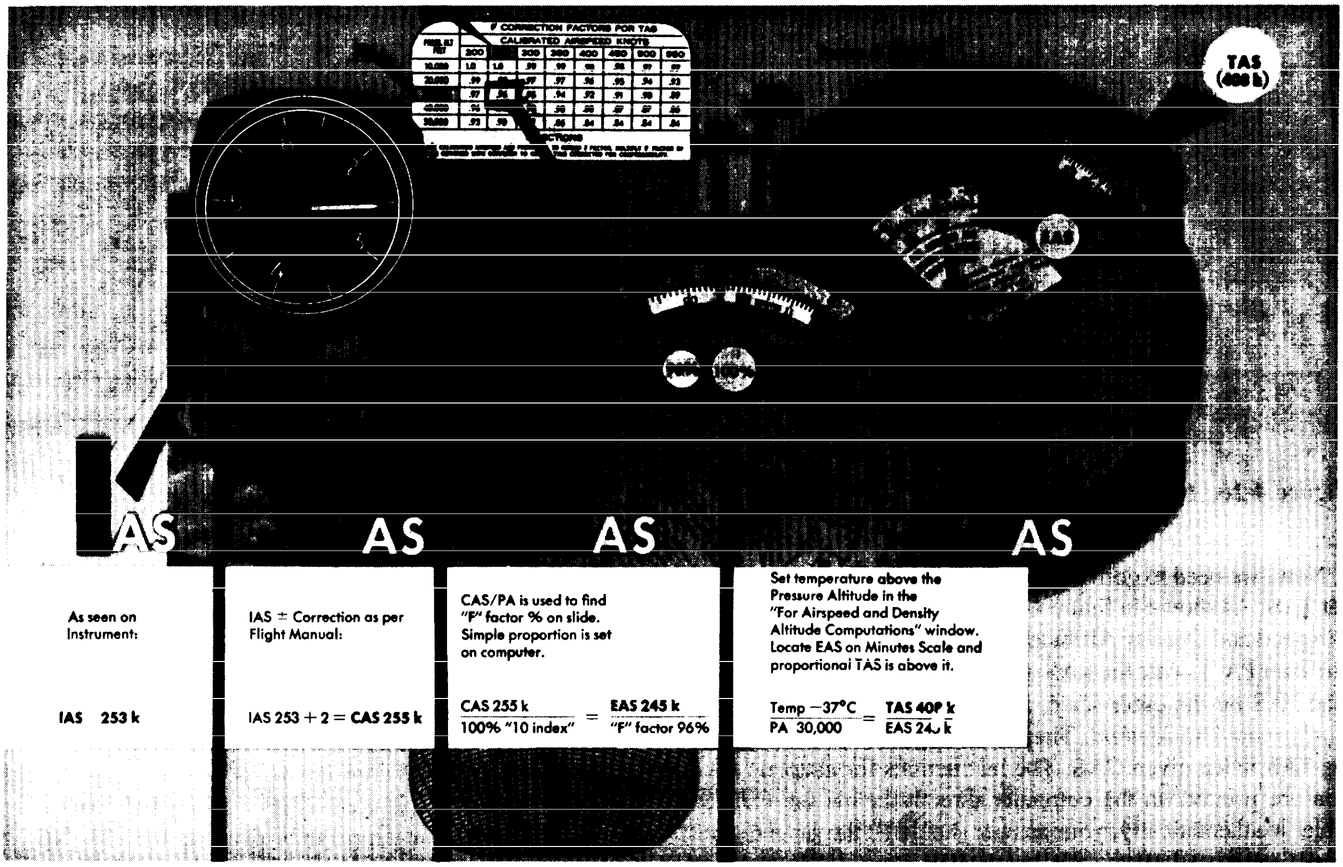


Figure 4-25. ICE-T Method.

density. As the density of the atmosphere decreases with height, pitot pressure for a given airspeed must also decrease with height. Thus, an airspeed indicator operating in a less dense medium than that for which it was calibrated will indicate an airspeed lower than true speed. The higher the aircraft flies, the greater the discrepancy. The necessary correction can be found on the DR computer. Using the window on the computer above the area marked FOR AIRSPEED DENSITY ALTITUDE COMPUTATIONS, set the pressure altitude against the true air temperature (TAT). Opposite the calibrated airspeed on the minutes scale, read the density airspeed on the miles scale. At lower airspeeds and altitudes, density airspeed may be taken as true airspeed with negligible error. However, at high speeds and altitudes, this is no longer true and compressibility error must be considered. (Compressibility error is explained in the equivalent airspeed section.) When density altitude is multiplied by the compressibility factor, the result is true airspeed.

True Airspeed (TAS). True airspeed is equivalent airspeed which has been corrected for air density error. By correcting EAS for true air temperature and pressure altitude, the navigator compensates for air density error and computes an accurate value of TAS. The true airspeed increases with altitude when the indicated airspeed remains constant. When the true airspeed remains constant, the indicated airspeed decreases with altitude. Calibrated and equivalent airspeeds can be determined by referring to the performance data section of the aircraft flight manual.

Computing True Airspeed

ICE-T Method. To compute true airspeed (TAS) using the ICE-T method on the DR computer, solve for each type of airspeed in the order of I, C, E, and T; that is, change indicated airspeed to calibrated, change calibrated to equivalent, and change equivalent to true. This process is illustrated by the following sample problem. (Refer to definitions as necessary.)

Given: Pressure Altitude (PA): 30,000′
Temperature: −37°C
Indicated Airspeed (IAS): 253 knots
Flight Manual Correction Factor: + 2 knots

Find: Calibrated Airspeed (CAS)
Equivalent Airspeed (EAS)
True Airspeed (TAS)

Answer: CAS is determined by algebraically adding to IAS the correction factor taken from the chart in your flight manual. (This correction is insignificant at low speeds but can be higher than 10 knots near Mach 1.)

To correct CAS to EAS, use the chart on the slide of the computer entitled F CORRECTION FACTORS FOR TAS. See figure 4-25. Enter the chart with CAS and PA. The F factor is .96. This means we multiply CAS by .96 or take 96% of 255 knots. To do this, place 255 knots on the inner scale under the "10" index on the outer scale. Locate 96 on the outer scale and read EAS on the inner scale: 245 knots.

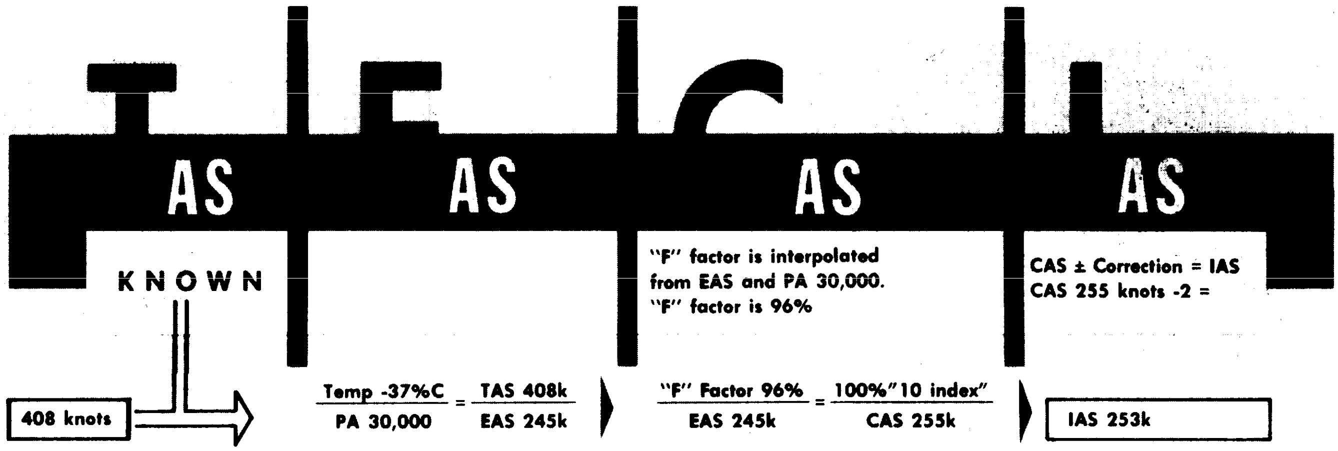


Figure 4-26. ICE-T in Reverse.

Now, we need to correct EAS for temperature and altitude to get TAS. As shown in figure 4-25, in the window marked "For Airspeed and Density Altitude Computations," place temperature over PA. Locate the EAS of 245 knots on the inner scale and read TAS on the outer scale. The TAS is 408 knots.

Alternate TAS Method. There is an alternate method of finding TAS when given CAS. The instructions for alternate solution are printed on the computer directly below the F factor table. Mathematically, your answer should be the same regardless of the procedure you use, but the ICE-T method is used most often because the computation can be worked backwards from TAS. If you wish to maintain a constant TAS, you can determine what CAS or IAS to fly by working the ICE-T method in reverse as illustrated in figure 4-26.

Machmeters

Machmeters indicate the ratio of aircraft speed to the speed of sound at any particular altitude and temperature during flight. It is often necessary to convert TAS to a Mach number or vice versa. Instructions are clearly written on the computer in the center portion of the circular slide rule.

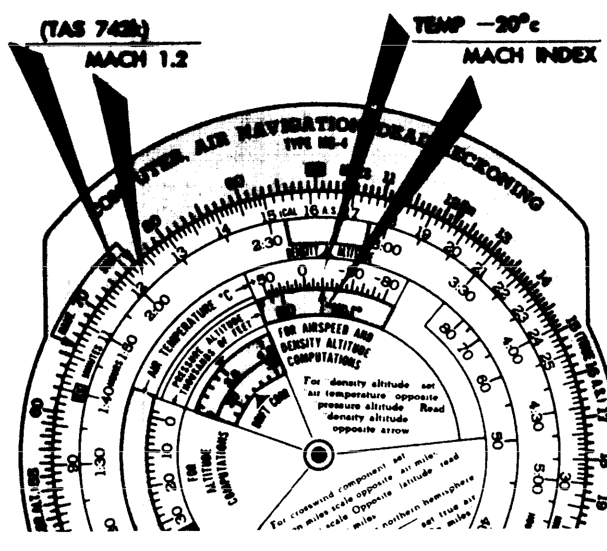


Figure 4-27. Finding TAS from Mach Number.

Locate the window marked FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS and rotate the disk until the window points to the top of the computer (toward the 10 index on the outer scale). Within the window is an arrow entitled MACH NO. INDEX (figure 4-27). To obtain TAS from a given Mach number, set air temperature over the MACH. NO. INDEX and, opposite the Mach number on the MINUTES scale, read the TAS on the outer scale.

Example: If you are planning to maintain Mach 1.2 on a cross-country flight, place the air temperature at flight altitude over the MACH NO. INDEX. Read the TAS on the outer scale opposite 1.2 on the inner scale. If the temperature is − 20°C, the TAS will be 742 knots.

AIRSPEED INDICATORS

True Airspeed Indicator

Most true airspeed indicators display true airspeed by a single pointer on a fixed circular scale as illustrated in figure 4-28. They employ an aneroid cell, a differential pressure diaphragm, and a temperature diaphragm to measure impact pressure, barometric pressure, and free air temperatures. The combined actions of the diaphragms mechanically compensate for air density error to provide an indication of true airspeed.

Maximum Allowable Airspeed Indicator

This indicator (figure 4-29) displays indicated airspeed in 100s of knots by an indicated airspeed pointer on a fixed circular scale. It displays values of less than 100 knots on a rotating scale in a readout window. A maximum allowable indicated airspeed pointer continuously indicates the maximum allowable indicated airspeed for the particular aircraft. Its indications are governed by an aneroid cell which expands as altitude increases, causing the maximum allowable indicated airspeed pointer in-

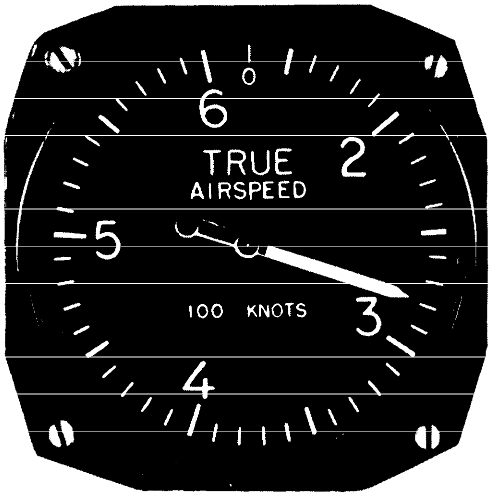


Figure 4-28. True Airspeed Indicator.

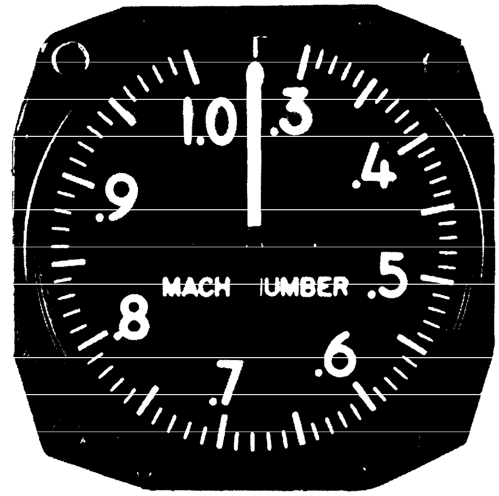


Figure 4-30. Mach Indicator.

dications to decrease. The maximum allowable machmarker is set to the maximum allowable indicated Mach number for the aircraft.

★ Mach Indicator

The Mach indicator, shown in figure 4-30, displays the Mach number which is the ratio between the true airspeed of the aircraft and the speed of sound at flight altitude. In computing a true airspeed from indicated airspeed, air density must be taken into account. This requires that a correction for temperature and altitude be made. With a Mach number this correction is unnecessary because the existing temperature at flight level determines the speed of sound at flight level. The Mach number is determined by the speed of sound, which in turn is determined by air density; thus, Mach is always a valid index to the speed of the aircraft.

Combined Airspeed-Mach Indicator

The combined airspeed-Mach indicator, shown in figure 4-31, is usually found in high-performance aircraft or where instrument panel space is limited. It simultaneously displays indicated airspeed, indicated Mach number, and maximum allowable airspeed. It contains a differential pressure diaphragm and two aneroid cells. The diaphragm drives the airspeed-Mach pointer. One aneroid cell rotates the Mach scale, permitting indicated airspeed and Mach number to be read simultaneously. The second aneroid cell drives the maximum allowable airspeed pointer. This pointer is preset to the aircraft's maximum indicated airspeed. Unlike the maximum indicated airspeed and unlike the maximum allowable airspeed, Mach number increases with altitude. An airspeed marker set knob positions a movable airspeed marker. This marker serves as a memory reference for desired airspeed.

Air Data Computer

The air data computer is an electro-pneumatic unit which utilizes pitot and static pressures and total air temperature to compute outputs for various systems. These output parameters of voltage and resistance represent functions of altitude, Mach number, true airspeed, computed airspeed, and static air

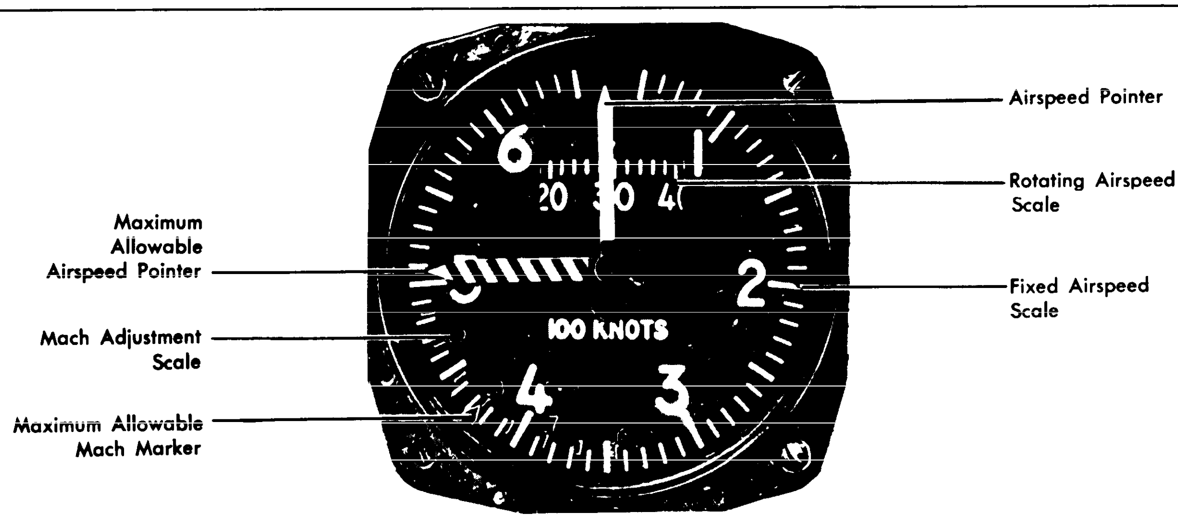


Figure 4-29. Maximum Allowable Airspeed Indicator.

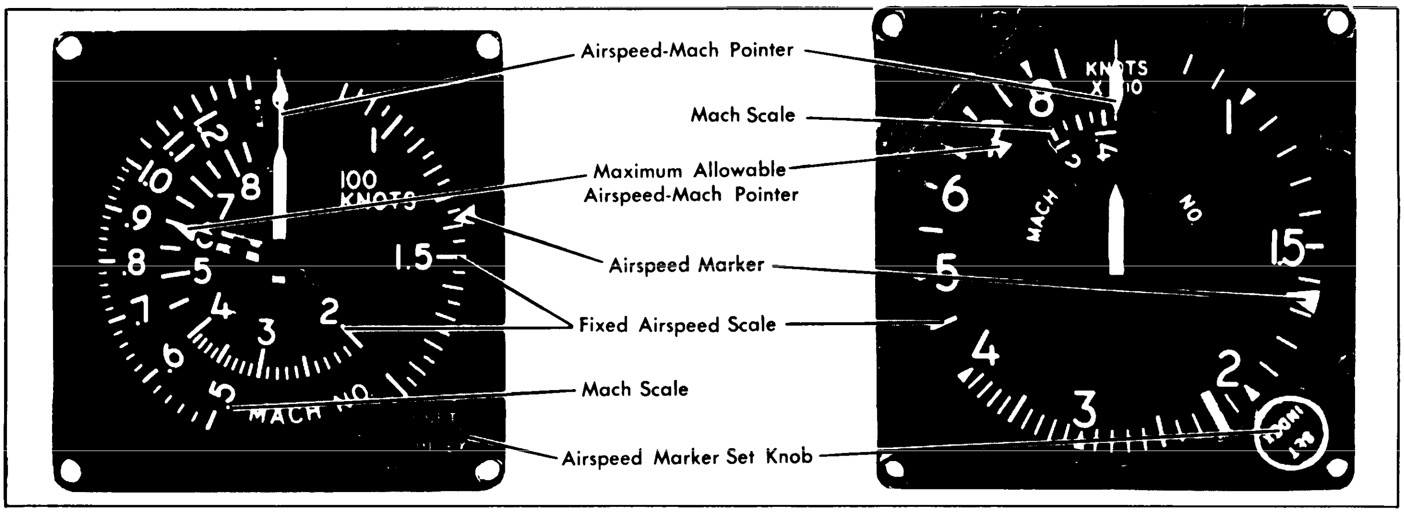


Figure 4-31. Combined Airspeed-Mach Indicators.

temperature. Air data computer outputs are used with the flight director computers, automatic flight controls, cabin pressurization equipment, and normal basic indicators. The air data computer provides extreme accuracy and increased reliability.

DRIFTMETER

Several methods of wind determination depend on the knowledge of the drift angle—the angle between true heading and track. When the Earth's surface (land or sea) is visible, this angle can be measured directly with an instrument, found on some older aircraft, known as a driftmeter.

The principle of the driftmeter is very simple. Suppose that the ground is observed through a hole in the floor of an aircraft. As the aircraft flies along its track, objects on the ground appear to move across the hole in the direction exactly opposite to the track.

Thus, in figure 4-32, if the aircraft track is in the direction of line BA, a house appears to move across the hole from A to B. Suppose now that a wire is stretched across the hole parallel to the longitudinal axis of the aircraft. This wire YX represents the true heading of the aircraft. Since BA is the track and YX is the true heading, the drift angle is the angle AOX. The driftmeter measures this angle AOX. A simple driftmeter might be built as shown in figure 4-33. A glass plate which may be rotated by means of the handle on the right is placed over a hole in the floor of the aircraft. On the glass are drawn parallel drift lines. The

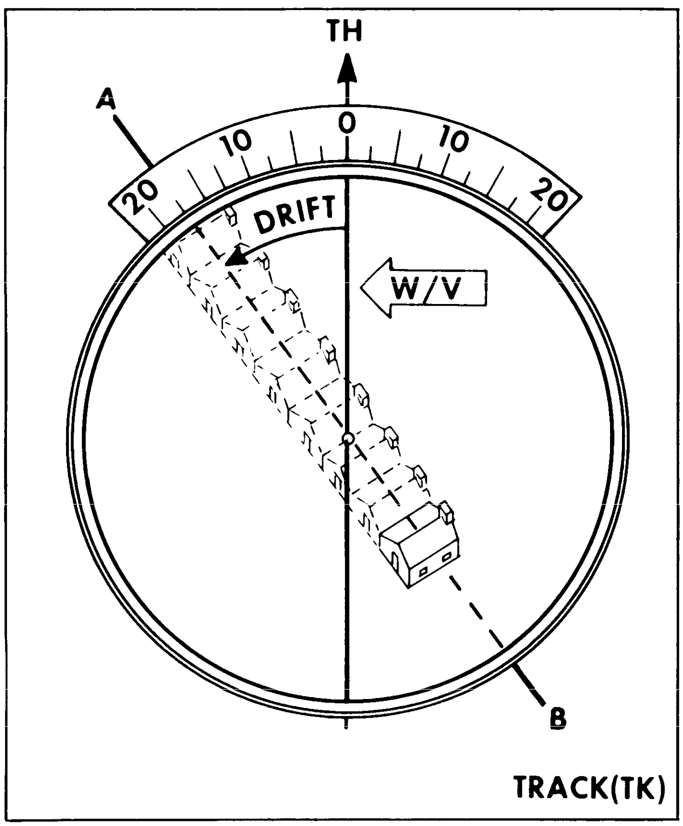


Figure 4-32. Principle of a Driftmeter.

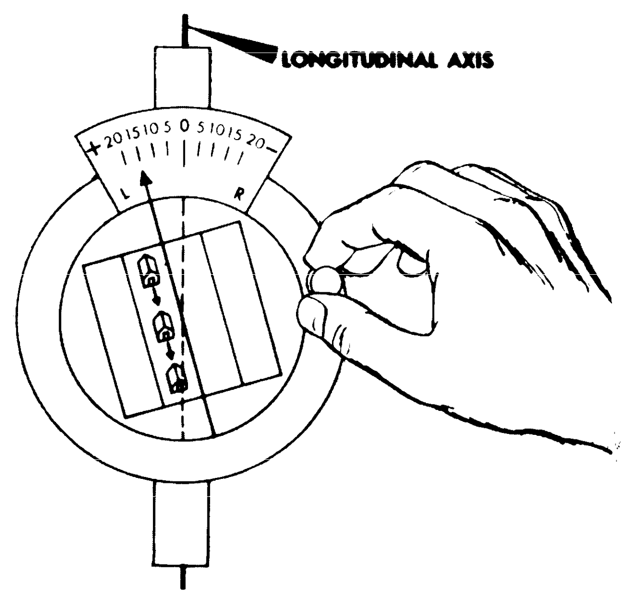


Figure 4-33. Read Drift on Scale Opposite Pointer.

drift lines, together with the two or three cross lines (timing lines) usually present in a driftmeter, are called the reticle. The center drift line extends to the edge of the plate as a pointer. On the floor ahead of the hole is a drift scale which shows the position of the drift lines relative to the longitudinal axis of the aircraft. Thus, when the pointer is on 0°, the drift lines are parallel to the longitudinal axis; and, when the pointer is on 10°R, the drift lines make a 10° angle to the right of the axis.

To use this simple driftmeter, turn the glass plate so that objects on the ground move across the hole parallel to the drift lines. Then, the drift lines are parallel to the track of the aircraft. Read the drift scale opposite the pointer. If the pointer indicates 15°L, the aircraft is drifting 15° to the left. Therefore, if the true heading is 090°, the track is 075°.

On every driftmeter, the drift scale is marked with the words "right" and "left" or with the letters "R" and "L." These words always refer to the drift and not to the drift correction. Normally, driftmeters have a plus and minus sign on the scale. These give the sign of the drift correction which is discussed later. More advanced driftmeters have the capability to measure groundspeed when used with a stopwatch and a radar altimeter by timing passing targets.

DOPPLER

Since people first flew, they have searched for ways to determine aircraft groundspeed and drift angle without aid from the ground. Various models of the driftmeter provided only a partial answer to the problem. Their use consumed a great deal of the navigator's time, and they could not be used over smooth water or when weather obscured the surface.

Doppler radar provides the navigator with continuous, instantaneous, accurate readings of groundspeed and drift angle in all weather conditions, both over land and over water. It does this automatically with equipment that is of practical size and weight. Its operation makes use of the Doppler effect.

Doppler Effect

The Doppler effect was discovered in 1842 by Christian Johann Doppler. This effect, simply stated, is that transmitted energy undergoes an apparent shift in frequency as the distance between the transmitter and receiver decreases or increases. It is this frequency shift which makes possible the instantaneous sensing and measuring of groundspeed and drift angle by Doppler radar.

The Doppler effect applies to all wave motion including electromagnetic, light, and sound. The effect on sound waves can be observed by listening to the whistle of a passing train. As the train approaches, its whistle, as heard by a stationary observer, has a fairly steady pitch; that is, higher than the true pitch. As the train passes, the pitch drops quickly to a frequency below the true pitch and remains at approximately the lower value as the train moves away from the observer. This principle is illustrated in figure 4-34.

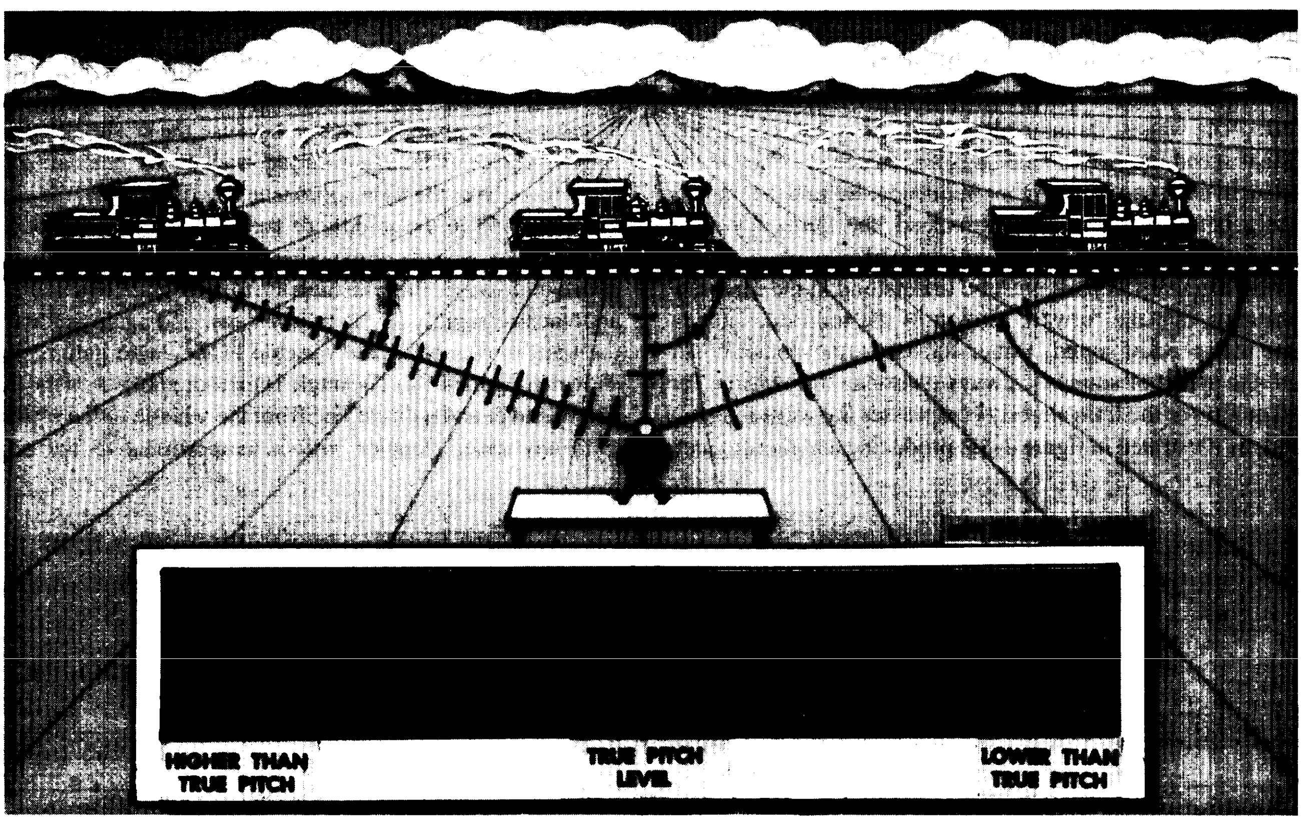


Figure 4-34. Doppler Effect.

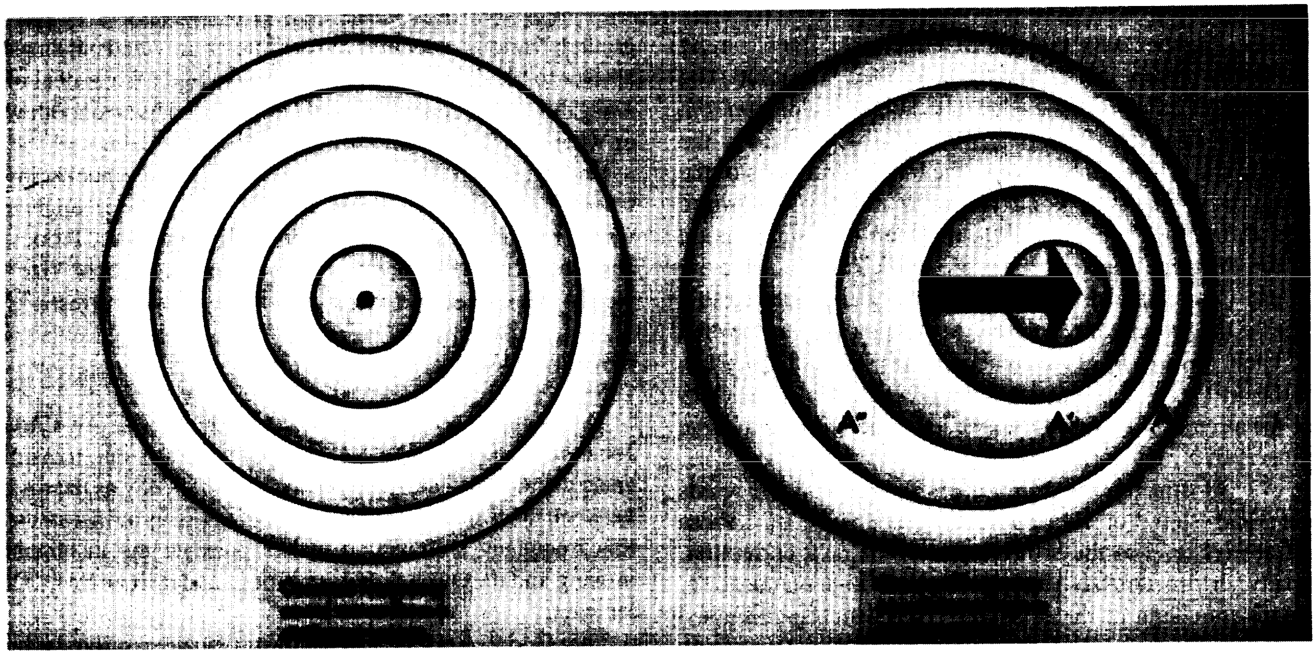


Figure 4-35. Moving Source of Sound Affects Frequency Reception.

The change in pitch, which is a change in frequency, is due to the relative motion between the train and the observer. Moreover, the degree of change is proportional to the relative velocity between the two. It should be noted that this is actually a change in frequency to the observer standing near the track but to a person riding on the train, there is no change in pitch and that individual hears a steady whistle. The reason for this shift is that as the train speeds ahead from left to right, as in the illustration, each successive sound wave is emitted slightly farther ahead on its path. The waves, though still spreading in all directions at a constant speed, no longer share a common center. They crowd together in front causing a higher frequency. Behind the train the distance between the waves is stretched, the frequency is decreased, and the pitch is therefore lowered.

Single Doppler Shift. It must be understood in the foregoing explanation that the forward motion of the train does not increase the speed of sound. Under constant atmospheric conditions, the speed of sound is always constant. Instead, the forward motion of the train slightly compresses the wave length of sound, as illustrated in figure 4-35, producing a higher frequency which the observer at A hears as a higher pitch. When the train whistle is directly abeam the observer at A′, a true pitch is heard because relative motion between "transmitter" and "receiver" is zero. As the train moves off, its forward motion slightly expands the wave length of sound, and the observer at A″ hears a lower-than-true pitch. This illustration is an example of single Doppler shift.

Note that this explanation describes the whistle's pitch as "fairly constant" as the train approaches and moves off. It actually drops slightly. This is because the observer stands at some distance from the railroad tracks. To hear an exactly constant pitch as the train approaches and moves off, the observer must stand in the middle of the tracks. When the observer stands off to one side or the other, a second variable comes into play which causes the whistle pitch to drop gradually as the train approaches, rapidly as the train passes, and again gradually as the train moves off. This variable is the angle gamma (γ) as shown in figure 4-34. The angle is measured between the train's line of travel and a direct line from the whistle to the observer.

In any case, Doppler shift is proportional to the relative

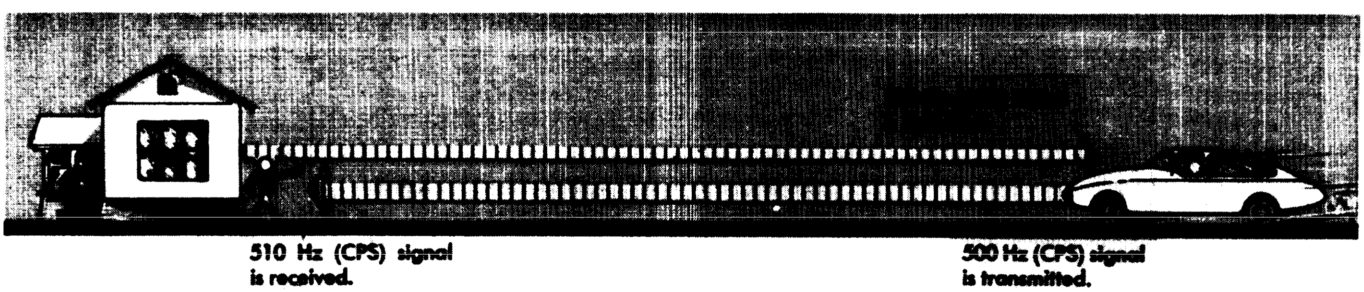


Figure 4-36. Double Doppler Shift.

velocity between the train and the observer. If the observer stands on the tracks, relative velocity is determined by the train's rate of closure and angle γ. Stated another way, relative velocity is proportional to the cosine of angle γ.

Angle γ changes gradually when the train is at a distance, and rapidly as the train passes. Thus, the whistle's pitch drops gradually when the train is at a distance, and rapidly as the train passes.

Double Doppler Shift. Double Doppler shift occurs when the emitting source is in motion and receives its echo from a stationary reflecting surface, or when the emitting source is stationary and receives its echo from a moving reflecting surface (figure 4-36).

If the man in the automobile blows the horn (producing a tone of 500 Hz) as he approaches the building, another man by the building would hear a higher tone (510 Hz, a single Doppler shift). If the building reflects the horn's sound back to the automobile, the driver would hear the echo at a still higher frequency (520 Hz, a double Doppler shift). This occurs in much the same manner with an airborne Doppler radar set. Figure 4-37 illustrates a functioning Doppler system transmitting a silent beam of radar energy from the aircraft to the ground. The beam is transmitted at a known angle γ from the direction of aircraft travel. The ground reflects some radar energy back to the aircraft. The Doppler system is in motion while the ground is stationary, a situation comparable to the automobile example. Thus, the frequency of radar energy returned to the aircraft is increased by double Doppler shift. Since angle γ is intentionally kept constant, any variation in the frequency of returned radar energy represents a proportional variation in groundspeed.

Antenna Configuration

Two basic Doppler radar systems are currently in use—the four-beam and the three-beam. Both types use either continuous wave (CW) or pulse wave (PW) transmission. CW transmission requires one antenna for transmission and a second antenna for reception.

Four-Beam Doppler Radar. Figure 4-38 illustrates the four-beam system. Two beams are directed forward and two beams are directed aft. The system computes groundspeed and drift. Groundspeed is measured by comparing frequencies from the forward beams with frequencies from the aft beams. The amount of frequency shift is converted to groundspeed.

Frequencies from the four beams are compared in a slightly different manner to measure drift. The frequency shift between the right forward and left aft beams is compared with the frequency shift between the left forward and right aft beams. If the two shifts are equal, drift is zero. Figure 4-39 illustrates the right forward and left aft beams producing the higher frequency shift; thus, drift is to the left. Figure 4-40 illustrates that the system's drift computing elements have sensed the distance in frequency shift and used this difference to align the antenna with ground track. When the antenna has been so aligned, the two sets of beams indicate equal Doppler shifts, or zero drift, while the angle to which the antenna has been rotated equals drift.

Three-Beam Doppler Radar. The three-beam Doppler principle of operation differs somewhat from that of the four-beam Doppler. The three beams are directed 70° below the horizontal plane, and are offset 20° from the longitudinal axis of the aircraft. This arrangement of the beams, illustrated in figure 4-41, is called the lambda configuration because it resembles the Greek letter lambda (λ).

The frequency from each beam undergoes a shift because of forward motion, wind drift, and vertical travel of the aircraft. The frequency shift is a function of aircraft velocity. The aircraft forward, lateral, and vertical velocities are obtained by combining these frequency-shifted signals. Vertical velocity is determined by the frequency shifts from beams D_3 minus D_1. Forward velocity is determined by the frequency shifts from D_3 plus D_2. Lateral velocity is determined by the frequency shifts from D_2 minus D_1.

The three velocities are resolved into velocities along heading and across heading. The resultant equals groundspeed and the

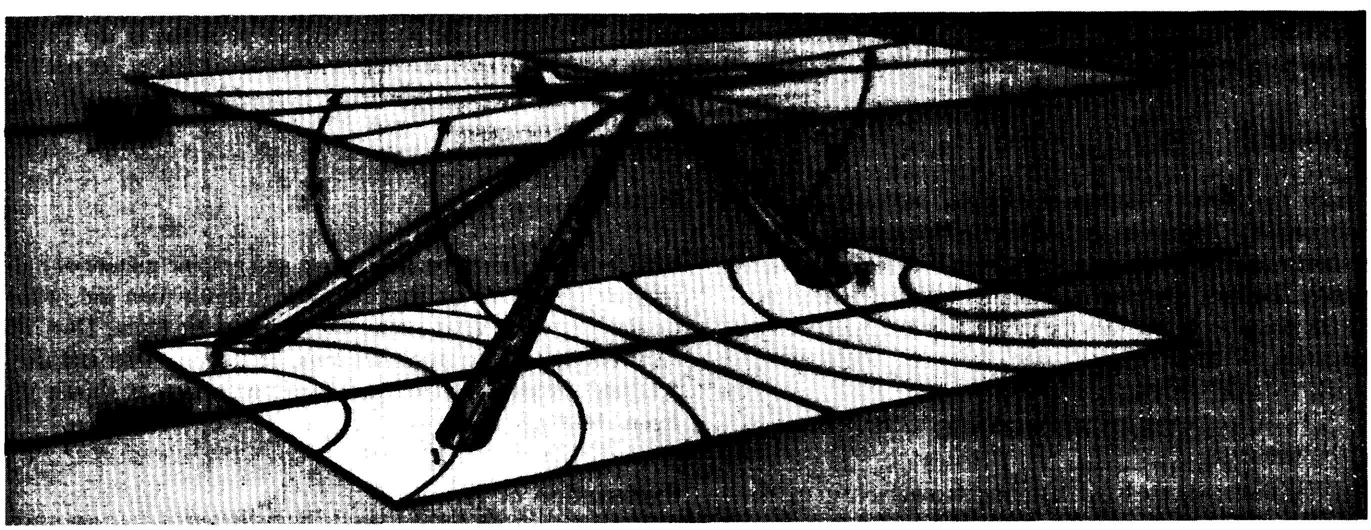


Figure 4-37. Gamma Angle from Airborne Doppler System.

Figure 4-38. Configuration for Groundspeed Measurement.

angle equals drift. See figure 4-42. Drift is then resolved around true heading to produce ground track.

Summary

Since the primary outputs of Doppler are drift angle and groundspeed, it is obvious that any navigational problem requiring these components has received a boon with the innovation of Doppler. Because Doppler information helps resolve an accurate DR position, it provides the means to solve many complex navigation problems.

DEAD RECKONING

Having discussed the basic instruments available to the navigator, we will now review the mechanics of dead reckoning procedures, plotting, determining wind effect, and MB-4 computer solutions. Using basic skills in dead reckoning procedures, a navigator can predict aircraft positions in the event more reliable navigation equipment is unavailable or not operative. Therefore, a good foundation in dead reckoning is imperative for the navigator.

Plotting

Chart work should be an accurate and graphic picture of the progress of the aircraft from departure to destination and, with the log, should serve as a complete record of the flight. Thus, it also follows that the navigator must be familiar with and use accepted standard symbols and labels on charts as shown in figure 4-43.

Explanation of Terms

Several terms have been mentioned in earlier portions of this manual. Precise definitions of these terms must now be under-

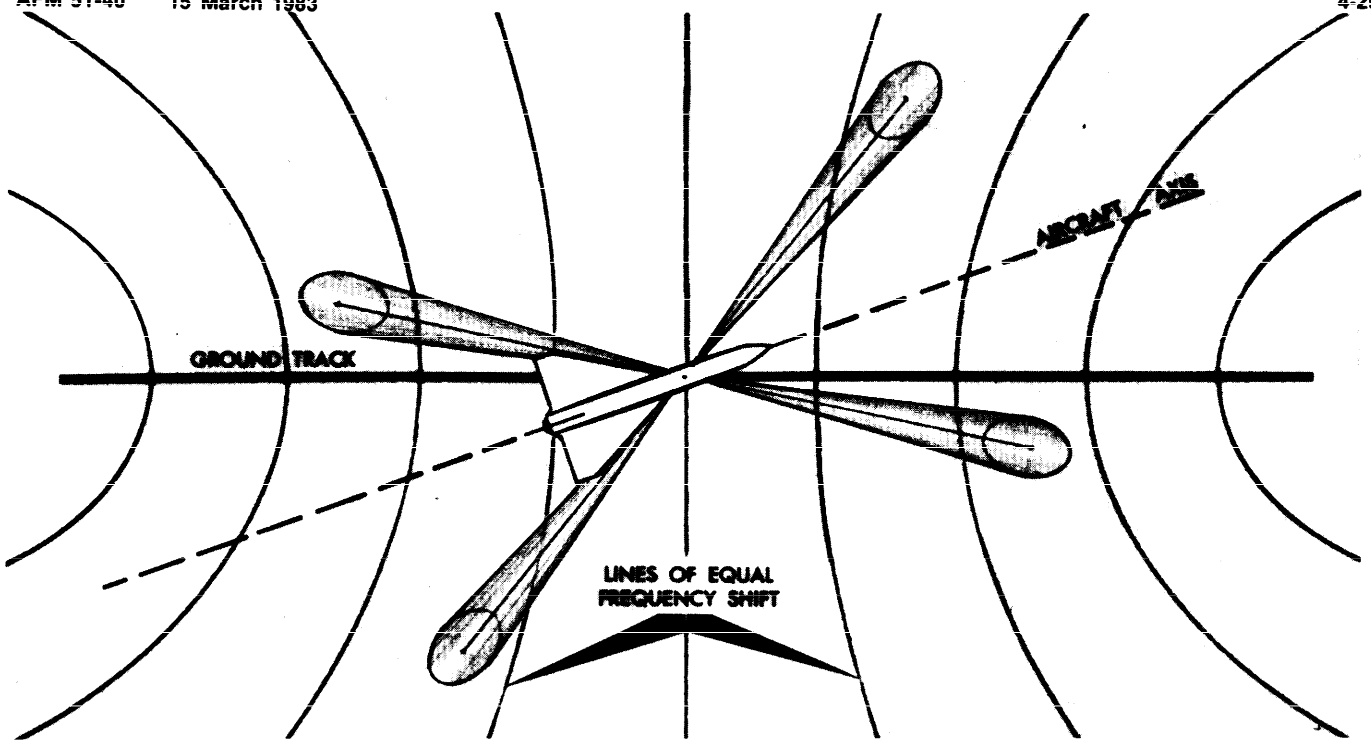


Figure 4-39. Antenna Position before Drift is Measured.

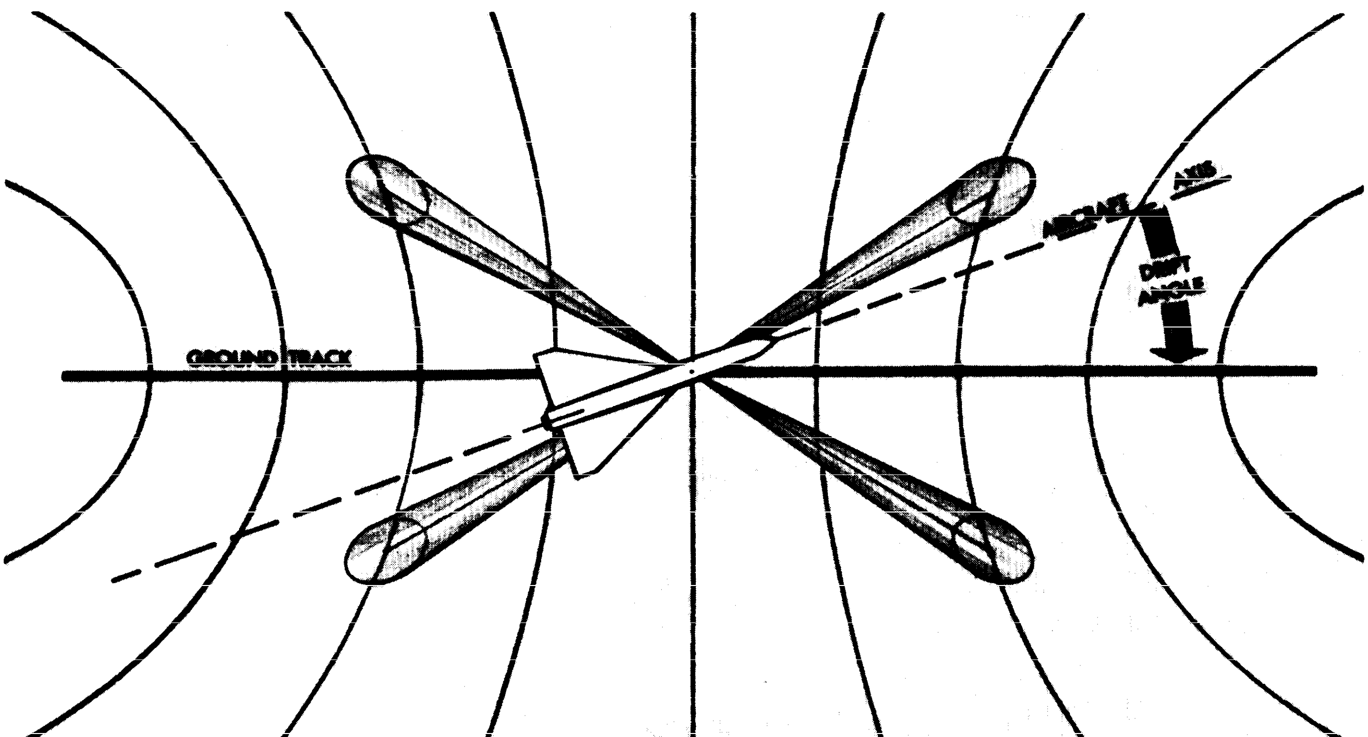


Figure 4-40. Antenna Position after Drift is Measured.

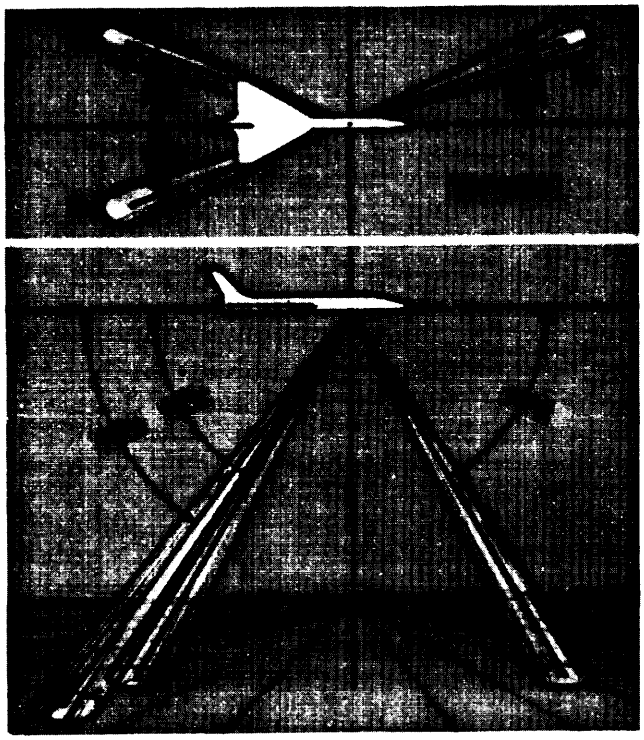


Figure 4-41. Three-Beam Doppler Radar.

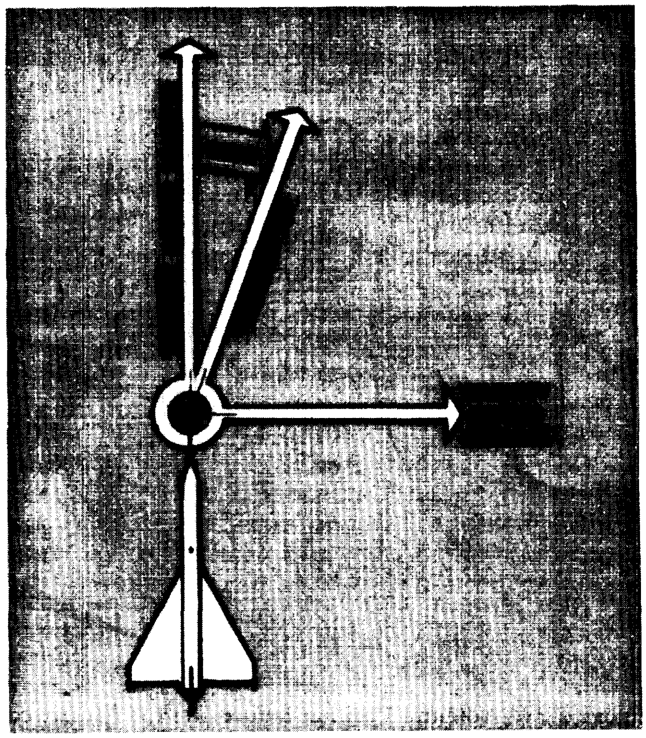


Figure 4-42. Resultant Groundspeed and Drift Angle.

stood before the mechanics of chart work are learned.

TRUE COURSE (TC) is the intended horizontal direction of travel over the surface of the Earth, expressed as an angle measured clockwise from true north (000°) through 360 degrees.

COURSE LINE is the horizontal component of the intended path of the aircraft comprising both direction and magnitude or distance.

TRACK (Tr) is the horizontal component of the actual path of the aircraft over the surface of the Earth. Track may, but very seldom does, coincide with the true course or intended path of the aircraft. The difference between the two is caused by an inability to predict perfectly all in-flight conditions.

TRUE HEADING (TH) is the horizontal direction in which an aircraft is pointed. More precisely, it is the angle measured clockwise from true north through 360 degrees to the longitudinal axis of the aircraft. The difference between track and true heading is caused by wind and is called drift.

GROUNDSPEED (GS) is the speed of the aircraft over the ground. It may be expressed in nautical miles, statute miles, or kilometers per hour, but, as a navigator, you will use nautical miles per hour (knots).

TRUE AIRSPEED (TAS) is the rate of motion of an aircraft relative to the air mass surrounding it. Since the air mass is usually in motion in relation to the ground, airspeed and groundspeed seldom are the same.

DEAD RECKONING POSITION (DR Position) is a point in relation to the Earth established by keeping an accurate account of time, groundspeed, and track since the last known position. It may also be defined as the position obtained by applying wind

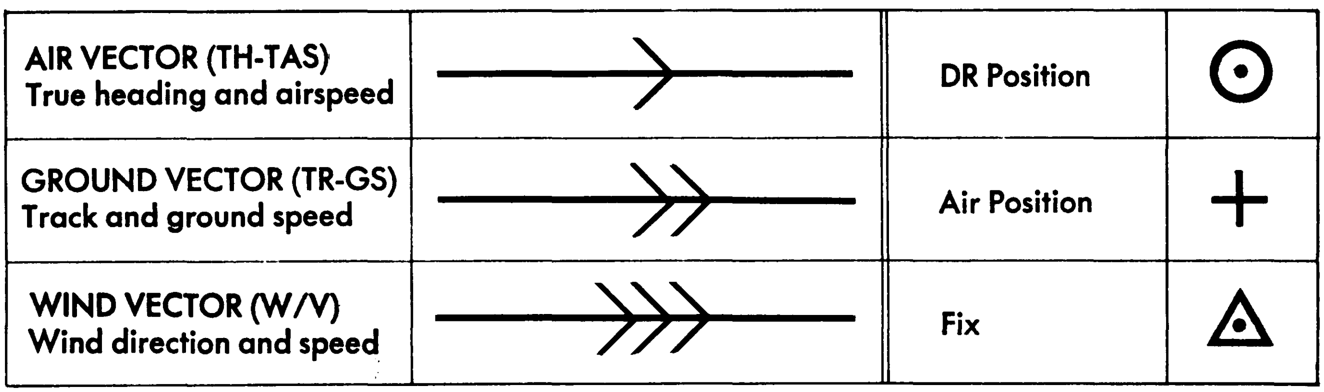


Figure 4-43. Standard Plotting Symbols.

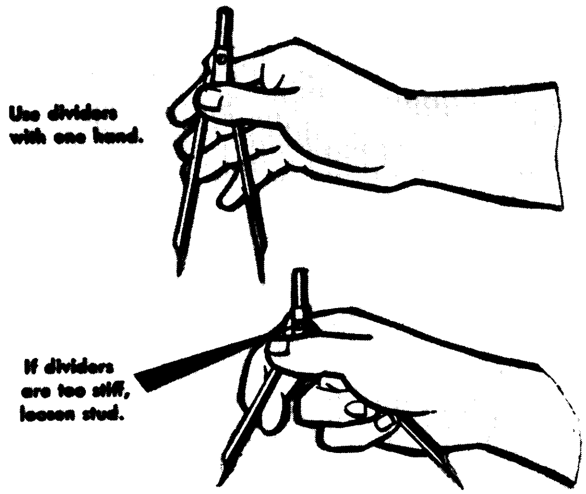


Figure 4-44. Use of Dividers.

effect to the true heading and true airspeed of the aircraft.

A FIX is an accurate position determined by one of the aids to DR.

AIR POSITION (AP) is the location of the aircraft in relation to the air mass surrounding it. True heading and true airspeed are the components of the vector used to establish an air position.

MOST PROBABLE POSITION (MPP) is a position determined with partial reference to a DR position and partial reference to a fixing aid.

Plotting Equipment

Nothing reflects a navigator's ability more than keeping neat, clean, and accurate charts and logs. An untidy chart, smudged and worn through in places, often causes one to conclude that the navigation performed was careless. In addition to having some type of fine-tipped, soft pencil, a good pair of dividers, and plotter are imperative for accurate chart work.

Dividers. It is desirable to manipulate the dividers with one hand (figure 4-44), leaving the other free to use the plotter, pencil, or chart as necessary. Most navigation dividers have a tension screw which you can adjust to prevent the dividers from becoming either too stiff or too loose for convenient use. Adjust the points of the dividers to approximately equal length. A small screwdriver, required for these adjustments, should be a part of the navigator's equipment.

Plotters. A common Air Force plotter is shown in figure 4-45. This plotter is a semicircular protractor with a straight edge attached to it. A small hole at the base of the protractor portion indicates the center of the arc of the angular scale. Two complete scales cover the outer edge of the protractor and are graduated in degrees. An abbreviated, inner scale measures the angle from

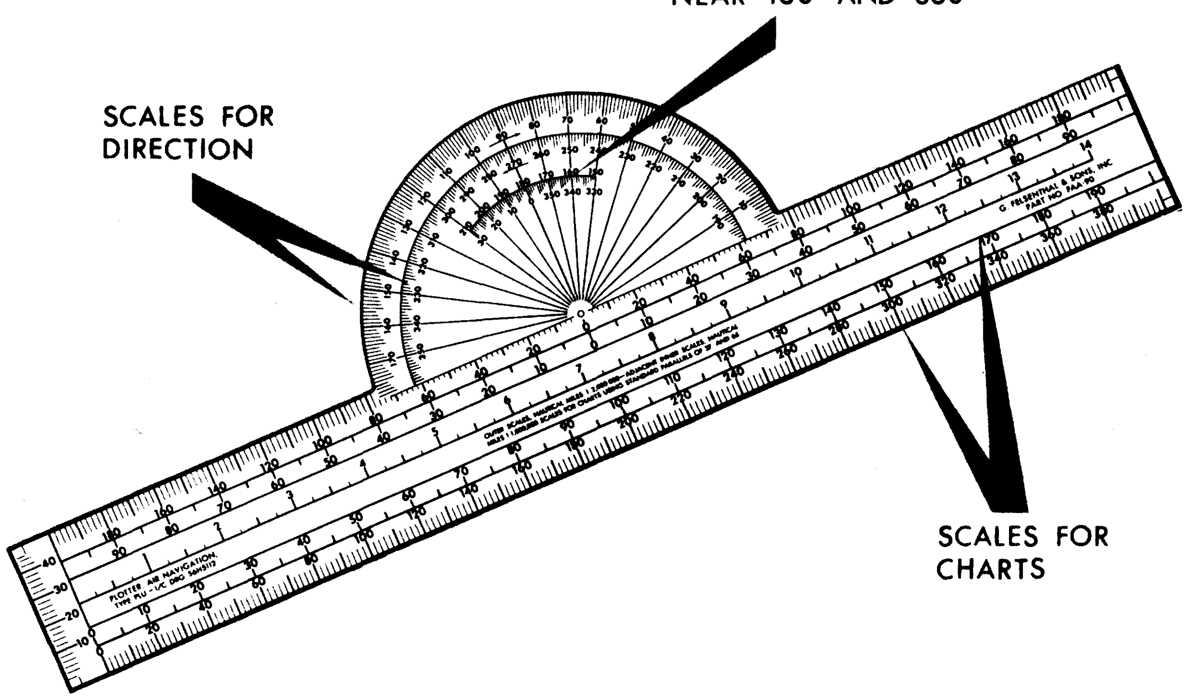


Figure 4-45. Typical Plotter.

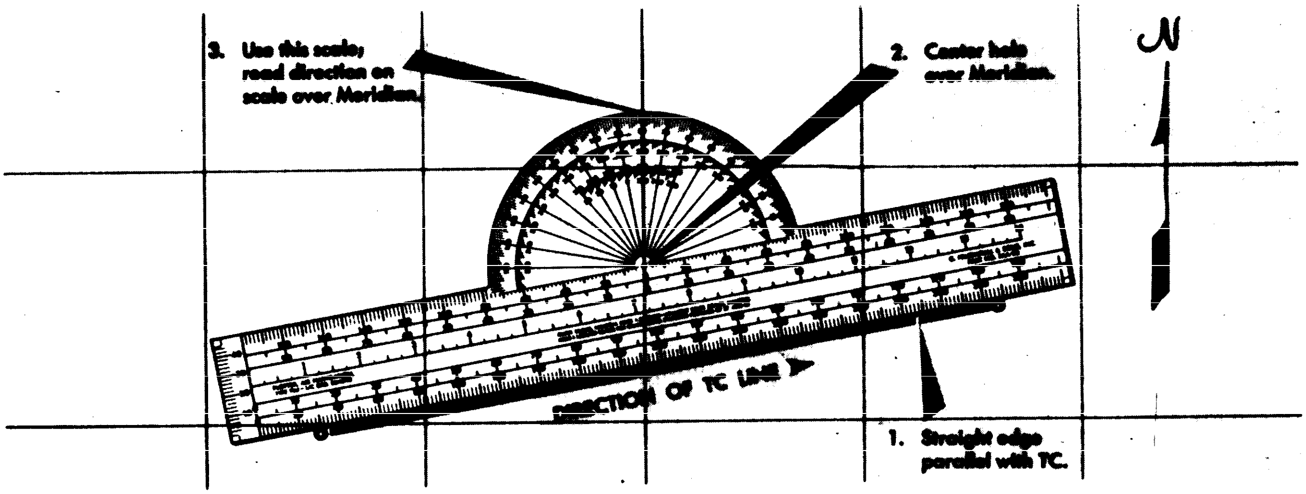


Figure 4-46. To Measure True Course.

the vertical. (See figures 4-46 and 4-47.)

The angle measured is the angle between the meridian and the straight line. The outer scale is used to read all angles between north through east to south, and the inner scale is used to read all angles between south through west to north.

Plotting Procedure, Mercator Chart

Preparation. A great many charts and plotting sheets are printed on the Mercator projection. Before starting any plot, note the scale and projection of the chart and check the date to

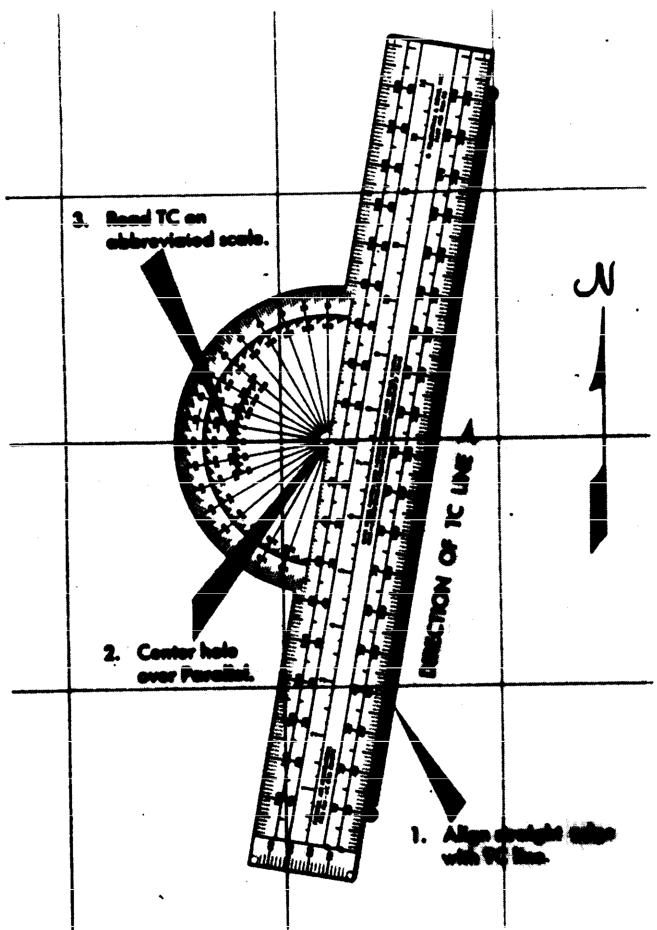


Figure 4-47. To Measure True Course Near 180° or 360°.

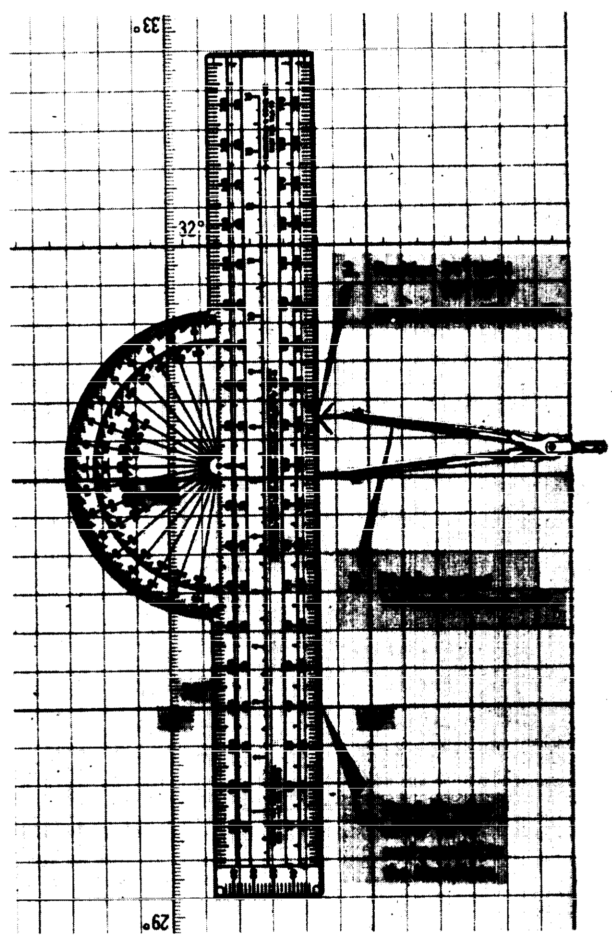


Figure 4-48. Plotting Positions on a Mercator.

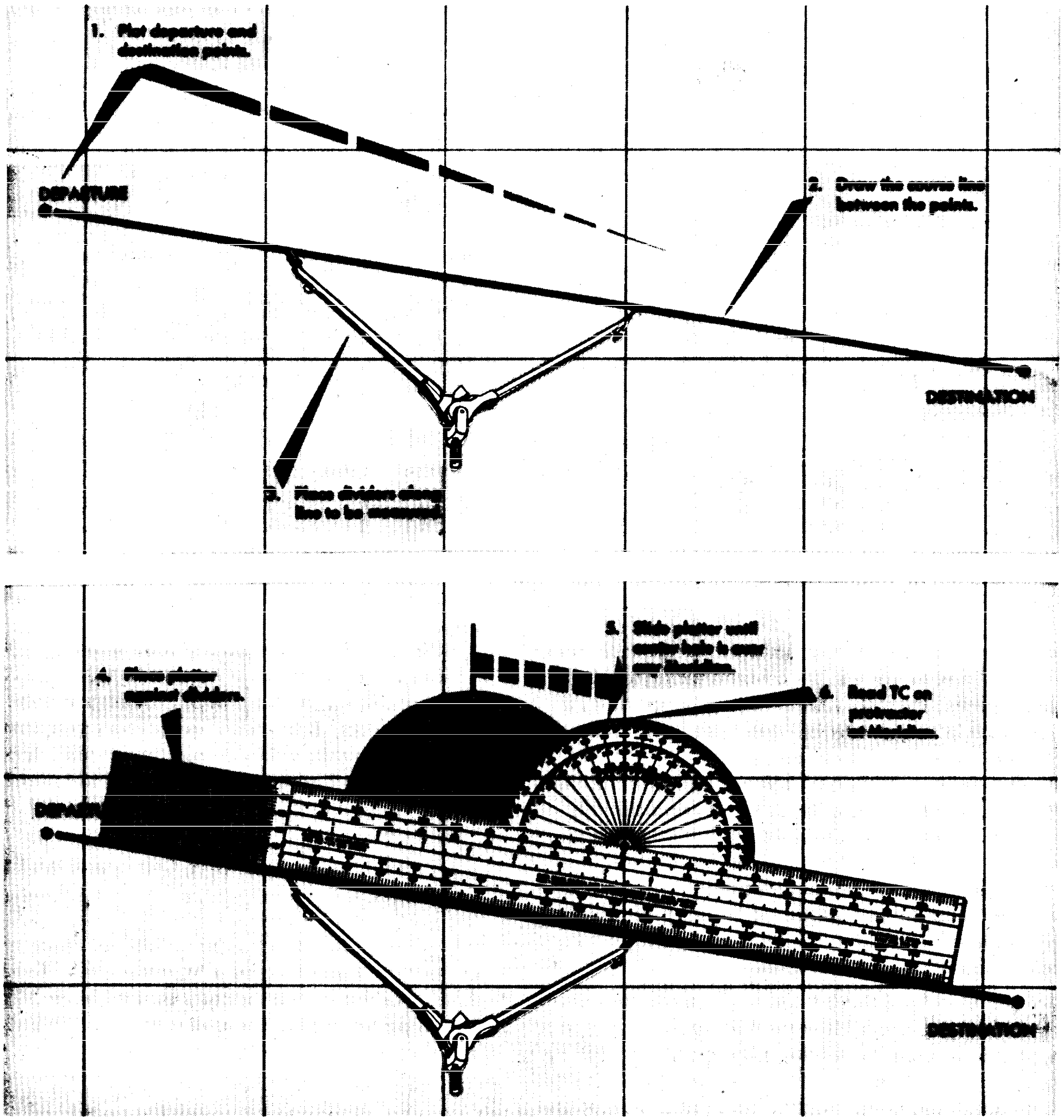


Figure 4-49. Reading Direction of a Course Line.

make sure that it is the latest edition. The latitude scale is used to represent nautical miles. The longitude scale should never be used to measure distance. Some charts carry a linear scale in the margin, and, where present, it indicates that the same scale may be used anywhere on the chart.

Plotting Positions. On most Mercator charts, the spacing between meridians and parallels is widely spaced, necessitating the use of dividers. There are several methods by which positions can be plotted on Mercator charts. One method is illustrated in figure 4-48. Place the straight edge of the plotter in a vertical position, at the desired longitude. Set the dividers to the desired number of minutes of latitude. Hold one point against the straight edge on the parallel of latitude corresponding to the whole degree of latitude given. Let the other point also rest against the straight edge and lightly prick the chart. This marks the desired position. In measuring the latitude and longitude of a position already plotted, reverse the procedure.

Plotting and Measuring Courses. Plot departure and destination on the chart, as shown in figure 4-49, Step 1. Step 2 is to draw the course line between the two points. If they are close together, the straight edge of the plotter can be used. If they are far apart, two plotters can be used together, or a longer straight

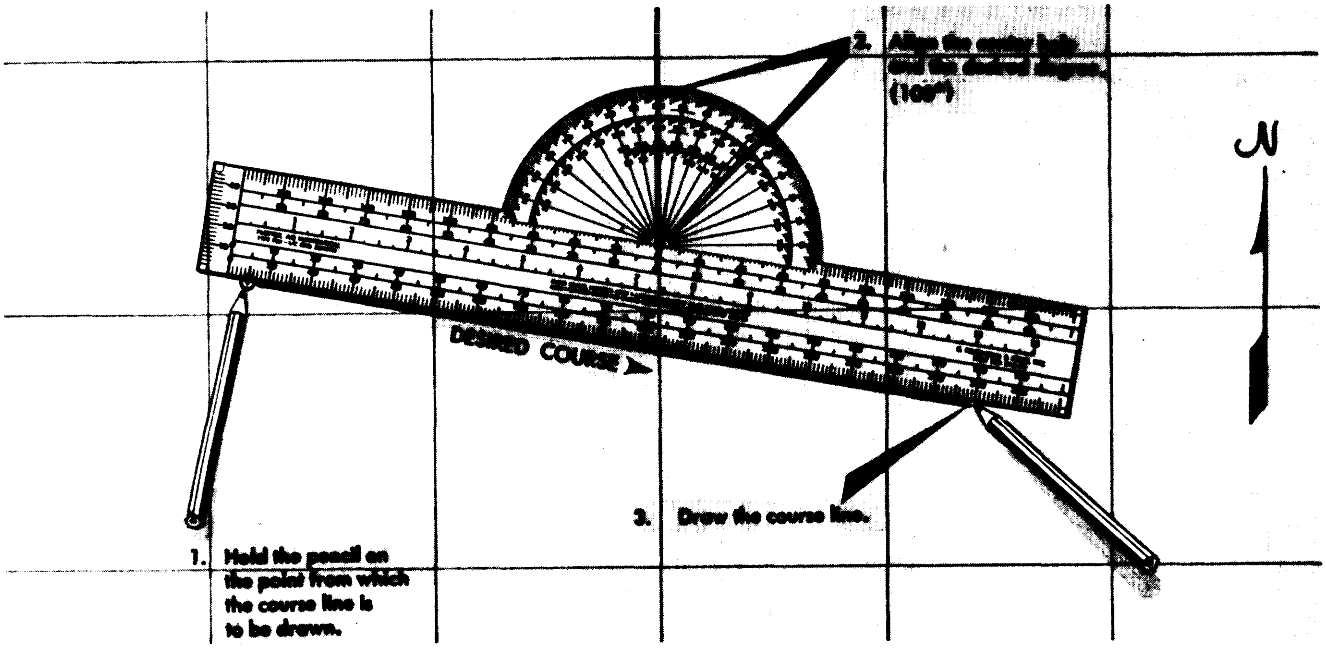


Figure 4-50. Plotting Course from Given Position.

edge can be used. If none of these methods is adequate, fold the edge of the charts so that the fold connects the departure and destination points, and make a series of pencil marks along the edge. A plotter or straight edge can then be used to connect the points where the chart is unfolded.

After the course line has been plotted, the next step is to determine its direction. Place the points of the dividers or a pencil anywhere along the line to be measured, Step 3. Place the plotter against the dividers, Step 4. Slide the plotter until the center hole is over any meridian as shown in Step 5. Read TC on the protractor at the meridian, Step 6. Make a mental estimate of the approximate direction of the line when reading the protractor to avoid obtaining a reciprocal heading.

Plotting Course From Given Position. A course from a given position can be plotted quickly in the following manner: Place the point of a pencil on the position and slide the plotter along this point, rotating it as necessary, until the center hole and the figure on the protractor representing the desired direction are lined up with the same meridian. Hold the plotter in place and draw the line along the straight edge (figure 4-50).

Measuring Distance. One of the disadvantages of the Mercator chart is the lack of a constant scale. If the two points between which the distance is to be measured are approximately in a north-south direction and the total distance between them can be spanned, the distance can be measured on the latitude scale opposite the midpoint. However, the total distance between any two points that do not lie approximately north or south of each other should not be spanned unless the distance is short.

In the measurement of long distances, select a midlatitude lying approximately halfway between the latitudes of the two points. By using dividers set to a convenient, reasonably short distance, such as 60 nautical miles picked off at the midlatitude scale, you may determine an approximate distance by marking off units along the line to be measured as shown in figure 4-51.

The scale at the midlatitude is accurate enough if the course line does not cover more than 5 degrees of latitude (somewhat less in high latitudes). If the course line exceeds this amount or if it crosses the equator, divide it into two or more legs and measure the length of each leg with the scale of its own midlatitude.

Plotting Procedures—Lambert Conformal and Gnomonic Charts

Plotting Positions. On a Lambert conformal chart, the meridians are not parallel as on a Mercator chart. Therefore, plotting a position by the method described under Mercator charts may not be accurate. On small scale charts or where there

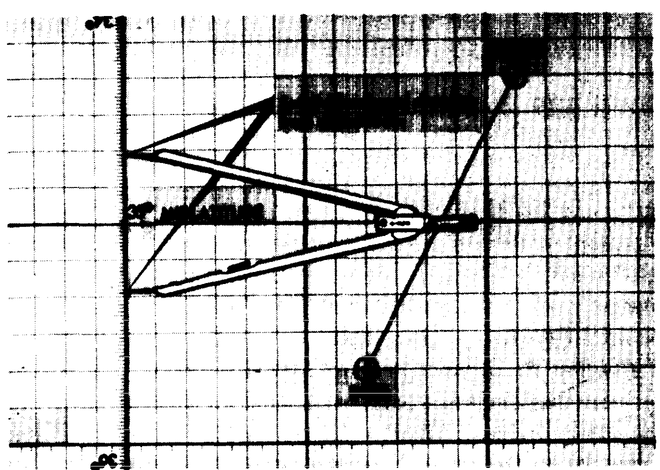


Figure 4-51. Midlatitude Scale.

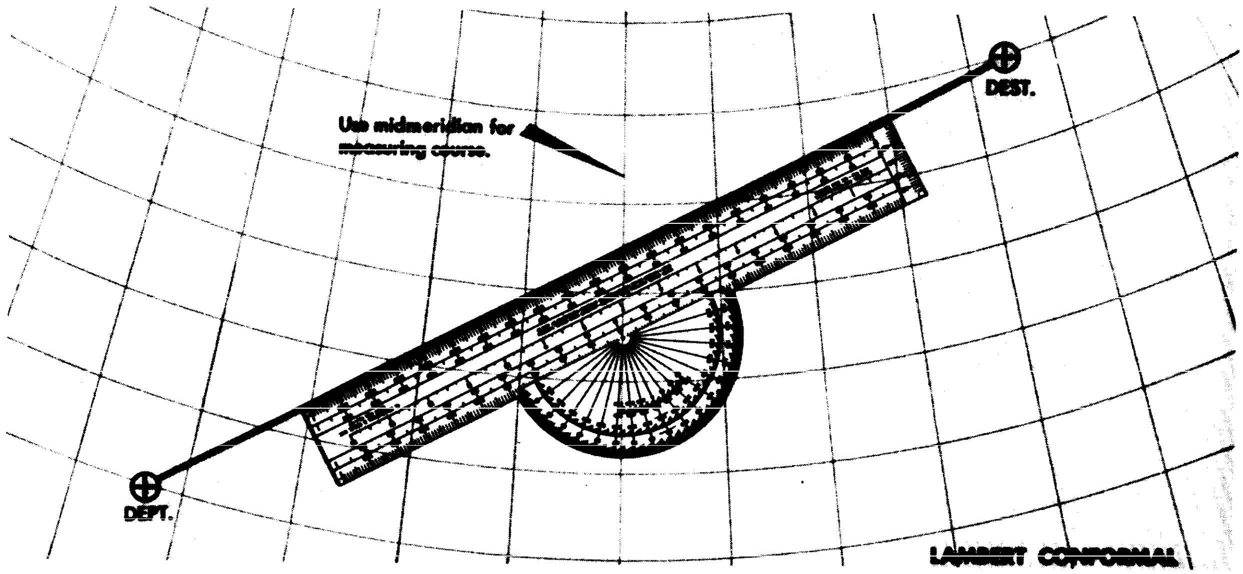


Figure 4-52. Use Midmeridian to Measure Course on a Lambert Conformal.

is marked convergence, the plotter should intersect two graduated parallels of latitude at the desired longitude rather than parallel to the meridian. Then, mark off the desired latitude with your dividers. On a large scale chart, the meridians are so nearly parallel that this precaution is unnecessary.

The scale on all parts of a Lambert conformal chart is essentially constant. Therefore, it is not absolutely necessary to pick off minutes of latitude near any particular parallel except in the most precise work.

Plotting and Measuring Courses. Any straight line plotted on a Lambert conformal chart is approximately an arc of a great circle. In long distance flights, this feature is advantageous since the great circle course line can be plotted as easily as a rhumb line on a Mercator chart.

However, for shorter distances where the difference between the great circle and rhumb line is negligible, the rhumb line is more desirable because a constant heading can be held. For such distances, the approximate direction of the rhumb line course can be found by measuring the great circle course at midmeridian as shown in figure 4-52. In this case, the track is not quite the same as that indicated by the course line drawn on the chart, since the actual track (a rhumb line) appears as a curve convex to the equator on a Lambert conformal chart, while the course line (approximately a great circle) appears as a straight line. Near midmeridian, the two have approximately the same direction (except for very long distances) along an oblique course line as indicated in figure 4-53.

For long distances involving great circle courses, it is not

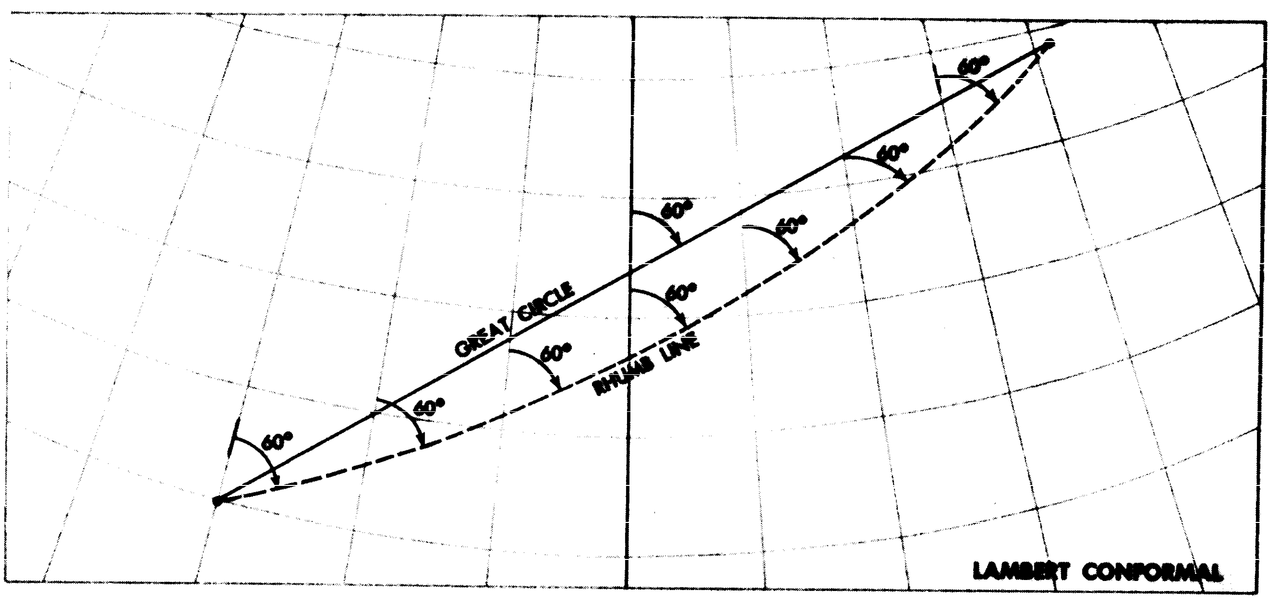


Figure 4-53. At Midmeridian, Rhumb Line and Great Circle have Approximately the Same Direction.

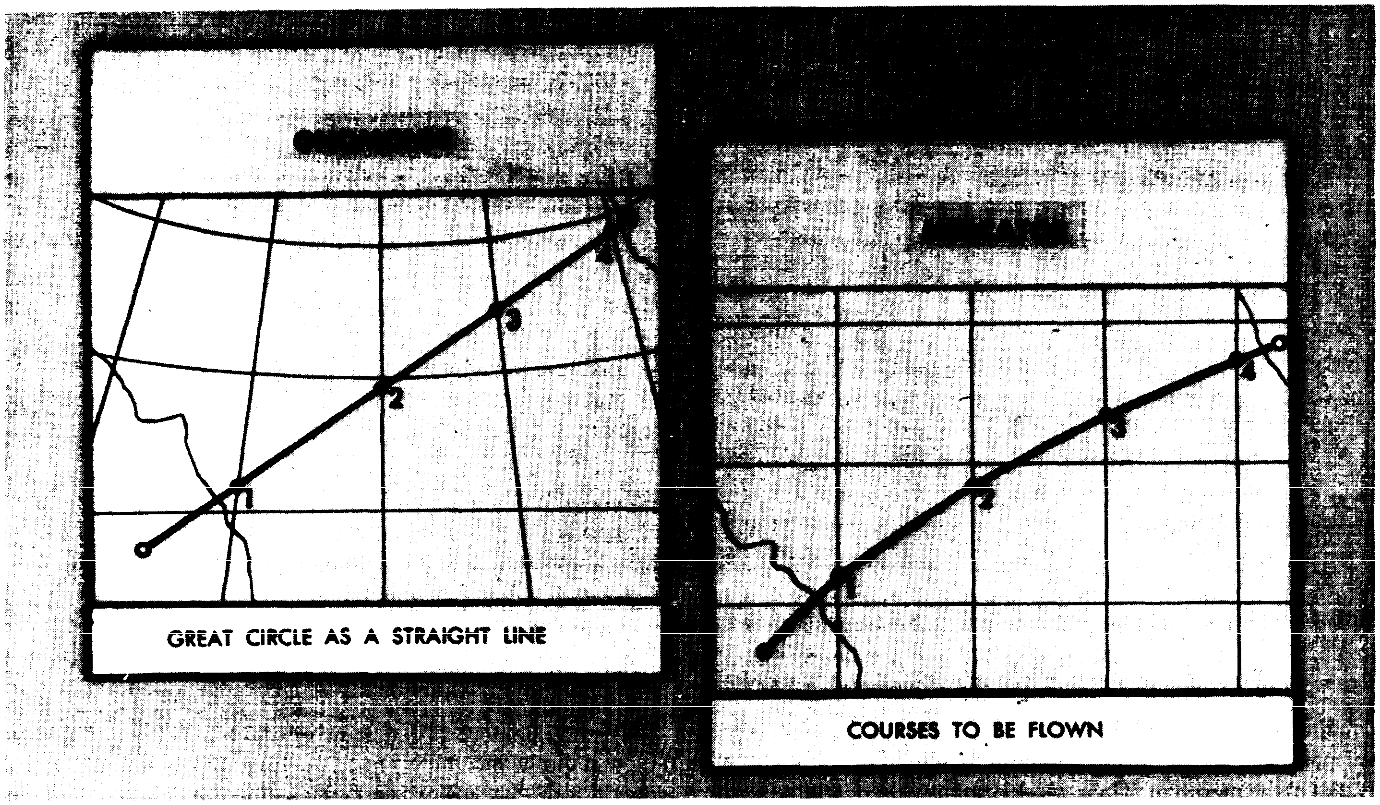


Figure 4-54. Transferring Great Circle Route from Gnomonic to Mercator Chart.

feasible to change heading continually, as is necessary when following a great circle exactly, and it is customary to divide the great circle into a series of legs, each covering about 5 degrees of longitude. The direction of the rhumb line connecting the ends of each leg is found at its midmeridian.

Measuring Distance. As previously stated, the scale on a Lambert conformal chart is practically constant, making it possible to use any part of a meridian graduated in minutes of latitude to measure nautical miles.

Plotting on a Gnomonic Chart. Gnomonic charts are used mainly for planning great circle routes. Since any straight line on a gnomonic chart is an arc of a great circle, a straight line drawn from the point of departure to destination will give a great circle route. Once obtained, this great circle route is transferred to a Mercator chart by breaking the route into segments as shown in figure 4-54.

Plotting Hints. The following suggestions should prove helpful in developing good plotting procedures:

• Measure all directions and distances carefully. Check and double-check all measurements, computations, and positions.

• Avoid plotting unnecessary lines. If a line serves no purpose, erase it.

• Keep plotting equipment in good working order. If the plotter is broken, replace it. Keep sharp points on dividers. Use a sharp-pointed, soft pencil and an eraser that will not smudge.

• Draw light lines at first, as they may have to be erased. When the line has been checked and proven to be correct, then darken it if desired.

• Label lines and points immediately after they are drawn. Use standard labels and symbols. Letter the labels legibly. Be neat and exact.

DR COMPUTER

Almost any type of navigation requires the solution of simple arithmetical problems involving time, speed, distance, fuel consumption and so forth. In addition, the effect of the wind on the aircraft must be known; therefore, the wind must be computed. To solve such problems quickly and with reasonable accuracy, various types of computers have been devised of which the computer described in this manual is one. This computer is simply a combination of two devices: (1) a circular slide rule for the solution of arithmetical problems (see figure 4-55), and (2) a specially designed instrument for the graphical solution of the wind problem (figure 4-56).

The slide rule is a standard device for the mechanical solution of various arithmetical problems. Slide rules operate on the basis of logarithms. Slide rules are either straight or circular; the one on the DR computer is circular.

The slide rule face of the computer consists of two flat metallic disks, one of which can be rotated around a common center. These disks are graduated near their edges with adjacent, logarithmic scales to form a circular slide rule approximately equivalent to a straight, 12-inch slide rule. Since the outer scale

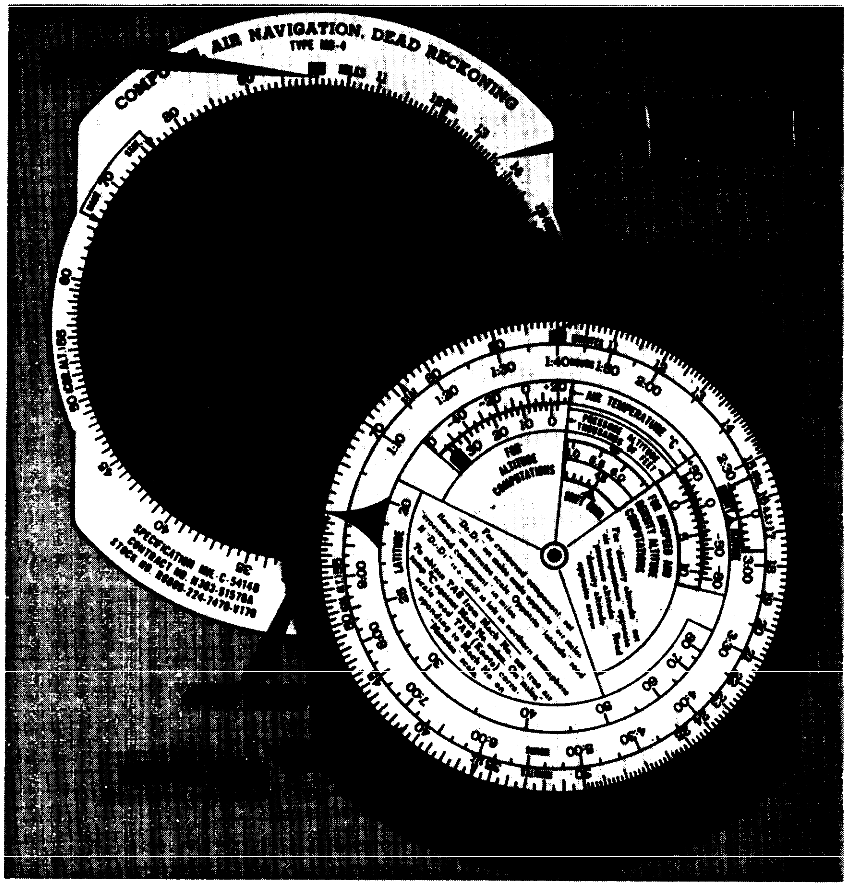


Figure 4-55. DR Computer Slide Rule Face.

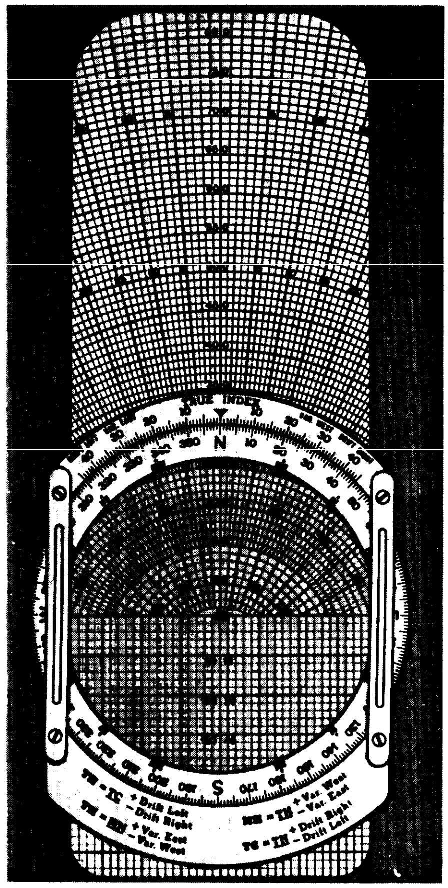


Figure 4-56. DR Computer Wind Face.

usually represents a number of miles and the inner scale, a number of minutes, they are called the miles scale and the minutes or time scale, respectively. (Refer to figure 4-55.)

The numbers on each scale represent the printed figure with the decimal point moved any number of places to the right or left. For example, the figure 12 on either scale can represent 1.2, 12, 120, 1200, etc.

Since speed (or fuel consumption) is expressed in miles (or gallons or pounds) per hour (60 minutes), a large, black arrow marked Speed Index is placed at the 60-minute mark.

Graduations of both scales are identical. The graduations are numbered from 10 to 100 and the unit intervals decrease in size as the numbers increase in size. Not all unit intervals are numbered. The first element of skill in using the computer is a sure knowledge of how to read the numbers.

Reading the Slide Rule Face

The unit intervals which are numbered present no difficulty. The problem lies in giving the correct values to the many small lines which come between the numbered intervals. There are no numbers given between 25 and 30 as shown in figure 4-57, for example, but it is obvious that the larger intermediate divisions are 26, 27, 28, and 29. Between 25 and (unnumbered) 26, there are five smaller divisions, each of which would therefore be .2 of the larger unit.

Problems on the Slide Rule Face

Simple Proportion. The slide rule face of the computer is so constructed that any relationship between two numbers, one on the miles scale and one on the minutes scale, will hold true for all other numbers on the two scales. Thus, if the two 10s are placed opposite each other, all other numbers will be identical around the circle. If 20 on the minutes scale is placed opposite 10 on the miles scale, all numbers on the minutes scale will be double those on the miles scale. This feature allows one to supply the fourth term of any mathematical proportion. Thus, the unknown in the equation

$$\frac{18}{45} = \frac{x}{80}$$

could be solved on the computer by setting 18 on the miles scale over 45 on the minutes scale and reading the answer (32) above the 80 on the minutes scale. It is this relationship that makes possible the solution of time-speed-distance problems.

Time, Speed, and Distance. An aircraft has traveled 24 miles in 8 minutes. How many minutes will be required to travel 150 miles? This is a simple proportion which can be written as

$$\frac{24}{8} = \frac{150}{x}$$

Setting the 24 over the 8 on the computer as illustrated in

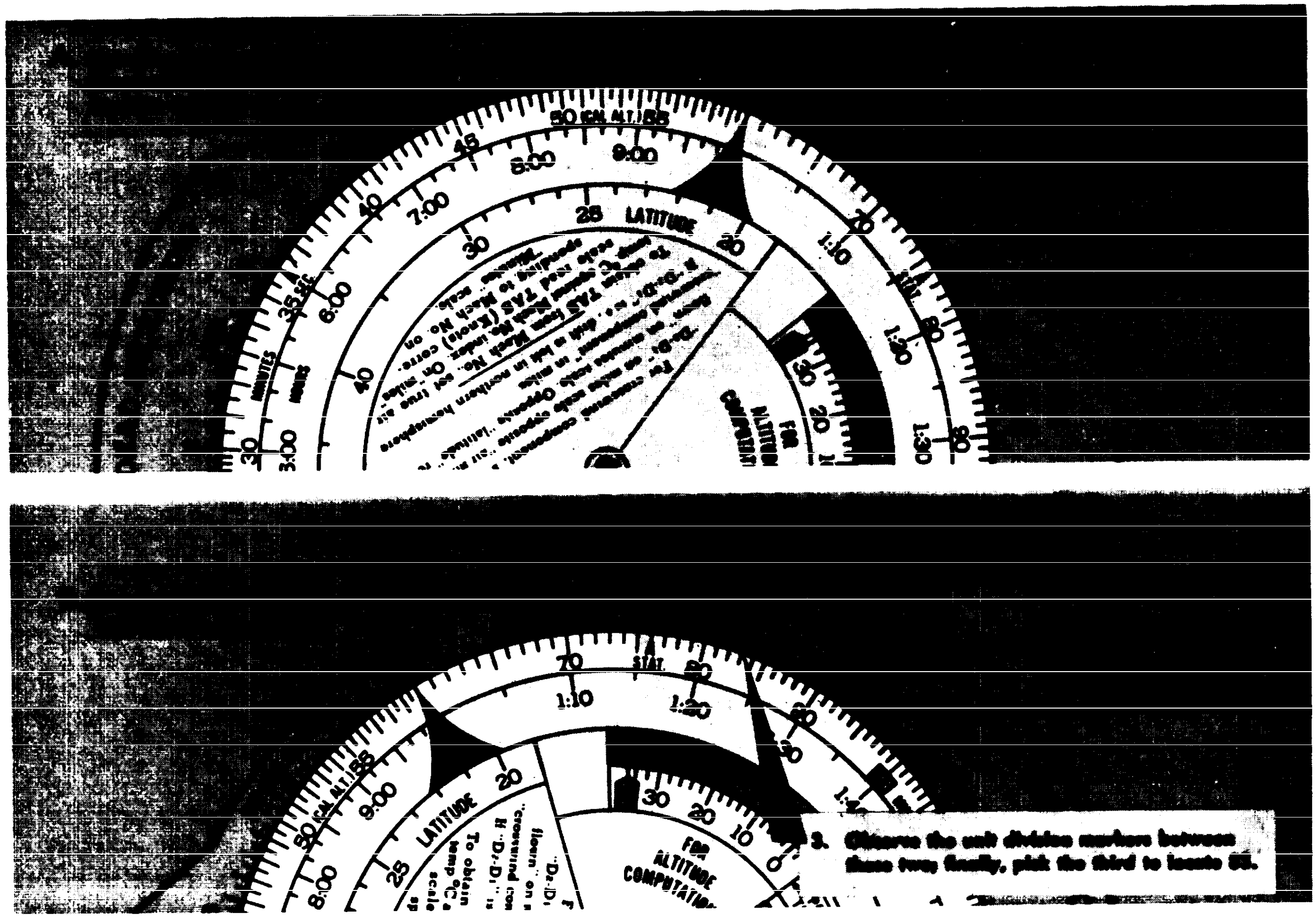


Figure 4-57. Reading the Slide Rule Face.

figure 4-58 and reading under the 150, we find the answer to be 50 minutes.

A problem that often occurs is to find the groundspeed of the aircraft when a given distance is traveled in a given time. This is solved in the same manner, except that the computer is marked with a speed index to aid in finding the correct proportion. In the problem just stated, if 24 is set over 8 as in the original problem, the groundspeed of the aircraft, 180 knots, is read above the speed index as shown.

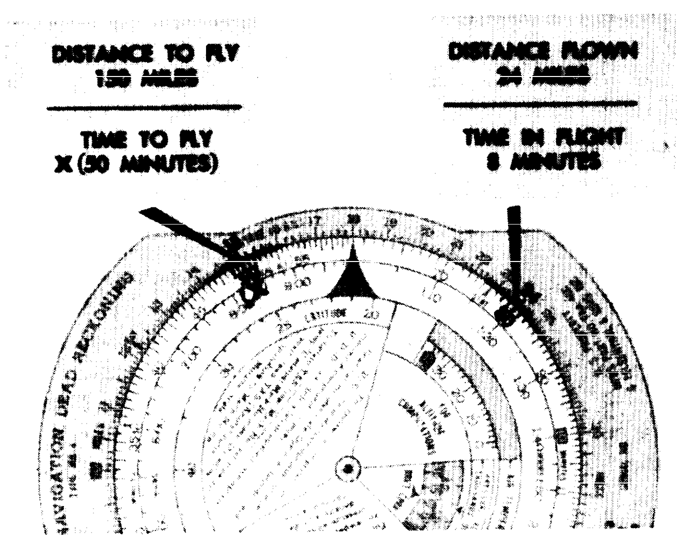


Figure 4-58. Solve for X.

Example: To find distance when groundspeed and time are known.

Given: Groundspeed 204 knots.

Required: Distance traveled in 1 hour 15 minutes (75 minutes).

Solution: Set the speed index on the minutes scale to 204 on the miles scale. Opposite 75 on the minutes scale, read 255 nautical miles on the miles scale. The computer solution is shown in figure 4-59. The solutions for time and speed when the other variables are known follow the same basic format. See figures 4-60 and 4-61.

Seconds Index. Since 1 hour is equivalent to 3,600 seconds, a subsidiary index mark, called seconds index, is marked at 36 on the minutes scale of some computers. When placed opposite a speed on the miles scale, the index relates the scales for converting distance to time in seconds. Thus, if 36 is placed opposite a groundspeed of 144 knots, 50 seconds is required to go 2 nautical miles, and in 150 seconds (2 minutes 30 seconds) 6.0 nautical miles are covered. Similarly, if 4 nautical miles are covered in 100 seconds, groundspeed is 144 knots (figure 4-62).

Conversion of Distance. Subsidiary indexes are placed on

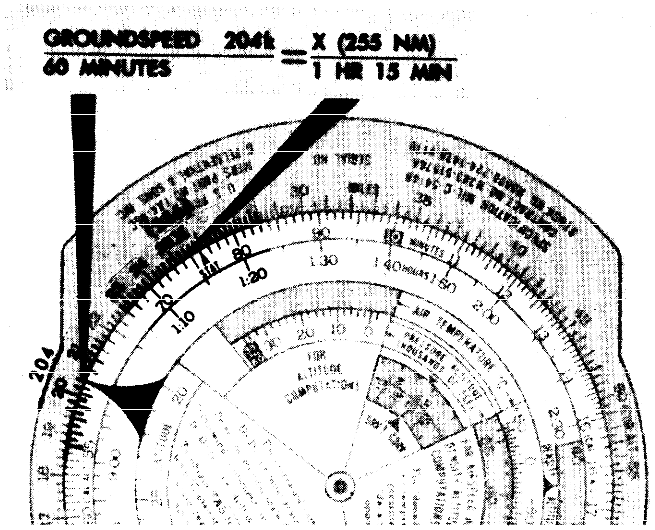


Figure 4-59. To Find Distance when Speed and Time are Known.

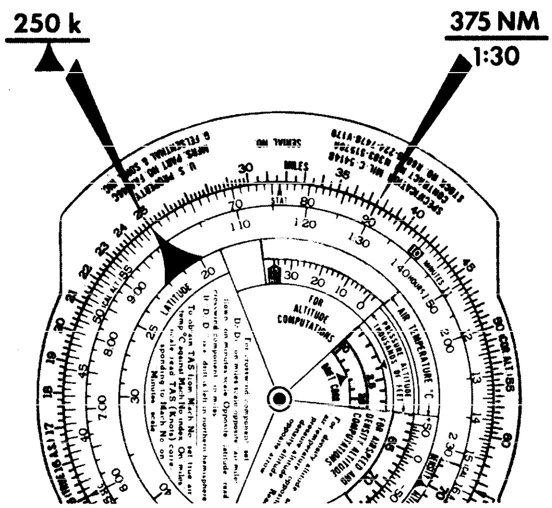


Figure 4-60. To Find Time when Speed and Distance are Known.

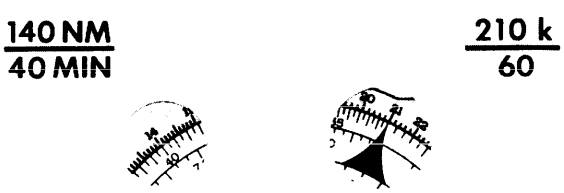


Figure 4-61. To Find Speed when Time and Distance are Known.

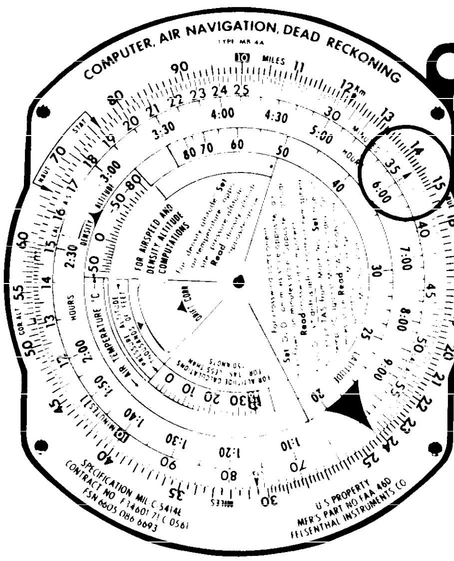


Figure 4-62. Use of the Seconds Index.

some computers to aid in the conversion of distances from one unit of measure to another. The most common interconversions are those involving statute miles, nautical miles, and kilometers.

Statute-Nautical Mile Interconversion. The miles scale of the computer is marked with a statute mile index at 76 and a nautical mile index at 66. The units are interconverted by setting the known distance under the appropriate index and reading the desired unit under the other.

Example: To convert 136 statute miles to nautical miles, set 136 on the minutes scale under the STAT index on the miles scale. Under the NAUT index on the miles scale, read the number of nautical miles (118) on the minutes scale (figure 4-63).

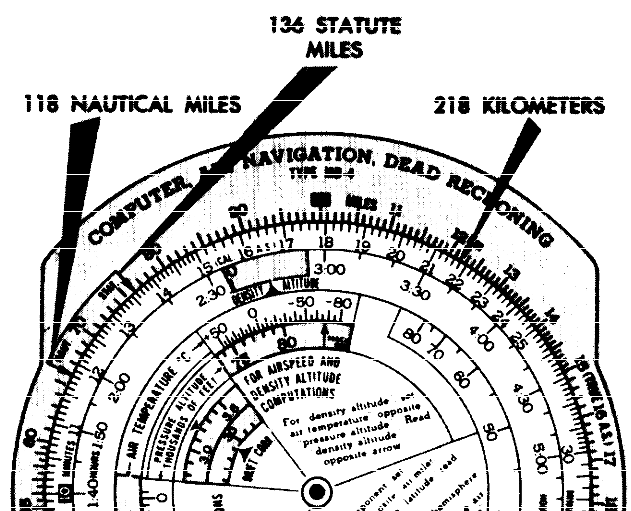


Figure 4-63. Statute Mile, Nautical Mile, Kilometer Interconversion.

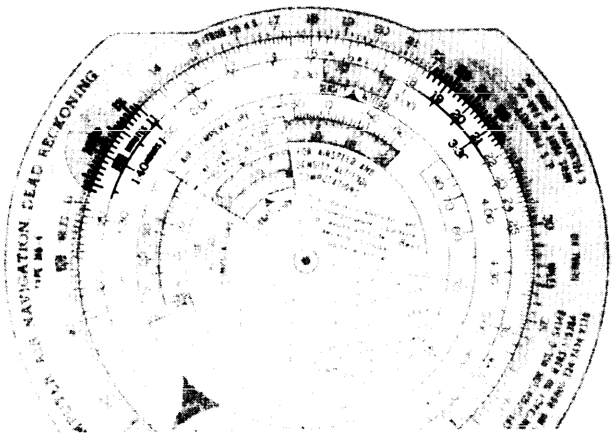


Figure 4-64. To Multiply Two Numbers.

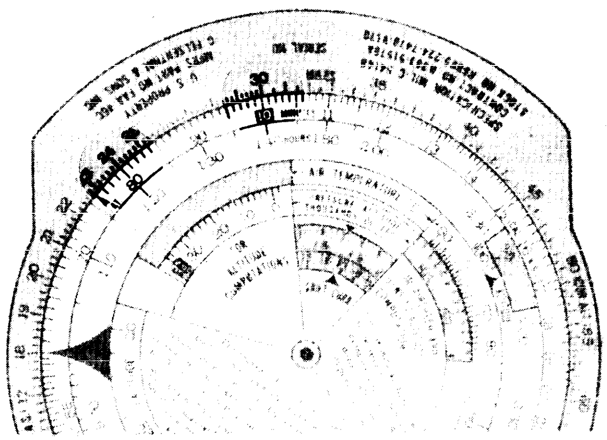


Figure 4-65. To Divide One Number by Another.

Conversion of Nautical or Statute Miles to Kilometers. A kilometer index is indicated on the miles scale of the computer at 122. When nautical or statute miles are placed under their appropriate index on the miles scale, kilometers may be read, on the minutes scale, under the Km index.

Example: To convert 118 nautical miles to kilometers, place 118 on the minutes scale under the NAUT index on the miles scale. Under the Km index on the miles scale, read kilometers (218) on the minutes scale.

Multiplication and Division. To multiply two numbers, for example 12 × 2, the index (printed as 10 on the minutes scale) is placed opposite one of the numbers to be multiplied (12), and the product (24) is read on the miles scale above the other number (2) on the minutes scale (figure 4-64).

To divide one number by another, for example 24 ÷ 8, set the divisor (8) on the minutes scale opposite the dividend (24) on the miles scale, and read the quotient (3) on the miles scale opposite the index on the minutes scale (figure 4-65).

The rules for placing the decimal point are given in most algebra texts. However, in the computations encountered in air navigation, as in the above examples, a mental estimate will aid in placing the decimal point.

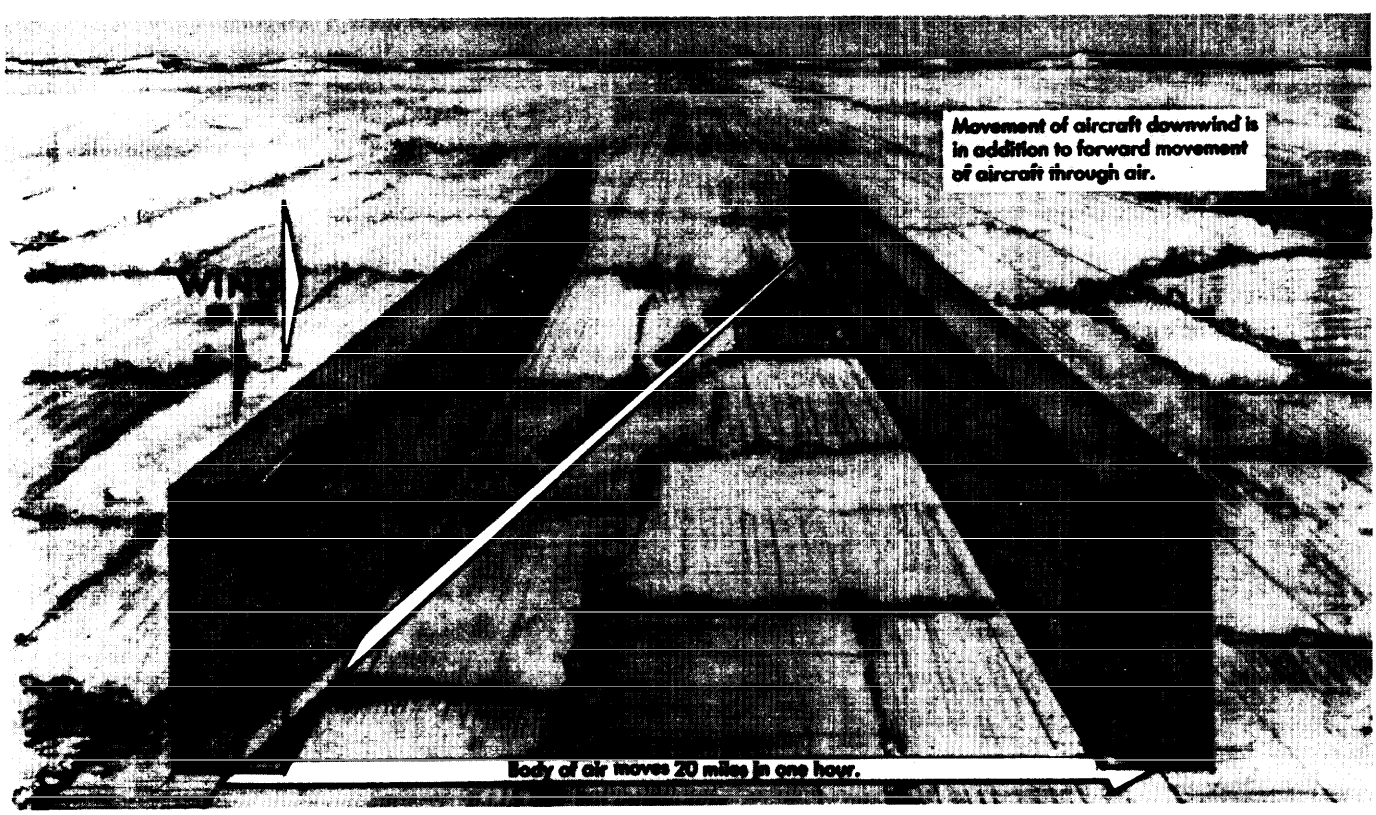


Figure 4-66. Two Factors Determine Path of Aircraft.

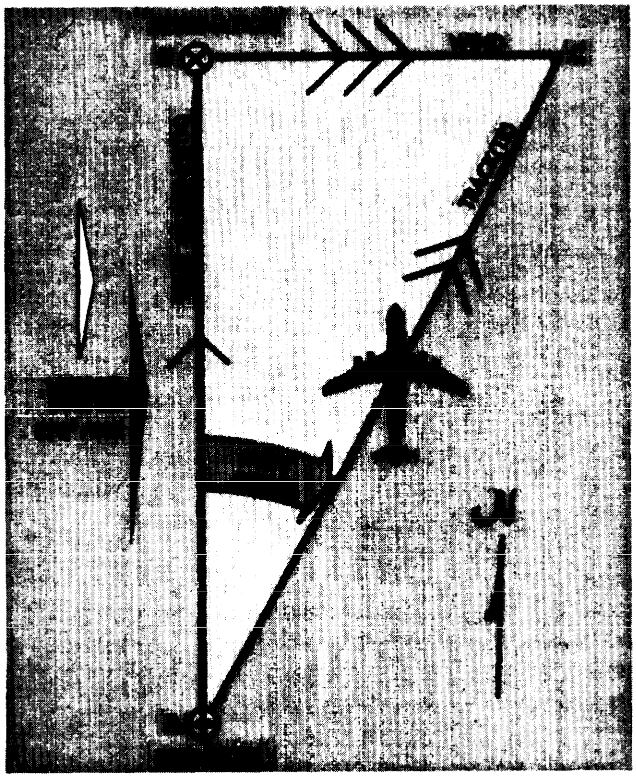


Figure 4-67. In 1 Hour, Aircraft Drifts Downwind an Amount Equal to Wind Speed.

EFFECT OF WIND ON AIRCRAFT

Any vehicle traveling on the ground, such as an automobile, moves in the direction in which it is steered or headed and is affected very little by wind. However, an aircraft seldom travels in exactly the direction in which it is headed because of the wind effect.

Any free object in the air moves downwind with the speed of the wind. This is just as true of an aircraft as it is of a balloon. If an aircraft is flying in a 20-knot wind, the body of air in which it is flying moves 20 nautical miles in 1 hour. Therefore, the aircraft also moves 20 nautical miles downwind in 1 hour. This movement is in addition to the forward movement of the aircraft through the body of air.

The path of an aircraft over the Earth is determined by the two unrelated factors shown in figure 4-66: (1) the motion of the aircraft through the air mass, and (2) the motion of the air mass across the Earth's surface. The motion of the aircraft through the air mass is directly forward in response to the pull of the propellers or thrust of the jet units, and its rate of movement through the air mass is true airspeed. This motion takes place in the direction of true heading. This motion of the air mass across the Earth's surface may be from any direction and at any speed. The measurement of its movement is called wind and is expressed in direction and speed (W/V).

Drift Caused by Wind

The effect of wind on the aircraft is to cause it to follow a different path over the ground than it does through the air mass. The path over the ground is its track (Tr). The terms TC and Tr

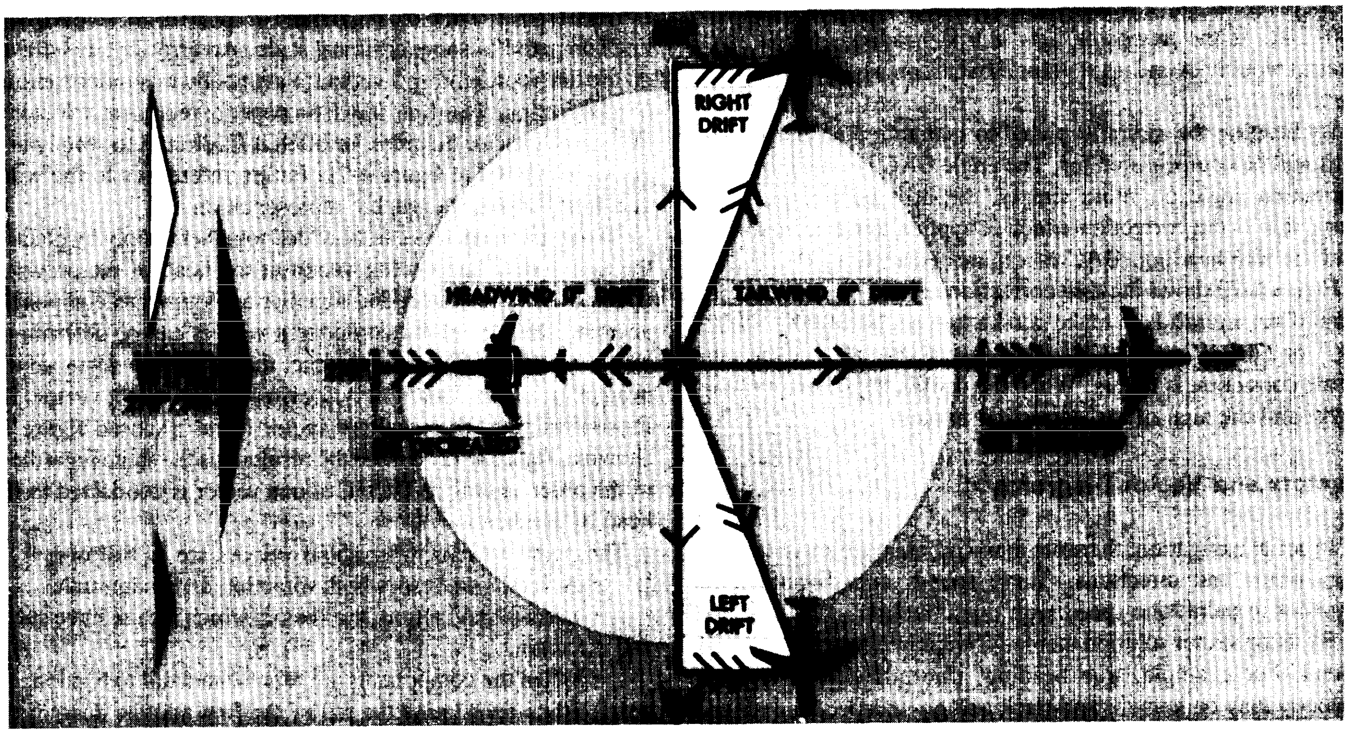


Figure 4-68. Effects of Wind on Aircraft Flying in Opposite Directions.

are often considered synonomous. True course represents the intended path of the aircraft over the Earth's surface. Track is the actual path that the aircraft has flown over the Earth's surface. True course is considered to be future, while track is considered to be past.

The lateral displacement of the aircraft caused by the wind is called drift. Drift is the angle between the true heading and the track. As shown in figure 4-67, the aircraft has drifted to the right; this is known as right drift.

With a given wind, the drift will change on each heading. A change of heading will also affect the distance flown over the Earth's surface in a given time. This rate traveled relative to the Earth's surface is known as groundspeed (GS). Therefore, with a given wind, the groundspeed (GS) varies on different headings.

Figure 4-68 shows the effect of a 270°/20k wind on the groundspeed and track of an aircraft flying on headings of 000°, 090°, 180°, and 270°. The aircraft flies on each heading from point X for 1 hour at a constant true airspeed.

Note that on a true heading of 000°, the wind causes right drift, whereas on a true heading of 180°, the same wind causes left drift. On the headings of 090° and 270° there is no drift at all. Note further than on a heading of 090° the aircraft is aided by a tailwind and travels farther in 1 hour than it would without a wind; thus, its groundspeed is increased by the wind. On the heading of 270°, the headwind cuts down on the groundspeed and also cuts down the distance traveled. On the headings of 000° and 180°, the groundspeed is somewhat increased.

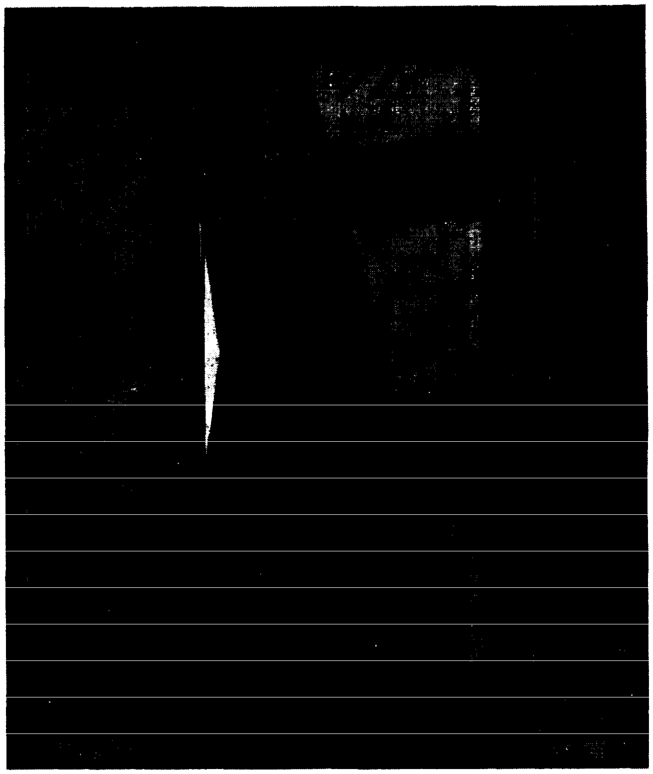


Figure 4-69. Aircraft Heads Upwind to Correct for Drift.

Drift Correction Compensates for Wind

In figure 4-69, suppose the navigator wants to fly from point A to point B, on a true course of 000°, when the wind is 270°/20k. If the navigator flew a true heading of 000°, the aircraft would not end up at point B but at some point downwind from B.

By heading the aircraft upwind to maintain the true course, drift will be compensated for. The angle BAC is called the drift correction angle or, more simply, the drift correction. Drift correction is the correction which is applied to a true course to find the true heading. BAC is a minus correction.

Figure 4-70 shows the drift correction necessary in a 270°/20k wind if the aircraft is to make good a true course of 000°, 090°, 180°, or 270°. When drift is right, correct to the left, and the sign of the correction is minus. When the drift is left, correct to the right, and the sign of the correction is plus.

Vectors and Vector Diagrams

In aerial navigation, there are many problems to solve involving speeds and directions. These speeds and directions fit together in pairs; one speed with one direction.

By using vector solution methods, unknown quantities can be found. For example, true heading, true airspeed, and wind velocity may be known, and track and groundspeed unknown. To solve such problems, the relationships of these quantities must be understood.

The vector can be represented on paper by a straight line. The direction of this line would be its angle measured clockwise from true north, while the magnitude or speed is the length of the line compared to some arbitrary scale. An arrowhead is drawn on the line representing a vector to avoid any misunderstanding of its direction. This line drawn on paper to represent a vector is known as a vector diagram, or often it is referred to simply as a vector as shown in figure 4-71. Future references to the word vector will mean its graphic representation.

Two or more vectors can be added together simply by placing the tail of each succeeding vector at the head of the previous vector. These vectors added together are known as component vectors. The sum of the component vectors can be determined by connecting, with a straight line, the tail of one vector to the head of the other. This sum is known as the resultant vector. By its construction, the resultant vector forms a closed figure as shown in figure 4-72. Notice the resultant is the same regardless of the order as long as the tail of one vector is connected to the head of another.

The points to remember about vectors are as follows:

- A vector possesses both direction and magnitude.
- In aerial navigation, the vectors which we use have speed and direction.
- When the components are represented tail to head in any order, a line connecting the tail of the first and the head of the last represents the resultant.
- All component vectors must be drawn to the same scale.

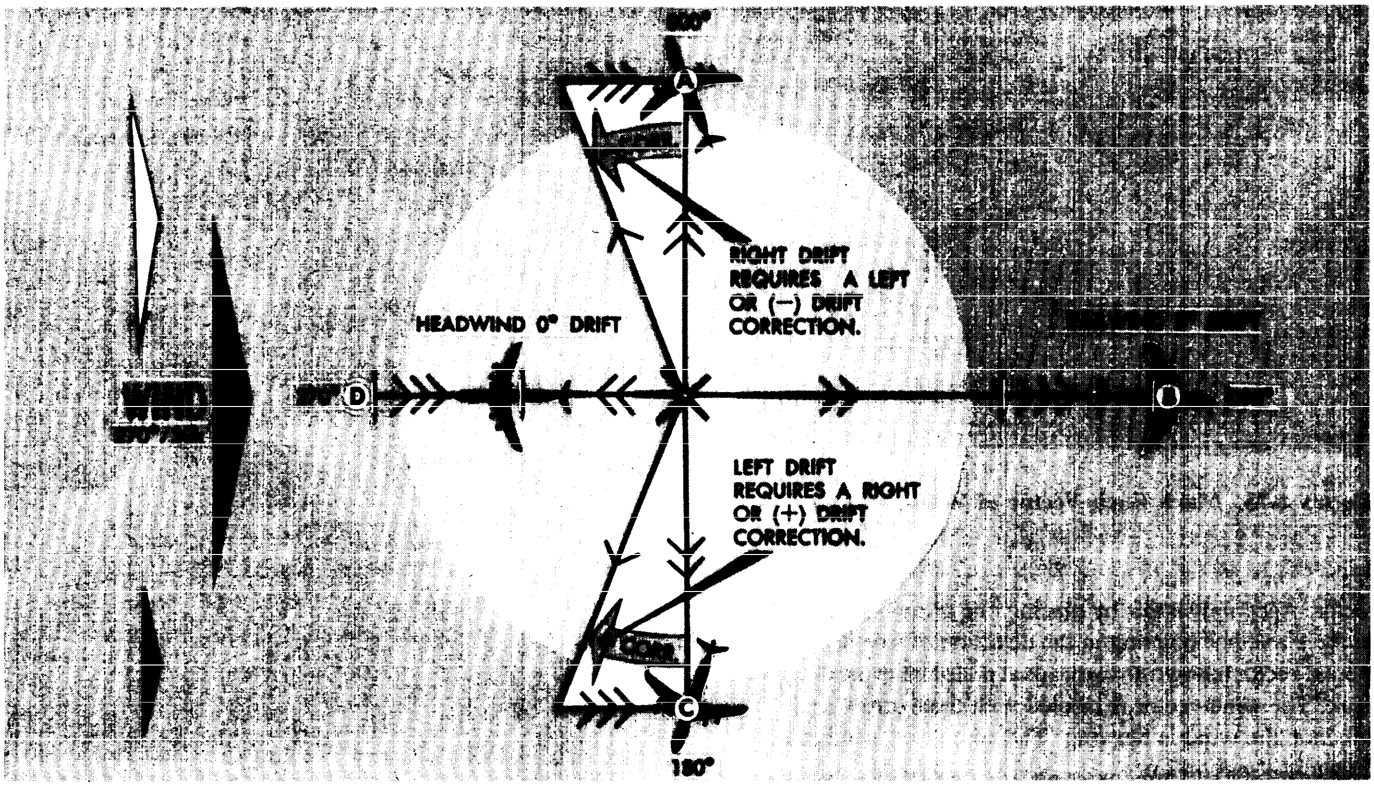


Figure 4-70. Maintaining Course in Wind.

Wind Triangle and Its Solution

A vector illustration showing the effect of the wind on the flight of an aircraft is called a wind triangle. Draw a line to show the direction and speed of the aircraft through an air mass (TH and TAS); this vector is called the air vector. Using the same scale, connect the tail of the wind vector to the head of the air vector. Draw a line to show the direction and speed of the wind (W/V); this is the wind vector. A line connecting the tail of the air vector with the head of the wind vector is the resultant of these two component vectors; it shows the direction and speed of the aircraft over the Earth (Tr and GS). It is called the ground vector.

To distinguish one from another, it is necessary to mark each

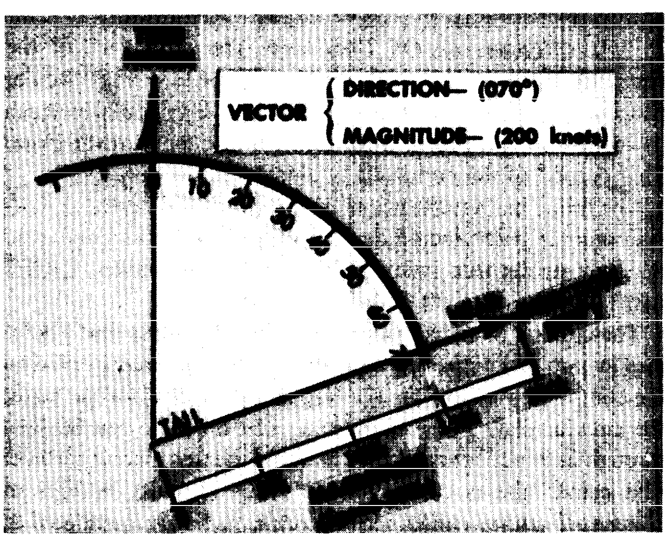


Figure 4-71. A Vector has both Magnitude and Direction.

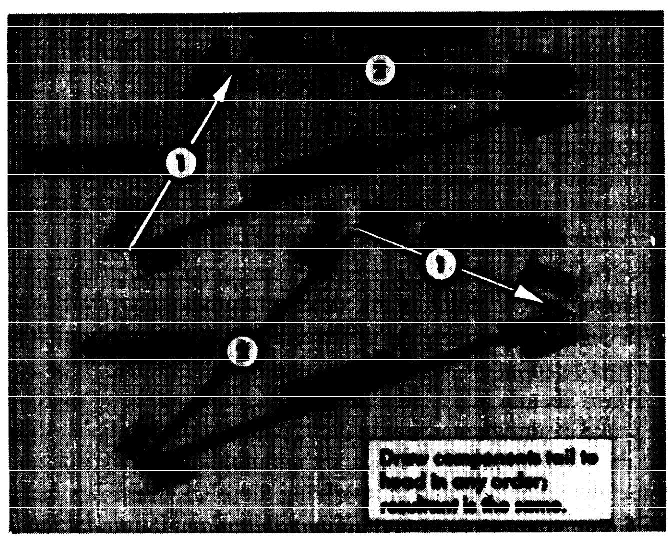


Figure 4-72. Resultant Vector is Sum of Component Vectors.

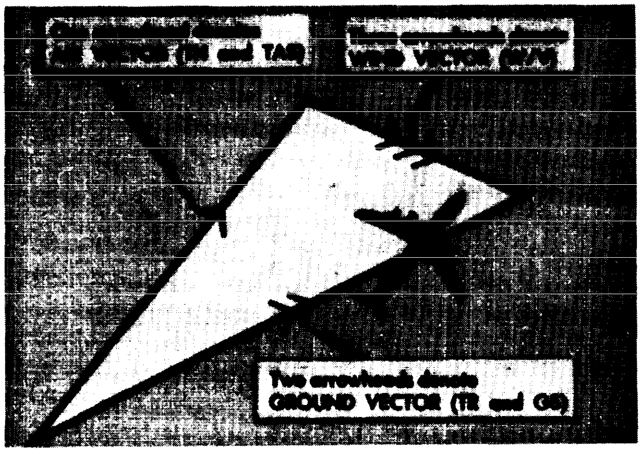


Figure 4-73. Mark Each Vector of Wind Triangle.

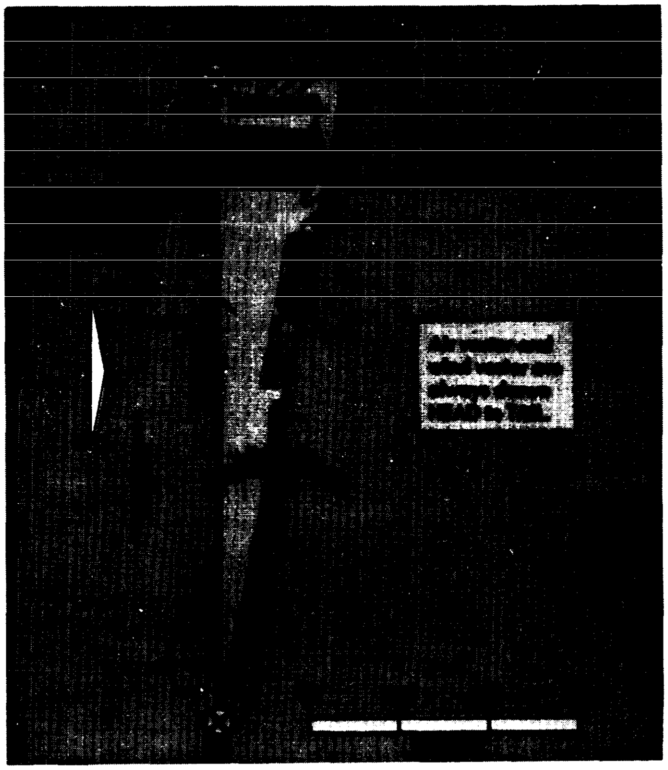


Figure 4-74. Wind Triangle.

vector. Accomplish this by placing one arrowhead at midpoint on the air vector pointing in the direction of true heading. The ground vector has two arrowheads at midpoint in the direction of track. The wind vector is labeled with three arrowheads in the direction the wind is blowing. The completed wind triangle is shown in figure 4-73.

Remember that wind direction and wind speed compose th wind vector. True airspeed and true heading form the air vector and groundspeed and track compose the ground vector.

The ground vector is the resultant of the other two; hence, the air vector and the wind vector are always drawn head to tail. An easy way to remember this is that the wind always blows the aircraft from true heading to track.

Consider just what the wind triangle shows. In figure 4-74, the aircraft departs from point A on the true heading of 360° at a true airspeed of 150 knots. In 1 hour, if there is no wind, it reaches point B at a distance of 150 nautical miles.

In actuality, the wind is blowing from 270° at 30 knots. At the end of 1 hour, the aircraft is at point C, 30 nautical miles downwind. Therefore, the length BC represents the speed of the wind drawn to the same scale as the true airspeed. The length of BC represents the wind and is the wind vector.

Line AC shows the distance and direction the aircraft travels over the ground in 1 hour. The length of AC represents the groundspeed drawn to the same scale as the true airspeed and wind speed. Thus, the line AC, which is the resultant of AB and BC, represents the motion of the aircraft over the ground and is the ground vector.

Measuring the length of AC determines that the groundspeed is 153 knots. Measuring the drift angle, BAC, and applying it to the true heading of 360°, results in the track of 011°.

If two vectors in a wind triangle are known, the third one can be found by drawing a diagram and measuring the parts. Actually, the wind triangle includes six quantities; three speeds and three directions. Problems involving these six quantities make up a large part of dead reckoning navigation. If four of these quantities are known, the other two can be found. This is called solving the wind triangle and is an important part of navigation.

The wind triangle may be solved by trigonometric tables; however, this is unnecessary since the accuracy of this method far exceeds the accuracy of the data available and of the results needed. In flight, the wind triangle is solved graphically, either on the chart or on the vector or wind face of the computer.

The two graphic solutions of the wind triangle—the chart solution and computer solution—perhaps appear dissimilar at first glance. However, they work on exactly the same principles. Plotting the wind triangle on paper has been discussed; now, the same triangle is plotted on the wind face of the computer.

Wind Triangles on DR Computer. The wind face of the computer has three parts: (1) a frame, (2) a transparent circular plate which rotates in the frame, and (3) a slide or card which can be moved up and down in the frame under the circular plate. This portion of the computer is illustrated in figure 4-75.

The frame has a reference mark called the TRUE INDEX. A drift scale is graduated 45 degrees to the left and 45 degrees to the right of the true index; to the left this is marked DRIFT LEFT, and to the right, DRIFT RIGHT.

The circular plate has around its edge a compass rose graduated in units of 1 degree. The position of the plate may be read on the compass rose opposite the true index. Except for the edge, the circular plate is transparent, so that the slide can be seen through it. Pencil marks can be made on the transparent surface. The center line is cut at intervals of two units by arcs of concentric circles called speed circles; these are numbered at intervals of 10 units.

On each side of the center line are track lines, which radiate from a point of origin off the slide as shown in figure 4-76. Thus,

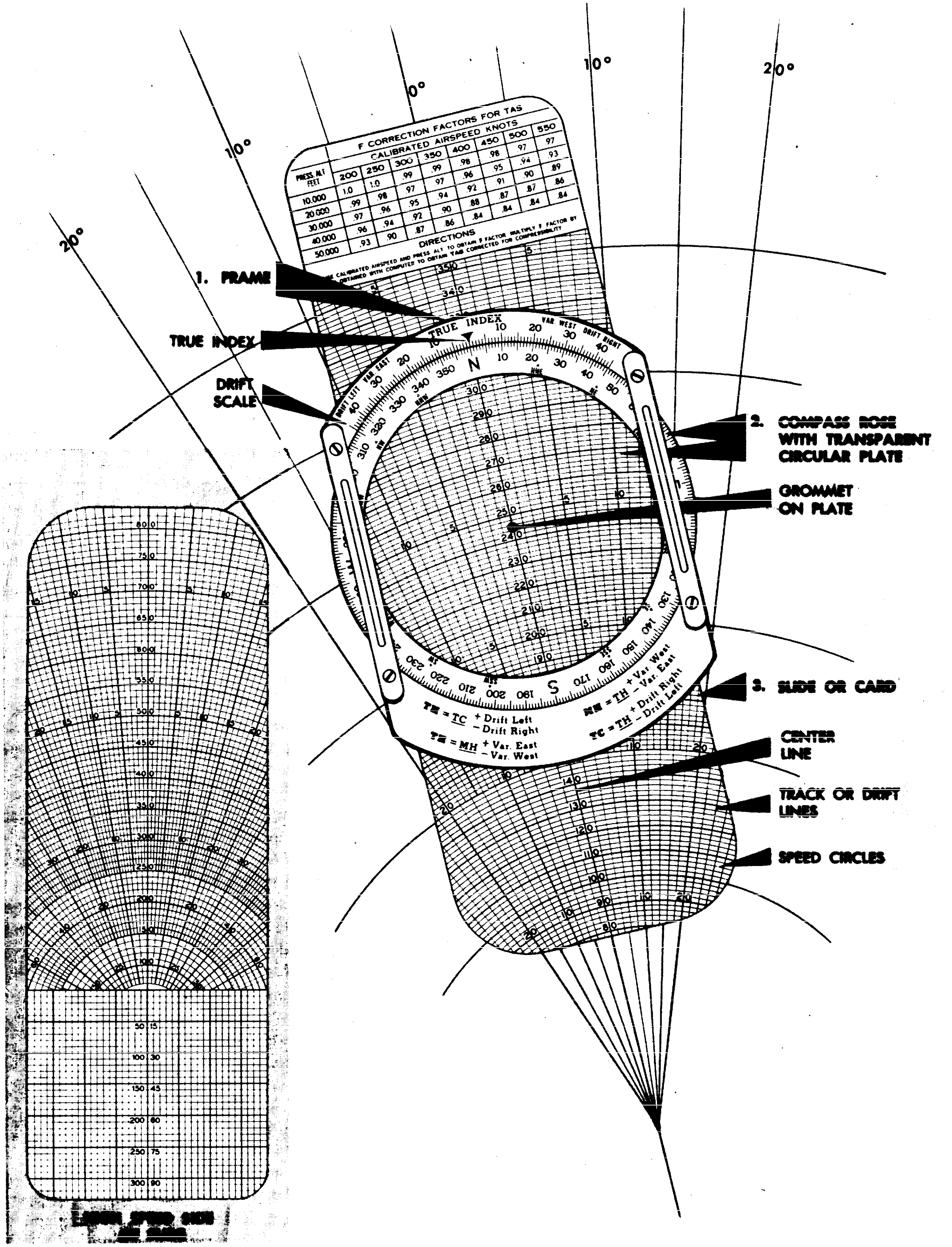


Figure 4-75. Wind Face of DR Computer.

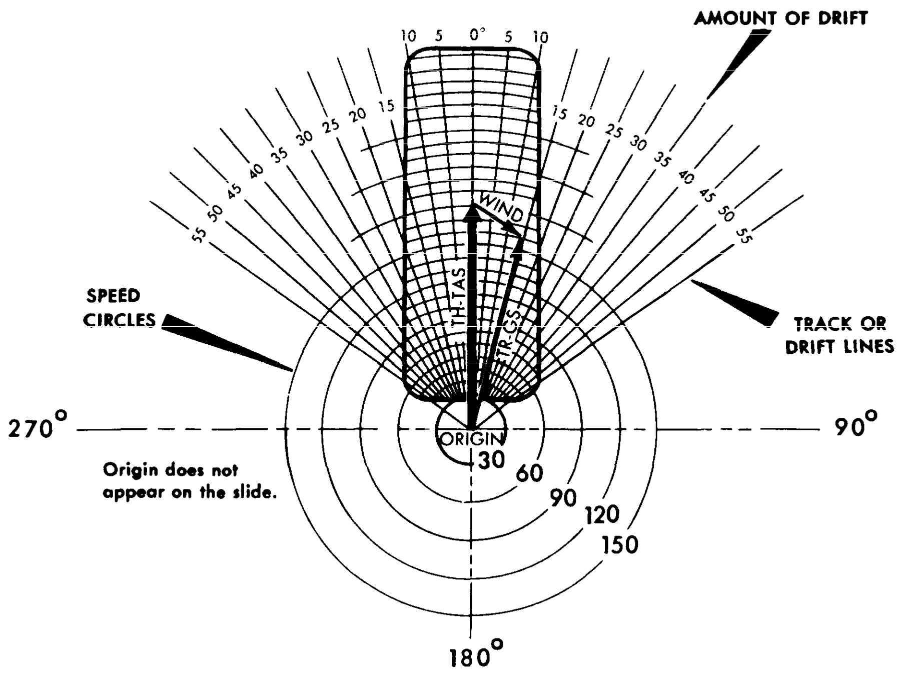


Figure 4-76. Speed Circles and Track Lines.

the 14° track line on each side of the center line makes an angle of 14° with the center line at the origin. And the point where the 14° track line intersects the speed circle marked 160 is 160 units from the origin.

In solving a wind triangle on the computer, plot part of the triangle on the transparent surface of the circular plate. For the other parts of the triangle, use the lines which are already drawn on the slide. Actually, there isn't room for the whole triangle on the computer, for the origin of the center line is one vertex of the triangle. When learning to use the wind face of the computer, it may help to draw in as much as possible of each triangle.

The center line from its origin to the grommet always represents the air vector. If the true airspeed is 150 knots, move the slide so that 150 is under the grommet; then the length of the vector from the origin to the grommet is 150 units as illustrated in figure 4-77A.

The ground vector is represented by one of the track lines, with its tail at the origin and its head at the appropriate speed circle. If the track is 15° to the right of the true heading, and the groundspeed is 180 knots, use the track line 15° to the right of the center line and consider the intersection of this line with the 180 speed circle as the head of the vector as illustrated in figure 4-77B.

The tail of the wind vector is at the grommet and its head is at the head of the ground vector as shown in figure 4-77C.

Thus far, nothing has been said about the direction of the vectors. Since the true index is over the center line beyond the head of the air vector, this vector always points toward the index. Therefore, true heading is read on the compass rose opposite the true index.

Since track is true heading with the drift angle applied, the value of track can be found on the scale of the circular plate opposite the drift correction on the drift scale. The wind vector is drawn with its tail at the grommet as shown in figure 4-78. Since wind direction is the direction from which the wind blows, it is indicated on the compass rose by the rearward extension of the wind vector. Therefore, the most convenient way to draw the wind vector is to set wind direction under the true index and draw the vector down the center line from the grommet; the scale on the center line can then be used to determine the length of the vector.

Conversely, to read a wind already determined, place the head of the wind vector on the center line below the grommet and read wind direction below the true index.

Wind Triangle Problems. Depending on which of the six quantities of the wind triangle are known and which are unknown, there are three principal types of problems to solve. They are to solve for (1) the ground vector, (2) the wind vector, and (3) true heading and groundspeed. The following discussion gives the steps for the computer solution for each type. Work each sample problem and notice that the same wind triangle is shown on the computer that is shown on the chart, even though it is not completely drawn on the computer.

To find ground vector when air vector and wind vector are known:

Sample Problem:

Given:	TH 100°
	TAS 210k
	W/V 020/25k
To Find:	Tr and GS

This type of problem arises when true heading and true airspeed are known by reading the flight instruments and when the wind direction and velocity are known from either the metro forecast or from determinations in flight.

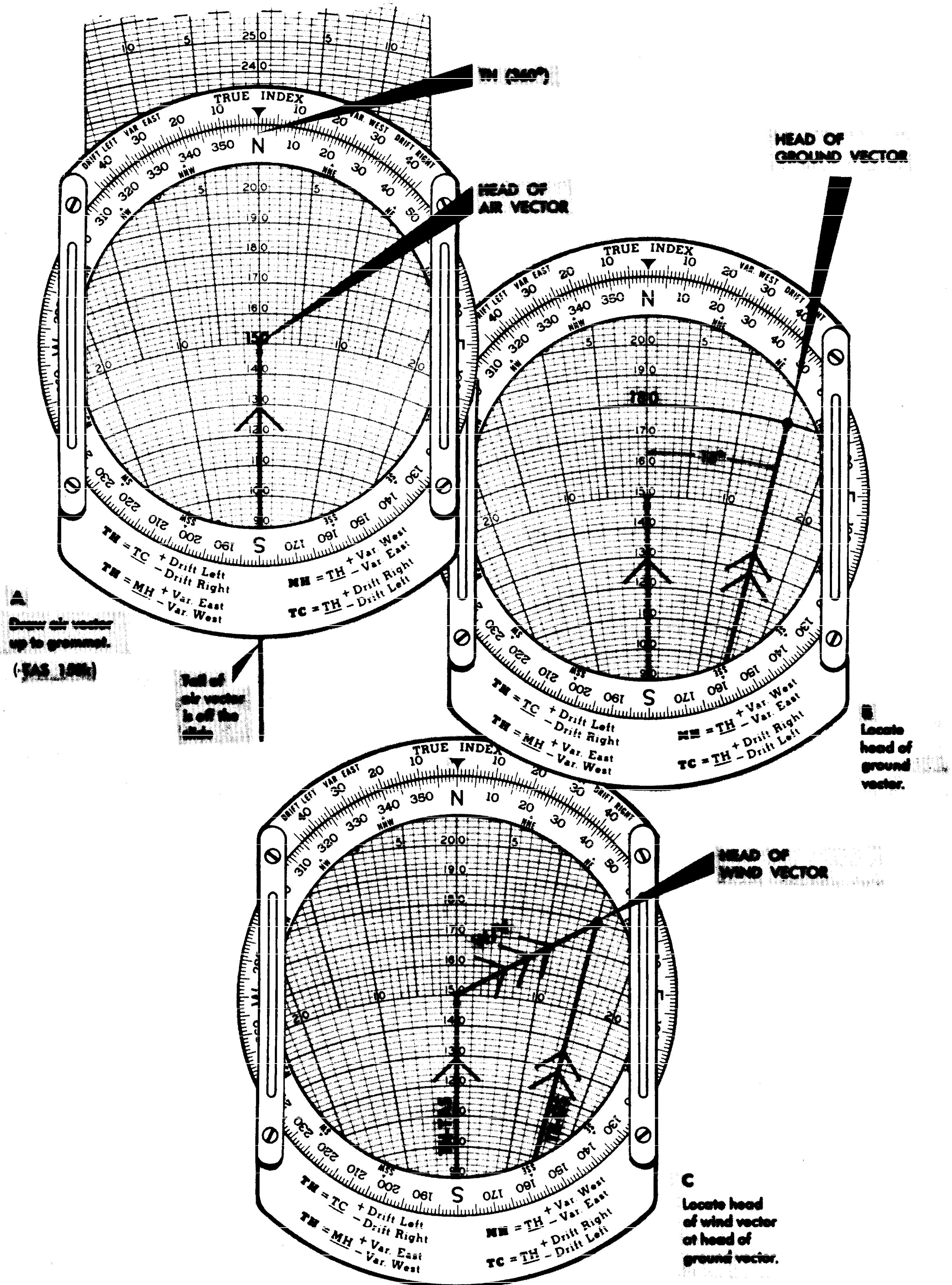


Figure 4-77. Plotting a Wind Triangle on Computer.

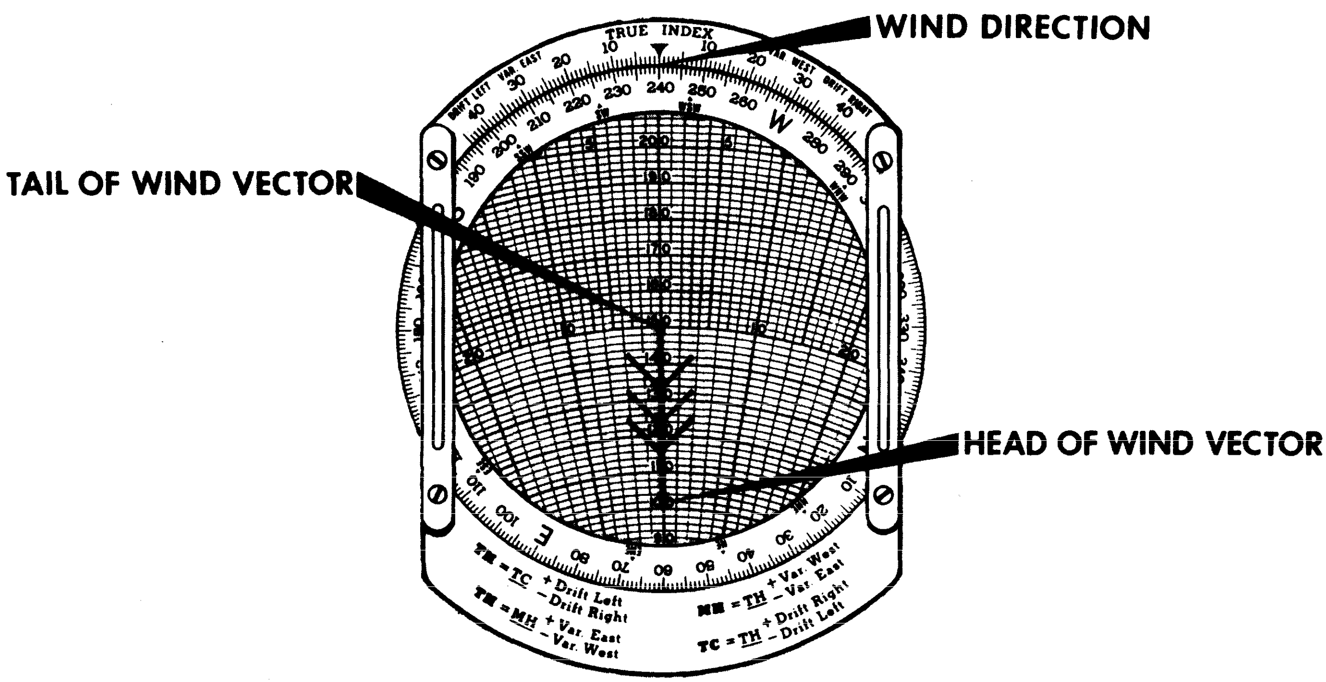


Figure 4-78. Draw Wind Vector Down from Grommet.

Study figure 4-79 and determine what has happened. By flying on a true heading of 100° at a true airspeed of 210 knots in a wind of 020°/25k, the aircraft has actually moved over the ground along a track of 107° at a groundspeed of 208 knots.

Computer Solution: First, set the data:

1. Set wind direction (020°) under the true index.
2. Draw the wind vector from the grommet down the center line, making its length (25 units) along the speed scale to conform with the wind speed (25k).
3. By rotating the compass rose, set the true heading (100°) under the true index.
4. Slide the card up or down until the true airspeed (210k) is under the grommet. The wind triangle is now constructed on the computer as illustrated in figure 4-80. The ground vector lies along one of the radiating track (Tr) lines with its head at the head of the wind vector.

Now read the answers.

5. Read groundspeed (208k) on the speed circle which passes through the head of the ground vector.
6. Read the drift angle (7° right) by counting the number of degrees from the center line to the ground vector; that is, to the head of the wind vector.
7. Determine track (107°) by applying the drift angle to the true heading. If the track is right of the center line, it is greater than the true heading; so the drift angle must be added to the true heading. An alternate method of determining track on the computer is to read the drift angle at the head of the ground vector, then transform this value to the drift scale on the same side of the

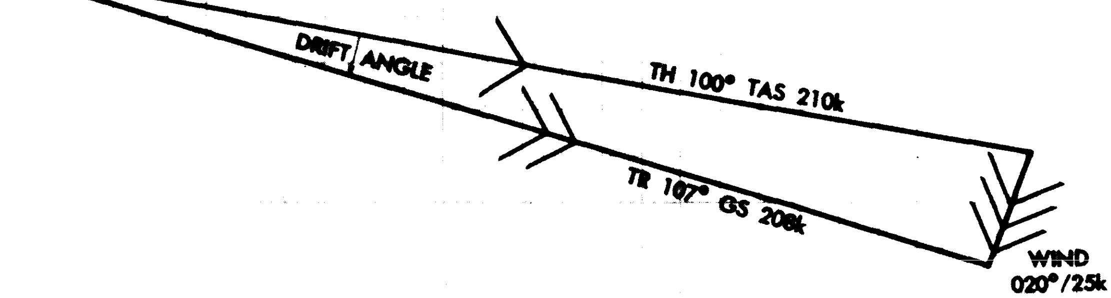


Figure 4-79. To Find Track and Groundspeed Using Chart.

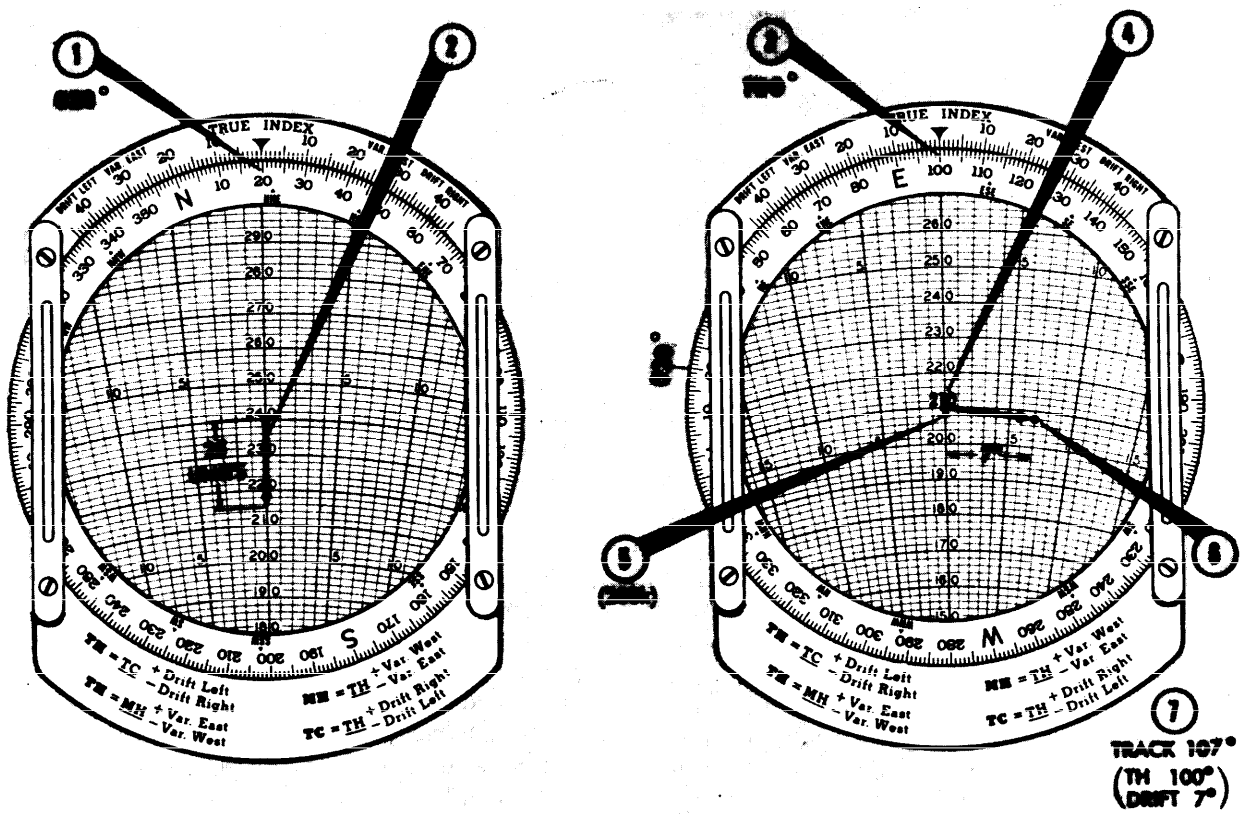


Figure 4-80. To Find Track and Groundspeed Using Computer.

true index and read the track on the compass rose of the circular disk.

To find wind vector when air vector and ground vector are known.

Sample Problem:

Given: TH 270°
Tr 280°
TAS 230k
GS 215k

To Find: W/V

This type of problem arises when determination of true heading and true airspeed can be done by reading the flight instruments and finding track and groundspeed either by measuring the direction and distance between two established positions of the aircraft or by determining the drift angle and groundspeed by reference to the ground. Refer to figure 4-81 for a graphic solution.

Computer Solution (figure 4-82). First, set in the data:

1. Set the true heading (270°) under the true index.
2. Set the true airspeed (230k) under the grommet.
3. Find the drift angle (10° right) by comparing the true heading (270°) with the track (280°). If the track is greater than

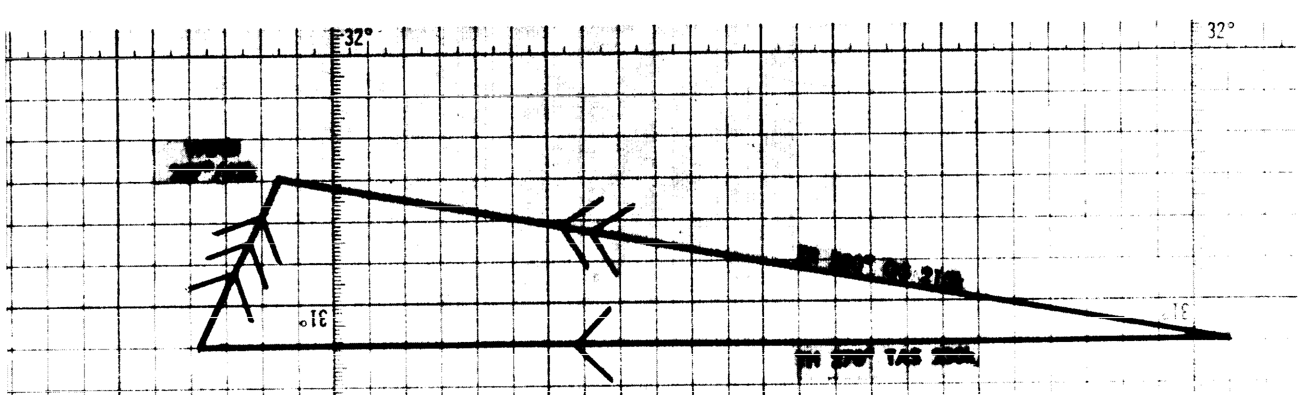


Figure 4-81. To Find Wind Using Chart.

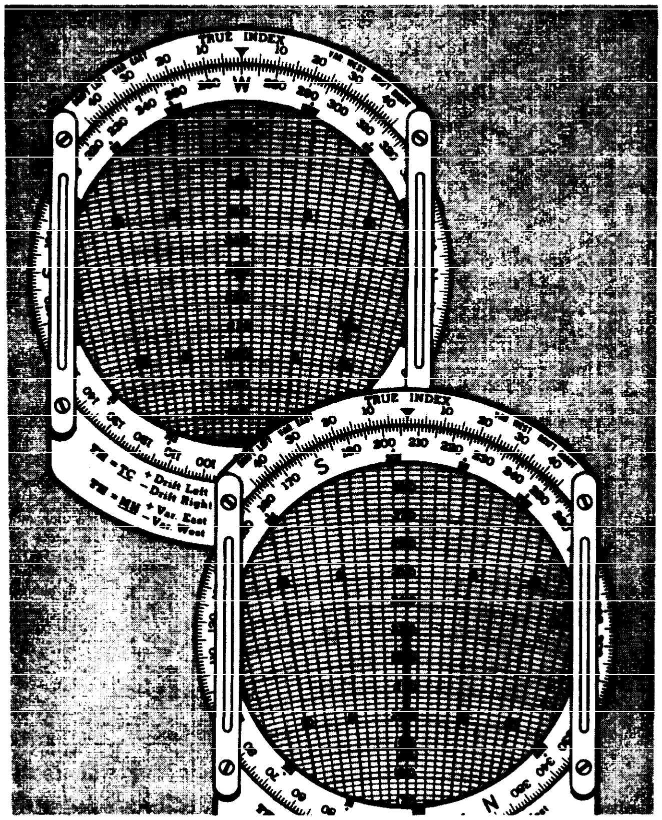


Figure 4-82. To Find Wind Using Computer.

the true heading, drift is right; if it is less, drift is left. Find the appropriate track line on the computer (10° right of center line).

4. Find the speed circle (215k) corresponding to the groundspeed circle.

The wind triangle is now constructed. The mark made is the head of the wind vector and the head of the ground vector.

5. Rotate the compass rose until the head of the wind vector is on the center line below the grommet. Read the wind direction (207°) under the true index.

6. Read the wind speed (42k) on the speed scale between the grommet and the head of the wind vector.

To find true heading and groundspeed when true course, true airspeed, and wind vectors are known:

Sample Problem:

Given:	TC 230°
	TAS 220k
	W/V 270°/50k
To Find:	TH and GS

This type of problem arises before a flight or during a flight, when you need to determine a true heading to fly and a groundspeed with which to compute an ETA.

Chart Solution (figure 4-83). First, construct the triangle.

1. From any origin, draw the wind vector in any convenient scale in the direction toward which the wind is blowing (090°) and to the length representing the wind speed (50k).

2. From the same origin, draw a line in the direction of the true course (230°) and of indefinite length, since the groundspeed is not known.

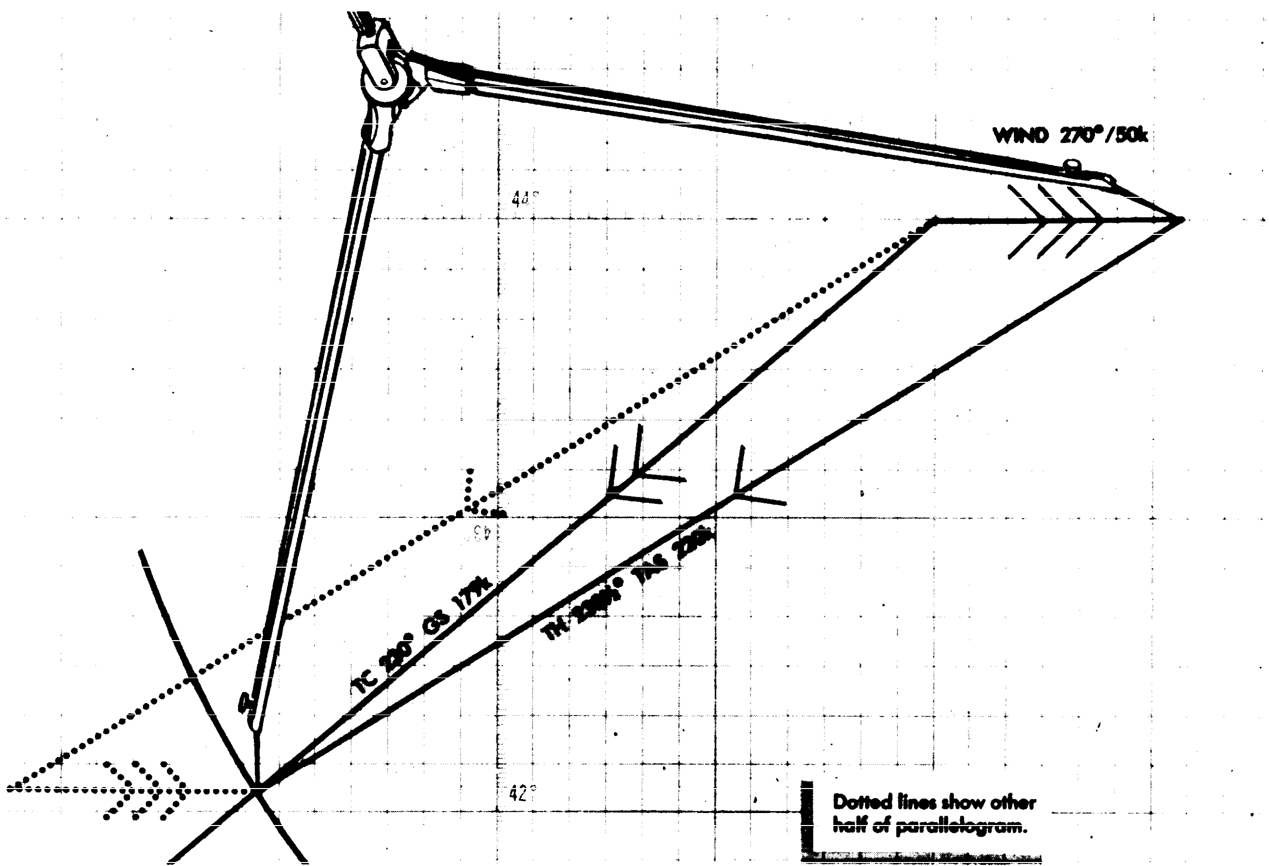


Figure 4-83. To Find True Heading and Groundspeed Using Chart.

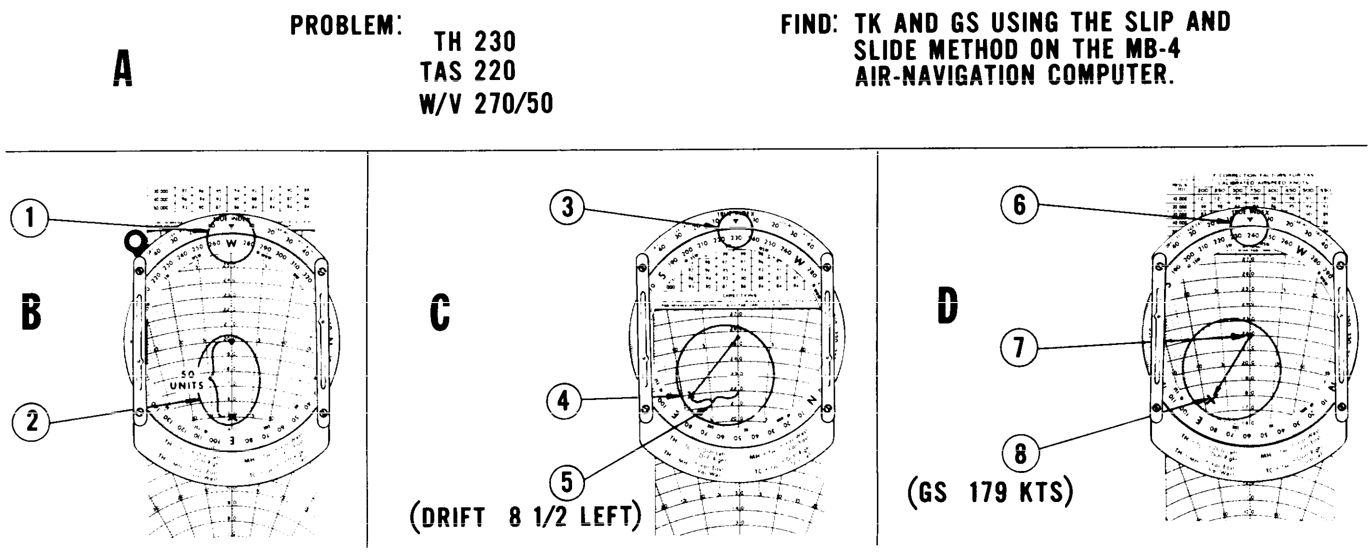


Figure 4-84. To Find True Heading and Groundspeed Using Slip and Slide Method.

3. Using the same scale as in step 1, open the dividers an amount equal to true airspeed (220k); then, from the head of the wind arrow, swing an arc with a radius of 220 nautical miles to intersect the true course line.
4. Draw a line from the point of intersection of the arc and the true course line to the head of the wind arrow.
5. To determine the true heading (238 1/2°), measure the direction of the air vector.
6. To determine the groundspeed (179k), measure the length of the ground vector, using the same scale as before.

COMPUTER SOLUTION. There are two methods to solve for true heading and groundspeed. They are the "slip and slide" method and the "juggle" method. Both will be discussed; however, the slip and slide method is normally preferred.

Slip and Slide Method. (figure 4-84.)
1. Set wind direction (270°) under the true index.
2. Draw the wind vector down the center from the grommet, making its length along the speed scale correspond to the wind speed (50k).
3. Set the true course (230°) under the true index.
4. Set end of wind vector on the true airspeed (220k) by moving the slide.
5. Read drift left or right (8 1/2° left)
6. Apply drift correction mathematically to true course and set this computed true heading under the true index (238 1/2°).
7. Move the slide up until the grommet is on true airspeed (220k). The wind triangle is now set up correctly.
8. Read groundspeed at the end of the wind vector (179k).

The Juggle Method (figure 4-85.)
First, set in the data:
1. Set wind direction (270°) under the true index.
2. Draw the wind vector down the center from the grommet, making its length along the speed scale correspond to the wind speed (50k).
3. Set the true airspeed (220k) under the grommet.
4. Set the true course (230°) under the true index (figure 4-85).

The wind triangle is set up incorrectly, for true course rather than true heading is set under the true index. However, since the true heading is not known, the true course is used as a first approximation of the true heading. This will give a first approximation of the drift angle, which can be applied to the true course to get a more accurate idea of the true heading.
5. Determine the drift angle (10° left) on the approximate

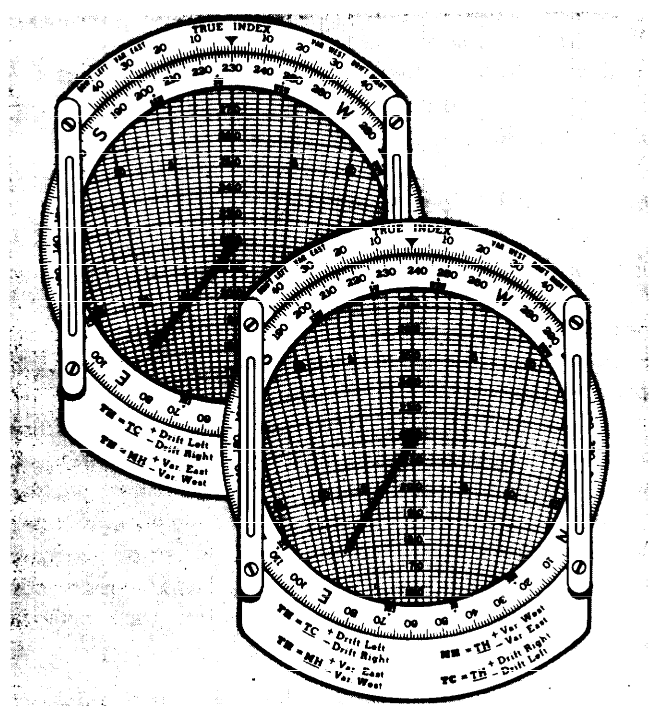


Figure 4-85. To Find True Heading and Groundspeed Using the Juggle Method.

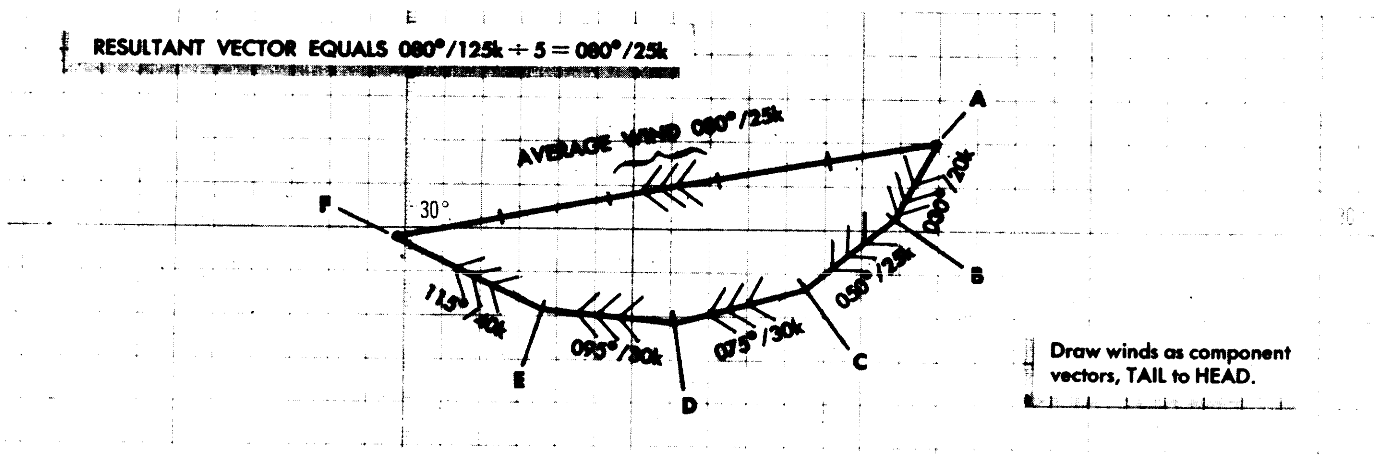


Figure 4-86. To Find Average Wind Using Chart.

heading (230°) to obtain a second approximation of the true heading (240°). If the drift angle is right, the drift correction is minus; if it is left, the drift correction is plus.

6. Set the second approximate heading (240°) under the true index. Read the drift angle for this heading (8° left). The wind triangle still is set up incorrectly. To be correct, the drift angle which is read at the head of the wind vector must equal the difference between the true course and the true heading which is set under the true index. As it stands, the drift angle is 8° left, while the difference between true course and the indicated true heading is 10° left.

7. Juggle the compass rose until the drift angle equals the difference between true course and true heading. In this example, the correct drift angle is 8 1/2° left.

Now the wind triangle is set up correctly.

8. Read the true heading (238 1/2°) under the true index.

9. Read the groundspeed (179k) on the speed circle passing through the head of the wind vector.

Average Wind Affecting Aircraft

An average wind is an imaginary wind which would produce the same wind effect during a given period as two or more actual winds which affect the aircraft during that period. Sometimes an average wind can be applied once instead of applying each individual wind separately.

If the wind directions are fairly close together, a satisfactory average wind can be determined by arithmetically averaging the wind directions and wind speeds. However, the greater the varition in wind direction, the less accurate the result will be.

It is generally accepted that winds should not be averaged arithmetically if the difference in directions and speeds exceeds 090° and (or) 15 knots. In this case, there are other methods which may be used to obtain a more accurate average wind. A chart solution is shown in figure 4-86.

COMPUTER SOLUTION. Winds can be averaged by vectoring them on the wind face of the DR computer using the square grid portion of the slide and the rotatable compass rose. Average the following three winds by this method—030°/15k, 080°/20k, and 150°/35k:

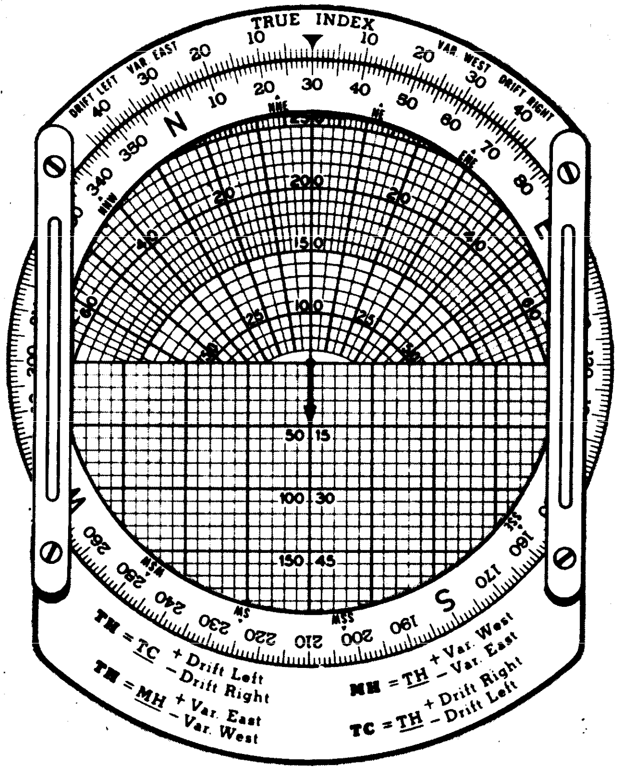
1. Place the slide in the computer so that the top line of the square grid portion is directly under the grommet and the compass rose is oriented so that the direction of the first wind (030°) is under the true index. The speed of the wind (15k) is drawn down from the grommet (figure 4-87A).

2. Turn the compass rose until the direction of the second wind (080°) is under the true index and then reposition the slide so that the head of the first wind vector is resting on the top line of the square grid section of the slide. Draw the speed of the second wind (20k) straight down (parallel to the vertical grid lines) from the head of the first wind arrow (figure 4-87B).

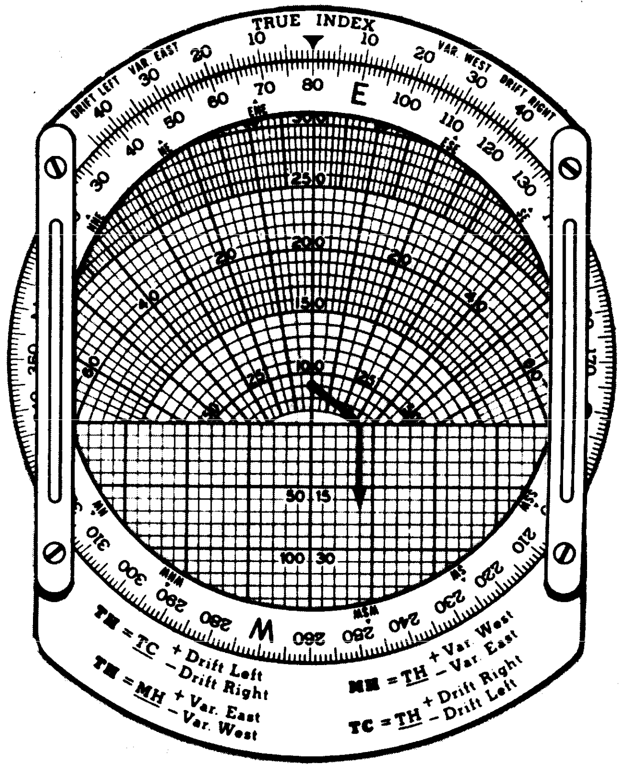
3. Again turn the compass rose so that the direction of the third wind (150°) is under the true index and reposition the slide so that the head of the second wind vector is resting on the top line of the square grid section of this slide. Draw the speed of the third wind (35k) straight down from the head of the second wind arrow (figure 4-87C).

4. Turn the compass rose so that the head of the third wind arrow is on the center line directly below the grommet and reposition the slide to place the grommet on the top line of the square grid section of the slide. The direction of the resultant or average wind may be read directly beneath the true index (108°). The wind speed is determined by measuring the length of the resultant wind vector (46) on the square grid section of the slide and dividing it by the number of winds used (3). This will give a wind speed of 15 1/3 knots or 15 1/2 knots which is as close as it is possible to read the computer. The average wind then is 108°/15 1/2k (figure 4-87D).

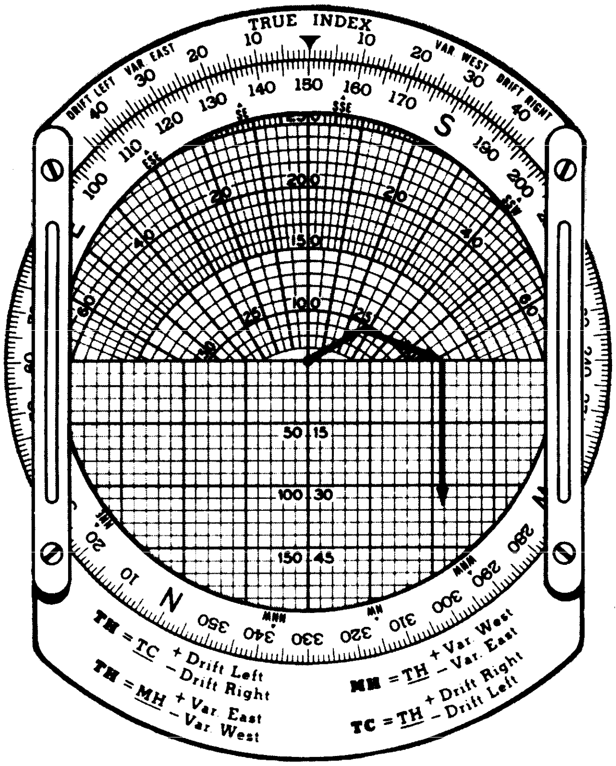
In some cases, because of the number of winds to be averaged or because of high wind speeds, it is not possible to draw in all the wind vectors on the computer unless the wind speeds are cut by 1/2 or 1/3, etc, before drawing the vector. If one wind speed is cut, all wind speeds must be cut. In determining the resultant wind speed, the length of the total vector must be multiplied by 2 or 3, depending on how the wind speed was cut, and then divided by the total number of winds used. In cutting the speeds, the direction is not affected and the wind direction is read under the true index.



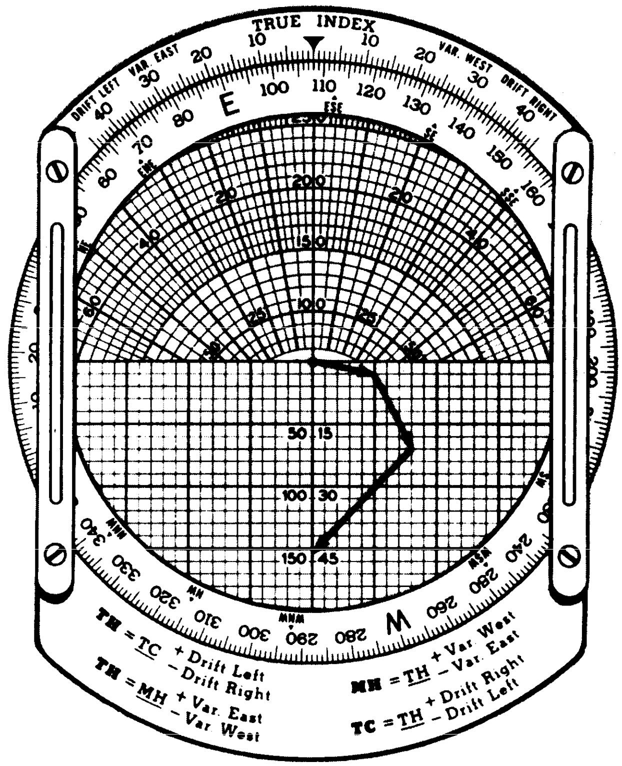
A. First wind is drawn down from the grommet.



B. Reposition slide and draw down again.



C. Reposition slide for each wind.



D. Divide Resultant by number of winds.

Figure 4-87. To Find Average Wind Using Computer.

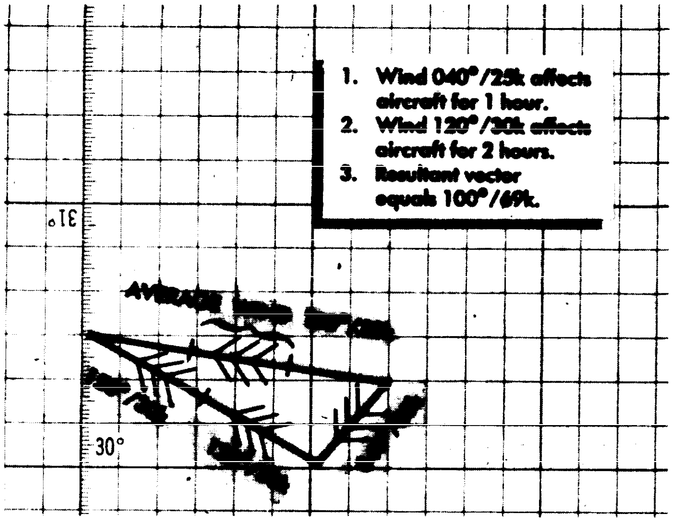


Figure 4-88. Weight Winds in Proportion to Time.

Wind effect is proportional to time (figure 4-88). To sum up two or more winds which have affected the aircraft for different lengths of time, weight them in proportion to the times. If one wind has acted twice as long as another, its vector should be drawn in twice as shown. In dividing to get the average wind speed, of course, this wind must be counted twice.

Resolution of Rectangular Coordinates

Data for radar equipment is often given in terms of rectangular coordinates, therefore, it is important that the navigator be familiar with the handling of these coordinates. The DR computer provides a ready, easy method of interconversion.

Example: Converting wind to rectangular coordinates (figure 4-89).

Given: A wind of 340°/25k to be converted to rectangular coordinates.

Procedure:

1. Plot the wind on the computer in the normal manner. Use the square grid side of the computer slide for the distance.
2. Rotate the compass rose until north, the nearest cardinal heading, is under the true index.
3. Read down the vertical scale to the line upon which the head of the wind vector is now located. The component value (23) is from the north under the true index.
4. Read across the horizontal scale from the center line to the head of the wind vector. The component value (9) is from the west. The wind is stated rectangularly as N-23, W-9.

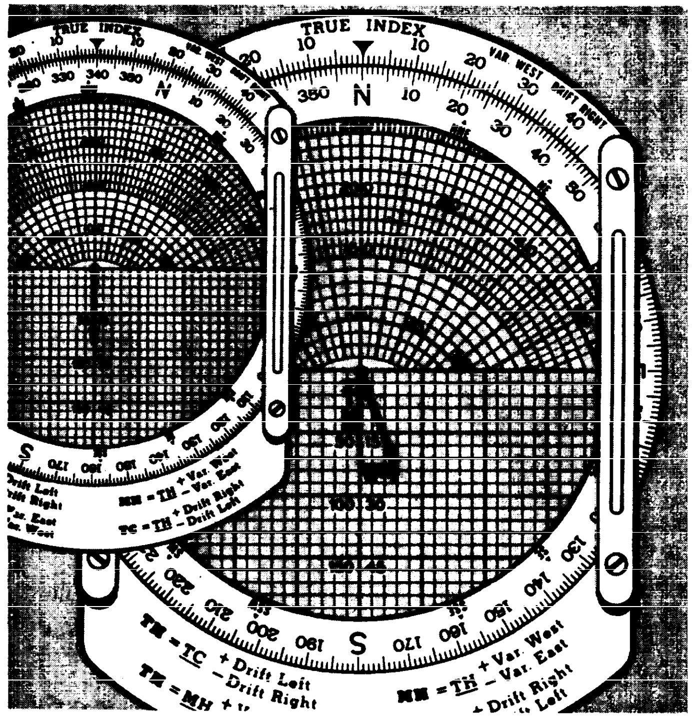


Figure 4-89. Convert Wind to Rectangular Coordinates.

Example: Converting rectangular coordinates to a wind.

Given: Coordinates, S-30, E-36, to convert to a wind.

Procedure:

1. Use the square grid side of the computer.
2. Place either cardinal heading (east or south) under the true index and the grommet on zero of the square grid.
3. Read down from the grommet along the center line for the value (30) of the cardinal direction under the true index.
4. From the other cardinal direction (east), read horizontally along the value located in step 3 from the center line of the value of the second cardinal direction and mark the point.
5. Rotate the compass rose until the marked point is over the center line of the computer.
6. Read the wind direction (130) under the true index and velocity (47 knots) from the grommet to the point marked.