TM 1-225

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

NAVIGATION FOR ARMY AVIATION

HEADQUARTERS, DEPARTMENT OF THE ARMY
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NAVIGATION FOR ARMY AVIATION

*** This manual, together with TM 1-215, 8 December 1958, and TM 1-300, 23 April 1958, supersedes TM 1-215, 27 December 1955.**

PART ONE
PILOTAGE AND DEAD RECKONING
CHAPTER 1
GENERAL

1. Purpose

This manual provides a reference for basic and advanced air navigation as applied to Army aviation. It is also to be used as an instructional text for students undergoing Army aviation training in schools or in the field.

2. Definition of Air Navigation

As discussed in this manual, air navigation is defined as the art of directing the aircraft along a desired course and determining position along this course at any time. Such navigation may be by means of pilotage, dead reckoning, or radio aids, as explained hereafter, and includes those procedures which are used during instrument flight in directing the aircraft to a safe landing.

3. Scope

The scope of this manual is as follows:

a. Part One, Pilotage and Dead Reckoning. Part One includes basic concepts of air navigation which will assist the Army aviator in planning and completing a flight by means of pilotage and/or dead reckoning.

b. Part Two, Radio Navigation. Part Two includes information on radio navigational aids and their employment in flight.

c. Part Three, Navigation Peculiar to Instrument Flight. Part Three includes facilities and procedures peculiar to navigation under instrument flight conditions. It does not include theory and techniques of attitude instrument flying or descriptions of flight or navigation instruments; this information is covered in TM 1–215.

CHAPTER 2
BASIC CONCEPTS

Section I. THE EARTH IN SPACE

4. The Earth as a Sphere

A perfect sphere is a body whose surface is at all points equidistant from a point within called the center. *Any* straight line which passes from one side, through the center of the sphere, to the opposite side is called the *diameter* of the sphere. Although the earth is actually a spheroid (being slightly flattened at the poles), for navigational purposes it is considered a perfect sphere.

5. Rotation of the Earth

The earth makes one complete rotation around an imaginary line called its axis every 24 hours. The ends of this imaginary line or axis are known as the North and South Poles. In addition, the earth revolves around the sun in an elliptical path (fig. 1). The axis of the earth is inclined approximately 23½° from a perpendicular to the plane of its orbit around the sun. This inclination is such that the North Pole points almost directly to the North Star (Polaris).

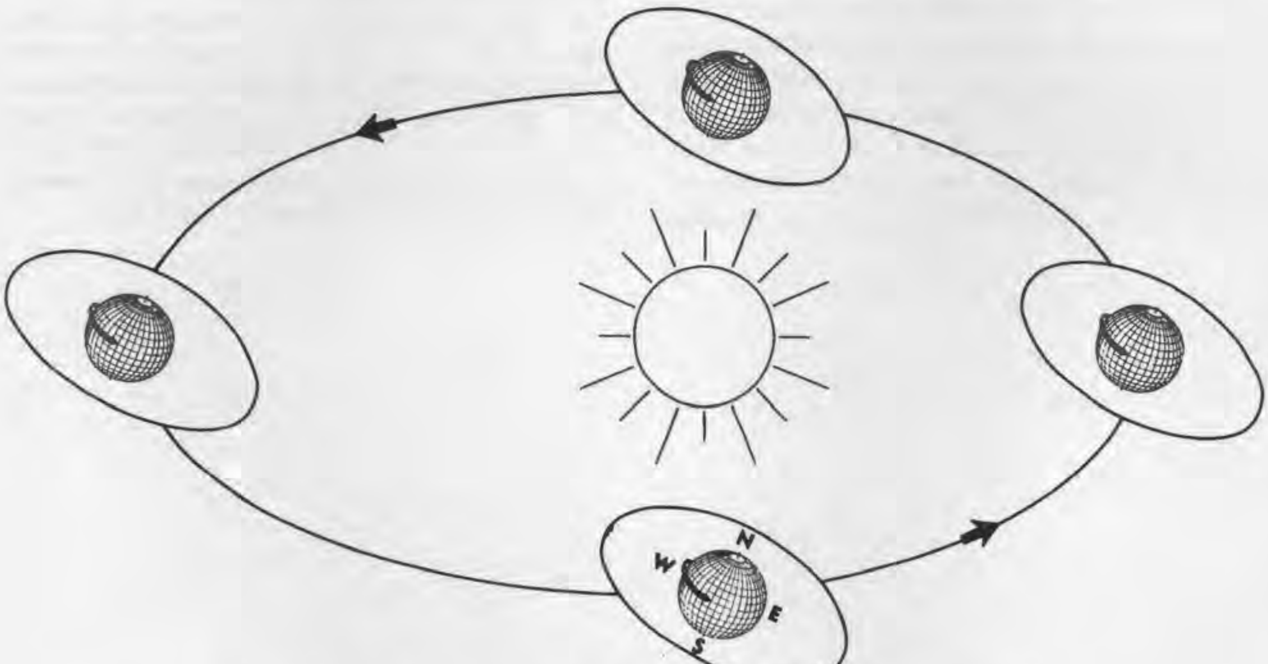


Figure 1. West to east rotation of the earth and its revolution around the sun.

Section II. MEASURING POSITION ON THE EARTH

6. Position Designated by Coordinates

To facilitate the location of a point on the surface of the earth, a universal system of expressing position without reference to geographic features is a necessity. Such a system, known as a *coordinate* or *grid* system (fig. 2), designates location or position and expresses angular magnitude with respect to two reference lines which intersect at right angles. By reference to these lines, any point may be so positioned. This system of coordinates is formed by the intersecting of great and small circles (par. 7*a*).

7. Circles on a Sphere

a. Great and Small Circles. The cut of a plane through a sphere forms a *circle*. If a straight cut passes through the center of the earth, the circle formed is a *great circle*. This is the largest circle that can be cut from a sphere. Any other circle, regardless of size, is called a *small circle*, since the plane of a small circle does not pass through the center of the sphere and, hence, will not divide it in half (fig. 2).

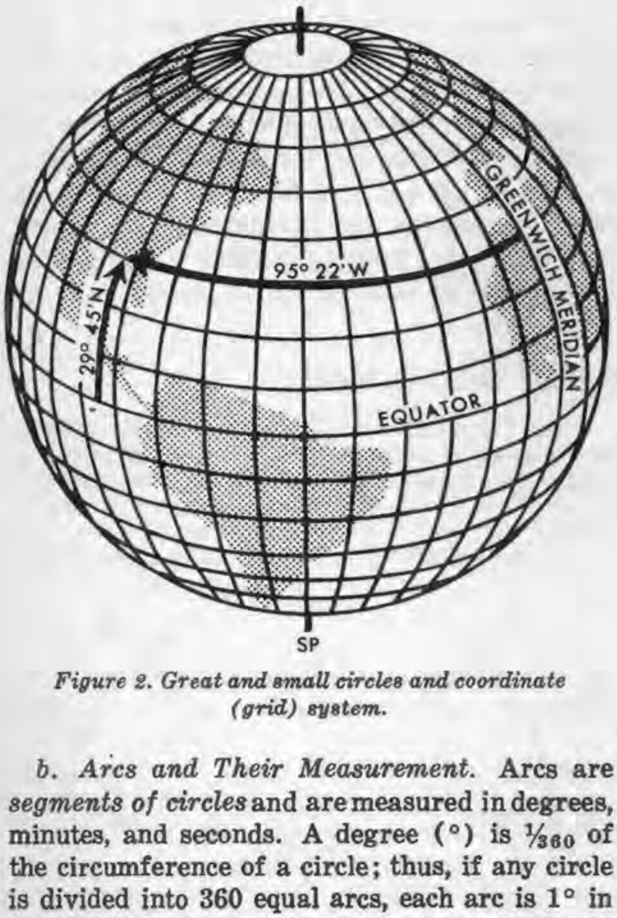


Figure 2. Great and small circles and coordinate (grid) system.

b. Arcs and Their Measurement. Arcs are *segments of circles* and are measured in degrees, minutes, and seconds. A degree (°) is $\frac{1}{360}$ of the circumference of a circle; thus, if any circle is divided into 360 equal arcs, each arc is 1° in length, regardless of the size of the circle. A minute (′) is $\frac{1}{60}$ of 1°, a second (″) is $\frac{1}{60}$ of 1 minute.

c. The Central Angle. Straight lines drawn from each end of an arc to the center of a circle form an angle at the center called the *central angle*. Angles, like arcs, are measured in degrees, minutes, and seconds. The angle at the center of the circle contains the same number of degrees, minutes, and seconds as the arc which subtends it.

d. Angular and Linear Distances. The angular distance between two points on a circle can be expressed in degrees, minutes, and seconds of arc. This distance is actually a measure of the central angle and is independent of the size of the circle. The angular distance depends upon what portion of the circle separates the two points. The linear distance between two points depends upon the size of the circle (fig. 3).

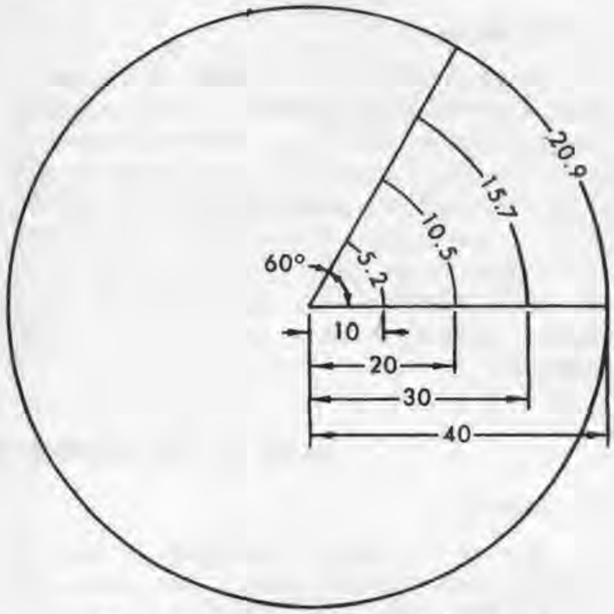


Figure 3. Angular and linear distances.

8. Reference Circles on the Earth

The axis of the earth is the only distinctive, natural geometric line of the earth. The North and South Poles are distinct points on the earth and are used as central points for one set of reference circles known as *parallels of latitude*. The only great circle of this set of circles is the Equator (fig. 2).

9. Equator

The Equator is a great circle located halfway between the North and South Poles and serves as a reference line for all parallels of latitude (fig. 2). Since the poles are 180° apart, every point on the Equator is 90° from each pole. The plane of the Equator is at right angles to the earth's axis and divides the earth into Northern and Southern Hemispheres.

10. Parallels

Any small circle whose plane is parallel with the plane of the Equator is a parallel of latitude (fig. 2). Every point on a given parallel is equidistant from the Equator, the poles, and any other parallel. The Equator and all parallels are concentric around the polar axis. An infinite number of parallels may be drawn; however, only a few are shown on the globe. A parallel on the earth's surface is designated by its angular measurement north or south of the Equator.

11. Meridians

A great circle passing through both poles is called a *meridian of longitude* (fig. 2). As with parallels, there may be an infinite number of meridians even though few are shown on the globe. The meridian passing through the observatory at Greenwich, England, has arbitrarily been selected as the reference or *prime meridian*. All other meridians are designated by their angular distance east or west of the prime meridian.

12. Latitude and Longitude

a. Latitude. The latitude of a point on the surface of the earth is its angular measurement north or south of the Equator measured on the plane of the meridian passing through the point. Latitude ranges from 0° at the Equator to 90° north or south at the poles.

b. Longitude. The longitude of a point is its angular measurement east or west of the prime meridian, measured on the plane of the Equator or of a parallel. Longitude ranges from 0° at the prime meridian to 180° at the meridian diametrically opposite the prime meridian.

c. Parallels of Latitude and Meridians of Longitude. Naming the parallel and meridian which passes through a point is essentially the same as giving its coordinates. Each is named according to its angular measurement from the Equator or prime meridian. A meridian of longitude is a line, but longitude is an angle; a parallel of latitude is a line, but latitude is an angle. In giving the coordinates of a place, latitude is given first, followed by the longitude; *for example*, 29°45′N 95°22′W (fig. 2).

Section III. MEASURING DIRECTION ON THE EARTH

13. General

A system of giving directions by use of *cardinal points* (north, east, south, west) or *intercardinal points* (northeast, southeast, southwest, etc.) of the compass is cumbersome and easily misunderstood over voice radio. In air navigation a simple numerical system is used to indicate direction (fig. 4).

14. Measuring Direction

The compass rose (fig. 4) divides the horizon into 360 parts or degrees. Starting with north as 000° and continuing clockwise through east, south, west, directions are expressed in degrees measured from north to 360°. East is 090°, and west is 270°. Figure 5 shows point B in a direction of 045° (northeast) and C in a direction of 270° (west) of aircraft A. Aircraft A is headed in a direction of 120°. A line by itself does not indicate a single direction; arrows or labels along the line may be used to indicate the intended direction.

Note. The direction of *C from A* is not the same as the direction of *C to A*. The direction of a line is measured by the *angle the line forms with the meridian.*

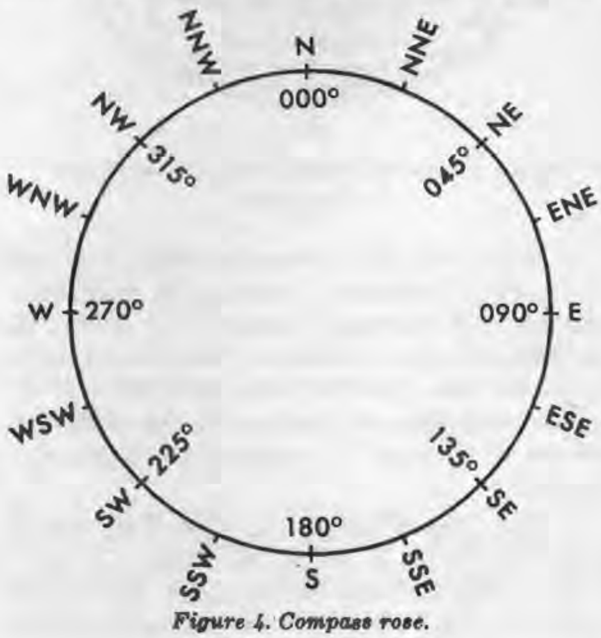


Figure 4. Compass rose.

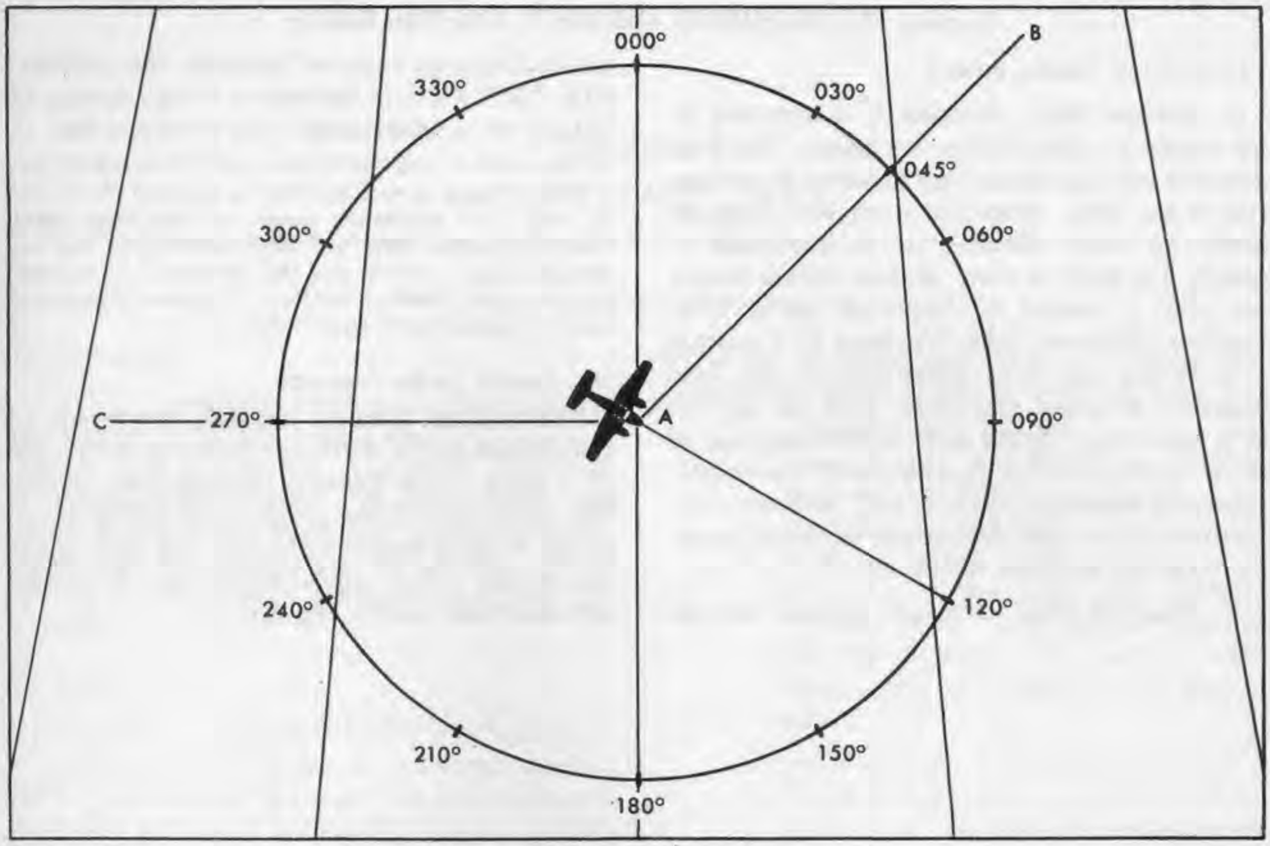


Figure 5. Measurement of direction.

In figure 5, the direction from A is measured at A. If the meridians are drawn as parallel lines, the direction of a straight line may be measured at any point. In measuring the direction from C to A (A from C), measurement will be made with reference to the meridian passing through C.

15. Course

The direction which an aircraft is to fly to reach a given destination is the *course* to that destination.

16. Rhumb Line

A rhumb line is a line of constant direction that crosses successive meridians at the same oblique angle (fig. 6). Parallels of latitude, the Equator, and meridians are often called rhumb lines even though they do not fully conform with the definition. A true rhumb line, if continued, will spiral toward the poles never quite reaching either of them. Such a spiral is called a *loxodromic curve* (fig. 6).

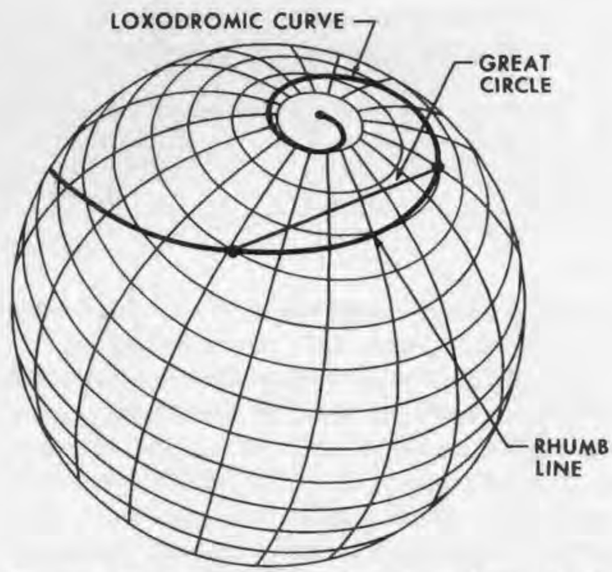


Figure 6. Rhumb line, loxodromic curve, and great circle.

Section IV. MEASURING DISTANCE ON THE EARTH

17. Units of Measurement

a. Statute Mile. Distance is determined by the length of a line joining two points. The most common unit for measuring distance in navigation is the mile. Since the word *mile* does not define an exact distance, it is important to specify the type of mile. In the United States, one mile is defined by statute as being 1,760 yards or 5,280 feet. This is called a U. S. statute mile. There are some differences in the legal definition in other countries. With the growth of cross-country flying and the development of better aviation charts, the statute mile is rapidly becoming obsolete. Pilots will, however, encounter statute mile indications on some charts, plotters, and airspeed indicators.

b. Nautical Mile. Military airmen use the nautical mile as a unit of distance. The nautical mile (6076.1 ft) is equivalent to one minute of latitude or approximately 1.15 statute miles. A statute mile is approximately 0.87 nautical miles.

Note. There is no rule whereby nautical miles must be used in air navigation except in filing flight plans. Usually, nautical miles are more convenient. The important thing is *not* to mix the two units. If information is mixed, convert so that *all* measurements are either in nautical or in statute miles.

18. Great Circle Distance

The shortest distance between two points on the surface of the earth lies along the minor arc of a great circle passing through both points. The minor arc of the great circle between two points is more nearly a straight line than is the arc of any other circle which can be drawn between these points (fig. 6).

CHAPTER 3
NAVIGATIONAL CHARTS

Section I. CHART PROJECTIONS

19. General

An air navigation chart is a diagrammatic representation of the earth's surface, or a part thereof, on a flat surface. The chart, in greater or lesser detail, shows elevation, cities and towns, principal highways and railroads, oceans, lakes, and rivers, radio aids to navigation, danger areas, and other features useful to the navigator.

20. Scale

a. General. The ratio between the distance on a chart and the distance it represents on the earth is the scale of the chart. A chart showing the entire surface of the earth is drawn to small scale for convenient size. A chart covering a small area and much detail is drawn to a larger scale.

b. Types of Scales. The scale of a chart may be expressed simply, such as "1 inch equals 30 miles," which means that a ground distance 30 miles long is one inch in length on the chart. On aeronautical charts, the scale is shown in representative fractions and/or graphic scales.

(1) *Representative fraction.* A scale may be given as a representative fraction such as 1:500,000 or 1/500,000. This means that one unit on the chart represents 500,000 units of the same dimension on the earth. ***For example:*** 1 inch on a chart may represent 500,000 inches on the earth or approximately 6.9 nautical or 8 statute miles.

(2) *Graphic scale.* A graphic scale (fig. 7) shows the distance on a chart labeled in terms of the actual distance it represents on the earth. The distance between parallels of latitude is a convenient graphic scale since one degree of latitude always equals 60 nautical miles. Meridians are often divided into minutes of latitude with each division representing one nautical mile.

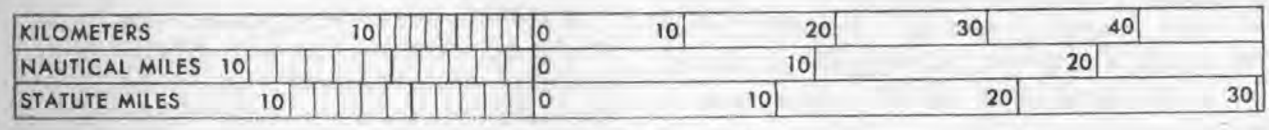


Figure 7. Graphic scale.

21. Distortion

A developable surface (fig. 8) is a curved surface that can be flattened without tearing, stretching, or wrinkling. Surfaces such as a plane, cylinder, or cone are developable surfaces. The surface of a sphere or spheroid is said to be *nondevelopable* because no part of it can be laid out on a flat surface without distortion (misrepresentation of direction, shape, and relative size of the features on the earth's surface). This can be understood by attempting to flatten half of an orange peel. A small piece of orange peel because it is nearly flat can be flattened with little stretching or tearing. Likewise, a small area of the earth's surface which is nearly flat, can be represented on a flat surface with little distortion. Distortion becomes a serious problem in charting large areas and can never be completely eliminated; it can, however, be controlled and systematized. A chart for a particular purpose can be drawn so as to minimize the type of distortion which is most detrimental. The globe is the only means of representing the entire surface of the earth without distortion.

22. Chart Characteristics

Each type of chart has distinctive features which make it preferable for certain uses; no one chart is best for all uses. If it were possible to construct a perfect chart, the chart would have—true shape of all physical features; correct angular relationship (conformality); representation of areas in their correct relative proportions; true scale value for measuring distances; and great circles and rhumb lines represented as straight lines. It is possible to preserve one and sometimes more than one of the above properties in any one projection, but it is impossible to preserve all of them. For example, a chart cannot be both conformal and equal area. Desirable but less important second properties are—ease in finding and plotting coordinates of points; ease in joining two or more charts; cardinal directions parallel throughout the chart; and simplicity and ease in construction.

23. The Graticule

a. General. Exact coordinates of any point on the earth may be found by astronomical means. With reference to control points established in this manner, the exact location of nearby features may be found by geographic survey or by aerial photography. A chart can then be made by drawing the established geographical features on a framework of meridians and parallels known as a *graticule.* Once the graticule is drawn, features may be plotted in their correct positions with references to meridians and parallels.

b. Form and Size. Form of the graticule determines the general characteristics and appearance of the chart; its size determines the scale. Since meridians and parallels cannot be shown on a plane surface exactly as they would appear on a sphere, there is no perfect method of constructing the graticule. For example, the meridians and parallels may be shown as straight lines, as variously curved lines, or some as straight and some as curved lines; they may be spaced in various ways and may intersect at various angles.

24. Projection

a. Definition. The method of representing all or part of the surface of a sphere or spheroid on a plane surface is known as a *projection.* The actual projection of a graticule is accomplished by application of mathematical formulas.

b. Classifications. Projections are classified primarily as to the type of developable surface to which the spherical or spheroidal surface is transferred. Figure 8 shows developable and nondevelopable surfaces. They are sometimes further classified as to whether the projection (but not necessarily the chart made by it) is centered on the Equator (equatorial), a pole (polar), or some point or line between the Equator and the poles (oblique), or tangent at a meridian (transverse). Some cartographers drop the term oblique and call all such projections transverse. The name of a projection often indicates the type and its principal feature. Charts most commonly used in air navigation are classified as Lambert, Mercator, and polar stereographic.

c. Purpose of Charts. Charts are used in navigation principally for two purposes—chart reading; and plotting and measuring. Chart reading is location of position by identification of landmarks (par. 32). Plotting refers to establishment of points and lines on a chart. Measuring means measurement of direction and distance on a chart (par. 41).

25. Lambert Conformal Projection

a. Appearance of the Graticule. The Lambert conformal projection (Lambert chart) is a conic projection using the cone for a developable surface. All meridians are straight lines meeting at the apex of the cone. All parallels are concentric circles, the center of which is also the apex of the cone. Meridians and parallels intersect at right angles and the angle formed by any two lines is correctly represented (fig. 9).

b. Standard Parallels. As shown in figure 10, the cone intersects the sphere at two parallels. The parallels are known as standard parallels for the area to be represented. In general, for equal distribution of scale error, the standard parallels are chosen at 1/6 and 5/6 of the total length of that portion of the meridian to be represented.

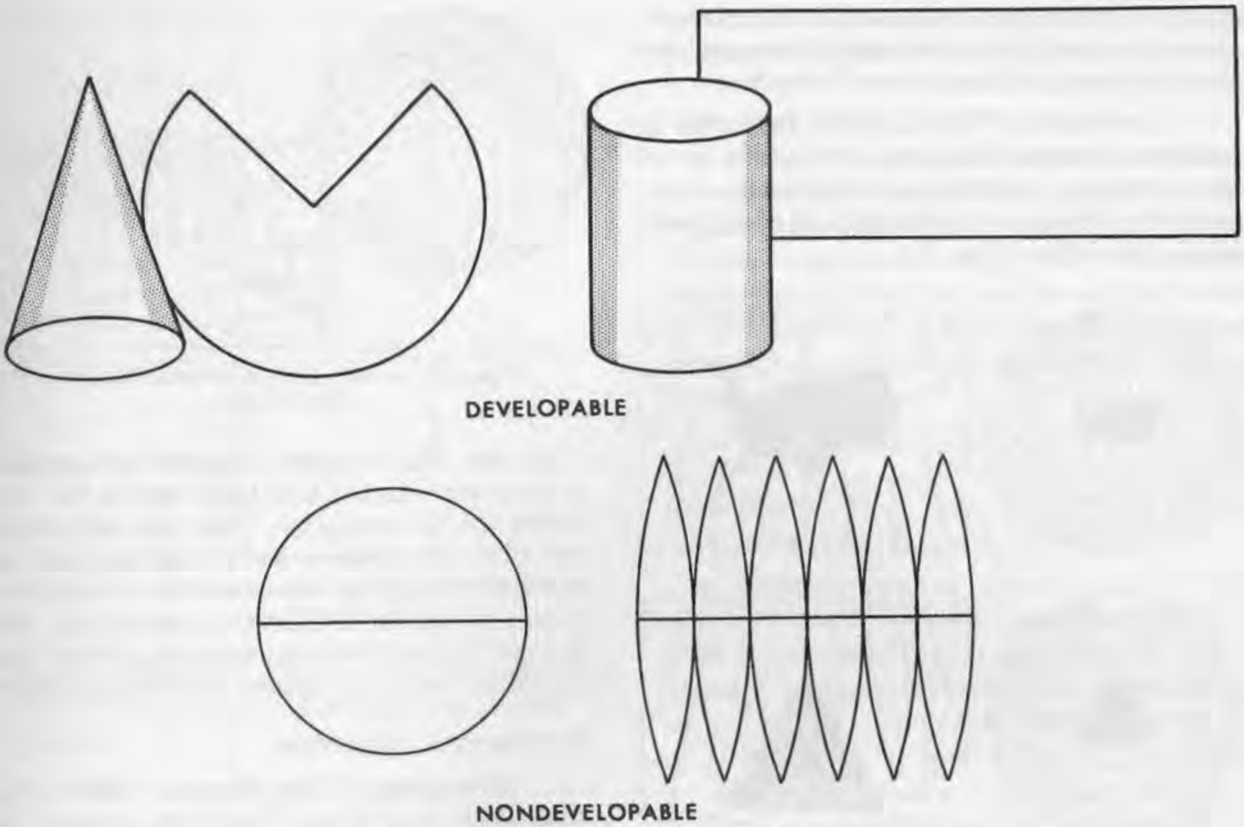


Figure 8. Developable and nondevelopable surfaces.

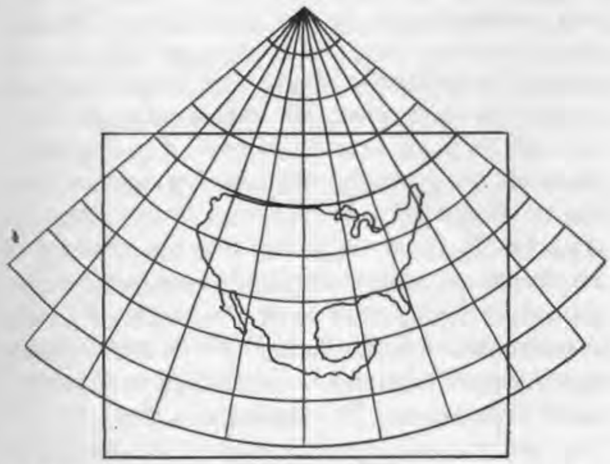


Figure 9. Appearance of the graticule of Lambert projection.

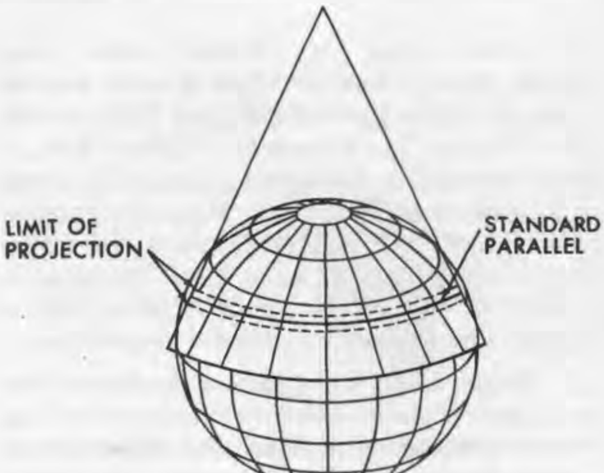


Figure 10. Lambert standard parallels.

c. Accuracy. On two selected standard parallels, arcs of longitude are represented in true scale. Between the parallels, scale will be too small; beyond them, too large. Four-degree bands are now in use, placing standard parallels 2°40′ apart. This gives a maximum scale range of 0.03 percent too small between standard parallels and 0.07 percent too large at 1°10′ beyond either parallel. The older method, using standard parallels 7°–20°, 33°–45°, and 55°–65°, has a scale change of 0.55 percent between standard parallels. Some standard series charts still exist using old standard parallels but rapid conversion is in effect. For practical purposes, scale can be considered constant for a large scale chart of a small area. Accuracy is greatest for charts of dominantly east-west dimensions.

d. Conformality. The Lambert projection is conformal because the scale is uniform in all directions about any point, and angles are shown correctly. Because of uniformity of scale, areas retain true shape (fig. 11).

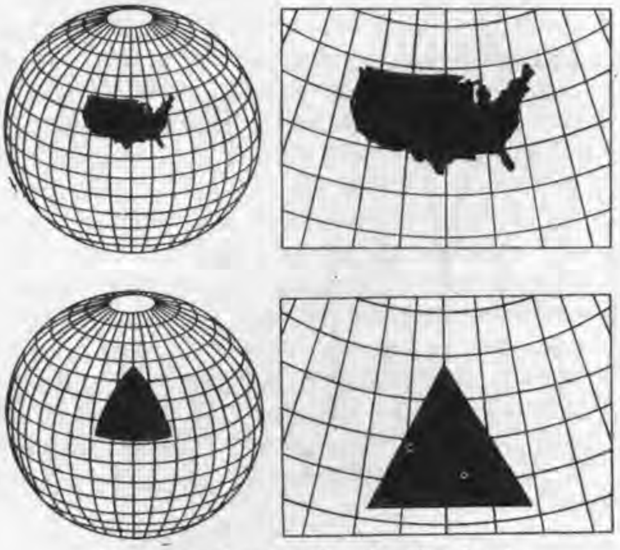


Figure 11. Areas and angles (Lambert).

e. Great Circle vs. Straight Line. Any straight line on a Lambert chart is nearly a great circle (fig. 12). In the distance of 2,572 statute miles between San Francisco and New York, a great circle and a straight line connecting them on a Lambert chart are only 9½ miles apart at midlongitude. For shorter distances, the difference is negligible. For all practical purposes, if a flight is only a few hundred miles long, a straight line may be considered a great circle.

f. Rhumb Line. A rhumb line is a curved line on a Lambert chart. The closer its direction is to east-west, the more a rhumb line departs from a straight line. Over distances of 100 to 200 miles, in the latitude of the United States, a rhumb line departs little from a straight line; but over long distances, the difference is large. Between San Francisco and New York, the length of a rhumb line differs from a straight line by about 170 miles. An accurate rhumb line cannot be drawn on a Lambert chart, but it can be approximated by a series of short straight lines.

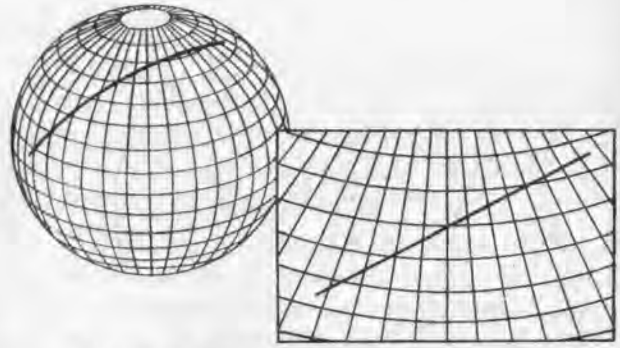


Figure 12. Great circle vs. straight line on a Lambert chart.

g. Use. The constant scale and conformality of Lambert charts place them among the best charts for air navigation. They are suitable for use with long-distance radio bearings and, for problems involving distances and true directions, are superior to Mercator charts (par. 26). For plotting positions and measuring rhumb line directions, they are inferior to Mercator charts.

26. Mercator Projection

a. Description. The Mercator chart is a cylindrical projection. Meridians appear as straight lines which are equidistant and parallel. Parallels of latitude are parallel to each other and perpendicular to the meridians. The distance between parallels increases with an increase in latitude. Since the meridians are parallel to each other, the east-west scale is increased with increase in latitude. Consequently, parallels must be placed in such a manner that the north-south scale increases proportionately. As a result, the scale at any point is constant in all directions. Since meridians and parallels intersect at right angles as on the earth, all angles are shown correctly. Every rhumb line appears as a straight line, and every straight line is constant in direction. The Equator and the meridians are the only great circles which appear as straight lines; all other great circles appear as curved lines (fig. 13).

b. Use, Advantages, Disadvantages. The Mercator chart is used in air navigation only for long-range overwater flying. Its greatest advantage is that on the chart a rhumb line is a straight line. Plotting is easier because of the rectangular graticule. On the other hand, long-range radio bearings cannot be plotted without

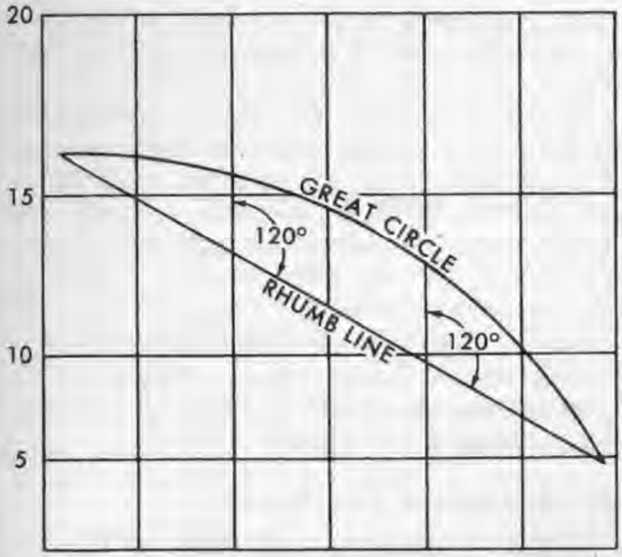


Figure 13. Mercator chart showing rhumb line vs. great circle.

special corrections. Because of the expanding scale of this chart, distances are difficult to measure.

27. Polar Stereographic Projection

a. General. The polar stereographic projection (fig. 14) is based on a plane, tangent at the pole, with the point of projection at the opposite pole. Meridians are straight lines converging at the pole. Parallels are concentric circles with the pole as their common center. For the world aeronautical chart (WAC) series, discussed in paragraph 29, the polar stereographic is modified by using a secant plane. This modification makes the polar stereographic and Lambert charts the same scale at 80° latitude. The polar stereographic becomes true scale at 80°14′ since the secant plane intersects the earth's surface at that latitude, with the scale decreasing as the pole is approached. The polar stereographic chart is the best chart for navigation in polar regions.

b. Area of Coverage. A polar stereographic chart may include a whole hemisphere; however, a chart used for air navigation will not extend more than 20° or 30° from the pole.

c. Scale. Since the interval between parallels increases with distance from the pole, the north-south scale also increases away from the pole. The east-west scale increases in the same proportion, so that at any point the scale is constant in all directions. For all practical purposes, scale is constant within the limits of a navigational chart.

d. Angles. All angles are correctly shown since meridians appear as radii of circles representing parallels, and meridians and parallels intersect at 90° on the chart.

e. Straight Lines vs. Rhumb Lines vs. Great Circles. Meridians, which are great circles, appear as straight lines; hence, any great circle passing through the center of the chart appears as a straight line. Other great circles appear as slightly curved; however, the closer they are to center, the straighter they appear. Within the limits of a navigational chart, a great circle is shown as a straight line. Rhumb lines appear as curved lines.

Figure 14. The polar stereographic projection.

Section II. AERONAUTICAL CHARTS

28. United States Sectional Charts

a. General. United States sectional charts are Lambert conformal charts published by U. S. Coast and Geodetic Survey. The scale is 1:500,000 (1 in. equals approximately 6.9 nautical miles or about 8 statute miles). The purpose of the charts is to provide coverage for the United States and the Hawaiian Islands at a scale appropriate for flights of short duration. They are intended primarily for pilotage (visual flight) but are suitable for all forms of navigation. The large scale of the sectional chart permits information to be included in great detail.

b. Topographical. Topographical features, such as bodies of water, rivers, and streams, are shown in their respective positions; elevation of terrain is indicated by contour lines and color variations; high peaks are shown with the highest elevation in italics.

c. Cultural. Cultural features, such as railroads and major roads and, in sparsely settled areas, even dirt roads or paths, may be shown. Cities and towns, mines, lookout towers, and many other good landmarks are indicated by symbols.

d. Aeronautical. Aeronautical features such as airports, airways, radio ranges, etc., are shown in these charts. In a rectangle near each airport, information relative to the airport is listed and includes such data as lighting, type and length of longest runway, frequencies available for contacting the tower, etc.

e. Other Information. Most sectional charts cover an area containing 2° of latitude and 6° of longitude with a marginal overlap on the adjoining chart. These charts are designated by name and series (e. g., Des Moines—sectional). Clarification of chart symbols and other pertinent information is printed on the reverse side of the chart. Some charts are scheduled for revision every six months; others annually. Date of the chart and scheduled time for next edition is located in the lower right hand margin of the chart face.

29. World Aeronautical Chart

The world aeronautical chart (WAC) is published by the U. S. Coast and Geodetic Survey. Scale is 1:1,000,000 (1 in. equals approximately 14 nautical or 16 statute miles). From 0° to 80° latitude, WAC charts are based on the Lambert conformal projection; from 80° to the poles, they are based on the modified polar stereographic projection. Their purpose is to provide a standard series of aeronautical charts covering the world at a size and scale convenient for overland navigation. The smaller scale of the WAC chart does not permit as much detail as the sectional chart. All types of topographical and cultural features, including railroads and major roads, are shown. All important navigational aids and air facilities are included on the overprint. Scheduled revisions every six months (12 months in Alaska) supersede previously printed charts. Time for the next scheduled edition is below the date in the lower right hand corner of the margin.

30. Aeronautical Planning Chart

The aeronautical planning chart (AP) is used for long-range flight planning. One of these charts covers the United States. Its scale is 1:5,000,000. Information gathered from this chart is transferred to other charts for the purpose of navigation. Similar charts for the rest of the world are termed *world planning charts* and are of the same scale and are also used for flight planning. These charts are based on the Lambert conformal projection from 75°N to 75°S; the modified polar stereographic projection is used for areas outside these limits.

31. Photomaps

Photomaps prepared by the Army Map Service, Corps of Engineers, are used for air navigation over small areas. These maps may be constructed by use of a single photomap or mosaic of several photomaps. They may be printed on the reverse side of tactical maps. The scale varies from 1:5,000 to 1:60,000. Meridians and parallels are indicated on the margin of the map. Positions are located by reference to a system of horizontal and vertical grid lines.

CHAPTER 4
CHART READING AND PILOTAGE

32. General

Chart reading is the identification of landmarks with their representation on a chart. The degree of success in navigating by observation of landmarks (pilotage) depends upon the pilot's proficiency in chart interpretation.

33. Accuracy of Charts

The latest revised aeronautical charts of the United States are accurate and complete. Charts of other parts of the world may not be as accurate or complete due to lack of information or utility. Aeronautical charts undergo repeated revision. It is important that the chart being used by the aviator is the latest revision.

34. Chart Content

Although charts do not picture all details, those particular features useful to the airman are emphasized, and include those features which have the most distinctive appearance from the air. For emphasis, many features are shown out of proportion to their true size, though centered in their correct positions. For example, the line representing a road on a WAC chart may appear to be a quarter of a mile wide according to the scale of the chart. Radio stations are prominently shown even though they are inconspicuous from the air. Many lines, such as meridians, parallels, isogonics, airways, and contours, take up space on the chart even though they are invisible on the ground.

35. Symbols

Since a chart is a diagram, it consists of symbols which do not necessarily resemble shape or appearance of objects they represent. Skill in chart reading depends on a complete understanding and interpretation of these symbols.

a. Relief.

(1) Aeronautical charts show elevation and inequalities of the earth's surface, which are known collectively as relief. Mountains are good landmarks but also a hazard to flying. Aeronautical charts give elevations of the highest peaks and other spot elevations in italics.

(2) Most charts represent relief by means of contours (lines connecting points of equal elevation (fig. 15)). The shoreline of the ocean might be thought of as the 0 foot contour, since every point on it is at sea level. The 1,000 foot contour is a line connecting all points that are 1,000 feet above sea level. On a steep slope, contours are close together; on a gentle slope, they are farther apart.

(3) On sectional and WAC charts, contours are brown lines, each labeled with the elevation it represents (fig. 15). Contour intervals vary from chart to chart. On charts where only low elevations exist, the contours are at 500 foot intervals; where high elevations exist, the contours are 1,000 feet apart. On charts where unexplored areas are shown, mountains may be indicated by hachures or shading with elevations of peaks shown as accurately as they are known.

(4) Hachures may be used on contour charts to show prominent hills or buttes too small to depict otherwise. The relief shown by contours is further emphasized on sectional and WAC charts by a gradient system of coloring. The area between sea level and 1,000 feet is dark green; between 1,000 feet and 2,000 feet, light green; and between successively higher contours, different shades of brown from light to dark. The darker-colored mountain peaks stand out conspicuously. Other

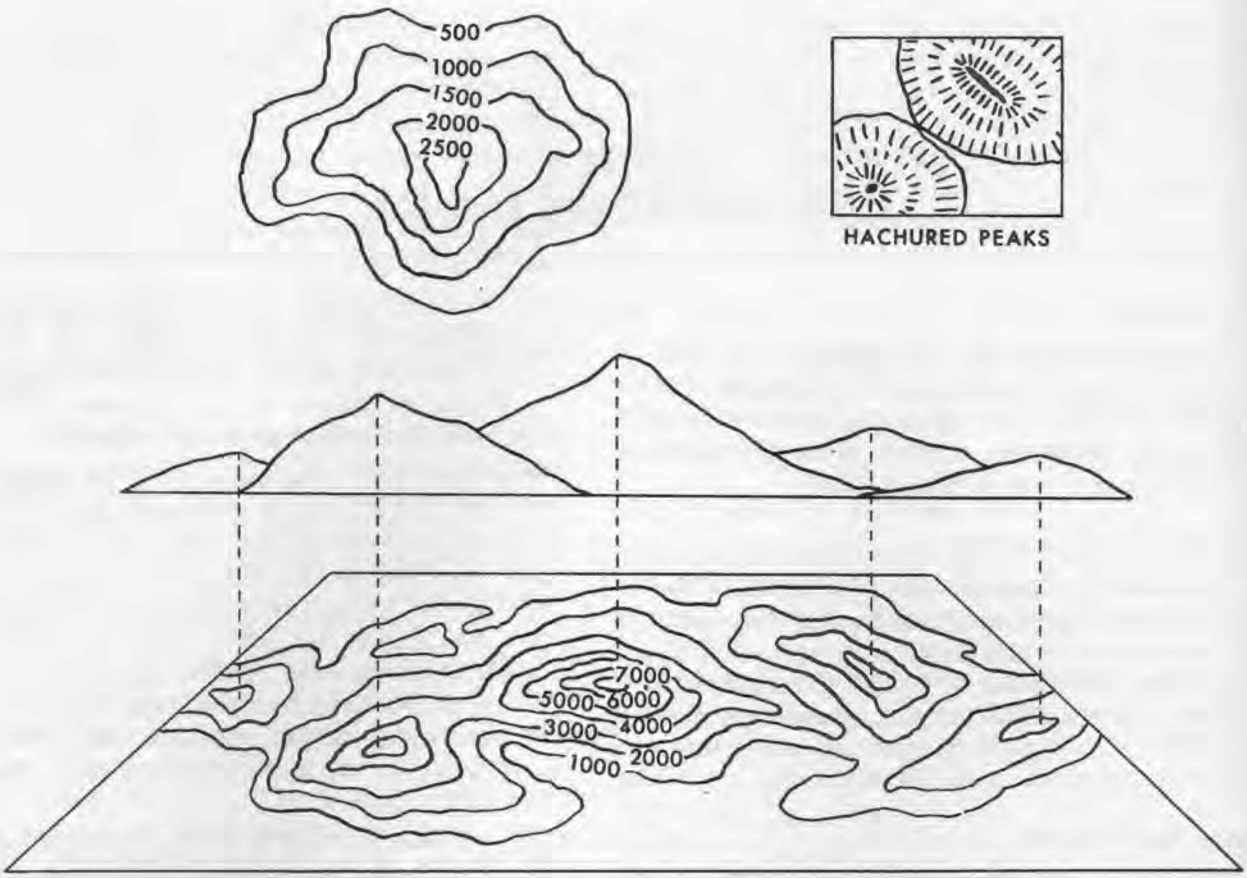


Figure 15. Relief.

aeronautical charts have different color schemes, or show only contour lines. The color shading block indicates elevation levels on the chart.

b. Cultural. Cultural symbols (fig. 16) represent man-made features. Cities and towns are shown by several methods. A circle or square denotes a small town, but does not show the shape of the town. The town can be recognized from the air only by its position relative to nearby features such as roads; railroads, rivers, streams, etc. A city is represented according to its shape and size. Comparatively few roads are shown on WAC charts, and on detailed sectional charts many conspicuous roads are omitted, especially in congested areas. All railroads are shown on aeronautical charts; normally they have greater permanence than roads and are thus more likely to be accurately depicted. A chart may or may not show a bridge where a road or railroad crosses a body of water. Many cultural features, such as racetracks, oil fields, tank farms, and ranger stations, are shown by special symbol.

Note. There are no standard symbols for many conspicuous features, such as smokestacks, water towers, monuments, and prominent buildings. These are often indicated by brief, descriptive notes, and each feature is indicated with an arrow and perhaps a dot showing the location.

c. Aeronautical Information. Aeronautical information is printed in red or purple on sectional and WAC charts. Classes of airports are distinguished by different symbols, and the elevation of each airport is given (fig. 17). Light beacons (with their code signals) and radio stations (with their call letters, frequencies, and the position of each radio beam) also are shown (fig. 18). Airways, danger areas, and isogonic lines are clearly marked (figs. 19 and 20).

d. Water and Forest. Bodies of water are valuable to the navigator because they are relatively permanent and easily seen from the air. Conventionally, water is shown in blue with coastlines accurately drawn. (The color does not

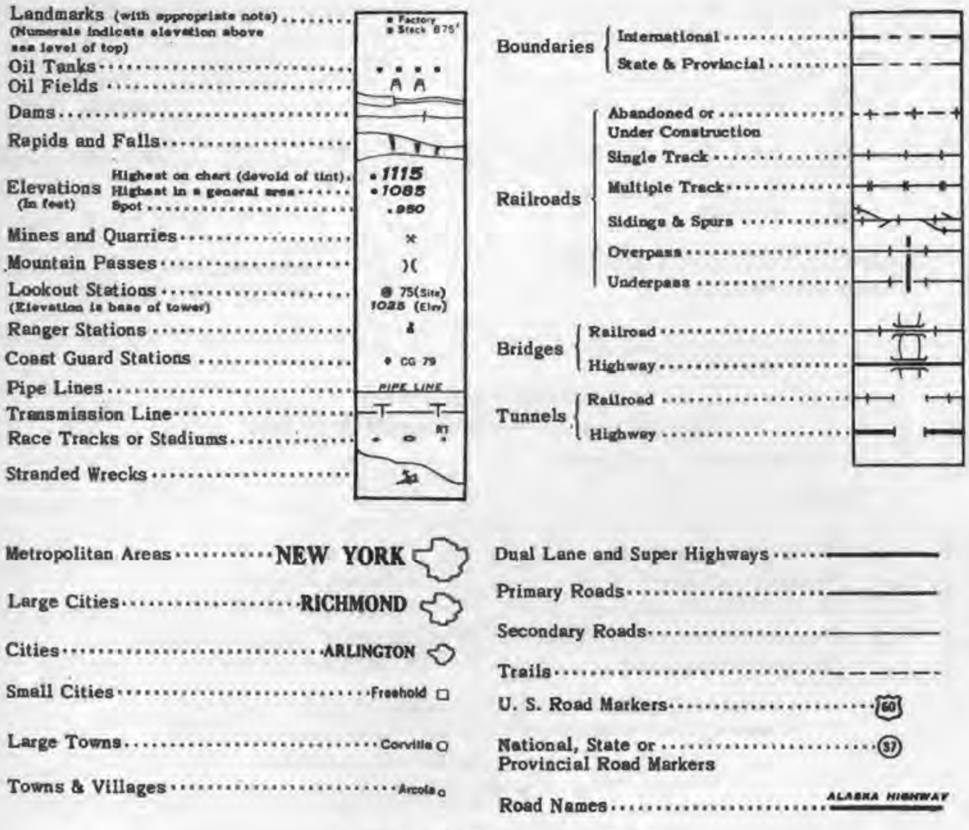


Figure 16. Cultural symbols.

mean that the water looks blue from the air.) In arid regions, the most important rivers, often having little water showing above the ground, may have their courses marked by comparatively dense vegetation. *European charts* show forest areas in green; on charts of the United States, forests are not shown.

e. Reverse Side of Chart. The following items are shown on the reverse side of sectional and WAC charts: aeronautical symbols; a list of all airports within the limits of the chart, with information concerning latitude and longitude, elevation, number and length of runways, etc.; a list of prohibited, restricted, caution, and warning areas in the chart area; a chart of the United States showing the sectional charts required for each area; and much other information of value to the pilot.

36. Checkpoints (Daylight Hours)

a. A landmark used to fix the aircraft's position is called a *checkpoint.* A checkpoint must be a unique feature, or group of features, in a given area. The value of the type of checkpoint will vary with the terrain. In open areas or farm country, any town, railroad, or highway can be used. In more densely populated areas, minor features such as roads and small towns, are difficult to distinguish. It is easier to identify important highways, large towns with distinctive shapes, or towns near lakes or rivers. In forested areas, swaths cut for pipe lines and powerlines are easily traced. In mountainous areas, mines, ranger stations, prominent peaks, passes, and gorges can be used. In a desert, where checkpoints are few, minor features often afford checkpoints.

b. If there is any uncertainty of position, every possible detail should be checked before identifying a checkpoint. The pilot may have to check back and forth *from chart to ground* to compare the angles at which roads or railroads leave a town, the position of bridges and intersections, or bends in streams and roads. Because the chart shows only significant details, it is essential that the pilot select reliable features

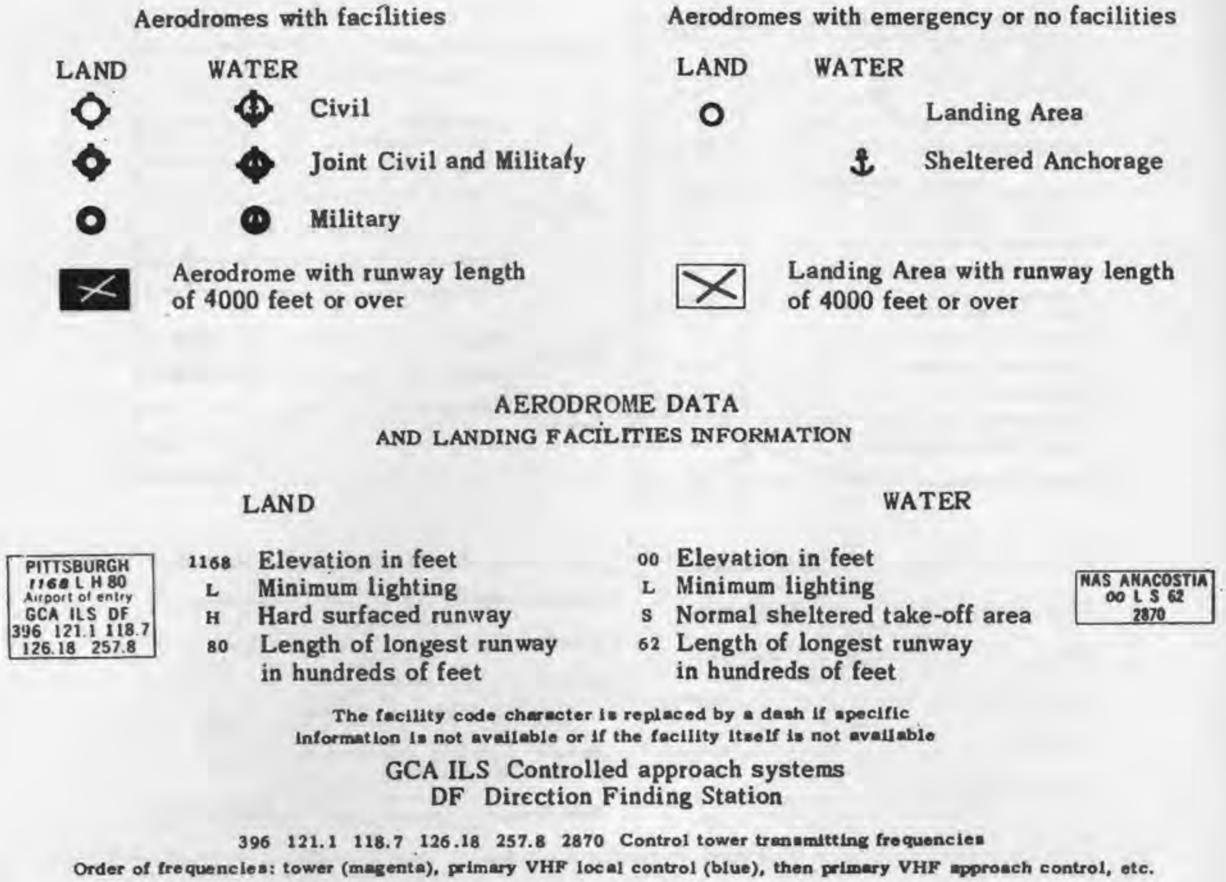


Figure 17. Aeronautical symbols—airdromes.

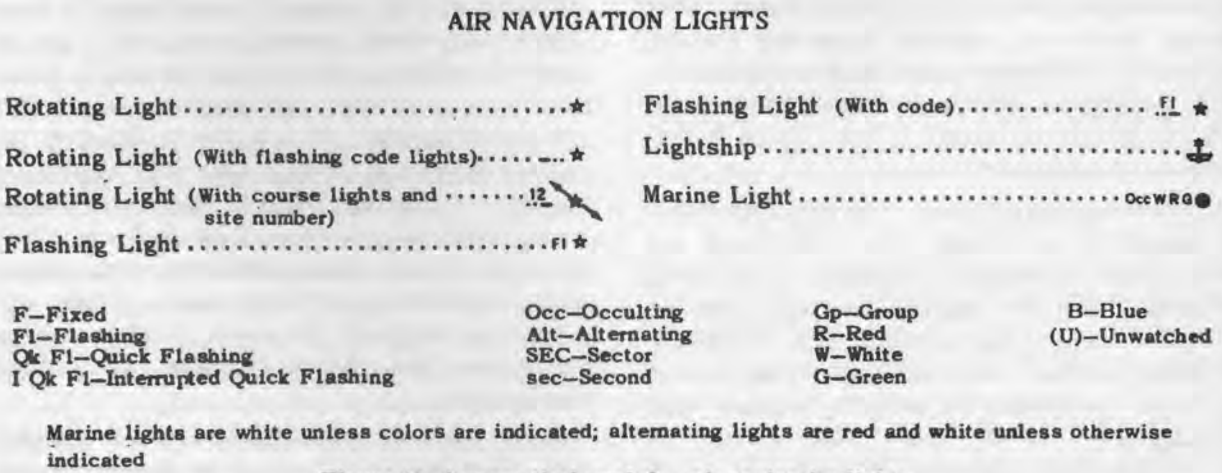


Figure 18. Aeronautical symbols—air navigation lights.

on the chart to compare with features on the ground. Figure 21 shows the characteristics of good and poor checkpoints.

37. Estimating Distance

One method of estimating ground distance is by comparison with the distance between two other points measured on the chart. Another method (fig. 22) is to estimate the angle between the horizontal at the aircraft and the line of sight. This is called the "angle of depression." The distance in feet is equal to the absolute

All radio facility data are printed in blue with the exception of certain LF/MF facilities such as tower frequencies, radio ranges and associated airways, which are printed in magenta.

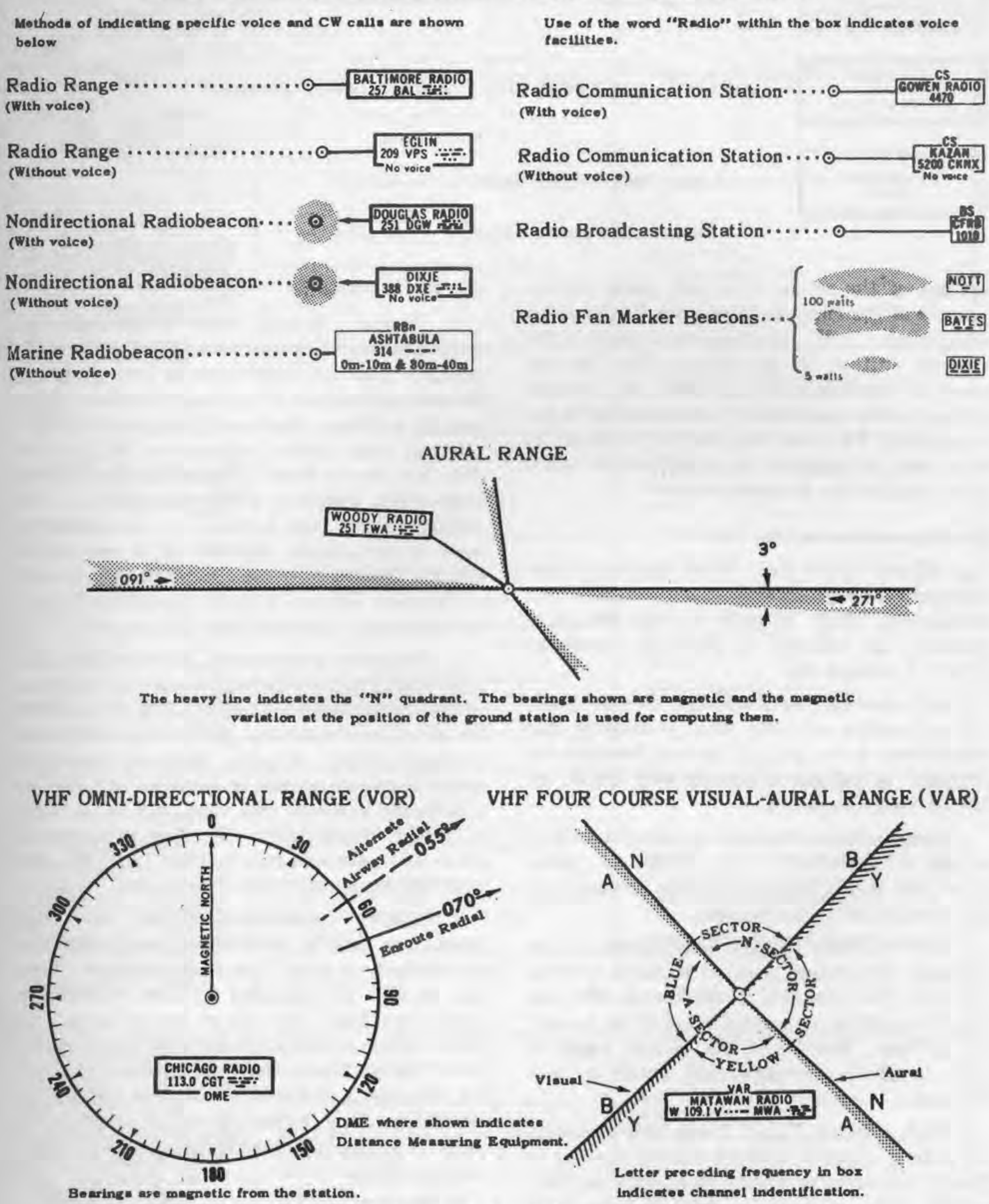


Figure 19. Aeronautical symbols—radio facilities.

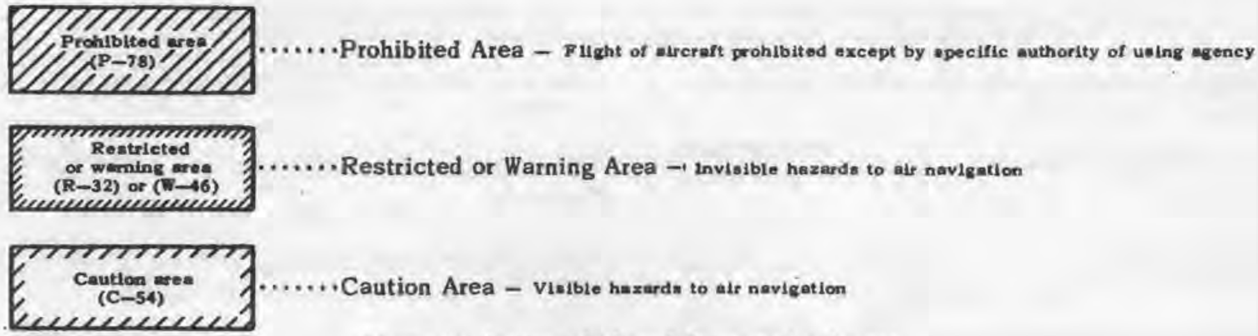


Figure 20. Aeronautical symbols—restricted areas.

altitude of the aircraft, in feet, times the cotangent of the angle of depression. If the angle of depression is 45°, the distance is equal to the absolute altitude; if the angle is 30°, the distance is approximately 1.7 times the absolute altitude; if the angle is 60°, the distance is approximately 0.6 times the absolute altitude. A mark may be made on the windshield to assist in estimating the depression angle.

38. Appearance of the Terrain

a. Effects of the Sun. When the sun is low, shadows are long, causing strong contrasts and emphasizing relief. At noon or when the sun is obscured, the absence of shadows causes the terrain to appear flat.

b. Obstructions to Visibility. Smoke, haze, and dust reduce visibility, often permitting only observation of the ground directly beneath the aircraft. A partial undercast may block the ground view completely.

c. Seasonal Changes. Snow on the ground may conceal a landmark. The outline of lakes, rivers, and ponds, especially in low, flat country, may change with the seasons.

d. Low Altitude Flight. When flying at low altitudes, the ground appears to move rapidly, and only brief glimpses of checkpoints are possible. In addition, only small areas of the terrain can be seen. Because of the oblique angle of sight, depth is increased and detail is pronounced.

e. High Altitude Flight. From high altitudes, the ground appears to move slowly, making it difficult to determine when a checkpoint has been passed. When visibility is good, a large area can be seen. Distance appears small and the terrain looks flat with little detail.

39. Night Pilotage

a. General. During hours of darkness, an unlighted landmark may be difficult or even impossible to see and lights can be very confusing because they appear to be closer than they really are. In addition, stars near the horizon may be confused with lighted landmarks. Ability to locate the North Star (Polaris) will assist in orientation. Polaris is always due north and its altitude above the horizon is approximately equal to the latitude. Objects can be more easily seen by looking at them from the side or rods of the eye. Vertigo is easily produced at night by staring at objects and must be avoided.

b. Unlighted Landmarks. In moonlight, and occasionally on moonless nights, some of the more prominent unlighted landmarks are visible from the air. Coastlines, lakes, and rivers usually may be seen without difficulty. Reflected moonlight causes a stream or lake to stand out brightly for a moment; however, this view may be too brief to permit recognition. By close observation, roads and railroads may be seen after the eyes have become accustomed to darkness.

c. Lighted Landmarks. Cities and large towns are usually well-lighted and stand out more clearly at night than in the daytime. They can usually be identified by their distinctive shapes and frequently can be seen at great distances, often appearing closer than they actually are. Smaller towns that are darkened early in the evening are hard to see and difficult to recognize. Busy highways are discernible because of automobile headlights, especially in the early evening.

d. Beacons.

Caution: **Light lines are becoming obsolete. When a light needs major repair, it is deleted**

CONDITIONS	GOOD CHECK POINTS	POOR CHECK POINTS
	MOUNTAINOUS AREAS Prominent peaks, cuts and passes, gorges. General profile of ranges, transmission lines, railroads, large bridges over gorges, highways, lookout stations. Tunnel openings and mines. Clearings and grass valleys. Radio Aids.	Smaller peaks and ridges, similar in size and shape.
	COASTAL AREAS Coastline with unusual features. Lighthouses, marker buoys, towns and cities, structures. Radio Aids.	General rolling coastline with no distinguishing points.
	SEASONAL CHANGES Unusually shaped wooded areas in winter. Dry river beds if they contrast with surrounding terrain. Dry lakes.	Open country and frozen lakes in winter unless in forested areas. Small lakes and rivers in arid sections of country — in summer — when they may dry up. Lakes (small) in wet seasons in lake areas, where ponds may form by surface waters.
	HEAVILY POPULATED AREAS Large cities with definite shape. Small cities with some outstanding check point; river, lake, structure, easy to identify from others. Radio aids, prominent structures, speedways, railroad yards, underpasses, rivers and lakes. Race tracks and stadia, grain elevators, etc.	Small cities and towns, close together with no definite shape on chart. Small cities or towns with no outstanding check points to identify them from others. Regular highways and roads, single railroads, transmission lines.
	OPEN AREAS FARM COUNTRY Any city, town, or village with identifying structures or prominent terrain features adjacent. Prominent paved highways, large railroads, prominent structures, race tracks, fairgrounds, factories, bridges, and underpasses. Lakes, rivers, general contour of terrain; coastlines, mountains, and ridges where they are distinctive. Radio Aids.	Farms, small villages rather close together, and with no distinguishing characteristics. Single railroads, transmission lines and roads through farming country. Small lakes and streams in sections of country where such are prevalent, ordinary hills in rolling terrain.
	FORESTED AREAS Transmission lines and railroad right-of-ways. Roads and highways, cities, towns and villages, forest lookout towers, farms. Rivers, lakes, marked terrain features, ridges, mountains, clearings, open valleys. Radio Aids.	Trails and small roads without cleared right-of-ways. Extended forest areas with few breaks or outstanding characteristics of ter:ain.

Figure 21. Good and poor checkpoints.

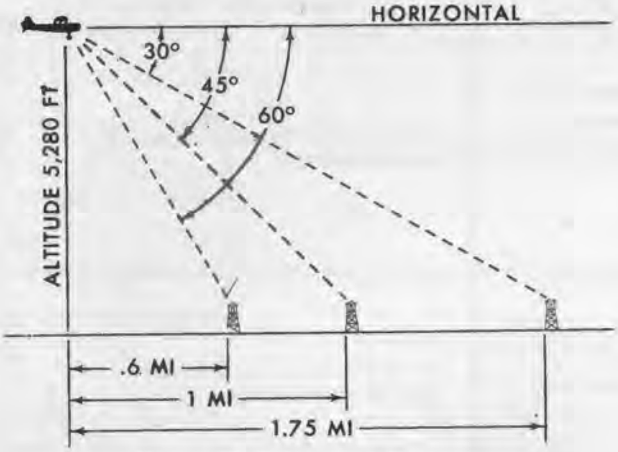


Figure 22. Estimating distance.

from the line. The following discussion is based on the assumption that all light lines on a leg of a flight are in operation.

(1) *Light Lines.* Airways are marked at night by rotating beacon lights spaced at intervals of approximately 10 miles. Seen from the air, the beacons form an on-course *light line* which is visible from 20 to 40 miles during clear weather. Aeronautical charts indicate each beacon by a star with an open center. An arrow combined with this symbol indicates that the beacon has course lights and shows the direction of the light line. Location of a bêacon on an airway is indicated by a flashed code letter which shows its distance from the origin of the airway.

(2) *Numbering.* Beacons are numbered from west to east and from south to north between terminal cities. The number of a beacon multiplied by 10 gives its approximate distance in miles from the origin of the airway. For example, beacon number 1 is 10 miles from the origin of the airway, while beacon number 5 is 50 miles. The beacon number is identified by a letter flashed in the international morse code. The first letter of each word in the following sentence corresponds to the number given with it: (1) When, (2) Undertaking, (3) Very, (4) Hard, (5) Routes, (6) Keep, (7) Directions, (8) By, (9) Good, (10) Methods. Only ten letters are used; hence, it is necessary that the same letters represent the number of beacons that are more than 100 miles from the origin of the airway. The code letter flashed by the

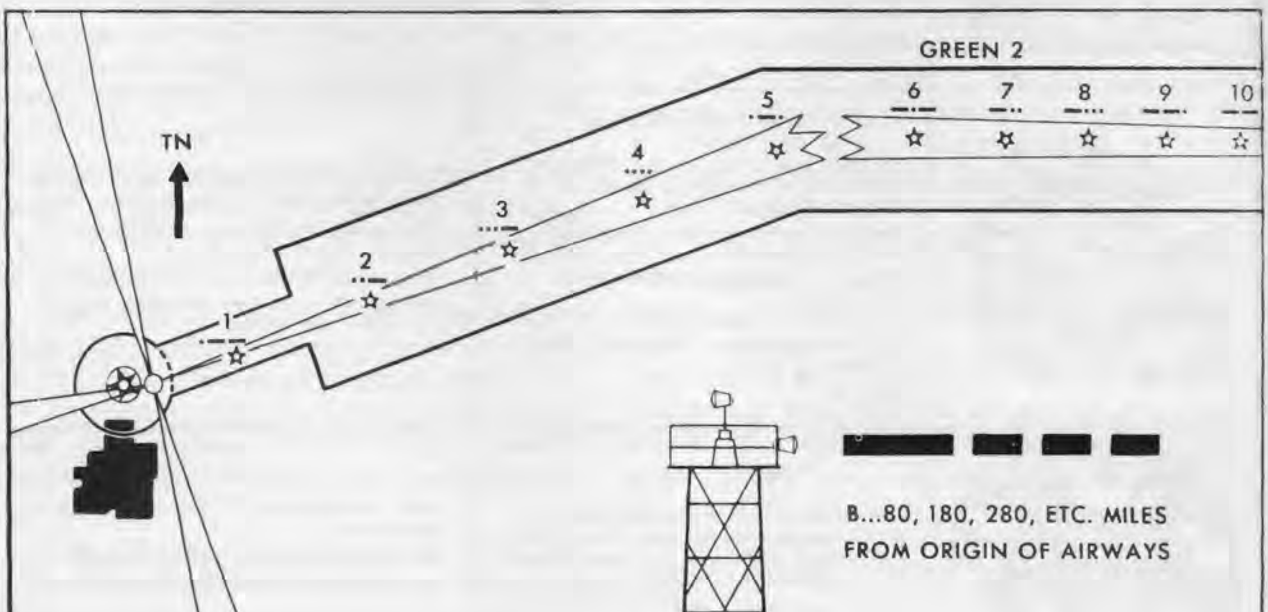


Figure 23. Light line.

beacon represents only the last digit. For example, W is the code letter for beacons numbered 1, 11, 21, etc., which are respectively 10 miles, 110 miles, 210 miles, etc., from the origin (fig. 23).

(3) *Identification.* Airway beacons show six clear flashes per minute. The identifying code letters are visible only to aircraft that are on-course. The letter is flashed in green if the beacon is located at an airport; if not, it is flashed in red. The number of the beacon, as well as the corresponding code signal, is printed beside the beacon symbol on aeronautical charts. The number is also painted on the roof of the beacon power shed for daytime identification.

40. Chart Reading In-Flight

a. Preparation on the Ground. Ground preparation for navigation will save much time and worry in flight. The course line should be drawn so that, when in the air, a glance at the chart will give an indication of the aircraft's location with respect to the desired course. If both departure and destination are on the same chart, the course line is drawn along a straight edge between them. If they do not appear on the same chart, the course line is drawn along a straight edge between them. If they do not appear on the same chart, the aeronautical planning chart may be used to determine the principal points over which the flight will proceed. The course line is then drawn on each of the charts being used. The total distance should be measured. If the course line is marked off in increments (for example) of 20 miles, the trouble of unfolding the chart and measuring in the air is avoided.

b. Orienting the Chart. When in flight, orient the chart so that north on the chart is toward true north. The course line on the chart will then parallel the intended course of the aircraft, and all objects will be oriented with the chart.

CHAPTER 5

PLOTTING AND MEASURING

41. General

Plotting is the establishment of points and lines on a chart with reference to meridians and parallels. Measuring, as used in this chapter, refers to the measurement of distance and direction on the chart. The chart serves as a record of the flight and provides information necessary for the successful completion of the flight. Chart work is a fundamental part of navigation and must be accurate.

42. Plotting Tools

a. Pencil and Eraser. Use a sharp, soft lead pencil and a soft eraser. A sharp, soft pencil makes a fine, black line which is easy to see and makes chart work more precise. A soft eraser will not damage the chart.

b. Dividers. Use dividers to step off distances on a chart. The dividers should have the points separated to the desired distance, using the proper scale (latitude or graphic scale), with the distance transferred to the working area of the chart. In this way, lines of desired length can be marked off. By reversing the process, unknown distances on the chart can be spanned and compared with the scale. Manipulate the dividers with one hand, leaving the other free to move the plotter, pencil, or chart as necessary. While measurement is being made, the chart must be flat and smooth between the dividers. A wrinkle may cause an error of several miles.

c. Plotters. A plotter is an instrument designed primarily to aid in drawing and measuring lines. The Mark II Weems plotter (par. 43) is the type commonly used by the Army aviator.

43. Description of the Mark II Weems Plotter

a. General. The Mark II Weems plotter (fig. 24) is made of transparent plastic and has lines and scales printed in black. The rectangular part of the plotter has a straightedge for drawing lines, and scales for measuring distances. The semicircular part of the plotter has two circular scales for measuring direction.

b. Rectangular Part. Midway between the edges of the rectangular part is an inch scale. Along each edge is a scale for measuring *nautical* miles on a WAC chart. Between this scale and the inch scale is another scale for measuring statute miles on a *sectional* chart. The rectangular part of the plotter has several lines parallel with the straightedge, to aid in judging when the straightedge is parallel with the course line.

c. Circular Scales. The circular scales are calibrated in degrees. The outer scale, reading from 0° to 180° (right to left), is for direction

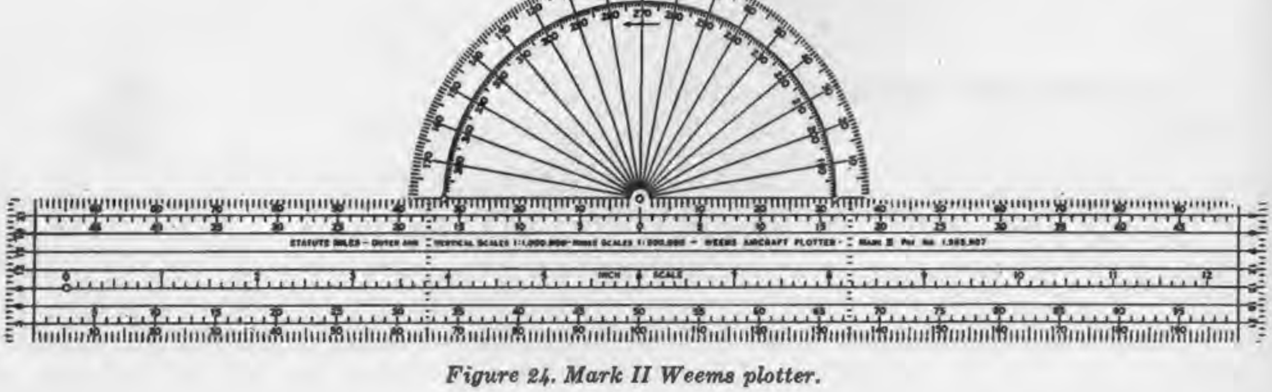


Figure 24. Mark II Weems plotter.

in the first and second quadrants (north through east to south). Since these directions are to the right on the chart, the outer scale has an arrow pointing to the right (fig. 25). The inner scale, reading from 180° to 360° (right to left), is for directions in the third and fourth quadrants (fig. 26). The center of curvature of both scales is marked by a small hole.

44. Technique for Using the Mark II Weems Plotter

a. Measuring a True Course. To measure true course, place the center hole on the midmeridian and the straightedge parallel with the true course line (fig. 27). If a ruler or pair of dividers is used along the course line, the straightedge of the plotter will remain parallel to the course line as it is moved so that the center hole lies over a meridian (fig. 28). Figure 27 shows the method of reading direction. Observe the small arrows to estimate correct direction. To avoid using the plotter inverted, check to see that information on plotter does not read backward.

b. Drawing Course Line From a Known Point. To draw a given course line from a known point, place pencil at the known point. While the plotter is being pushed and pivoted against the pencil, the straightedge will remain on the known point while the center hole and the scale reading are being alined with a meridian. The pencil will be in place for drawing the course line when the plotter has been properly alined with a meridian (fig. 29).

c. Measuring and Drawing Courses Near 000° or 180°. In drawing a course line that is nearly north or south, it may be difficult to use the plotter in the usual manner. Courses near 000° and 180° can be read with sufficient accuracy by reading the scale against a parallel and adding or subtracting 90°. Estimating direction will determine whether 90° is to be added or subtracted from the scale reading (fig. 30). (The new Mark II plotter has a special scale for measuring courses near north and south).

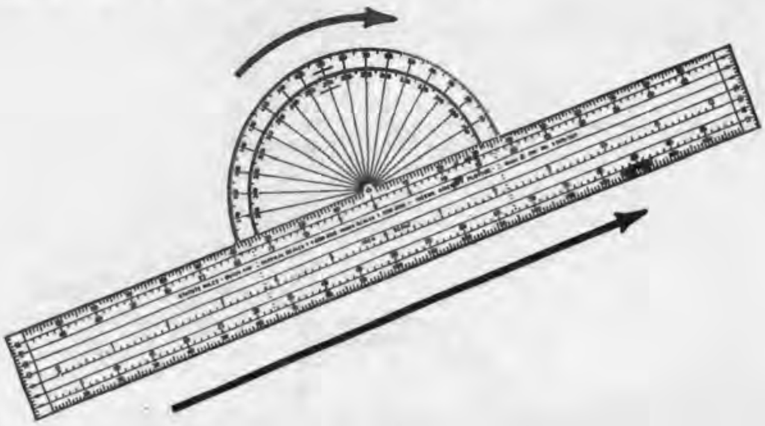


Figure 25. Measuring course in the first and second quadrants.

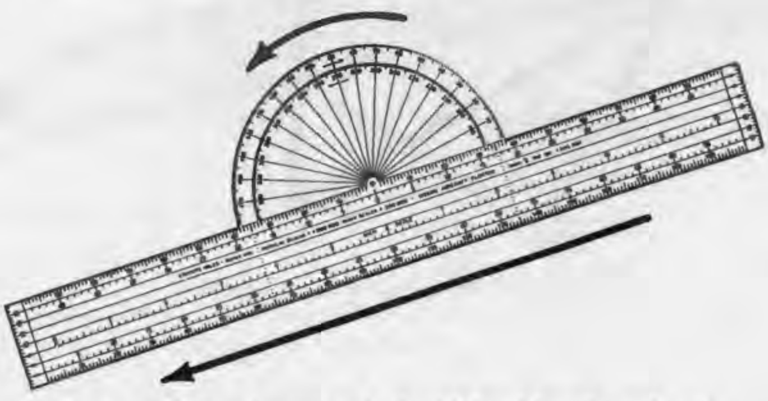


Figure 26. Measuring course in the third and fourth quadrants.

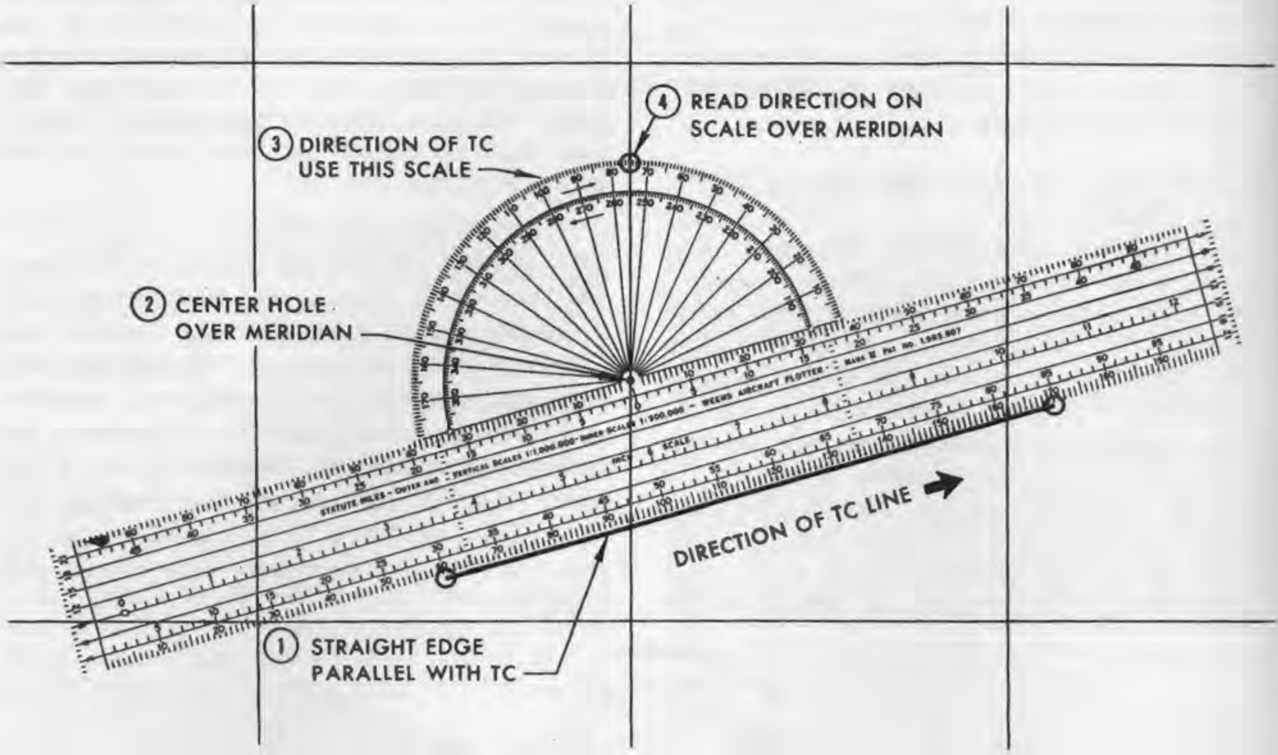


Figure 27. Measuring course.

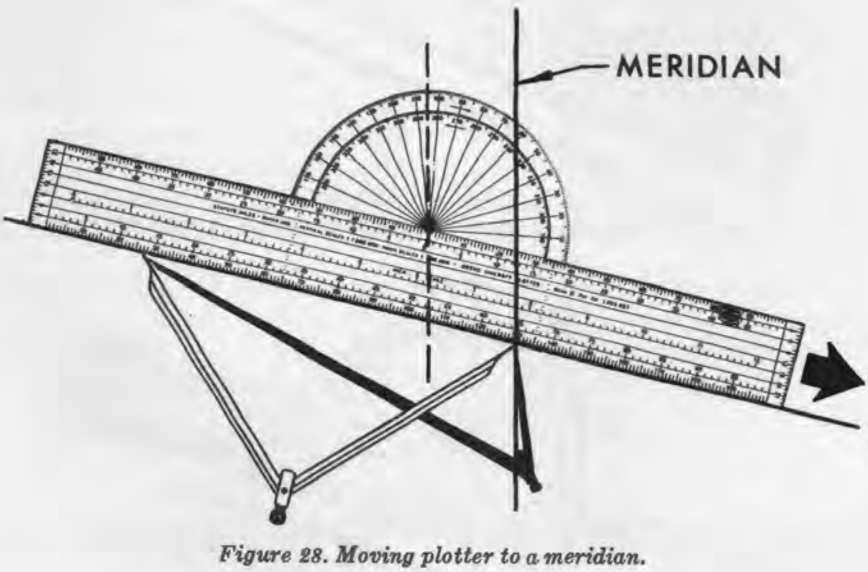


Figure 28. Moving plotter to a meridian.

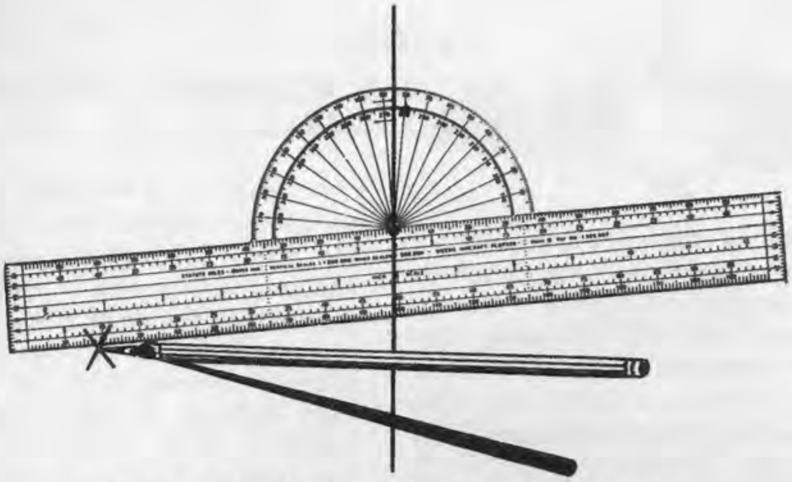


Figure 29. Drawing a course line from a known point.

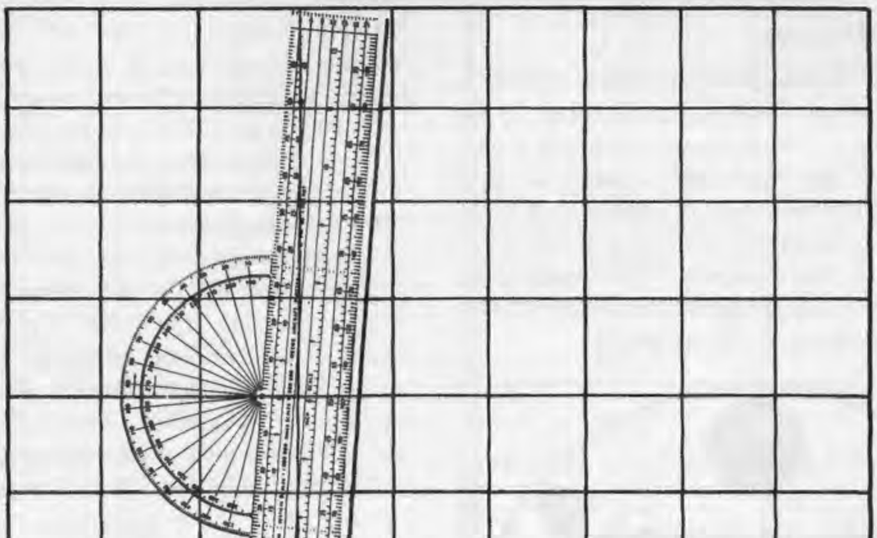


Figure 30. Measuring and plotting courses near 0° or 180°.

CHAPTER 6
INSTRUMENTS USED FOR DEAD RECKONING NAVIGATION

45. General

Instruments used by the pilot-navigator for dead reckoning navigation are the magnetic compass, heading indicator, outside air temperature gage, airspeed indicator, altimeter, and clock. From these, information can be read concerning direction, airspeed, altitude, and time, each of which must be correctly interpreted for successful navigation. Information on the instruments discussed in this manual is general in nature. For complete description, theory, and operation of these instruments, see TM 1–215.

46. Magnetic Compass

a. General. The magnetic compass (fig. 31) is the only direction seeking instrument in an aircraft. It has a compass card marked at 5° increments and numbered 30° apart. A fixed line known as the *lubberline,* is located on a glass aperature of the compass case and is a reference line for reading the compass. The reading on the compass card, under the lubberline, indicates the compass heading of the aircraft.

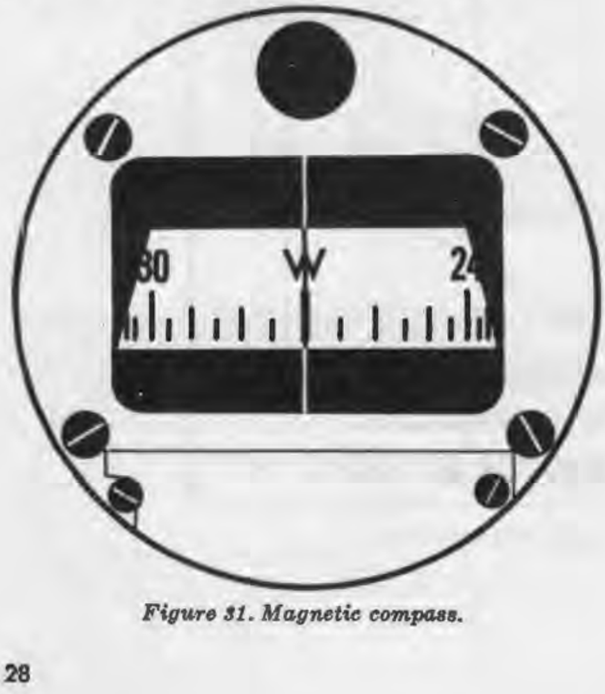


Figure 31. Magnetic compass.

b. Magnetic Variation. Navigational charts are printed in geographical true directions. Since the magnetic compass derives its directional qualities by the needle alining itself with the direction of the earth's magnetic field, it points to magnetic north, not true north (fig. 32). The angular difference between the true and magnetic meridian is called *magnetic variation* or simply *variation.* It is necessary to correct for this error in order to maintain *true* direction as plotted on a chart. Magnetic variations affects the compass on any heading and varies with latitude and longitude by the amount of existing magnetic variation at any particular point. Magnetic variation is indicated on navigation charts by means of *agonic* and *isogonic* lines.

(1) *Agonic Line.* An agonic line is a line on a chart connecting all points where *no* magnetic variation exists and is labeled 0°.

(2) *Isogonic Lines.* An isogonic line is a line on a chart connecting all points of *equal* magnetic variation. They are drawn one or more degrees of variation apart according to the size of the chart. Each line is labeled according to the number of degrees of variation and shows the east or west deflection of

Figure 32. Magnetic variation.

Figure 33. Isogonic chart of the United States.

the compass needle. If the magnetic pole is to the east of the true north pole, variation is east; if to the west, it is west (fig. 33). A true course corrected for variation becomes a magnetic course.

c. Magnetic Deviation. A magnetic compass is affected by magnetic fields other than those of the earth. Any piece of ferrous material or electrical equipment close to the compass tends to deflect the needle away from magnetic north. This angular deflection of the compass needle from magnetic north is called *magnetic deviation.* If the needle is deflected to the east, deviation is east; if to the west, deviation is west. A magnetic course corrected for deviation becomes a compass course.

(1) *Compass North.* The direction in which the compass needle points is called *compass north.* Compass directions may be expressed relative to compass north just as true or magnetic directions are expressed relative to true or magnetic north (fig. 34).

(2) *Deviation Card.* A deviation card records the errors in the compass indications. The card is mounted next to the compass and includes the aircraft number, date on which the compass was swung, and a compass heading to be flown for each magnetic heading in increments of 45° (fig. 35).

Note. Deviation may change with each change of heading of the aircraft, whereas, variation changes with change of locality.

47. Applying Compass Corrections

a. System for Applying Compass Corrections.

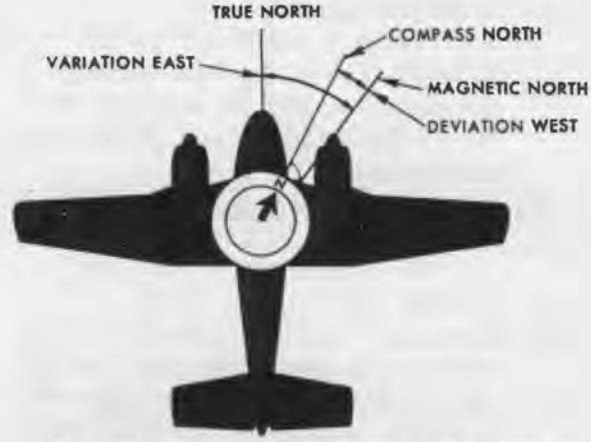


Figure 34. Application of variation and deviation.

AIRCRAFT 15088
SWUNG: 5 JUNE 58

TO FLY	STEER
N	001
045	047
090	093
135	136
180	181
225	224
270	268
315	315

Figure 35. Deviation card.

To find what the compass should read to follow a given course, corrections for drift, variation, and deviation are applied. When drift correction (par. 53) is applied to a true course ($TC \pm DC = TH$), it becomes a true heading. A good method for recording application of variation and deviation is as follows:

(1) Write the equation

$$TH \pm V = MH \pm D = CH$$

in which *TH* is the true heading; *V* the variation; *MH* the magnetic heading; *D* the deviation; and *CH* the compass heading.

(2) Below each factor, place the known information.

$$TH \pm V = MH \pm D = CH$$
$$168° \quad 12°E \qquad\qquad 5°W$$

(3) When making calculations from a true heading to a compass heading, easterly error is subtracted and westerly error is added. Completing the above problem, subtracting the 12°*E* from the *TH* gives a magnetic heading (*MH*) of 156° adding the 5°W to the *MH* gives a compass heading (*CH*) of 161°. Place these headings in their proper places in the equation.

b. Reversing the Equation. To find a true heading when the compass heading is known, the same equation is written as in the above problem. Placing the known information in the proper places, it would appear as follows:

$$TH \pm V = MH \pm D = CH$$
$$12°E \qquad\qquad 5°W \quad 161°$$

(1) When changing from a compass heading to a true heading, easterly error is added and westerly error is subtracted. It is the reverse of changing from *TH* to *CH*.

(2) Subtract the 5°*W* from the *CH* (161°). Place this figure (156°) below the *MH*.

(3) Add the 12°*E* to the *MH* (156°) to obtain the *TH* (160°). Place this figure below the *TH*.

48. The Heading Indicator (Directional GYRO)

The heading indicator assists in making turns to predetermined headings and aids in maintaining a heading. It is *not* a direction seeking instrument and must be adjusted to agree with the magnetic heading of the aircraft. Bearing drag causes some precession (failure to remain rigid in space) of the instrument and it is necessary to reset it about every 15 minutes. Precession should not exceed 3° in 15 minutes.

49. Airspeed, Groundspeed, and the Airspeed Indicator

a. General. True airspeed (TAS) is the speed of the aircraft through the air. Groundspeed (GS), of primary interest to the pilot in navigation, is the speed of the aircraft with reference to the ground. Wind determines whether true airspeed is greater, equal to, or less than groundspeed. The airspeed indicator is an instrument that indicates airspeed but not necessarily the true speed of the aircraft through the air.

b. Indicated Airspeed. The airspeed indicator does not always indicate true airspeed. The reading is called *indicated airspeed* (IAS). Since calibration cards are not used in Army aircraft, indicated airspeed and *calibrated airspeed* (CAS) are synonymous to the Army aviator. To find true airspeed, however, corrections must be made to the indicated airspeed for pressure altitude and temperature.

c. Changing Indicated Airspeed to True Airspeed. A "rule of thumb" for calculating true airspeed is to add 2 percent of the indicated airspeed for each 1,000 feet of altitude. This rule of thumb may be used where information necessary for use of other systems is not available. Temperature and altitude corrections are calculated by use of the airspeed computation window of the E–6B computer. This procedure is covered in detail in paragraph 85.

50. Pressure Type Altimeter

The pressure type altimeter measures atmospheric pressure at flight level in terms of feet above a specified pressure level.

CHAPTER 7
WIND AND ITS EFFECT

51. Wind Direction and Speed

Wind direction is named by the direction *from* which the wind blows. Wind speed is rate of wind motion without regard to direction. In the United States, wind speed is usually expressed in knots. Wind velocity (*W/V*) includes both direction and speed of the wind. For example, a west wind of 25 knots is recorded as *W/V* 270°/25 knots. "Downwind" is movement *with* the wind; "upwind" is movement *against* the wind.

52. Effect of Wind

a. General. Moving air exerts a force in the direction of its motion on any object within it. Objects that are free to move in air will move in a downwind direction at the speed of the wind. An aircraft will move as does the balloon shown in figure 36. In addition to its forward movement through the air, if an aircraft is flying in a 20 knot wind, it will move 20 nautical miles downwind in one hour. The path of the aircraft *over the earth* is determined by the motion of the aircraft through the air and the motion of the air over the earth's surface. The direction and movement of the aircraft through the air is determined by the direction in which the nose of the aircraft is pointed and the speed of the aircraft through the air (fig. 37).

b. Drift. The sideward displacement of the aircraft caused by the wind is called drift. Drift is measured by the angle between the ***true heading*** (true direction in which the nose is pointed) and the ***track*** (actual path of the aircraft over the earth).

Note. Track must not be confused with true course which is the plotted course or intended track.

c. Example of Drift. As shown in figure 38, an aircraft departs point X on a true heading of 360° and flies for one hour in a wind of 270°/20 knots. The aircraft is headed toward point M directly north of X. Its true heading is represented by line XM. Under no-wind conditions, the aircraft would be at point M at the end of one hour. However, there is a wind of 20 knots and the aircraft moves with it. At the end of one hour, the aircraft is at point N, 20 nautical miles downwind from M. The line XM is the path of the aircraft through the air; the line MN shows the motion of the body of air; and the line XN is the actual path of the aircraft over the earth.

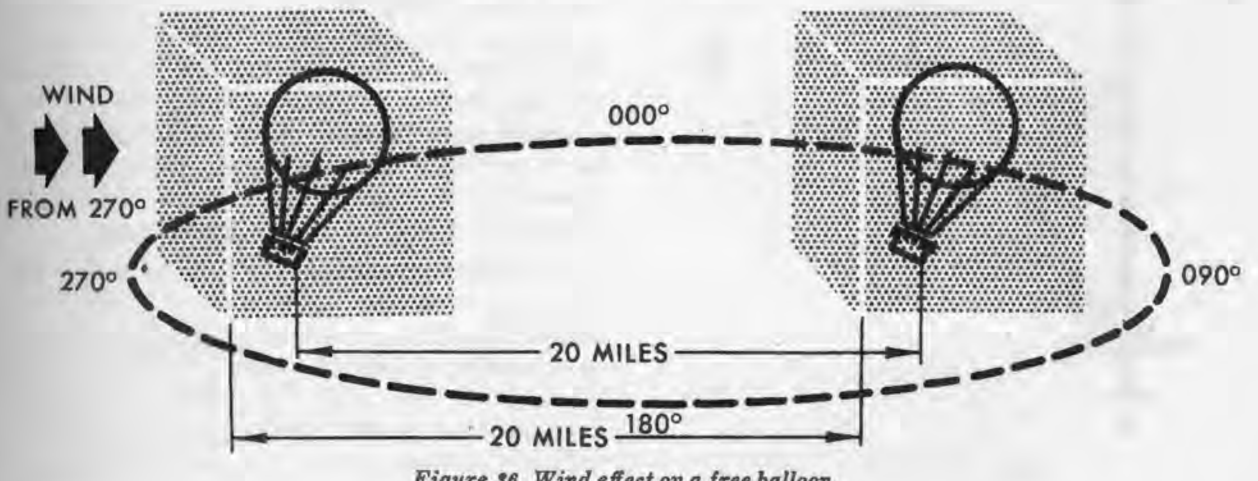


Figure 36. Wind effect on a free balloon.

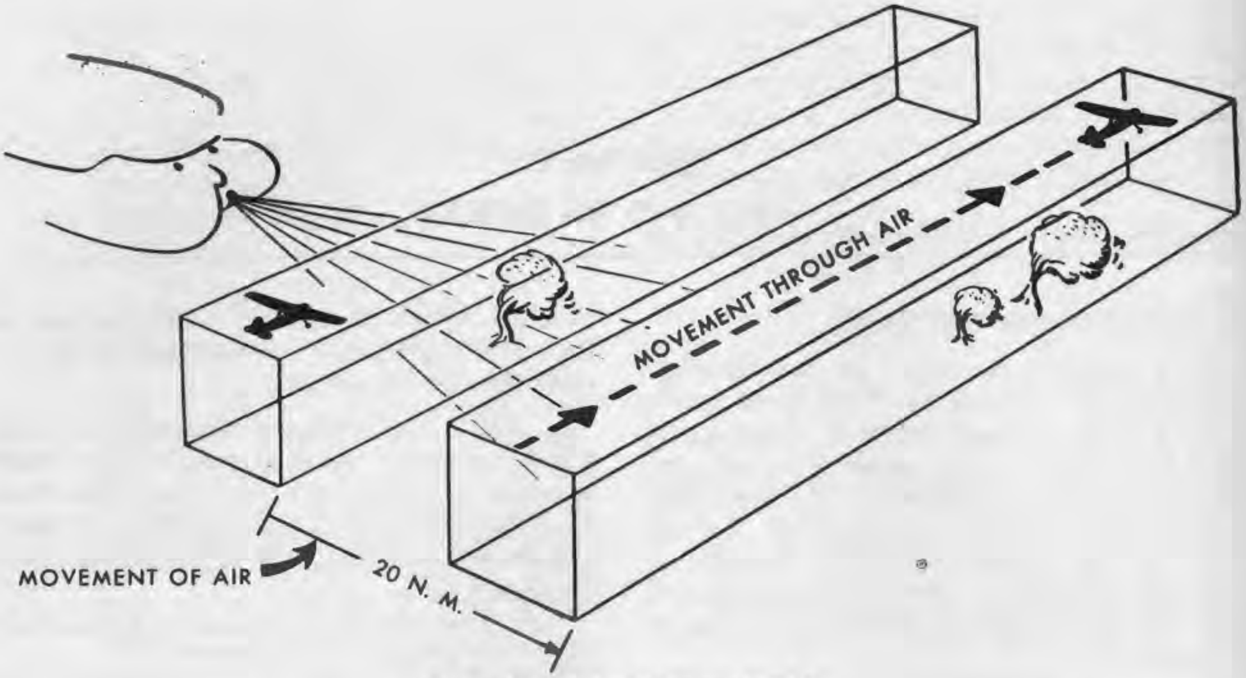


Figure 37. Wind effect on an aircraft.

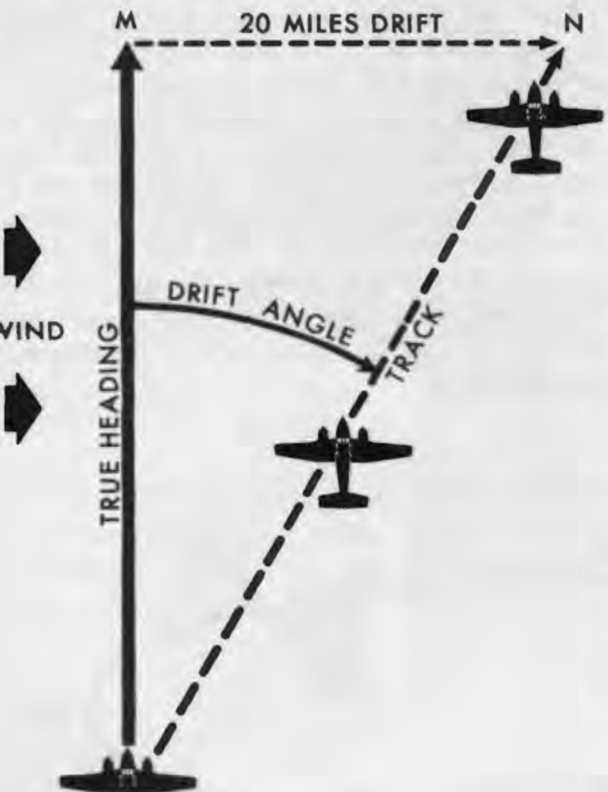


Figure 38. Drift.

d. Drift and Groundspeed Change With Heading Change. A given wind causes a different drift on each heading and effects the distance traveled over the ground in a given time. With a given wind, the groundspeed (GS), varies on different headings.

e. Effect of Wind on Different Headings With Respect to Track and Groundspeed. Effect of wind on different headings in relation to track and groundspeed is shown in figure 39. A wind of 270°/20 knots is affecting the groundspeed and track of an airplane flying on headings of 000°, 090°, 180°, and 270°. On each heading the airplane flies from point X for one hour at a constant true airspeed. Length of each dashed line represents the distance the aircraft has traveled through the body of air or the distance it would have traveled over the ground in one hour had there been no wind. Each solid line represents the track of the aircraft. The length of each solid line represents groundspeed.

f. Headwind, Tailwind, Crosswind Effect. As shown in figure 39, the wind of 270°/20 knots causes right drift, on a heading of 000°, whereas on a heading of 180° it causes left drift. On the headings of 090° and 270°, there is no drift. On a heading of 090°, the airplane, aided by a tailwind, travels farther in one hour than it

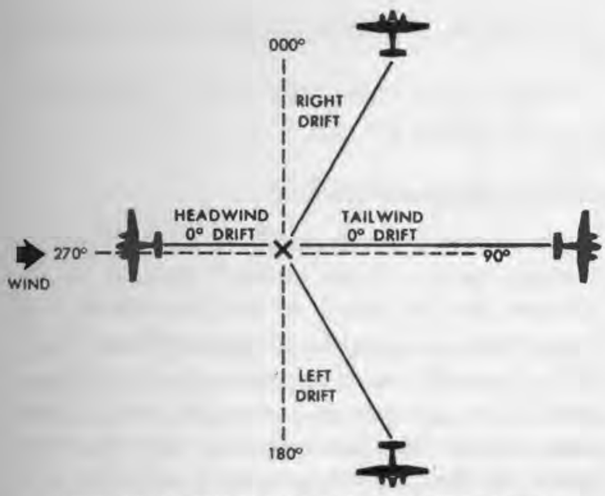


Figure 39. Effects of different headings on track and ground speed.

would with no wind; thus, its groundspeed is increased by the wind. On the heading of 270°, the headwind reduces the groundspeed. On a heading of 000° and 180°, the groundspeed is somewhat increased.

53. Drift Correction

Drift correction must be applied to a true course to determine the true heading. The amount of drift correction must be just enough to compensate for the amount of drift on a given heading. The drift correction angle (DCA) (sometimes called *crab angle*) is equal to but in the opposite direction from the drift angle (DA). As shown in figure 40, if a pilot attempts to fly to a destination due north of his point of departure (*TC* 000°) on a true heading of 000°, and a west wind were blowing, he would arrive somewhere east of his destination because of right drift (A, fig. 40). To correct for right drift so that the aircraft would remain on course and arrive at the desired destination, the nose would have to be pointed to the *left* of the true course or upwind (B, fig. 40).

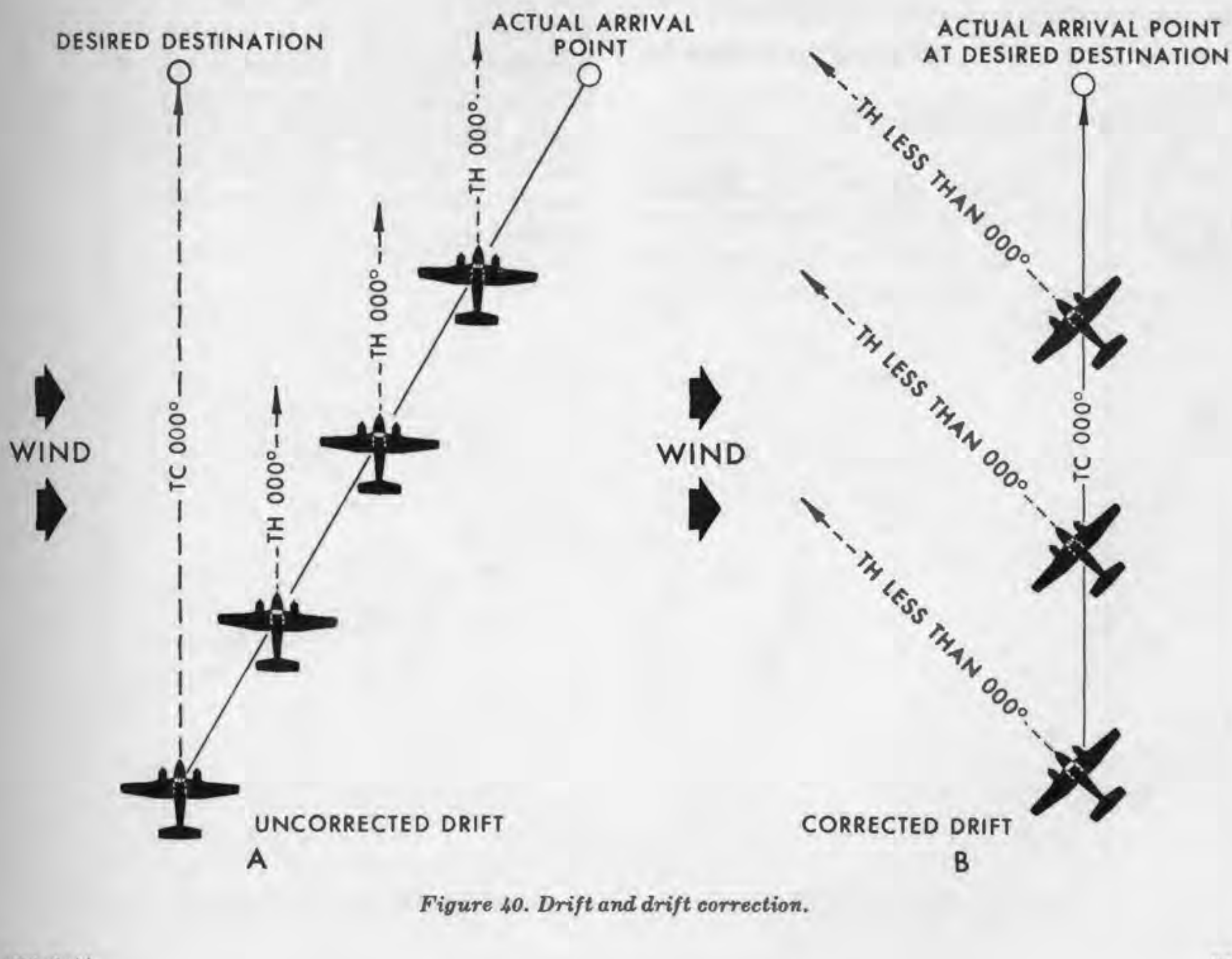


Figure 40. Drift and drift correction.

54. Summary of Drift and Drift Correction

a. Wind from the right causes drift to the left.

b. Wind from the left causes drift to the right.

c. If *TH* is greater than *TR* or *TC*, drift is to the left.

d. If *TH* is less than *TR* or *TC*, drift is to the right.

e. If drift is to the right, *DC* is to the left.

f. If drift is to the left, *DC* is to the right.

g. Drift is always downwind.

h. Drift correction is always upwind.

55. Applied Problems of Drift and Drift Corrections

a. *Problem*. *TH* 160°, *TR* 170°. Is drift right or left? Is drift correction to be made to right or left?

b. *Solution*. Since *TH* is less than *TR*, *DR* is right; *DC* is left.

c. *Problem*. *TH* 350°, *DR* 4° left. What is the track? What is the drift correction?

d. *Solution*. Since *DR* is left, *TH* must be greater than *TR*.

TR equals 346° (350°–4°).
DC 4° right.

e. *Problem*. *TR* 005°, *DR* 10° right. What is the true heading? What drift correction is required?

f. *Solution*. Since *DR* is right, *TH* is less than *TR*.

TH equals 355° (005°–10° or 365°–10°).
DC equals 10° left.

56. Groundspeed (GS)

Groundspeed is the resultant of wind and the forward motion of the aircraft through the air. In calm air, the speed of the aircraft over the ground (GS) is equal to its true airspeed (TAS). If the aircraft is moving against the wind (headwind), the groundspeed is equal to the difference between the true airspeed and the windspeed. If the aircraft is moving with the wind (tailwind), the groundspeed is equal to the sum of the true airspeed and the windspeed. If the aircraft is moving at an angle to the wind, the groundspeed may be any speed between the extremes of the groundspeeds determined by headwinds and tailwinds. Those groundspeeds that are less than the true airspeed are the result of hindering winds; those greater than the true airspeed are the result of helping winds. Wind directions that are approximately 90° to the longitudinal axis of the aircraft (beam winds) have a minimum effect on groundspeed. Winds may be classified as headwinds (hindering winds), tailwinds (helping winds), and cross winds.

CHAPTER 8
VECTORS AND THE TRIANGLE OF VELOCITIES

57. General

In dead reckoning, problems involving speed and direction are primarily concerned with course, groundspeed, heading, true airspeed, wind direction, and wind speed. In order to solve these problems, it is necessary to understand the relationship of these six values.

58. Representing Vector Quantity

A vector may be represented on paper by a straight line. The direction of the vector is shown by the bearing of the line with reference to north. It is usually drawn like an arrow, so that there can be no doubt as to direction. The magnitude of the vector is shown by the length of the line in comparison with an arbitrary scale. For example, if 1 inch equals 20 knots, then a velocity of 50 knots would be shown by a line $2\frac{1}{2}$ inches long (fig. 41). Although the line is only a diagram of the vector, the term "vector" is loosely applied to the line itself.

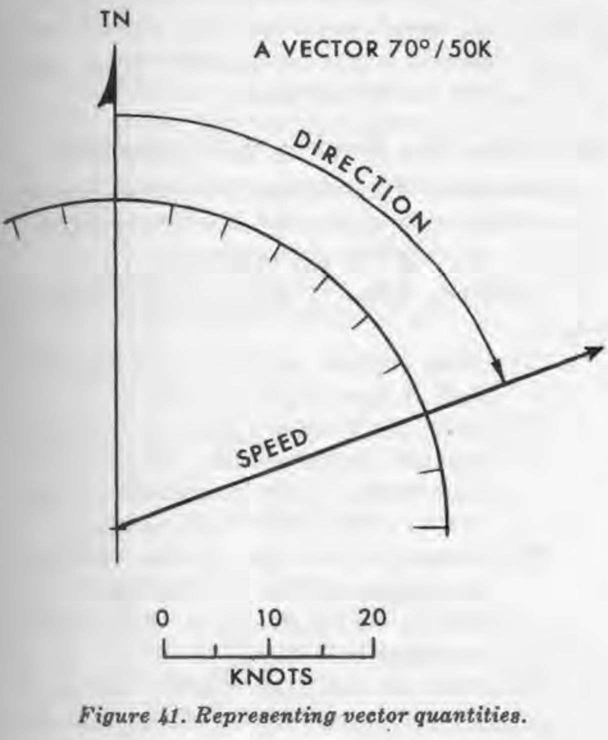


Figure 41. Representing vector quantities.

59. Vector

As used in air navigation, a vector is a velocity (speed in a given direction). A vector may be represented by a line segment which has magnitude, direction, and a point of origin. A series of line segments, representing vectors, are used in solving problems concerning winds, courses, headings, and speeds. The velocity of an aircraft relative to the air (air vector) includes heading and true airspeed; relative to the surface beneath it (ground vector), track or course and groundspeed.

60. Vector Diagrams

When two or more vectors are components of a third vector, this relationship may be shown by means of a *vector diagram.* If the components are drawn tail to head, in any order, a line from the tail of the first component to the head of the last component represents the resultant. A diagram of a vector sum forms a closed figure (fig. 42).

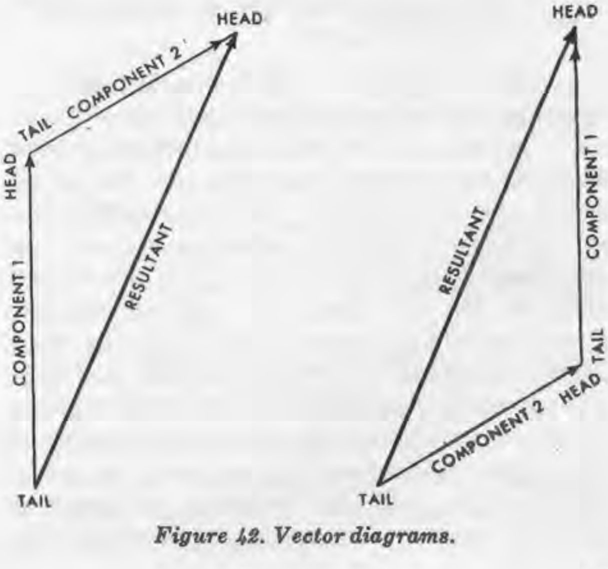


Figure 42. Vector diagrams.

61. Triangle of Velocities

a. General. A *triangle of velocities* is a vector diagram drawn for the purpose of analyzing the effect of wind on the flight of an aircraft. The complete diagram includes an air vector, ground vector, and wind vector. The air vector is composed of the heading and true airspeed; the ground vector, track or course and groundspeed; the wind vector, wind direction and wind speed. Each vector must include the factors and only such factors as are required to form the component of the triangle of velocities. When any four of the above mentioned factors are known, the remaining two can be determined.

b. Drawing a Triangle of Velocities. The necessary steps for drawing the triangle of velocities are as follows:

(1) Draw a vertical datum or reference line with an arrow at the top indicating true north to facilitate angular and linear measurement. This is the theoretical true meridian passing through the point of origin to which all vectors are referred.

(2) Draw a very short line intercepting the reference line at a convenient point to indicate the point of origin in the diagram.

(3) Draw in the known vectors.

(4) Close the triangle to determine two unknown factors. Known and unknown factors will vary but each factor can be determined provided each vector includes its own factors, namely direction and length.

c. Basic Methods of Drawing Triangle of Velocities. There are two basic methods of drawing a triangle of velocities. One method is used when the wind velocity is known; the other when solving the wind velocity. For quick recognition of the various vectors, some navigators use arrowheads along each vector. One arrowhead indicates the air vector; two arrowheads, the ground vector; and three arrowheads, the wind vector. A system of lettering various points is also essential. Regardless of which four factors are known they are drawn first and the closing of the triangle determines the remaining two. Additional vertical reference lines may be drawn to facilitate angular measurements provided they are parallel to the first. The method used when wind velocity is known is shown in A, figure 43; B, figure 43 when determining the wind velocity. Further explanation of the use of these two triangles of velocities will be found in paragraphs 62, 63, and 64.

d. Lettering Used in Vector Problems. Throughout this manual, except when solving for wind, the following lettering is used:

(1) *A* is point of origin.

(2) *B* is point of intended landing.

(3) *D* is the downwind end of the wind vector.

(4) *E* is the end of the first hour of flight.

(5) When solving for wind, the letter *X* will be used for the upwind end of the wind vector; the letter *Y* for the downwind end.

(6) Letters *C, F, G,* and *E* are used only in *radius of action* problems and will be explained under discussion of these problems (pars. 65, 67, and 68).

e. Vector Lettering. With the exception of the problems solving for the wind, the vectors are lettered as follows:

(1) Line *AD* is the wind vector.

(2) Line *AE* is the ground vector.

(3) Line *DE* is the air vector.

(4) In problems involving the solution for the wind vector, line *AX* is the air vector; line *AY*, the ground vector; line *XY* the wind vector.

62. Finding True Heading and Groundspeed

a. Problem. True course 090°, wind velocity 160°/30 knots, true airspeed 120 knots. What is the true heading and groundspeed?

b. Solution. Refer to figure 44 and solve as follows:

(1) Draw vertical reference line and label point *A* (par. 61*b*(1), (2)).

(2) Using the Weems plotter to determine angular measurement, draw in the wind vector at the reciprocal of 160° $(160 + 180 = 340°)$ (fig. 44 ①).

(3) Determine the scale to be used and measure along the wind vector to find point *D*. Mark this point with a sharp cross line and label *D*.

(4) Draw in the true course line ② at 090° for an indefinite distance.

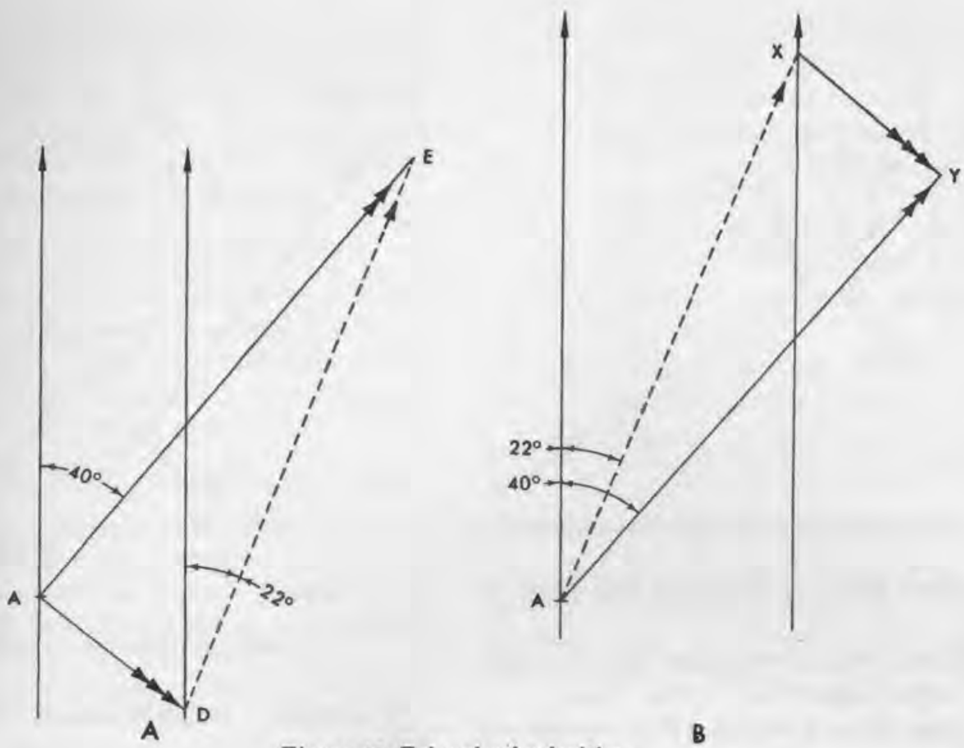


Figure 43. Triangle of velocities.

(5) Using the same scale used in (3) above, draw a line from *D* intersecting the true course line at 120 nautical miles from *D*. Place a sharp mark at this point and label it *E*.

(6) Since the air vector crosses the vertical reference line, the true heading can be determined by measuring the angle between the vertical reference line and the air vector. (If the air vector did not cross the reference line, the air vector could be extended.) In this problem, the true heading is 104°.

(7) Measure distance *AE* to find the groundspeed (106 knots).

Figure 44. Finding true heading and groundspeed.

63. Finding True Heading and True Airspeed

a. Problem. True course is 120°, wind velocity 090°/20 knots, groundspeed 90 knots. What is the true heading and true airspeed?

b. Solution. Refer to figure 45 and solve as follows:

(1) Draw vertical reference line and label point *A* (par. 61*b*(1), (2)).

(2) Draw in wind vector ① at 270° (090° + 180°), 20 knots, and label point *D*.

(3) Draw in ground vector ② at 120° and measure 90 nautical miles to find and label point *E*.

(4) Draw a line ③ from *D* to *E*.

(5) Determine true heading by measuring the angle formed by the interception of the reference line and the true heading line (115°).

(6) Determine true airspeed by measuring line *DE* (108 knots).

64. Finding Wind Velocity

a. Problem. True heading 130°, true airspeed 100 knots, track 140°, groundspeed 90 knots. What is the wind velocity?

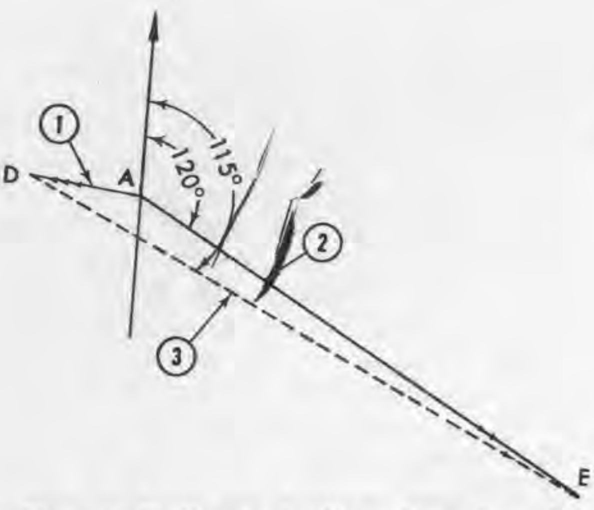


Figure 45. Finding true heading and true airspeed.

b. Solution. Refer to figure 46 and solve as follows:

(1) Draw vertical reference line and label point *A* (par. 61*b*(1) and (2)).

(2) Draw ground vector *AY* ① at 140° at 90 knots and label point *Y*.

(3) Draw air vector at *AX* ② at 130°, 100 knots and label point *X*.

(4) Draw a line from *X* to *Y*.

(5) Draw another vertical reference line through point *X*, parallel with the original to facilitate angular measurement.

(6) Measure the angle formed ③ between the vertical reference line and the wind vector and subtract 180° so as to name the wind by the direction from which it blows (075°). (Wind always blows from heading to track.)

(7) Measure line *XY* (20 knots).

65. Radius of Action (Fixed Base)

Radius of action refers to the maximum distance an aircraft can fly on a given course and still be able to return to the original point of departure within a given time. The radius of action is the *distance out only*.

a. Problem. A pilot is ordered to scout as far as possible on a true course of 090° returning to his point of departure in 2 hours. He maintains a true airspeed of 100 knots. The wind is 030°/20 knots. What is the true heading and groundspeed on each leg? What is the radius of action?

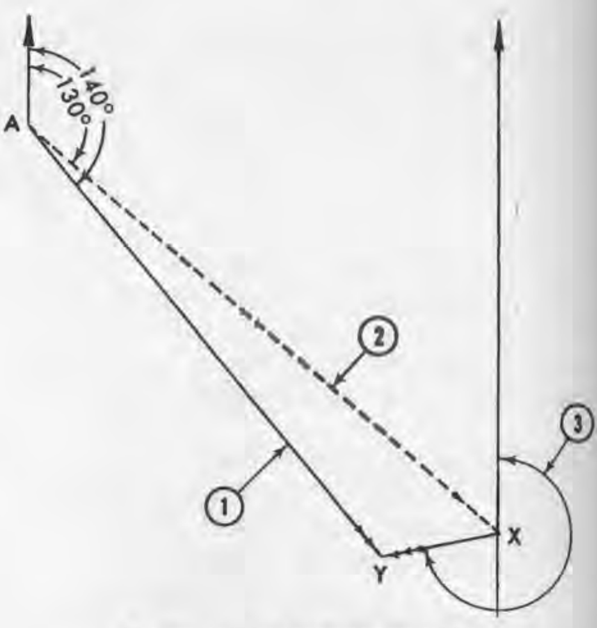


Figure 46. Finding wind velocity.

b. Solution. Refer to figure 47 and solve as follows:

(1) Draw vertical reference line and label point *A* (par. 61*b*(1) and (2)).

(2) From point *A*, draw in the wind vector ① 030°/20 knots, and label point *D*.

(3) Through point *A*, draw in the true course line ②, 090° and 270°, for both the outbound and inbound flight. This line is indefinite in length in both directions.

(4) Draw a line from *D* intercepting the outbound course line at an airspeed distance (100 knots) from *D*, and label *E*.

(5) Draw a line from *D* intercepting the inbound course line at an airspeed distance from *D* and label *E′*.

(6) Draw a parallel reference line through *D* and measure the angle (080°) between the reference line and the outbound air vector. This is the true heading outbound.

(7) Measure line *AE* (89 knots). This is the groundspeed on the outbound leg.

(8) Measure the angle (280°) between the reference line and the inbound air vector. This is the true heading on the inbound leg.

(9) Measure line *AE′* (108 knots). This is the groundspeed on the inbound leg.

(10) The distance out (radius of action) is the product of the total time in hours multiplied by the product of groundspeed out and the groundspeed back divided by the sum of these two speeds. The mathematical formula is—

$$TX \frac{GS_1 \times GS_2}{GS_1 + GS_2} = R/A$$

in which T is the total time in hours; GS_1 is the groundspeed on the outbound leg; GS_2 is the groundspeed on the inbound leg; and R/A is the radius of action or, in the above case.

$$2X \frac{89 \times 108}{89 + 108} = 97.6 \text{ nautical miles } (R/A).$$

c. Checking Accuracy of Computations. To check the accuracy of computations, the time on each leg is calculated and added. The sum must agree with the total time allowed. Calculate as follows: dividing the radius of action 97.6 nautical miles by the groundspeed out (89 knots) equals 1.1 hours or 66 minutes (time on outbound leg). Dividing 97.6 nautical miles by groundspeed back (108 knots) equals 0.9 hours or 54 minutes. Time utilized on both headings is equal to the total time (2 hours) allowed.

66. Finding Track and Groundspeed

a. Problem. Wind 300°/20 knots, true heading 045°, true airspeed 100 knots. What is the track and groundspeed?

b. Solution. Refer to figure 48 and solve as follows:

(1) Draw vertical reference line and label point *A* (par. 61*b*(1) and (2)).

(2) Draw wind vector at 120° (the reciprocal of 300°), 20 nautical miles from *A*, label point *D*.

(3) Draw another vertical line through *D* that is parallel with the original reference line.

(4) From *D*, draw in the air vector at 045°, 100 nautical miles and label *E*.

(5) Close the triangle by drawing a line from *A* to *E*.

(6) Measure the angle between the reference line and the track line *AE* (055°).

(7) Measure the length of *AE* (107 knots) to determine the groundspeed.

67. Radius of Action (Alternate Base)

a. General. Radius of action to an alternate refers to the maximum distance an aircraft can fly toward an intended airport or on a given course before returning so as to arrive at an alternate airport (point other than departure point) within a specified time. Fuel is generally the factor controlling the amount of available time. An understanding of speeds of separation and closing are not essential in the graphic analysis of this problem but are discussed in paragraph 96.

b. Lettering. In the graphic representation of radius of action to an alternate base, lettering is still an important item. The same lettering is used in this problem as in others (par. 61*d*) but some letters must be added to indicate points not used in other problems: *C* is the alternate airport; *F* for the calculations of relative motion; *E'* the end of the first hour of flight on the

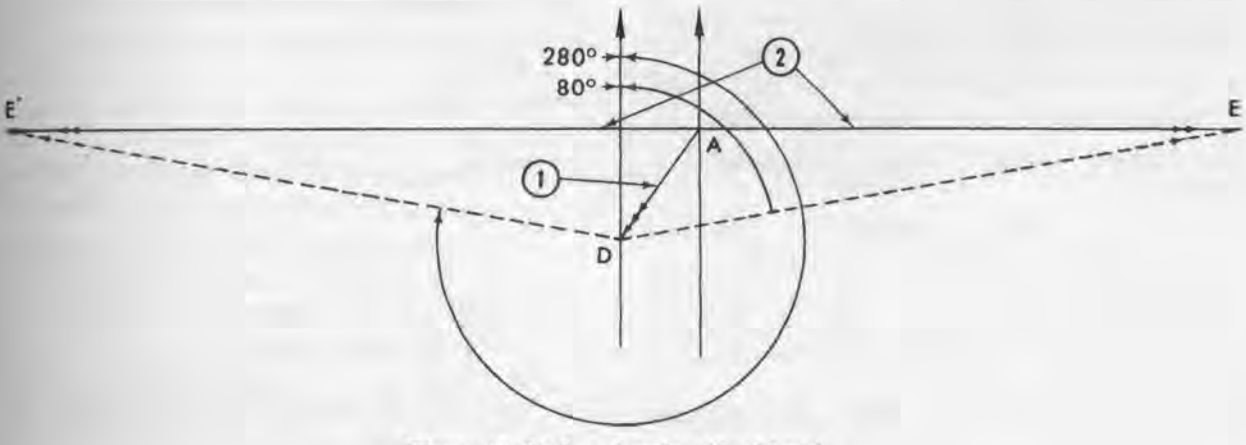


Figure 47. Radius of action (fixed base).

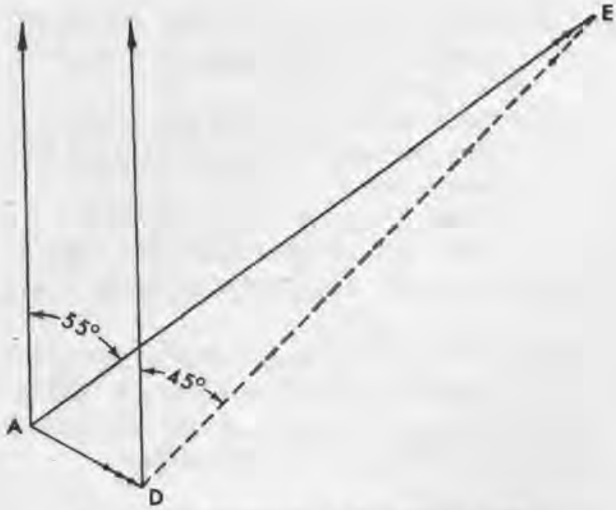


Figure 48. Finding track and groundspeed.

second leg; and *G* the point to turn to the alternate base.

c. Vectors. Line *AB* is from point of start to the intended airport; *AC* from point of start to the alternate airport; *AD* is the wind vector; *AE* the true course and groundspeed vector on the first leg; *AG* is the distance on first leg; *DE′* is the true heading and true airspeed vector for the second leg; *AE′* is the groundspeed on second leg; and distance *GC* is the distance on the second leg.

68. Problem, Radius of Action (Alternate Base)

a. Problem. Airport *B* bears 090°, 300 nautical miles from *A*. Airport *C* bears 120°, 240 nautical miles from *A*. The wind velocity is 315°/30 knots, true airspeed is 100 knots, and total time is 3 hours. What is the true heading and groundspeed on the first leg? What is the true heading and groundspeed on the second leg? What is the true course on the second leg? What is the time and distance on the first leg? What is the time and distance on the second leg?

b. Solution. Refer to figure 49 and solve as follows:

(1) Draw vertical reference line and label point *A* (par. 61*b* (1) and (2)).

(2) Draw line *AB*, 090°, 300 nautical miles.

Note. Any appropriate scale may be used, but scale must be the same throughout the problem.

(3) Draw line *AC*, 120°, 240 nautical miles.

(4) Draw line *AD*, 135°, (315° —180°).

(5) Draw a line from *D* intersecting line *AB* at a true airspeed distance (100 knots) from *D* and label *E*.

(6) Divide distance *AC* (240 nautical miles) by the total time in hours (3). 240 divided by 3 equals 80.

(7) Lay off 80 miles along *AC* from *A* and label *F*.

(8) Draw a line from *E* through *F* indefinitely.

(9) Draw a line from *D* intersecting the extension of line *EF* at an airspeed distance from *D* and label *E′*.

(10) Draw a line from *A* to *E′*.

(11) Draw a line from *C* parallel to *AE′* intersecting *AB* and label this point *G*.

c. Analysis of Drawing (fig. 49). The drawing is analyzed as follows:

(1) Find true heading on the first leg by extending line *DE* (since it does not cross the vertical reference line) so that it intersects the vertical reference line and measure the clockwise angle between the vertical reference line and the true heading line *DE*, 078°.

(2) Groundspeed on first leg is distance *AE* (110 knots).

(3) True heading on the second leg is found by measuring the angle between the vertical reference line and line *DE′* (204°).

(4) Groundspeed on second leg is distance *AE′* (114 knots).

(5) True course on second leg is found by measuring the angle between the vertical reference line and line *AE′* (190°).

(6) Distance on the first leg is distance *AG* (230 nautical miles).

(7) Time on first leg is found by dividing distance *AG* (230 nautical miles) by groundspeed (119 knots) and equals 1.94 hours or 1 hour and 56 minutes.

(8) Distance on second leg is distance *GC* (121 nautical miles).

(9) Time on second leg is found by dividing distance *GC* (121 nautical miles) by groundspeed *AE′* (114 knots) and

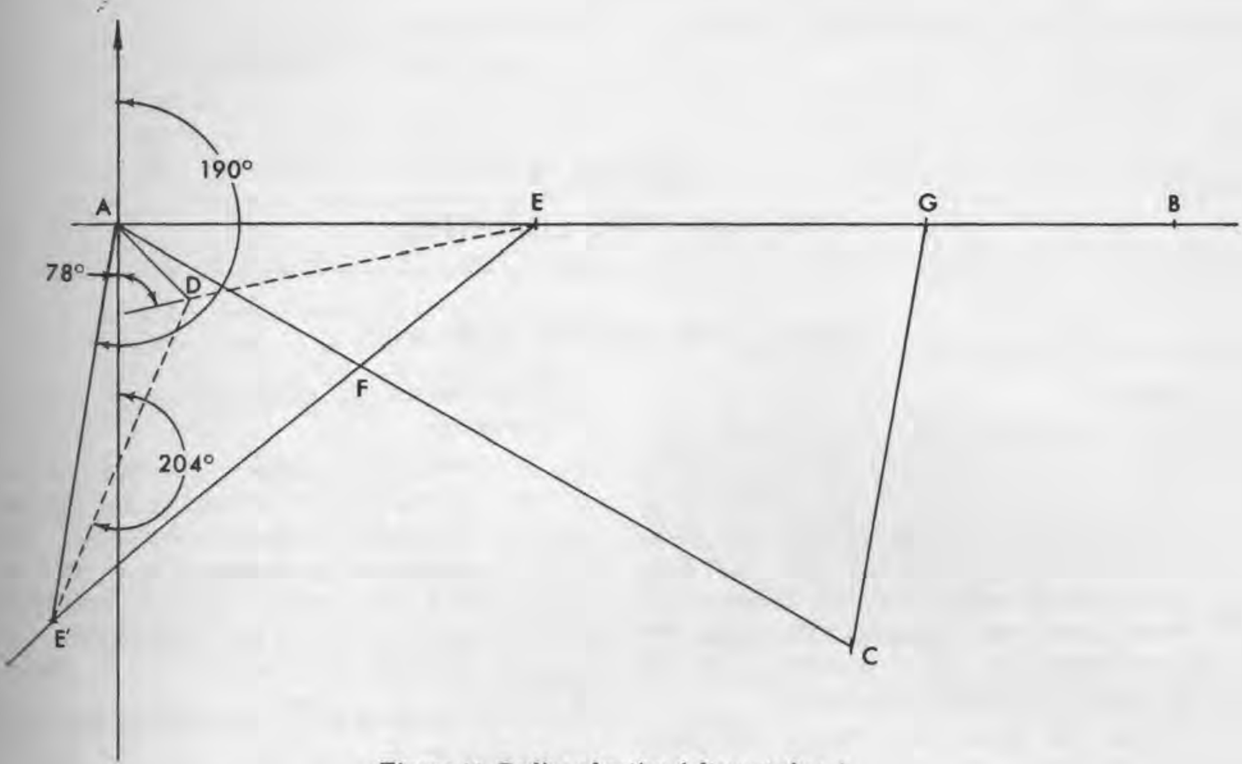


Figure 49. Radius of action (alternate base).

equals 1.06 hours or 1 hour and 4 minutes.

(10) To verify veracity of drawing and analysis, add time on first leg (1:56) and time on second leg (1:04). This should be equivalent to the total time allowed for the flight (3 hours).

69. Average Groundspeed

Average groundspeed is calculated by dividing the total distance flown by the total time (in hours) required for the flight. While climbing, airspeed is generally less than while cruising. While descending airspeed is generally the same or higher than while cruising. Groundspeed will also vary when flying in headwinds, tailwinds, and crosswinds. For example, an aircraft flies at a constant true airspeed of 100 knots for one hour against a 30-knot headwind and then returns to the starting point. On the outbound flight, 70 nautical miles are flown. The pilot may think that the average groundspeed is equivalent to the true airspeed (100 knots) because the tailwind will help as much as the headwind will hinder him. The return trip, however, requires 32 minutes (0.53 hours) at a groundspeed of 130 knots; the total flight 1.53 hours. The total distance (140 nautical miles) divided by total time (1.53 hours) equals the average groundspeed (91 knots).

CHAPTER 9
THE E–6B TYPE COMPUTER

Section I. THE CIRCULAR SLIDE RULE

70. General

a. Use. In air navigation, a circular slide rule is used for solving problems in multiplication and division, distance conversions, corrections of altitude and airspeed for temperature and pressure variations, rate-time-distance problems, fuel consumption, radius of action formula, and off-course corrections. The slide rule face of the E–6B computer (fig. 50) is standard with all major types of navigation computers.

b. Ratio and Proportion Scales. The outer and inner scales on the slide rule face of the E–6B computer are used to express the *ratio* and *proportion* of numerical values of any denomination.

(1) *Ratio.* The ratio of any two numbers is the *quotient* when the first number is divided by the second number. This ratio may be expressed as a fraction. The first number will be the numerator and the second the denominator. For example, the ratio of 6 to 8 may be expressed as $\frac{6}{8}$. In solving ratio problems on the E–6B computer, consider a number on the outer scale of the com-

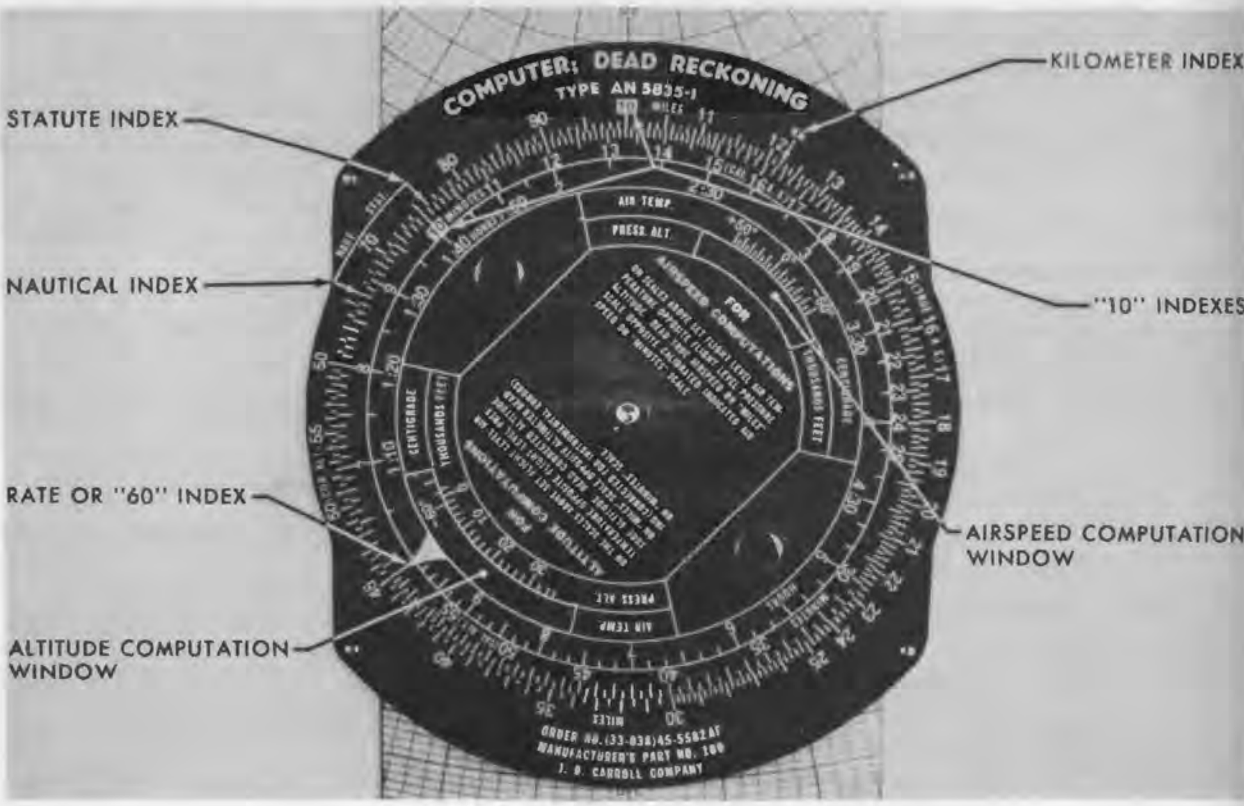


Figure 50. Slide rule face.

puter as a numerator and a number on the inner scale as a denominator.

(2) *Proportion.* A proportion is the expression of *equality* of two or more ratios. For example the ratio of 6 to 8 is equal to the ratio of 3 to 4 $\left(\frac{6}{8} \text{equals} \frac{3}{4}\right)$. When any ratio is set on the computer, any other equal ratios may be read. If 6 is set over 8, 12 is over 16, 18 over 24, etc. This gives a proportion as follows:

$$\frac{6}{8}=\frac{12}{16}=\frac{18}{24}\text{etc.}$$

(3) *Applying ratios and proportions to practical problems.* To what number does 45 have the same ratio as 6 to 8? By setting 6 over 8, the unknown number is found under 45. In this case, the unknown number is 60. It can then be said that 45 is to 60 as 6 is to 8 or $\frac{45}{60}=\frac{6}{8}$. For example, if 6 men earn 8 dollars, at the same rate 9 men will earn 12 dollars; if an aircraft climbs 6,000 feet in 8 minutes, at the same rate it will climb 9,000 feet in 12 minutes; if 6 gallons of fuel are consumed in 8 minutes, 9 gallons will be consumed in 12 minutes (fig. 50).

71. Description

a. Scale. The numbers on any computer scales, as on any slide rule, represent multiples of 10 of the values shown. For example, the number 24 on the outer scale may represent 0.24, 2.4, 24, 240, or 2400. The numbers on the inner scale for 24 have like values. On the inner scale, minutes may be converted to hours by reference to the adjacent hour scale. For example, adjacent to 24, in this case meaning 240 minutes, is found 4 hours (fig. 50).

b. Scale Divisions. Relative values should be kept in mind when reading the computer. For example, the numbers 21 and 22 on either scale are separated by 5 dividing lines, spaced 2 units apart. The second division past 21, would be read as 21.4, 2140, etc. Spacing of these divisions should be studied, as the breakdown of dividing lines may be into units of 1, 2, 5, or 10.

c. Indexes. The computer has four indexes on the outer scale (fig. 50). Three of the indexes are used in establishing proportional relationship between statute miles, nautical miles, and kilometers; the fourth is an index for multiplication and division. These indexes are called the nautical index marked "Naut" at 66, the statute index marked "Stat" at 76, and the kilometer index marked "*Km*" at 122. A rate arrow on the inner scale is also known as the 60 index. The 10's on both scales are indexes for multiplication and division.

d. Airspeed and Altitude Computation Windows. There are two windows for use in making temperature and pressure corrections for airspeed and altitude. One is marked "FOR AIRSPEED COMPUTATIONS"; the other, "FOR ALTITUDE COMPUTATIONS."

72. Distance Conversion

a. Problem. How many statute miles equal 90 nautical miles? How many kilometers equal 90 nautical miles?

b. Solution. Using an E–6B computer, refer to figure 51 and solve as follows:

(1) Set 90 on inner scale to "Naut" index.

(2) Read 104 under "Stat" index (104 statute miles).

Figure 51. Distance conversion.

(3) Read 166 under *"Km"* index (166 kilometers).

73. Determining Groundspeed

Groundspeed equals distance divided by time.

a. Problem. What is the groundspeed if it takes 35 minutes to fly 80 nautical miles?

b. Solution. Using an E–6B computer, refer to figure 52 and solve as follows:

(1) Set 35 (inner scale) opposite 80 (outer scale).

(2) Over 60 index read groundspeed (137 knots).

Figure 52. Determining groundspeed.

74. Determining Time Required

Time equals distance divided by groundspeed.

a. Problem. How much time is required to fly 335 nautical miles at a groundspeed of 174 knots?

b. Solution. Using an E–6B computer, refer to figure 53 and solve as follows:

(1) Set rate or 60 index on 174 (outer scale).

(2) Under 335 (outer scale) read 115 minutes (inner scale) 1+55 (hours scale).

Figure 53. Determining time.

75. Determining Distance

Distance equals groundspeed multiplied by time.

a. Problem. How far does an aircraft travel in 2 hours, 15 minutes at a groundspeed of 133 knots?

b. Solution. Using an E–6B computer, refer to figure 54 and solve as follows:

(1) Set 60 index at 133 (outer scale).

(2) Over 135 (inner scale) or 2 hours, 15 minutes (hours scale), read 300 nautical miles (outer scale).

76. Determining Rate of Fuel Consumption

Rate of fuel consumption equals gallons of fuel consumed divided by time.

a. Problem. What is the rate of fuel consumption if 30 gallons of fuel are consumed in 111 minutes (1 hour and 51 minutes)?

b. Solution. Using an E–6B computer, refer to figure 55 and solve as follows:

(1) Set 111 (inner scale) under 30 on outer scale (in this case, outer scale is used to represent gallons).

(2) Opposite 60 index, read 16.2 gallons per hour (gph).

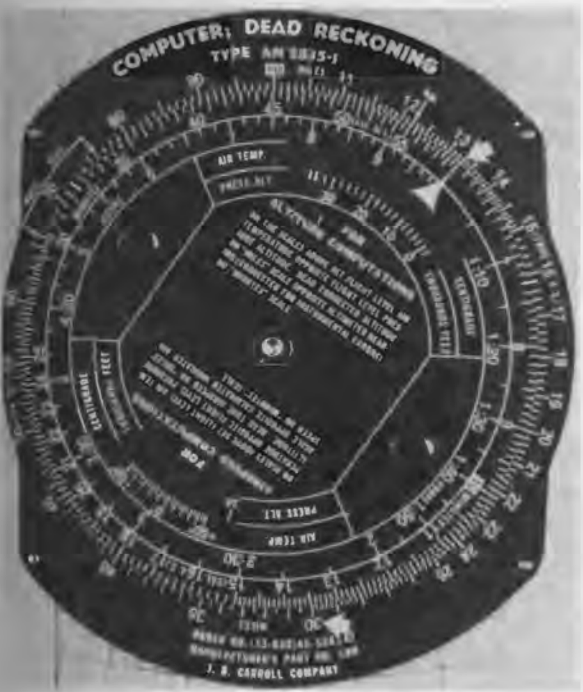


Figure 54. Determining distance.

Figure 55. Determining rate of fuel consumption.

77. Determining Gallons Used in a Given Time

Place 60 index under rate (gph) and read gallons used over time.

78. Altitude Gained in a Given Time at a Given Rate of Climb

Outer scale is used to represent rate of climb and height climbed. The 10 index is used instead of 60 index.

a. Problem. How many feet of altitude are gained in 9 minutes if an aircraft climbs at a rate of 330 feet per minute?

b. Solution. Using an E–6B computer refer to figure 56 and solve as follows:

(1) Set 10 index under 330 (outer scale).

(2) Over 9 minutes (inner scale) read 2,970 feet climbed.

Figure 56. Altitude gained in a given time at a given rate of climb.

79. Average Rate of Climb

Rate of climb equals height climbed divided by time in minutes.

a. Problem. What is the average rate of climb in feet per minute if an aircraft climbs from 4,000 feet to 5,220 feet altitude in 4 minutes?

b. Solution. Using an E–6B computer refer to figure 57 and solve as follows:

(1) 5,220 —4,000 = 1,220 feet (number of ft climbed).

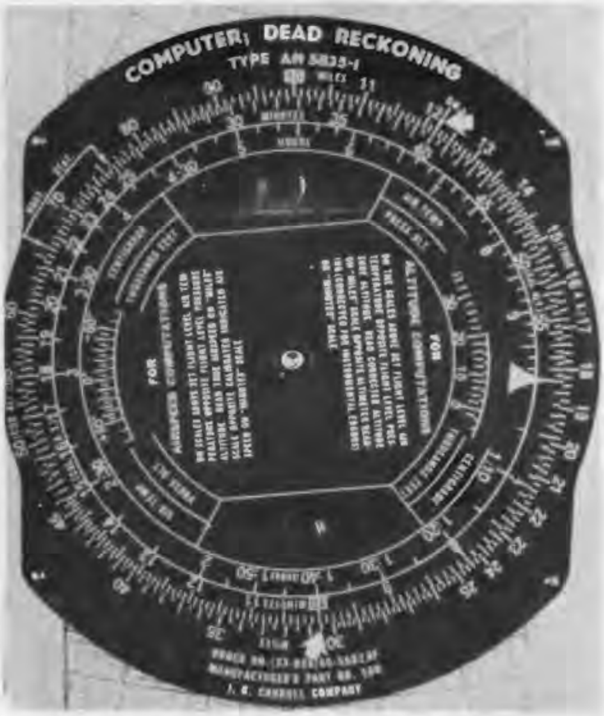


Figure 57. Average rate of climb.

Figure 58. Time and distance.

(2) Set 4 minutes under 1,220 feet (outer scale).

(3) Over 10 index, read 305 fpm (outer scale).

80. Time-Distance

Time-distance problems are worked on the inner (minutes) scale and the outer (miles) scale.

a. Problem. If 50 minutes are required to travel 120 nautical miles, how many minutes are required to travel 86 nautical miles at the same rate?

b. Solution. Using an E–6B computer, refer to figure 58 and solve as follows:

(1) Set 50 (inner scale) under 120 (outer scale).

(2) Under 86 (outer scale), read 36 (inner scale) minutes required.

81. Use of the 36 Index

The number 36 on the inner scale is used in solving rate-time-distance problems in instrument flight when time must be calculated in seconds and minutes, instead of minutes and hours. An example of such a problem is to determine the time required to fly from the outer marker to the middle marker or from the middle marker (par. 188*c*) to the point of touchdown during an instrument approach.

a. Formula. Problems where seconds must be used as a unit of time may be solved by the formula

$$\frac{GS}{36} = \frac{\text{Distance}}{\text{Seconds}}$$

in which GS is the groundspeed; 36 represents the number of seconds in one hour (3,600); distance is the number of miles or decimal parts of miles to be flown; and seconds is the time required to fly that distance.

b. Problems involving less than 60 seconds.

(1) *Problem.* What is the time required from the middle marker to the point of touchdown if the groundspeed is 100 knots and the distance between these points is 0.5 nautical miles?

(2) *Solution.* Set 36 (inner scale) under groundspeed (100 on the outer scale). Under 5 (0.5) on the outer scale, read 18 seconds on the inner scale.

c. Problems involving more than 60 seconds.

(1) *Problem.* What is the time required to fly from the outer marker to the middle marker if the groundspeed is 95 knots

and the distance between the two points is 5 nautical miles?

(2) *Solution.* Set 36 (inner scale) under the groundspeed (95 knots on the outer scale). Under 5 on the outer scale, read 190 seconds, or 3 minutes, 10 seconds.

Note. When using the minutes scale as a second scale, the hour scale becomes a minute scale.

82. Fuel Consumption

Use same scales as used with the time-distance problems discussed in paragraph 80 and solve the following fuel consumption problem:

a. Problem. Forty gallons of fuel have been consumed in 135 minutes (2 hours + 15 minutes) flying time. How much longer can the aircraft continue flying if 25 gallons of available fuel (usable fuel not including reserve) remain and the rate of consumption remains unchanged?

b. Solution. Using an E–6B computer, refer to figure 59 and solve as follows:

(1) Set 135 (inner scale) under 40 (outer scale).

(2) Under 25 (outer scale), read 84½ (inner scale) minutes fuel remaining.

Figure 59. Fuel consumption.

83. Off-Course Correction

An aircraft headed one degree off-course will be one mile off-course for each 60 miles flown. This is the *rule of 60*. Inversely, for each mile an aircraft is off-course after each 60 miles of flight, one degree of correction will be required to *parallel* the intended course. Applied to other distances (multiples of 60), such as 1½ miles off-course in 90 miles, 2 miles off-course in 120 miles, or 2½ miles off-course in 150 miles, a correction of one degree will be required to parallel the intended course. To converge at destination, an extra correction must be made based on the same rule of 60.

a. Formulae. The degrees correction required to converge at destination is determined by adding the results of the following formulas:

Correction to parallel course =

$$\frac{\text{miles off-course}}{\text{miles flown}} = \frac{\text{degrees correction.}}{60}$$

Additional correction to converge.

$$\frac{\text{miles off-course}}{\text{miles to fly}} = \frac{\text{degrees correction.}}{60}$$

b. Problem. An aircraft is 10 nautical miles to the left of course when 150 nautical miles from departure point *A*. How many degrees correction are required to parallel course? If 80 nautical miles remain to destination *B*, how many additional degrees are required to converge? In what direction is the correction applied?

c. Solution. Using an E–6B computer, refer to figure 60 and 61, and solve as follows:

(1) Set 150 (inner scale) under 10 (outer scale) (fig. 60).

(2) Over the 60 index, read 4° (correction required to parallel).

(3) Set 30 (inner scale) under 10 (outer scale) (fig. 61).

(4) Over 60 index, read 7½° to converge.

(5) 4° + 7½° = 11.5°, total correction to converge at destination. Since aircraft is off-course to the left, correction will be made to the right, or added to the original heading. For example, if the original heading was 090°, the new heading is 101½° or 102° to the nearest degree.

Figure 60. Off-course correction to parallel.

Figure 61. Off-course correction to converge.

84. Radius of Action (Fixed Base)

As discussed in paragraph 65, radius of action to the same base refers to the maximum distance an aircraft can be flown on a given course and still be able to return to the starting point within a given time. The amount of available fuel (not including reserve fuel) is usually the factor determining time.

a. Problem. The groundspeed on the outbound leg of the flight is 160 knots; on the return leg, 130 knots. Available fuel permits 4½ hours (270 minutes) total time for the flight. How many minutes will be available for the outbound leg of the flight? How many minutes will be required for the return leg of the flight? What is the radius of action?

b. Solution. The sum of the groundspeed out (GS_1) and the groundspeed on the return leg (GS_2) is to the total time in minutes (T), as the groundspeed on the return leg (GS_2) is to the time in minutes on the outbound leg (t_1). Minutes on the outbound leg of the flight can be calculated by the formula $\frac{GS_1 + GS_2}{T} = \frac{GS_2}{t_1}$. The formula for calculating time required for the return leg of the flight is $\frac{GS_1 + GS_2}{T} = \frac{GS_1}{t_2}$, in which t_2 is the time required for the return leg of the flight. These formulas can be calculated on the E–6B computer as ratio and proportion problems and appear on the E–6B computer as they appear in mathematical form. To solve radius of action fixed base problems with the E–6B computer, use the problem given in *a* above, referring to figures 62 and 63, and proceed as follows:

(1) Find the sum of the groundspeeds (160 + 130 = 290).

(2) Set the total time (T = 4½ hours or 270 minutes) *under* the sum of the groundspeeds (290) (fig. 62).

(3) *Under* 130 (GS_2), read the time on the outbound leg, 2 hours + 1 minute or 121 minutes (fig. 62).

(4) Without changing the setting of the computer, under 160 (GS_1), read the time required for the return leg, 2 hours + 29 minutes or 149 minutes (fig. 62).

(5) These two amounts of time should be equivalent to the total amount of time of the flight.

(6) Place the 60 index under 160 (GS_1) and *over* 121 minutes (time on the outbound leg), read the radius of action, 324 nautical miles (fig. 63).

Figure 62. Reading time for outbound and inbound leg.

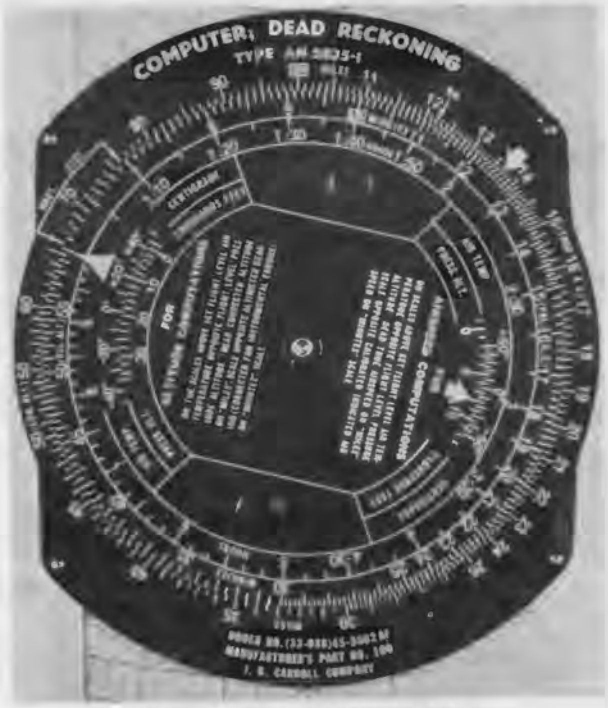


Figure 64. Airspeed computation.

Figure 63. Finding radius of action.

Figure 65. Altitude computation.

85. Airspeed Computations

The window marked FOR AIRSPEED COMPUTATIONS provides a means for computing true airspeed when indicating airspeed, temperature, and altitude are known or vice versa. To change from one to the other, it is necessary to correct for altitude and temperature differences existing from those that are standard at sea level. Free air temperature is read from a free air thermometer and the pressure altitude is found by setting the altimeter at 29.92" Hg and reading the altimeter directly.

a. Problem. The indicated airspeed is 125 knots, free air temperature is —15° centrigrade, and the pressure altitude is 8,000 feet. What is the true airspeed?

b. Solution. Using an E–6B computer, refer to figure 64 and solve as follows:

(1) Set 8,000 against —15° C. in the airspeed computation window.

(2) Over 125 knots (inner scale), read true airspeed 137 knots (outer scale).

86. Altitude Computations

The window marked FOR ALTITUDE COMPUTATIONS provides a means for computing corrected altitude by applying any variation from standard temperature to indicated (or calibrated) altitude.

a. Problem. The pressure altitude is 9,000 feet, indicated altitude is 9,100 feet, and the free air temperature is —15° C. What is the corrected altitude?

b. Solution. Using an E–6B computer, refer to figure 65 and solve as follows:

(1) Set 9,000 against —15° C. in the altitude computation window.

(2) Above 9,100 feet (calibrated) indicated altitude (inner scale), read corrected altitude 8,700 on the outer scale (corrected altitude).

Section II. GRID SIDE OF E–6B COMPUTER

87. Plotting Disc and Correction Scales

The grid side of the E–6B computer (fig. 66) enables the pilot to quickly and conveniently solve triangle of velocity problems during flight. It consists of a transparent, rotatable plotting disc mounted in a metal or plastic frame on the

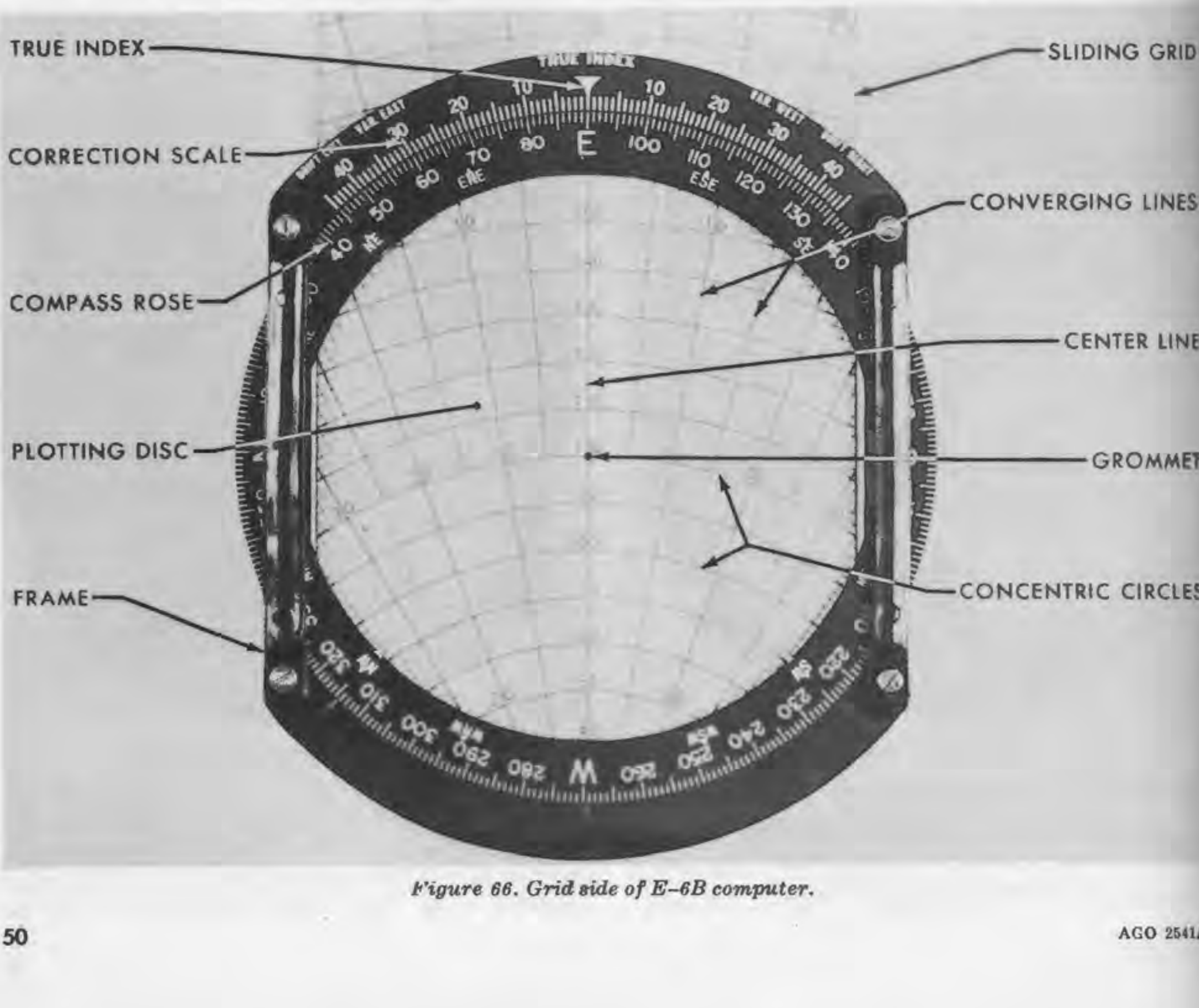


Figure 66. Grid side of E–6B computer.

reverse side of the circular slide rule. A compass rose is located on the periphery of the plotting disc. The correction scale, on the top frame of the circular grid, is graduated in degrees right and left of the *true index*. This scale is used for calculating drift or drift correction and is labeled *drift right and drift left*. The scale may also be used for correcting for variation east or west. A small reference circle or *grommet* is located at the center of the plotting disc.

88. Sliding Grid

A reversible sliding grid (fig. 66) inserted between the circular slide rule and the plotting disc is used with the plotting disc for computing triangles of velocities. The slide is imprinted with converging lines spaced 2° apart between concentric circles marked 30 to 100 and 1° apart above the 100 concentric circle. The concentric circles are used for calculations of speed and are spaced 2 units (usually knots or miles per hour) apart. Direction of the centerline coincides with the true index. The common center of the concentric circles and the point at which all converging lines meet is at a point below the lower end of the slide. On one side of the sliding grid the speed circles are numbered from 30 to 300; on the reverse side from 230 to 400. This reverse side also has a rectangular grid numbered from 0 to 90.

Section III. TRIANGLE OF VELOCITIES (CENTERLINE AS GROUND VECTOR)

89. General

In solving a triangle of velocities on the computer, part of the triangle is plotted on the transparent surface of the circular disc. Lines which are printed on the slide are used for the other two sides of the triangle. Actually, there is not room on the computer for the whole triangle, for the center of the concentric speed circles (fig. 67) is one vertex of the triangle. There are many methods applicable for computing any one problem but the following method for each type of problem is standard for use by the Army aviator. This section includes problems where the *centerline* is used as ground vector and the *wind vector* is plotted *above* the grommet.

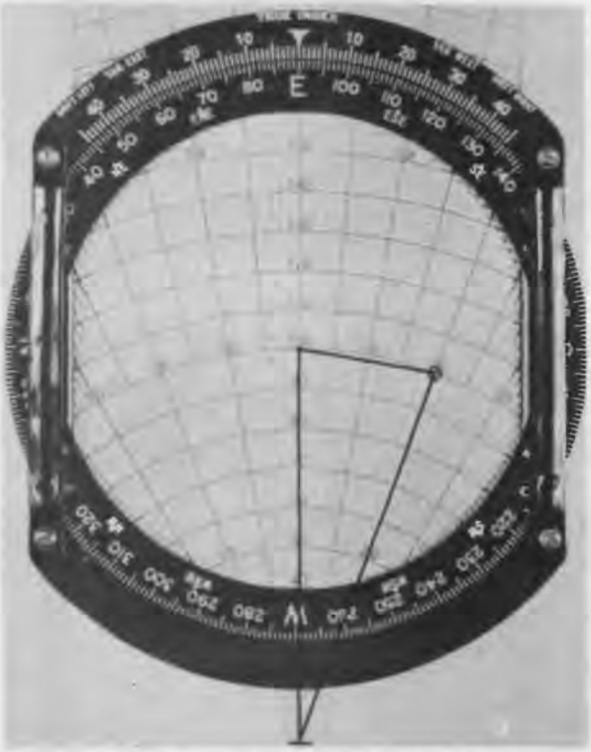


Figure 67. Triangle of velocities plotted on the E–6B computer.

90. Heading and Groundspeed Computation

When plotting heading and groundspeed with course, true airspeed and wind velocity known, the following method is used:

a. Problem. The wind is from 160°/30 knots, the true airspeed 120 knots, true course 090°. What is the heading and groundspeed? This is the same problem used in paragraph 62.

b. Solution. Using an E–6B computer, refer to figures 68 and 69 and solve as follows:

(1) Set 160° (direction *from* which the wind is blowing) to the true index (fig. 68).

(2) Plot the wind vector *above* the grommet 30 units (wind speed) and place a dot within a circle at this point.

(3) Set 090° (true course) at the true index (fig. 69).

(4) Adjust sliding grid so that the true airspeed (120 knots) is at the wind dot.

(5) Note that the dot is at the 14° converging line to the right of centerline.

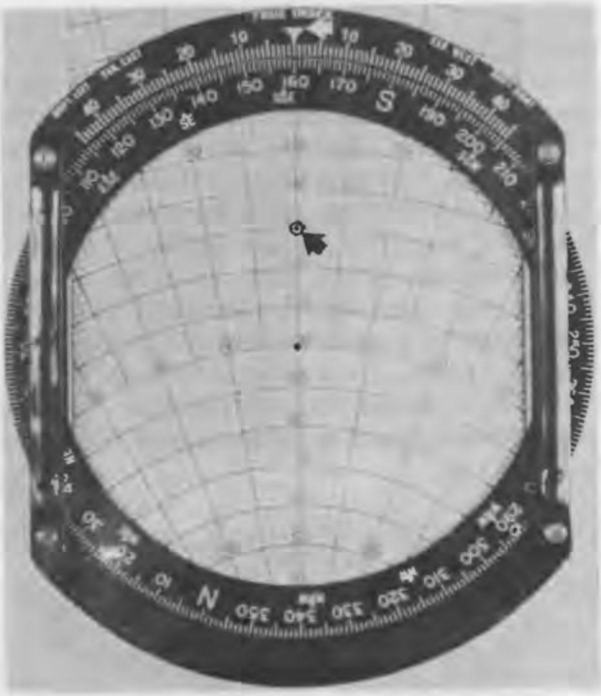


Figure 68. Plotting the wind vector with course, true airspeed, and wind velocity known.

(6) Under the 14° correction scale (labeled "Drift" scale) to the right of center at the top of the computer, read the true heading (104°).

(7) Under the grommet, read the groundspeed (106 knots).

91. Heading and True Airspeed Computation

This problem was solved graphically in paragraph 63. Here, it is solved by the E–6B computer.

a. Problem. Wind is from 090°/20 knots, true course 120°, groundspeed 90 knots. What is the true heading and true airspeed?

b. Solution. Using an E–6B computer, refer to figure 70 and 71 and solve as follows:

(1) Set 090 (wind direction) under the true index and plot wind vector 20 units above the grommet using dot within circle (fig. 70).

(2) Set true course (120°) to the true index (fig. 71).

(3) Move sliding grid so that groundspeed (90 knots) concentric circle is at the grommet.

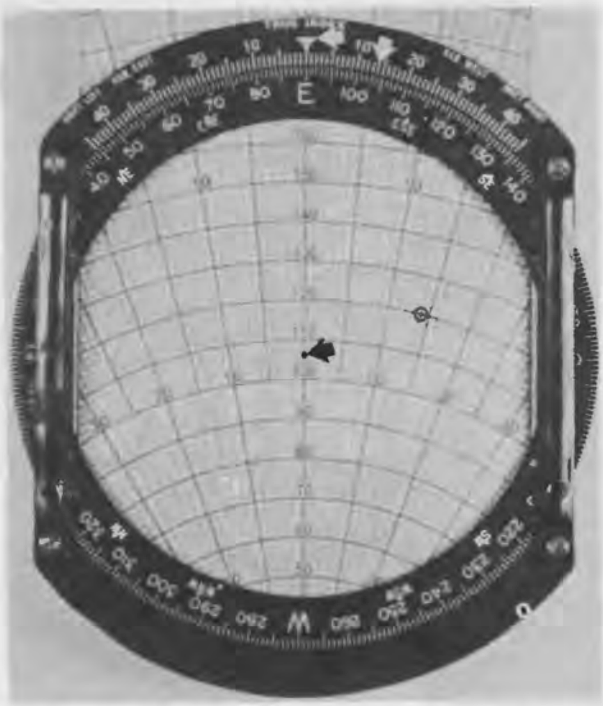


Figure 69. Reading heading, wind correction, and groundspeed.

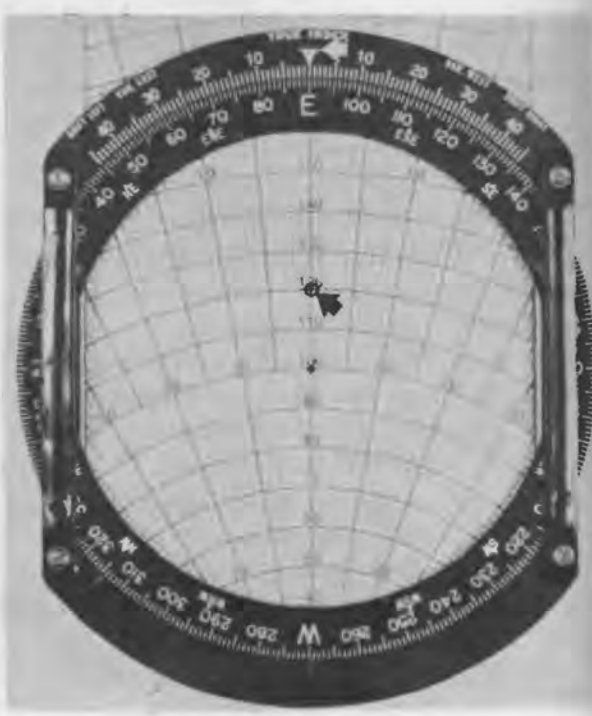


Figure 70. Plotting wind vector.

(4) The wind dot is now on the converging line 5° to the left of true index, read the true heading (115°).

(5) Under the wind dot, read the true airspeed (108 knots).

92. Wind Velocity Computation

This is identical to the problem solved graphically in paragraph 64. Here, it is solved on the E–6B computer.

a. Problem. True heading 130°, true airspeed 100 knots, track 140°, groundspeed 90 knots. What is the wind velocity?

b. Solution. Using an E–6B computer, refer to figures 72 and 73 and solve as follows:

(1) Set track (1409) at true index and grommet over the groundspeed (90 knots).

(2) Since the true heading is 10° less than the track, find where the 10° converging line to the left of centerline crosses the 100 knots (true airspeed) line and place a dot within a circle at this point (fig. 72).

(3) Turn circular grid until the dot is directly *above* the grommet (fig. 73).

(4) Under the true index, read direction from which the wind is blowing (075°). The distance in units between the dot and the grommet indicate the speed of the wind (20 knots).

93. Radius of Action (Fixed Base) Computation

This problem was solved graphically in paragraph 65. Here, the same problem is solved on the E–6B computer.

a. Problem. The true course out is 090°, true airspeed 100 knots, wind velocity 030°/20 knots, total flight time 2 hours. What is the true heading and groundspeed out? The true heading and groundspeed back? The radius of action?

b. Solution. Using an E–6B computer, refer to figures 74 and 75 and solve as follows:

(1) Set (not shown) the wind direction (030°) to the true index and plot the wind vector 20 units above the grommet using a dot within a circle.

Note. This wind dot is also used to plot return leg.

(2) Set true course outbound (090°) under the true index.

(3) Move sliding grid so that wind dot is at the true airspeed (100 knots).

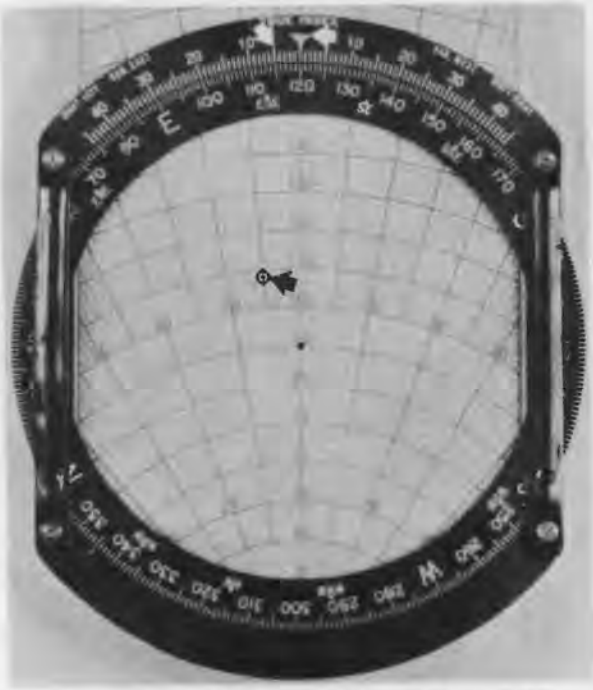


Figure 71. Reading true heading, drift correction, and true airspeed.

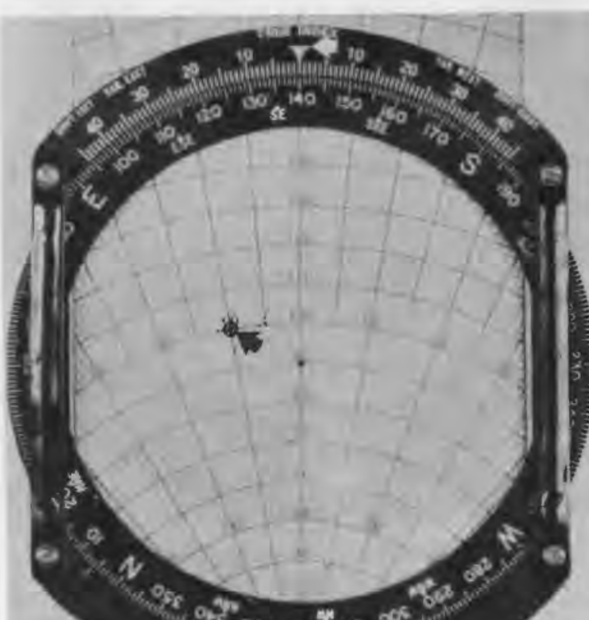


Figure 72. Preparing computer.

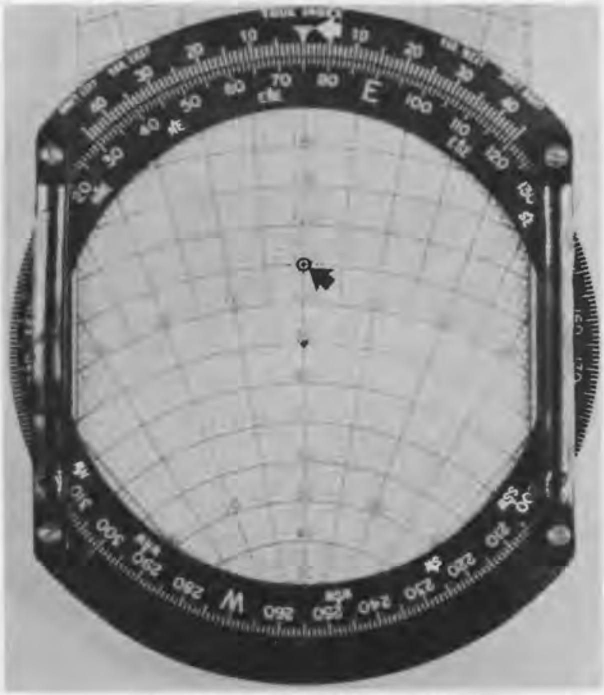


Figure 73. Reading wind velocity.

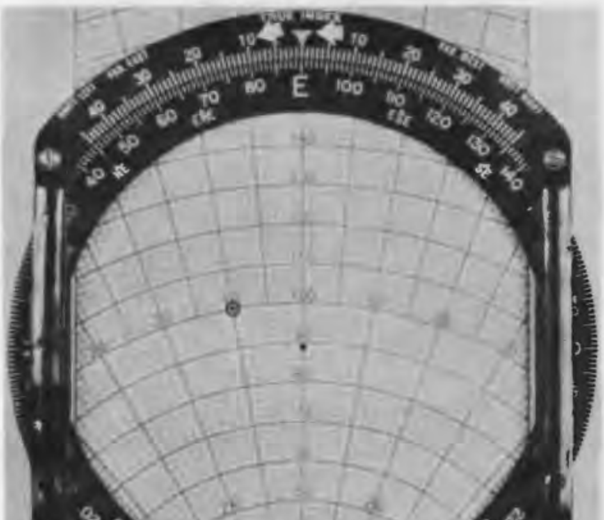


Figure 74. Solving true heading and groundspeed for outbound leg.

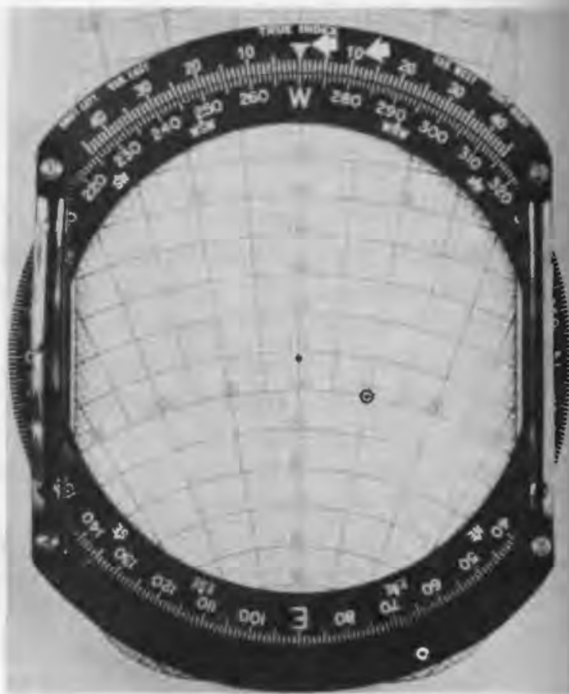


Figure 75. Solving true heading and groundspeed for return leg.

(4) The wind dot is now on the converging line 10° to the left of centerline (fig. 74). Under the 10° left correction scale, read the true heading on the outbound leg (080°).

(5) Under the grommet, read the groundspeed on the outbound leg (89 knots).

(6) Under the true index, place the *reciprocal* of the *outbound course* (090° ± 180°) 270° (fig. 75).

(7) Move sliding grid so that 100 knots is under the wind dot.

(8) The wind dot is now on the converging line 10° to the right of centerline (fig. 75). Under the 10° right correction scale read true heading for return flight (280°).

(9) Under the grommet, read groundspeed for the return leg (108 knots).

(10) For radius of action, use formula in paragraph 84. *Answer*. radius of action, 98 nautical miles.

94. General

The previous problems have been basically course-to-heading problems. In those problems, the centerline was always used as the ground vector and the wind vector was plotted *above* the grommet. For the preceding type of problems this system is preferable because it deletes the necessity of *juggling* the computer. There are certain problems, however, that would require juggling if they were plotted in such manner. The following are such problems and the centerline is used as an air vector and the wind is plotted *below* the grommet.

95. Finding Track and Groundspeed

This is the identical problem solved graphically in paragraph 66. Here, it is solved on the E–6B computer.

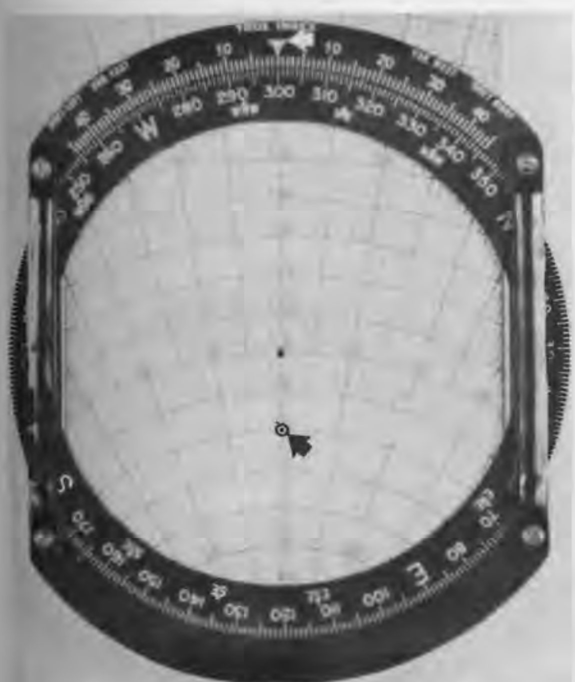


Figure 76. Plotting the wind, below the grommet.

a. Problem. Wind 300°/20 knots, true heading 045°, true airspeed 100 knots. What is the track and groundspeed?

b. Solution. Using an E–6B computer, refer to figures 76 and 77 and solve as follows:

(1) Set wind direction (300°) to the true index.

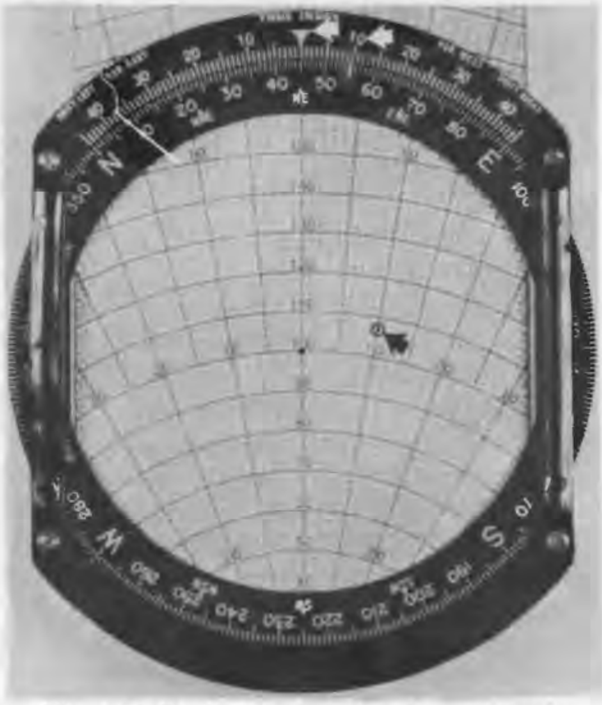


Figure 77. Reading track, drift and groundspeed.

(2) Plot wind vector 20 units *below* the grommet, using dot inside of circle (fig. 76).

(3) Set true heading (045°) to the true index (fig. 77).

(4) Move the sliding grid so that the *grommet* is at the *true airspeed* (100 knots).

Note. In the preceeding problems, the dot was placed on the true airspeed. In all of the following problems, the grommet is used for the true airspeed, and the dot indicates groundspeed.

(5) The dot is now on the 10° converging line to the right of the centerline. Under 10° on the correction scale to the right of the true index, read the track 055°.

(6) Under the wind dot, read the groundspeed (107 knots).

96. Theory of Radius of Action to an Alternate Base

a. General. As discussed in paragraph 67, radius of action to an alternate base refers to the maximum distance that an aircraft can fly toward an intended airport or on a given course before having to turn in order to arrive at the alternate at a given time.

b. Theory. The theory of radius of action to an alternate base problem is based on the following concepts:

(1) The base of departure is assumed to move toward the alternate, maintaining a constant bearing between alternate and aircraft at all times, arriving at the alternate at the same time as the aircraft arrives at the point where it must turn.

(2) On the first leg, the aircraft is separating from the moving base at a rate designated S_1. This is rate of separation, ***not a groundspeed.***

(3) On the second leg, the aircraft is closing in with the moving base at a rate designated as S_2. This is the rate of closure, ***not a groundspeed.***

(4) The maximum time allowable for the first leg is calculated by use of the formula $\frac{S_1 + S_2}{T} = \frac{S_2}{t_1}$ in which S_1 is the rate of separation; S_2 is the rate of closure; T is the total allowable flight time; and t_1 is the time allowed on the first leg.

(5) The time required for the second leg is calculated by the formula $\frac{S_1 + S_2}{T} = \frac{S_1}{t_2}$ in which t_2 is the time on the second leg.

(6) When the time required and groundspeeds are known for both legs, calculations for the distances of each leg can be made on the slide rule face of the computer.

97. Radius of Action (Alternate Base) Computation

This is the identical radius of action alternate base problem solved graphically in paragraph 68. Here, it is solved on the E–6B computer.

a. Problem. Base C (alternate airport) bears 120°, 240 nautical miles from A. The pilot is instructed to depart base A on a true course of 090°, fly as far as possible on this course, landing at base C at the end of 3 hours. Wind velocity is 315°/30 knots. True airspeed is 100 knots. What is the rate of separation? What is the rate of closure? What is the true heading and groundspeed on the first leg? What is the true heading and groundspeed on the second leg? What is the time on the first leg? What is the time on the second leg? What is the distance on the first leg? What is the distance on the second leg?

b. Solution. Using an E–6B computer, refer to figures 78, 79, 80, 81, 82, and 83 and solve as follows:

(1) Set (not shown) wind direction (315°) to the true index.

(2) Place (not shown) a dot within a circle 30 units (windspeed) *below* the grommet and label D.

(3) Set 120° (bearing of C from A) to the true index (fig. 78).

(4) Invert the sliding grid so that the rectangular grid may be used as a guide (fig. 78).

(5) Plot point S 80 units (distance A to C, 240 nautical miles divided by the total time in hours, 3) below the wind dot and label S (fig. 78).

(6) Set 090° (true course on the first leg) to the true index and draw a line from D parallel with the vertical grid lines (fig. 79).

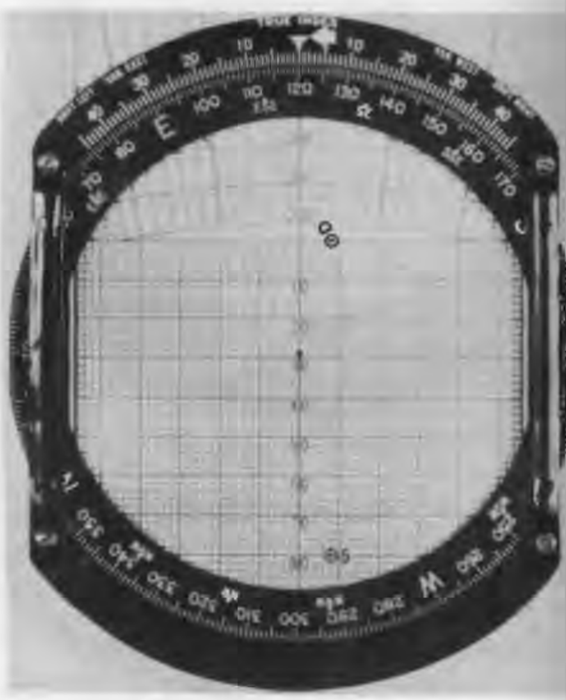


Figure 78. Plotting point S.

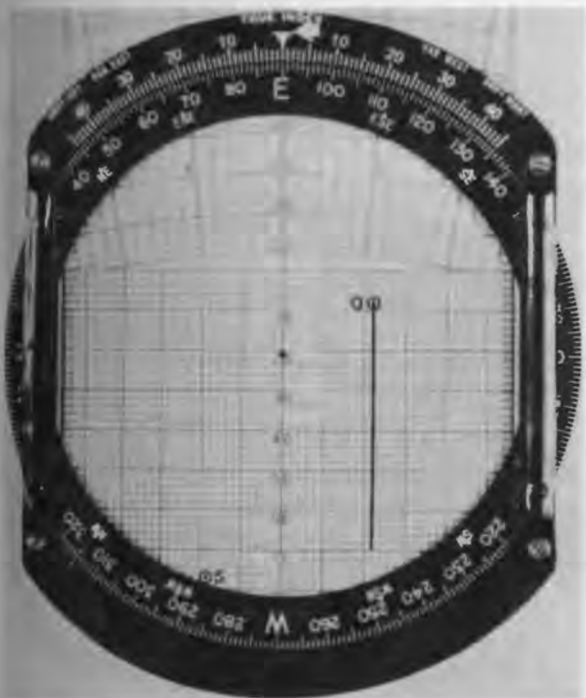


Figure 79. Draw line from D.

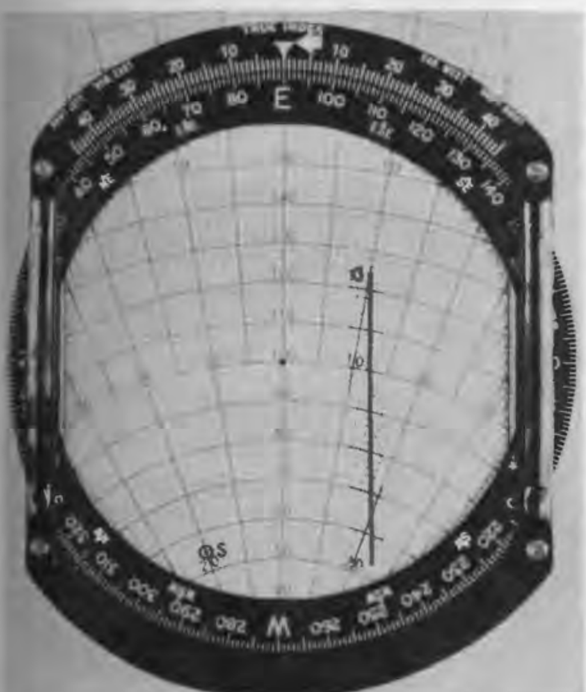


Figure 80. Slide inverted to initial side, true airspeed under grommet.

(7) Invert sliding grid to initial side and set true airspeed (100 knots) under the grommet (fig. 80).

(8) Turn compass rose so that line drawn from D is parallel with nearest converging lines (fig. 81).

(9) Under the true index, read true heading for first leg (078°).

(10) Under the wind dot (*D*), read groundspeed for first leg (119 knots).

(11) Under point *S*, read S_1 (64 knots).

(12) Draw a line along converging line from *S*.

(13) Turn compass rose so that guide line drawn from *S* parallels a converging line on the *opposite* side of centerline (fig. 82).

(14) Under the true index, read true heading for the second leg (204°).

(15) Under wind dot (*D*), find groundspeed for second leg (114 knots).

(16) Under point *S*, read S_2 (115 knots).

(17) To find time on the first leg, add S_1 and S_2 (64 + 115) 179; below this number on the slide rule face of the computer, place the total flight time (3 hours) (fig. 83).

(18) Under S_2 (115) find t_1 (1 hour, 56 minutes), time on first leg.

(19) Without shifting the setting of the computer, under S_1 (64), find t_2 (1 hour, 4 minutes), time on second leg.

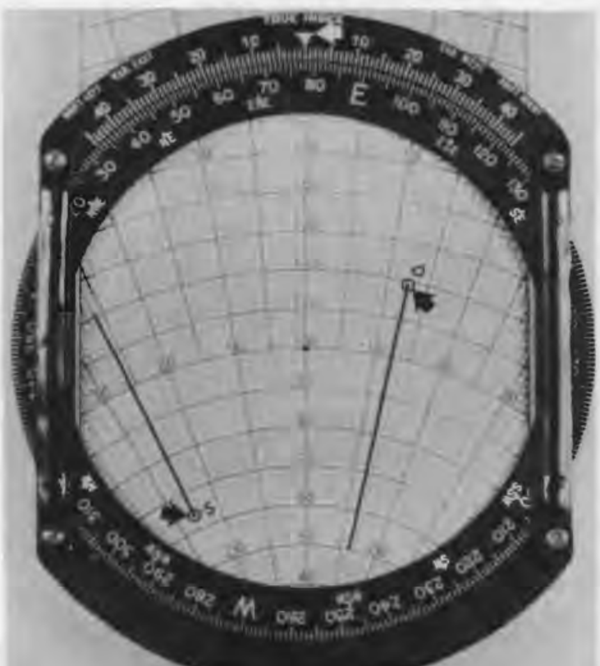


Figure 81. Final setting, first leg.

(20) Place (not shown) the 60 index at the groundspeed for first leg (119 knots) and above the time on the first leg (1 hour, 56 minutes), read the distance on the first leg (230 nautical miles).

(21) Place (not shown) the 60 index at the groundspeed for the second leg (114 knots) and above the time for the second leg (1 hour, 4 minutes), read the distance on the second leg (112 nautical miles).

(22) To check accuracy of calculations, add the time on the first and second legs (1 hour 56 minutes plus 1 hour 4 minutes) to verify that their sum is equal to the total flight time (3 hours).

98. Double Drift Wind

a. Problem. True airspeed of aircraft on all headings 100 knots. On a true heading of 120°, 4° of right drift is observed; on a true heading of 220°, there is 5° of left drift. What is the wind velocity?

b. Solution. Using an E–6B computer, refer to figures 84, 85, and 86 and solve as follows:

(1) Set first true heading (120°) under the true index and true airspeed (100 knots) under the grommet (fig. 84).

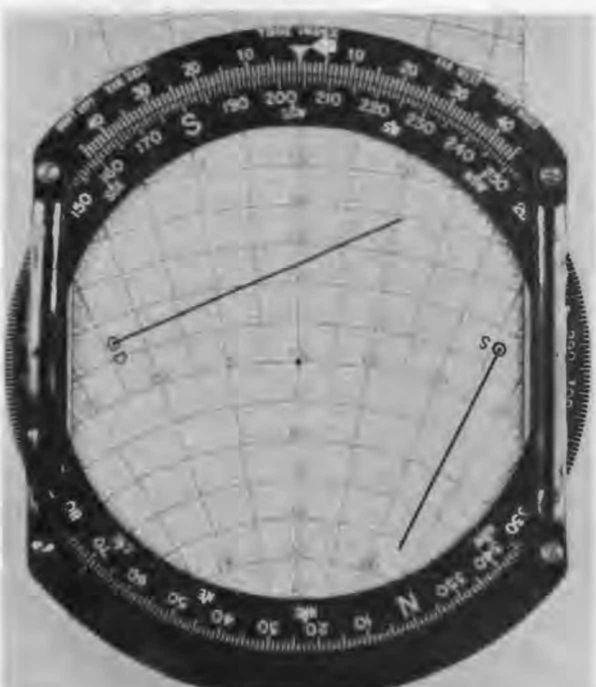


Figure 82. Final setting, second leg.

(2) Draw line along the converging line 4° to the right of centerline (fig. 84).

(3) Set second true heading (220°) under the true index and draw a short line

Figure 83. Finding time on first and second legs.

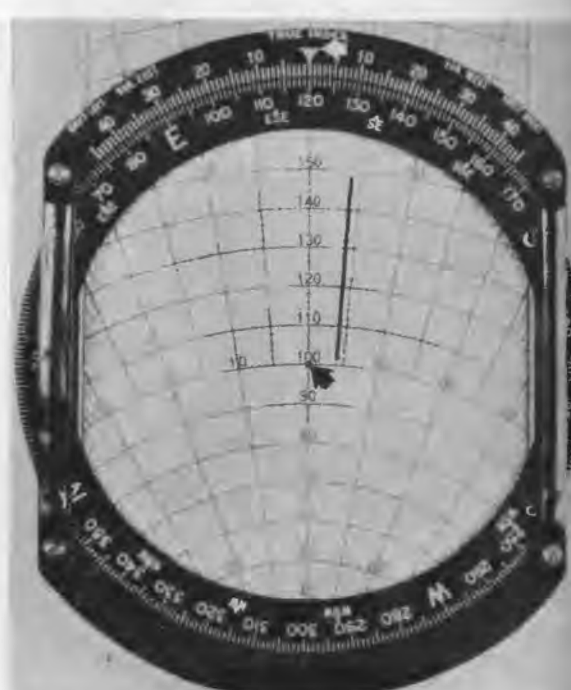


Figure 84. Drift on first heading.

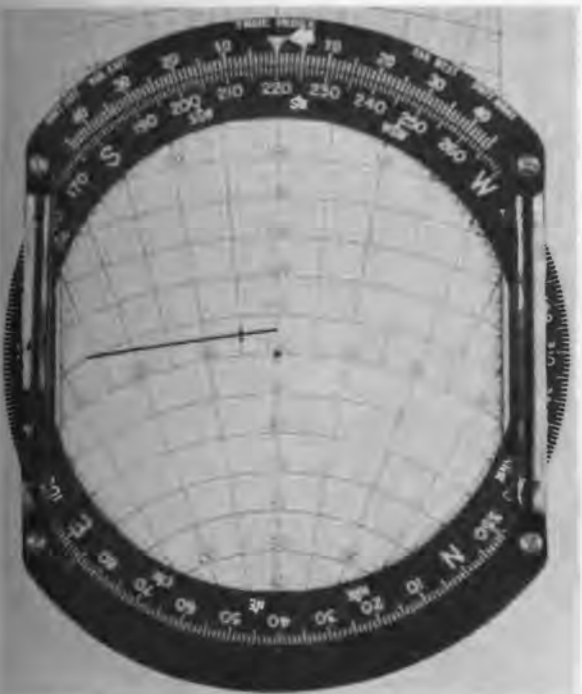


Figure 85. Drift on second heading.

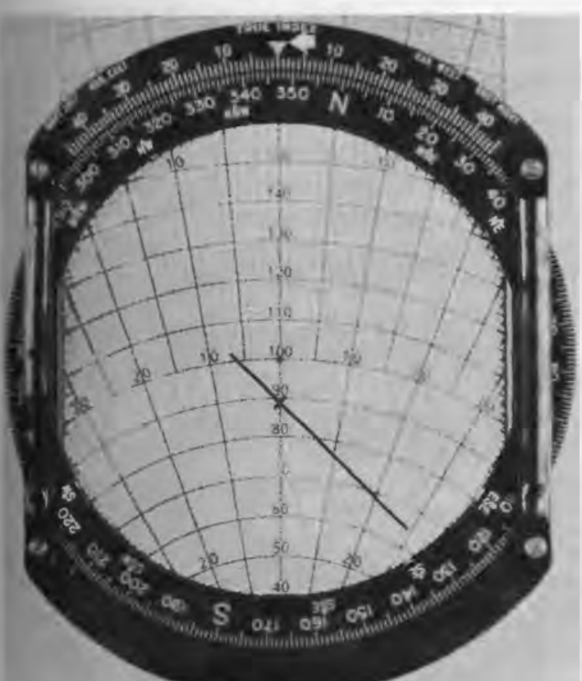


Figure 86. Reading wind direction and speed.

5° to the left of centerline crossing the line previously drawn (fig. 85).

(4) Turn the cross until it is directly below the grommet (fig. 86).

(5) Under the true index, read the wind direction, 347° (fig. 86).

(6) By counting the units between the cross and the grommet, determine the windspeed, 11 knots (fig. 86).

99. Off-Course Correction

a. Problem. Airport B is 260 nautical miles from airport A. After some time, while maintaining a true heading of 060°, the pilot determines that he is 6 nautical miles to the right of his intended course and 110 nautical miles from point of departure. What is the correct heading to reach destination?

b. Solution. Using an E–6B computer, refer to figures 87, 88, and 89, and solve as follows:

(1) Place the rectangular grid under the plotting disc.

(2) Set the true heading (060°) under the true index.

(3) Using the grommet as a starting point, draw a line 6 nautical miles to the right of the centerline (each division has a value of 2 nautical miles) (fig. 87).

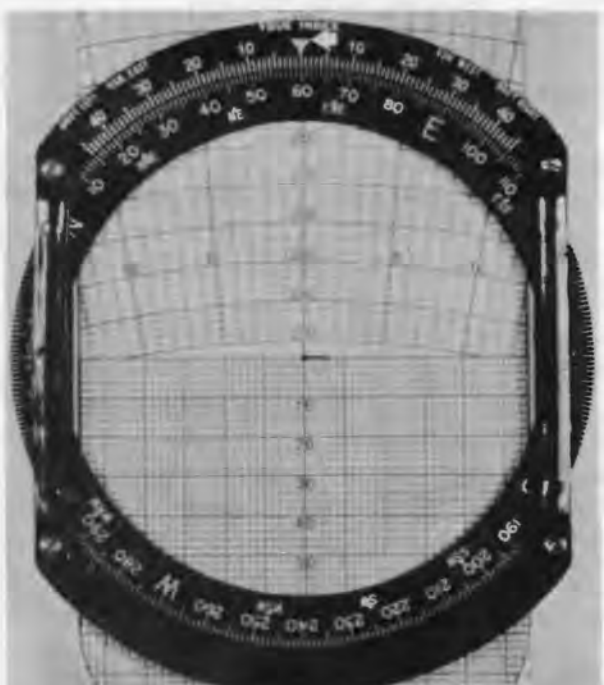


Figure 87. Drawing the off-course line.

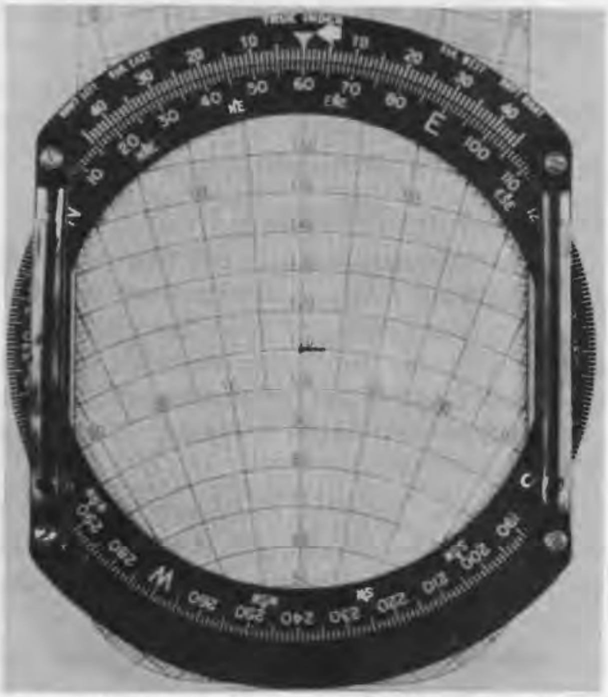


Figure 88. Finding the number of degrees to parallel.

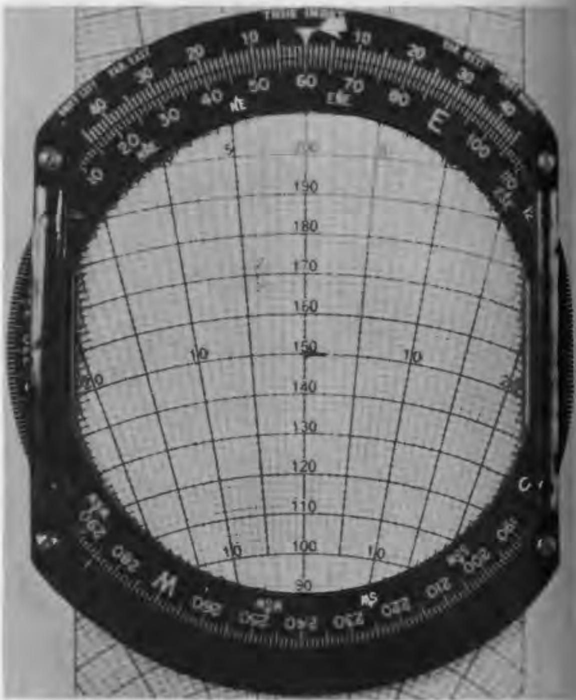


Figure 89. Finding the number of degrees further necessary to converge.

(4) Reverse the sliding grid and set the distance flown (110 nautical miles) under the grommet (fig. 88).

(5) From the converging line at the end of the horizontal line, determine 3° to the right of course (fig. 88).

(6) Set the distance to go 150 nautical miles (260 nautical miles (total distance) minus 110 nautical miles flown) under the grommet (fig. 89).

(7) From the converging line at the end of the horizontal line, determine 2° necessary for convergence on destination (fig. 89).

(8) Since the aircraft is to the right of course, correction is made to the left.

(9) Adding the 3° to parallel to the 2° to converge gives 5° of correction to converge at destination.

(10) Since correction is to the left, correction must be subtracted from the original true heading. The new true heading is 055° (060° —5° = 055°).

PART TWO
RADIO NAVIGATION

CHAPTER 10
RADIO PRINCIPLES

100. General

Radio communication is an absolute necessity during instrument flight, and the pilot should have a knowledge of the principles of radio and be familiar with the capabilities and employment of the airborne radio equipment used by the Army.

101. Wave Transmission

Communication by means of sound, light, or electricity has in common the phenomenon that energy is transmitted by waves.

a. Wave. A wave is a spurt of energy traveling through a medium by means of vibrations from particle to particle. For example, when a stone is dropped into a pond, the energy of motion of the stone disturbs the water, causing the water to rise and fall. The ripples (waves of energy) travel outward from the place where the stone struck the water, but the water itself does not move outward. This rise and fall above and below the normal undisturbed level can be pictured as a curved line.

b. Cycle. A cycle is a recurring alternation of an electromagnetic wave from one amplitude to another, beginning and ending at zero amplitude. As shown in figure 90, a cycle is represented by the portion of the wave from A to E, from B to F, from C to G, or between any other

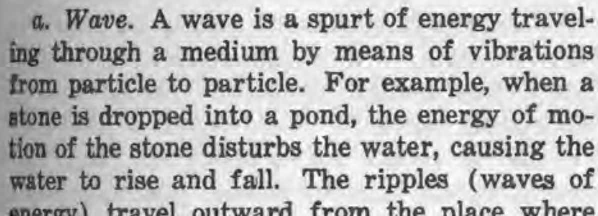


Figure 90. Wave.

two points encompassing exactly one complete series of events.

c. Frequency. The frequency of a wave is measured by the number of cycles that are completed in one second. If two cycles are completed in one second, the wave frequency is two cycles per second. Since the number of cycles run into high figures when discussing radio frequencies, larger basic units are used. Through common usage, frequencies are expressed as kilocycles or megacycles per second. The "per second" is dropped but understood. Thus, 1,000 cycles equal 1 kilocycle (kc) and 1,000 kilocycles equal 1 megacycle (mc).

d. Wavelength. The linear distance of a cycle is known as the *wavelength.* In figure 90, the portion of the wave from A to E expressed in meters, foot, miles, or any other measurement of length is the wavelength of that particular wave.

e. Amplitude. The amplitude of a wave is the linear distance from the normal level of the wave to its highest or its lowest point. In figure 90, the amplitude is represented by the line BH, ID, or FJ.

102. DC and AC Current

When electrons are made to move through a conductor, an electrical current is said to be flowing. Direct current (dc) flows in only one direction. An alternating current (ac) flows in one direction for a time and then flows in the opposite direction for the same length of time, the reversal being continuous. An alternating current (fig. 91) can be represented as a continuous change of direction of flow of electrons from positive (+) to negative (—).

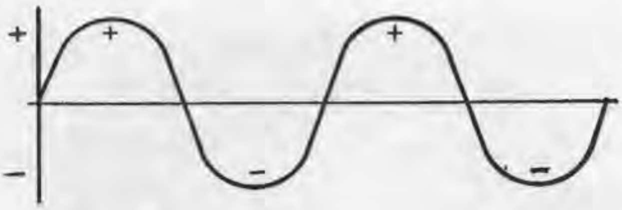


Figure 91. Alternating current.

103. Radio Waves

When an electrical current flows through a wire, a magnetic field is built up around the wire. When alternating current flows through a wire, the magnetic field alternately builds up and collapses. An alternating current of high frequency is used to generate radio waves which are emitted by the building and collapsing of the magnetic field around a conductor (antenna). Radio frequencies extend from 50 kilocycles to 10,000 megacycles and higher.

104. Principles of the Transmitter

a. Generating and Transmitting a Radio Signal. Fundamentally, a radio signal is transmitted by generating a radio frequency current and connecting it to an antenna suitable for radiation of that particular frequency (fig. 92).

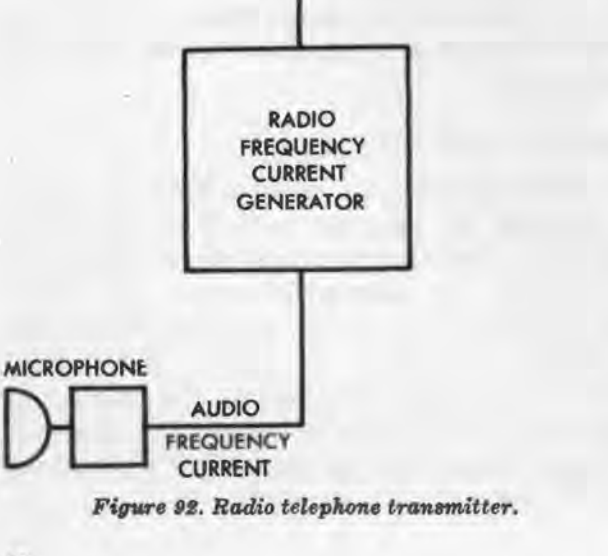


Figure 92. Radio telephone transmitter.

b. Altering the Radiated Signal. In order to transmit information, the radiated signal must be altered (fig. 93) in some manner and the alterations decoded at the receiver. Code is transmitted by breaking the signal up into dots and dashes. Voice is transmitted by molding, or modulating, the signal to the vibrations of the voice. The amplitude, or strength, can be molded or the frequency can be made to change over a small range of frequencies. The latter method is called "frequency modulation." Amplitude modulation is generally used in aircraft radios.

c. Continuous Wave and Modulated Wave. An unmodulated signal is called a continuous wave (cw) signal. The principle use of cw signals is transmission of International Morse Code. A modulated signal is commonly referred to as a modulated carrier wave (mcw). If a steady tone, instead of voice, is used to modulate the transmitted signal, the signal is still a mcw signal, commonly called a tone signal.

105. Principles of the Receiver

a. Tuning. Radio waves set up minute currents in receiving antennas just as an alternating current is set up in any conductor which is placed near another conductor that carries an alternating current. The method of selecting the desired signal and rejecting the many undesired signals is called tuning. The tuning circuit in the receiver is adjusted to *resonance* with the frequency of the desired signal; other frequencies are rejected by the tuning circuit and the desired one is allowed to flow to a device for rectifying the frequency electric current (detector).

b. Demodulating. Radio frequency current is beyond audio range. The audio frequency current used to modulate the signal at the transmitter actuates the earphones. Audio frequency is recovered by a process called demodulation and is accomplished by the detector. The output of the detector is a direct current, pulsating (changing in amplitude) at an audio rate, and is used to operate the headphones. The vibrating diaphragm of the headphones causes air to be set in motion, producing sound. The sound is a reproduction of that which entered the microphone at the transmitter (fig. 94).

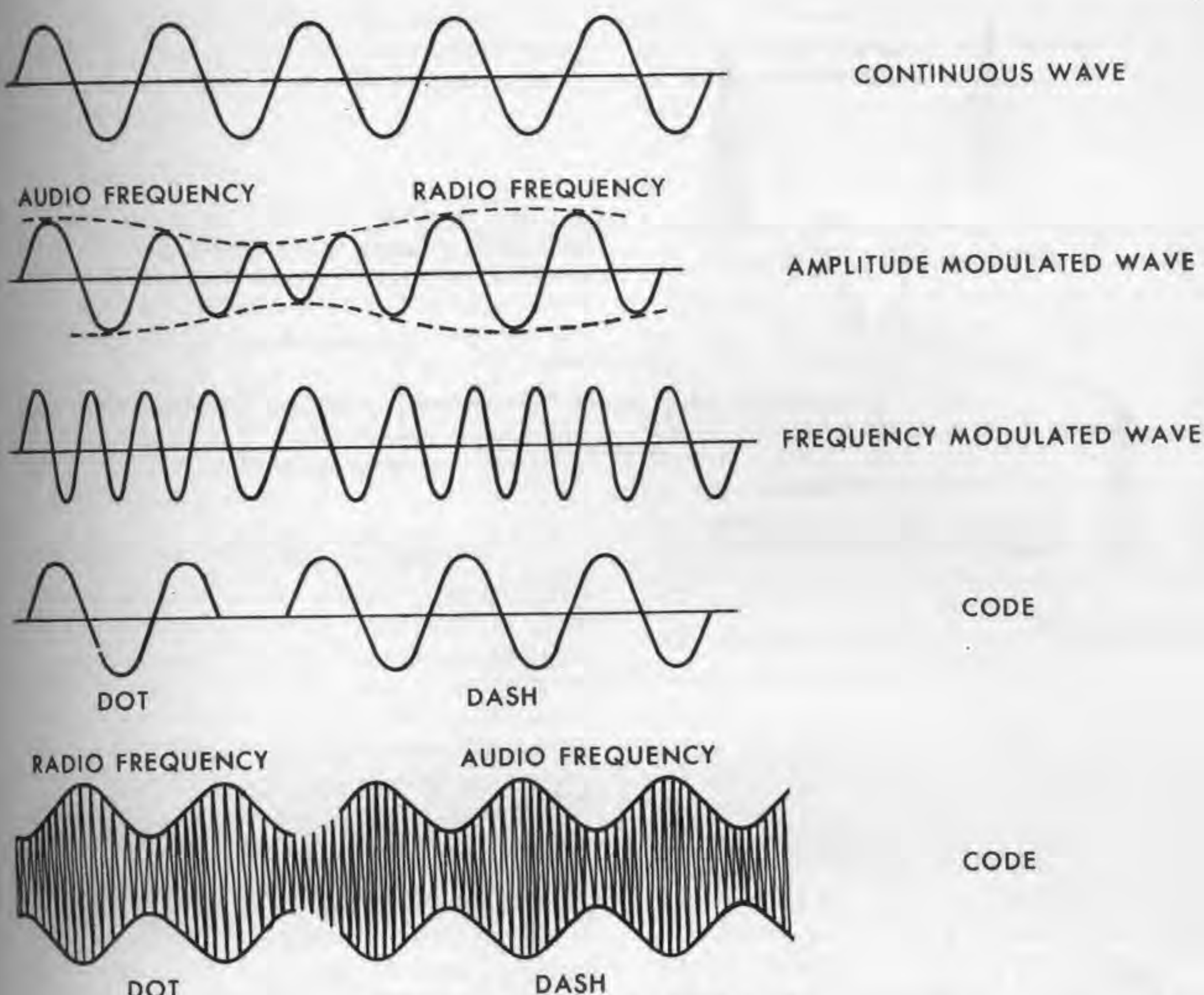


Figure 93. Altering the radiated signal.

106. Classification of Frequencies

a. Audio (AF). Twenty to 20,000 cps (cycles per second).

b. Radio (RF).

(1) Very low frequency (VLF) 10 to 30 kc (kilocycles).
(2) Low frequency (LF), 30 to 300 kc.
(3) Medium frequency (MF), 300 to 3,000 kc.
(4) High frequency (HF), 3,000 to 30,000 kc.
(5) Very high frequency (VHF), 30 to 300 mc (megacycles).
(6) Ultrahigh frequency (UHF), 300 to 3,000 mc.
(7) Superhigh frequency (SHF), 3,000 to 30,000 mc.
(8) Extremely high frequency (EHF), 30,000 to 300,000 mc.

107. Low Frequency Radio Wave Propagation

A radio wave (fig. 95) leaves the antenna in all directions. That portion of the radiated wave following the ground is called the *ground wave.* The ground wave is conducted along the earth until its energy is absorbed (attenuated). The remainder of the radiated energy is called *sky wave.* The sky wave is radiated up into space and would be lost were it not for the reflecting layers in the atmosphere. These layers are called ionosphere (region of ionized air caused by radiation of the sun). The reflecting effect on the waves permits signals to be received at distant points. The effect on distance is determined by the height and density of the ionosphere and

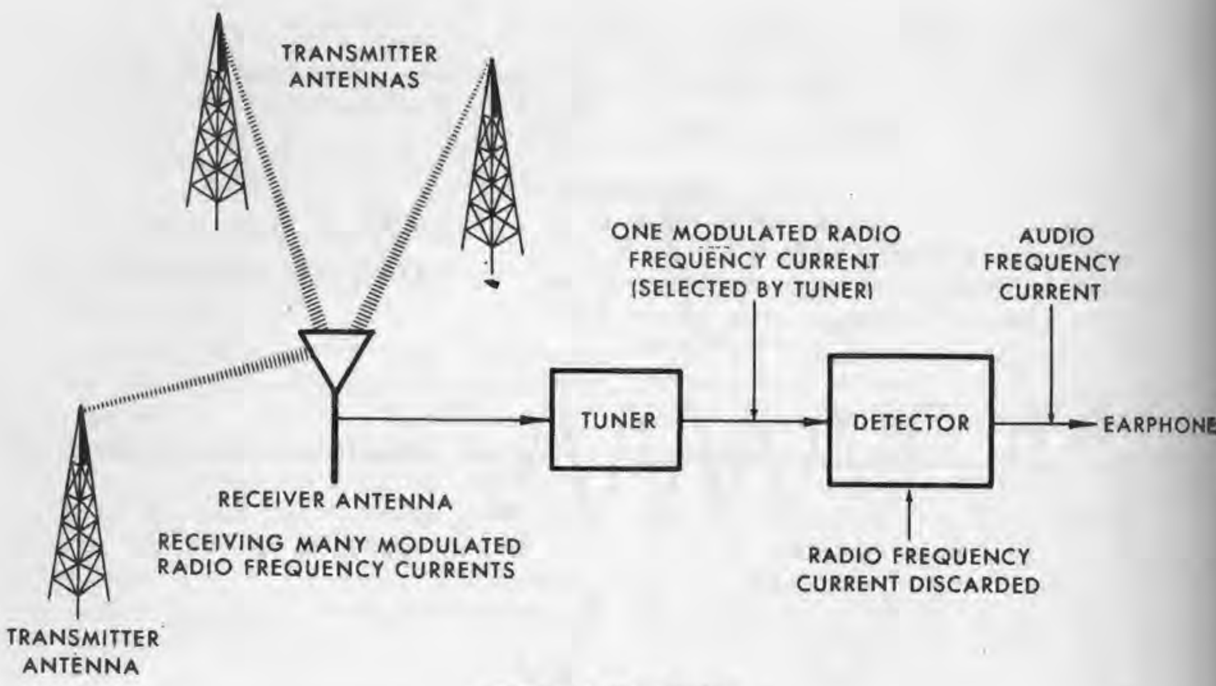


Figure 94. The receiver.

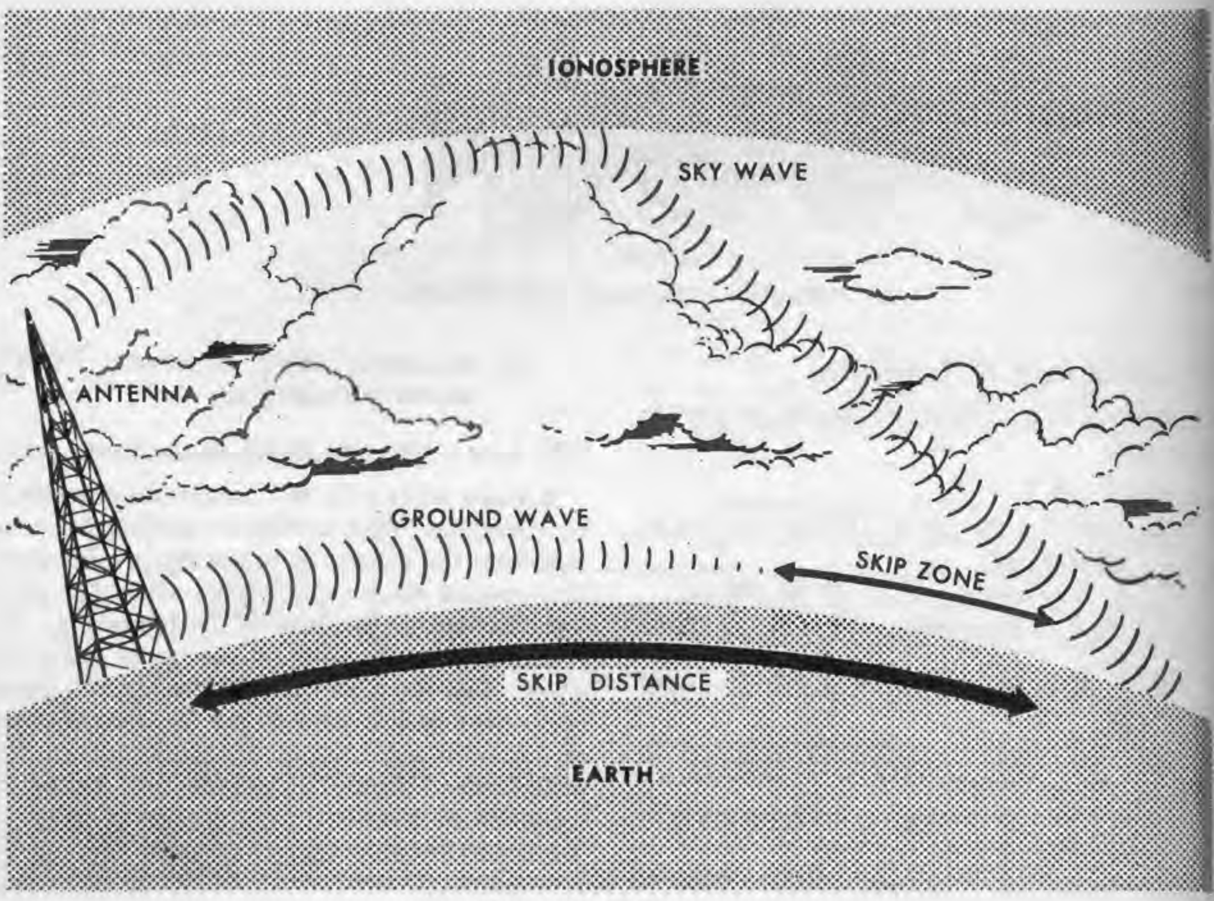


Figure 95. Radio waves.

upon the angle at which the radiated wave strikes the ionosphere. The ionosphere varies in height and density with the seasons, time of day, and latitude.

108. Skip Distance

The distance between the transmitting antenna and the point where the sky wave first returns to the ground is called the *skip distance* (fig. 95). The distance between the point where the ground wave can no longer be received and the sky wave returned is called the *skip zone*. Since radiation varies the position and density of the ionosphere, a great change in skip distance occurs at dawn and dusk, and fading of signals is more prevalent.

109. Effect of All Matter on Radiation

All matter within the universe has a varying degree of conductivity or resistance to radio waves. The earth itself acts as the greatest resistor to radio waves. The part of the radiated energy that travels near the ground induces a voltage in the ground that subtracts energy from the wave. The result is that the ground wave is attenuated, or decreased in strength, as the distance from the antenna becomes greater. The atmosphere acts in the same way in that the molecules of air, water, and dust absorb the energy of radiation. Other matter on the surface of the earth such as trees, buildings, and mineral deposits also acts to absorb radiation.

110. Effect of Static Upon Low and Medium Frequency Reception

Static disturbance is either manmade interference or natural interference. For example, manmade interference is caused by an ordinary electric razor. Each small spark, whether originating at a spark plug, contact point, or brushes of an electric motor, is a source of radiation. All frequencies from zero to approximately 50 megacycles are transmitted from each spark and consequently add to any reception within this range. Natural static may be divided into two types, called atmospheric static and precipitation static. Interference which originates from natural sources away from the aircraft is known as *atmospheric static*. Interference which is caused by electrostatic discharges from the aircraft, resulting from aerological conditions, is known as *precipitation static*.

111. General Nature of High Frequency Propagation (3,000 kc—30 mc)

The attenuation of the ground wave at frequencies above approximately 3,000 kc is so great as to render the ground wave of little use for communication except at very short distances. The sky wave must be utilized, and since it reflects back and forth from sky to ground, communication can be maintained over long distances (12,000 miles, for example). With the use of higher frequencies, the absorption of radiation by the atmosphere is reduced.

112. General Nature of Very High Frequency Propagation (30–300 mc)

Practically no ground wave propagation occurs at frequencies above about 30 megacycles and ordinarily there is no reflection from the ionosphere, so that communication is possible only if the transmitting and receiving antennas are raised sufficiently above the surface of the earth to allow the use of a direct wave. This type of radiation is known as "line-of-sight" transmission. Thus, VHF (UHF) communication is dependent upon the position of the receiver in relation to the transmitter. When using airborne VHF (UHF) equipment, it is of utmost importance for the pilot to understand the factors limiting his range of communication.

113. Range of VHF Transmission

The range of VHF (UHF) transmissions is normally about one-third more than direct line-of-sight (par. 112). The approximate range in nautical miles of VHF (UHF) transmission can be determined by multiplying the square root of the aircraft's altitude in feet by 1.4 (1.4 altitude in feet). For example, an aircraft at 1,600 feet altitude will receive a VHF (UHF) signal from a transmitter 56 nautical miles away.

CHAPTER 11
RADIOTELEPHONE PROCEDURE

114. Radio Phraseology

Voice transmissions can be accomplished more successfully if the message contains standard words and phrases. Where reception is poor, the message may still be understood if the person receiving the message knows what to expect from the person transmitting.

115. Standard Control Tower Phrases

Control tower operators transmit standard words and phrases because they save time, insure more positive instructions, and lessen the chance of misunderstanding. Unusual situations may not be covered by standard phrases, but normally the tower operator can be expected to use standard phraseology. If the pilot memorizes the standard phrases, successful communications will result even when reception is difficult.

116. Phonetic Alphabet

It is often necessary in transmitting to identify certain letters and/or groups of letters, or to spell out difficult words, since certain sounds have low intelligibility when mixed with a background of other noises. The standard phonetic alphabet (table I) identifies each letter of the alphabet with a word that is more easily understood—to make the message clear when individual letters are transmitted, and to spell out words that are hard to understand on the air.

117. Use of Numerals

Numbers are usually of extreme importance in radio messages and are difficult to hear among other noises. The pronunciations in table I have been adopted as standard because they have been found to be most intelligible.

a. Normally, all numbers are transmitted in serial form speaking each digit separately. For example, to transmit 80, say "Ait Zero"; for 6181, say "Six Wun Ait Wun."

b. There are certain exceptions to the above rule. Figures indicating hundreds and thousands in round numbers, up to and including 9,000, shall be spoken in hundreds and/or thousands as appropriate. For example, for 500, say "Fife Hundred"; for 1,300, say "Wun Thousand Tree Hundred." Beginning with 13,000 the individual digits in thousands of feet are called out, for example, for 13,000 say "Wun Tree Thousand"; for 20,000 say "Two Zero Thousand"; for 24,500 say "Two Fower Thousand Fife Hundred."

c. Aircraft identification numbers will be spoken as individual digits; for 8,143, say "Ait Wun Fower Tree," for 6,075, say "Six Zero Seven Fife."

d. Time will be stated in four digits according to the 24-hour clock. The first two digits indicate the hour; the last two, minutes after the hour (table II).

e. Field elevations will be stated in feet in accordance with table II.

Table I

Phonetic alphabet			Numerals
A—Alpha	J—Juliett	S—Sierra	0—Zero
B—Bravo	K—Kilo*	T—Tango	1—Wun
C—Charlie	L—Lima**	U—Uniform	2—Too
D—Delta	M—Mike	V—Victor	3—Tree
E—Echo	N—November	W—Whiskey	4—Fo-wer
F—Foxtrot	O—Oscar	X—X-ray	5—Fife
G—Golf	P—Papa	Y—Yankee	6—Six
H—Hotel	Q—Quebec***	Z—Zulu	7—Seven
I—India	R—Romeo		8—Ait
			9—Ni-ner

*Kee-loo ** Lee-mah *** Kay-beck

Note. Number 3 pronounced "Thu-ree"; number 5 pronounced "Fi-yiv," per ACP 125(B) April 1956.

Table II

Time	Field elevation
0000—Zero Zero Zero Zero	10 ft.—Field elevation Wun Zero.
0920—Zero Niner Too Zero	75 ft.—Field elevation Seven Fife.
1200—Wun Too Zero Zero	583 ft.—Field elevation Fife Ait Tree.
1645—Wun Six Fower Fife	600 ft.—Field elevation Six Zero Zero.
	1,250 ft.—Field elevation Wun Too Fife Zero.
	2,500 ft.—Field elevation Too Fife Zero Zero.

118. Procedure Words and Phrases

It is impossible to offer precise wording for all phrases that might be required in radiotelephone communications. Table III contains standard words and phrases used by Army aviators. They should be memorized and practiced until they become a part of the pilot's everyday vocabulary.

119. Radio Call Signs

A radio call sign is used to notify a particular station (ground or air) that it is being called. The station identifies itself by this call sign when transmitting. The call sign of every ground station, in nontactical operations, is the name of the field plus the type of communication service.

a. When calling a control tower, the name of the base at which the tower is located plus the word "radio" is used. For example, "Atlanta Tower," "Maxwell Tower." For a radio range station, the name of the range station plus the word "radio" is used. For example, "Atlantic Radio," "El Paso Radio."

Table III

Word or phrase	Meanings
Acknowledge	Let me know that you have received and understand this message.
Affirmative	Yes.
Break	I hereby indicate the separation between the portions of the message. (This is to be used only where there is no clear distinction between the text and the other portions of the message.)
Correction	An error has been made in this transmission. The correct version is ____________.
Go ahead	Proceed with your message.
How do you hear me?	Self explanatory.
I say again	Self explanatory.
Negative	That is not correct.
Out	This conversion is ended and no response is expected.
Over	My transmission is ended and I expect a response from you.
Read back	Repeat all of this message back to me exactly as received after I have given "over."
Roger	I have received all of your last transmission. (To acknowledge receipt; shall not be used for any other purpose.)
Say again	Self explanatory.
Speak slower	Self explanatory.
Stand by	If used by itself it means, I must pause for a few seconds. If the pause is longer than a few seconds or if "standby" is used to prevent another station from transmitting, it must be followed by the word "out."
That is correct	Self explanatory.
Verify	Check coding, check text with the originator and send correct version.
Words twice	As a request—Communication is difficult: Please say every word twice.

b. Each aircraft equipped with a radio transmitter has a call sign and when any call is made to that aircraft, the call sign is given first. An aircraft call sign is composed of numbers, letters, words, or a combination of them. The call sign of a single Army aircraft making a nontactical flight within the continental limits of the United States is the last four digits of the aircraft serial number, preceded by the word "Army"; however, if the ground station requests, the complete serial number should be given. After communication is established, and when no confusion will result, it is permissible to reduce the number of digits in the aircraft call sign to the last two digits of the serial number.

120. Establishing Communication

Communication must be initiated by call-up and reply when—communication has not been established; or contact has been terminated. Always monitor the channel before using it; if no signal is heard, assume that the channel is clear. To establish contact, make the initial call-up as follows:

a. Calling a Control Tower.

(1) Monitor channel and give call sign of the receiving station__"Ozark Tower."

(2) Introduction______________"This is."

(3) Call sign of transmitting station__________"Army Fife Fower Wun Tree."

(4) Frequency on which reply is expected_______"Receiving Wun Wun Niner Day-see-mal Fife."

(5) Invitation to reply___________"Over."

b. Calling a Radio Range Station. "Atlanta Radio, this is Army Fife Fower Wun Tree receiving Wun Wun Niner Day-see-mal Fife, Over."

c. Answer. The station called answers in the same manner; e.g.________"Army Fife Fower Wun Tree, this is Atlanta Radio, Over."

121. Voice Procedure After Communication Has Been Established

After communication has definitely been established, it is not necessary to repeat the call sign of the receiving station at the beginning of each transmission. However, at the beginning of each transmission, the words "this is" and the aircraft call sign are transmitted. At the beginning of each transmission from a control tower, Air Traffic Communication Station (ATCS) or AACS (Airways and Air Communication Service) station, the operator includes the aircraft call sign. When communications are difficult, call signs, phrases, words, or groups of words, may be transmitted twice by the use of the procedural phrase, "words twice."

a. Reception may be verified by the use of the phrase "read back." When an error is made by the transmitting operator, the word "correction" is used, followed by the correct version of that word, group, or phrase.

b. Under special circumstances, when communication conditions are favorable and when the frequency channel used is comparatively exclusive, the procedure preceding each transmission may be cut short in order to expedite the exchange of a large number of transmissions.

122. Use of Headset and Microphone

a. Headset. The headset should be properly adjusted for both comfort and efficiency. Most of the noise can be sealed out if the headset fits well.

b. Microphone. Before the microphone is used, tune to and monitor the station. Speak straight into the microphone. By touching the microphone to the upper lip, a great deal of the aircraft noise will be eliminated; also more voice vibrations will reach the diaphragm of the microphone, thereby making reception clearer.

123. Voice Control

Learning to talk properly over radiotelephone is easier than training the ears to listen. Be careful when transmitting to speak as clearly as possible. When speaking over interphone or radiotelephone, *volume, tempo, pronunciation,* and *pattern of speech* determine maximum effectiveness. While practicing voice procedure, concentrate on one factor at a time until the correct practice for each becomes familiar. Good speech habits lead to automatic use under all flight conditions.

a. Volume. Clarity increases with volume up to a level just short of shouting. Speaking loudly, without extreme effort or noticeably straining the voice, results in maximum *intelligibility.* To be understood, the spoken sound must be louder at the face of the microphone than the surrounding noises. Open the mouth so that the tone will carry to the microphone. The tone of the voice should be slightly higher than normal since a high-pitched tone is easier to hear. The best way to judge one's own speech is to listen to the side tone in the earphones. A good, clear side tone is the most reliable assurance of correct volume.

b. Tempo. After learning to control the volume of the voice, the next important factor in voice transmission is control of the rate of speech. No fixed rate is best for all occasions. The correct rate of speech depends upon the speaker, the nature of the message, and the conditions of transmission and reception. To develop the correct rate of speech for maximum effectiveness, practice the following:

(1) Talk slowly enough so that each word and syllable is spoken distinctly.

(2) Talk fast enough to sound natural.

(3) Talk slowly enough so that the listener will have time, not only to hear, but to absorb the meaning.

(4) Group words so that ideas are clear.

(5) Pause between ideas, but *do not* "hem" and "haw"; eliminate all "uh's" and "er's."

(6) Speak key words and phrases more slowly.

c. Pronunciation. A person may learn to speak with the proper volume and at an effective rate and still not be completely intelligible while transmitting in noise. An important factor in producing good readability is clear and distinct pronunciation of all sounds, syllables, and words. Once the habit of making each sound of every word clear and distinct is developed, practice the special points mentioned below to develop good speech.

(1) Give all words the commonly accepted, correct pronunciation. Avoid extreme regional accents and local pronunciations. Make the transmitted speech as nearly general American English as possible.

(2) Be particular to pronounce the end sounds in words. In transmitting words ending in "ing," make the "g" clear.

(3) Unaccented syllables must be pronounced. Do not slur over them. When saying "e-leven," do not say "leven."

(4) Do not talk out of the corner of the mouth.

(5) Pronounce words so that they sound natural to the listener.

d. Normal Patterns of Speech. For complete readability, some attention must be devoted to the fourth factor, naturalness in phrasing. No matter how loud and clear the words are, the listener will have trouble understanding the meaning of the message if words are not grouped as he is accustomed to hearing them. Any message transmitted falls into natural phrase groups.

124. Reports

The correct sequence and information for giving position reports, changes in flight plans, and inflight weather reports are listed in the Jeppensen manual and in radio facility charts. These procedures must be followed as closely as possible. Additional information and procedures concerning Air Defense Identification Zone (ADIZ) reports, given in the same publications, will be followed to the letter.

a. Position Reporting. When flying under visual flight rules, maintain a continuous listening watch on CAA frequencies and make a position report at least once every sixty minutes to CAA communications stations along the route. When it is impractical to contact a CAA station, transmit the position report to a military airways station, or to a control tower. When flying under instrument flight rules, make a position report to CAA communications stations upon passing compulsory reporting points and at other points specifically directed by air traffic control.

b. Distress Reporting (Position Known). If imminent danger is threated or immediate help is needed, the following procedures will be used. The radiotelephone distress call is "Mayday."

If the pilot knows his position, he should transmit—

(1) "Mayday, Mayday, Mayday."

(2) "This is Army____. This is Army____. This is Army____." (Giving call number.)

(3) Type of aircraft.

(4) Position of aircraft.

(5) Nature of distress.

(6) Nature of help requested.

c. Position Reporting (*Position Unknown*). If position is not known, or if there is not sufficient time for transmission of the above information, transmit—

(1) "Mayday, Mayday, Mayday."

(2) "This is Army____. This is Army____. This is Army____." (Giving call number.)

(3) Press tone button for twenty seconds.

(4) Give any additional information possible and repeat the aircraft call sign.

CHAPTER 12
LOW/MEDIUM FREQUENCY RADIO RANGE SYSTEMS

Section I. DESCRIPTION

125. General

The low/medium frequency (L/MF) radio range system provides an aid to navigation and a communication facility throughout the United States and Canada. The signals, emitting from several hundred transmitters, provide the basis for a network of well-defined aerial highways along which radio "beams" are directed. L/MF ranges utilize the 200 to 550 kilocycle band.

126. Classification

Two types of L/MF ranges in general use in the United States are the loop (L) and the Adcock (A), named for the type antenna used on each. The following power classifications are used on loop and Adcock ranges:

a. Loop (RL), Adcock (RA)—150 watts or more.

b. Loop (MRL), Adcock (MRA)—50 to 150 watts.

c. Loop (ML)—less than 50 watts.

127. The Loop Range

a. The Transmitting Antenna. At the station, the transmitting antenna of a loop range consists of two rectangular shaped loops constructed at right angles to each other (fig. 96). Poles suspend the loops in the vertical plane. The dimensions of the loops are 40 by 300 feet. One loop is used for broadcasting the N signal and is called the *N antenna.* The other loop is used for broadcasting the A signal and is called the *A antenna.* When voice is being transmitted both antennas are used.

b. Type of Transmitted Signal. The transmitter produces a modulated carrier wave (mcw) with an audible tone of 1,020 cps (cycles per second). This solid tone is fed alternately to the two antennas by a keying device in the following sequence: dash, dot; dot, dash; dash, dot; dot, dash; etc. This results in an N signal (dash, dot) on the N antenna and an A signal (dot, dash) on the A antenna. Actually, a solid tone is broadcast (fig. 97) but because of the directional quality of each antenna, a well-defined N or A signal is created in the quadrants and the solid tone can be heard only when the signals from the N and A antenna are received with equal intensity. Once each 30 sec-

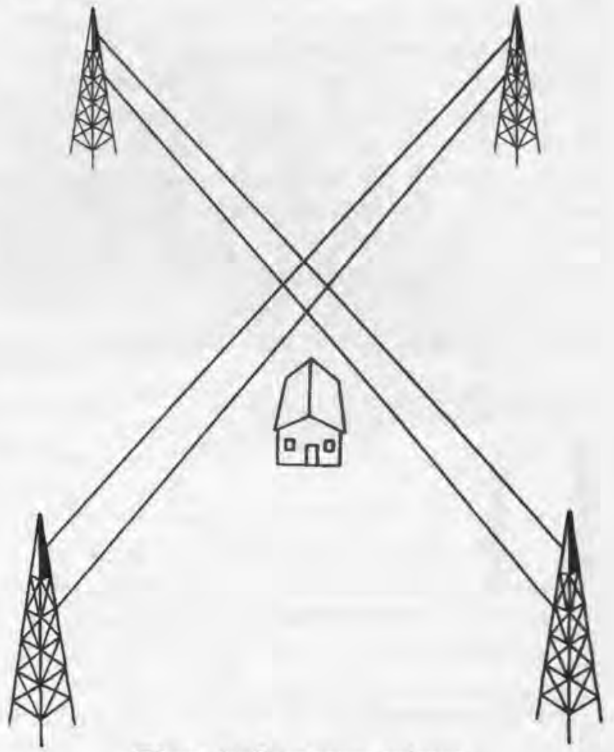


Figure 96. Loop range antenna.

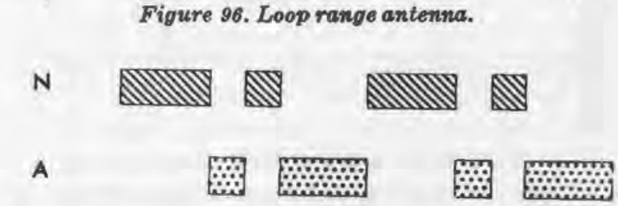


Figure 97. Interlock of A and N signals.

onds, the A and N keying is discontinued and the station call letters are transmitted twice, first over the N antenna, then over the A antenna.

c. The Signal Pattern. The two vertical portions of the loop antenna radiate signals that are 180° out of phase. At any point in line with the two vertical portions of the loop, the radio waves received are more nearly in phase (owing to the greater distance traveled). This condition gives the maximum intensity of the transmitted signal (A, fig. 98). At any point on a line through the inside diameter (perpendicular to the plane of the loop) the signals are 180° out of phase (B, fig. 98) since the distances from each side of the loop are equal. The transmission area of a single loop covers a figure-eight pattern, with the strongest signal in line with the plane of the loop. Signals grow progressively weaker on either side (fig. 98).

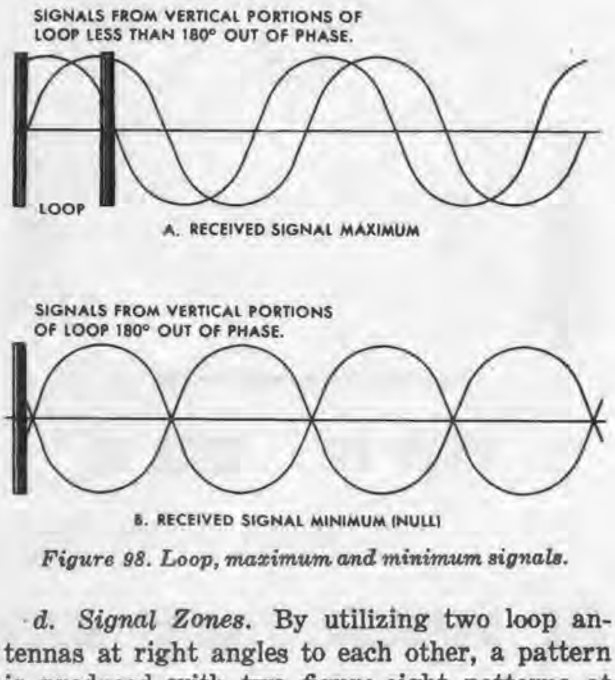


Figure 98. Loop, maximum and minimum signals.

d. Signal Zones. By utilizing two loop antennas at right angles to each other, a pattern is produced with two figure-eight patterns at right angles to each other. Because of the keying of the signal, the directional quality of the antennas, and the relative position of the two figure-eight patterns, the following zones (fig. 99) are formed:

(1) *The quadrants.* Sectors where one signal predominates.

(2) *The on-course* (*or beam*) *zone.* This is a line where the N and A signals blend together to form the 1,020 cycle solid tone. The on-course is in the center of each of the four bisignal zones ((3) below).

(3) *The bisignal zone.* This is the area on either side of the on-course within the overlap of the two figure-eight patterns. The N and A station identification signals are heard with unequal strengths. In the bisignal zone of the N quadrant, the N is distinguishable as an N, and A forms a solid background tone. In the bisignal zone of the A quadrant, the A is distinguishable as an A, and the N forms a solid background tone. The width of the bisignal zone and its area are dependent upon receiver sensitivity and volume control.

(4) *The clear signal zone.* This is the area outside of the area of overlap. In the clear signal zone, the quadrant signal is heard with no background tone.

(5) *Cone of silence.* This is a cone-shaped extent of space extending upward from a radio range transmitting station, in which signals are unheard or greatly reduced in volume. While over the cone of silence, when the station identification signal is heard, the first identification signal being broadcast over the N antenna follows the same volume intensity pattern as the N, and the second identification signal being broadcast over the A antenna follows the same volume intensity as the A. When on-course, the first and second identification signals are of equal intensity.

e. Night Effect. Sky waves radiating from the horizontal portions of the loop-type antenna often cause the range to become unreliable during the night hours beyond about 30 miles. The sky waves are reflected by the ionosphere and the reflected waves come back to the earth at some point beyond 30 miles from the station. A reflected wave may or may not be in phase with the ground wave at the same point, thus resulting in an increase or decrease in the intensity of the N or A signal. Because of the shifting of the ionosphere at sunset and sunrise, erratic

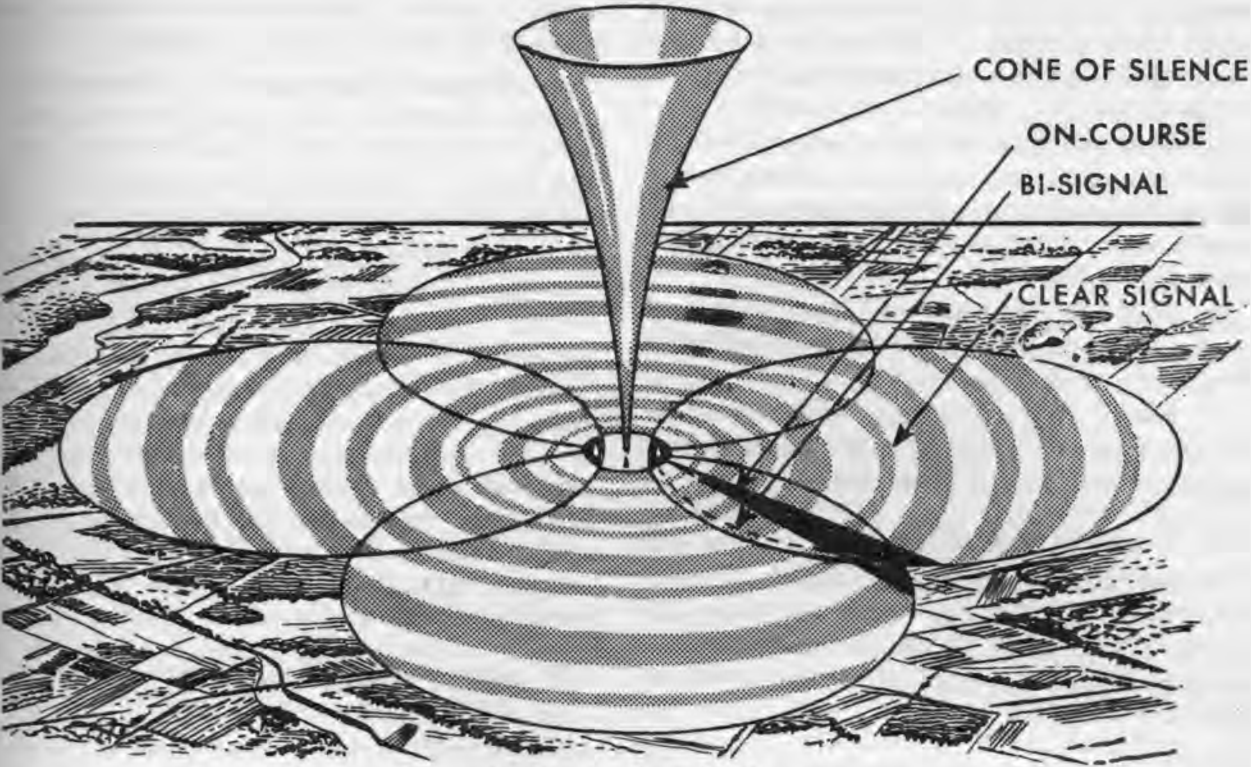


Figure 99. Signal pattern of radio range.

phase combinations occur which result in the apparent swinging of the on-course signal. This swinging of the on-course is very apparent on the loop range but does not occur when using the Adcock range.

128. The Adcock Simultaneous Range

The Adcock simultaneous range was designed to overcome the disadvantages of the loop range, and has replaced the loop range at important air terminals and airway intersections.

a. Adcock Antenna. The Adcock simultaneous range employs four sturdy steel towers approximately 125 feet high (called vertical radiators), in place of the suspended loops of a loop-type range. Two towers placed approximately 800 feet apart are fed alternating current 180° out of phase. The transmission lines from the transmitter to the towers are buried and shielded, thus reducing the radiation of sky waves and eliminating night effect. By placing two such pairs of towers at right angles to each other, the same signal zones are formed as by two loops. A fifth tower, located in the center of the other four, transmits a constant carrier wave that is used for the simultaneous voice facility.

b. Type of Signal Transmitted. The center tower broadcasts a continuous carrier wave in all directions on the station's assigned frequency. The outlying towers broadcast an unmodulated carrier wave to form the signal pattern and always use a frequency 1.02 kilocycles higher. For example, a station with an assigned frequency of 250 kilocycles broadcasts a signal from the outlying towers on a frequency of 251.02 kilocycles. Interference between the two frequencies creates a beat-frequency of 1.02 kilocycles or 1,020 cycles per second difference, to give the modulated tone in the head set. When voice is being broadcast, a filter system prevents interference between the range operator's voice and the range signals. Voice tones between 850 and 1,225 cycles are filtered out, so that only tones below or above this band are transmitted; thus, the range signal tone has a clear channel and does not interfere with normal voice tones (about 300–800 cycles).

129. Course Positioning

The four beams of most radio ranges are *not* evenly spaced at a 90° angle to each other. Variation of the angle of a course is accomplished by changing the signal pattern to make some lobes stronger or weaker as necessary. Thus, the on-course signal is shifted toward the weaker quadrant. Some of the methods used to change the signal pattern are as follows:

a. Changing Antenna Power. Antenna power can be changed in one or both loops, or in any combination of vertical radiators, either separately or in pairs.

b. Utilizing a Goniometer. The Bellini Tosi goniometer is an integral part of the transmitter that regulates phasing.

c. Adding Extra Antennas. These new parts of antennas, with qualities of absorption or radiation, can alter the signal pattern.

130. Quadrant Position

In the United States, the quadrant containing the *true inbound* bearing of 180° is designated the basic N quadrant. If a range leg falls on this bearing, the basic N quadrant is the northwest quadrant.

131. Normal Range Irregularities

There are several types of range irregularities, which bear titles such as swinging beams, false cones, and misalined beams. Causes of these irregularities can be grouped under the following two general headings:

a. Reflection and Absorption. A radio wave can be reflected or absorbed by objects such as the terrain, ore deposits, metallic structures, or the ionosphere. If a reflected wave joins, at some point, with a wave that has not been reflected, an increase or decrease in signal intensity can result. This change in intensity results from the relative phasing of the two waves. The degree to which the reflected wave may be in or out of phase with the wave not reflected is dependent upon the difference in the distance travelled by the two waves. A practical example: a pilot is flying a path over the geographical location that should normally give him an on-course signal (where N and A signals are equal); however, the N signal is affected by a reflected wave. The interference decreases the N signal strength, so the pilot hears a distinct A signal with the N signal forming the background. The pilot could fly toward the N quadrant and receive the on-course signal. Therefore, a pilot following the on-course signal in this situation would receive signals indicating a position over the terrain other than his true position.

b. Antenna Power Output. Incorrect power output in an antenna could result in a misalined beam. Occasionally, the process of course shifting causes a broadening or sharpening of the on-course and possibly a leaning cone.

c. Permanent and Temporary Irregularities. Irregularities resulting from ground wave reflection are usually permanent features, and notices of the unreliability of a range or portion thereof are usually reported in NOTAMS or Radio Facility Charts. Irregularities caused by sky wave reflection can be expected on any loop range at night. Irregularities resulting from mechanical malfunction are usually temporary and are quickly corrected; however, they may be reported either in NOTAMS or in the remarks section of the hourly teletype report.

132. Nonconformity of the Received Signal Pattern

The type of equipment, attitude of the aircraft, and/or type of weather, and improper manipulation of the receiving set can cause the received signal pattern not to conform with the transmitted pattern. This nonconformity should not be confused with range irregularities.

a. Volume Control. Increase or decrease of volume causes increase or decrease in the size of the lobes of the pattern. The position of the edge of the lobes is controlled by the amount of volume being used. Overloading the receiver can cause the strongest part of the signal to spill, resulting in a reversal of signals. Automatic volume control tends to broaden the width of the on-course. Filters decrease the volume.

b. Type of Equipment. The type of antenna might cause a slightly distorted pattern because of directional reception qualities. On account of its position, the antenna might be affected by refraction of the waves around the leading edge of the wing, or might be blanked out. Banking the aircraft when it is in or near the on-course can cause false signals from a loop range.

c. Static. Precipitation static has the effect of reducing the size of the pattern and making the signals unintelligible. One countermeasure is to use the shielded loop antenna of the radio compass for radio range reception.

133. Additional Radio Aids

a. Station Location Marker. The station location marker, designated by the letter Z, operates on a frequency of 75 megacycles (mc) and is modulated at 3,000 cycles per second (cps). Nominal power output is 5 watts and operation continuous. There is no identification keying of this marker. The radiated pattern is conical in shape and can be received for 15 seconds 1,000 feet above the transmitter flying 120 mph with the receiver in high sensitivity.

(1) The purpose of the Z marker is to help the pilot in positively identifying his position over a range station. Prior to the advent of the Z marker, the pilot had to depend entirely on the cone of silence to establish his position over the station. This method proved unreliable in many instances, due to the irregular shape of the cone of silence and difficulty in distinguishing the true cone of silence from a false one. If the aircraft passed slightly to one side of the station, the cone of silence would be missed entirely.

(2) Reception of the Z marker is accomplished by a radio receiver which actuates a small light on the instrument panel. The pilot may also receive indications of the Z marker by listening to the 3,000 cps tone which is fed into his earphones. Receipt of the Z marker signal positively places the position of the aircraft as over the range station.

b. Fan Marker. Another type of location marker is the fan marker. Fan markers are located at strategic points along the airways and on one or more courses of a range station to enable the pilot to check his distance from the station. These markers operate continuously on a frequency of 75 mc and are modulated at 3,000 cps. Fan markers are of two general types.

(1) The high power marker, designated FM, has a power output of 100 watts and radiates a "Fan" pattern which, at about 3,000 feet above the transmitter, is approximately 5 to 7 miles through the minor axis along the range course and 20 miles long across the major axis with the receiver in high sensitivity.

(2) The low power fan marker, designated LFM, has a power output of 5 watts and radiates a small pattern essentially the same shape as that of the Z marker. LFM markers are usually located within 5 miles of a range station.

c. Bone-Shaped Fan Marker. The latest FM design incorporates a bone-shaped fan marker which provides a more narrow pattern and enables the pilot to determine, much more precisely, the exact time he is over the marker site. This feature is particularly important when the fan marker is being used as an approach control holding fix. In approach control, delays are reduced by assigning in advance a time for each holding aircraft to leave the marker inbound on a straight-in approach. Having a precise starting point makes it possible for the pilot to vary his holding pattern in such a manner that he can be over the marker, inbound to the range station, at the exact time specified.

d. Homing Facilities. Radio beacons operate in the frequency band of 200–400 kc. The radiated pattern is circular, or nondirectional, which permits reception from any point within the service area of the facility. Beacons are classified as follows:

(1) HH facility—power output 2,000 watts or greater; operates continuously.

(2) H facility—power output greater than 50 watts but less than 2,000 watts; operates continuously.

(3) MH facility—power output less than 50 watts; operates on request unless otherwise stated in airman's guide.

(4) L facility—LOM (locator, outer marker), LMM (locator, middle marker) have power output of 25 watts; operates continuously. These facilities are called "compass locator" stations and are component parts of the ILS.

Note. These facilities transmit a continuous carrier wave with 1,020 cps modulation keyed to provide identification letters except when voice is being transmitted. Voice transmissions are made on homing facilities with the exception of the L facility, although CAA may adapt this facility for voice transmission. Homing facilities can only be used for radio direction finding and homing purposes. In this respect, any radio station transmitting a continuous carrier wave can be used as a homing beacon if within aircraft receiver range.

Section II. OPERATING PROCEDURES

134. Tuning

a. Station Frequencies and Identification. Station frequencies and identification call signs are found in the Jeppesen Manual and the Radio Facility Chart. They may also be found on sectional and WAC charts.

b. Steps in Tuning. After determining the station frequency and call sign, the following steps are used to tune in the station:

(1) Turn on the receiver and permit enough time for the receiver to warm-up.

(2) Turn the tuning knob until the station frequency is alined with the index.

(3) Adjust the volume control to a comfortable level.

(4) Since the tuning dial may not be exactly correct, monitor the aural signal for exact tuning and maximum readability.

(5) Positively identify the station. The dial calibration may not be exact or radio phenomena might result in receiving a station other than the one desired.

(6) During the station identification signal, move the tuning control back and forth slightly to assure good readability.

135. Fundamentals of Orientation

Radio range orientation (par. 137) is accomplished by determining aircraft position through interpretation of aural signals from a radio range station.

a. Factors Involved. Fundamentals of radio range orientation include—

(1) Range identification.

(2) Quadrant identification.

(3) Determining and flying an average bisector.

(4) Volume fade and build.

(5) Beam interception and identification.

(6) Beam following.

(7) Station recognition.

b. Conditions Affecting the Received Signal and Its Interpretation. The signal received and its interpretation are dependent upon the type of station, its power, its location in relation to terrain features, the time of day, the atmospheric conditions, the distance the received signal has traveled, the geographic location of the aircraft, the type of equipment being used, the attitude of the aircraft, manipulation of the receiver, and the general procedures used.

136. Visualizing Aircraft Position

To use the radio range as a navigational aid, the position of the aircraft must be visualized by use of the aural signal. Figure 100 graphically represents the cone of silence, the on-course, the bisignal zones, and the clear quadrants of the facility.

a. In a Clear Quadrant. While flying along course X to point B (fig. 100), a clear N signal with no background and the N quadrant station identification signal is heard. During the time allotted for the second station identification signal, no aural signal is received.

b. Crossing a Range Leg. As the aircraft proceeds from B to C, a gradually increasing background hum with an apparent decrease in the intensity of the N signal is heard. The N quadrant station identification signal maintains normal volume, but upon approaching the on-course, the A quadrant station identification signal gradually increases in volume. The background signal intensity becomes predominant when the aircraft reaches the on-course. At this point neither the A nor N signal can be identified, because these signals overlap to produce the hum of the on-course and both station identification signals are equal in volume. The on-course beam is 3° in width, varying from a few feet at the station to about 2,640 feet ten miles from the station.

c. Leaving a Range Leg. After passing through the on-course, a faint A signal is heard and the preceding pattern is reversed. The A

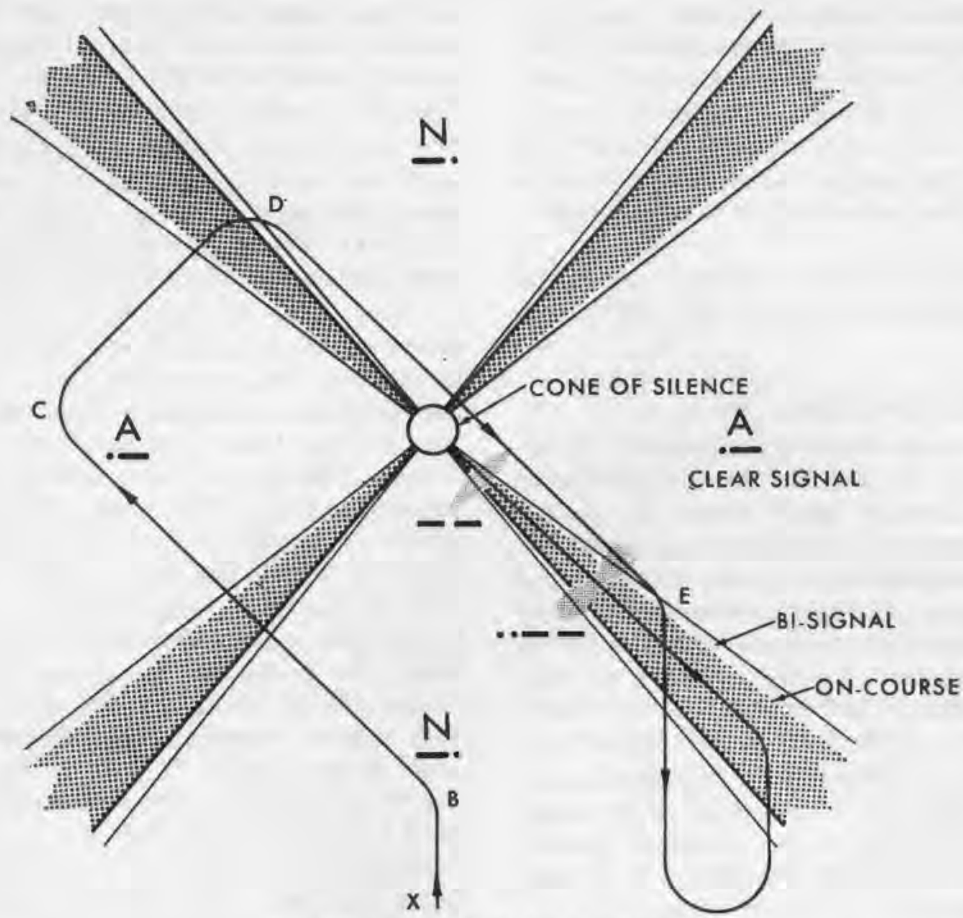


Figure 100. Flying the radio range.

signal gradually becomes more intense. The background hum and the N quadrant station identification signal become weaker, until the A signal and the second station identification signal are all that can be heard. From point C to D another range leg is crossed with the signal pattern similar to the one from B to C except that it starts in the A quadrant and ends in the bisignal zone of the N quadrant. Upon approaching the station, paralleling the on-course, the bisignal gradually fades out.

d. Close In. As the aircraft flies from D to E, it is perpendicular to the northeast leg. Here, close to the station, the bisignal zone is narrow and flight passage rapid. After passing the on-course, the bisignal zone of the northeast leg is received; then a very short clear A signal; and then the bisignal of the southeast leg. After proceeding along the southeast leg, a procedure turn is made and the beam leading to the station bracketed.

e. Over the Station. The cone of silence is identified by the absence of aural signal and indicates that the aircraft is over the radio range station. As can be seen in figure 99, the area containing an absence of aural signals is conical in shape. The diameter of the cone increases with altitude. The cone of silence is sharply defined by a rapid buildup, then an abrupt loss of signal, while passing through it; then a sudden surge of signal after it has been passed; followed by a fade.

f. Interpreting Volume Build and Fade. The signal pattern of the radio range is characterized by an increase in volume while the aircraft approaches the transmitting station and a decrease in volume while flying away from it. Recognition of this varying level of signal intensity is essential to radio range navigation. Signal intensity, in conjunction with signal interpretations, orients the aircraft with reference to the range station. While flying from the maximum reception distance toward the station, the volume build is gradual until nearing the station, where the rate increases, reaching its maximum immediately prior to intersection of the cone of silence. As the aircraft flies away from the station, signal strength drops rapidly at first and then slowly until complete fadeout.

g. Automatic Volume Control. Automatic volume control is not suitable for radio range flying.

137. Radio Range Orientation

a. Need. Radio range orientation is an accurate method of obtaining aircraft position in relation to a radio range station by systematically eliminating all conflicting possibilities. It is not necessarily an emergency procedure and should be used at every opportunity in clear weather to develop confidence in its use during inclement weather. Various elements of radio range orientation can be used to advantage whether flying under VFR or IFR conditions.

b. Sources of Radio Range Information. Information required to accomplish radio range orientation is found in the Jeppesen Manual, USAF and USN Pilot's Handbook, and Radio Facility Charts.

c. Obtaining Clearances. After tuning the receiver (par. 134), Air Traffic Control clearance is obtained through the range station to work the orientation. This clearance is mandatory and must be obtained before an orientation is started.

d. Average Bisector. After obtaining clearance to work an orientation problem, the aircraft is turned to the nearest bisector heading of the quadrant being received. Average bisector headings for each range are found in the publications mentioned in *b* above. If these publications are not available, one of the average bisectors may be calculated by adding all four of the range leg bearings (either inbound bearings or outbound bearings may be added but they must not be mixed) and dividing the result by 4. The other three bisectors are found by adding 090° to the result, repeating the addition of 090° for each average bisector. For example, if the inbound bearings of the legs are 130°, 200°, 310°, and 020°, adding these bearings gives 660. Dividing this sum by 4 gives 165°, and sequential adding of 090° gives 255°, 345°, and 435°. Since 435° is more than 360°, subtracting 360° gives 075°. Thus, the average bisectors are 165°, 255°, 345°, and 075°.

e. True-Fade 90° Method. One of the quickest and most accurate methods of identifying an intercepted beam leg is the true-fade 90° method (fig. 101). The instant the last quadrant signal fades and the on-course signal is received, check the time. Stop the timing when the first off-course signal of the other quadrant is identified. If the total time across the leg is 7 seconds or less, use close-in procedure (par. 137*g*). If the time is more than 7 seconds, make a 90° turn to the left immediately upon identifying the first off-course signal. If the on-course is not received within one minute, and a fade of the background signal is noted, the beam on the left of the original quadrant was intercepted (fig. 101). In this case, make a 180° turn to the left which places the aircraft in a position where it will reintercept the beam at a 45° angle (fig. 101), with normal beam-following procedures thereafter to the station. If reentry was made during or after the 90° identifying turn, the right hand beam was intercepted. An immediate turn is made to the right to the published inbound beam heading with normal beam-following procedures thereafter to the station.

f. True-Fade Parallel-Perpendicular Method. To intercept a definite leg of a radio range in order to avoid danger areas, restricted areas,

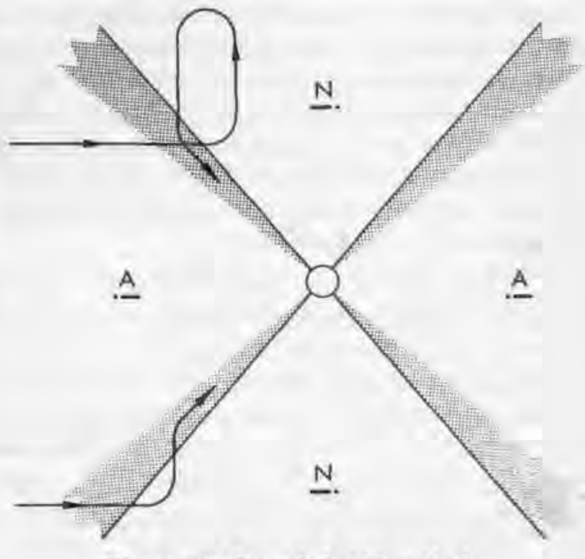


Figure 101. True-fade 90° method.

etc., identify the quadrant, then turning parallel to the undesired leg (or perpendicular to the desired leg). Use this method of orientation (fig. 102) only when the aircraft is near the center of the quadrant, since in flying parallel and near to the undesired leg, strong winds may drift the aircraft into restricted area. Furthermore, this orientation is time consuming and should be used only when the pilot must intercept a certain leg.

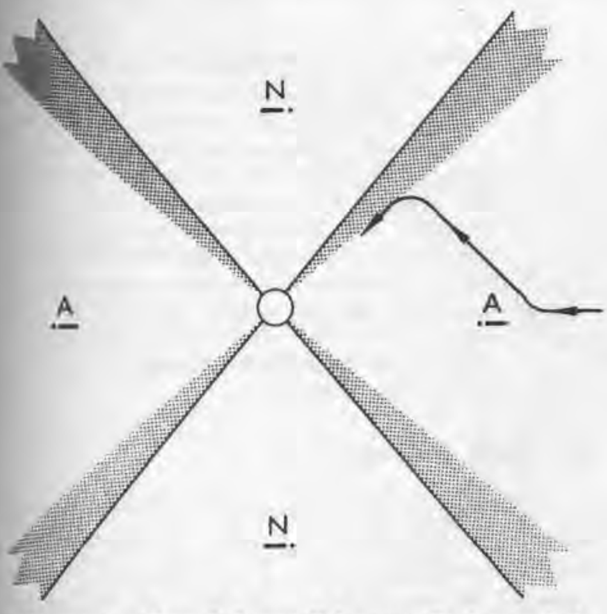


Figure 102. True-fade parallel-perpendicular method.

g. Close-In Procedure. A close-in procedure (fig. 103) is used when the initial interception of a range leg is made too close to the station to permit normal beam following or when there is a rapid change of signals. While flying inbound on the bisector heading, a long time in the clear quadrant and a large number of volume adjustments indicate the interception of the range leg close to the station. Close-in orientation and procedures position the aircraft on the holding leg, being accomplished as follows:

(1) If the aircraft passes through the on-course in seven seconds or less, turn to the published outbound heading of the holding leg.

(2) Fly the aircraft on this heading for a minimum of one minute to determine whether the station has been passed and on which side of the holding leg the aircraft is located.

(3) Adjust the volume for minimum readability and check for a fade or build. If the volume is building, the station is ahead; if it is fading, the station has been passed.

(4) If a fade is noticed, report the time the first beam was crossed as station passage. If a build is noticed, anticipate another beam crossing and report the time it is crossed as station passage also.

(5) The quadrant signal being received when the volume is decreasing determines on which side of the leg the aircraft is located. If the aircraft is on one side of the holding leg and the procedure turn is to be made on the other, turn to the procedure-turn heading; cross the on-course; and start the timing for the procedure turn when the first off-course signal is received. If the aircraft is on the same side of the holding leg on which the procedure turn is to be made, turn 45° toward the beam; hold this heading until the first on-course is received; then turn to the procedure-turn heading.

h. On-Course Orientation. On-course orientation procedures are used when an on-course signal is received by the pilot after proper radio

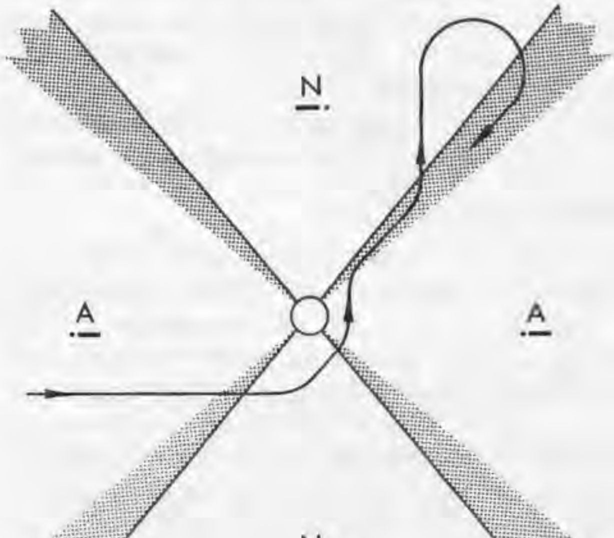


Figure 103. Close-in procedure.

tuning and station identification. In the following procedures, assume the nearest bisector heading ((1) below) is 090°, and using figure 104 as a guide, proceed as follows:

(1) When the on-course signal is received, the aircraft is either at position A, B, C, or D (fig. 104). Turn the aircraft to the bisector heading nearest the original heading of the aircraft.

(2) Continue this heading until the first off-course signal is received.

(3) Identify signal. Considering the heading of the aircraft, two legs of the range (A/B or C/D) will be eliminated since there are only two positions from which the pilot can enter the off-course signal which is being received on the bisector heading being flown (090°).

(4) Make a 90° left turn.

(5) If the on-course signal is received within one minute (B or C), proceed as discussed in (7) and (8) below.

(6) If the on-course signal is not received within one minute, make a 180° turn away from the station (F) or a 270° turn away from the station (G) to intercept the on-course signal.

(7) Turn to the published inbound heading for that range leg. If the turn cannot be executed without overshooting the on-course (E), proceed through the on-course and execute a procedure turn back to the inbound heading of the range leg.

(8) Use normal beam following procedures (par. 139) and proceed to the station.

138. Beam Interception

a. General. Although any angle of interception may be used when intercepting an on-course beam, an angle of 45° is recommended. This angle is large enough to counteract drift, and will permit an expeditious flight path to the station. As the aircraft approaches the on-course beam, the background (monotone) signal will become stronger and the two station identification signals will approach an equal level of intensity. If during the interception, station identification signals are transmitted just as the on-course is entered, a comparison of the intensity of the two signals provides a means for recognizing the on-course. Flying from a clear quadrant signal, through the bisignal zone to the on-course, results in an apparent fade in signal strength because the background signal, a monotone, becomes predominant and is not as audible as the clear quadrant A or N signal.

b. Procedures. Beam interception procedure for both outbound and inbound legs is identical, and is accomplished as follows:

(1) Turn aircraft to intercept the on-course beam at 45°.

(2) Turn aircraft to published beam heading as soon as the on-course is heard.

Note. Width of the on-course is directly proportional to the distance from the station; hence, when more than three minutes from the station, it is not necessary to lead the turn. If less than three minutes from the station, start the turn slightly before receiving the on-course to prevent passing through the beam into the opposite quadrant. Rate of build of the background signal permits an estimate of the approximate lead for the turn to the beam heading.

139. Beam Following

a. After completing the turn to the published beam heading, follow the beam to the station. Beam following is control of the flight path along a course, determined by interpreting the aural signals. If the heading indicator is correct, the only other factor that will cause the aircraft to leave the beam is a crosswind.

b. If the wind is known during the initial interception, turn the aircraft to the beam heading as corrected for the wind. If the wind is unknown, make the turn to the published beam heading and monitor the radio signal closely. Memorize the position of the N and A quadrants relative to the on-course, so that corrective turns can be made in the proper direction as soon as the first off-course signal is identified. As long as the on-course is received, make no change in heading.

c. The first off-course signal indicates drift direction of the aircraft. If the aircraft is to the left of the beam, the wind is from the right; if to the right of the beam, the wind is from the left. When the off-course is identified, proceed as follows:

(1) Make a 20° turn toward the beam.

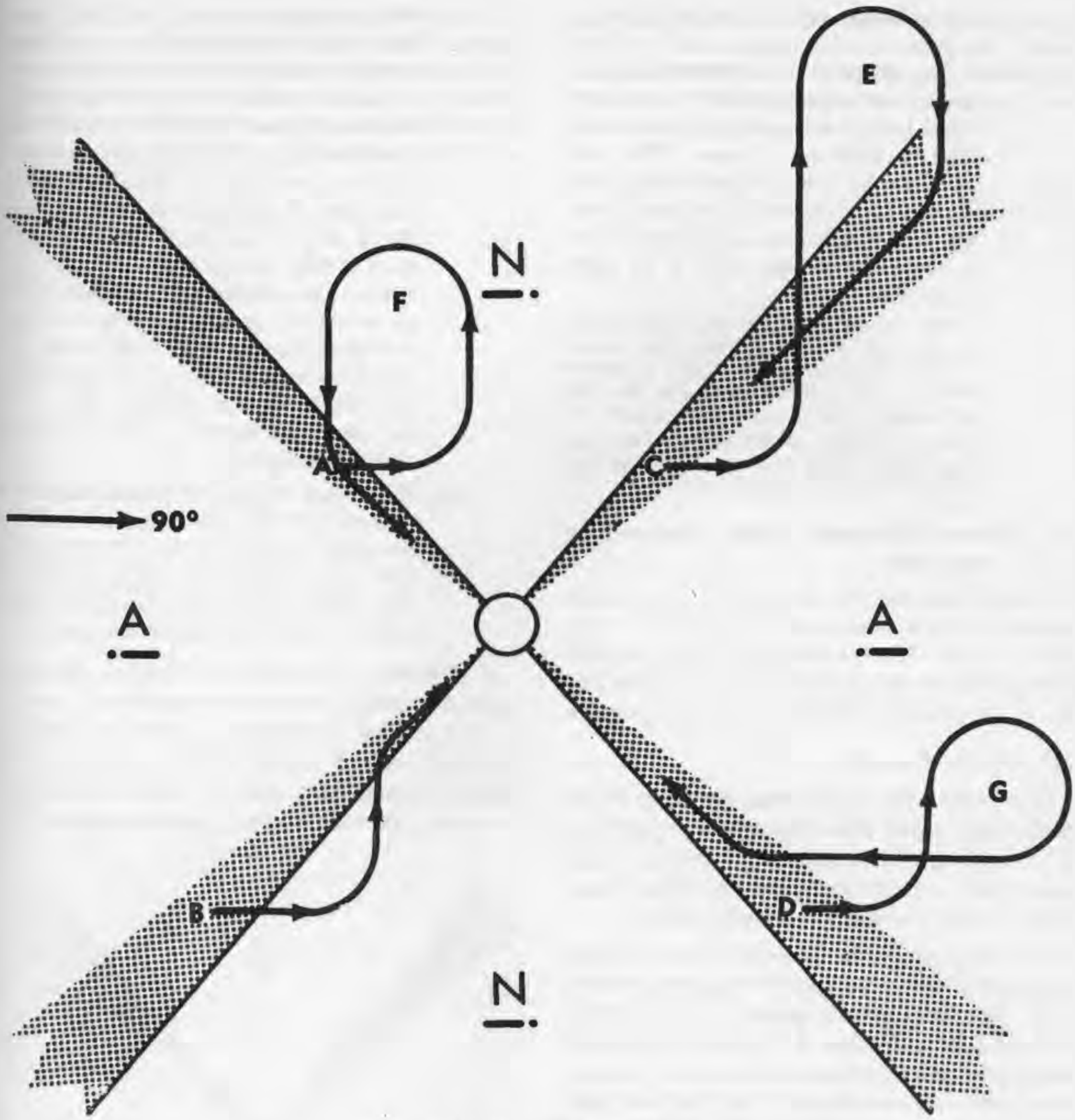


Figure 104. On-course orientation.

(2) When the on-course is reintercepted, make a 10° turn toward the published beam heading. The aircraft is now proceeding toward or away from the station with 10° drift correction.

(3) If the 10° correction is inadequate, turn to the original interception heading ((1) above). Since this heading returned the aircraft to course initially, the same heading should be used to reintercept the desired beam.

(4) When the beam has been reintercepted, turn 5° toward the published beam heading. The aircraft is now proceeding to or from the station with a 15° drift correction.

Note. As the station is approached, the width of the on-course becomes smaller and heading changes of more than 5° should not be made.

(5) If the original 10° correction ((2) above) was excessive, turn to the published beam heading and allow the aircraft to drift onto course. When the on-course has been reintercepted, turn 5° away from the published beam heading. The aircraft is now proceeding to or from the station with a 5° drift correction.

Note. If the initial 20° turn ((1) above) is not enough to reintercept the track, another 20° turn (total correction of 40°) is used to intercept, and a 20° correction is the first trial heading ((2) above). This procedure is commonly known as *bracketing*, and each course interception involves removal of half the turn toward the desired beam.

140. Volume Adjustment When Approaching the Station

During approach to the station, the volume builds and must be controlled to obtain a constant volume. The frequency of volume adjustments indicates the proximity of the station and is a valuable aid in anticipating station passage.

141. Station Passage

In weather which allows clear reception of the radio range signal, little difficulty is experienced in recognizing station passage. However, when atmospheric conditions produce disturbances such as static, recognition becomes difficult.

a. Approaching the Station. Correct interpretation of the aural signals indicates proximity to the station and its passage. The necessity for continual reduction in volume to maintain a comfortable level indicates that station passage can be expected immediately. Just before station passage, the volume builds quickly, dropping off suddenly as the cone of silence is entered and surging as the station is passed, with fade at a rapid rate.

b. Recognizing Station Passage When Off-Course. Although it is desirable to pass through the cone of silence for precision, station passage can be easily recognized when the aircraft is off-course. Recognition occurs when flying through the beam leg right or left of the cone of silence.

(1) For example, in figure 105, the heavy black line shows how the aircraft has drifted off-course to the left just prior to passing the station. At this point, the heading must be held constant or, if necessary, a correction not in excess of 5° may be applied. The signal heard is a clear N without background, and the N will be received until the aircraft enters the on-course of the left beam. The change from a clear N to an on-course is very abrupt with no noticeable bisignal. At this point, the on-course is only a second or two wide, and after passing through the beam the clear A signal of the opposite quadrant is heard.

(2) This rapid change in signal indicates station passage. Drifting across the beam may occur if correction is applied just prior to station passage; therefore, listen for a fade in volume as a definite check on station passage.

c. Utilizing the Station Z-Marker. Another method of recognizing station passage is by use of the station Z-marker. If the aircraft is equipped with a marker beacon receiver, the marker beacon light goes on when the aircraft is within the zone of the Z-marker signal. In

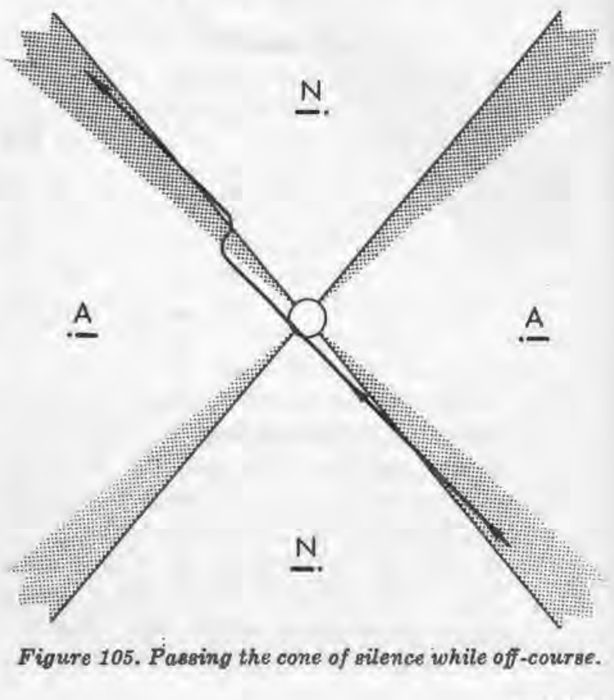


Figure 105. Passing the cone of silence while off-course.

most marker beacon installations, there is also an aural Z-marker signal. This can be recognized by a high-pitched hum, which increases in volume as the aircraft approaches the station. The hum reaches the maximum volume directly over the station and rapidly dissipates upon passing the station. The variable signal pattern width of the marker beacon makes its use impractical for precision navigation or timing; therefore, it is only used as an aid in recognizing station passage.

CHAPTER 13
THE RADIO DIRECTION FINDER

Section I. THEORY

142. General

The radio direction finder is a radio receiver which determines the bearing of the transmitting station to which tuned. The position of the plane of the loop in reference to the station increases or decreases the receiver's ability to receive signals. Army aviation employs two types of direction finders, the manual direction finder (loop) and the automatic direction finder (ADF). With the loop, bearings are taken by manually rotating the loop to an aural null position. Special operating techniques are required in solving for ambiguity. Bearings are more easily taken with the automatic direction finder because no problem of ambiguity is present.

143. Directional and Nondirectional Antennas

A directional antenna is one that conducts radio signals more efficiently in one direction than in others. A single-wire vertical antenna is nondirectional, in that, its efficiency in conducting received or transmitted signals is equal in all directions at the same time. A loop of wire or two single wires suitably connected have important directional characteristics either for conducting transmitted or received radio signals. In this discussion on radio direction finding, only the receiving characteristics of the antenna are considered.

144. The Loop

Directional antennas for direction finding receivers are usually in the form of loops which extract a portion of the signal energy.

a. Maximum Position. In figure 106, the radio waves are passing a loop antenna whose plane is parallel to the radio path. For the instant shown, the crest of the wave is at side A of the loop, and, for example, a charge of +5 mv (0.00005 volts) is induced in this side of the loop. Some time later, the crest of the wave is at side B of the loop and a similar voltage is induced in that side. At a given instant of time, the voltages induced in the two sides of the loop are unequal, resulting in current flow through the receiver (—5, +2 mv). A maximum signal is heard when there is a maximum difference in the induced voltages in the sides of the loop. By rotating the loop 180°, the phase of the receiver signal is inverted but there is no effect on the intensity of the received signal. Thus, there are two maximum positions 180° apart.

b. Minimum or Null Positions. If the loop is rotated 90° from the maximum position (fig. 106), the crest of the wave will pass both sides of the loop at the same time. No current will pass through the receiver since equal voltages are induced in both sides of the loop simultaneously. This is called a *null* (minimum signal) position. There are two null positions 180° apart.

c. Response Pattern. The figure-eight response pattern of a loop receiving antenna is identical to that of the loop-type low frequency radio range antenna (fig. 99). In figure 107, signals received from transmitters 1, 2, and 3 are of equal strength. The loop antenna is positioned to maximum position for transmitter 1, approximately null position for transmitter 3, and between the maximum and null positions for transmitter 2.

d. Use of Null Position. More accurate bearings are obtained by use of the null (minimum) rather than the maximum signal. Rotating the loop 3° or 4° from the null position may have as much effect on volume change as 20° or 30° of rotation from the maximum position.

e. Ambiguity. Consider a loop in null position, or position of minimum signal volume, when its plane is perpendicular to the longitudinal axis

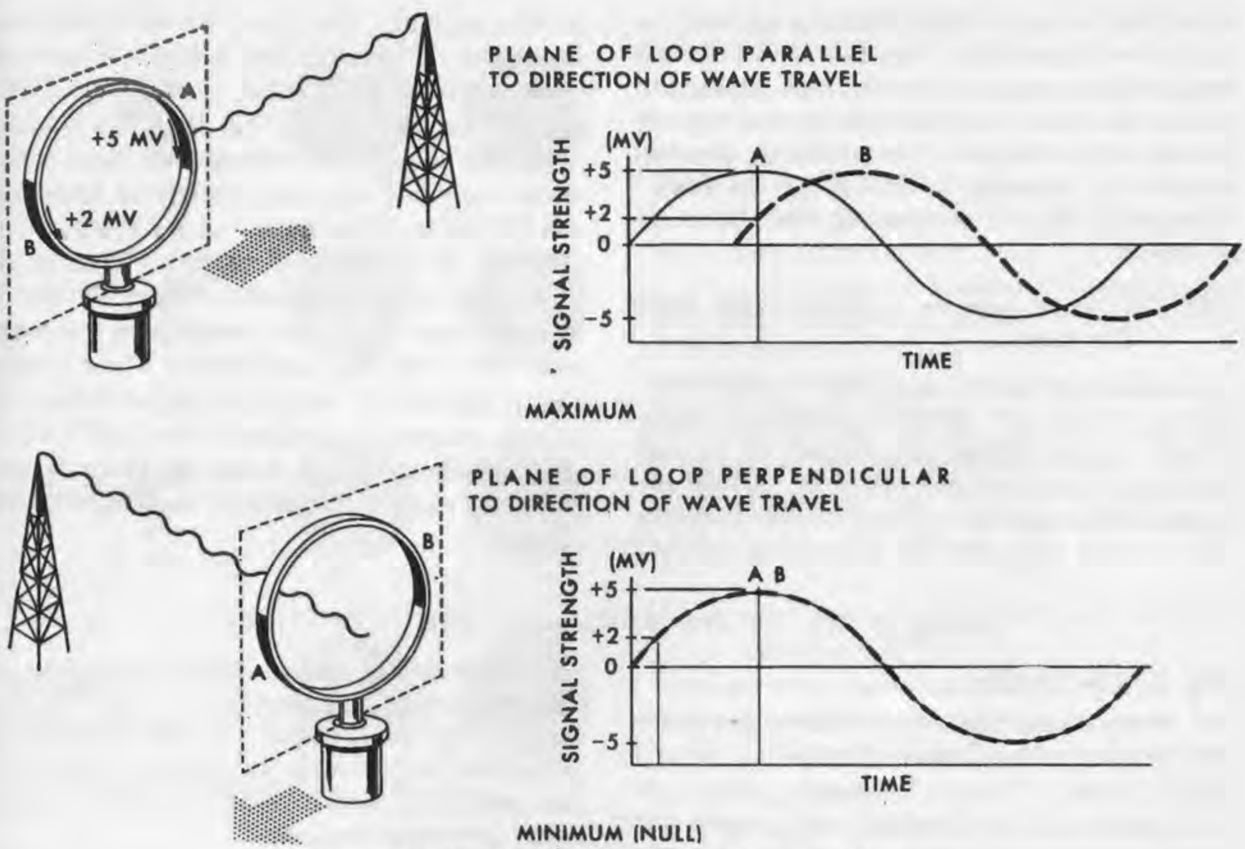


Figure 106. The loop, maximum and minimum positions.

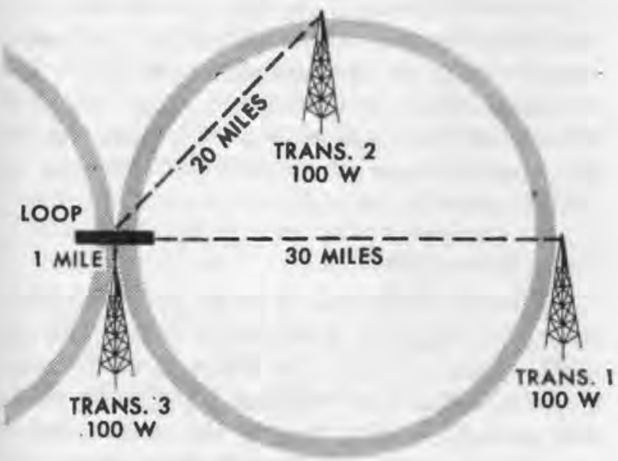


Figure 107. Loop response pattern.

of the aircraft. Because of two null positions, the transmitter may be ahead of or behind the aircraft. This is called *ambiguity*. In like manner, a loop indicating a null when its plane is parallel to the longitudinal axis of the aircraft indicates that the transmitting station is either to the right or left. Ordinarily, the bearing of the

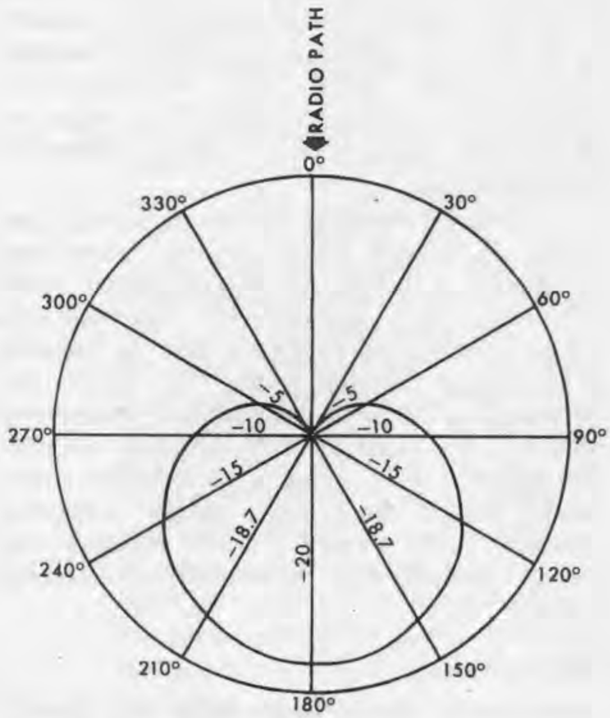


Figure 108. Cardioid pattern.

transmitter is known with sufficient accuracy to resolve the uncertainty, but this is not always true. When using a wingtip null, ambiguity can be determined by noting whether the relative bearing of the station is increasing or decreasing. If it is increasing (090°–100°), the station is on the right; if decreasing, the station is on the left.

145. The Sense Antenna in Combination With The Loop

Automatic resolving of ambiguity (determining the sense of the incoming signal) is accomplished by combining the output of a loop antenna with that of a single-wire vertical antenna (sense antenna). The directional pattern of a vertical wire antenna is a circle centered on the antenna. The phase is the same in all directions. If the combined outputs of loop and sense antenna are plotted, a cardioid (heart-shaped) pattern results (fig. 108). Comparison of figures 99 and 108 reveal two main differences—only one minimum appears in figure 108, and the single minimum or null is 90° away from those of the simple loop pattern. That is, the single null is now in the direction of the station transmitting. It is 180° away from the maximum and there is no ambiguity. These convenient properties of a combined signal make possible an automatic direction finder (ADF) which continuously shows, on a dial, the relative bearing of a radio transmitting station to which tuned.

Section II. USE OF THE AUTOMATIC DIRECTION FINDER

146. Usable Stations

a. Frequencies. The automatic direction finder can be tuned to any frequency between 100 and 1,750 kilocycles. Station frequencies, types, and power output of low frequency radio ranges and homing stations are contained in the Jeppesen Manual and the Radio Facility Chart. Supplementary Flight Information and CAA Flight Information Manual contain information relative to the hours of operation, geographical location, frequency, and power output of commercial broadcasting stations. To obtain maximum use of the radio compass refer to these publications for information.

b. Choice of Stations. Whenever possible, use either an Adcock range station, commercial broadcasting station, or nondirectional radio beacon for radio compass work. The loop type range is undesirable because it does not transmit a continuous carrier wave. The main disadvantage of using a commercial broadcasting station is the inability to immediately identify the station. When using a commercial broadcasting station, use a "clear channel" station if possible. Low-powered "local" stations are closely grouped and interference is common between them.

147. Tuning

Inaccurate tuning may cause the azimuth needle to fluctuate, making accurate bearings impossible. When the equipment is used for direction finding, it is essential to tune for maximum tuning meter deflection. This is especially important when using an Adcock range since the continuous carrier wave is 1.02 kilocycles below the range frequency.

148. Orientation (Relative Bearing)

Relative bearing is the angle measured clockwise from the nose of the aircraft to the station and is read on the azimuth indicator. The relative bearing of a station straight ahead of the aircraft is 0°, directly off the right wingtip 90°, straight back of the tail 180°, directly off the left wingtip 270°, etc.

149. Homing (ADF)

Radio compass homing is flying the aircraft on any heading that is necessary to keep the azimuth needle of the radio compass on 0° until the station has been reached. Figure 109 shows this procedure. The face of the radio compass indicator is graduated through 360°, the 0° and 180° graduation being the longitudinal axis of the aircraft.

a. Initial Turn. To head the aircraft toward the station, make a turn that will zero the azimuth needle of the radio compass. In making this turn, use the heading indicator (not the radio compass) to determine where to end the turn. (The radio compass has dip error during

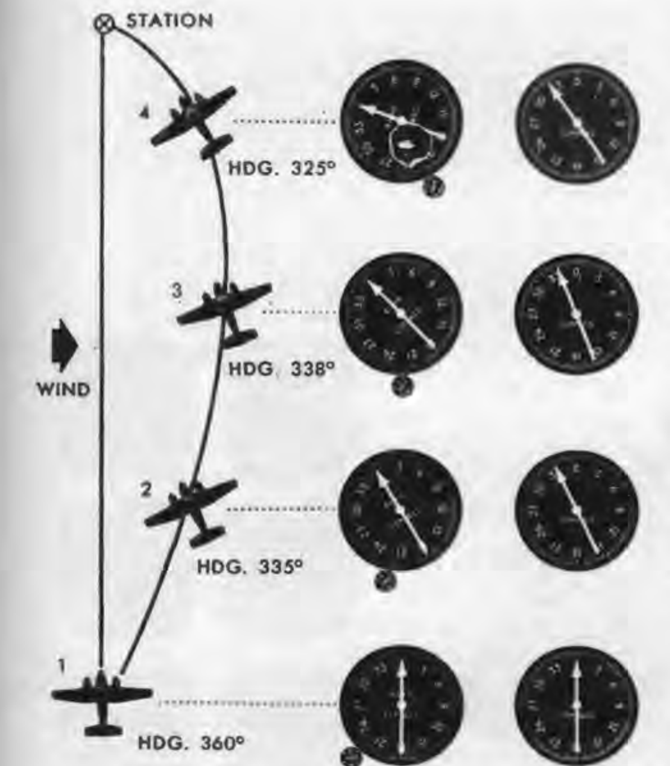


Figure 109. Radio compass homing.

a turn and can be relied upon only in straight and level flight.) To decide what the heading indicator should read at the completion of the turn, first check the radio compass to find how many degrees left or right of zero it indicates, then add or subtract (subtract with station to the left; add with it to the right) to the reading of the heading indicator. For example, if the radio compass reads 335°, and the heading indicator reads 090°, it would be necessary to turn to a heading of 065°. (335° is 25° to the left of 360° (straight ahead)). Since the station is to the left, this 25° is subtracted from the original 090° heading. After the initial turn is made, check the azimuth indicator to be sure it is zeroed.

b. Maintaining Zero on the Azimuth Needle. After the azimuth needle is zeroed, it will remain so unless the heading is changed or wind is affecting the track of the aircraft. While homing, if there is no wind, the aircraft will follow a straight track to the station. If a crosswind is drifting the aircraft, the homing track will be a curve that eventually ends over the station headed straight into the wind. In homing, wind is not taken into consideration; the azimuth is maintained on zero until station passage.

c. Approaching the Station. As the station is approached, it is almost impossible to keep the azimuth needle zeroed. Slight changes in heading move the needle to the side opposite the turn. If tuned in on a low frequency range station, a surge in volume is noticed as the station is approached, despite automatic volume control. Only slight changes in heading should be made at this point.

d. Passing the Station. As mentioned in *c* above, the azimuth needle will vary from side to side when approaching the station. Just as the station is passed, the azimuth needle will swing to 180°. This is a definite indication of station passage.

150. Interception of Predetermined Magnetic Bearings (ADF)

To accelerate the movement of air traffic, ATC may issue a clearance to track into or away from a radio facility on a definite magnetic bearing.

a. Intercepting a Magnetic Bearing Inbound. To intercept a magnetic bearing inbound (A, fig. 110) proceed as follows:

(1) Determine position of the aircraft in relation to the station by turning the aircraft to the magnetic heading of the bearing to be intercepted (1, A, fig. 110).

(2) Determine whether the station and the desired magnetic bearing are to the left or right of the aircraft. If the needle is left of the 0° position of the azimuth scale, the station and the desired bearing are to the left of the aircraft's position, and vice versa.

(3) Note the number of degrees the needle is deflected from 0° position. Double this amount (this is the angle of interception) and turn the aircraft this number of degrees toward the desired magnetic bearing (2, A, fig. 110).

(4) Fly the aircraft on this new heading until the azimuth needle is deflected the same number of degrees from the 0° position as the angle of interception (3, A, fig. 110).

(5) When this reading has been obtained,

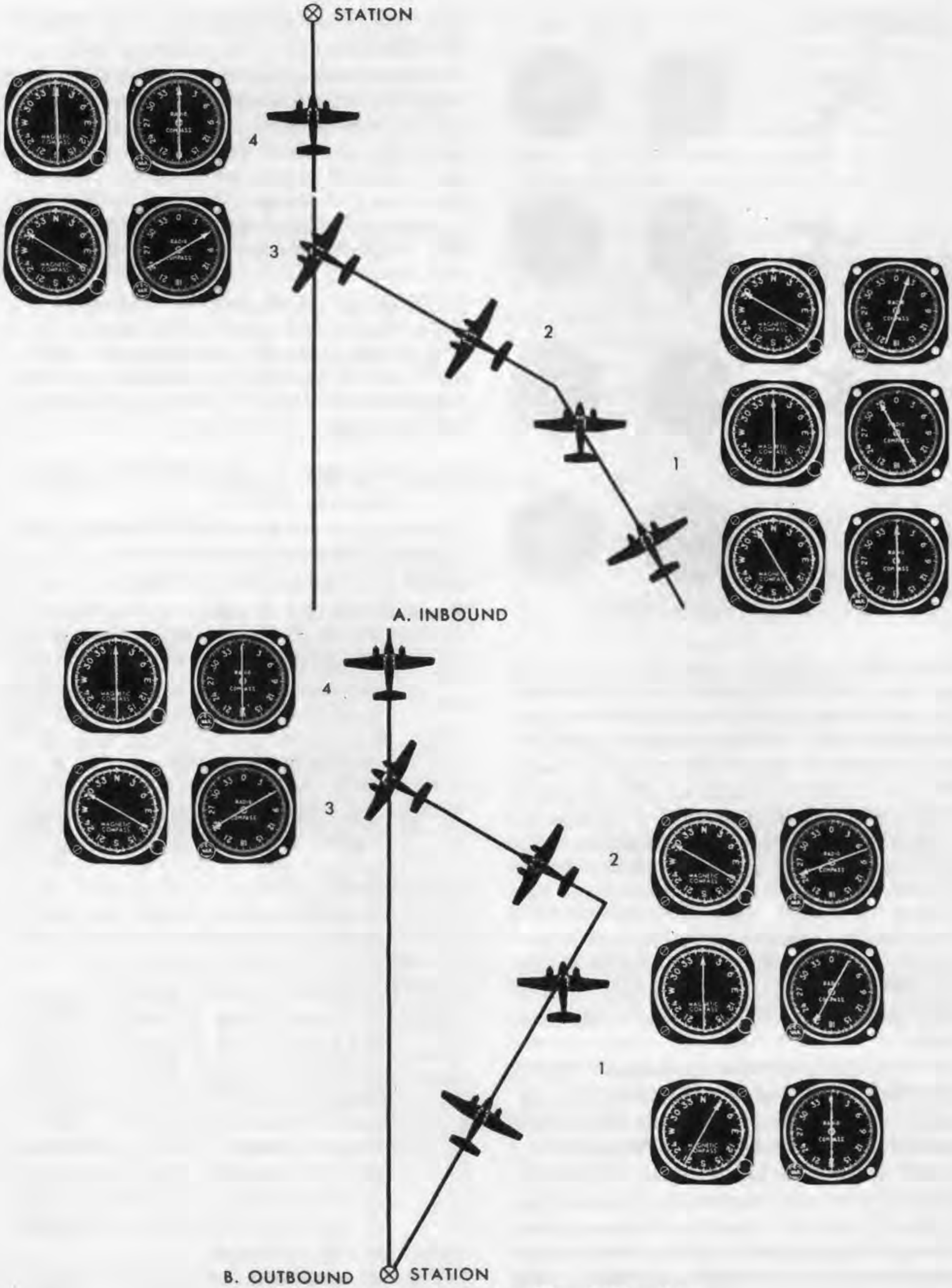


Figure 110. Interception of predetermined bearings.

the aircraft has intercepted the desired bearing. Turn to the desired heading (4, A, fig. 110) and begin normal tracking procedures (par. 159).

b. Intercepting a Magnetic Bearing Outbound. Procedures for interception of a magnetic bearing outbound (B, fig. 110) are identical to those used in intercepting bearings inbound (A, fig. 110); however, the 180° position of the azimuth scale on the radio compass is used instead of the 0° position. Compute the angle of interception by doubling the number of degrees of deflection from the 180° position. The direction of the station and the desired bearing are indicated by left or right deflection of the needle from the 180° position.

c. Magnitude of Interception Angle. The angle of interception should never be less than 20° nor more than 90°. When intercepting a desired course, start the turn before intercepting the course; otherwise, the radius of the turn will carry the aircraft past the desired course. The necessary number of degrees of lead will depend on true airspeed, existing wind, distance from the station, and rate of turn. Use the greatest amount of lead when intercepting bearings at an angle of 90°. For any angle of interception, and any distance from the station, approximate the number of degrees of lead to use by interpreting the rate at which the azimuth needle is approaching the desired indication.

151. Tracking Procedures (ADF)

a. Purpose. Air traffic control (ATC) instructions, terrain, or restricted areas may make it necessary or advisable to maintain a definite geographical flight path. The maintenance of such a flight path is known as *tracking*. *Desired track* is synonymous with *desired magnetic bearing*. During tracking, the position of the aircraft, in relation to the desired track, is indicated visually by the azimuth needle of the radio compass. The problem in tracking is to establish a heading that will keep the aircraft on the desired track regardless of wind speed or direction. Precision instrument flight is necessary. Any deviation in heading will cause an equal deviation in the reading of the radio compass azimuth needle; therefore, any change noted by the azimuth needle will require an immediate check of the heading indicator to determine if the change is in heading. Headings must be maintained.

b. Tracking Inbound. To track inbound to a station, turn the aircraft to the desired inbound heading and proceed as follows:

(1) Turn aircraft until azimuth needle of radio compass is zeroed (1, A, fig. 111). Maintain this heading until aircraft has drifted off-course, as determined by left or right deflection of the azimuth needle from zero.

(2) When a distinct change in azimuth indication (5°) is observed (2, A, fig. 111), make a 20° turn in the direction of needle deflection (3, A, fig. 111).

Note. Utilize the directional gyro (heading indicator) or magnetic compass in making *all* turns. Start the turn to the magnetic heading of the desired track before reaching the track. The amount of lead will depend on station distance, existing wind, number of degrees to be turned, true airspeed, and rate of turn.

(3) When azimuth needle is deflected 20° (from zero) (4, A, fig. 111), the desired track has been reintercepted. Make a 10° turn toward desired heading (5, A, fig. 111). The aircraft is now proceeding toward the station with a 10° correction for wind.

(4) If aircraft drifts off course in the original direction (6, A, fig. 111), turn to the original interception heading (7, A, fig. 111).

Note. Since this heading returned the aircraft to course initially, the same heading should be used to reintercept the track.

(5) When the desired course has been reintercepted (8, A, fig. 111), turn 5° toward the desired heading (9, A, fig. 111) and proceed toward the station with a 15° correction for wind.

Note. When close to the station, correction of more than 5° may result in overshooting the track.

(6) If the 10° correction in (3) above, is excessive, parallel the desired course and allow the aircraft to drift onto course. When the course is reintercepted, turn 5° away from the desired course and proceed toward the station with a 5° correction.

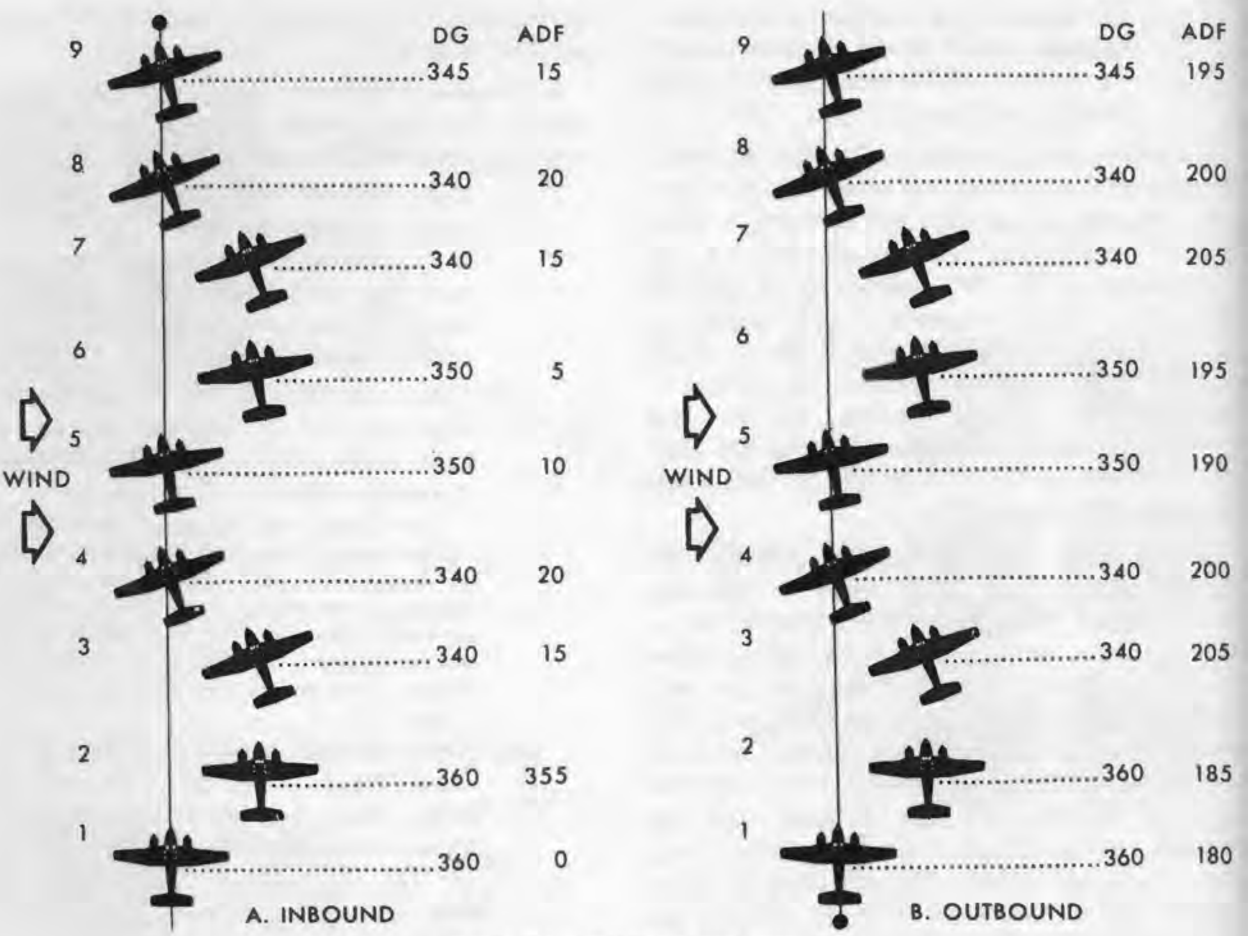


Figure 111. Tracking procedures.

Note. If the initial 20° turn is not enough to reintercept the track, another 20° turn (total correction of 40°) is used to intercept, with a 20° correction as the first trial heading. This procedure is commonly known as bracketing; each course interception involves removal of half the turn toward the desired track.

c. Tracking Outbound. Procedures for tracking away from a station (B, fig. 111) are identical to inbound tracking procedures discussed in *b*, above. However, the reaction of the radio compass azimuth needle is different. When inbound to a station, a turn toward the desired track causes the needle to move toward 0° on the azimuth scale. When flying *away* from the station, a turn in the direction of displacement causes the azimuth needle to be deflected *farther* from the 180° position. The pilot must visualize the 0° to 180° line on the azimuth scale as the longitudinal axis of the aircraft, and use the 180° position instead of the 0° position.

Section III. MANUALLY OPERATED DIRECTION FINDER

152. General

The manually operated direction finder is a forerunner of the automatic direction finder. Some of these are part of the automatic direction finder and use the same radio compass for indications; others have only a manually operated dial for relative bearing indications. Often, in bad weather, it is impossible to use the automatic direction finder because of static effect on the radio compass. Under this condition, only the aural null of the manually operated direction finder can be relied upon.

153. Aural Null Procedures

An aural null (minimum reception) results when the plane of the loop is perpendicular to a line from the station. Navigation procedures are the same as when using ADF; however, the azimuth needle is positioned manually to locate the null by sound.

154. Width of Null

The width of the null is controlled by volume. An increase in volume narrows the null; a decrease in volume widens the null. A null width of approximately 5° is satisfactory for aural null work. At great distances, the width of the null is increased even though maximum volume is used. Regardless of width, the center of the null provides a reasonable bearing to the station. Under static conditions, the center of the null may be more easily recognized by decreasing the volume.

155. Resolving Ambiguity

If an aural null is obtained when the azimuth indicator reads zero, the station may be ahead or to the rear of the aircraft. The same is the case when the azimuth indicator reads 180°. If the azimuth indicator is set at 090°, the station could be off of either wingtip. This is called 180° ambiguity. In homing or direction finding, it is necessary to determine this ambiguity. To solve 180° ambiguity, refer to figure 112 and proceed as follows:

a. Rotate the loop to either 090° or 270°.

b. Turn the aircraft until an aural null is received.

c. Maintain the aural null by rotating the azimuth indicator as necessary while holding the heading obtained in *b* above.

d. If the azimuth indicator shows an increase while maintaining the null, the station is to the right; if it shows a decrease, it is to the left.

156. Homing (Loop)

Homing to the station by use of the loop antenna is accomplished by changing the heading of the aircraft to keep the null on zero. As the station is approached, the width of the null decreases, requiring constant decreases in volume to maintain a null width of 5°. Recheck the width of the null after each change in volume.

157. Station Passage (Loop)

There are four definite indications of station passage—three on the nose position (used for initial station passage), and the fourth on the wingtip position. Station passage from the nose position can be recognized by any one of the following indications:

a. Constant narrowing of the null followed by a definite widening indicates station passage. Station recognition is necessary when the air-

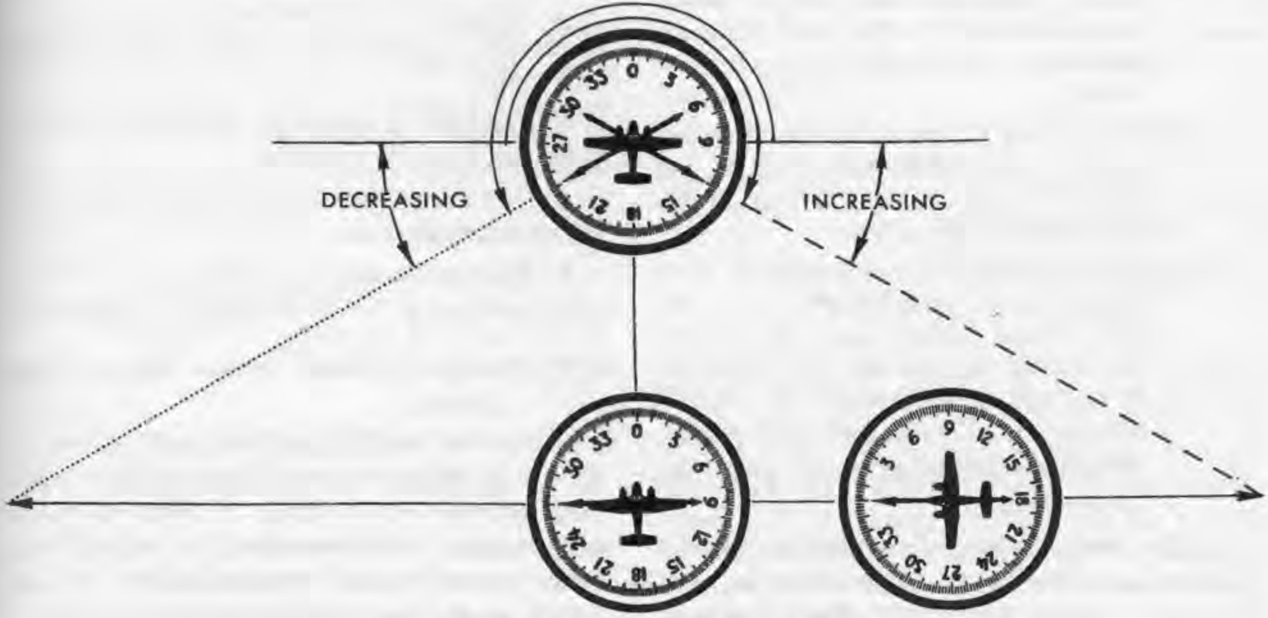


Figure 112. Solving 180° ambiguity.

craft passes directly over the station. Here, the null may disappear and reappear quickly. In this case, look for an immediate widening of the null. In static or during a change in heading, the disappearance of the null is not necessarily an indication of station passage unless the null becomes wider immediately. If the volume has not changed, the widening of the null indicates the aircraft is going away from the station.

b. A rapid movement of the null away from the nose position indicates station passage. When the aircraft passes to either side of the station, with a constant magnetic heading, station passage can be recognized by a rapid movement of the null away from the nose position. (It is impossible to follow the null completely around to the 180° position.)

c. Station passage can be recognized by an apparent shifting of the null from one side of the nose position to the other when the aircraft passes very close to but not directly over the station. In this case, the null stays slightly to one side of nose position and then disappears. If the null reappears quickly on the opposite side, without a change in heading, the station has been passed.

d. In summarizing recognition of station passage from nose position nulls, the best indications are—

(1) The rapidity with which the volume must be reduced to maintain a constant null width of 5°. The null must be monitored constantly when near the station.

(2) When using a commercial broadcasting station or an Adcock range station, the voice or range signals become audible above the carrier wave.

(3) When atmospheric conditions or other interferences make recognition of station passage difficult, turn the aircraft 30° to the right of the track heading. If the null moves toward the zero indication, the station has been passed. Should the null move farther away, the station is ahead.

e. The fourth method of recognizing station passage (azimuth needle to the wingtip position) may be used after initial station passage. The use of this method is possible after initial station passage because it is easy to approximate the time to the station. To accomplish this method, proceed as follows:

(1) Move the azimuth needle to the wingtip position when approximately one minute from the station; then adjust the volume to a normal level. Continue to adjust the volume so as to maintain this level. A definite null will be noticed when the station is passed.

(2) As the station is approached, a constant increase in volume indicates proximity to the station. If an aural signal or voice is being transmitted, either may become audible above the carrier wave.

158. Tracking (Loop)

Aural-null tracking procedures are identical to those used for ADF tracking (par. 151). When the null has moved 5°, turn toward the desired track. If the null moves to the left, the aircraft is drifting to the right of course. Turn to the left to get back on track. When the null moves from the nose or tail position the same number of degrees as the angle of interception, the aircraft is on track. During tracking, follow the null at all times except when making a change in heading. For example, when the aircraft drifts off course and a 20° correction is made to reintercept the track—

a. Turn 20°, using the heading indicator, to intercept the track; then relocate the null immediately.

b. Continue to follow the null until it is 20° from the 0° or 180° position.

c. Turn back toward the original heading 10° and relocate the null.

d. Make additional corrections of 5° if original correction of 10° is excessive or inadequate.

159. Position of Loop While Flying Range Signals

If there is a radio range facility at destination, aural-null procedures with the loop as an auxilliary antenna may be used. If using an Adcock range station, either aural-null or normal radio range procedures may be accomplished. If using a loop range, aural-null procedures are not as accurate because the loop range does not transmit a continuous carrier wave. When using the loop antenna for aural reception of a loop range, have the plane of the loop alined with the station and follow normal radio range procedures. With plane of the loop alined in this manner, the on-course, and the A and N signals can be readily recognized. When using an Adcock station, if the plane of the loop is alined with the station, normal radio range procedures are used; if the plane of the loop is perpendicular to the station, aural-null procedures are used.

160. Radio Bearings, Lines of Position, and Fixes

a. Radio bearings and lines of position are used to determine a *fix*. A fix is a fairly accurate determination of the position of an aircraft. To resolve a fix, use two or more stations that have a large angular difference relative to the aircraft. For example, if one station is at a relative bearing (par. 148) of 315° and another station at a relative bearing of 045°, these lines would form a 90° angle at the aircraft. Any angle can be used, but the closer this angle is to 90° the more accurate is the fix.

b. The formula for solving the bearing of a station is—

$$MH + RB = MB$$

in which *MH* is the magnetic heading of the aircraft; *RB* is the relative bearing; and *MB* the magnetic bearing to the station. If it is desirable to find the true bearing instead of the magnetic bearing of the station, change the formula to—

$$TH + RB = TB$$

in which *TH* is the true heading, and *TB* is the true bearing to the station. If 180° is added to a bearing, it becomes a *line of position* (direction from the station to the aircraft). When two or more lines of position are determined, and lines drawn from their respective stations, a fix is established at the point where the lines cross.

161. Time-Distance Calculations

a. Computation of Time to the Station. To compute the time to the station, proceed as follows:

(1) Turn aircraft until the azimuth indicator shows a relative bearing of 090° or 270°.

(2) Note the time and fly a constant magnetic heading.

(3) Note the elapsed time required for the azimuth to change a predetermined number of degrees (5°, 10°, or 20°).

(4) The amount of change flown should be regulated according to the amount of time necessary to obtain a definite change. For example, a 20° change requires too much time when quite a distance from the station.

(5) Apply the formula—

$$\text{Time to station} = \frac{60 \times \text{minutes flown between bearings}}{\text{Degrees change in bearing}}$$

b. Problem. An aircraft is flying on a magnetic heading of 090° at a true airspeed of 100 knots, and the pilot finds a station to have a relative bearing of 90°. He flies the same magnetic heading and after 10 minutes have elapsed, the station is at a relative bearing of 100°. To calculate time to the station, he uses the above formula.

$$\frac{60 \times 10}{10} = 60 \text{ minutes to the station.}$$

c. To compute distance in miles from the station, use the following formula:

$$\text{Distance from station} = \frac{\text{True airspeed} \times \text{minutes flown}}{\text{Degrees change in bearing}}$$

d. In problem *b* above, the distance to the station is—

$$\frac{100 \times 10}{10} = 100 \text{ nautical miles.}$$

e. To save time, it is often desirable to take a bearing on a station ahead of the aircraft and calculate time or distance to the station instead of using a wingtip null. To accomplish this, proceed as follows:

(1) Tune in a station that is between 10° and 45° off the nose.

(2) Fly a constant magnetic heading until the angle from the nose doubles.

(3) The time or distance required to double the angle on the nose is equal to the time or distance to the station.

f. Problem. A pilot is flying on a magnetic heading of 270°, and tunes in a station that has a relative bearing of 330°. He knows that this station is 30° off the nose on the left. He holds the same magnetic heading until the relative bearing of the station is 300°. He has doubled the angle on the nose from 30° to 60°. He knows that the time or distance to the station is equivalent to the time or distance flown.

162. Factor Affecting Accuracy of Radio Bearings

a. Quadrantal Error. Quadrantal error is caused by radio waves striking the aircraft. When incoming radio waves strike an aircraft, a number of reradiated fields are created around the metallic portions of the aircraft. These fields bend the radio waves prior to their reception by the loop antenna. Thus, all bearings are in error by the amount of this deflection. Quadrantal error is at a maximum when the radio waves cross the wings or stabilizer surfaces before striking the loop; that is, when the relative bearing is 045°, 135°, 225°, or 315°. In the automatic radio compass, quadrantal error is removed by a compensator installed at the base of the loop. Even after the error has been removed, however, bearings taken fore and aft or directly to the side tend to be more reliable than bearings taken over the wings or stablizer.

b. Determining Quadrantal Error. When flying across the beam of a radio range, a simple check on the compensation of the loop can be made. To accomplish such a check, proceed as follows:

(1) With the magnetic heading of the aircraft set at the index of the azimuth indicator, turn the function switch to "Comp."

(2) Compare the magnetic bearing indicated by the azimuth pointer with the published magnetic bearing of the range leg. The two bearings should be the same. If they are not the same, the difference is quadrantal error (fig. 113).

c. Shoreline Effect. As radio waves transmitted from land cross a shoreline, their direction of travel often changes. This is known as shoreline effect. Shoreline effect is present in a radio compass bearing which is taken on an inland station from an aircraft flying over water, provided the bearing crosses the shoreline at an angle of less than 30°. When the crossing angle is greater than 30°, bending is negligible. Therefore, when taking bearings over water, choose either stations located on the shore, such as marine stations, or stations so located with respect to the aircraft that bearings on them cross the shoreline at angles greater than 30°.

d. Mountain Effect. The reflection of radio

Figure 113. Quadrantal error.

waves from mountains, like their reflection from the ionosphere, causes fluctuation in bearings. Furthermore, mountain effect often causes the actual splitting or bending of radio waves. The splitting of beams caused by mountains is known as *multiple effect.*

Section V. DF STEER

163. VHF/DF Steers

A wide network of VHF/DF direction finding stations exists in this country and overseas. These stations operate on frequencies of from 100 to 156 megacycles. When all navigational radio gear is inoperative or the pilot is lost, the DF steer offers the only certain means of bringing the aircraft within visual or GCA range of an airfield.

a. VHF/DF stations provide steers for all aircraft on selected VHF channels. Equipment is available for operation during normal working hours at most stations and on 5-minute notice at all other times. This equipment has an effective range of approximately 100 miles "line of sight," although greater distances can be obtained when the signal strength of the aircraft's radio transmitter and its altitude are ideal. The Guard Channel (121.5 mc) is the emergency frequency. When an emergency exists, say so in your transmission. If no emergency exists, request a practice VHF/DF steer.

b. The following is typical VHF/DF homing procedure:

(1) Tune in on VHF/DF frequency.

(2) Transmit (for example), "Ozark DF, this is Army 5088, request practice steer (or emergency steer) over."

(3) VHF/DF station replies, "Army 5088, this is Ozark DF, transmit for steer, over."

(4) Pilot replies, "Ozark DF, this is Army 5088." (Pilot then depresses tone button on VHF box for 20 seconds. If aircraft is not equipped with tone button, a 5- to 10-second voice signal (ah-h-h-h), or counting from 1 to 5 and back, is transmitted, with volume remaining as constant as possible.) "Over."

(5) VHF/DF station replies, "Army 5088, this is Ozark DF, steer 180 for Ozark, over."

(6) Pilot acknowledges, "Ozark DF, this is Army 5088, my steer is 180, out."

c. Every few minutes from then on, the controlling facility will request transmission from the pilot and give correct steers until aircraft is within sight of field, oriented, or a GCA unit picks it up on scope and guides it to a safe landing.

CHAPTER 14
OMNIDIRECTIONAL RADIO RANGE SYSTEM

164. Visual Omnidirectional Range

The VHF omnidirectional ranges (VOR) increase the number of available airways' courses. The omnisystem could be likened to the standard low frequency range if there were but one leg bearing under the control of the pilot and if the on-course indication were given visually by the vertical needle of the deviation indicator. In the omnisystem, the pilot sets up any track he desires by means of his course selector and flies that track by reference to the deviation indicator. The VOR is a VHF facility which eliminates atmospheric static and multiple courses; it enables the pilot and the traffic controller to use any of 360 courses *to* or *from* a range station. The magnetic courses FROM the station are known as *radials*.

165. VOR Transmitter

a. Frequency and Power. Omniranges operate on a frequency band of from 112 to 118 megacycles and have a power output of approximately 200 watts. Lower power omniranges known as TVOR (terminal omnirange) and LVOR (low-power omnirange) have a frequency of between 108 and 112 megacycles using only the even decimals of the frequency band (111.4, 111.6, etc.). TVOR is a low-powered (50 watt) omnirange intended primarily for installation in terminal areas, on or adjacent to an airport, to provide navigational guidance to aircraft during approach and letdown to the airport. LVOR is essentially the same as a TVOR and is intended primarily for installation in enroute areas to supplement the navigation aid service provided by the VOR system. The LVOR serves as a "gap filler" in the VOR system.

b. Reference and Variable Signals. The transmission principle of the omnirange is based on the creation of a phase difference between two radiated audio frequency signals. Magnetic north is used as the baseline for measuring the phase relationship. Of the two signals transmitted, one is directional and has a constant phase throughout its 360° of azimuth. It is the *reference* phase and is radiated from the center antenna of a five-element group. The second signal is a rotating signal with a speed of 1,800 revolutions per minute. It is called the *variable* phase and is radiated from four stationary antennas, which are connected in pairs to a motor driven goniometer, or inductor. As the goniometer revolves, the radio frequency voltage fed to each pair of antennas varies sinusoidally at the rate of 30 cycles per second to produce the rotating field. The two signals are initially alined exactly in phase at magnetic north and out of phase in all other directions. This difference in phasing is electronically translated by the omnireceiver as azimuth angle from magnetic north.

c. VOR Irregularities (Tolerances). Minor irregularities in VOR facilities consist of course shifting, and may be slightly affected by the altitude of the aircraft. Slow movement of the deviation needle is called *course bends*, while fast deviations of the needle are referred to as *course scalloping*. Pilots flying over unfamiliar routes should be on the alert for these inaccuracies. The Jeppesen Manual gives valuable information concerning the defects of stations. The radials of a VOR transmitter are monitored on magnetic north and magnetic south, and the allowable tolerance for shift is 1½°. Radials published as usable will not be displaced more than 3½° from the theoretical location of the radial.

166. Receiver Equipment (VOR)

The receiver measures the phase relationship between variable and reference signals and gives a visual indication of the direction of the aircraft in relation to the omnistation. For example, if the received signals are in phase, the visual indications show the aircraft on the 360° radial or on a bearing of magnetic north from the station. Desired directional information for any position around the station is obtained since the phase difference is constant for any direction from the station. In addition, the receiver incorporates circuits which indicate whether the direction for a given radial is *to* or *from* a station. The omnirange receiver indicates the aircraft's position with reference to the station.

a. Instrumentation. Navigation circuits connect to a frequency selector, a manually operated course selector, a deviation indicator (localizer pointer of the ILS indicator), and a special device known as a sense indicator (TO-FROM indicator).

(1) *Frequency selector.* The frequency selector allows the pilot to tune the receiver to any one of 280 channels in a frequency range of 108 to 136 megacycles. This frequency range covers all of the ILS, VAR, VOR and many VHF aeronautical communication channels.

(2) *Course selector.* The course selector is manually operated and can be adjusted to phase in any radial of a range as desired.

(3) *Deviation indicator.* The deviation indicator is composed of a dial and a vertical needle. It will center when the aircraft is directly on the radial to which the course selector is adjusted. A full swing from center to one side of the dial indicates an off-course of 10°. The deviation indicator retracts an OFF flag when a usable signal is being received and shows the flag when the signal is not reliable. Fluctuation of the flag indicates a weak signal; the signal will become stronger as the station is approached.

(4) *Sense indicator.* The sense indicator is seen as a window in the face of the course selector and provides TO-FROM indications.

b. Communications Capabilities. The VOR receiver can be used for normal voice communications throughout its full frequency coverage in addition to the navigational frequencies.

c. Tuning. After the omnireceiver is turned on and allowed to warm, turn the frequency selector to the desired frequency and carefully retune until the flag retracts. Reidentify the station to be sure that the desired station is tuned.

d. Reading the Deviation Indicator. To simplify reading the deviation indicator, have the TO-FROM indicator read TO when headed *toward* the station and FROM when headed *away from* the station. When the TO-FROM indicator reads in this manner, the deviation indicator is directional. If the course set on the course selector is to the right, the deviation indicator will point to the right; if to the left, it will point left. If the desired reading is not on the TO-FROM indicator, the course selector is turned 180° to get the correct reading. If the course selector is set so as to have a FROM indication when headed *toward* the station or set to TO when headed *away from* the station, the deviation indicator will point to the left when the course is to the right and to the right when the course is to the left.

e. Checking the Deviation Indicator. The course sensitivity may be checked by noting the number of degrees of shift in the course selector required for full swing of the deviation indicator from center to the last dot on one side. This should be between 10° and 12°.

f. Receiver Tolerance. The omnireceiver is allowed a tolerance of plus or minus 6° for an air check. When a ground check is being made, this tolerance is reduced to plus or minus 4°.

167. Orientation (VOR)

To become oriented by use of omni, proceed as follows:

a. Turn on the receiver with the OMNI-VAR selector switch to OMNI and permit the set to warm.

b. Tune in the desired station, check to see that the flag is retracted, and identify the station.

c. Turn the course selector until the deviation indicator centers with a TO indication on the sense indicator. (If the sense indicator reads FROM, turn the course selector 180° until the deviation indicator centers again. This will give a TO indication).

d. The magnetic direction TO the station is now read from the course selector. For example, if the course selector reads 180° with a TO indication, the station is south.

168. VOR Tracking

Tracking procedures using omni are identical to beam following (par. 139) and ADF tracking (par. 151).

Note. When tracking inbound, always have a TO indication on the sense indicator; when tracking outbound, a FROM indication. This keeps the deviation indicator directional.

169. Track Interception (VOR)

Airway Traffic Control may specify the course an aircraft must fly. Often the specified course is not the one on which the aircraft is flying at the time, and the pilot must work a track interception problem (fig. 114). To accomplish track interception, proceed as follows:

a. Turn the aircraft parallel to the radial to be intercepted, either inbound or outbound.

b. Determine the difference between the present radial and the radial to be intercepted by rotating the course selector, if necessary.

c. To determine the interception angle, double that difference. (However, the interception angle will never be less than 20° or more than 90°.)

d. Turn course selector to the desired radial or inbound course.

e. Turn the aircraft to the interception heading.

f. Holding a constant magnetic heading, fly until the deviation indicator is centered. When the deviation indicator is centered, the aircraft is on track.

g. Turn to the magnetic heading of the track, plus or minus a correction for wind, and follow normal tracking procedures. (It may be necessary to lead the final turn so as not to overshoot the intended course due to the radius of the turn.)

h. For example, an aircraft is on the 180° radial (south of the station) and the pilot is instructed to intercept the 225° radial, inbound. His inbound course to the station is 045° (225°—180°). He would—

(1) Turn the aircraft to the desired course heading of 045° (B, fig. 114).

(2) Determine the number of degrees difference between the desired course and his present position (000° + 045° = 045°).

(3) Double this angle (045° + 045° = 090°). This is the interception angle.

(4) Set course selector to desired course inbound (045°), causing the deviation indicator to deflect full to the left.

(5) Turn the aircraft toward the desired course, to a heading equivalent to the course heading, plus or minus the interception angle (045°—090° = 315°) (C, fig. 114).

(6) Hold a heading of 315° and wait for the deviation indicator to center, allowing for lead in the turn if necessary.

(7) Turn the aircraft to 045° plus or minus wind correction (D, fig. 114).

(8) Follow normal tracking procedures until the sense indicator changes from TO to FROM, which will occur when passing the station.

i. The preceding problem is for interception inbound. The same method is used when intercepting outbound.

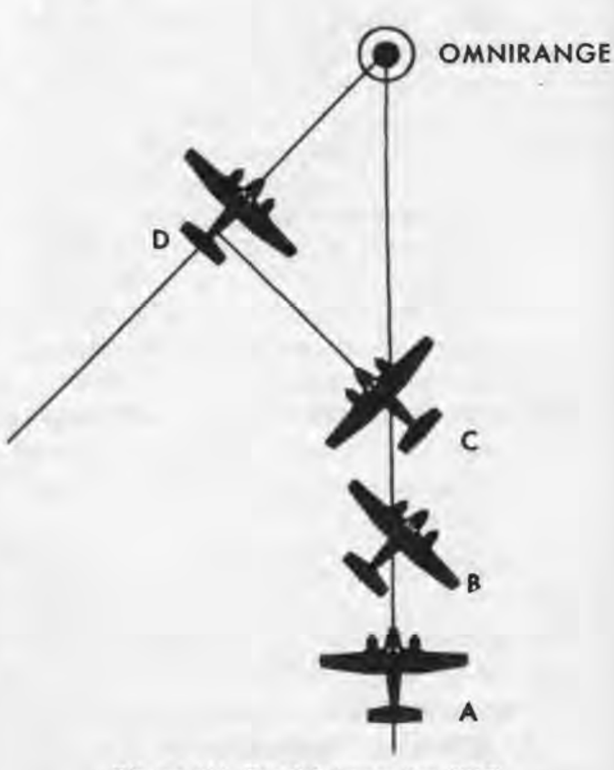


Figure 114. Track interception, VOR.

170. Time and Distance To Station

The following VOR problem is based on the same formula as radio compass time-distance problems (par. 161). Greater accuracy can be obtained with VOR equipment because of its sensitivity; a small error in heading while working a problem does not introduce appreciable error. To solve a time-distance problem, refer to figure 115 and proceed as follows:

a. Turn on the omnirange receiver and identify the desired station.

b. After station has been identified, check for maximum tuning, noting that the flag on the deviation indicator is down and the loudest signal is being received with a constant volume setting.

c. Turn the course selector so that the sense indicator reads TO and the deviation indicator needle is centered.

d. Turn the aircraft to the heading indicated by the big arrow of the course selector. The aircraft is then headed toward the station (1).

e. Turn the aircraft 80° right or left (left in the figure) of this heading, then turn the course selector to the nearest 10° increment in the opposite direction to the turn.

f. Hold this heading and when the deviation needle centers (2), note the time on the second hand of the clock.

g. Holding the same heading, turn the course selector another 10° (3) in the same direction as previously turned (opposite the direction the aircraft was turned).

h. When deviation indicator again centers (4), observe the elapsed time.

i. Turn the aircraft, immediately, to the heading indicated by the big arrow.

j. Determine time or distance to the station, using formulas in paragraph 161.

k. Another method of determining time-distance is based on the geometric principle of the isosceles triangle. This method is desirable when flying airways. For example, an aircraft is flying to a station with the deviation needle

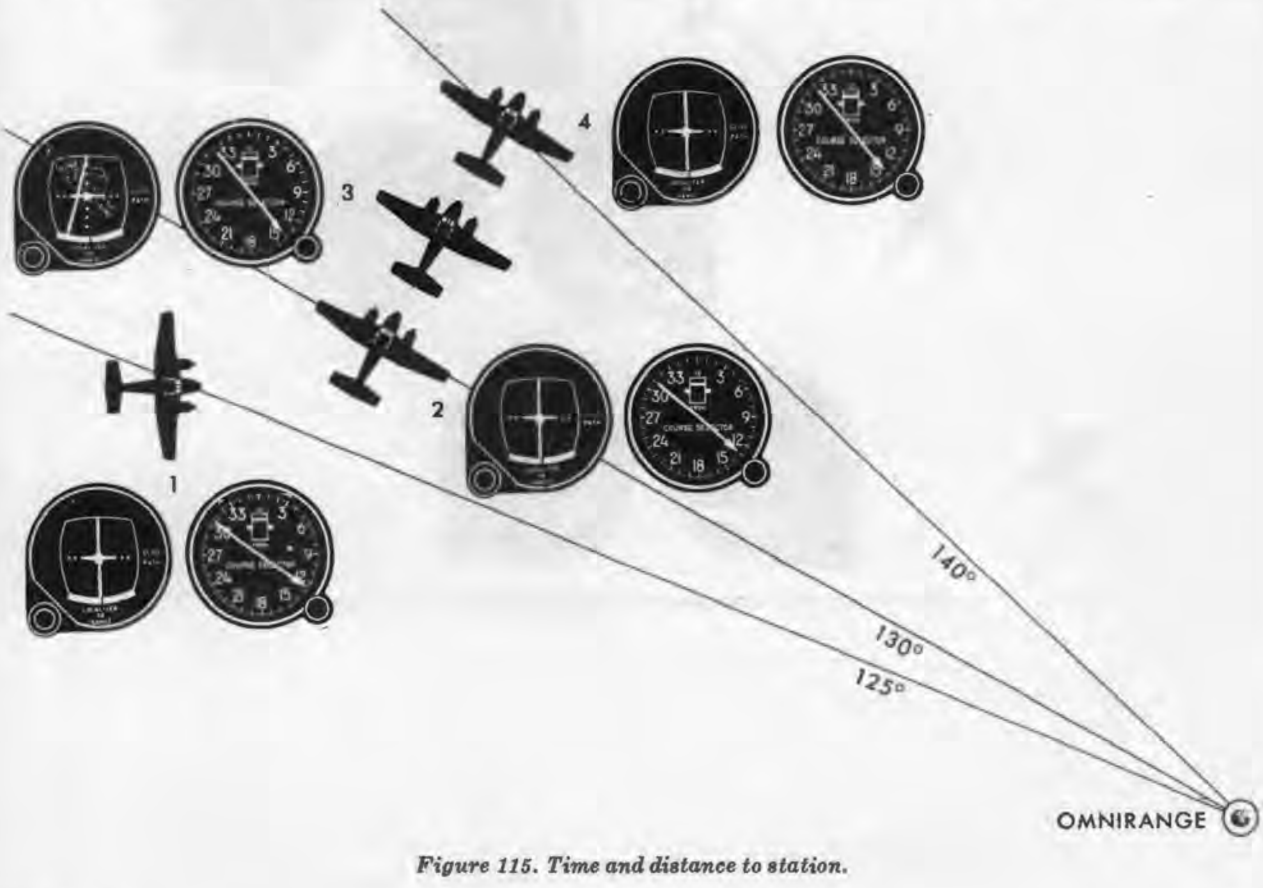


Figure 115. Time and distance to station.

centered. The pilot wishes to determine the time to the station. He proceeds as follows:

(1) Turn the course selector 10° to the left.

(2) Turn the aircraft 10° to the right and check the time.

(3) Holding a constant heading, wait until the deviation needle centers and check the time again. Time to the station is the same as the amount of time required to make the 10° change of bearing (fig. 116).

171. Plotting Position With VOR

Procedures to plot bearings to stations with VOR are similar to those in plotting bearings with the loop antenna. The principal difference is that relative bearings do not apply, since magnetic bearings are read directly. In figure 117, a pilot flying in the vicinity of Albany determines that he is on the 290° radial of the Albany VOR and the 190° radial of the Columbus VOR. The intersection of these two radials indicates the position of the aircraft. Both sectional and WAC charts have magnetic compass roses

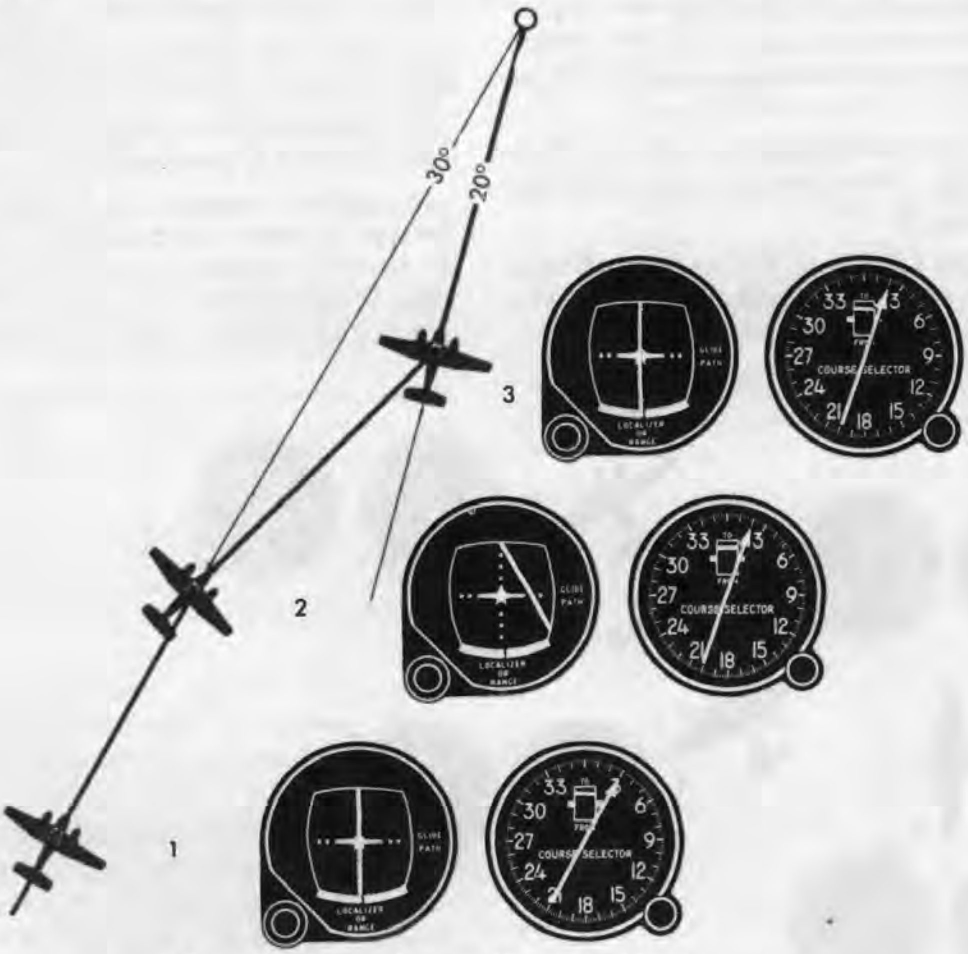


Figure 116. Time-distance problem without leaving course.

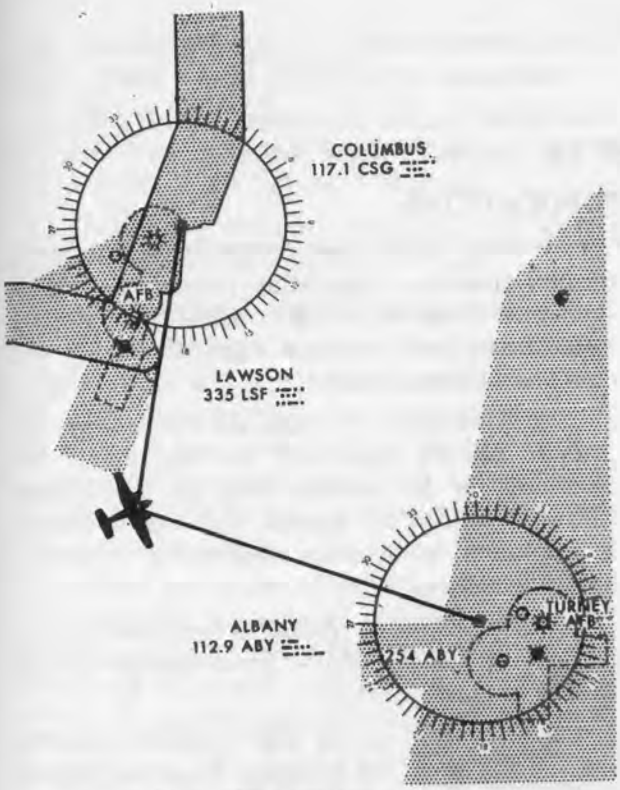


Figure 117. Plotting a VOR fix.

around each omni station. A straightedge is used to draw the lines.

172. Limitations

The operating range of omni is limited to line of sight. Range can be estimated by the following formula:

$$R = 1.4\sqrt{A}$$

in which R is the range in miles; A the altitude in feet. Table IV also gives omnireception distances.

Table IV

No physical obstructions intervening—sending stations at zero elevation.

Altitude above ground station	Reception distance (statute miles)
500	30
1,000	45
3,000	80
5,000	100
10,000	140
15,000	175
20,000	200

CHAPTER 15
NAVIGATIONAL PUBLICATIONS

173. Introduction

Any flight must be well-planned. An instrument flight requires greater planning and the more intense the weather, the more planning necessary. To assist in flight planning, pamphlets, charts, books, and technical orders are available for use. It is not necessary to memorize the contents of these references, but it is necessary to become familiar with their contents. From these publications, a pilot, while planning his flight, may gather such information as—choice of airfields for destination; choice of intermediate refueling stops; choice of route and altitudes; choice of alternate airports; information for plotting the course; radio data; how to complete clearance forms; how to give position reports; how to change a flight plan while enroute; information for letdowns; etc. Publications issued for use of the Army pilot are as follows:

a. Jeppesen Airway Manual.

b. Army Aviation Flight Information Digest.

c. Supplementary Flight Information Document.

d. Flight Information Manual.

e. Airman's Guide.

f. NOTAMS.

Note. USAF, USN Radio Facility Charts and Pilot's Handbook are also available in Army operations' offices.

174. Jeppesen Airway Manual (TM 11–2557-series)

These manuals are the major publications for the individual Army aviator. They are designed for use in preflight planning and for flights under visual or instrument conditions. They contain Army airfield data in addition to data on civil and other military airfields.

a. TM–11–2557–1. Contains navigation, planning, conversion, and radio procedure (LF/MF/VOR) charts; radio direction finding facilities; commercial broadcasting stations; airport diagrams; emergency operating procedures; meteorological data; air traffic control matters and procedures; and civil air regulations for the continental United States.

b. TM–11–2557–2. Contains instrument approach, landing area, and vicinity charts for terminals in the eastern half of the United States. Included are special area charts depicting detailed information concerning congested air traffic areas.

c. TM–11–2557–3. Contains the same type of material as TM–11–2557–2 covering the western half of the United States.

d. TM–11–2557–4 and TM–11–2557–5. Covers the UKEM area and contains the same type of material as TM–11–2557–1, TM–11–2557–2, and TM–11–2557–3.

e. TM–11–2557–6. Covers the Alaskan area and contains the same type of material as TM–11–2557–1.

f. TM–11–2557–7. Covers the Alaskan area and contains the same material as TM–11–2557–2 and TM–11–2557–3.

g. TM–11–2557–8. Covers the Latin American area and contains the same type of material as TM–11–2557–1.

h. TM–11–2557–9. Covers the Latin American area and contains the same material as TM–11–2557–2 and TM–11–2557–3.

i. TM–11–2557–10. Covers the Pacific area and contains the same type material as TM–11–2557–1, TM–11–2557–2, and TM–11–2557–3.

175. Army Aviation Flight Information Digest

The Army Aviation Flight Information Digest is published weekly by the Department of the Army. It provides current and pertinent flight information for Army, National Guard, and Army Reserve aviation activities. Included in this digest are notices of permanent and temporary hazardous conditions concerning airfield and communication facilities, special notices, flight procedures, and other related aeronautical items. These notices fall into two categories.

a. Those of a permanent nature, which are published (and repeated when necessary) until they appear in the Jeppesen Manual.

b. Temporary notices, publication of which is impractical in the Jeppesen Manual.

176. U. S. Air Force and U. S. Navy Publications

a. *Radio Facility Charts*. These publications contain radio and air navigation information, and other supplementary data serving the specific operational requirements of the United States Air Force and the United States Navy, and are required by AAF operations' offices for use by transient pilots.

b. *Pilot's Handbook, East, West* (*PHACUS*). This publication contains operational flight data pertaining to radio facilities, flight procedures, and approach and landing procedures serving the specific operational requirements of the United States Air Force and the United States Navy and required by AAF operations offices for use by transient pilots.

c. *Supplementary Flight Information Document* (*SFID*). This publication contains operational data of a more permanent nature required for the use of air crew members. Normally, it is revised every six months (automatically issued to all holders of publication listed in *a* above).

177. Flight Information Manual

The CAA Flight Information Manual is distributed every six months (usually February and August). Much information is available in this manual which is not normally accessible to a pilot. Some of the items included are—air traffic control procedures; air space reservations; danger areas; direction finding and loran station data; enroute radio communications procedures; Federal airway lighting aids; minimum enroute IFR altitudes and minimum crossing altitudes; radio navigational aids; standard broadcasting stations; automatic direction finding; ground control approach systems; instrument landing systems; low frequency ranges; VHF omniranges (VOR); VHF visual-aural (VAR) ranges, and much other valuable information.

178. CAA Airman's Guide

This publication contains continental United States radio and navigational information and other supplementary data on civil airports only, and is required by AAF operations' offices for use by the Army, National Guard, and Reserve aviators.

179. Notices To Airmen (NOTAMS)

Throughout the year, climatic conditions (snow, floods, storms, etc.) render many fields temporarily unusable or unsafe. In addition, there is intermittent maintenance in progress on many fields; radio facilities may suffer temporary power failures or course misalinements; and lighting facilities may fail. Because these temporary conditions cannot be given immediate coverage in navigational publications, a system of teletype NOTAMS brings such conditions to the pilot's attention promptly. These NOTAMS are displayed in a prominent file in the operations office. NOTAMS include three different types, explained below.

a. FILLI—This refers to a notice concerning landing field and lighting facilities.

b. ROCOM—This refers to any notice about radio communications.

c. MISEL—This means miscellaneous and refers to any notice which cannot be covered under the first two classifications.

PART THREE
NAVIGATION PECULIAR TO INSTRUMENT APPROACHES
CHAPTER 16
PROCEDURE TURNS, HOLDING, AND STACKING

180. Introduction

The most exact enroute navigation is useless unless a landing can be successfully completed at the destination. Minimum conditions of ceiling and visibility have been established for each airport, depending on equipment available and terrain or obstructions. Pilots are permitted to descend on instruments to the established minimums; thereafter, if the airport is not visible, a "missed approach" procedure must be followed. To successfully complete this portion of the flight, the pilot must have a thorough understanding of holding patterns and approach procedures.

181. Procedure Turns

A procedure turn (fig. 118) is a maneuver for reversing the heading of an aircraft on a course. Minimum procedure-turn altitudes are listed on approach charts.

a. Standard Procedure Turn. A standard procedure turn (A, fig. 118) involves an initial left turn away from the outbound course, followed by a turn to the right toward and intercepting the final approach course inbound. The direction of the turn will be specified as the side north, south, east, or west of the final approach course. The degree of turn and the point at which the turn will be made is left to the discretion of the pilot, but maneuvering must be completed within the procedure-turn maneuvering area, not below the established altitude. The procedure-turn maneuvering area is limited to seven miles on the maneuvering side of the outbound course, and 4.34 miles on the opposite side within a distance of 10 miles of the facility. Procedure turns beyond 10 miles are authorized only in cases where a definite requirement exists for an extended maneuvering area. In all cases, a five mile buffer zone is provided beyond the maximum distance outbound authorized for the procedure turn. Where it is necessary, due to terrain, obstructions, traffic, etc., to emphasize the limitation of the procedure turn, a note "Not authorized beyond ______ miles" is shown on the chart. When a procedure turn must be established at a distance other than 10 miles from the facility, an explanatory note is included on the approach chart. A procedure turn need not be made when the final approach can be executed from an established holding point or a final approach-fix specified in the procedure.

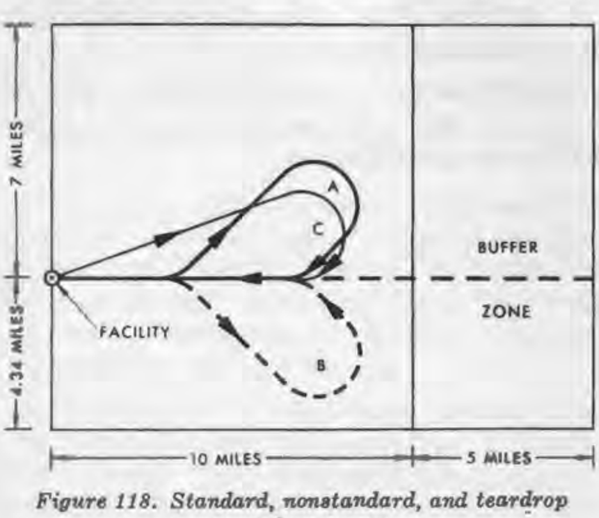


Figure 118. Standard, nonstandard, and teardrop procedure turns.

b. Nonstandard Procedure Turn. A nonstandard procedure turn (B, fig. 118) may be authorized when a turn cannot be made on the left side of the outbound course due to unusually high obstructions, air traffic control considerations, or for other reasons. In such cases, the turn will be made on the right side of the outbound course and an explanatory note is sometimes included in the procedure chart, such as, "All turns to be made on the east side of the course, high terrain to the west."

c. Teardrop Procedure Turn. A teardrop procedure turn (C, fig. 118) may be established when a standard or nonstandard procedure turn is not operationally desirable or feasible. A teardrop procedure turn normally starts over the facility on an outbound course to the left of the reciprocal of the inbound course. The actual outbound course selected and the point at which the turn toward the inbound course is made need not be the ones indicated on the procedure and are therefore left to the discretion of the pilot. However, the maneuvering area and altitude are specified on the procedure chart, requiring the maneuver to be completed within the teardrop procedure-turn maneuvering area at or above the altitude established for this type procedure turn. Dimensions for the teardrop procedure turn for conventional aircraft are the same as those specified for a standard procedure turn (*a* above).

182. Types of Procedure Turns

There are normally three types of procedure turns used in executing standard and nonstandard procedure turns.

a. The 60-Second Type. The 60-second type procedure turn can be used when moderate wind conditions exist (fig. 119), and is accomplished as follows:

(1) Turn to a heading 45° left or right of the outbound course.

(2) Maintain new heading for 60 seconds after leaving the outbound course.

(3) Make a 180° turn *away* from the facility.

(4) Maintain this heading until turning inbound on the desired course.

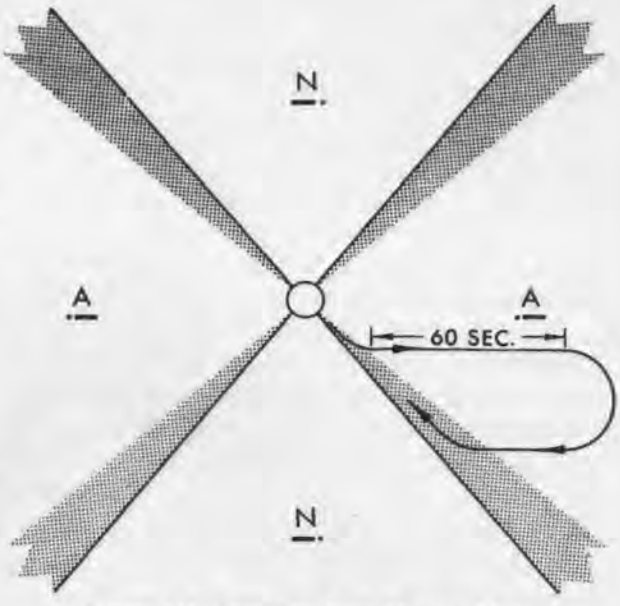


Figure 119. Procedure turn, 60-second type.

b. The 40-Second Type. The 40-second type procedure turn (fig. 120) is accomplished as follows:

(1) Turn to a heading 45° left or right of the outbound course.

(2) Under no-wind conditions, maintain this heading for 40 seconds after leaving the outbound course. If there is a wind, add or subtract one second for each degree of wind drift correction previously required or estimated, to keep the aircraft on the outbound course. When the 45° turn is downwind, subtract the correction from 40 seconds; if the 45° turn is upwind, add the correction to 40 seconds.

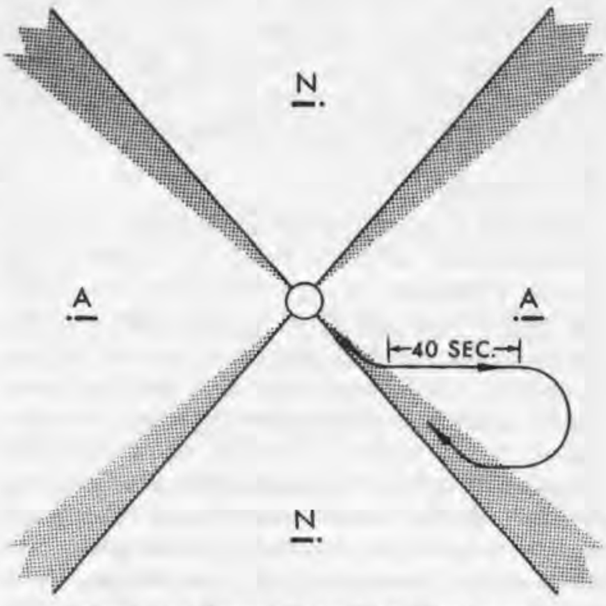


Figure 120. Procedure turn, 40-second type.

c. The 90°-Type. The 90°-type procedure turn (fig. 121) is normally used when tracking on the outbound course and does not incorporate any time factor. It consists of a 90° turn right or left from the heading required to maintain the desired outbound course, then an immediate reversal of the turn. Make this reverse turn to the heading required to maintain the inbound

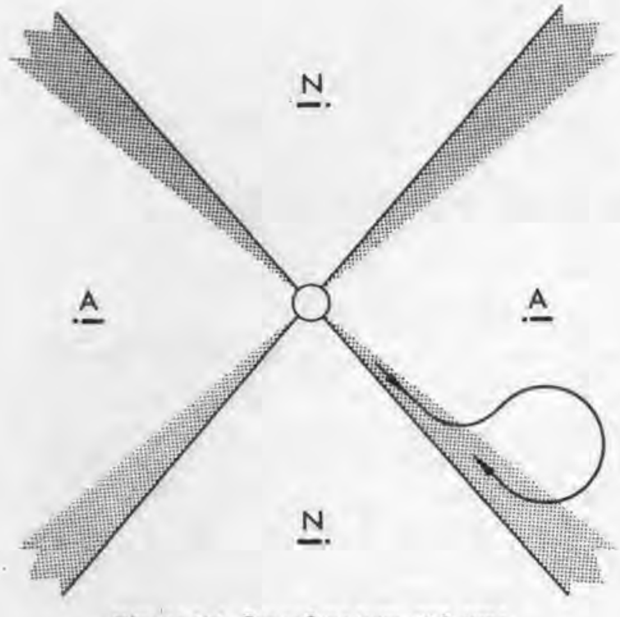


Figure 121. Procedure turn, 90°-type.

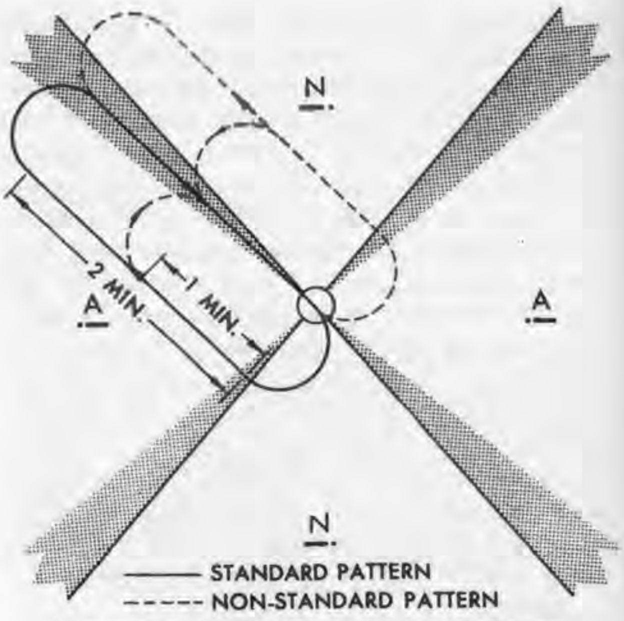


Figure 122. Standard and nonstandard holding patterns (no wind).

course. Both turns should be made at the same rate. This type of procedure turn is the most expeditious method of reversing the direction of an aircraft on a course. It is especially adaptable to low-visibility approaches.

183. Holding

Holding is maneuvering an aircraft within a predetermined airspace prior to obtaining an approach clearance or departing on course. Holding instructions are given by approach control, or by appropriate ATC agency at the destination or enroute. A holding point is a specified location or radio facility, identified by visual or other means, in the vicinity of which the position of the aircraft in flight is maintained in accordance with Air Traffic Control instructions. This holding point may be a radio range station, fan marker, the intersection of two courses, or a radio beacon. The direction to hold with relation to the holding fix is always specified by using magnetic directions with reference to eight general points of the compass (north, northeast, east, southeast, south, southwest, west, or northwest) from the holding fix.

a. Standard Holding Pattern (No Wind). The standard holding pattern (fig. 122) is based on a true airspeed at sea level (standard atmosphere) of 180 statute miles per hour (155 knots) with a rate of turn of 3° per second. In the doubled holding pattern, airspace area from 19,000 to 29,000 feet inclusive, and the tripled holding pattern airspace area above 29,000 feet, the rate of turn is normally 1½° per second. In any case, the pilot is *not* expected to exceed a 30° angle of bank when holding in the prescribed holding pattern. The pilot *is* expected to stay within the prescribed holding patterns. He should therefore take into consideration all operational factors affecting his ability to remain within the prescribed holding pattern. Where the pilot determines that the boundaries of the prescribed holding pattern will be exceeded, he will notify Air Traffic Control as far in advance as possible prior to entering the assigned holding pattern.

(1) The standard holding flight path of an aircraft follows the specified course inbound to the holding fix, makes a 180° turn to the right, flies a parallel straight course outbound from the holding fix for two minutes, makes another 180° turn to the right, and again follows the specified course inbound.

(2) A nonstandard holding pattern is one in which all turns are made to the left and/or time outbound is other than two minutes.

(3) When holding at an approach control fix and receiving instructions speci-

fying the time of departure from the holding point, the pilot should adjust his flight path within the limits of the established holding pattern in order to leave the approach fix inbound at the exact time specified. A procedure turn need not be executed since aircraft holding in the elliptical pattern may proceed inbound on the final approach directly from the holding pattern after receipt of approach clearance.

b. Standard Holding Pattern (With Wind). Pilots are *not* expected to adjust the length of the legs of the holding pattern to compensate for wind along the holding course in either direction. In *no* event should a pilot exceed the time of two minutes (one minute if appropriate) in flying the outbound leg of the pattern. To counteract wind in a holding pattern, refer to figure 123 and proceed as follows:

(1) If drift correction inbound is 10° or *less*, counteraction of wind effect is accomplished by doubling the amount of drift correction used on the inbound leg, when flying outbound. For example, if the drift correction on the inbound leg is 8° left, use a drift correction of 16° right when flying outbound.

(2) If drift correction inbound is more than 10°, add 10° of correction while flying outbound. For example, if drift correction inbound is 20° right, drift correction outbound is 30° left.

Note. The extra drift correction used on the outbound leg changes the pattern in such a manner that the standard-rate turn to the inbound leg will end on course. While turning upwind, the radius of the turn is smaller than while turning downwind (fig. 123).

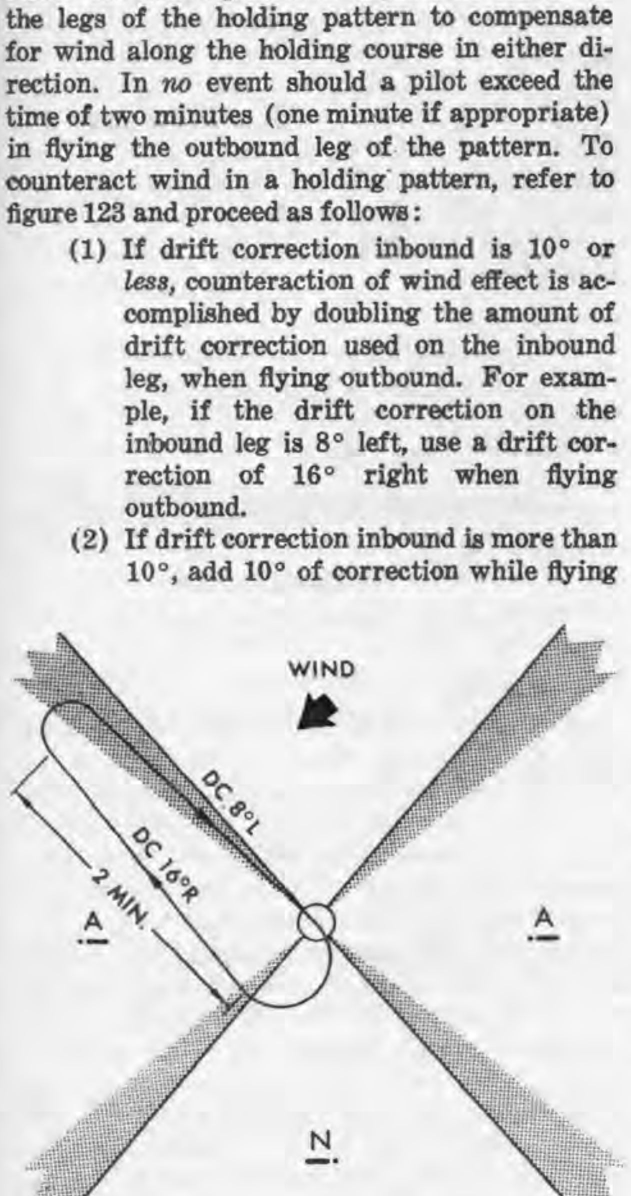


Figure 123. Counteracting wind in a holding pattern.

c. Nonstandard Holding Pattern. A nonstandard pattern is one in which turns are made to the left and/or when the time outbound is other than two minutes. When it is desired by ATC that a nonstandard pattern be flown, the clearance will contain information on those elements of the holding pattern that are nonstandard.

d. Entering the Holding Pattern. To enter a holding pattern, head the aircraft inbound to the station on the desired course. If inbound to the station on the holding course, the first turn of the holding pattern is started upon initial station passage. If approaching the station on the reciprocal of the holding course, proceed to the station and fly outbound on the holding course for not more than two minutes, reverse course, and commence the first turn of the holding pattern when back over the station. All turns required in connection with entry or exit from a holding pattern are made on the same side of the course as the pattern.

Note. If approaching the station on any course other than the above, proceed to the station, intercept the holding leg, proceed outbound on the holding leg, reverse course not more than two minutes outbound from the holding fix, and commence the first turn of the holding pattern when over the fix inbound.

e. Holding at Intermediate Aids. When holding on a fan marker (fig. 124), enter the pattern in the same manner as when holding on a range station (*d* above). The final circuit of the holding pattern will be varied as necessary to allow departure from the center of the fan marker at the departure time. Entrance into a holding pattern on a homer (fig. 125) is identical to that for a radio range (*d* above). The clearance to hold will specify the bearing on which to hold. When the designated holding point is the intersection of two beam legs (fig. 126), the ground control agency will specify the holding leg and the direction of the pattern. If the aircraft has only one L/F receiver, the pilot determines his aircraft position relative to the intersection by

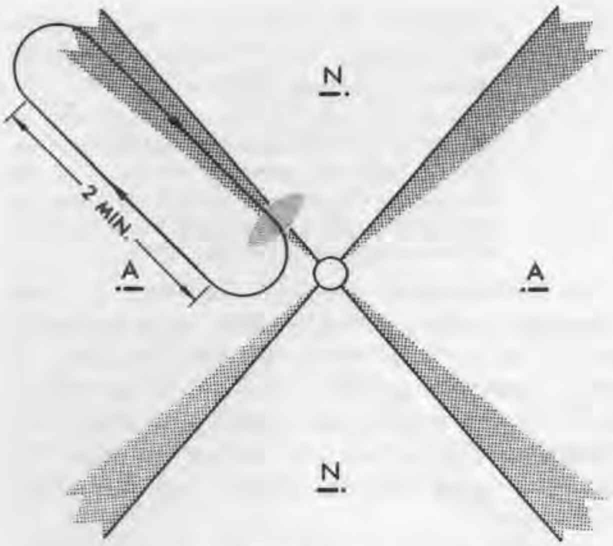


Figure 124. Holdng on fan marker.

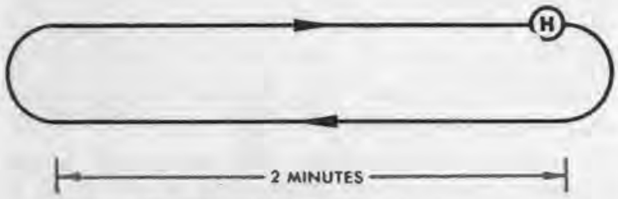


Figure 125. Holding on homer.

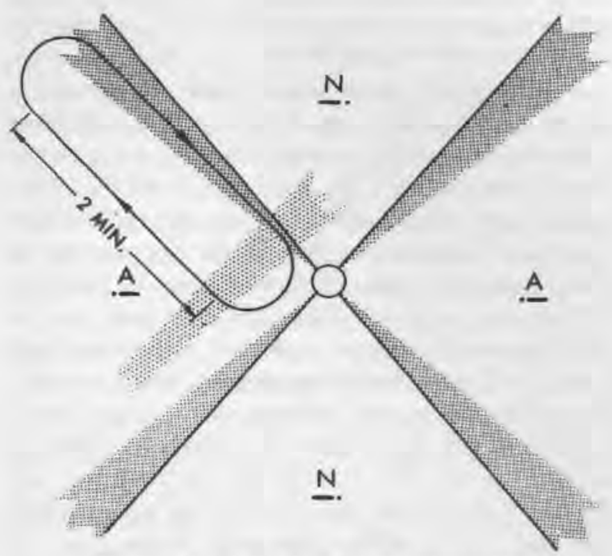


Figure 126. Holding on beam intersection.

tuning his radio to the station transmitting the intersecting leg. Upon receipt of the "on-course" of the intersecting leg, start the elliptical holding pattern. After the turn while on the outbound leg, tune the radio to the station transmitting the inbound leg. After two minutes has elapsed, turn 180° to the right to the inbound heading. Repeat the radio tuning procedure after each turn, each time around the pattern (fig. 126).

f. Holding Pattern Airspace Area. The standard holding pattern buffer area is shown in figure 127. Where one-minute holding pattern airspace areas are established because of limited airspace or to expedite traffic, the length of the airspace area is reduced from 19 to 16 statute miles. This three-mile reduction is made at the far end of the airspace area, which reduces the 15-statute mile dimension to 12-statute miles. The dimensions of the holding pattern airspace area are doubled for jet aircraft between 19,000 and 29,000 feet and tripled for holding above 29,000 feet.

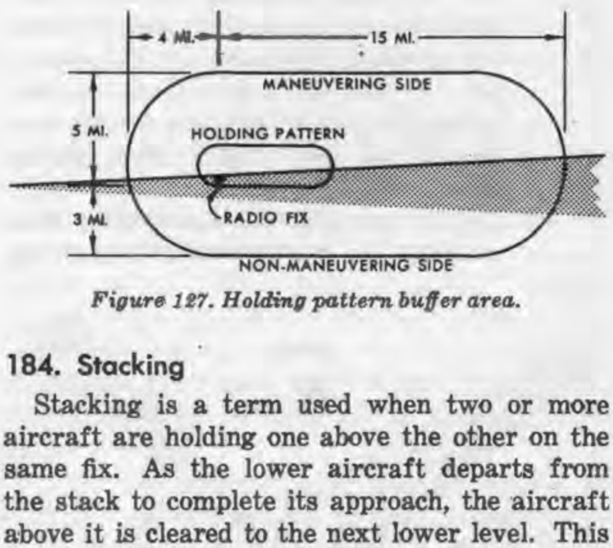


Figure 127. Holding pattern buffer area.

184. Stacking

Stacking is a term used when two or more aircraft are holding one above the other on the same fix. As the lower aircraft departs from the stack to complete its approach, the aircraft above it is cleared to the next lower level. This clearance will be given when the approaching aircraft has reported vacating that altitude and leaving the radio facility inbound. The second aircraft is cleared for an approach when the first aircraft is sighted by the tower and the tower considers a normal landing safe. The length of time an aircraft is required to hold in a stack is dependent upon the time the aircraft in the lower positions take to land. Since the delay may be of considerable duration, the pilot must fly at an airspeed and power setting which will provide maximum endurance.

CHAPTER 17
INSTRUMENT LANDING SYSTEM

Section I. GROUND INSTALLATION

185. Introduction

The Instrument Landing System (ILS) was formerly a three-element system consisting of VHF localizer, UHF glide slope, and 75-megacycle marker beacons. Additional components have been incorporated in the original system, including compass locators for holding, transition, and tracking; high intensity approach lights for visual guidance in the latter part of the approach; and monitoring by radar for additional safety.

186. Localizer

a. The ILS localizer (VHF), located on the upwind end of the instrument runway, provides a directional beam (fig. 128) which enables the pilot to navigate a straight course to the landing runway. The beam, formed by overlap of two transmitted "lobes" modulated at different frequencies, is projected along the centerline of the runway. The portion of this beam projected *toward* the associated fan markers is termed the *front course*; the portion extending in the *opposite* direction is termed the *back course*.

b. The localizer transmitter is designed to provide an on-course signal at a minimum distance of 25 miles from the runway at a minimum altitude of 2,000 feet. The right side, looking from the outer marker toward the transmitter, is modulated at 150 cycles. This is identified as the *blue sector* on maps and charts, and on the crosspointer indicator in the aircraft. The left side is modulated at 90 cycles and identified as the *yellow sector*. The on-course is an equisignal area between the modulated sides and is very sharp along the entire length of the radiated pattern. The localizer course width is normally 5° and represents a span of approximately 4,600 feet at a distance of 10 miles from the transmitter. The course width, at the point of touchdown, is between 50 and 100 feet depending upon the length of the runway. The ILS localizer provides information outside of the actual course sector, in the form of full "fly-left" or "fly-right" indications.

c. Each localizer is identified by a three letter coded designator transmitted intermittently and is preceded by international Morse Code I (two

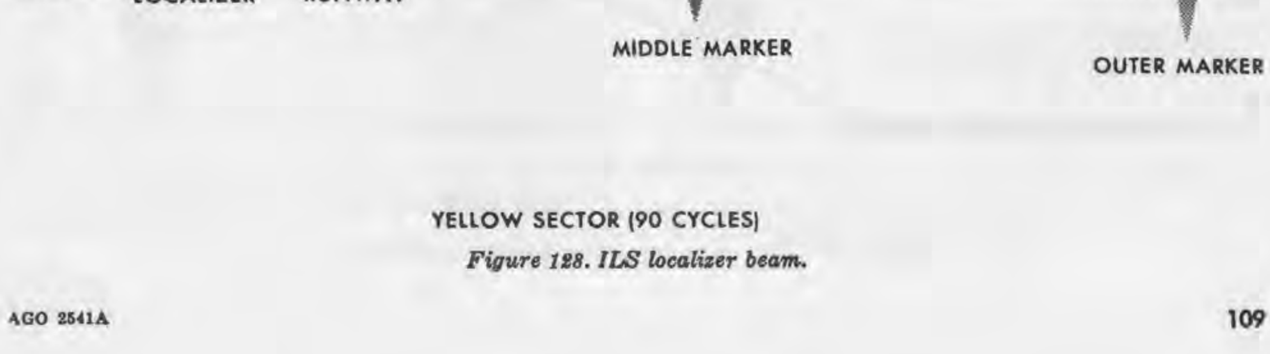


Figure 128. ILS localizer beam.

dots). Time interval between the I designator and the first letter of the assigned identifier will be 0.6 seconds. Voice transmissions can be impressed upon the localizer frequency to transmit approach control instructions from the airport control tower.

187. Glide Slope

The glide slope (fig. 129) provides a directional beam emanating from the desired point of touchdown on the runway. This beam, similar to the localizer "on-course", is formed by the overlapping of a 90 and 150 cycle modulated signal. The beam is "flown" by centering the horizontal needle of the cross pointer indicator (par. 193).

a. Where the minimum obstruction clearance can be obtained in the approach area of the glide slope, the glide slope is set to the normal optimum setting of 2½° to 2¾°. This will obtain desirable interception of the glide slope with the middle marker at an elevation of about 200 feet above the runway.

(1) Where terrain and obstruction clearances can be provided, the glide slope may be set at a lower angle. The minimum glide slope angle is 2°.

(2) When necessary to obtain the minimum obstruction clearance, the glide slope may be raised to an angle of 3°. Angles greater than 3° are not normally used. Where minimum obstruction clearance cannot be obtained with the 3° glide slope angle and if the length of the runway permits, the glide slope unit is placed inward from the standard location.

b. In addition to the desired course, all glide slope facilities produce five additional courses at higher vertical angles. The lowest is at approximately 12½°. These high courses should not cause confusion since they will not be encountered when making an approach at the proper approach altitude. Unlike the localizer, the glide slope transmitter emits its signals in the direction of the final approach and sends no signal to the far end of the runway. The transmitter unit is located at the approach end of the runway and is adjacent to the point of touchdown. A glide slope course is normally 1° wide. Ten miles from point of touchdown, this represents a vertical distance of approximately 920 feet, narrowing to a few feet at touchdown.

188. Marker Beacons

a. Two marker beacons (fig. 129) are used with the ILS. These markers are of approximately 2 watts output and operate on a frequency of 75 mc. The ILS marker radiation pattern is essentially a cone with an elliptical cross section whose minor axis is parallel to the approach path and major axis at right angles to it. The ratio of major to minor axis is approximately 2 to 1.

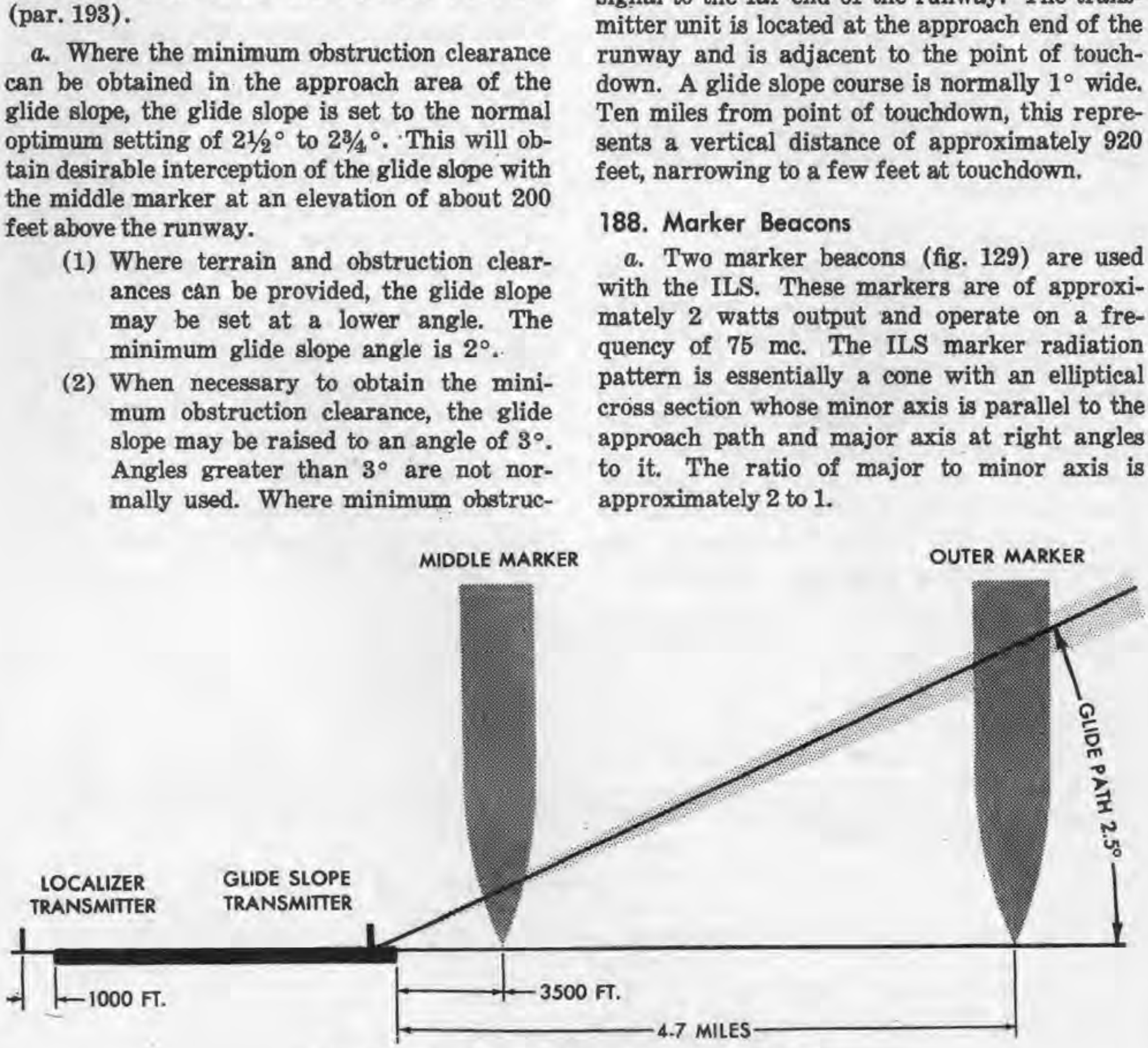


Figure 129. Glide slope and marker beacon installation.

b. The outer marker is located on the front course of the localizer. Its distance from the airport is generally determined by the point at which the glide slope intersects the minimum holding altitude, provided this point is within 4 to 7 miles of the airport. It is modulated at 400 cycles per second and keyed to emit dashes continuously at a rate of 2 per second.

c. The middle marker is located approximately 3,500 feet from the approach end of the runway, between the runway and the outer marker. This marker is modulated at 1,300 cycles per second and keyed to emit alternate dots and dashes.

Note. The Z-marker of a radio range station which is located along the localizer beam, will often serve as the outer or middle marker.

189. Compass Locators

The compass locator is a low-powered (25 watt) nondirectional radio beacon, providing a signal received on the 200 to 400 kc band of a conventional airborne ADF receiver. When used in connection with ILS, compass locators are installed at the outer and/or middle marker sites. Compass locators simplify transition to ILS and subsequent holding. They also simplify correcting for drift on the ILS localizer beam, and determining when markers have been passed. The compass locator is identified by a two letter code transmitted intermittently on the carrier, utilizing a 1,020-cycle tone. The coding identification at the outer marker consists of the first two letters of the station identifier and at the middle marker consists of the second and third letters of the station identifier.

190. High Intensity Lighting

Normal approach and letdown on the ILS is divided into two distinct stages. In the first stage, only radio guidance is available. In the last stage of the approach, visual contact with the ground is necessary for accuracy and safety. The approach light lane is an integral part of the ILS system and furnishes visual guidance to the runway in use. At major airports, the light line consists of high intensity incandescent lamps on bars spaced 100 feet apart and extending 3,000 feet from the end of the runway almost to the middle marker.

191. ILS Monitor System

a. The flag alarm system of the cross pointer indicator in the aircraft gives no indication of malfunctioning of ILS ground equipment. Since a malfunctioning of ILS equipment could place the pilot in a critical position, some automatic means is provided for continuous monitoring. The present monitoring system provides a continuous check of all ILS ground facilities and, for the localizer and glide slope, provides automatic changeover to standby equipment when the monitor indicates malfunctioning of the main system.

b. However, markers and compass locators must be turned to OFF position manually when the tower light and aural alarm indicates that these two facilities are malfunctioning.

c. As an additional safety measure, precision approach radar at all major airports enables approach control personnel to monitor the actual positions of aircraft using ILS.

Section II. AIRBORNE EQUIPMENT

192. Antenna Array (fig. 130)

The localizer receiver utilizes a dipole receiving antenna bent into a U-shape to provide streamlining and a circular pattern. The glide slope receiver may utilize another dipole receiving antenna mounted as a unit with the localizer antenna forward on the aircraft fuselage. In the interest of improved antenna pattern and further streamlining, localizer antennas are available without the glide slope dipole. In this latter type installation, the glide slope antenna is mounted either on or within the nose of the fuselage.

193. Localizer and Glide Slope Receivers

a. The AN/ARN–30A receiver (fig. 131) and R–13B receiver (fig. 132) provide both omni and localizer beam reception by manual operation of switches on the receiver control unit. To operate on the localizer beam, the "Omni-VAR-Loc" switch (figs. 131 and 132) on the control unit is switched to VAR-Loc position and the receiver manually tuned to a desired localizer frequency. When a usable signal is received, if the receiver is operating properly, the flag alarm on the cross pointer indicator will retract.

b. The R–746/AR glide slope receiver is used in conjunction with the localizer portion of the

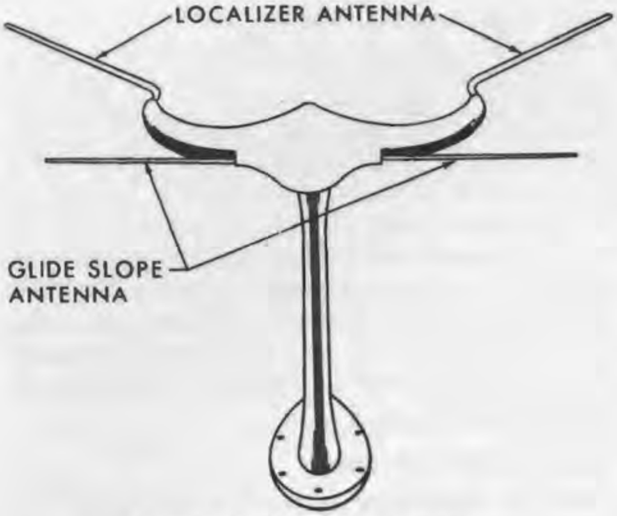


Figure 130. ILS antenna array.

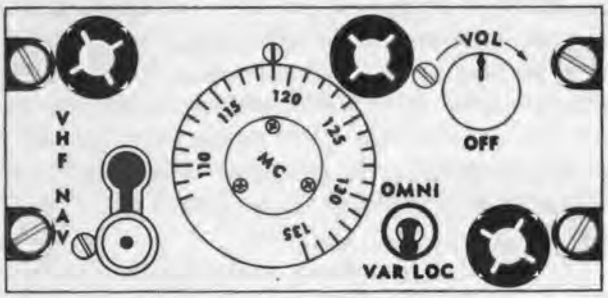


Figure 131. Control unit for AN/ARN–30A receiver.

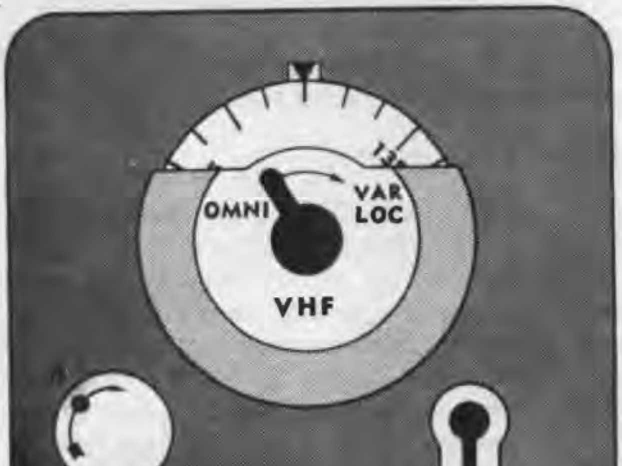


Figure 132. Control unit for R–13B receiver.

navigation receivers and controlled by a SLA–85C control unit (fig. 133). The R–746/AR is a 20-channel, fixed frequency receiver designed to receive the 90/150 cycle tone modulated glide slope beam and produce vertical guidance during the ILS operation. The control unit is equipped with a frequency control knob and volume control knob. The volume control knob is used to control power to the glide slope receiver. The frequency control knob is calibrated from 108 to 135 megacycles. When the operator sets frequency of the localizer station on the glide slope control unit, the glide slope receiver is tuned automatically to receive the proper glide slope frequency.

c. There are 20 localizer channels assigned, using only the odd decimals of a frequency band between 108.1 and 111.9 mc. Every localizer frequency has a corresponding glide slope frequency, of which there are 10 channels. Localizer channels and glide slope channels are paired as indicated in table V.

Table V. Localizer and Glide Slope Frequencies

Localizer frequency	Corresponding glide slope frequency
108.1 mc	334.4 mc
108.3 mc	335.0 mc
108.5 mc	329.6 mc
108.7 mc	330.2 mc
108.9 mc	330.8 mc
109.1 mc	331.4 mc
109.3 mc	332.0 mc
109.5 mc	332.6 mc
109.7 mc	333.2 mc
109.9 mc	333.8 mc
110.1 mc	334.4 mc
110.3 mc	335.0 mc
110.5 mc	329.6 mc
110.7 mc	330.2 mc
110.9 mc	330.8 mc
111.1 mc	331.4 mc
111.3 mc	332.0 mc
111.5 mc	332.6 mc
111.7 mc	333.2 mc
111.9 mc	333.8 mc

194. Cross Pointer Indicator

To enable the pilot to follow the localizer and glide slope beams, the aircraft is equipped with an instrument called a cross pointer indicator (fig. 134). It has two crossed indicating needles; one vertical and the other horizontal. The lo-

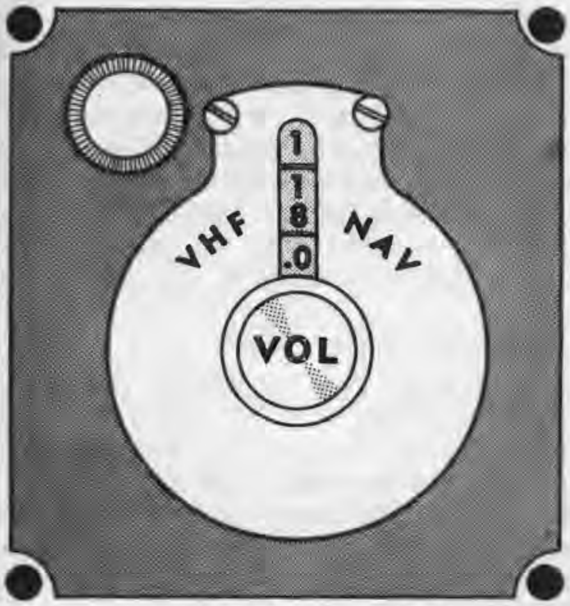


Figure 133. SLA–35C control unit.

calizer pointer is pivoted at the top of the dial and moves left and right. The glide path pointer, pivoted at the left side of the dial, moves up and down.

a. The *localizer pointer* (vertical needle) indicates, by deflection, the color area of the sector in which the aircraft is flying (fig. 134). If the aircraft is flying in the blue sector of the transmitted signal, the vertical pointer will be deflected into the blue area of the indicator. Conversely, if the aircraft is flying in the yellow sector, the pointer will be deflected into the yellow area of the indicator. When the aircraft is directly on the localizer course, the pointer will be centered vertically across the circle in the middle of the dial.

b. When the aircraft is inbound on the front course or outbound on the back course, the action of the needle is directional; that is, if the pointer is deflected to the right, the aircraft is turned right to reach the center of the course. When the aircraft is inbound on the back course or outbound on the front course, the sensing of the pointer will be reversed; that is, if the pointer is deflected to the right, the aircraft is turned left to reach the center of the course. Regardless of the position or heading of the aircraft, the localizer pointer *will always* be deflected in the color area in which the aircraft is flying.

c. The pointer is very sensitive and will give a full scale deflection when the aircraft is 2½°

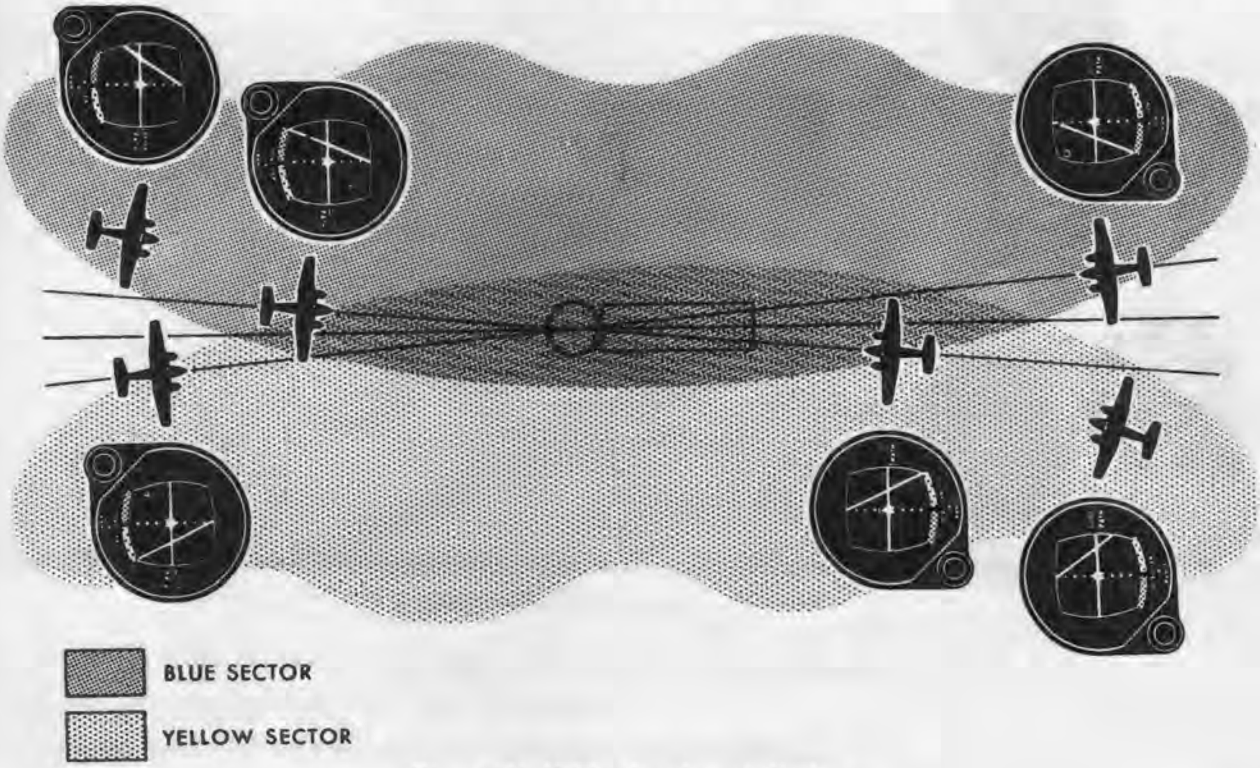


Figure 134. ILS localizer beam indicatons.

to either side of the on-course. This high sensitivity permits the use of the indicator for accurate runway location. If the pointer is no farther off center than one-quarter scale, the aircraft will land on the runway.

d. The *glide slope pointer* (horizontal needle) indicates, by deflection, the position of the aircraft with respect to the glide slope (fig. 135). When the aircraft is above the glide slope, the pointer is deflected downward. Conversely, when the aircraft is below the glide slope, the pointer will be deflected upward. When the aircraft is directly on the glide slope, the pointer will be centered horizontally across the circle in the middle of the dial.

e. Since the glide slope course is much sharper than the localizer course (approximately 1° from "full up" to "full down" on the instrument), it is necessary that the aircraft be alined accurately on the glide slope at some distance from the field. Only very minor corrections are possible near the ground.

f. The *ILS alarm system* consists of two tiny voltmeters contained in the case of the cross pointer indicator and connected to the output of the localizer and glide slope receiver. Instead of a needle, each meter is equipped with a red flag, installed in such a manner that it will stick out across the indicator dial when an unusable signal is received either by the localizer or the glide slope receiver. This flag will also show when there is any malfunction in either receiver.

195. Marker Beacon Receiver

The receiver used to receive the marker beacons associated with the ILS system is the same 75-mc receiver used for reception of the Z-marker and fan marker (par. 133). The ILS markers serve as definite radio fixes to mark the progress of the aircraft along the approach course. They may also be utilized to monitor the alinement of the glide slope by comparing the altitudes at which each marker is actually crossed on the glide slope with the crossing altitudes specified on the instrument approach chart for the facility.

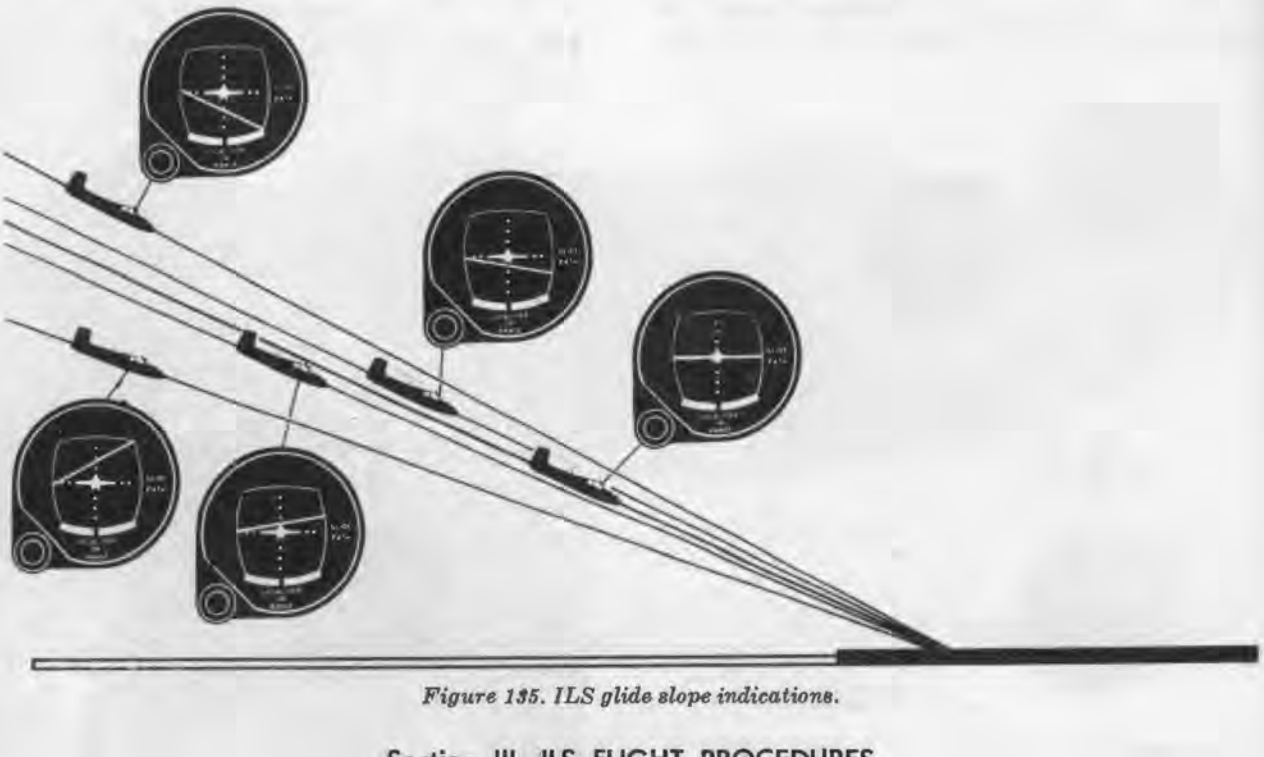


Figure 135. ILS glide slope indications.

Section III. ILS FLIGHT PROCEDURES

196. General

An ILS approach (fig. 136) requires considerable planning prior to execution. If the destination has an ILS facility, the airport diagram is shown in the Jeppesen Manual or USAF and USN Pilot's Handbook. These pub-

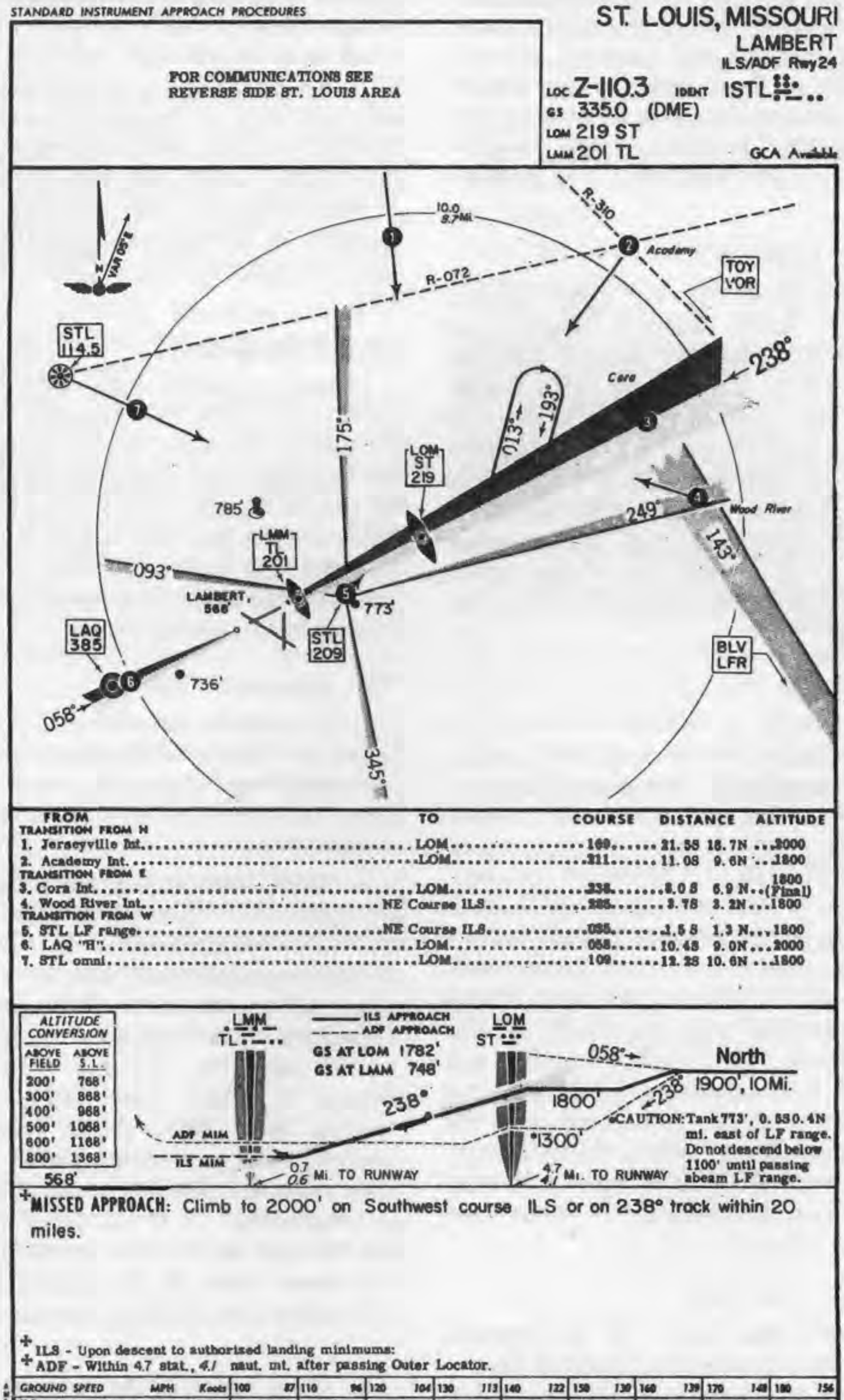


Figure 136. ILS approach.

lications show the physical setup and cross section of the localizer and glide path beams, location of the markers and compass locators, and the altitudes to fly to each position during the letdown. Information such as station frequency and inbound heading of the localizer beam can also be obtained from these publications.

197. Transition (ILS)

The transition from the last radio navigational aid to the ILS is shown in detail in the ILS charts of the Jeppesen Manual and the USAF and USN Pilot's Handbook. This transition, aided by the compass locators at the ILS marker beacons, may be from a VOR or a radio range facility, or the intersection of a range leg with the localizer beam. The minimum altitude for transition to the ILS from specified fixes provides at least 1,000 feet of obstruction clearance 4.34 miles each side of the transition course (fig. 136).

198. Tracking (ILS)

Once the aircraft is on-course, a constant heading is maintained. If the magnetic heading of the beam is accurately maintained, the rate of deflection of the localizer needle will indicate the force of the wind. In most weather conditions which require an ILS approach, the surface wind velocity obtained from the control tower is accurate at the different altitudes of the approach. Apply drift corrections in the same manner as in ADF tracking (par. 151). Make only small corrections once the needle is centered. Crosscheck the needle rapidly, and counteract the first off-course indication. All corrective turns must be coordinated, and the degree of bank should not exceed the number of degrees to be turned. Proper beam following will result if the exact heading can be determined and held within 1° or 2°.

199. Procedure Turns (ILS)

Procedure turn (par. 181) will be executed in accordance with procedures specified on approach chart or in accordance with approach control instruction. Crosscheck the localizer needle frequently during the last 90° of the turn to the inbound heading to determine the accuracy of the procedure turn. If the aircraft approaches a heading which is 45° from the inbound heading and the localizer needle continues to indicate a four-dot deflection, return the aircraft to level flight so as to approach the beam at an angle of 45° and accomplish a normal interception. On the other hand, if the aircraft approaches a 45° heading and the localizer needle starts moving toward the center, continue the turn. Then by crosschecking the needle, the rate of turn can be adjusted to have an on-course indication by the time the aircraft is on the inbound heading (fig. 135).

200. Holding (ILS)

Holding patterns (par. 183) on OM (outer marker) or LOM (locator outer marker) should be entered the same way as patterns for other holding fixes. Marker beacons and/or ADF may be used to identify OM and for orientation purposes around the OM. When departure time is specified, the holding pattern will be varied as necessary to depart the center of the marker at a designated departure time.

201. Approach (ILS)

It is extremely important to plan the letdown before the initial station passage (OM). Use the approach charts (fig. 136) as an aid during the approach, at all times, to assure proper use of procedures.

a. When approaching the localizer course at an angle of 45° (e.g., on the final portion of the procedure turn), start the final turn toward the inbound heading to arrive on the desired inbound course. Once the aircraft has reached the localizer on course, the heading should be maintained until the localizer pointer moves off center, at which time drift corrections are applied (par. 198). After passing the outer marker, wind corrections should be proportionately reduced in amount as the end of the runway is approached. It is extremely important that the heading be carefully maintained during the last three miles of the approach and that no corrections are applied in amounts greater than 2°.

b. Upon reaching the outer marker, if glide slope receiver is not available, reduce power to establish a descent at the rate listed on the ILS chart. As the aircraft progresses inbound, crosscheck the altimeter until minimum altitude is reached. Consult the ILS approach chart for the indicated altitude, since the minimum indicated altitude may vary considerably at different installations.

c. Upon reaching the outer marker, if a glide slope receiver is available, reduce power to establish a descent at the rate listed on the ILS chart. As the aircraft progresses inbound, cross-check the altimeter over the middle marker to determine the accuracy of the rate of descent. Consult the ILS chart for the correct altitude since the altitude at which the glide path intersects the middle marker will vary considerably at different installations.

Warning: **If the altimeter indicates a deviation of more than 50 feet from the prescribed altitude (with the altimeter set accurately and allowance made for instrument error), a go-around is initiated if the ground is not visible. If the altitude is correct and the approach is continued in preparation for an instrument landing, decrease the rate of descent when the aircraft is approximately 50 feet above field elevation.**

d. Some of the ILS installations provide compass locators at both the outer and middle markers (fig. 136). If this aid is available, tune the radio compass to the outer compass locator. After passing it on the final approach, retune to the frequency of the middle compass locator. Use the locators as a check on marker passage and the reliability of the localizer needle indications.

e. Utilization of the back course of an ILS may be authorized if suitable fixes exist which will allow a pilot to establish his position and proceed straight in without a glide slope on the localizer back course to the airport. If the instrument approach runway is equipped with a glide slope serving the back course of the ILS localizer, a separate procedure will be formulated. The back course will not be used for approaches when it is listed as "restricted" or "unusable".

f. The most critical period of the approach, in pilot technique, occurs while the pilot is busy holding the aircraft on the localizer course, maintaining constant airspeed, adjusting the power for a uniform rate of descent, and watching for the marker signals to determine distance and altitude from the runway. Strict attention to all of these factors is essential for a successful ILS approach.

202. Missed Approach (ILS)

Observe the minimum altitude listed on the appropriate chart. If the aircraft is not below the overcast when the minimums are reached, initiate a missed approach. The missed approach will also be executed—

a. When the aircraft's altimeter indicates an excessive deviation when crossing the middle marker.

b. When visibility is below minimum.

c. When directed by ATC.

Note. In the event of a missed approach, the pilot will follow the standard missed approach procedure, climbing to a missed approach altitude on the specified course or as directed by ATC and will contact approach control for further clearance (fig. 136).

CHAPTER 18
GROUND CONTROL APPROACH (GCA)

203. General

Ground Controlled Approach (GCA) is a radar "talkdown" system which enables a pilot to make a landing under conditions of reduced ceiling and visibility. No special airborne electronic equipment is required, except appropriate transmitter and receiver for communication with ground unit. Pilot checkout and familiarization with the system is not absolutely essential, although highly advisable.

204. Operation of Radar Systems

a. General. The ground radar operator obtains accurate and continuous information about the location of the incoming aircraft with respect to the correct approach to the runway. This information, in the form of range, azimuth, and elevation data, is interpreted by the operator as lateral and vertical deviations from the preselected approach or glide path.

b. Air Surveillance Radar. Initial radar contact with GCA is made with air surveillance radar. This radar scans 360° over a minimum range of 30 miles. In order to get a map-like display of relative distance and direction of the aircraft, a transparent plastic map (permitting the controller to see aircraft position in relation to radio range, fan markers, and obstructions) is used with a planned position indicator (PPI) presentation (fig. 137). The PPI utilizes two range scales, one a 30-mile range scale and the other a 15-mile range scale, each with concentric circles representing 5-mile intervals. The controller interpolates to determine other distances. The PPI presentation gives the controller no altitude information, and the pilot must watch his altimeter and rate of descent. The controller advises what the appropriate altitude should be at designated points. In the PPI approach, the controller vectors the pilot by radio to a point where he can begin his descent toward the selected runway. At installations utilizing both ASR and precision radar systems, the aircraft

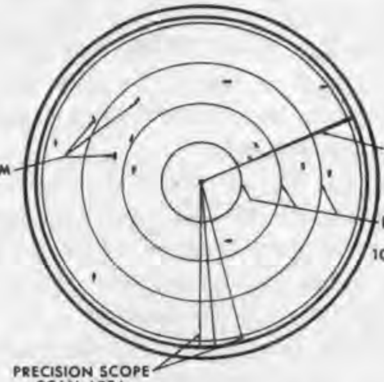


Figure 137. PPI presentation.

is directed by the precision radar upon reaching the final approach.

c. Precision Approach Radar. Precision approach radar (PAR) (fig. 138) is an entirely separate radar set which accurately determines the range, bearing, and elevation of an aircraft on final approach to a runway. Its accuracy is such that it can detect variations of 300 feet in range. At one mile, a variation of 10 feet elevation and 20 feet in azimuth can be discerned. Since it is only designed to watch aircraft on approach, its range is limited to 10 miles and its antenna-scans are restricted to 20° of azimuth and 7° of elevation. The data received from each of the precision scans is presented in a single scope with two pictures, the elevation picture being at the top. The precision scope has a two-mile range scope for the latter portion of the approach. A controller can follow and correct the approach of an aircraft, with accuracy, down to within 40 to 50 feet of the ground. Under favorable conditions, it is possible to determine point of touchdown within 10 to 15 feet.

205. Communications

a. General. The pilot desiring GCA assistance must establish communications with the appropriate control tower for preliminary approach

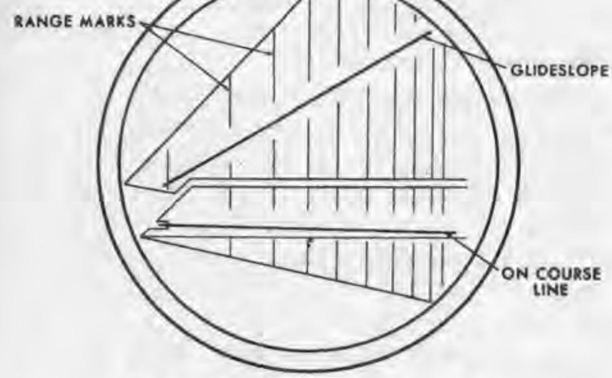


Figure 138. Precision radar scope.

instructions. He will then be instructed as to the proper frequency for contacting the GCA unit. Jeppesen GCA procedure charts give the frequencies that GCA operated units guard and transmit. Radio facility charts are the source of this information for military GCA units. Pilots are expected to read back altimeter settings and all headings and altitude instructions given by the GCA unit, except when instructed by the controller to remain silent during the final approach. Do exactly as the approach controller instructs, and, if for some reason his instructions cannot be followed, notify the controller immediately. If no transmission is received during any one-minute period, while in the initial approach phase, execute a standard missed approach or as directed by ATC, and contact ATC for further clearance.

b. GCA Voice Procedure. Assume that aircraft 6164 has just completed the initial position report to GCA for a landing at *X* field. (After initial contact, reduction of the 4-digit call sign is authorized.) If communication on final approach is lost for more than 5 seconds during a PAR approach, or for more than 30 seconds as on an ASR approach, a missed approach will be executed. Following is an example of standard GCA voice procedure:

GCA: 6164, turn right, heading 050, descend to 1,500.

Pilot: Roger, 64, 050, 1,500, over.

GCA: 6164, your last communication procedure is as follows: If no transmission is received for any one minute in the search pattern or any 5 seconds on final, climb to 1,600 on *X* Homer. Hold northwest, left turns, 2-minute legs with an inbound bearing of 105°. Contact approach control for further clearance.

Pilot: Roger, 6164.

GCA: 6164, I have positive radar contact. Your position is range 7 miles southeast, over.

Pilot: Roger, 6164.

GCA: 6164, the weather at *X* field is 100 ragged ceiling, visibility ½ mile, light rain, wind southeast 6, alimeter 29.98. Read back altimeter.

Pilot: Altimeter 29.98, 64.

GCA: 6164, you will be making a left hand precision approach to runway 14, active runway 14. Advise precision minimums are ceiling 300, visibility ¾ mile, over. (For pilots unfamiliar with field length, width and amount of overrun, such information will be given at this time.)

Pilot: Roger, 64.

GCA: 6164, turn left to heading of 320, altitude 1,500 downwind leg, over.

Pilot: Roger, left 320, altitude 1,500, 6164.

GCA: 6164, your position now is range 6 miles southeast, over.

Pilot: Roger, 64.

GCA: 6164, perform initial cockpit check, reduce to low cruise, over.

Pilot: Roger, 64, initial complete.

GCA: 6164, turn left to heading 230, altitude 1,500, base leg, over.

Pilot: Roger, heading 230, altitude 1,500, base, 6164.

GCA: 6164, perform final cockpit check, check gear down and locked, over.

Pilot: Roger, 64, final complete.

GCA: 6164, range now 8 miles northeast, intercept final in 1 mile. Tune transmitter to ______ megacycles, receiver to ______ megacycles for final controller, over.

Pilot: Roger, 64, transmit ______ megacycles, receive ______ megacycles.

GCA: Army, 6164, this is your final controller. How do you hear me? Over.

Pilot: 6164, loud and clear.

GCA: Turn left to heading 140, altitude 1,500, final approach, over.

Pilot: Roger, left, heading 140, altitude 1,500, 6164.

GCA: 6164, at this time set and line your gyro, do not reset for the remainder of this run, over.

Pilot: Roger, 6164.

GCA: 6164, this is your final controller. You need not acknowledge any further transmissions unless unable to comply. Your range 7 miles from touchdown. Turn right 5°, heading 145, altitude 1,500, range 5 miles from touchdown, intercepting glide path in approximately 30 seconds, suggest that you make final flap setting, recheck gear down, heading 145, altitude 1,500, approaching glidepath now, start your descent. Suggest 450 feet per minute. Entry to glidepath good. Turn left, heading 142, range 4 miles from touchdown. Going above glide 10–20 feet, adjust your rate of descent. Heading 142, on centerline, on glidepath, assume normal rate of descent. Drifting left, turn right 1°, heading 143, on glidepath 3½ miles from touchdown. Heading 143, on glidepath, on centerline, turn left 141, 3 miles from touchdown, now turn right, heading 142, on centerline, on glidepath, 2¾ miles from touchdown. Going below glidepath, adjust rate of descent, coming back to glidepath, assume normal rate of descent, on centerline, on glidepath, 2 miles from touchdown. Tower clears 6164 for a full-stop landing. On centerline, on glidepath. You are now passing through GCA IFR minimums, 1 mile from touchdown. Heading 142, approaching end of overrun, heading 142, on glidepath, approaching touchdown, over touchdown, heading 143, on glidepath. If you have the field in sight, take over visually and complete this full-stop landing. Contact tower on 123.3 or 121.9, otherwise execute missed approach, contact approach control for further instruction. GCA standing by, over.

Pilot: Have field in sight, 64, out.

GCA: Roger, out.

206. Flight Procedures

Information concerning availability of GCA units can be found in the Jeppesen Manual, Radio Facility Charts, and Airman's Guide. When a pilot has been cleared by Air Traffic Control for a ground controlled approach, the controller gives instructions to the pilot when he reports his position. These initial instructions to the pilot enable him to get into the ground controlled approach traffic pattern. Such patterns will provide basic transition and vectoring courses from the associated primary facilities or fixes upon which the initial approach to the area was conducted. Regardless of the types of pattern flown, the complete approach procedure is divided into four phases—the initial approach; the final approach; the prelanding phase; and the touchdown and landing roll.

a. Initial Approach. The initial approach phase of the pattern includes any holding or vectoring in the area. Proper airspeed during this phase is the one which is normally used on the downwind leg of a visual pattern. During the initial approach phase, the GCA operator gives the latest weather, direction of landing, length of runway, wind direction, other landing information, and emergency procedures. It is advisable to perform the landing check at this time because after reaching the final approach, there is not much time for anything except following instructions given by GCA. The procedure or transition patterns in this phase of the approach provide at least 1,000 feet clearance 3 miles each side of the pattern course and 500 feet clearance either side within an additional 2 miles either side of course.

b. Final Approach. The final approach phase of the pattern extends from the approach end of the runway to the maximum operational range of the precision radar (10 miles). Under normal conditions, interception of the final approach will be made at a distance of not less than 5 miles from the approach end of the runway and at an oblique angle rather than at right angles. Once on the final approach course, the final landing check is made and the aircraft is slowed to final approach speed. The controller will, while aircraft is on the approach course, tell the pilot when he is approaching the glidepath and when to start the desired rate of descent. The controller normally repeats any emergency procedure given initially in the initial approach phase.

c. Prelanding Phase. The prelanding phase of the pattern is flown after breaking out of the overcast, and continues until just before physical contact is made with the runway. During this phase, changeover from controlled flight by the GCA crew to visual flight by the pilot should be gradual. The pilot should continue to adhere to the instructions given by the controller until it is evident that visual contact with the ground will not be lost.

d. Touchdown and Landing Roll. During this phase, the approach controller notifies the pilot when the aircraft is over the end of the runway. If visual contact has not been established by this time and the aircraft is in a landing attitude with a rate of descent of less than 500 feet per minute, it is possible to execute a landing by maintaining this attitude until contacting the runway.

207. No-Gyro Approach

If the directional gyro becomes inoperative, the pilot will be directed in the pattern and on final approach to "turn left" or "turn right." These turns will be standard rate turns of 3° per second. The controller will time the turn and, when the approximate heading is reached, the pilot will be directed to "stop turn." The ability to roll smoothly and rapidly in and out of a standard rate turn, while maintaining a compass heading on partial panel, are the only requisites for flying no-gyro approaches

208. Missed Approach

During the initial approach phase and on the final approach, GCA will give the missed approach course and altitude. The GCA minimum for Army aviators is listed in AR 95-8. This minimum or the published minimum for the particular GCA, whichever is higher, will be adhered to by Army aviators. The missed approach will be initiated at the point—

a. where the aircraft has descended to authorized landing minimums and visual contact has not been established,

b. when directed by ATC or the GCA unit,

c. when no transmissions are received for a period of 5 seconds during final approach with precision radar and for a period of 30 seconds on final approach utilizing surveillance radar only.

CHAPTER 19

AUTOMATIC DIRECTION FINDER (ADF) APPROACH

209. General

The letdown and low approach phase of an ADF problem is a combination of intercepting bearing (par. 150), tracking (par. 151), and holding (par. 183), if necessary. The successful completion of the approach requires precision in both flying techniques and planning. Approach procedures are published in the Jeppesen Manual and USAF and USN Pilot's Handbook. It is extremely important to plan and memorize the approach. Use the appropriate approach chart as an aid at all times during the approach to make sure that proper procedures are followed.

210. Flight Procedures (ADF)

a. Procedure Turn. Whenever outbound from the radio facility, for example outbound on holding course, it may be necessary to reverse course. If so, execute any one of the three types of procedure turns (par. 182).

b. Holding. The procedure for entering an ADF holding pattern is the same as that used for entering any standard holding pattern (par. 183). To fly a standard ADF holding pattern (fig. 139)—

(1) Follow the specified magnetic course inbound to the holding fix.

(2) Make a 180° standard rate turn to the right.

(3) Fly a course outbound for two minutes. Commence timing when 90° to the station.

(4) Make another 180° turn to the right and fly the specified magnetic course inbound to the station.

(5) When approach clearance has been received, execute the prelanding check and start the approach. Do not allow the aircraft to descend below the procedure turn altitude prior to heading inbound on final approach.

(6) Start the approach from any position in the holding pattern provided a prelanding check and safe descent to final approach altitude can be made prior to reaching the station.

c. Approach.

(1) Make radio contact according to instructions received from the traffic control agency, or, in the absence of such instructions, as soon as practicable.

(2) Always make radio contact prior to reaching the station.

(3) If clearance for approach is received prior to reaching the station, make an immediate descent to the initial approach altitude if at a higher altitude.

(4) When crossing the station on initial approach, turn to intercept the outbound bearing, reduce airspeed to low cruise, note the time, make a position report, and perform the prelanding check.

(5) While tracking outbound, make a descent to procedure turn altitude.

(6) Start the procedure turn as soon as practicable (normally within two minutes after station passage). Make the procedure turn in the direction prescribed in the approach instructions.

(7) After completing the procedure turn, let down to final approach altitude while tracking to the station on the approach course. Final approach area extends laterally 4.34 miles on each side of the final approach course at a distance of 10 miles from the facility, decreases uniformly inbound to 1.7 miles on each side of the course, and provides 500 feet clearance above obstructions. Final approach altitude *from* the facility provides obstruction clearance of 300 feet at 6 miles, 400

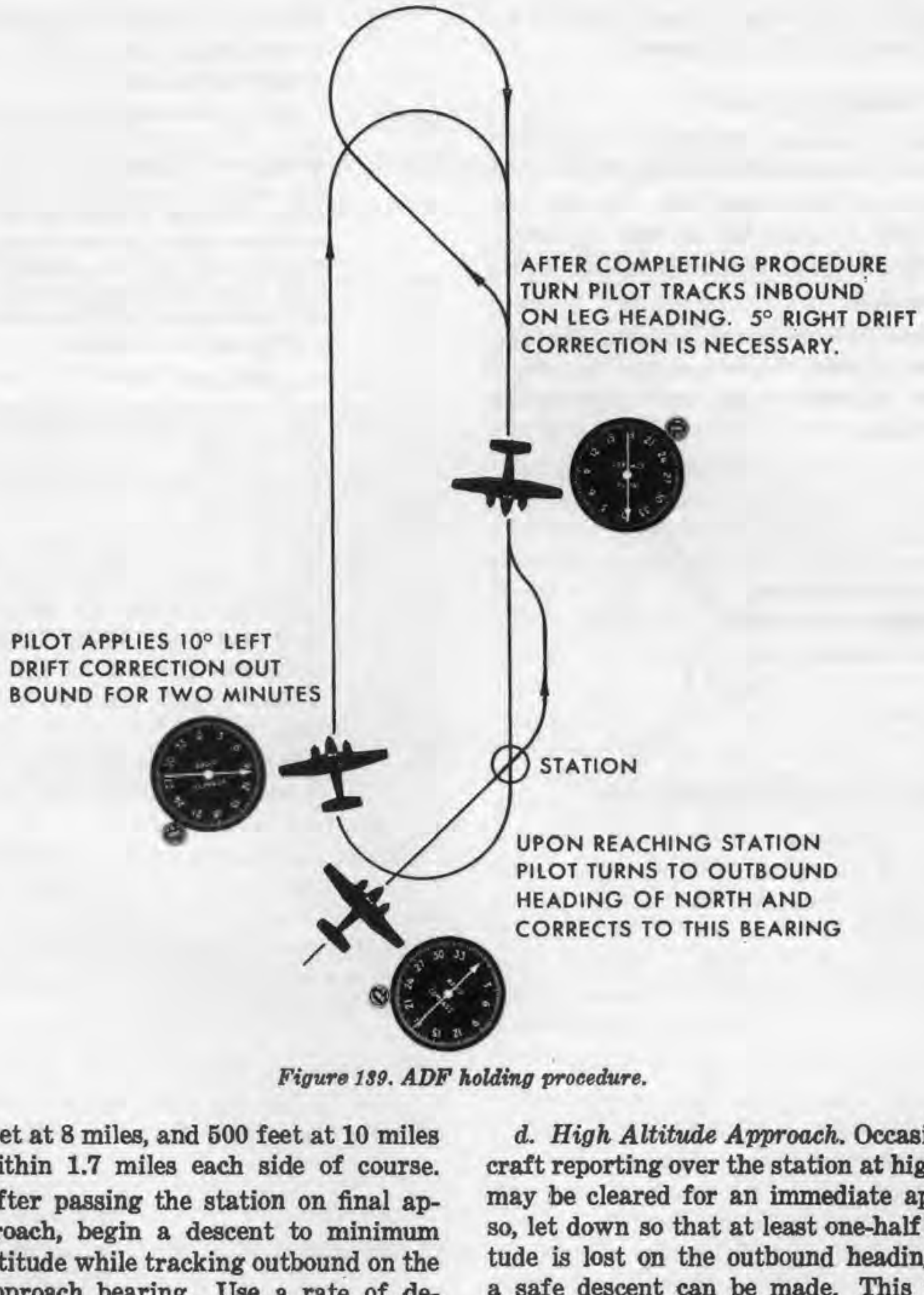


Figure 139. ADF holding procedure.

feet at 8 miles, and 500 feet at 10 miles within 1.7 miles each side of course.

(8) After passing the station on final approach, begin a descent to minimum altitude while tracking outbound on the approach bearing. Use a rate of descent that will assure reaching the minimum altitude before the time from the station to field has elapsed.

(9) If runway is not in sight after station-to-field time as elapsed, make a missed approach as outlined on the approach chart, and immediately contact the controlling agency for further instructions.

d. High Altitude Approach. Occasionally, aircraft reporting over the station at high altitudes may be cleared for an immediate approach. If so, let down so that at least one-half of the altitude is lost on the outbound heading, provided a safe descent can be made. This will assure final approach altitude before reaching the low cone on the inbound heading.

e. Missed Approach. The time required to fly from the station to the field must be determined by the pilot from airspeed, wind, and distance. The distance shown on the approach chart is the distance from the station to the nearest usable portion of the field. If field is not sighted after station-to-field time has elapsed, use pull-up procedure listed on the chart, report missed approach, and request further clearance.

211. Low Visibility Approach

If existing conditions (borderline visibility) are such that it is impractical to execute a visual straight in or circular approach to a landing, alinement with the service runway is accomplished in one of these two methods (fig. 140):

a. First Method.

(1) Turn directly downwind over the service runway. Upon passing the end of the runway, turn 90° (preferably right).

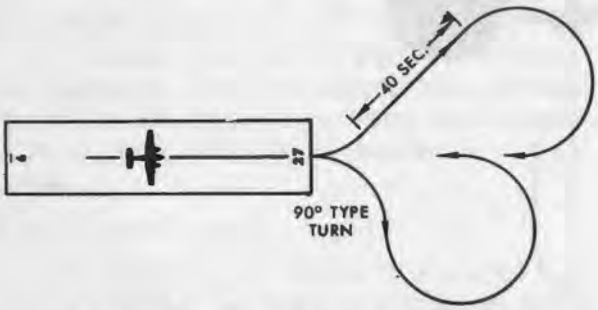


Figure 140. Low visibility approaches.

(2) After reaching 90° change of heading, immediately start a 270° turn in the opposite direction.

Note. Both turns should be standard rate turns. By making the first turn to the right, the pilot in a side-by-side aircraft will be on the inside of the final turn, thereby affording better visibility of the runway. The entire maneuver should be executed by reference to instruments until the aircraft is definitely lined up on the landing approach or until the approach can be continued entirely by visual contact with the runway.

b. Second Method.

(1) Turn directly downwind over the service runway.

(2) At the lee end of the runway, turn 45° to the right.

(3) Fly 40 seconds on this heading, then start a standard rate turn to the left until the heading of the runway has been reached. This heading should place the aircraft on the landing approach closely lined up with the runway.

Note. Necessary corrections for wind must be made in executing these maneuvers.

CHAPTER 20
LOW FREQUENCY RADIO RANGE APPROACH

212. General

a. Approach charts found in the Jeppesen Manual and the USAF and USN Pilot's Handbook, contain complete information on instrument approach procedures. This information includes—magnetic courses, minimum altitudes, graphic description of the range, associated airports, radio facilities, and frequencies. Also included is a sketch of the letdown which shows minimum altitudes, direction of procedure turns, and field elevation.

b. Before the letdown can be started, the station must be tuned in and identified, clearance received from the appropriate control agency, and the initial approach to the station completed. By following the range leg to the cone of silence, valuable information on wind direction and speed can be estimated.

c. Make the approach in accordance with the clearance given and the minimums established. After locating the station, check time over the station, turn to outbound heading of approach leg plus or minus wind correction, reduce power, and give position report to the radio station.

213. L/MF Procedure Turn

While making the procedure turn (par. 182) to the inbound beam heading, descent may be made to procedure turn minimum altitude (fig. 141).

214. L/MF Holding

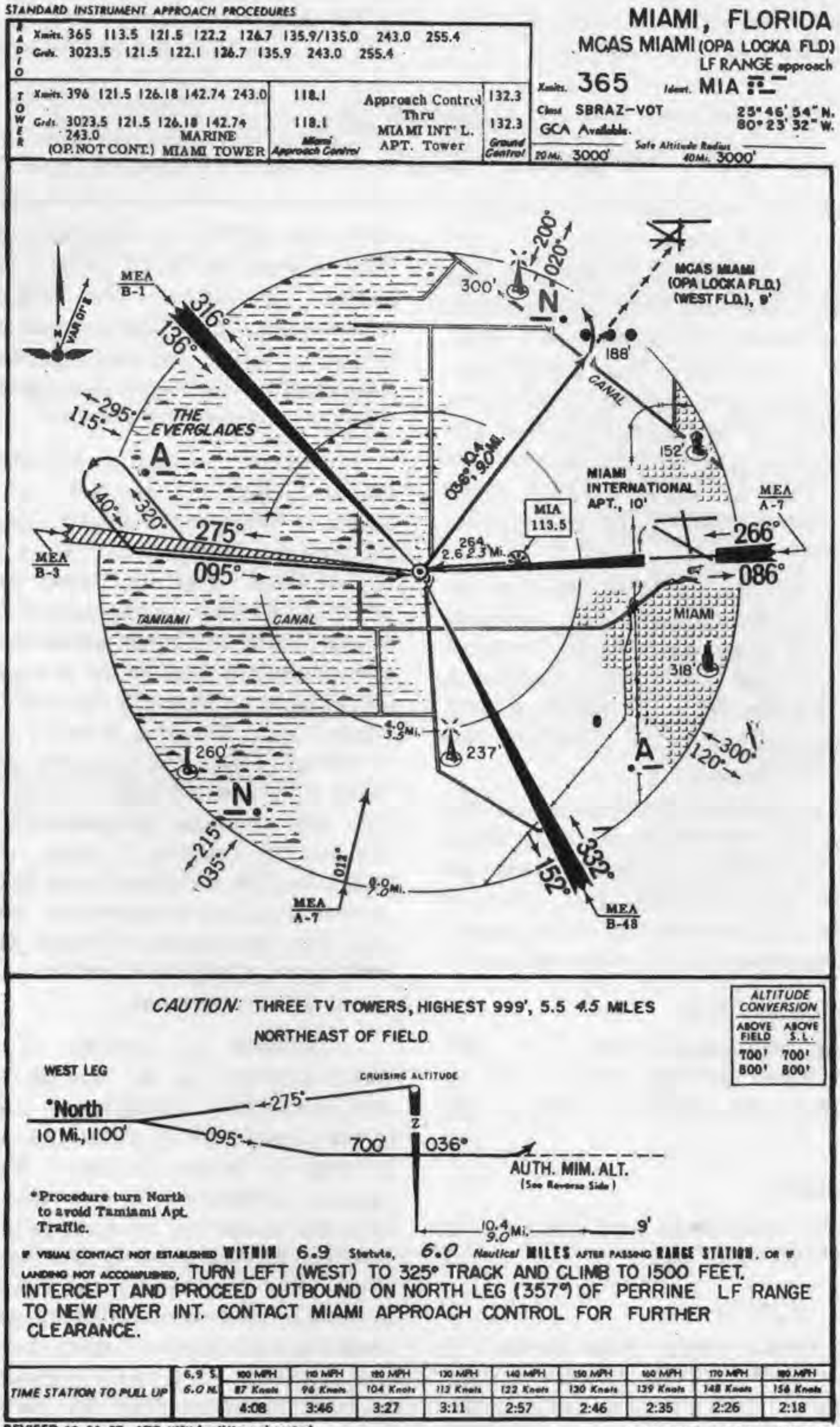
L/MF holding procedures are identical to those used with ADF (par. 210).

215. Approach (L/MF)

The final approach starts when headed inbound after completion of the procedure turn. At this stage, the aircraft should be put in readiness for landing. Time is carefully checked to determine maximum station-to-field time. The altimeter setting is rechecked and low cone altitude reached as rapidly as safety permits. The low cone will be of minimum size and every effort should be made to pass through it for positive recognition. This will require exact beam following. Volume must be closely controlled. Failure to recognize station passage will require a pull-up and another letdown thus wasting valuable time and fuel.

a. Airports Located on the Range Leg. Since station-to-field legs are flown at low altitudes, precision flying is a necessity. Correct altimeter settings are imperative. Do not exceed station-to-field time. This time must be corrected for wind to the best of the pilot's knowledge. Do not go below minimum altitudes. If the associated airport is located on a range leg, the on-course must be carefully maintained until visual contact with the field is made or until pull-up is evident. Check the time over the low cone and reach minimum altitude as soon as practicable. This will minimize the possibility of not seeing the field if visibility is poor. At the letdown minimum, the maximum safe distance from the station must not be exceeded. When station-to-field time has elapsed, if visual contact with the field is not established, pull up and try again or proceed to an alternate.

b. Airports Not Located on a Range Leg. When airports are not located on a range leg, station-to-field bearings are used. No aural check is available to determine how closely the bearing is being followed. Positive station passage recognition is necessary to determine the time to take up the bearing to the field. The heading necessary to fly this bearing must include wind correction; and the success of the approach will depend on the accuracy with which wind was determined during previous stages of the approach. The radio compass may be used to track outbound from the station to the airport. Often, the airports off the range are equipped with nondirectional radio beacons, and direction finding equipment may be used to complete the approach.



TIME STATION TO PULL UP	6.9 S. / 6.0 N.	100 MPH 87 Knots	110 MPH 96 Knots	120 MPH 104 Knots	130 MPH 113 Knots	140 MPH 122 Knots	150 MPH 130 Knots	160 MPH 139 Knots	170 MPH 148 Knots	180 MPH 156 Knots
		4:08	3:46	3:27	3:11	2:57	2:46	2:35	2:26	2:18

Figure 141. L/MF radio range approach.

216. Missed Approach (L/MF)

The missed approach is identical to ADF missed approach procedures except that the pull-up may be necessitated by failure to recognize station passage. Whatever the reason, do not hesitate. Commence the pull-up in accordance with established procedure, report intentions, and request further clearance (fig. 141).

CHAPTER 21
VHF OMNIRANGE APPROACH

217. General

The omnirange is an ideal letdown aid when the facility is properly oriented with reference to the instrument runway. The instrument approach procedures for VOR (fig. 142) are similar to other approaches. Approach charts are found in the Jeppesen Manual and USAF and USN Pilot's Handbook.

218. Flight Procedures (VOR)

a. Procedure Turns. Procedure turns may be made in any accepted manner. Make a 45° turn from the outbound bearing with the heading indicator. While completing the time on the 45° leg of the procedure turn, rotate the course selector 180° to the inbound heading. After the desired time has elapsed, execute a standard rate turn of 180°. This turn is always started away from the station. As the deviation indicator moves toward center, start the rollout to the inbound heading.

b. Holding. Holding on VOR (fig. 143), use the standard elliptical holding pattern (par. 183) unless otherwise specified. As soon as the sense indicator has settled to FROM, start a 180° standard rate turn to the right. During this turn, rotate the course selector 90° clockwise. This will cause the deviation indicator to read full right. As the outbound heading is reached and the aircraft crosses a perpendicular to the station, the deviation indicator will center momentarily and then indicate full left. As the needle centers, note the time because this marks the beginning of the 2-minute outbound leg. While maintaining the outbound heading, set the course selector back to the inbound course. After 2 minutes have elapsed, execute another standard rate turn to the right to bring the aircraft back to the inbound course. If the holding pattern is nonstandard requiring left turns, the course selector is turned counterclockwise after station passage.

c. Approach. The omnirange approach (fig. 142) is similar to the radio compass approach. After receiving approach clearance, the final approach radial is followed outbound from the station, descending no lower than the specified procedure turn altitude. On the inbound flight to the station, after making the procedure turn, descend to final approach altitude. The final approach obstruction clearance to the facility provides 500 feet vertically for a distance of 10 miles, with a width of 1.25 miles each side at the facility and increasing to 4.34 miles at 10 miles. The final approach obstruction clearance from facility to airport is the same as for L/MF radio range and ADF (par. 210*c*(7)). The time of station passage is noted on final approach and descent made to the minimum altitude. If visual contact with the ground is not established, minimum altitude is held until sufficient time has elapsed to allow the aircraft to be over the airport. If a landing cannot be accomplished by visual reference to the surface at that time, a missed approach is executed.

d. Missed Approach. The appropriate approach chart shows the missed approach procedure (fig. 142). This procedure specifies an altitude and course on which to climb. The specified course is a radial; however, some charts specify, as part of the missed approach procedure, a magnetic course that is flown to reach the course. When executing a missed approach, first start climbing in the correct direction and, second, advise ATC of the missed approach.

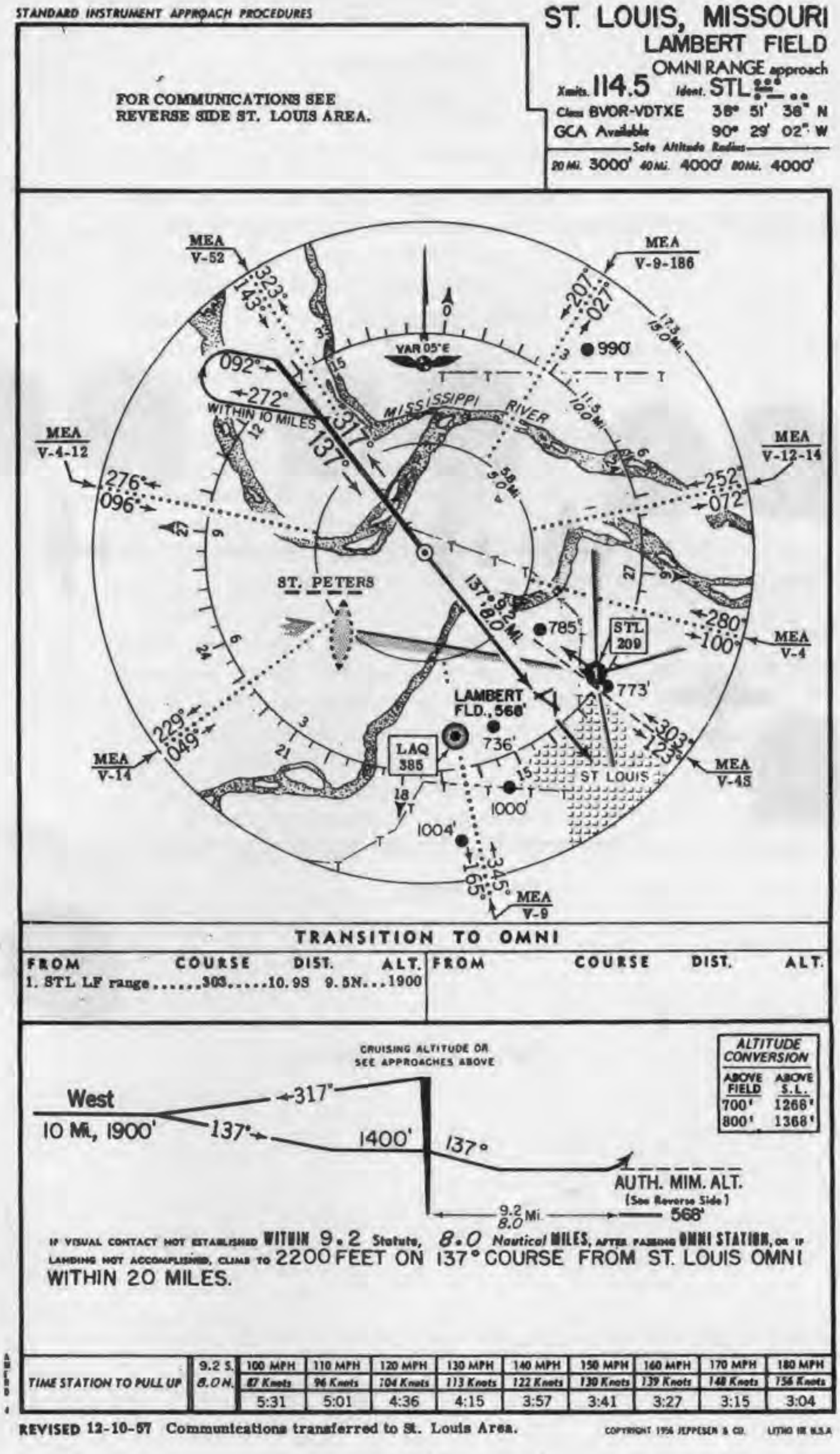


Figure 142. VOR approach.

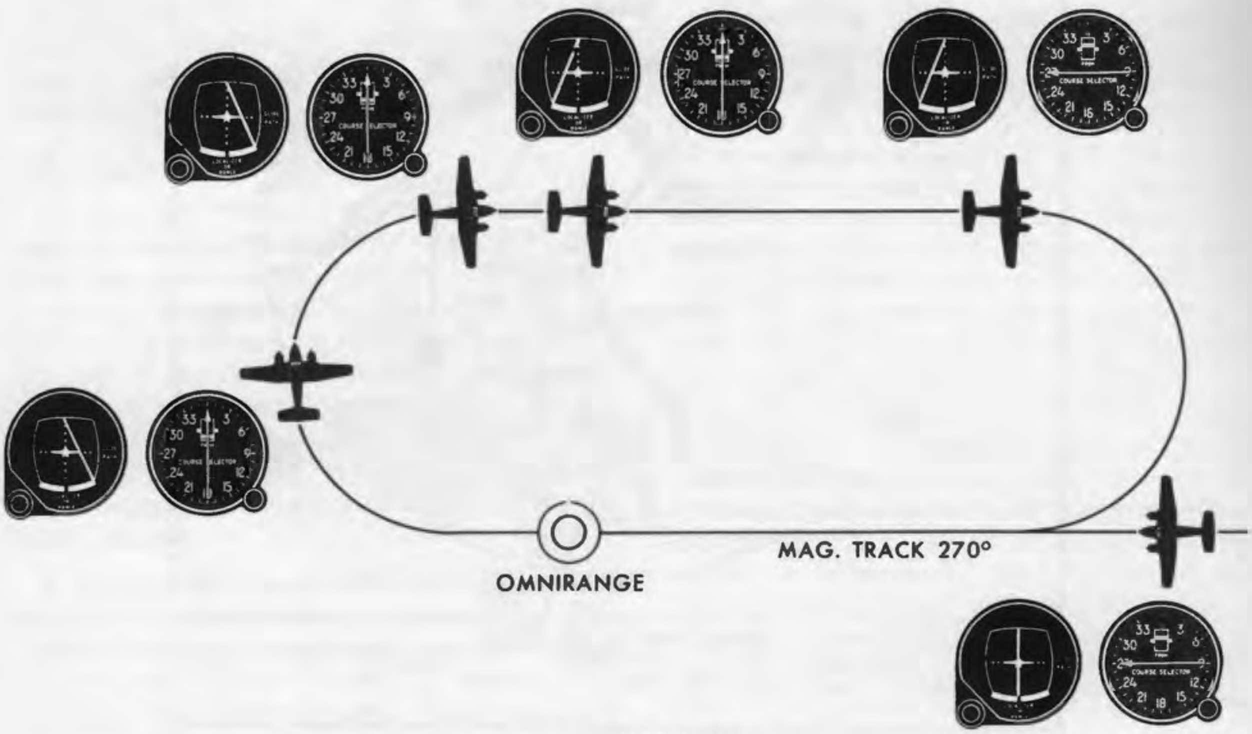


Figure 143. VOR holding.

APPENDIX I
REFERENCES

AR 95–8	Flight Regulations for Army Aircraft.
AR 95–11	Flight Service Interphone Communications System Procedures.
AR 95–14	Army Aviation Flight Information.
AR 320–5–1	Dictionary of United States Army Terms.
AR 320–50	Authorized Abbreviations and Brevity Codes.
FM 21–5	Military Training.
FM 21–6	Techniques of Military Instruction.
FM 21–30	Military Symbols.
TM 1–215	Instrument Flying, Theory and Procedures.
TM 1–250	Principles of Fixed Wing Flight.
TM 1–260	Principles of Rotary Wing Flight.
TM 1–300	Meteorology for Army Aviation.
TM 11–2557	Jeppesen Airway Manual.
TM 11–2557–26	United States Manual of Criteria for Standard Instrument Approach Procedures.
TM 11–2557–27	ANC Procedures for Control of Air Traffic.
DA Pam 108–1	Index of Army Motion Pictures, Filmstrips, Slides, and Phono-Recordings.
DA Pam 310-series	Military Publications Index (as applicable).
ANC	Procedures for the Control of Air Traffic.
CAA Bul. No. 1	Instrument Landing System.
CAA Bul. No. 2	Location Markers and Homing Facilities.
CAA Bul. No. 3	Visual-Aural Ranges and Omniranges.
CAA Bul. No. 6	Radar Fundamentals and Surveillance, Precision and Route Radar.

APPENDIX II
CLEARING AND CONTROLLING AGENCIES

1. Military Flight Service

Military Flight Service is an operation of the USAF Airways and Air Communications Service and is divided into various areas of operation (TM 11–2557–1). Flight Service serves as a central operations office, and is available at all times. It is used when local operations facilities are not available or when an installation commander requests Flight Service to act as his clearing authority. However, a flight plan will be transmitted to Flight Service for each military flight regardless of who is the clearing authority (AR 95–8). Flight Service provides the following services:

a. Provides flight clearances.

b. Handles aircraft movement messages and flight plans.

c. Monitors inflight position reports.

d. Is a control agency and evaluation center for direction-finding nets.

e. Conducts communications searches for overdue aircraft.

f. Provides inflight advisory service (weather reports, air navigation hazard warnings, etc.) on request.

g. Disseminates air raid warnings.

h. Selects airfields for emergency use.

i. Prepares joint hurricane evacuation plans and coordinates evacuation.

2. Air Traffic Control

For Air Traffic Control information, refer to TM 11–2557 and TM 11–2557–27.

APPENDIX III
EMERGENCY PROCEDURES

1. General

Emergency procedures described below provide general guidelines only. Circumstances involved in each emergency situation vary enough to preclude the establishment of exact detailed procedures to be followed.

2. Two-Way Radio Failure

If two-way radio communication between aircraft and ground station fails, the pilot will proceed as follows:

a. If operating under VFR conditions, proceed under VFR and land as soon as practicable; or,

b. If IFR conditions exist, proceed according to the last air traffic clearance.

3. IFR Procedure

If the pilot proceeds according to the latest traffic clearance but has not received clearance for an approach, and if instructions to the contrary are not received, he will proceed as follows:

a. If clearance has been received to the destination airport or the radio facility serving that point, maintain the altitude last assigned by ATC or the minimum enroute altitude, whichever is higher, to the radio facility serving the destination airport.

b. If clearance has been received to a point other than the destination airport, or the facility serving the destination airport, continue flight at the altitude last assigned by ATC or the minimum enroute altitude, whichever is higher, to the radio facility serving the destination airport.

c. If holding clearance has been received, comply with the clearance until such time as necessary to continue flight so as to arrive at the radio facility serving the destination airport at the expected approach time last received, maintaining the last assigned altitude or the minimum enroute altitude, whichever is higher.

d. If holding clearance has been received but no expected approach time, comply with the clearance until the time ATC has specified that further clearance may be expected; then continue, maintaining the last assigned altitude or the minimum enroute altitude, whichever is higher.

e. Descent from cruising altitude to the radio facility serving the destination airport will be made on the final approach course and shall start at the expected approach time last received. If no expected approach time has been received ·d acknowledged, descent will be started at the E 'A indicated by the elapsed time specified in th flight plan, or as soon as possible thereafter.

Note. All altitudes below the altitude at which the aircraft is to arrive over the destination fix are held open by ARTC on the approximate course for a period from ETA to 30 minutes thereafter.

4. Requesting Navigational Aid

a. If no immediate emergency exists but a pilot is in need of navigational aid, he may call for a DF steer (par. 163). Precede the call by the word "security" repeated three times. If the name of the DF station is known, call the station by name. After contacting the station, transmit a voice signal at a constant rate for ten seconds; a short count is preferred.

b. If an emergency exists and a pilot needs immediate navigational aid, precede the transmission with the word "pan" repeated three times; then proceed as outlined above.

5. Radar Assistance

When lost or in distress and unable to make radio contact, alert Air Defense Command (ADC) radar system as follows:

a. If only the receiver is operating, fly a triangular pattern to the right, holding each heading for 2 minutes. Complete a minimum of two such patterns before resuming original course, then repeat pattern at 20-minute intervals.

b. If the transmitter and receiver are both inoperative, fly the same pattern but use all left turns instead of right turns.

c. When contact is established with the rescue aircraft, fly trail formation with escort.

6. Use of Air Defense Command Service

Air Defense Command radar installations will provide advisories or vectoring services for avoiding dangerous weather. The primary mission of ADC is the defense of the country; therefore, pilots should exercise good judgment when requesting service from ADC radars. When contacting ADC radars for ADC vectoring service, the following procedures are used:

a. Using a frequency of 121.5 mc., transmit: "Stargazer, this is (identification, position, and heading) IFR/VFR flight plan, over." The call sign "Stargazer" automatically indicates a request for radar advisory and vectoring service. After contact, use the call sign of the radar station which responds.

b. If on an IFR flight plan, guard the normal ATC frequency while in contact with the radar. If it is necessary to leave the normal ATC frequency while in contact with radar, advise ATC, "Changing to radar advisory service." When using ADC service, the following rules will be observed:

(1) Obtain new ATC clearance if deviation from course is required.

(2) Immediately return to normal enroute frequency when radio or radar contact is lost or advisory service is completed.

Note. Information furnished by a radar facility is advisory only. Responsibility for safe aircraft operation rests with the pilot.

APPENDIX IV
CRUISE CONTROL

1. General

Cruise control is the scientific operation of an aircraft to obtain the greatest practical efficiency for the type of flight and the aircraft being flown. If the objective of the flight is speed, the engine is operated at maximum efficiency. If the objective of the flight is range, the aircraft should be operated at power settings and airspeeds that will result in maximum range. If neither maximum speed nor maximum range is a flight requirement, the aircraft should be operated for the most efficient engine output possible at the desired airspeed.

2. Efficiency Factors

a. Aerodynamic Efficiency. This is the efficiency of the wing and involves several variables such as air density, angle of attack, lift, and drag. These variables are explained in TM 1–250 and TM 1–260.

b. Engine Efficiency. Engine efficiency involves mechanical, thermal, and volumetric efficiency, and fuel consumption. However, from a pilot's point of view, engine efficiency is best when the engine delivers maximum useful horsepower with minimum fuel consumption.

c. Propeller Efficiency. Propeller efficiency is closely related to aerodynamic efficiency because the propeller blades are airfoils. The variables to consider in propeller efficiency are drag, thrust, lift, and torque (TM 1–250 and TM 1–260).

3. Flight Procedures

Either maximum range, constant indicated airspeed, constant power, or maximum endurance may be the requirement for a flight.

a. Maximum Range. To obtain maximum range there are two procedures: theoretical and practical.

(1) The theoretical operation requires that the airspeed be reduced as the flight progresses and weight becomes less. This system is not satisfactory because the airspeeds are comparatively low and the aircraft is somewhat unstable in rough air where control of altitude at slow speed requires joggling of the power to restablize the aircraft.

(2) In practical operation, the airspeed is increased over that required for theoretical range. The extent of this airspeed increase amounts to 3 or 4 percent. Range is reduced 1 or 2 percent under the theoretical range operation.

b. Constant Indicated Airspeed. Maximum range requires that airspeed be reduced as the weight of the aircraft is decreased by fuel consumption. However, if the indicated airspeed is held constant, the lightened aircraft will be operating at progressively smaller angles of attack. This will result in little loss of range provided the proper airspeed is selected. A certain range exists within which any increase in power results in reduced fuel consumption, and a decrease of power results in increased fuel consumption. By maintaining the desired constant indicated airspeed, this power-fuel relationship can be utilized advantageously. However, power must be reduced as the flight progresses, to prevent the airspeed from increasing as gross weight, and hence, angle of attack, becomes less.

c. Constant Power. In this procedure, the same power is maintained throughout the flight, conditions permitting. Constant power operation has a disadvantage in that the airspeed varies as it is subjected to the many variable factors arising in flight and that the same type of aircraft vary in airspeed under the same conditions of power, weight, and altitude.

d. Maximum Endurance. This procedure is of little value except in emergency. It enables the aircraft to remain airborne the longest possible time on a given amount of fuel. The amount of power required to remain aloft increases with an increase in altitude. Consequently, to fly at as low an altitude and airspeed as possible achieves maximum endurance.

4. Effect of Wind and Altitude

a. Wind. The effect of wind, together with airspeed, determines groundspeed and time required for a flight. The best economy for cruising is obtained when the greatest number of miles are flown using the least amount of fuel.

b. Altitude. As speed is increased above that required for maximum range, higher altitudes are desirable because of reduced air pressure and therefore reduced drag. However, there are two factors that must be considered when flying at higher altitudes: the wind may increase or decrease groundspeed according to its speed and direction, and the climb to altitude may require more fuel than the amount that is saved, especially on short flights. At slow speeds the horsepower required decreases with a decrease in altitude, but at higher speeds the horsepower required reduces as altitude is increased.

5. Flight Operation Charts

It appears practically impossible to operate an aircraft at maximum aerodynamic, engine, and propeller efficiencies. Peak overall operating efficiency is a compromise of these three efficiencies and is the fundamental principle upon which flight operation charts are based. Flight operation instruction charts are included in the Pilot's Handbook of Operating Instructions of every aircraft, to supply the pilot with complete instructions regarding engine operation, fuel data, operating range data, and various other items of cruise control procedure. By using these charts, the pilot can operate the aircraft in the most efficient manner consistent with the type of mission or flight. The charts contain data on takeoffs, climbs, cruising, and landings.

APPENDIX V
IFR SHORTHAND

1. General

The volume of flight clearances which must be delivered by ATC does not permit excessive repetitions of the clearance. Nor does the speaking rate allow time for longhand copying of the clearance. Occasionally ATC will issue a clearance which differs from the original flight plan. In such cases, the pilot must be particularly alert to be sure he receives and understands the clearance given. Clarification should be requested if any doubt exists. As an aid in copying clearances, a series of symbols have been devised and standardized for use as clearance shorthand, commonly referred to as IFR shorthand.

2. Shorthand and Symbols

WORDS AND PHRASES	*SHORTHAND*
ABOVE 5,000 FEET etc.	$\underline{50}$
ADF	ADF
ADVISE	ADV
AFTER	<
AIRPORT	A
AIRWAYS L/MF (GREEN 5, RED 10, etc.).	G5, R10
AIRWAYS VICTOR (114, 97, etc.)	V114, V97
ALL TURNS LEFT	↖
ALTERNATE INSTRUCTIONS	( )
ALTITUDE 6,000—17,000 etc.	60–170
AND	&
APPROACH	AP
APPROACH CONTROL	APC
AS A FIX	FX
AT (USUALLY OMITTED)	@
BEFORE	>
BELOW 5,000 feet—ALL CLOUDS	$\overline{50}$ — $\overline{\oplus}$
CLEARS OR CLEARED	C
CLIMB TO	↑
CONTACT	CT
CONTACT (CHICAGO) CENTER	(CHI)
CONTACT (CHICAGO) APPROACH CONTROL.	(CHI
COURSE	CR
CROSS	X
CRUISE	—
DELAY INDEFINITE	DLI
DEPART	DP
DESCEND (TO)	↓
DIRECT	DR
DIRECTION (BOUND) EASTBOUND	EB
WESTBOUND	WB
SOUTHBOUND	SB
NORTHBOUND	NB
INBOUND	IB
OUTBOUND	OB
EACH	EA
ENTER CONTROL AREA	⋌Δ
ESTIMATED TIME OF ARRIVAL	ETA
EXPECT APPROACH CLEARANCE (TIME).	EAC
EXPECT FURTHER CLEARANCE	EFC
FAN MARKER	FM
FINAL	F
FOR FURTHER CLEARANCE	FFC
FOR FURTHER HEADINGS	FFH
GCA	GCA
HEADING	HDG
HOLD—DIRECTION (WEST)	H—W
IF NOT or IF NOT POSSIBLE	or
ILS	ILS
INITIAL	I
INTERSECTION	Λ
LEFT TURN AFTER TAKEOFF	LT
LOCALIZER	L
MAINTAIN	M
MIDDLE COMPASS LOCATOR	ML
MIDDLE MARKER	MM
NO DELAY EXPECTED	Λ
NONSTANDARD PATTERN (ONE MINUTE).	①
OMNIRANGE	OR
ON COURSE	OC
OUTER COMPASS LOCATOR	OL
OUTER MARKER	OM
OUT OF CONTROL AREA	Δ̸
OVER (IDENTIFICATION)	$\underline{\text{CHI}}$
PPI	PPI
PROCEDURE TURN	PT
RADAR VECTOR	RV
RADIAL—270°	270°R
RANGE (L/MF)	R
REMAIN WELL TO LEFT SIDE	LS
REMAIN WELL TO RIGHT SIDE	RS
REPORTING DEPARTING	RD
REPORT INITIAL	RI
REPORT LEAVING	RL
REPORT OVER	RO
REPORT PASSING	RP
REPORT REACHING	RR

WORDS AND PHRASES	*SHORTHAND*
REQUEST FURTHER ALTITUDE CHANGES ENROUTE.	RFACE
REVERSE COURSE	RC
RIGHT TURN AFTER TAKEOFF	RT
RUNWAY	RY
STANDARD RANGE	SR
STANDBY	SBY
STRAIGHT-IN	SI
TAKEOFF (DIRECTION NORTH)	T/O N
TOWER	T
TRACK	TR
TRAFFIC IS	TFC
TVOR	TVOR
UNTIL	U
UNTIL ADVISED (BY)	UA
UNTIL FURTHER ADVISED	UFA
VFR CONDITIONS ON TOP	VFR
VIA FLIGHT PLANNED ROUTE	FPR
VICTOR	V
VOR	VOR
WHILE IN CONTROL AREAS	△

3. Examples:

a. ATC clears Army 6209 to the Tallahassee omnirange, via direct Dothan, Victor 7. Maintain 3,000 feet while in control area. Contact Tallahassee Approach Control 10 minutes northwest of the Tallahassee omnirange for further clearance.

C R6209 TLH OR DR DHN V7 M 30 △
(TLH) 10″ NW TLH OR FFC.

b. ATC clears Army 6209 to the Meridian VOR, via direct Andalusia intersection, direct to Evergreen VOR, direct to Meridian VOR, maintain 8,000 feet while in control area. Cross airways Blue 55 and Victor 115 at 6,000 feet.

C R6209 MEI VOR DR ANL △ DR EVR
VOR DR MEI VOR M80
△ X B55 & V115 @ 60.

APPENDIX VI
FLIGHT PLANNING

1. Route Planning

While planning either a VFR or IFR flight route, analyze the following factors:

a. Weather. Ice, rain, fog, thunderstorms, etc., are major flight hazards and will be avoided, if possible. If hazardous weather cannot be avoided, a detailed analysis of the weather forecast will assist in determining the route and altitudes which are least hazardous and within the limitations of both pilot and aircraft. If enroute weather is beyond these limitations, an alternate route is selected, or the flight delayed until weather conditions improve. During preflight briefing, the weather forecaster will advise the pilot of weather hazards which may be encountered enroute.

(1) *Ceiling and visibility.* If the flight is VFR, determine if VFR conditions will exist throughout the flight. Unless the pilot holds a current instrument rating and the aircraft is equipped for instrument flight, marginal weather should be avoided. For an IFR flight, ceiling and visibility for both destination and alternate must be above minimums (AR 95–8).

(2) *Turbulence. Light turbulence* can be dangerous to rotary wing aircraft because of the instability of such aircraft; light turbulence presents no problem to fixed wing aircraft. While flying rotary wing aircraft, *moderate turbulence* is extremely dangerous and instrument flight nearly impossible. Moderate turbulence should be avoided in fixed wing aircraft if possible. *Heavy turbulence* should be avoided by all aircraft.

(3) *Pressure pattern flying.* Pressure pattern flying is altering a course in order to take advantage of the tailwinds around high and low pressure areas (TM 1–300). On long flights, much time and fuel can be saved by taking advantage of such winds; however, for flights of 500 miles or less, the extra distance required would probably cause a loss of time. During the preflight weather briefing, the forecaster can evaluate the advantage or disadvantage of pressure pattern flying for the flight.

b. Fuel Requirements. To plan adequate refueling points, study the performance charts in the aircraft handbook. These charts give the fuel consumption for various power settings, and an estimate of fuel for warmup, taxiing, takeoff, and climb to flight altitude. Also check proposed refueling points for type of service available (TM 11–2557–1). For fuel reserve requirements, see AR 95–8.

c. Air Traffic. ARTC publishes a list of *preferred* routes between most major air terminals which bypass high-density areas. By following these routes, enroute delays can be avoided. Restricted, prohibited, and warning areas may also influence the determination of route.

d. Aids to Navigation. Study enroute checkpoints and radio aids, and when selecting checkpoints, consider the type of aircraft being flown, pilot experience in this type of aircraft, the time and accuracy of weather information, the time of day or night, and reserve fuel available; then determine which checkpoints are most valuable to navigation (pars. 36 and 39). If using radio as a navigational aid, check NOTAMS to determine the dependability of the aids. Also check the type and condition of the radio equipment in the aircraft. (Low frequency navigational aids are of little value when flying through extensive thunderstorm activity.)

e. Terrain Elevation. Gross weight for density altitudes is found in the aircraft performance chart and determines maximum allowable altitude. High water-vapor content or high air temperature reduces the capabilities of the aircraft. If the maximum allowable altitude is not great enough to fly at the required altitude, reroute the flight over lower terrain. Bypassing large bodies of water may also require alteration of the route. Consult AR 95–8 for oxygen requirements.

2. Final Flight Preparations

a. Weather. After the route has been determined, the weather must be reevaluated for the following factors:

(1) *Winds aloft.* Once the route has been established, the winds aloft must be studied to determine the altitude at which the most favorable winds exist. (Winds aloft are "true winds" and must be converted to magnetic winds when using published airway bearings.)

(2) *Temperature aloft.* Temperature aloft is used in calculating true airspeed and in determining icing and turbulence levels. Altitudes which provide favorable winds may also be altitudes where icing and turbulence exist.

b. Chart Preparation. Sectional or WAC charts should be prepared for IFR and VFR flights and are vital when radio failure occurs. On these charts, the course is drawn showing checkpoints, distances, and flight directions. If the flight is to be conducted wholly or in part by radio, the Jepco chart should be studied and the findings recorded on the flight log.

(1) *IFR flights.* Preparation for an IFR flight consists mainly of familiarization of the route, the airways, reporting points and intersections, radio aid frequencies, and approach charts for destination and alternate. It is advisable to plan for adjoining routes since Air Route Traffic Control may require an alternate route. Familiarization with each type of approach is essential, if more than one type of approach is available at destination or alternate.

(2) *VFR flights.* For VFR flights, select a chart of appropriate scale and carefully plot the desired course. Also plot lines which differ by 10° on each side of the course line to aid in determining off-course corrections. Mark selected checkpoints on the map and list them on the log with ETA for each point. Prominent checkpoints on either side of the course should also be noted.

c. Flight Log. After careful scrutiny of the aspects of the flight, enter the findings on a flight log. This log should contain, in chronological order, a record of the planned course or courses, headings, wind correction angles, estimated time of arrival over each checkpoint, and other information pertinent to the flight. Some type of log must be used to reduce the chance of arithmetical errors.

d. Miscellaneous. Before departure, see that the navigation kit contains proper charts, computer, plotter, pencils, flight log, copy of Aircraft Clearance (DD Form 175), operations order, and flashlight. A course of action should be outlined that may be followed in case of emergency.

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[AG 373 (9 Sep 58)]

By Order of *Wilber M. Brucker*, Secretary of the Army:

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General, United States Army,
Chief of Staff.

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NG: State AG (2); units—same as Active Army except allowance is one copy to each unit.

USAR: Same as Active Army except allowance is one copy to each unit.

For explanation of abbreviations used, see AR 320–50.

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