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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

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PART ONE

PILOTAGE AND DEAD RECKONING

CHAPTER 1

GENERAL

1-1. 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.

1-2. 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 its position along this course at any time. Such navigation may be by means of pilotage, dead reckoning, or radio aids, and includes those procedures which are used during instrument flight in directing the aircraft to a safe landing.

1-3. Scope

The scope of this manual is as follows:

a. Part One, Pilotage and Dead Reckoning. Part One includes the basic concepts and the implements of air navigation which 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, Instrument Approaches and Associated Navigation Systems. Part Three includes facilities and procedures peculiar to instrument approaches. It does not include the theory and techniques of attitude instrument flying or the descriptions of flight and navigation instruments contained in TM 1-215 and appropriate aircraft operator's manuals.

d. Part Four, Advanced Navigation Systems. Part Four includes the description and operation of advanced navigation systems currently used in certain models of Army aircraft.

CHAPTER 2

BASIC CONCEPTS

Section I. THE EARTH IN SPACE

2-1. Shape

A perfect sphere is a body whose surface is at all points equidistant from a point within, called its 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.

2-2. Rotation

The diameter of the earth, around which the spherical body rotates, is an imaginary straight line called the *axis*. The points formed by the intersection of the axis with the earth's surface are the North and South Poles. Any point on the earth's surface, except the North and South Poles, completes one rotation around the axis every 24 hours.

2-3. Revolution

As the earth rotates, it also revolves around the sun in an elliptical path (fig. 2-1), completing one orbit each year.

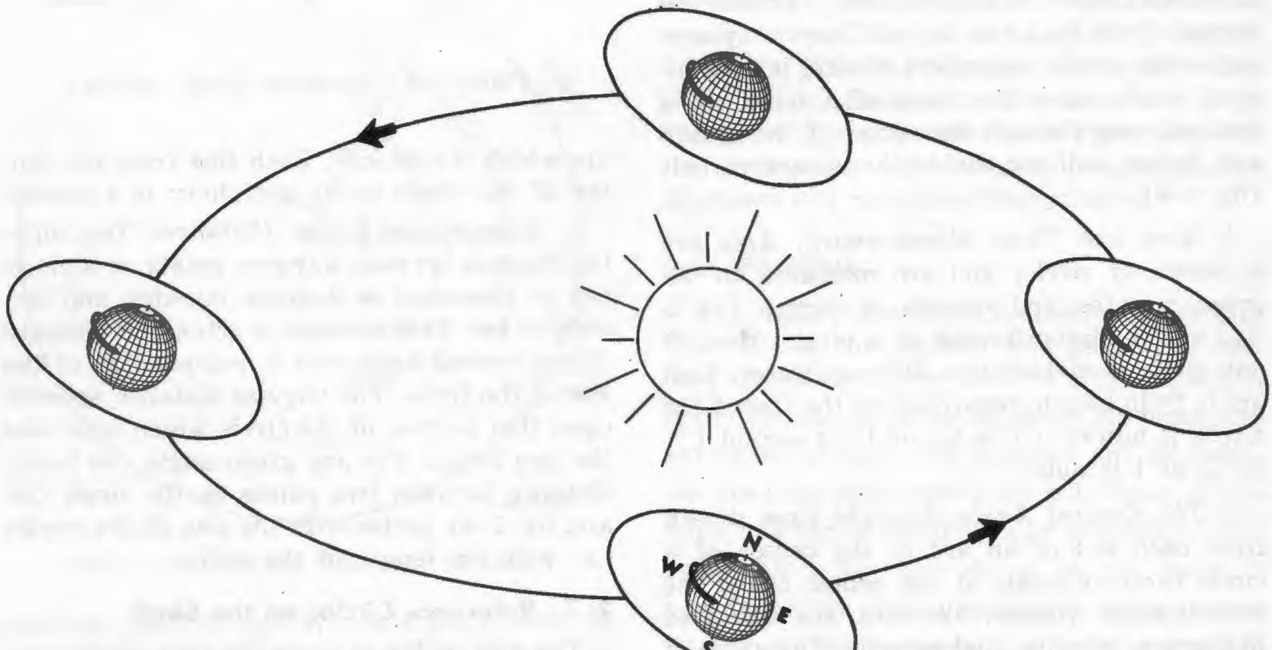


Figure 2-1. West to east rotation of the earth and its revolution around the sun.

2-4. Inclination

The axis of the earth is included approximately 23½° from the perpendicular to its plane of revolution. This inclination is such that the North Pole points generally toward the North Star (Polaris).

Section II. MEASURING POSITION ON THE EARTH

2-5. Position Designated by Coordinates

To identify the location of a point on the surface of the earth, a universal system of expressing geographical position without reference to physical features is a necessity. Such a system, known as a *coordinate* or *grid* system (fig. 2-2), designates location or position and expresses angular magnitude with respect to two reference lines (meridians and parallels) which intersect at right angles. By reference to these lines, any point may be accurately located. This system of coordinates is formed by the intersecting of great and small circles (par. 2-6*a*).

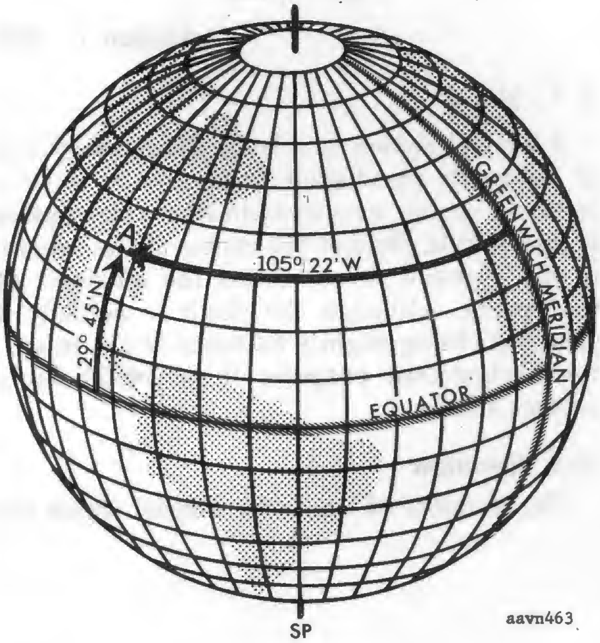


Figure 2-2. Coordinate (grid) system.

2-6. Circles on a Sphere

a. Great and Small Circles. The straight cut of a plane through a sphere forms a *circle.* If the 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 the sphere in half (fig. 2-3).

b. Arcs and Their Measurement. Arcs are *segments of circles* and are measured in degrees, minutes, and seconds. A degree (°) is 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 1/60 of 1°, a second (″) is 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 it subtends. Each line from the center of the circle to its periphery is a *radius.*

d. Angular and Linear Distances. The angular distance between any 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 that portion of the circle which separates the two points. For any given angle, the linear distance between two points on the circle (an arc, fig. 2-4) varies with the size of the circle; i.e., with the length of the radius.

2-7. 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

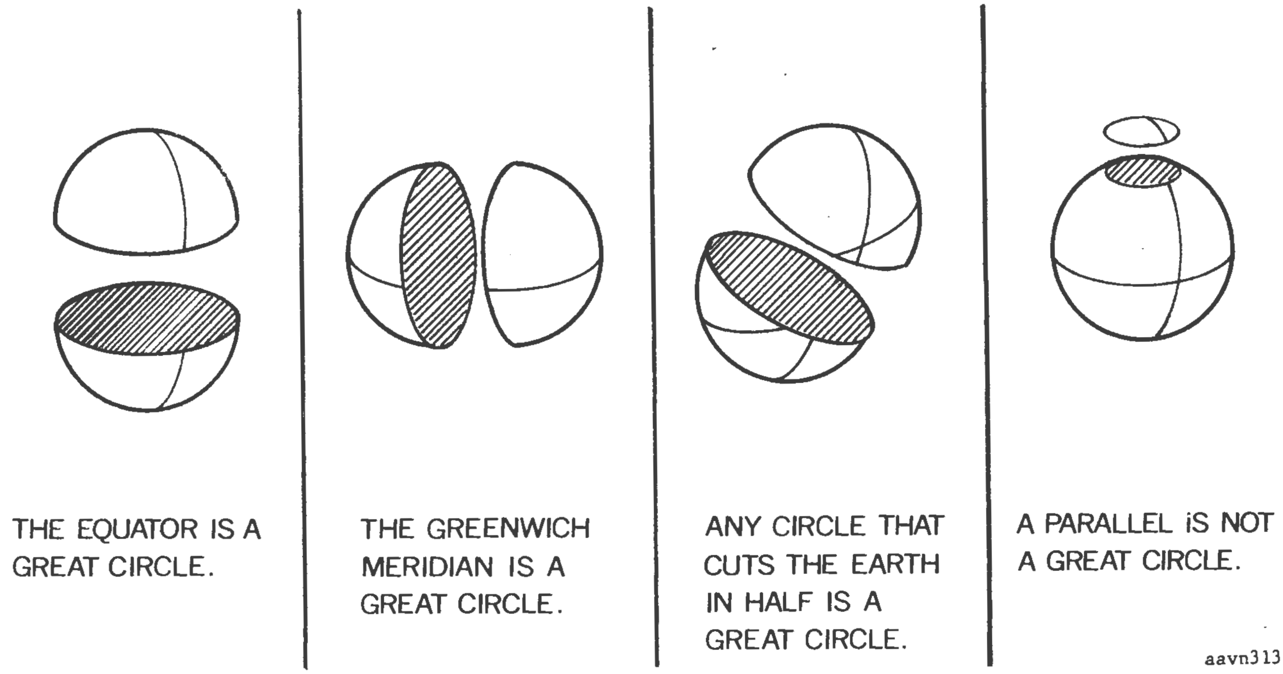


Figure 2-3. Great and small circles.

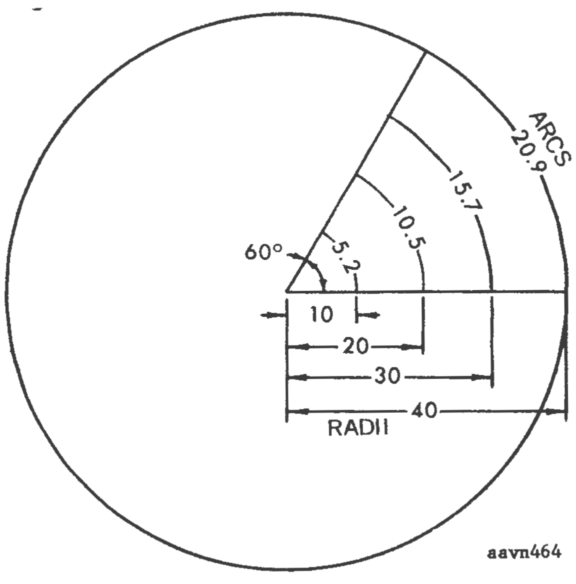


Figure 2-4. Angular and linear distances.

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. 2-2).

2-8. 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. 2-2). 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 the Northern and Southern Hemispheres.

2-9. Parallels

Any small circle whose plane is parallel with the plane of the Equator is a parallel of latitude (fig. 2-2). 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; e.g., point A (fig. 2-2) is a parallel 29°45′ north of the Equator.

2-10. Meridians

A great circle passing through both poles is called a *meridian of longitude* (fig. 2-2). 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; e.g., point A (fig. 2-2) is on a meridian 105°22′ west of the Greenwich meridian.

2-11. 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 (Greenwich) 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 (half-way around the world at the international date line).

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 point, latitude is given first, followed by the longitude; *for example,* point A (fig. 2-2) is positioned at latitude 29°45′N, longitude 105°22′W.

Section III. MEASURING DIRECTION ON THE EARTH

2-12. General

In air navigation, directions are indicated both by use of *cardinal points* (north, east, south, west) or *intercardinal points* (northeast, southeast, southwest, etc.) of the compass and by numbers (degrees) (fig. 2-5).

2-13. Measuring Direction

The compass rose (fig. 2-5) divides the horizon (fig. 2-6) into 360 parts or degrees. Starting with north as 0° and continuing clockwise through east, south, and west, directions are expressed in degrees measured from north (0°) to, but not including, 360°. East is 090°, and west is 270°. Figure 2-7 shows point B in a direction of 045° (north-east) and point 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 are used to indicate the intended direction. Note that the direction of C *from* A (270°) is not the same as the direction of C *to* A (090°), even though drawn as one line. The direction of a line is

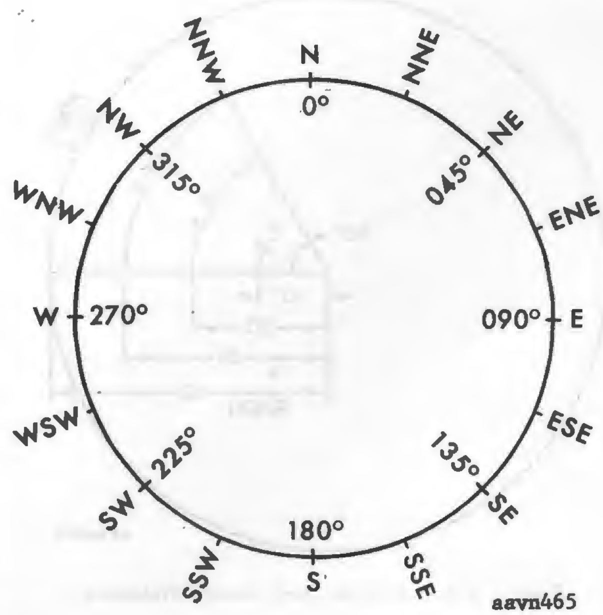


Figure 2-5. Compass rose.

measured from its point of origin and labeled by the angle the line forms with an intersecting

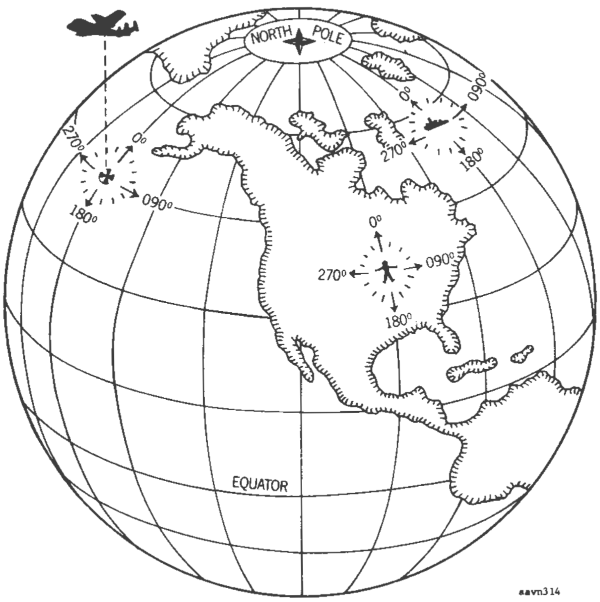


Figure 2-6. The horizon as a compass rose.

meridian. In figure 2-7, the direction from A is measured from point A. If the meridians are drawn as parallel lines, the direction of a straight line may be measured at any point along the line. In measuring the direction from C to A (A from C), measurement is made with reference to the mean meridian (DE) of points A and C because the meridians in figure 2-7 are not parallel; i.e., they converge toward the north as do the meridians on most aerial navigation charts.

Note. Three systems are in use for designating north as a direction on the compass rose. Although 0° is used throughout this manual, other reference books may use 000° or 360°.

2-14. Course

The direction which an aircraft is to fly to reach a given destination is the *course* to that destination. Therefore, the course from A to C (fig. 2-7) is 270°.

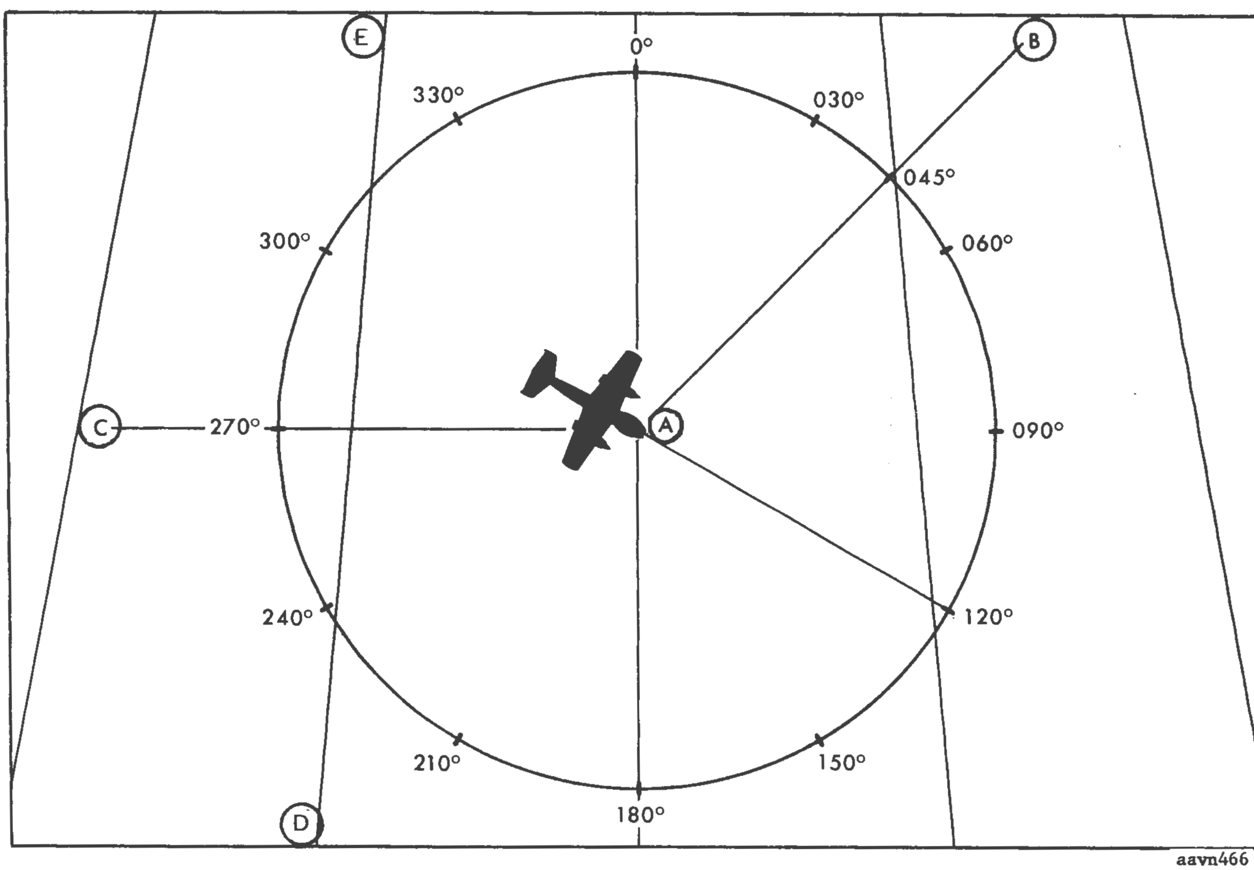


Figure 2-7. Measurement of direction.

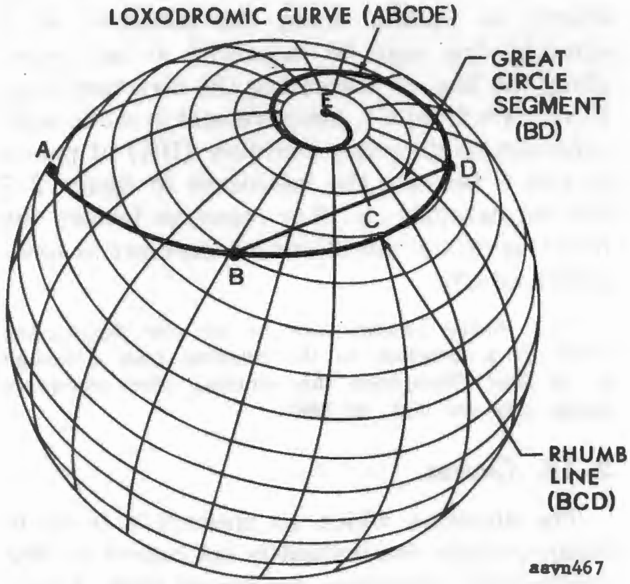


Figure 2-8. Rhumb line, loxodromic curve, and great circle.

2-15. Rhumb Line

The rhumb line is a line of constant direction that crosses successive meridians at the same oblique angle (fig. 2-8). 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. 2-8).

Section IV. MEASURING DISTANCE ON THE EARTH

2-16. Units of Measurement

a. Distance. The length of a line joining two points is its distance. 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.

b. Statute Mile. In the United States, 1 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. Aviators will, however, encounter statute mile indications on some charts, plotters, and airspeed indicators.

c. Nautical Mile. Military airmen use the nautical mile as a unit of distance. The nautical mile (6,076.1 ft.) is equivalent to 1 minute of latitude, or approximately 1.15 statute miles. A statute mile is approximately 0.87 nautical miles.

Note. The only requirement that nautical miles be used in air navigation pertains to filing flight plans. However, nautical miles are more convenient since distances on published aeronautical charts are shown in nautical miles, windspeeds are reported in nautical miles per hour (knots), and most airspeed indicators are calibrated in nautical units. If navigational data contains mixed units, convert *all* measurements either to nautical or to statute miles.

2-17. Great Circle Distance

The shortest distance between two points on the surface of the earth lies along any minor arc of a great circle passing through both points. A 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. 2-8).

CHAPTER 3

NAVIGATION CHARTS

Section I. CHART PROJECTIONS

3-1. General

An *air navigation chart* is a diagrammatic representation of the earth's surface, or a part thereof, on a flat surface. The chart 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.

3-2. Scale

a. General. The *scale* of the chart is the ratio between the distance on a chart and the distance it represents on the earth. 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." This means that a ground distance 30 miles long is 1 inch long 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 1 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. 3-1) 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 1° of latitude always equals 60 nautical miles. Meridians are often divided into minutes of latitude, with each division representing 1 nautical mile.

3-3. Distortion

Distortion is the misrepresentation of direction, shape, and relative size of features on the earth's surface which occur when the earth's round surface is projected onto a flat chart surface. A globe is the only means of representing the entire surface of the earth without distortion.

a. Developable Surfaces. A *developable* surface (fig. 3-2) is a curved surface such as a plane, cylinder, or cone that can be flattened without tearing, stretching, or wrinkling.

b. Nondevelopable Surfaces. The surface of a sphere or spheroid is *nondevelopable* because no part of it can be laid out flat without distortion. This can be understood by attempting to flatten half of an orange peel. However, a

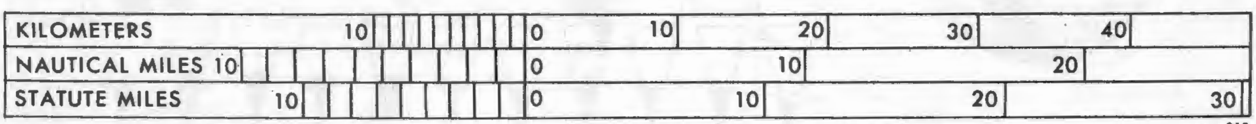


Figure 3-1. Graphic scale.

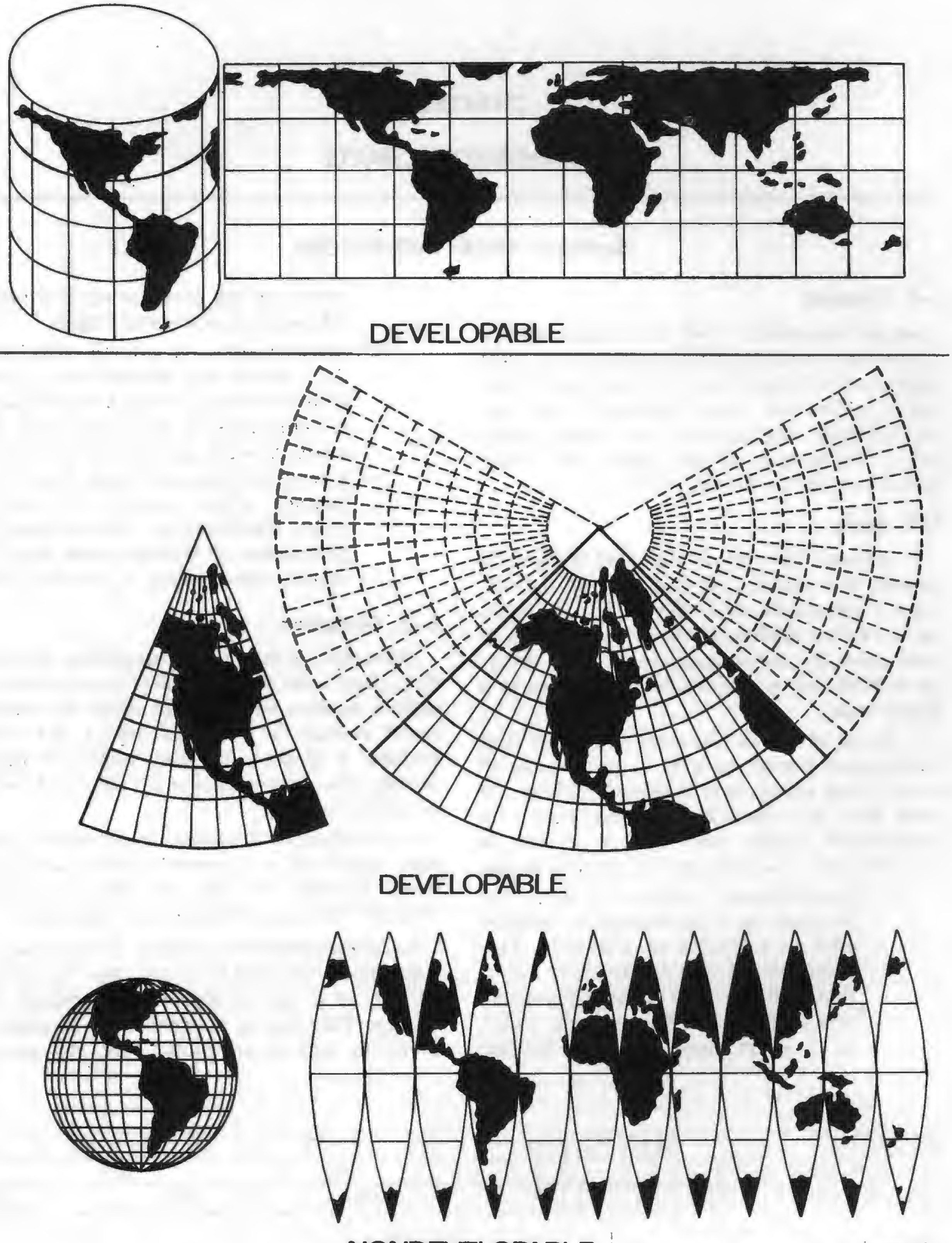


Figure 3-2. Developable and nondevelopable surfaces.

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 (fig. 3-2). Distortion becomes a serious problem in charting large areas and can never be completely eliminated. It can, however, be controlled and systematized; i.e., a chart for a particular purpose can be drawn so as to minimize the type of distortion which is most detrimental.

3-4. 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 the following: 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 obtain one and sometimes more than one of the above properties in any one projection, but it is impossible to retain all of them. For example, a chart cannot be both conformal and equal area. Desirable but secondary chart 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.

3-5. 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* (fig. 3-3). Once the graticule is drawn, features may be plotted in their correct positions with references to meridians and parallels.

b. Form and Size. The 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.

3-6. 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 (fig. 3-2) to which the spherical or spheroidal surface is transferred. 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.* Chart projections most com-

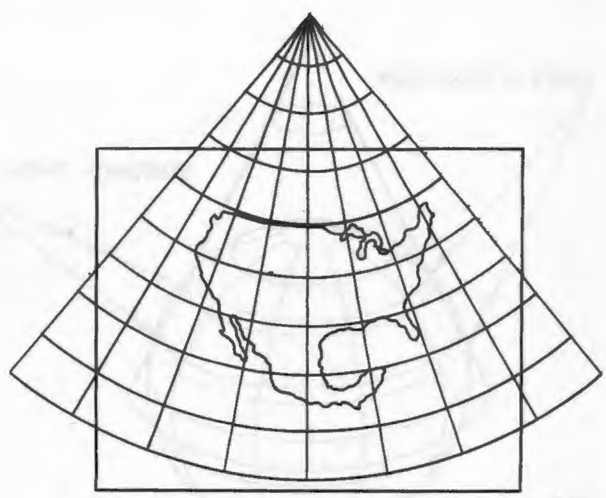


Figure 3-3. Appearance of the Lambert projection graticule.

monly used in air navigation are the Lambert conical, the Mercator cylindrical, and the polar stereographic, all three of which are conformal projections (par. 3–7*d*). (*Stereography* is the art of representing forms of the solid bodies on a plane surface).

c. Purpose of Charts. Charts are used in navigation principally for two purposes: (1) chart reading and (2) plotting and measuring. Chart *reading* is the location of one's position by identification of landmarks (par. 4–1). *Plotting* refers to establishment of points and lines on a chart. *Measuring* means measurement of direction and distance on a chart (par. 5–1).

3–7. 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. 3–3).

b. Standard Parallels. The cone intersects the sphere at two parallels (fig. 3–4). 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 one-sixth and five-sixths of the total length of that portion of the meridian to be represented.

c. Accuracy. Along the two standard parallels, areas are represented in true scale. Between the standard parallels, the scale will be too small; beyond them, too large. For practical purposes, the scale can be considered constant for a large scale chart of a small area (fig. 3–5). Accuracy is greatest for charts of predominantly east-west dimensions.

d. Conformality. The Lambert projection is conformal because the scale is practically uniform in all directions about any point, and the angles formed by parallels and meridians are shown correctly. Because of the scale uniformity, areas retain true shape (fig. 3–6).

e. Great Circle vs. Straight Line. Any straight line on a Lambert chart is nearly a great circle (fig. 3–7). In the distance of 2,572 statute miles between San Francisco and New York, a great circle and a straight line connect-

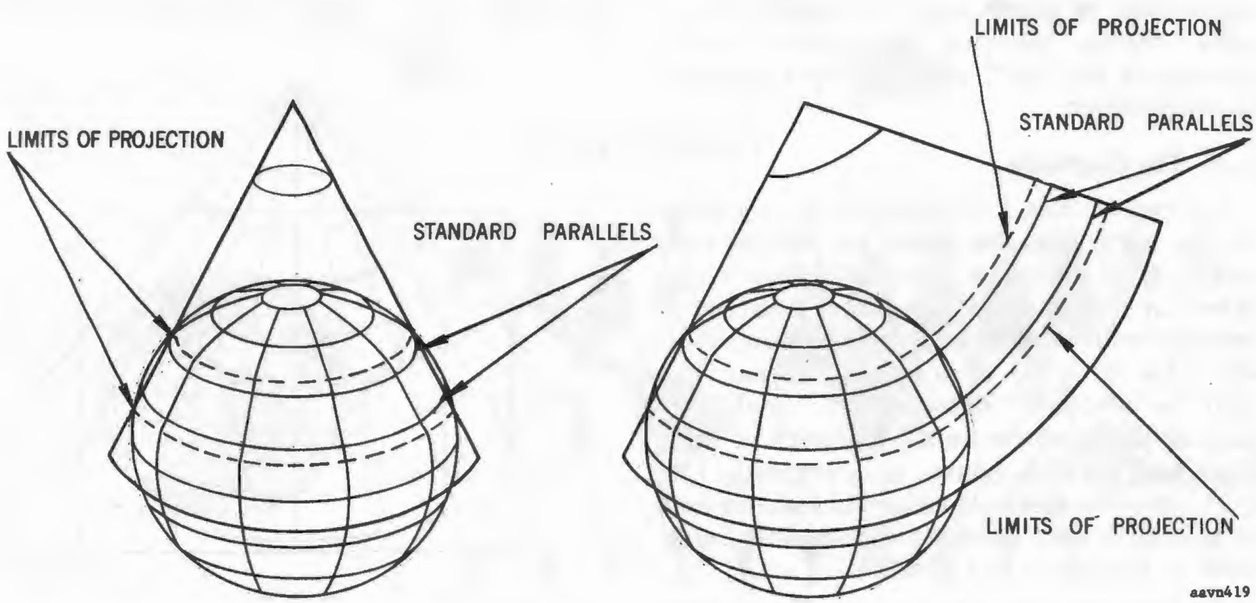


Figure 3–4. Standard parallels on Lambert conformal chart.

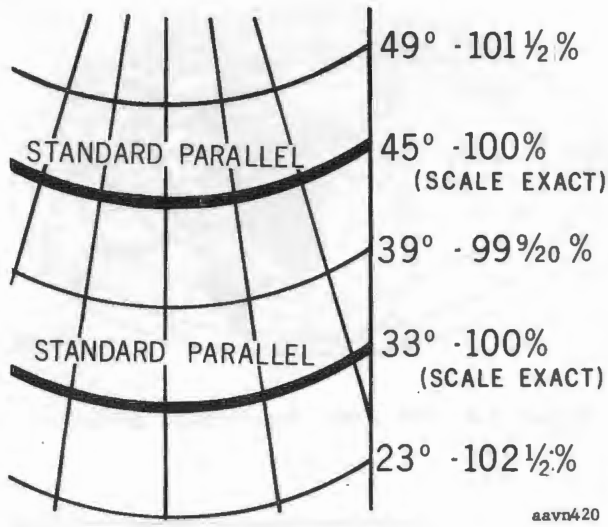


Figure 3-5. Variation of scale on typical Lambert projection.

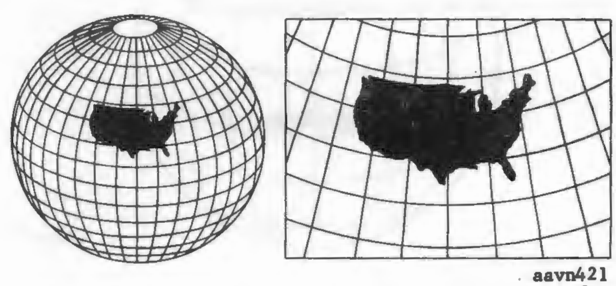


Figure 3-6. Areas and angles (Lambert).

ing 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 on a Lambert chart is a curved line. 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 becomes 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.

g. Use. The constant scale and conformity of Lambert charts place them among the best charts for air navigation. They are suitable for navigation using long-distance radio bearings and are superior to Mercator charts (par. 3-8) for problems involving long distances and true directions. However, for plotting positions and measuring rhumb line directions, they are inferior to Mercator charts.

3-8. 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 ap-

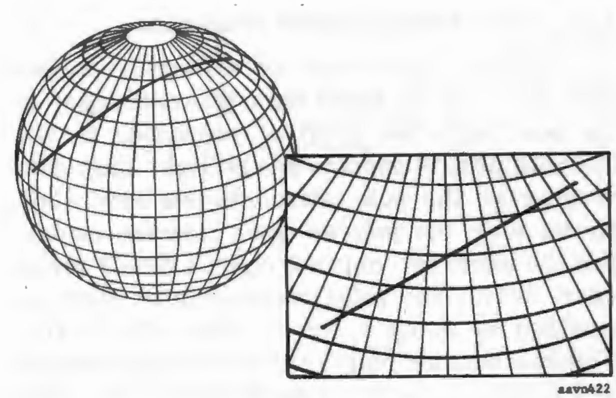


Figure 3-7. Great circle vs. straight line on a Lambert chart.

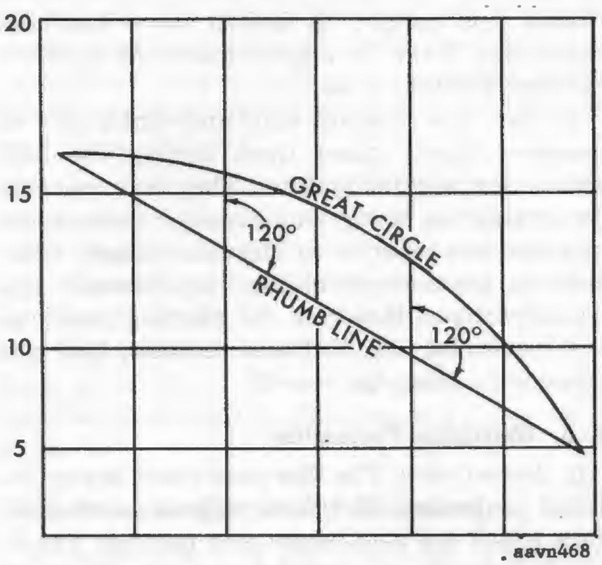


Figure 3-8. Mercator chart showing rhumb line vs. great circle.

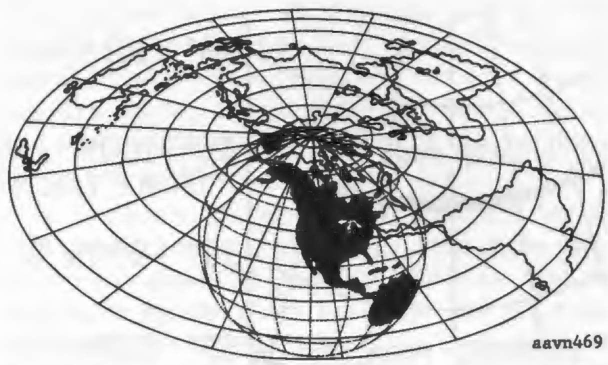


Figure 3-9. The polar stereographic projection.

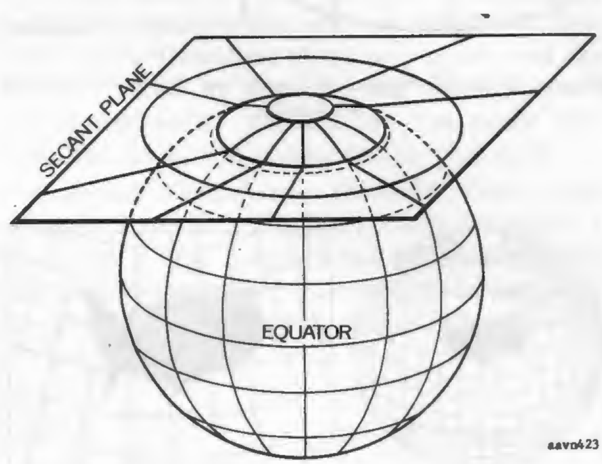


Figure 3-10. Modified polar stereographic projection.

pear as straight lines; all other great circles appear as curved lines (fig. 3-8).

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

3-9. Polar Stereographic Projection

a. General. The polar stereographic projection (fig. 3-9) 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 (par. 3-11), the polar stereographic chart is modified by using a secant plane (fig. 3-10). This modification makes the polar stereographic and Lambert charts the same scale at 80° latitude. The polar stereographic chart 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, the 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° angles 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 and rhumb lines appear as curved lines.

Section II. AERONAUTICAL CHARTS

3-10. 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 inch 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 6 months; others are scheduled for revision annually. Date of the chart and scheduled time for next edition is located in the lower right hand margin of the chart face.

3-11. 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 inch 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 navigation over land surfaces. 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 supersede previously printed charts. Time for the next scheduled edition is shown below the date in the lower right-hand corner of the margin.

3-12. 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 using 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, PILOTAGE, AND LOW-LEVEL NAVIGATION

Section I. CHART READING AND PILOTAGE

4-1. 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 aviator's proficiency in chart interpretation.

4-2. 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. Since aeronautical charts under-

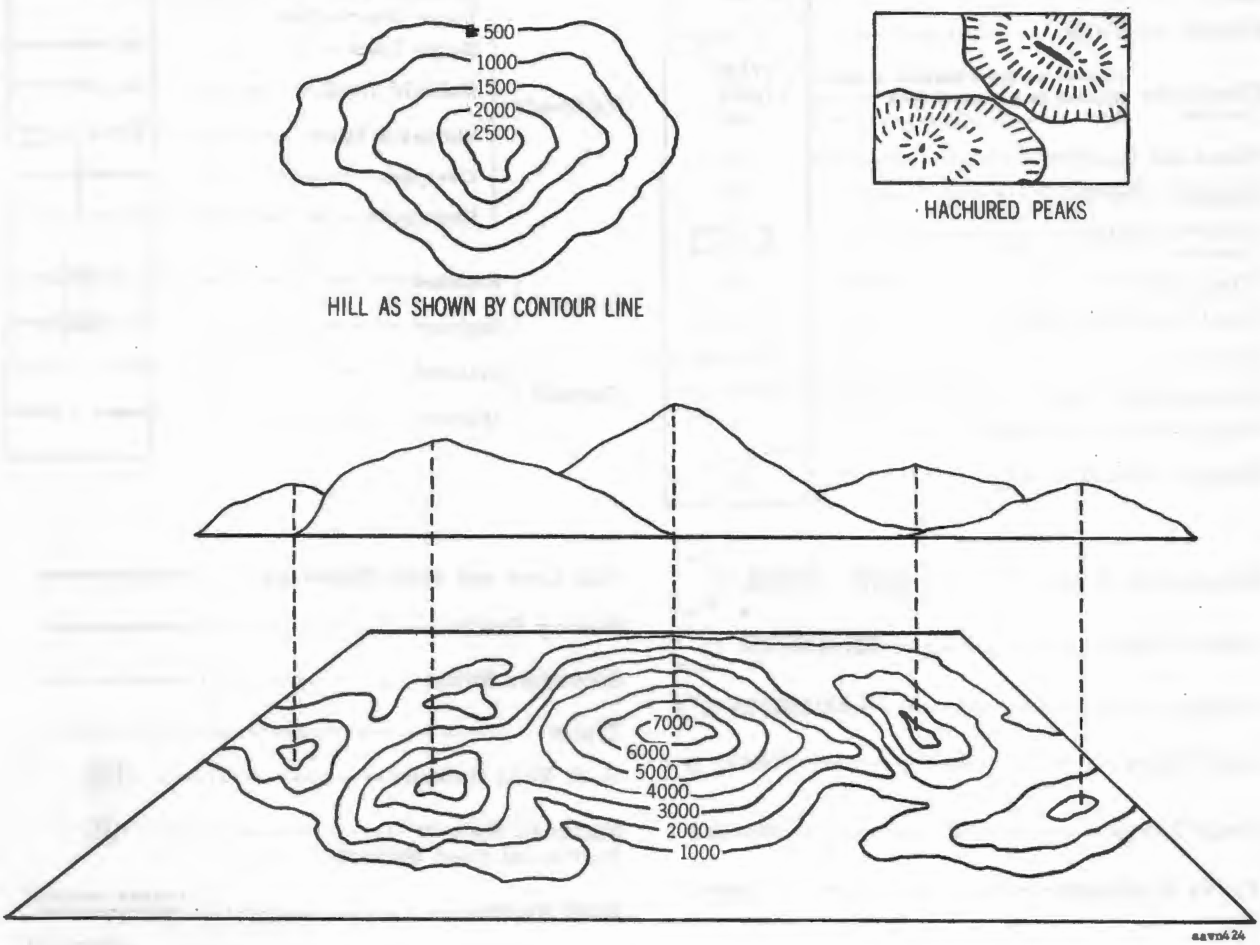


Figure 4-1. Relief.

go repeated revision, the chart used by the aviator should be the latest revision. Current aeronautical charts are listed in current navigation publications.

4-3. Chart Content

Although charts do not picture all details, those particular features useful to the aviator are emphasized, including 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.

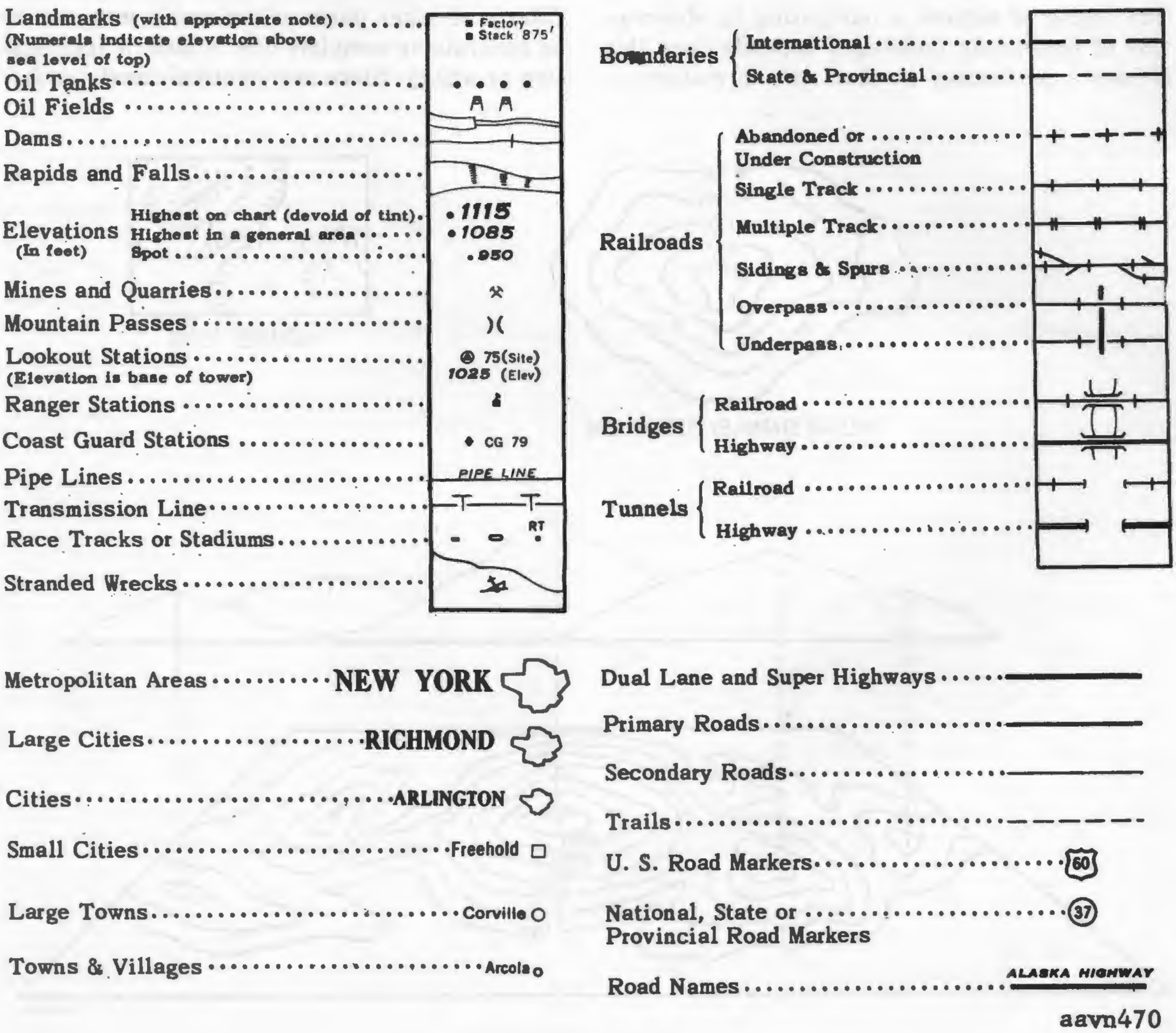


Figure 4-2. Cultural symbols.

4-4. Symbols

Since a chart is a diagram, it consists of symbols which do not necessarily resemble the shape or appearance of the 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 are also a hazard to flying. Elevations of the highest peaks and other significant spot elevations are shown in italics.

(2) Most charts represent relief by means of contours (lines connecting points of equal elevation (fig. 4-1)). 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 the average (mean) 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 line labeled with the elevation it represents (fig. 4-1). 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 by contours. 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 aeronautical charts have different color schemes, or show only contour lines. The color shading block of the legend indicates elevation levels on the chart.

b. Cultural. Cultural symbols (fig. 4-2) represent manmade 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 are more permanent than automobile roads and are 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 symbols.

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 magenta or blue color on sectional and WAC charts. Classes of airports are distinguished by different symbols, and the elevation of each airport is given (fig. 4-3). Light beacons (with their code signals) and radio stations (with their call letters and frequencies) are also shown (figs. 4-4 and 4-5). Airways, danger areas, and isogonic lines are clearly marked (fig. 4-6).

d. Water and Forest. Bodies of water are valuable to the navigator because they are relatively permanent and easily seen from the

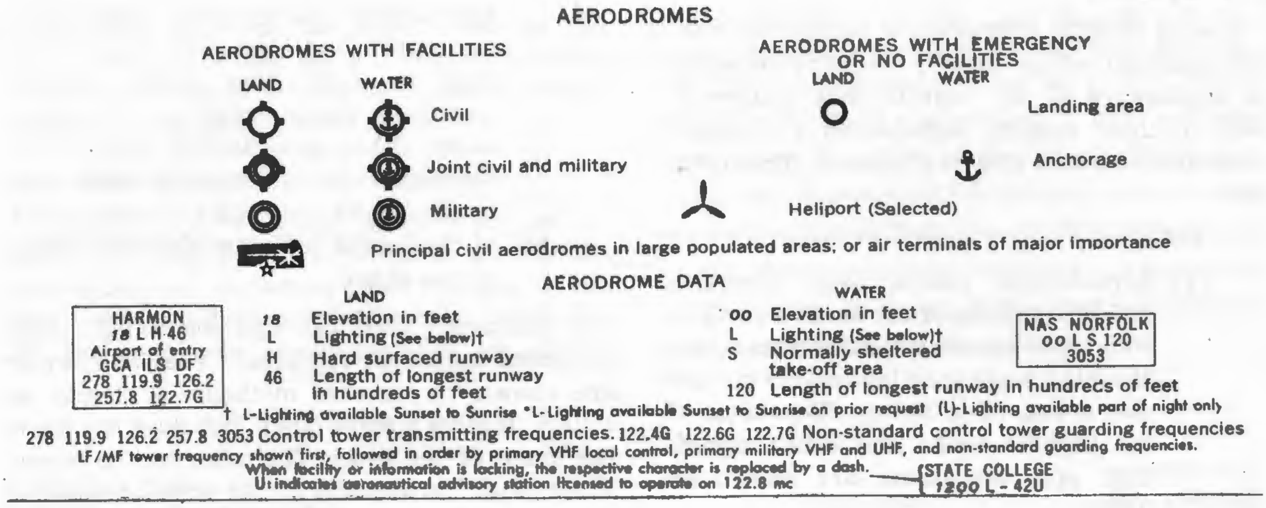


Figure 4-3. Aeronautical symbols—aerodromes.

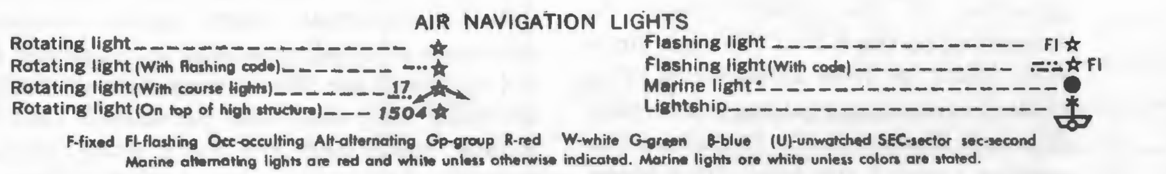


Figure 4-4. Aeronautical symbols—air navigation lights.

air. Conventionally, water is shown in blue with coastlines accurately drawn. (The color does not 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 outlined 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 Charts. The following items are shown on the reverse side of sectional and WAC charts:

(1) Aeronautical symbols.

(2) A list of all airports within the limits of the chart, with information concerning latitude and longitude, elevation, number and length of runways, etc.

(3) A list of prohibited, restricted, caution, and warning areas in the chart area.

(4) A chart of the United States, showing the sectional chart numbers required for each area.

(5) Other information of value to the aviator.

4-5. 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 geographical and cultural features of an area. In open areas or farm country, any town, railroad, or highway can be used for a checkpoint. In more densely populated areas, minor features such as roads and small towns are difficult to distinguish. Important highways, large towns with distinctive shapes, or towns near lakes or rivers are easily identified. In forested areas, swaths cut for pipelines and powerlines are easily traced.

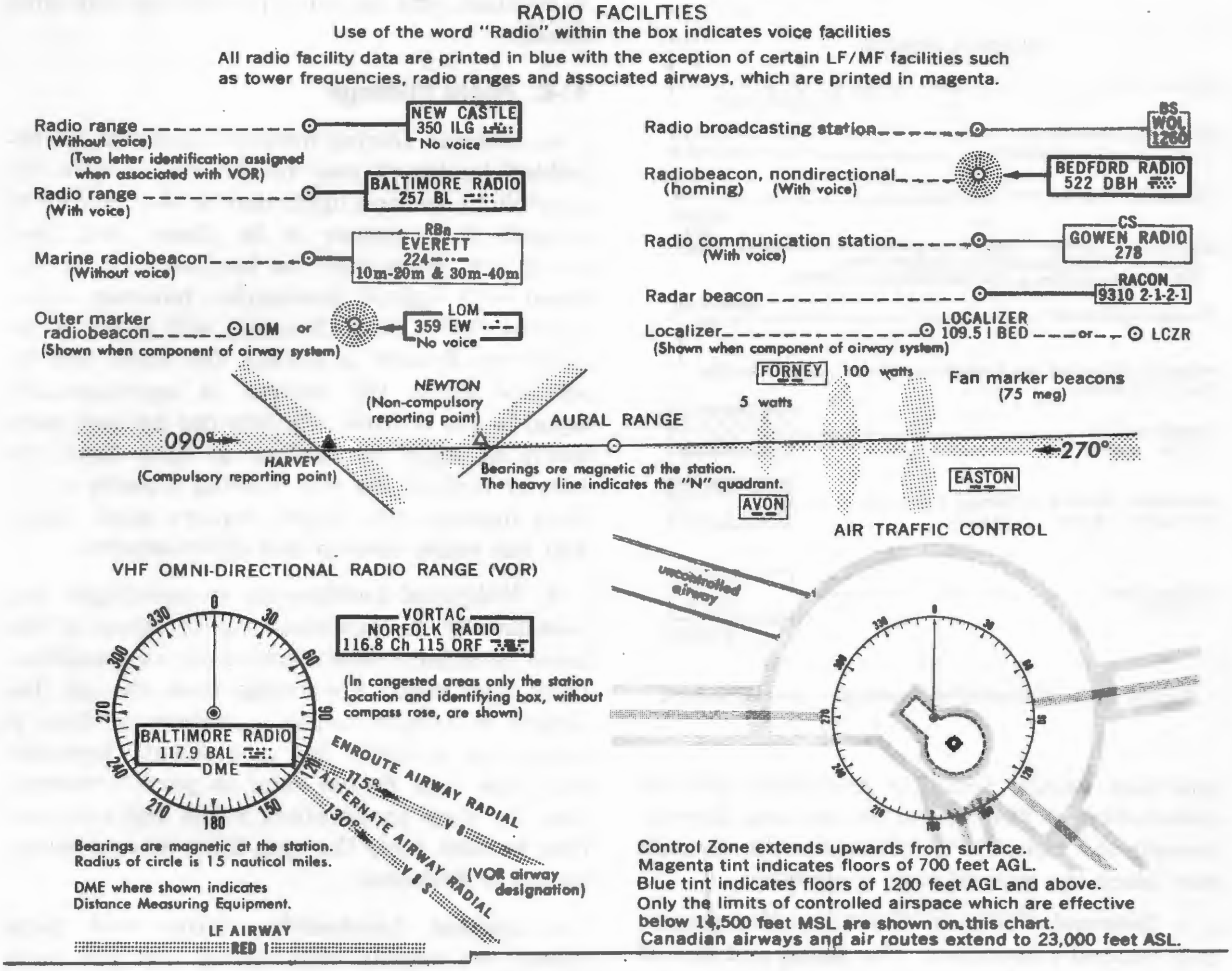


Figure 4–5. Aeronautical symbols—radio facilities.

In mountainous areas, mines, ranger stations, prominent peaks, passes, and gorges can be used. In a desert, where checkpoints are few, minor features may be satisfactory checkpoints.

b. If there is an uncertainty about the position, every possible detail should be checked before identifying a checkpoint. The aviator 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 aviator select reliable features on the chart to compare with features on the ground. Figure 4–7 shows the characteristics of good and poor checkpoints.

4–6. Estimating Distance

Ground distance can be estimated by comparison with the known distance between two other points measured on the chart.

4–7. Appearance of the Terrain

a. Effects of the Sun. When the sun is low, long shadows cause strong terrain contrasts and emphasize 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,

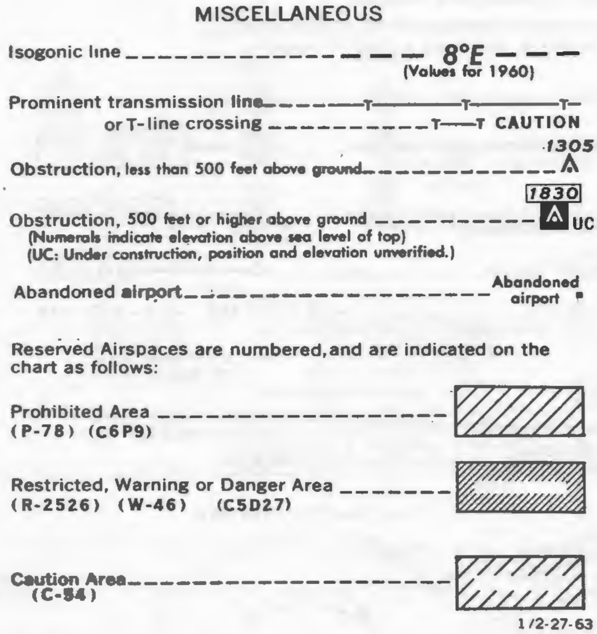


Figure 4-6. Aeronautical symbols—miscellaneous.

and dust reduce visibility and often restrict observation of the terrain to the area directly beneath the aircraft. Clouds below the aircraft may block the ground view completely.

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

d. Low Level Flight. When flying at low levels, only small areas of the terrain can be seen. Because of the oblique angle of sight, apparent object depth is increased and relief detail is pronounced. The ground appears to move rapidly, and only brief glimpses of checkpoints are possible. An aircraft flying at 100 feet above the terrain with a groundspeed of 70 knots has the same apparent speed over the ground as an aircraft flying at 2,000 feet with a groundspeed of 1,400 knots.

e. High Altitude Flight. From high altitudes the ground appears to move slowly, and the aviator has difficulty determining the exact time of checkpoint passage. When visibility is good, a large area can be seen, distances appear to contract, and the terrain looks flat with little detail.

4-8. 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. Stars near the horizon may be confused with lighted landmarks; however, locating 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 seen more easily at night by looking at them from the side or rods of the eye. Staring directly at objects during night flight impairs night vision and can cause vertigo and disorientation.

b. Unlighted Landmarks. In moonlight, and occasionally on moonless nights, some of the more prominent landmarks such as coastlines, lakes, and rivers are visible from the air. 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 are more visible at night than in the daytime. They can often 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 hours of darkness.

4-9. Chart Reading in Flight

a. Preparation on the Ground. Proper ground preparation for navigation will save much time and map searching in flight. The course line should be drawn so that a quick 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

CONDITIONS	GOOD CHECKPOINTS	POOR CHECKPOINTS

MOUNTAINOUS AREAS

Good checkpoints:
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.

Poor checkpoints:
Smaller peaks and ridges, similar in size and shape.

COASTAL AREAS

Good checkpoints:
Coastline with unusual features.
Lighthouses, marker buoys, towns and cities, structures.
Radio Aids.

Poor checkpoints:
General rolling coastline with no distinguishing points.

SEASONAL CHANGES

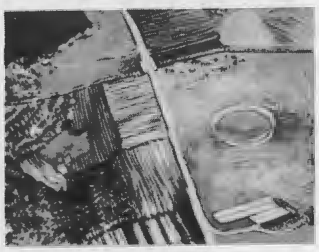
Good checkpoints:
Unusually shaped wooded areas in winter.
Dry river beds if they contrast with surrounding terrain. Dry lakes.

Poor checkpoints:
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

Good checkpoints:
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.

Poor checkpoints:
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

Good checkpoints:
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.

Poor checkpoints:
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

Good checkpoints:
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.

Poor checkpoints:
Trails and small roads without cleared right-of-ways.
Extended forest areas with few breaks or outstanding characteristics of terrain.

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Figure 4-7. Good and poor checkpoints.

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 distance in flight is avoided.

Note. Since aircraft cockpit lights are red, a red pencil mark on maps is invisible at night.

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

Section II. LOW-LEVEL NAVIGATION

4-10. Definition

Low-level navigation is the technique of directing an aircraft along a desired course at low altitudes and determining position along this course at any time. Low-level altitudes generally are considered to be below 500 feet.

4-11. General

a. Navigation at low levels differs considerably from that at higher altitudes. Low-level navigation requires comprehensive flight planning, accurate dead reckoning and/or pilotage, and extensive use of available checkpoints. The aviator and observer must work very rapidly in order to make and interpret in-flight observations with accuracy.

b. Reduced visibility, turbulence, and inconsistency of winds close to the terrain compound the problem of low-level navigation. In addition, the fundamentals of navigation, such as writing, measuring, computing, and plotting, are more difficult since the aviator must devote most of his attention to flying the aircraft.

c. The aviator-observer team must function in harmony and prearrange the exact duties to be performed by each. Normally, the aviator concentrates on flying the aircraft while the observer performs navigational duties. However, when operating at extremely low levels, as in nap-of-the-earth flight, the aviator must concentrate on clearing obstacles while maintaining the proper heading and airspeed; maximum viewing outside the cockpit is a necessity. The observer, in addition to navigating, should monitor the engine, transmission, and other instruments. He must remain oriented at all times and announce to the aviator the headings to be flown and time to the next checkpoint. When time permits, he describes the next checkpoint so that the aviator may assist in identifying the checkpoint. The aviator-observer team should be sufficiently familiar with the route to avoid study of the navigational chart for long periods of time during flight.

4-12. Pilotage and Dead Reckoning

a. Maps and Charts. There are no published charts designed specifically for the type of low-level navigation defined above. As the flight level lowers and visual distances lessen, surface features become more prominent. The terrain perspective changes from that of a plane surface to that of a silhouette, and the interpretation of relief becomes more important. In most cases aeronautical charts are too small in scale for this purpose, lacking detailed features of terrain. Tactical maps (available in scales of 1:25,000, 1:50,000, and 1:100,000) are the most satisfactory maps available for low-level navigation. These are large-scale maps, however, and even the slowest aircraft traverse the distance represented on an entire map sheet in a relatively short time. Therefore, the scale selected for a given operation will dedpend upon the distance to be traveled during the mission, the degree of detail required, and the speed of the aircraft. Whenever possible, scaled aerial photos should be used when adequate maps and charts are not available for a specific area, or at any other time for supplementary reference. In some instances, a combination of scales may be required. For example, a map of 1:100,000 scale or an aeronautical chart may be adequate for the flight from the departure airfield to an intermediate checkpoint; but beyond that point to the landing zone, as in an airmobile operation, more precise navigation may require using a map of 1:50,000 or 1:25,000 scale. To obtain greater detail, recent aerial photos of the target area or landing zone should be studied to detect terrain changes since the time of mapping. A strip map prepared during preflight planning will enhance in-flight pilotage.

b. Routes. During the conduct of tactical operations, low-level flight routes are selected which afford cover and concealment from visual and electronic detection to exploit surprise to the fullest.

(1) *Route selection.* Flight planning should take advantage of directional characteristics of natural or cultural features which will simplify navigation. Rather than planning long straight legs, slight deviations in the route may offer a better selection of navigation checkpoints. Roads, railroads, power transmission lines, canals, stream beds, and natural corridors are excellent for navigation; however, in steep, narrow valleys, enemy cables or other obstacles may be encountered. Turning points should be close to terrain features which can be identified at maximum range. Air control points (ACP), which are points of positive control and coordination between air and ground elements, are excellent choices for turning points. In operations employing formations of appreciable size, turns must be started prior to reaching checkpoints to insure departure on desired course after completion of the turn. The radius of the turn will vary with the type aircraft and size of formation involved. To insure adequate en route positioning, turns should be plotted in the flight planning. When formations are employed, turns may extend ETE's to the next checkpoint.

(2) *Route detours.* Deviations from a selected route may be necessary to avoid air-defended areas, cities and towns, or short sections of a route overly exposed to enemy observation. Route deviation can be effected by using an off-course checkpoint as a link between the usable portions of the route. If a checkpoint is not available, a geometrical pattern should be flown to insure return to the original course at the proper point (fig. 4-8).

c. Altitude. When selecting a flight altitude, particular attention must be given to terrain elevation, both along the intended flightpath and adjacent to it. The highest terrain feature, as well as abrupt or irregular changes in terrain elevation along the route, must be noted to insure clearance, particularly in the event of unforeseen weather. The selected altitude should also provide concealment from visual and electronic detection.

d. Checkpoints. Checkpoints should be selected not more than 5 minutes apart along the route. A 2-minute interval is recommended; however, this will vary with the specific mission, the speed of the aircraft, and the number of available checkpoints. Due to the perspective presented at low levels, checkpoints are divided into two general categories, which may overlap according to the terrain flown.

(1) *Distant.* Distant checkpoints keep the aviator oriented and offer a general course to follow. Both natural and manmade terrain features which stand out above the horizon and have distinctive profiles can be readily identified at long distances and will remain in view a relatively long period of time. Examples are—

Prominent mountains and hilltops.

Passes and cuts through high terrain.

Lakes.

Water and communication towers.

Gap in the tree line in forested areas.

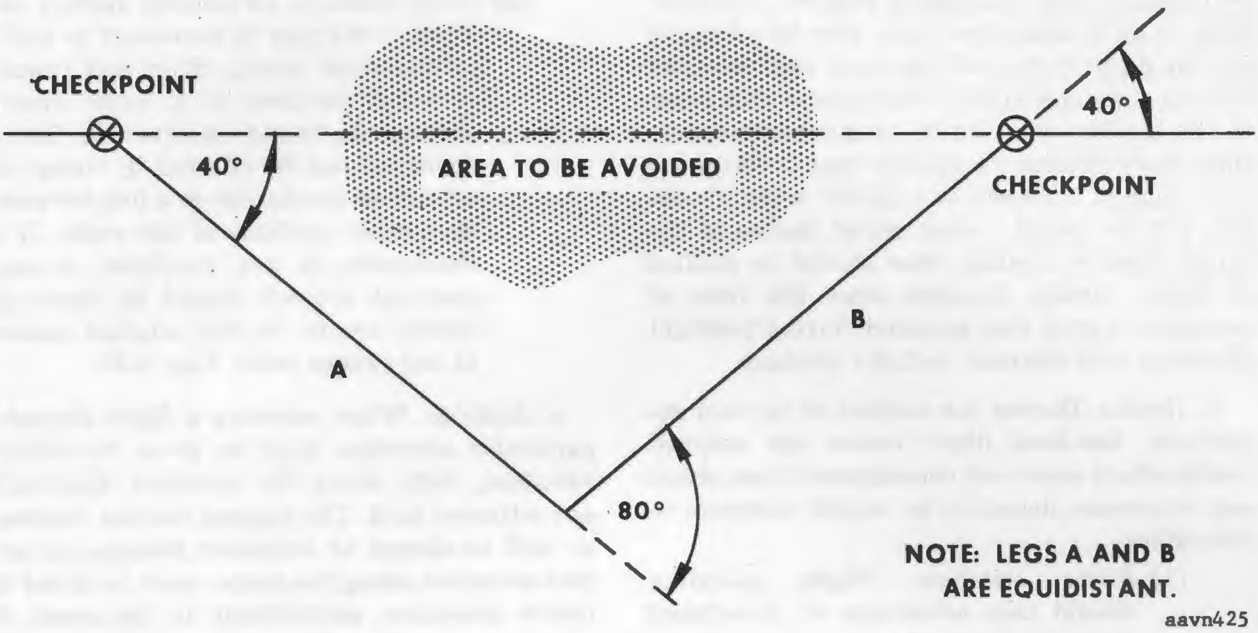


Figure 4–8. Geometrical pattern to return to original course.

Powerline and pipeline rights-of-way.

(2) Near. Some checkpoints must be selected on or very near the intended flightpath in order to obtain time/distance factors along a given course. These checkpoints are essential in obtaining accurate data on groundspeed and exact location at a given time. Such points include—

Railroad and highway bridges.

Junctions, crossings, and prominent curves and turns in railroads and highways.

Stream junctions and other prominent configurations.

Lakes and ponds.

Churches and schools.

Various patterns formed by the combination of timbered and adjacent cleared lands.

Roads, railroads, and streams usually can be detected in vegetation when approached at a shallow angle; however, approaches from the perpendicular may make them difficult to see due to the masking effect of vegetation.

4–13. Flight Plan Graph

Adherence to preplanned routes, and accuracy in estimated times of arrival for rendezvous, turning points, and initial points are of paramount importance to successful low-level navigation. Since one of the principal difficulties of low-level navigation is the physical manipulation of the ordinary navigational tools, a flight plan graph (FPG) will reduce the demand upon time and effort without sacrificing accuracy and reliability.

a. Description. The flight plan graph (fig. 4–9) is a device for monitoring flight progress of a mission. It precludes the necessity for carrying an excessive number of maps, or drawing unnecessary lines and notes on necessary maps. It is prepared during the mission planning phase and requires little attention during the flight. Basically, the flight plan graph consists of a line representing the flight plan time from departure to destination or turning point, and roughly parallels the true course of the flight. Predicted times to various points along the true course, together with departure and destination times, are plotted on this time scale. Thus, the flight plan graph represents a visual

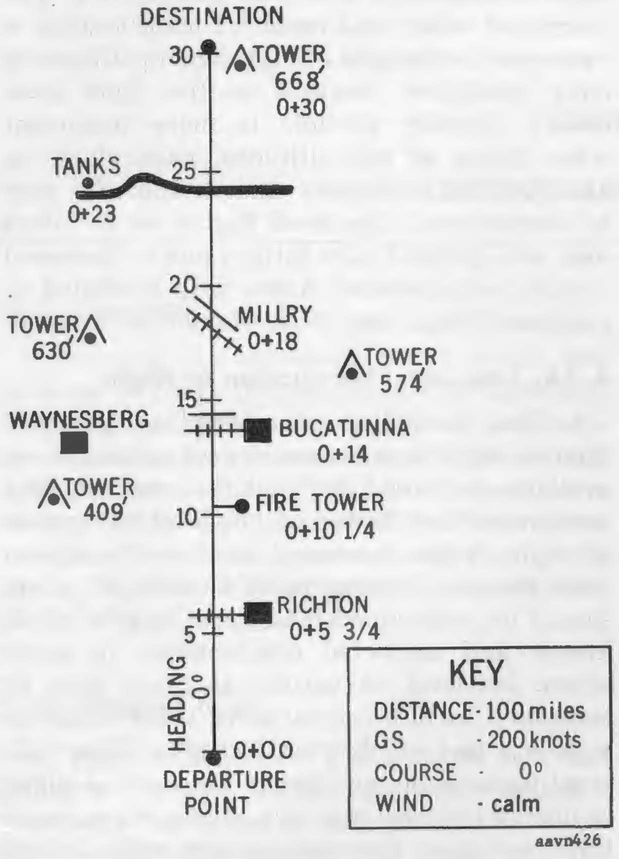


Figure 4-9. Flight plan graph.

time line comparable to the predicted track. Using the time line, the predicted estimated time of arrival to any point on the predicted track can be determined at any time without computation. Comparison with a fix, checkpoint, or obstacle gives the aviator or observer an indication of the time he is ahead or behind his flight plan. In addition, this time difference can be applied to destination and/or intermediate checkpoints to maintain accurate running estimated times of arrival for these positions.

b. Preparation. The flight plan graph can be prepared as follows:

(1) Draw a line to represent the true course. This line should be drawn parallel to the long axis of the paper.

(2) On the true course line, using a suitable scale, indicate departure and destination points. All time intervals are evenly spaced since groundspeed is held constant.

(3) Using conventional signs and symbols, indicate, at properly scaled times, the checkpoints, fixes, and terrain obstacles along and adjacent to the route of flight.

(4) With lines perpendicular to the true course and flight plan graph lines, connect checkpoints, fixes, and obstacles to the flight plan graph line.

(5) Label obstructions, checkpoints, and fixes, as deemed necessary, along with their elevations if known.

(6) Using a computer, and based on precalculated groundspeed, compute the time to each checkpoint, fix, or obstacle, recording this time outside the flight plan graph line where it intersects with the line drawn from the checkpoint, fix, or obstacle.

(7) If the route to be flown has several legs, this same procedure can be carried out for each leg.

4-14. Radio Navigation

The same principles of radio navigation found elsewhere in this manual apply to low-level navigation. The capabilities of navigational aids such as VOR, LF/MF radio beacons, and FM homers are greatly reduced at low altitudes, particularly in mountainous terrain; but these aids should be used when possible. Use of navigational aids for some portion of a low-level flight should be considered during preflight planning. As an example, ADF or FM homers might be used from a departure airfield or a loading zone to an intermediate checkpoint on outbound flights, and again for return flight to the base of operations. During airmobile operations, radio aids may also be employed by pathfinders as navigation aids from release points or other predetermined points to the objective area or landing zone; however, enemy capabilities of duplicating radio signals and establishing false stations must be considered.

4-15. Weather

During a tactical situation in which the security and success of the mission demand low-level flight, weather considerations increase in importance. For additional information concerning weather and its effects, see TM 1-300.

a. Visibility. Visibility is the primary weather factor in low-level navigation. During periods of restricted visibility, distant checkpoints essential to orientation and course selection become vague or obliterated, often limiting observation to the ground directly beneath the aircraft. During periods of reduced visibility, the aviator must rely heavily on dead reckoning.

b. Winds. In the conduct of low-level flight, the same attention must be given to the effects of wind as in navigation at higher altitudes. Winds at low levels, as well as those at higher levels, are subject to unexpected changes. Should in-flight observations indicate changed wind conditions, corrections should be calculated as quickly as possible.

(1) One advantage of low-level flight is the visual indication of surface wind from smoke, dust, etc. Because the aircraft is operating close to the surface, it usually will be in the same wind conditions. This allows direct reading of the wind direction rather than by computation as at higher altitudes.

(2) The combination of wind and certain types of terrain may produce turbulence intense enough to be a hazard to light aircraft. In rugged terrain, average or spot wind measurements frequently are nonrepresentative and should be used with caution. Under certain wind conditions, routes through such areas as deep valleys, gorges, and mountain passes may have to be avoided because of severe turbulence.

c. Temperature. Temperature (as well as humidity or dewpoint) and its influence on density altitude and icing conditions must always be considered in low-level navigation. The margin of safety and room for maneuvering to overcome the hazards of high density altitude or icing conditions decrease as the flight level lowers. Density altitude is more important when flying at low altitudes, particularly in areas where turbulence and downdrafts may be encountered. Low-level flights on hot days may also increase pilot fatigue due to increased cockpit temperatures. Areas with predicted or suspected icing conditions should be avoided.

4-16. Low-Level Navigation at Night

a. The feasibility of attempting low-level flight at night depends on the geographical area, available natural light, and the weather. The most important factor of low-level navigation at night is the increased danger of collision with terrain or manmade objects. A chart should be maintained listing the heights of all known and suspected obstructions. In areas where low-level navigation at night may be necessary, as in a combat zone, there would be a serious lack of obstruction lights. Many cultural features do not appear the same at night as during the day; however, rivers, lakes, coast lines, and most manmade objects with distinctive outlines are good checkpoints at night.

b. When flying in mountainous terrain, the aviator must realize that the actual horizon is near the *base* of the mountains. The summit of peaks used as a horizon would place the aircraft in an attitude of constant climb. To prevent vertigo, distraction of attention, and loss of night vision, cockpit lights should be used only when necessary. When possible, a copilot or observer should make any in-flight computation necessary and assist in monitoring flight and engine instruments. Aviators should be proficient in daytime low-level operations before attempting extensive low-level navigation at night. If a reasonable degree of safety is afforded, low-level flight can be conducted at night using the same navigational procedures as in daylight operations.

c. For additional information concerning navigation at night, see FM 1-100.

CHAPTER 5

PLOTTING AND MEASURING

5-1. 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 a 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 navigation skill and must be accurate.

5-2. Plotting Tools

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

b. Dividers. Use dividers to step off distances on a chart. The dividers should have their points separated to the desired distance as determined from the proper chart scale (latitude or graphic). The distance scale is thereby transferred to the working area of the chart and lines of desired length can be properly marked off. By reversing the process, unknown distances on the chart can be spanned with the dividers and compared with the chart 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. 5-3) is the type commonly used by the Army aviator.

5-3. Description of the Mark II Weems Plotter

a. General. The Mark II Weems plotter (fig. 5-1) 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 of the plotter is an inch scale. Along each edge is a scale for measuring *statute* miles on a WAC chart (scale 1:1,000,000). Between this scale and the inch scale is another scale for measuring statute miles on a *sectional* chart (scale 1:500,000). The rectangular part of the plotter has several lines parallel with the straightedge for assistance in alining the straightedge parallel to a plotted course line.

Note. Some plotters are scaled for measuring nautical miles.

c. Circular Scales. The circular scales are calibrated in degrees. The outer scale, reading from 0° to 180° (right to left), is for direction in the first and second chart quadrants (north through east to south, fig. 5-2). Since these directions are to the right on the chart, the outer scale has an arrow pointing to the right. The inner scale, reading from 180° to 360° (right to left), is for directions in the third and fourth quadrants (fig. 5-3). The center of curvature of both scales is marked by a small hole.

5-4. Technique for Using the Mark II Weems Plotter

a. Measuring a Course. To measure a course (fig. 5-4), place the center hole on a meridian

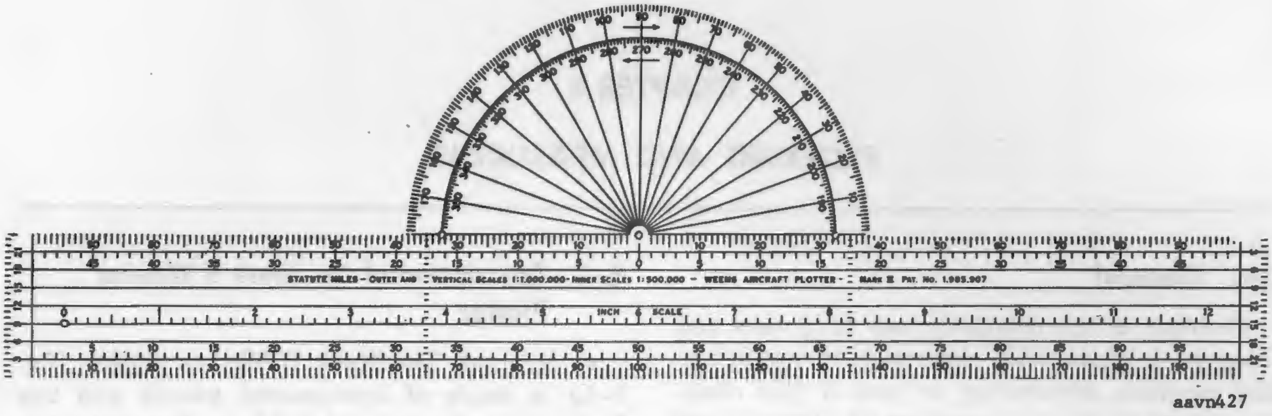


Figure 5-1. Mark II Weems plotter.

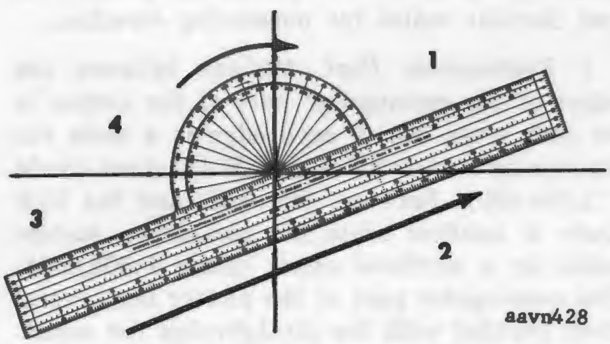


Figure 5-2. Measuring course in the first and second quadrants.

approximately midway along the plotted course line, and place the straightedge parallel with the course line. If the chart meridians do not intersect the course line, extend the line and move the straightedge of the plotter parallel to the course line until the center hole lies over a meridian (fig. 5-5). Figure 5-4 shows the method of reading direction. Observe the small arrows on the circular scale to determine correct direction. Read the scale on which the small black arrow points in the direction of the course, and always read "up" the scale from the smaller values toward the larger values.

Note. Another type Weems plotter is designated Mark II N. It is similar in construction to the Mark II, with the following exceptions: The outer scales are for measuring nautical miles (nm) on a WAC chart; the adjacent inner scales are for measuring statute miles on a sectional chart; the scale midway between the edges is for measuring statute miles on a sectional chart; and inside the circular scale is a small arc which is an aid when measuring courses that are nearly north or south.

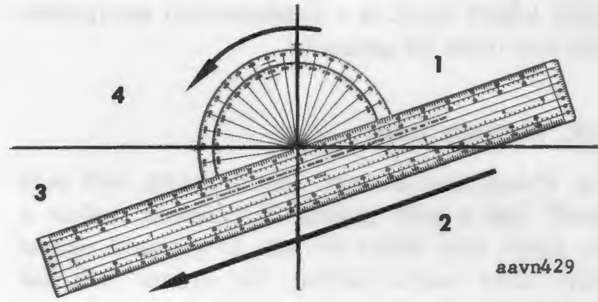


Figure 5-3. Measuring course in the third and fourth quadrants.

b.Drawing Course Line From a Known Point. To draw a given course line from a known point, place the point-end of a 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. 5-6).

c. Measuring and Drawing Courses Near 0° or 180°. In drawing a course line that is nearly north or south, it may be difficult to use the

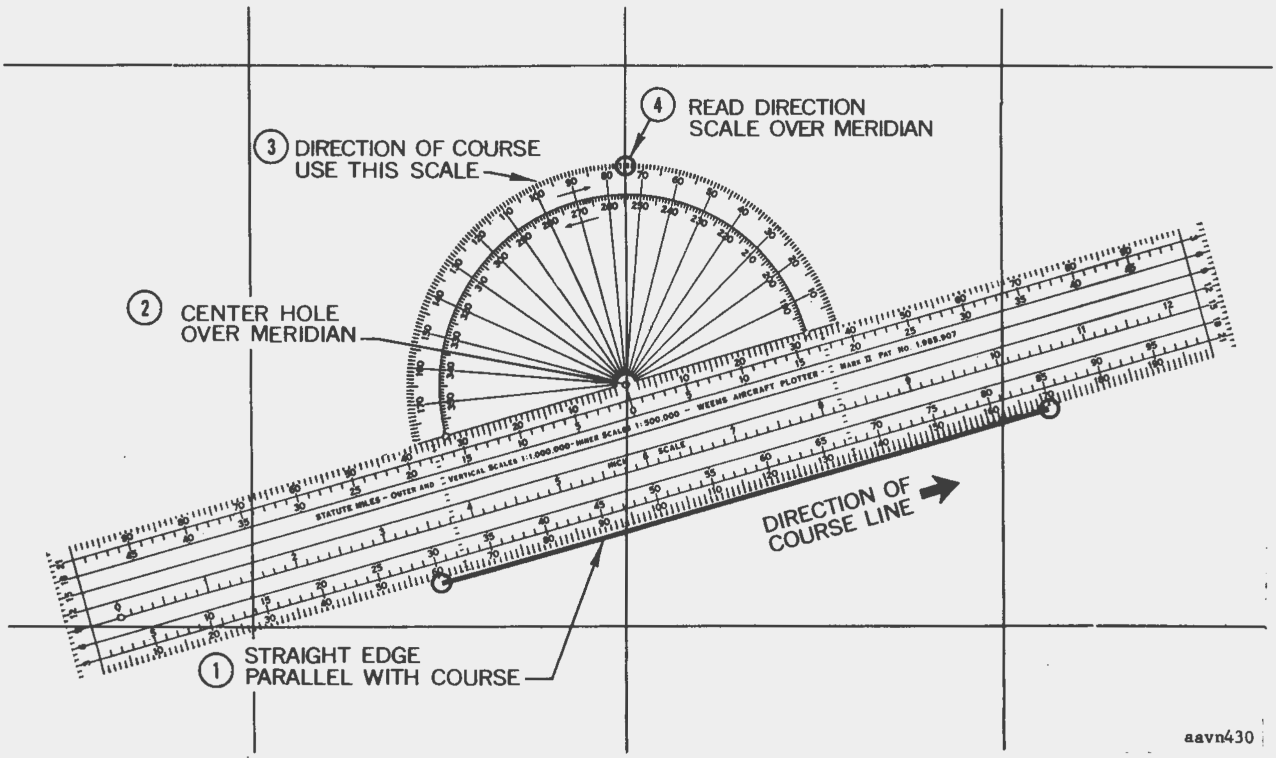


Figure 5-4. Measuring course.

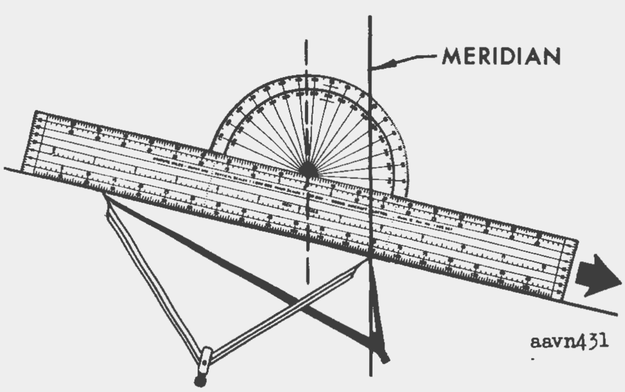


Figure 5-5. Moving plotter to a meridian.

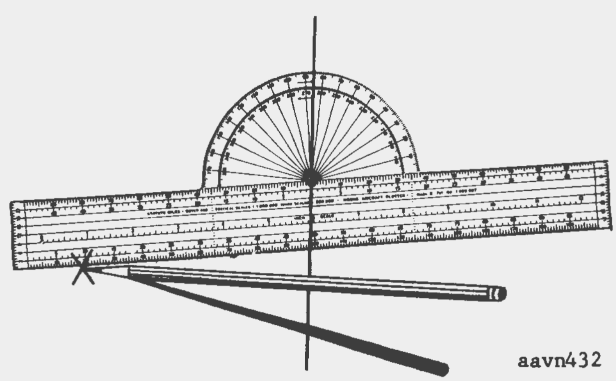


Figure 5-6. Drawing a course line from a known point.

plotter in the usual manner. Courses near 0° 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. 5-7). (The new Mark II plotter has a special scale for measuring courses near north and south (see note in *a* above and fig. 5-8).)

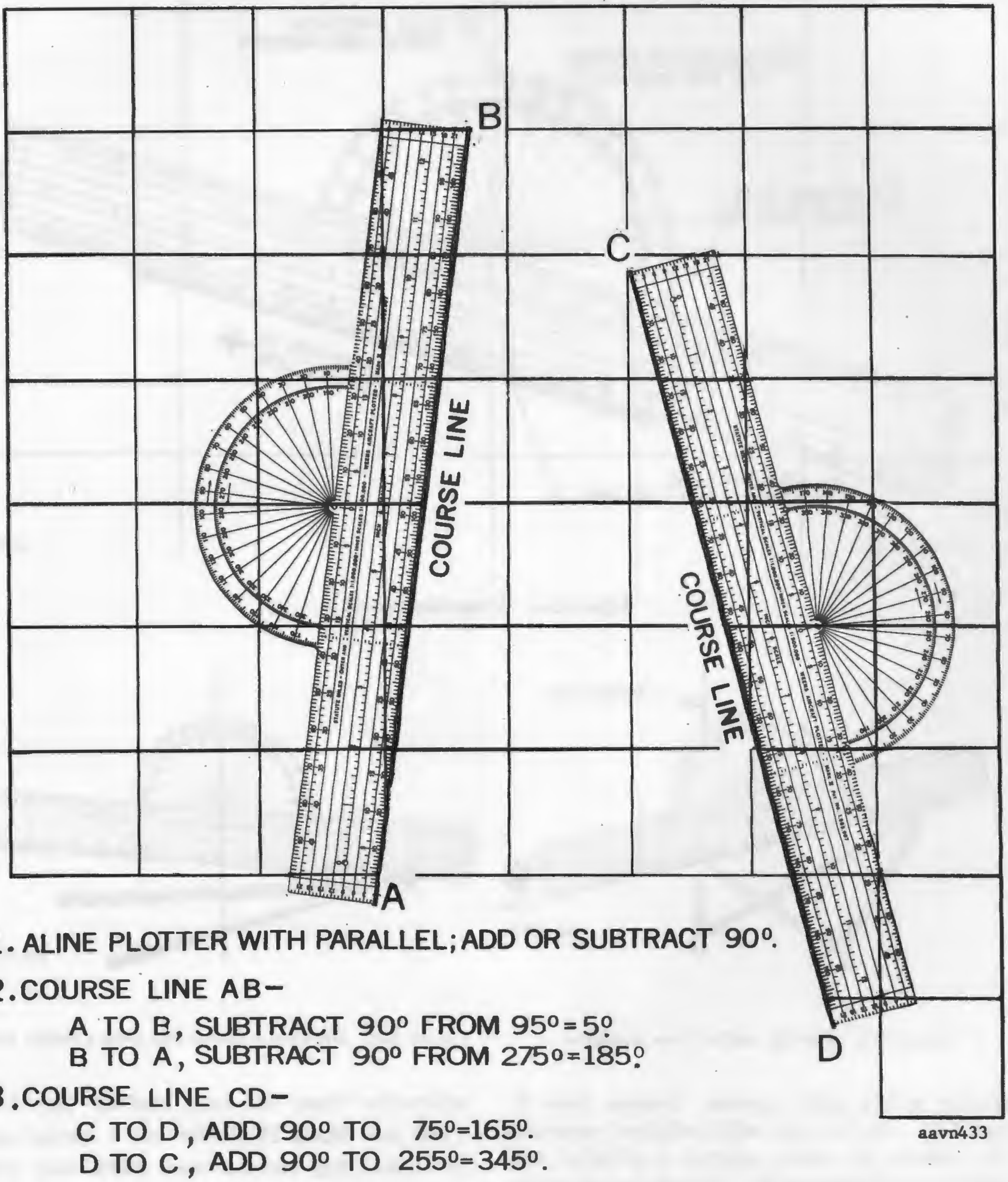
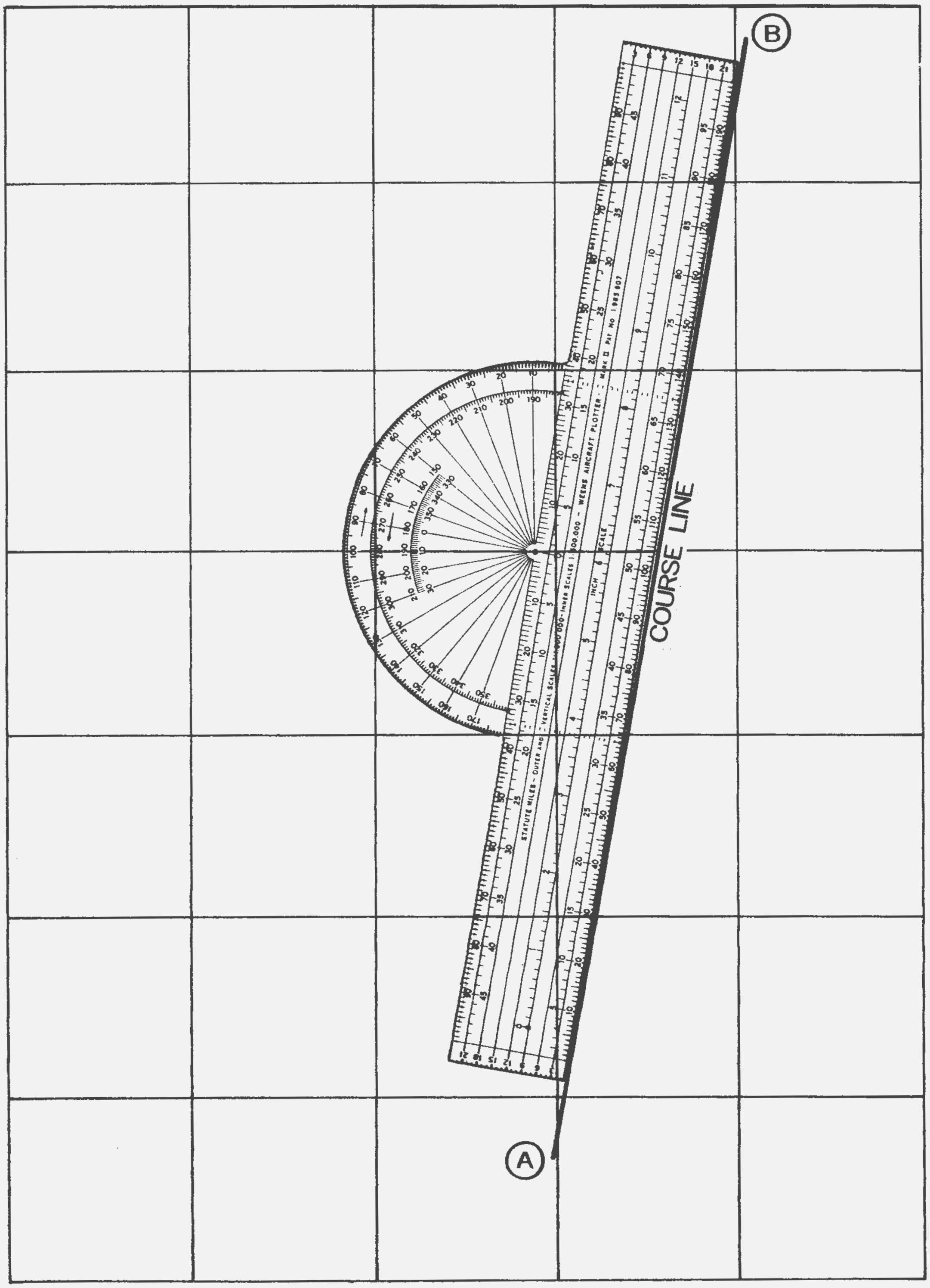


Figure 5–7. Measuring and plotting courses near 0° or 180°.



1. FROM A TO B, READ INNER SPECIAL SCALE (10°)
2. FROM B TO A, READ OUTER SPECIAL SCALE (190°).

NOTE. REVERSING PLOTTER POSITION FROM LEFT TO RIGHT SIDE OF THE COURSE LINE DOES NOT AFFECT READING. aavn434

Figure 5–8. Courses near 0° or 180° measured with special circular scale.

CHAPTER 6

INSTRUMENTS USED FOR DEAD RECKONING NAVIGATION

6–1. Introduction

a. Dead reckoning is the method for determining position by means of a heading indicator and calculations based on speed, time elapsed, wind effect, and direction flown from a known position.

b. The instruments used by the pilot-navigator for dead reckoning navigation include the outside air temperature gage, airspeed indicator, altimeter, clock, and one or both of the following compass systems:

(1) *Magnetic compass system* (par. 6–2).

(2) *Slaved gyro system* (TM 1–215).

c. These instruments provide information concerning direction, airspeed, altitude, and time, each of which must be correctly interpreted for successful navigation. Information on the instruments discussed in this chapter is general in nature. For complete description, theory, and operation of these instruments, see TM 1–215 and appropriate aircraft operator's manuals.

6–2. Magnetic Compass

a. General. The magnetic compass (fig. 6–1) is a direction seeking instrument with a rotating compass card marked at 5° increments numbered 30° apart. A fixed line called the *lubber line* is located on the window of the compass case and is a reference line for reading the compass. The reading on the compass card under the lubber line indicates the compass heading of the aircraft. The magnetic compass has certain inherent errors caused by variation, deviation, and other magnetic and external physical forces (explained in TM 1–215) that affect compass movement when the aircraft deviates from a straight and level flightpath. Therefore, the magnetic compass

Figure 6–1. Magnetic compass.

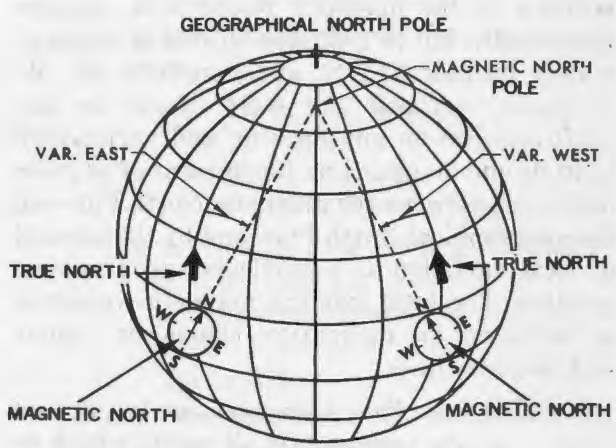


Figure 6–2. Magnetic variation.

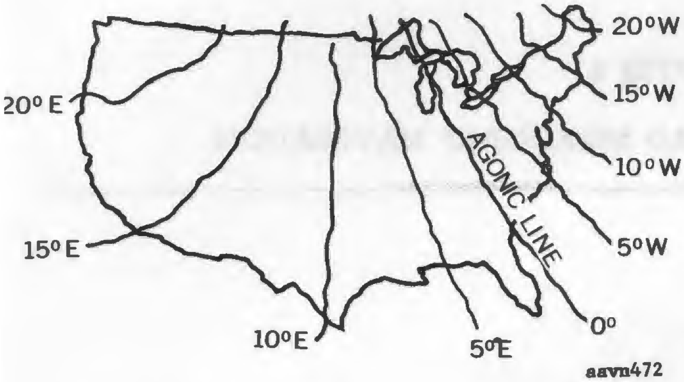


Figure 6-3. Magnetic variation in the United States (1960).

normally is used in conjunction with a gyro heading indicator (par. 6-3).

b. Magnetic Variation. Navigation charts usually are oriented in geographical true directions; i.e., the meridians converge at the geographical poles. However, the magnetic compass derives its directional qualities from the needle (or compass card) alining itself with the direction of the earth's magnetic field. The needle therefore points to the magnetic North Pole unless influenced by large mineral deposits near the surface below the aircraft (local variations). The angular difference between true north and magnetic north is called *magnetic variation* or simply *variation.* The position of the magnetic North Pole changes periodically, but in 1960 was located at approximately latitude 71° N. and longitude 96° W. Magnetic variation (fig. 6-2) affects the aircraft compass on any heading and varies with latitude and longitude by the amount of angular difference between the magnetic North Pole and the geographical North Pole, and by the amount of local variation at a particular geographical position. The total existing magnetic variation is indicated on navigation charts by *agonic* and *isogonic* lines.

(1) *Agonic line.* An *agonic line* is a line on a chart connecting all points where *no* magnetic variation exists. It is labeled 0° (fig. 6-3).

(2) *Isogonic line(s).* An isogonic line is a line on a chart connecting all points of *equal* magnetic variation. These lines are drawn at various intervals as determined by the chart size. Each line is labeled according to the number of degrees variation east or west of true north. Referring to figure 6-3, in the northeastern section of United States the magnetic compass points west of true north (variation is westerly); in southern and western United States the magnetic compass points east of true north (variation is easterly). Minor bends and turns in the isogonic lines are caused chiefly by local magnetic forces. A true course corrected for total magnetic variation becomes a magnetic course.

Note. Variation is called declination in many textbooks. The two terms are synonymous in aerial navigation.

c. Magnetic Deviation. A magnetic compass is also 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 caused by magnetic attractions in the aircraft itself (metal parts, ignition system, electric lights, tools and cargo, etc.) is called *magnetic deviation.* Deviation may change with each change of aircraft heading; *variation* changes only with changes of locality. If the compass needle deflects 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.

(2) *Deviation card.* A deviation card (fig. 6-4) records the deviation errors in the compass indications. The card is mounted next to the compass and in-

15088		COMPASS	
SWUNG: TO FLY	5 Aug. 64 STEER	BY: TO FLY	STEER ©
N	001	180	181
15	016	195	195
30	031	210	209
45	047	225	224
60	062	240	238
75	077	255	253
90	093	270	268
105	107	285	284
120	121	300	300
135	136	315	315
150	150	330	330
165	165	345	346

Figure 6–4. Deviation card.

cludes the aircraft number, date on which the compass was *swung* (see below), and a compass heading to be flown for each magnetic heading in increments of 15°.

Note. A compass is swung periodically by placing the longitudinal axis of the aircraft over surveyed, predesignated cardinal points with engine running and electrical equipment turned on. The compass is then adjusted mechanically to reduce or eliminate deviation errors. Any compass deviation which cannot be mechanically compensated is recorded for specific aircraft headings.

d. Applying Compass Corrections.

(1) *System for applying compass corrections.* To find what the compass should read in order to follow a given course, it is corrected for drift, variation, and deviation. When drift correction (par. 7–3) 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:

(*a*) Write the following equations:

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

TH is true heading; V, variation; MH, magnetic heading; D, deviation; and CH, compass heading.

(*b*) Below each factor, place the known information.

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

(*c*) When making calculations from a true heading to a compass heading, easterly error is subtracted; westerly error is added. Completing the problem, subtraction of the 12°E (variation) from the TH (168°) gives a magnetic heading (MH) of 156°. Place this figure under both of the MH's. Adding the 5°W (deviation) to the MH (156°) gives a compass heading (CH) of 161°. Place the compass heading under CH.

(2) *Reversing the equation.* To find the 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:

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

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

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

(*c*) Add the 12°E to the MH (156°) to obtain the TH (168°). Place this figure below the TH.

6-3. Heading Indicator (Directional Gyro)

The heading indicator assists in making turns to predetermined headings and aids in maintaining a desired heading. It is *not* a direction seeking instrument and must be adjusted to agree with the magnetic heading of the aircraft. Because of instrument *precession* (failure to remain rigid in space) (TM 1-215), it is necessary to reset the heading indicator about every 15 minutes. Precession should not exceed 3° in 15 minutes.

6-4. Airspeed Indicator

a. Indicated Airspeed. Because of variations in air density and instrument system errors, the airspeed indicator does not necessarily indicate the true airspeed of the aircraft (true airspeed (TAS) is the speed of the aircraft through the air). The reading on the airspeed indicator is called *indicated airspeed* (IAS). Since airspeed calibration cards are not used in the Army aircraft, indicated airspeed and *calibrated airspeed* (CAS) are synonomous to the aviator. To find true airspeed, corrections must be made to the indicated airspeed for temperature and pressure altitude.

b. Changing Indicated Airspeed to True Airspeed. A "rule of thumb" for calculating true airspeed is too 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 dead reckoning computer (par. 8-15).

CHAPTER 7

WIND AND ITS EFFECTS

7-1. Wind Direction and Speed

Wind direction is the direction *from* which the wind blows; e.g., and wind blowing from the northwest is a northwest wind. *Windspeed* is the rate of wind motion without regard to direction. In the United States, windspeed 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.

7-2. 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 with the wind as does the balloon shown in figure 7-1. 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 1 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 an airplane through the air is governed by the direction in which the nose of the airplane is pointed and by the speed of the aircraft (fig. 7-2).

b. Drift. The sideward displacement of the aircraft caused by the wind is called *drift* (fig. 7-3). Drift is measured by the angle between the *heading* (direction in which the nose is

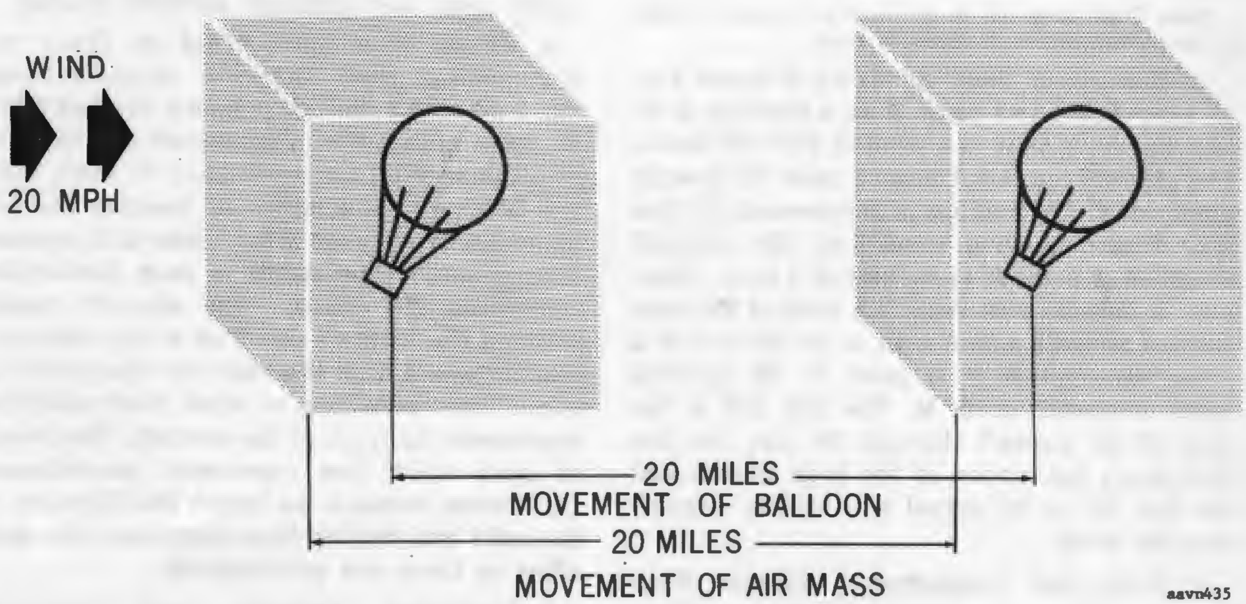


Figure 7-1. Wind effect on a free balloon in 1 hour.

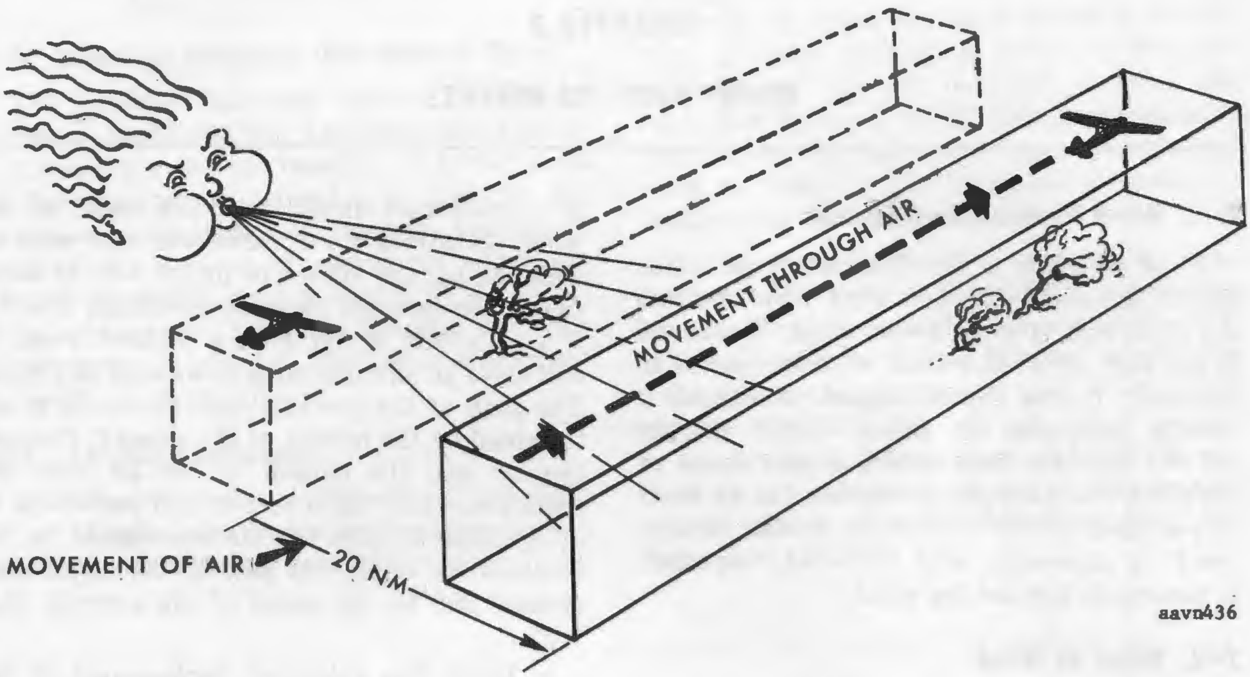


Figure 7–2. Wind effect on an aircraft.

pointed) and the *track* (actual path of the aircraft over the earth).

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

c. Example of Drift. As shown in figure 7–3, an aircraft departs point X on a heading of 0° and flies for 1 hour in a wind of 270°/20 knots. The aircraft is headed toward point M directly north of X. Its heading is represented by line XM. Under no-wind conditions, the aircraft would be at point M at the end of 1 hour. However, in this example there is a wind of 20 knots and the aircraft moves with it. At the end of 1 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.

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

e. Effects of a Given Wind on Track and Groundspeed With Different Aircraft Heading. Figure 7–4 illustrates how a wind of 270°/20 knots affects the groundspeed and track of an airplane flying on headings of 0°, 090°, 180°, and 270°. On each different heading the airplane flies from point X for 1 hour at a constant true airspeed. The length of each dashed line represents the distance the aircraft travels through the body of air. This is the same distance it would have traveled over the ground in 1 hour had there been no wind. Each solid line represents the track of the aircraft. The *length* of each solid line represents groundspeed. Differences between the length and direction of the solid and dashed lines represent the wind effect on track and groundspeed.

f. Headwind, Tailwind, and Crosswind Effect. As shown in figure 7–4, the wind of

Figure 7-3. Drift.

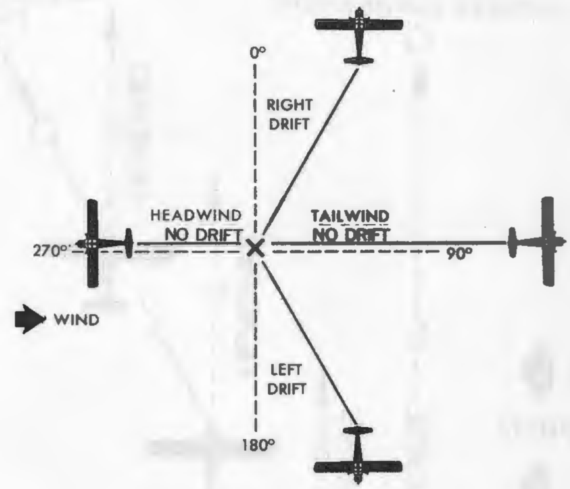


Figure 7-4. Effects of a given wind on track and groundspeed with aircraft flying on different headings.

270°/20 knots causes right drift on a heading of 0°; 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 1 hour than it 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 0° and 180°, the groundspeed effect is usually complicated by the drift correction applied.

7-3. Drift Correction

Drift correction must be applied to a course to determine the 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). If an aviator attempts to fly to a destination due north of his point of departure on a heading of 0°, and a west wind is blowing, he will arrive somewhere east of his destination because of right drift ((A), fig. 7-5). To correct for right drift so that the aircraft will remain on course and arrive at the desired destination, the nose will have to be pointed to the *left* of the course, or upwind ((B), fig. 7-5).

7-4. 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 heading is greater than track or course, drift is to the left.

d. If heading is less than track or course, drift is to the right.

e. If drift is to the right, drift correction is to the left.

f. If drift is to the left, drift correction is to the right.

g. Drift is always downwind.

h. Drift correction is always upwind.

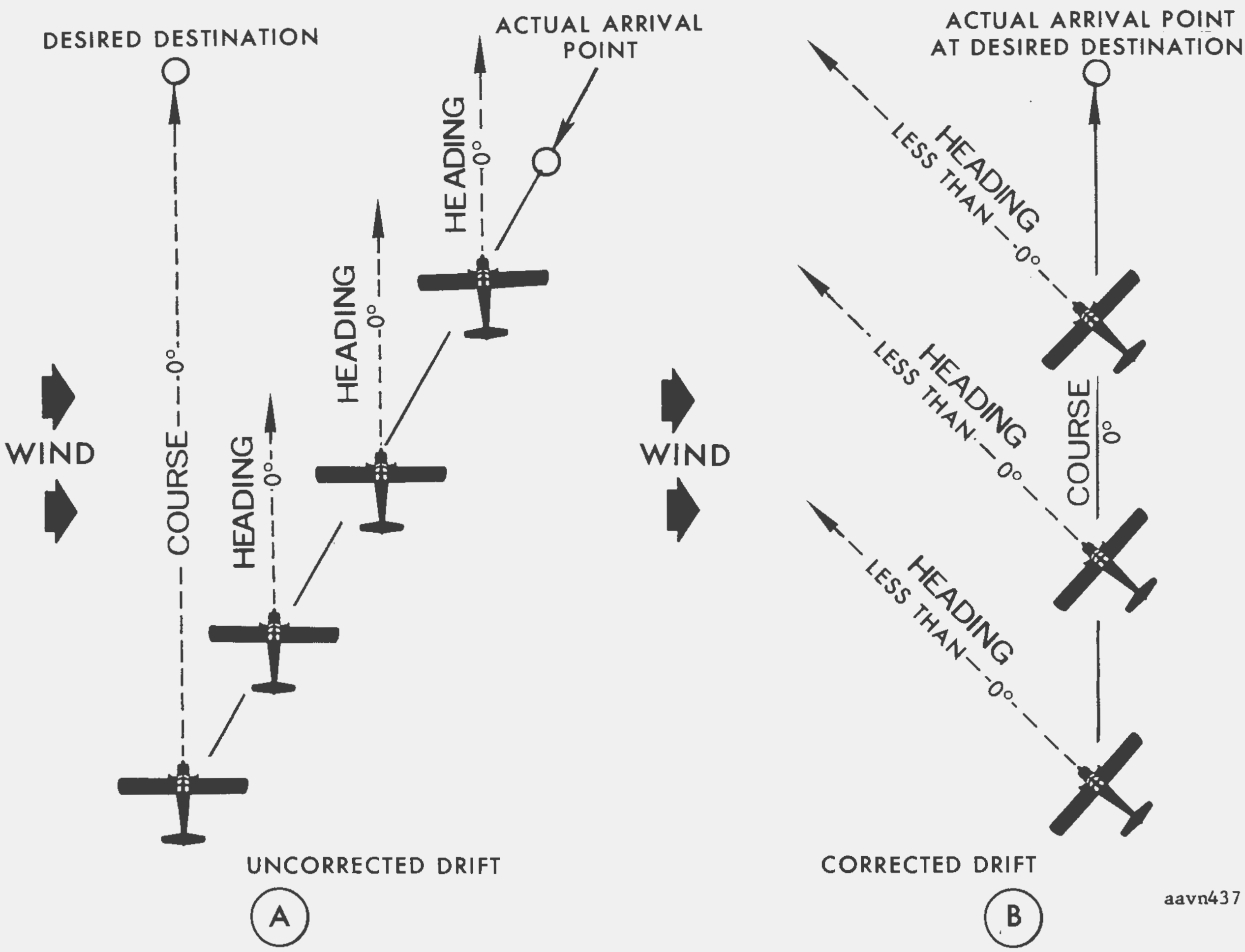


Figure 7–5. Drift and drift correction.

7–5. Applied Problems of Drift and Drift Corrections

a. Problem. Heading 160°, track 170°. Is drift right or left? Is drift correction to be made to right or left?

Solution. Since heading is less than track, drift is right; drift correction is left.

b. Problem. Heading 350°, drift 4° left. What is the track? What is the drift correction?

Solution. Since drift is left, heading must be greater than track. Track equals 346° (350° —4°).

Drift correction 4° right.

c. Problem. Track 005°, drift 10° right. What is the heading? What drift correction is required?

Solution. Since drift is right, heading is less than track.

Heading equals 355° (005°—10° or 365° 10°).

Drift correction equals 10° left.

7–6. Groundspeed (GS)

Groundspeed is the result of wind velocity 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 air-

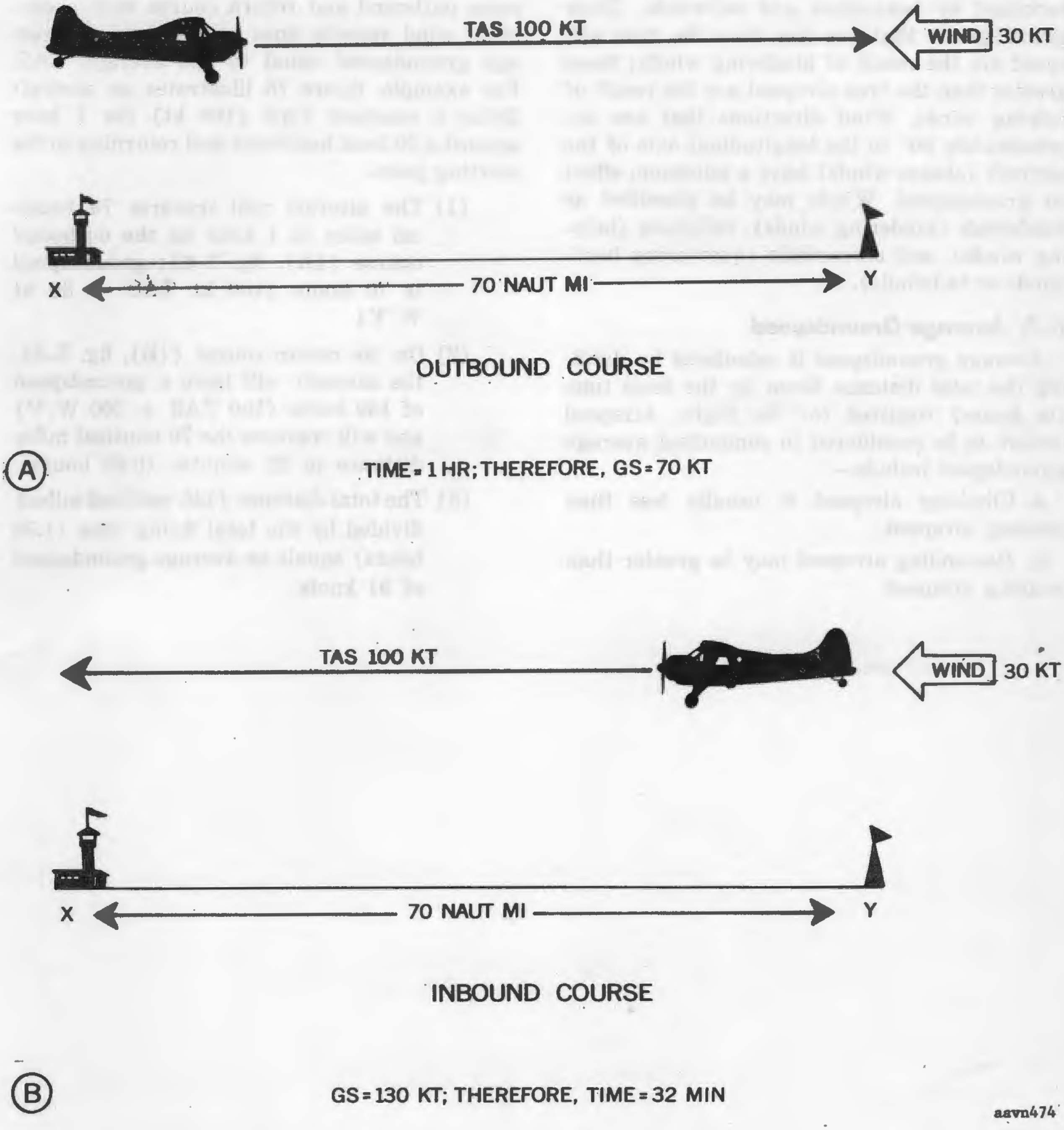


Figure 7–6. Average groundspeed.

speed (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 (abeam winds) have a minimum effect on groundspeed. Winds may be classified as *headwinds* (hindering winds), *tailwinds* (helping winds), and *crosswinds* (quartering headwinds or tailwinds).

7-7. Average Groundspeed

Average groundspeed is calculated by dividing the total distance flown by the total time (in hours) required for the flight. Airspeed factors to be considered in computing average groundspeed include—

a. Climbing airspeed is usually less than cruising airspeed.

b. Descending airspeed may be greater than cruising airspeed.

c. Flying a constant true airspeed on the same outbound and return course with a constant wind velocity does not produce an average groundspeed equal to the average TAS. For example, figure 76 illustrates an aircraft flying a constant TAS (100 kt) for 1 hour against a 30-knot headwind and returning to the starting point.

(1) The aircraft will traverse 70 nautical miles in 1 hour on the outbound course ((A), fig. 7-6); groundspeed is 70 knots (100 kt TAS — 30 kt W/V).

(2) On the return course ((B), fig. 7-6), the aircraft will have a groundspeed of 130 knots (100 TAS + 300 W/V) and will traverse the 70 nautical miles distance in 32 minutes (0.53 hours).

(3) The total distance (140 nautical miles) divided by the total flying time (1.53 hours) equals an average groundspeed of 91 knots.

CHAPTER 8

THE DEAD RECKONING (DR) COMPUTER

Section I. GENERAL

8-1. Construction and Purpose

A dead reckoning computer is a combination of two devices, one a specially designed instrument for solving wind triangles and the other a circular slide rule for solving mathematical problems.

8-2. The MB-4A DR Computer

Many different types of dead reckoning navigation computers exist, but the construction and design features of the major types are very similar. For illustrative purposes, the standard Army DR computer, type MB-4A, is used throughout this chapter.

Section II. THE SLIDE RULE FACE

8-3. The Slide Rule

a. Scales. The slide rule of the MB-4A computer consists of two circular scales. The outer scale is stationary and is called the MILES scale. The inner scale rotates and is called the MINUTES scale.

b. Scale Values. The numbers on any computer scales, as on most slide rules, represent multiples of 10 of the values shown. For example, the number 24 on either scale (outer or inner) may represent 0.24, 2.4, 24, 240, or 2,400. On the inner scale, minutes may be converted to hours by reference to the adjacent hour scale. For example, 4 hours is found in figure 8-1 adjacent to 24, in this case meaning 240 minutes. Relative values should be kept in mind when reading the computer. For example, the numbers 21 and 22 on either scale are separated by five spaces, each space representing two units. The second division past 21 would be read as 21.4, 2,140, 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. Three of the indexes on the outer stationary scale are used for converting statute miles, nautical miles, and kilometers. These indexes are appropriately labeled "Naut" at 66, "Stat" at 76, and "Km" at 122. On the inner rotating scale are two rate indexes. The large black arrow at 60 (called the SPEED index) is the hour index, and the small arrow at 36 is the second ("Sec") index (3,600 seconds equal 1 hour). The "Stat" index on the inner scale is used in mileage conversion. Each scale has a "10" index used as a reference mark for multiplication and division. The application of these

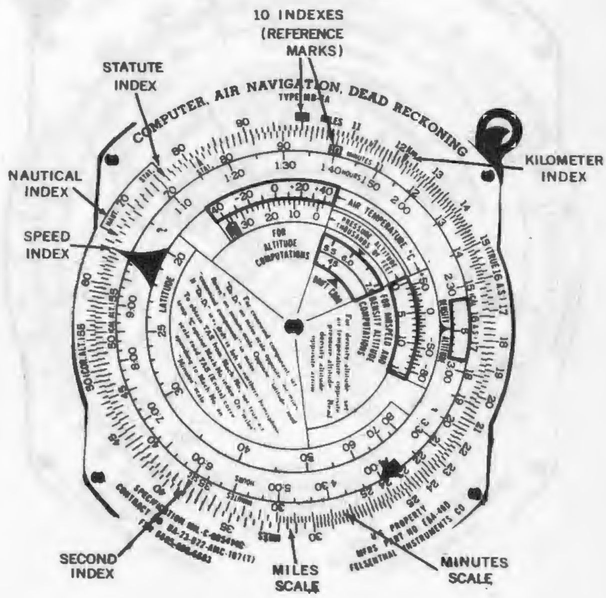


Figure 8-1. Slide rule face.

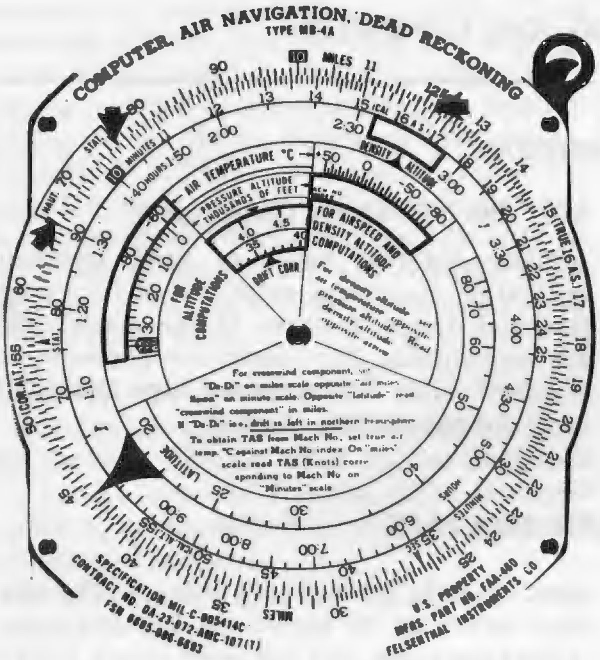


Figure 8-2. Distance conversion.

scales in solving computer problems is illustrated in the specific problems that follow.

8–4. Distance Conversion

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

b. Solution. Using the DR computer, refer to figure 8-2 and solve as follows:

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

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

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

Note. When several distance conversion problems are to be solved between statute and nautical miles, set the "Stat" index on the inner scale under the "Naut" index of the outer scale and read any ratio around the entire slide rule; i.e., 13 statute miles is 11.3 nautical miles, 13 nautical miles is 15 statute miles, etc. (fig. 8-3).

8–5. Simple Proportion

The slide rule face of the DR computer is so constructed that any relationship between two

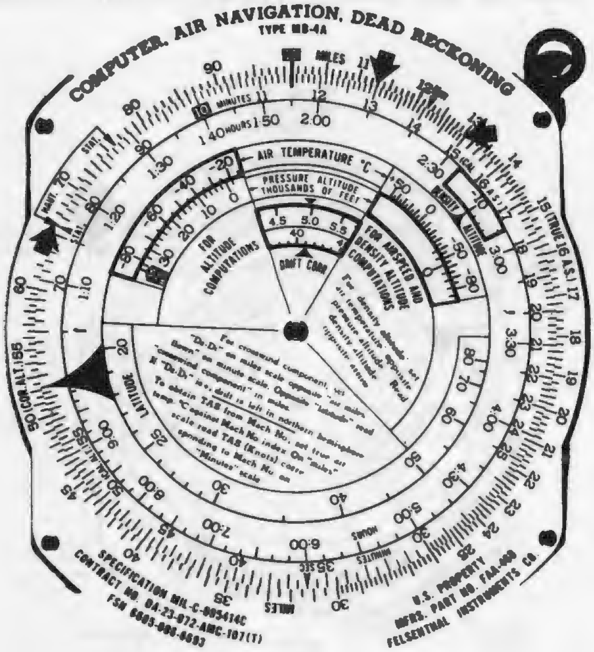


Figure 8-3. Converting several distances simultaneously.

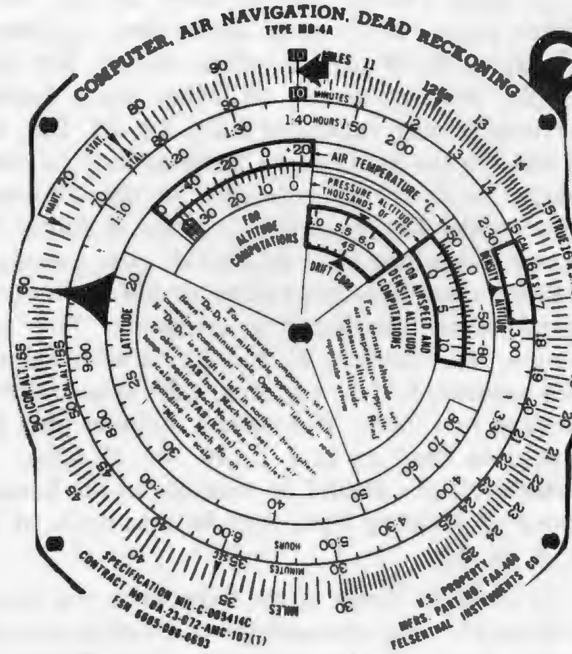


Figure 8-4. Numerical relationship between the two scales.

numbers, one on the stationary scale and one on the movable scale, will hold true for all other numbers on the two scales. For example, if the two 10 indexes are placed opposite each other (fig. 8-4), all other numbers around the entire circle will be identical. If 20 on the inner scale is placed opposite the 10 index on the outer scale, all numbers on the inner scale will be double those on the outer scale. If 12 on the outer scale is placed opposite 16 on the inner scale, all numbers will be in a 3 to 4 (¾) relationship. This scale design enables the aviator to find the fourth term of any mathematical proportion when three of the values are known.

8-6. 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 the DR computer, refer to figure 8-5 and solve as follows:

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

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

8-7. 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 the DR computer, refer to figure 8-6 and solve as follows:

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

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

8-8. Determining Time Required

Time equals distance divided by groundspeed.

a. Problem. How much time is required to fly 333 nautical miles at a groundspeed of 174 knots?

b. Solution. Using the DR computer, refer to figure 8-7 and solve as follows:

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

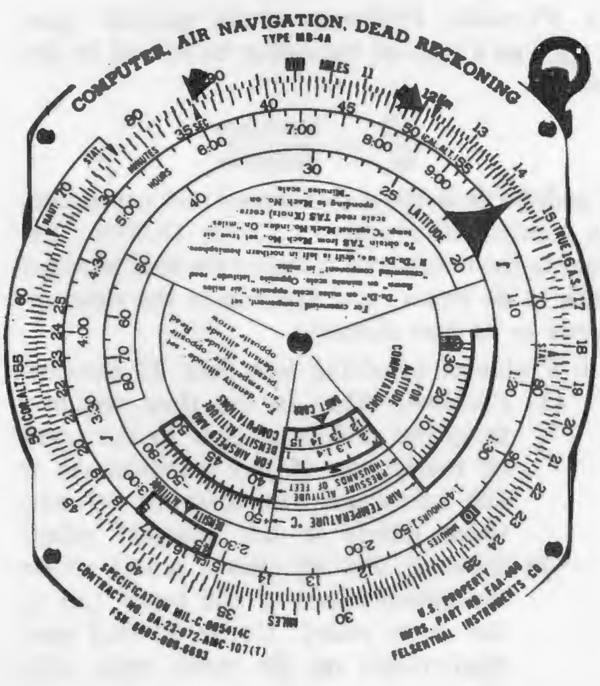


Figure 8-5. Time and distance.

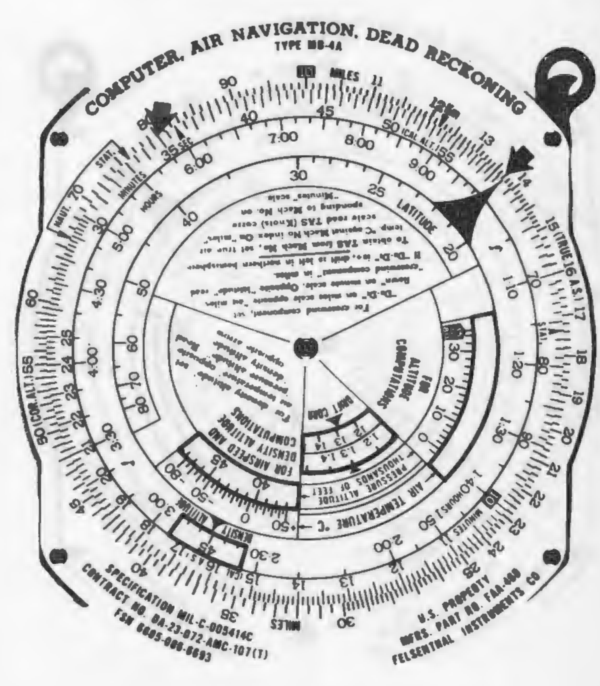


Figure 8-6. Determining groundspeed.

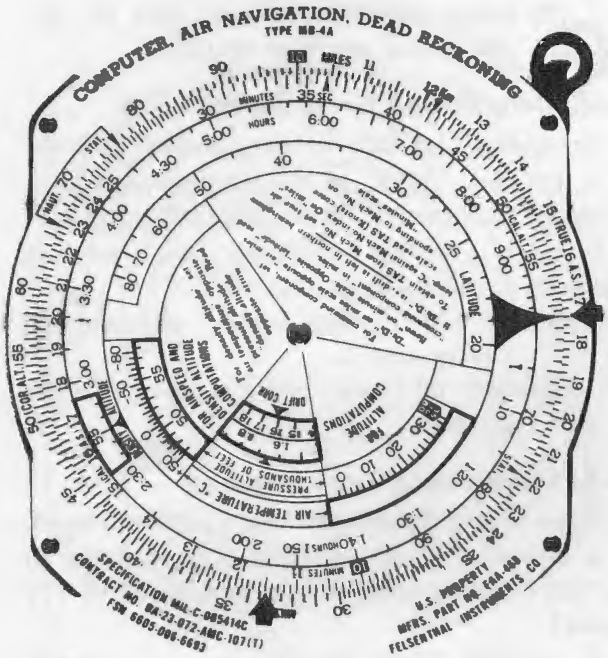


Figure 8-7. Determining time.

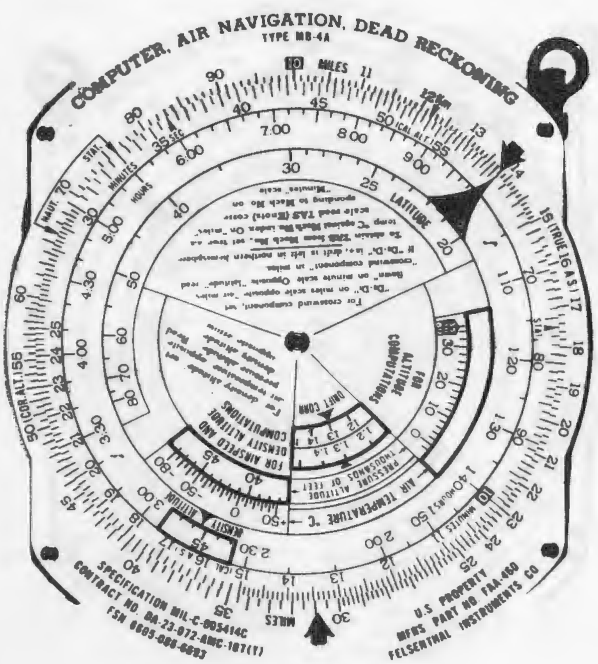


Figure 8-8. Determining distance.

(2) Under 333 (outer scale) read 115 minutes (inner scale) 1 + 55 (hours scale).

8-9. 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 138 knots?

b. Solution. Using the DR computer, refer to figure 8-8 and solve as follows:

(1) Set 60 index at 138 (outer scale).

(2) Over 135 (inner scale) or 2 hours, 15 minutes (hours scale), read 310 nautical miles (outer scale).

8-10. 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. For example, determine the time required to fly from the outer marker to the middle marker or from the middle marker (ch. 15) 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 1 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 the groundspeed of 100 knots (10 on the outer scale). Under 50 (0.5 nautical miles) on the outer scale, read 18 seconds on the inner scale (fig. 8-9).

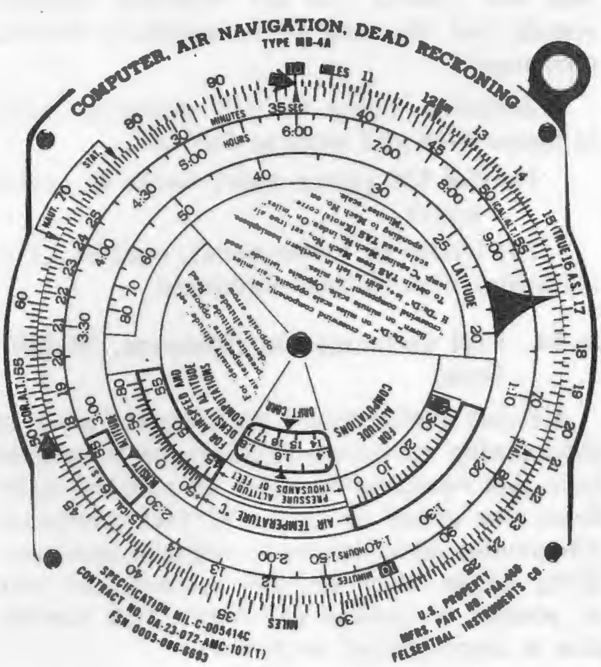


Figure 8-9. Rate-time-distance problems using minutes.

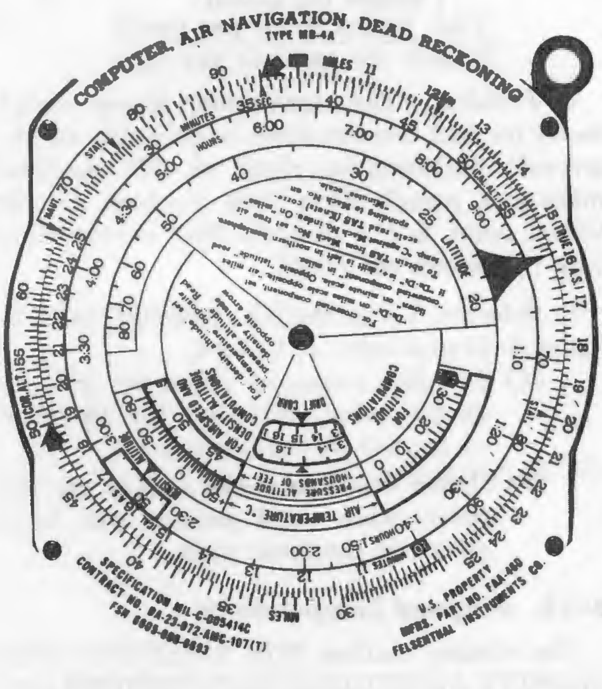


Figure 8-10. Rate-time-distance problems using seconds.

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 of 95 knots (95 on the outer scale). Under 50 (5 nautical miles) on the outer scale, read 19 (190 seconds), or 3 minutes, 10 seconds on the inner scale (fig. 8-10).

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

8-11. Determining Gallons or Pounds Used in a Given Time

Place the 60 index under rate (gph) and read gallons used over the given time. To convert gallons to pounds or pounds to gallons, the following conversion factors are used in simple proportion (par. 8-5):

a. Gasoline. 6.0:1.

b. JP-4 Fuel. 6.5:1.

8-12. 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 the DR computer, refer to figure 8-11 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 the 60 index, read 16.2 gallons per hour (gph).

8-13. Fuel Consumption

Use same scales as used with the time-distance problems discussed in paragraph 8-6 and solve the following fuel consumption problem:

a. Problem. Forty gallons of fuel have been consumed in 135 minutes (2 hours and 15 minutes) flying time. How much longer can the aircraft continue flying if 25 gallons of avail-

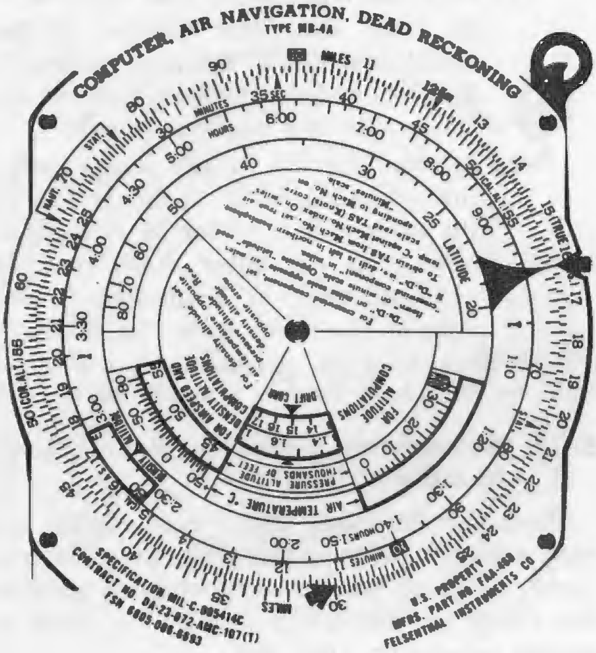


Figure 8–11. Determining rate of fuel consumption.

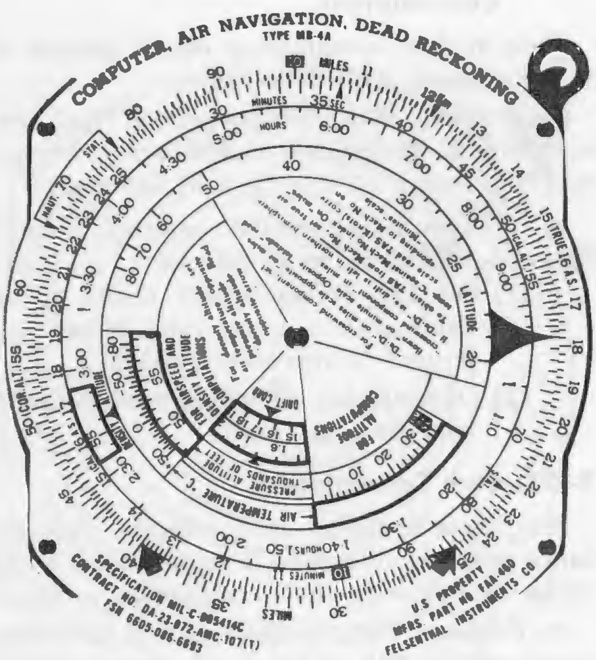


Figure 8–12. Fuel consumption.

able fuel (usable fuel not including reserve) remain and the rate of consumption remains unchanged?

b. Solution. Using the DR computer, refer to figure 8–12 and solve as follows:

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

(2) Under 25 (outer scale), read 84.5 (inner scale) minutes fuel remaining.

8–14. Fuel Consumption (Distance, Weight, Time)

Aircraft performance data charts used in determining maximum flying range sometimes base fuel consumption rates on nautical miles flown per pound or gallon of fuel consumed. The aviator often desires to compute maximum flying range based on fuel consumption rate in pounds or gallons per hour. This conversion is accomplished as follows:

a. Formula. The relationship between nautical miles per pound and pounds per hour is expressed as—

$$\frac{\text{Nautical miles per pound (or gallon)}}{\text{1 pound (or gallon)}} = \frac{\text{TAS (miles flown per hour)}}{\text{Pounds (or gallons) per hour}}$$

b. Problem. The maximum flying range based on fuel consumption is indicated on the aircraft performance chart as .231 nautical miles per pound. At a true airspeed of 196 knots, what is the aircraft fuel consumption rate in pounds per hour?

c. Solution. Using the DR computer, refer to figure 8–13 and solve as follows:

(1) Set .231 (nautical miles per pound) on the outer scale over the 10 index (1 pound) on the inner scale.

(2) Under the TAS (196 knots) on the outer scale, read pounds per hour (850) on the inner scale.

8–15. Airspeed Computations

The window marked FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS provides a means for computing true airspeed when indicated airspeed, temperature, and alti-

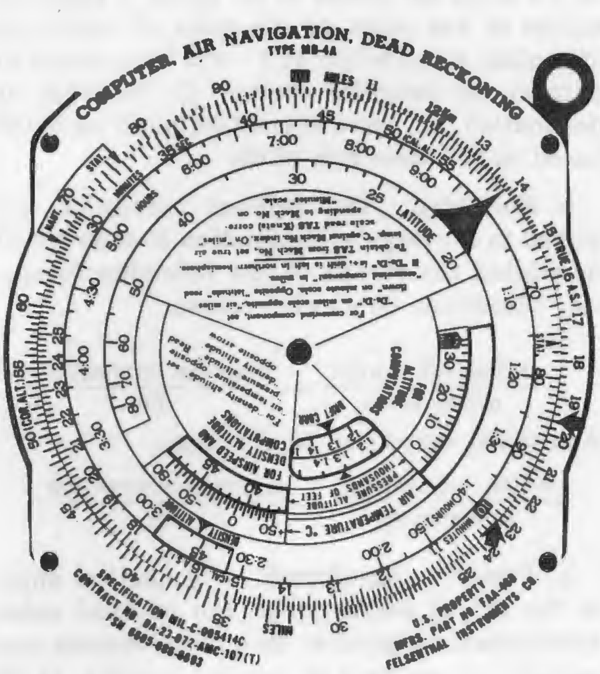


Figure 8–13. Converting nautical miles per pound to pounds per hour.

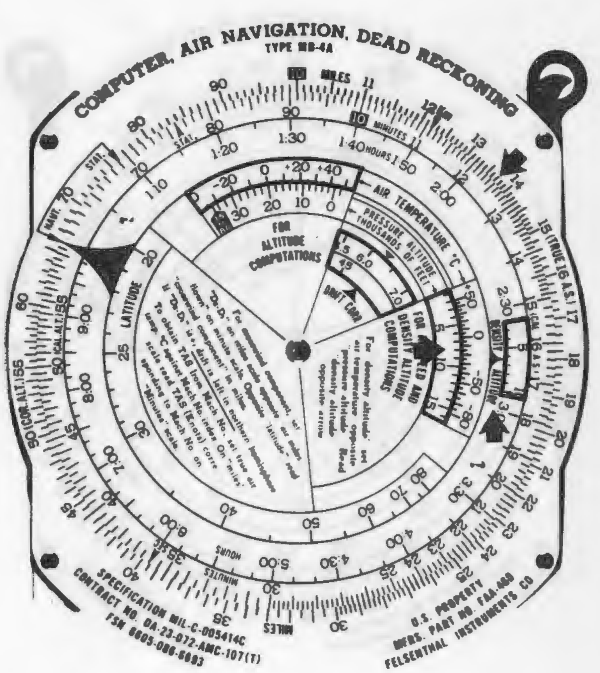


Figure 8–14. Airspeed computation.

tude 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° C. and the pressure altitude is 8,000 feet. What is the true airspeed?

b. Solution. Using the DR computer, refer to figure 8–14 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).

Note. In solving for IAS when TAS is known, locate TAS on outer scale and read answer (IAS) on inner scale.

8–16. Density Altitude

Density altitude is that altitude in the standard atmosphere at which a given air density exists. Because of variations of temperature and pressure, the density of the air on a given day at any given pressure altitude may be that density found several thousand feet higher or lower in the standard atmosphere. Such conditions can be critical in aircraft operations, especially in the operation of helicopters. To compute density altitude, rotate the movable scales of the MB–4 so that the free air temperature is set above the pressure altitude in the window labeled FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS. When set in this manner, the density altitude is read above the pointer in the window labeled DENSITY ALTITUDE (fig. 8–14). Accurate results can only be obtained by using *pressure altitude.* Pressure altitude can be read directly from the altimeter when the altimeter setting is 29.92.

8–17. Altitude Computations

The window marked FOR ALTITUDE COMPUTATIONS provides a means for computing corrected altitude by applying any variations

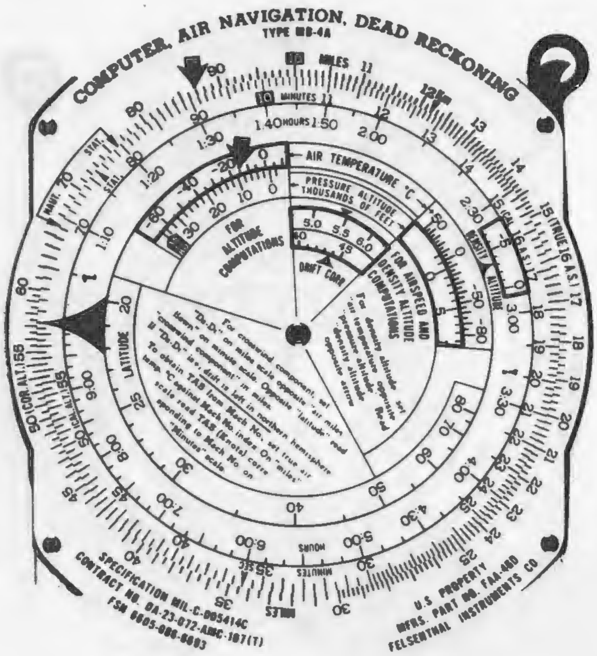


Figure 8–15. Altitude computation.

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 the DR computer, refer to figure 8–15 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).

8–18. Off-Course Correction (Rule of 60)

An aircraft headed 1° off course will be approximately 1 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, 1° of correction will be required to *parallel* the intended course. Applied to other distances (multiples of 60), such as 1.5 miles off course in 90 miles, 2 miles off course in 120 miles, or 2.5 miles off course in 150 miles, a correction of 1° 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. Formulas. 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?

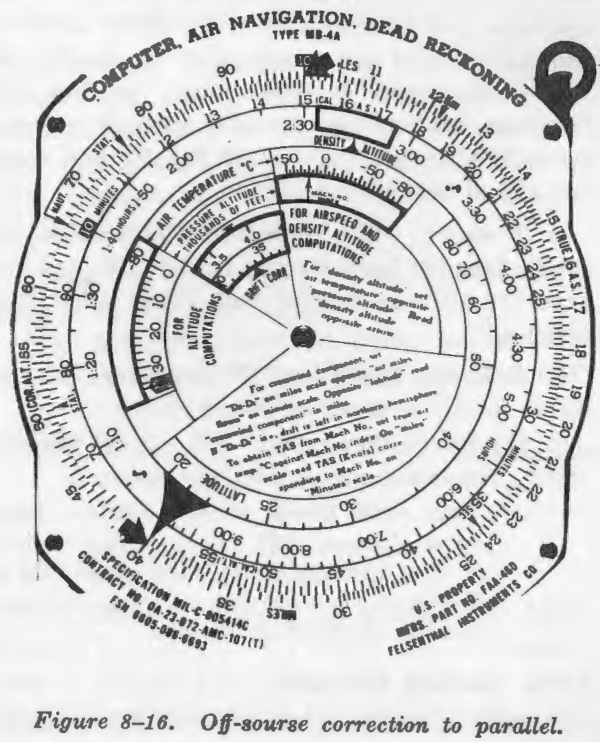


Figure 8–16. Off-sourse correction to parallel.

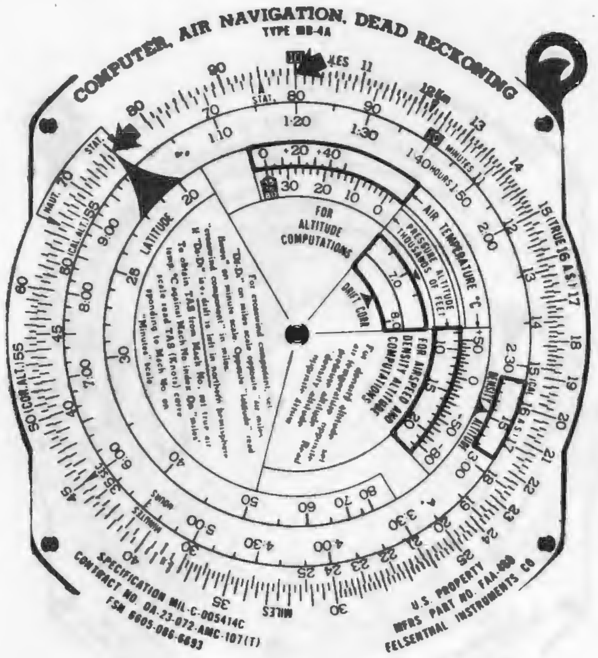


Figure 8–17. Off-course corection to converge.

c. Solution. Using the DR computer, refer to figures 8–16 and 8–17 and solve as follows:

(1) Set 150 (inner scale) under 10 (outer scale) (fig. 8–16).

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

(3) Set 80 (inner scale) under 10 (outer scale) (fig. 8–17).

(4) Over 60 index, read 7.5° to converge.

(5) 4° + 7.5° = 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 101.5° or 102° to the nearest degree.

8–19. Off-Course Correction (Drift Correction Window)

This scale in the drift correction window of the MB–4A computer is a refinement of the rule of 60 (par. 8–18). Actually an arc of 1 mile subtends an angle of 1° at a distance of 57.3 miles rather than 60 miles. The drift correction window scale incorporates this relationship correctly.

a. Problem. After traveling 400 miles, and the aircraft is 30 miles off course.

(1) What drift correction angle is necessary to parallel the desired course?

(2) What drift correction angle is necessary to intercept the desired course in 150 additional miles?

b. Solution.

(1) Set the miles off course (30) on the outer scale over the distance traveled (400) on the inner scale and read the correction angle to parallel the desired course in the drift correction window (4.3°) (fig. 8–18).

(2) To find the angle to intercept the desired course, place the miles off course (30) on the outer scale over the course miles to interception point (150) on the inner scale. Read the additional angle to intercept in the drift correction window (11.3°) (fig. 8–19). The total correction angle to

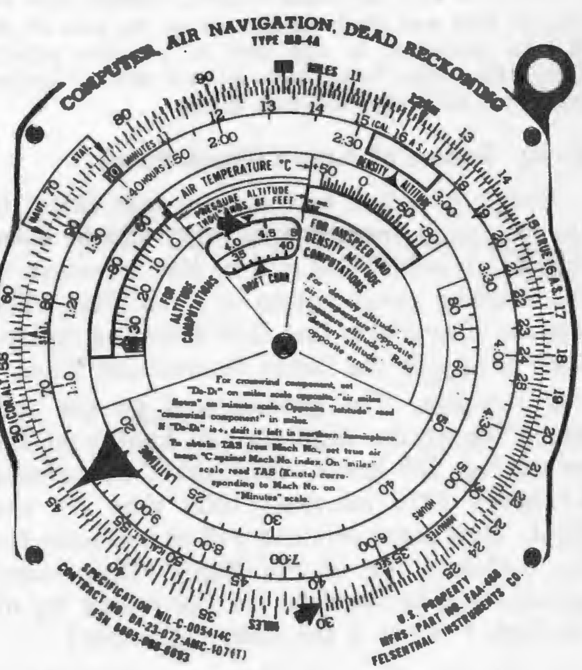


Figure 8–18. Drift correction computation to parallel.

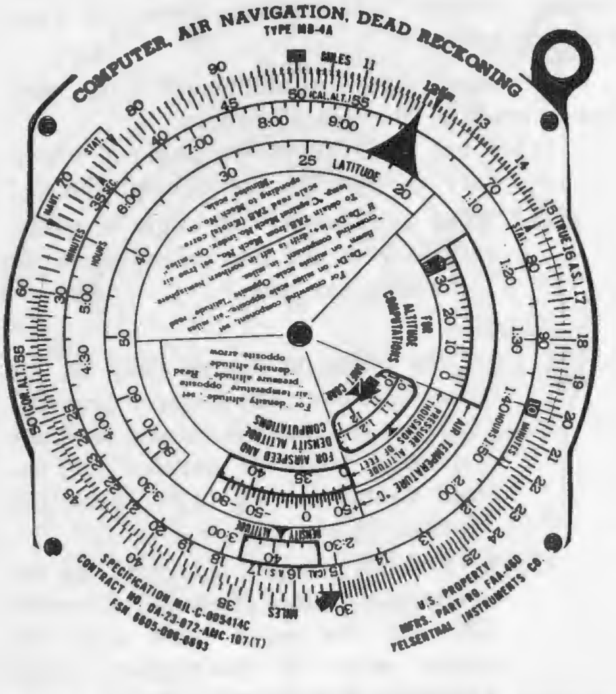


Figure 8-19. Drift correction computation to converge.

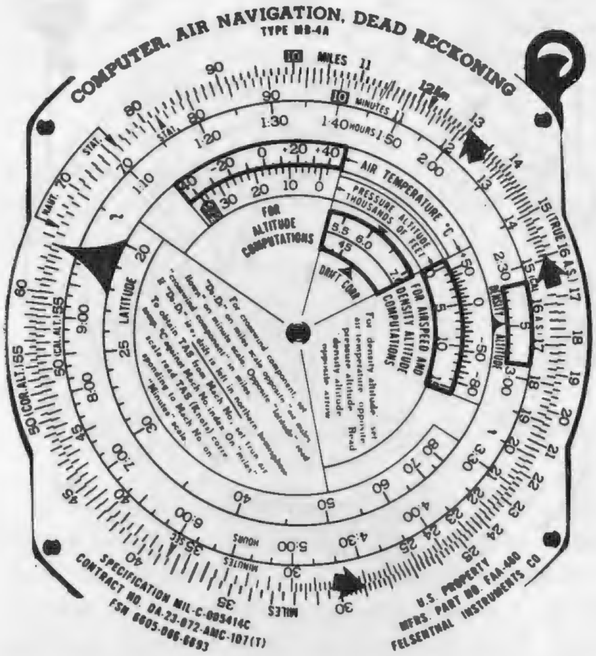


Figure 8-20. Radius of action time computation.

intercept the desired course is therefore 15.6° (4.3 + 11.3).

Note. The drift correction window, together with the D_2—D_1 data and the latitude scale on the face of the MB-4A computer, is also used in pressure pattern flying. Since the Army does not use this navigation technique, it is not explained herein.

8-20. Radius of Action (Fixed Base)

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 4.5 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

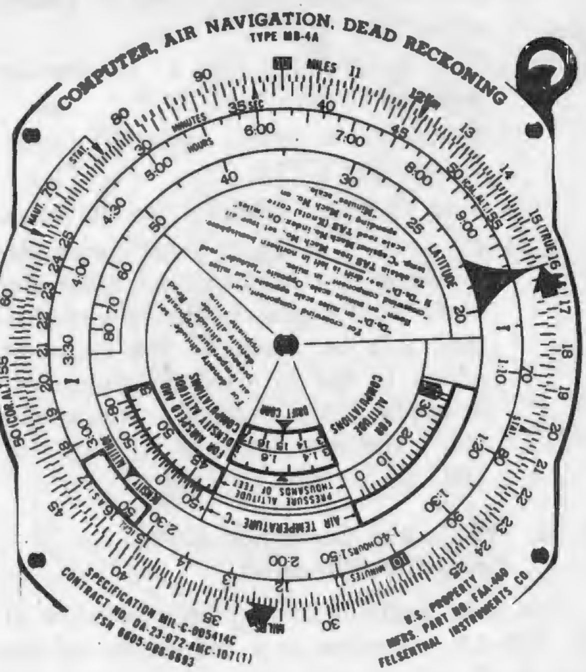


Figure 8-21. Radius of action distance computation.

(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 DR computer as ratio and proportion problems and appear on the DR computer as they appear in mathematical form. To solve radius of action fixed base problems with the DR computer, use the problem given in *a* above, referring to figures 8–20 and 8–21, and proceed as follows:

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

(2) Set the total time (T = 4.5 hours or 270 minutes) *under* the sum of the groundspeeds (290) (fig. 8–20).

(3) Under 130 (GS_2), read the time on the outbound leg, 2 hours + 1 minute or 121 minutes (fig. 8–20).

(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. 8–20).

(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 action, 322 nautical mlies (fig. 8–21).

Section III. GRID SIDE OF THE DR COMPUTER

8–21. Plotting Disc and Correction Scales

The grid side of the DR computer (fig. 8–22) enables the aviator to solve wind problems. It consists of a transparent, rotatable plotting disc mounted in a frame on the reverse side of the circular slide rule. A compass rose is located around 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* (labeled TRUE INDEX). This scale is used for calculating drift or drift correction and is labeled *drift right* and *drift left.* A small reference circle, or *grommet,* is located at the center of the plotting disc.

8–22. Sliding Grid

A reversible sliding grid (fig. 8–22) inserted between the circular slide rule and the plotting disc is used for wind computations. The slide has converging lines spaced 2° apart between the concentric arcs marked 0 to 150 and 1° apart above the 150 arc. The concentric arcs 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 index. The common center of the

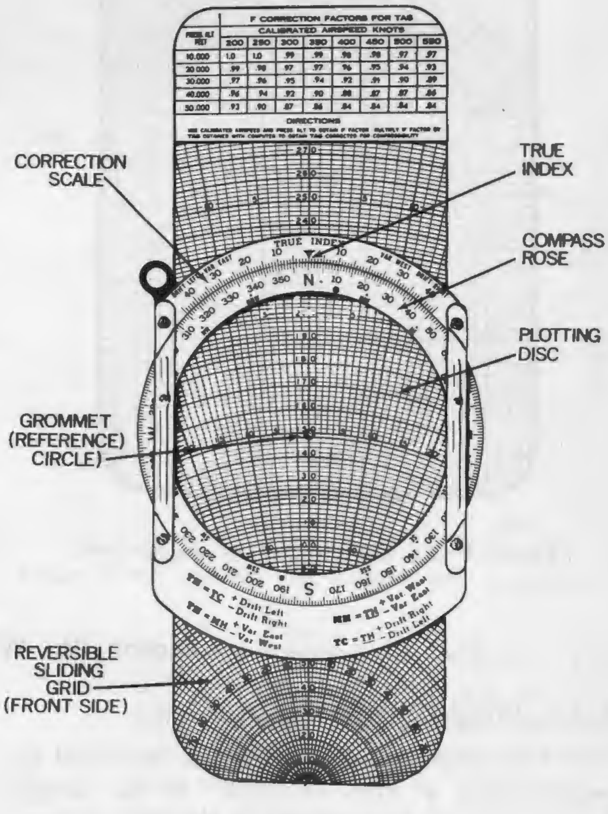


Figure 8–22. Grid side.

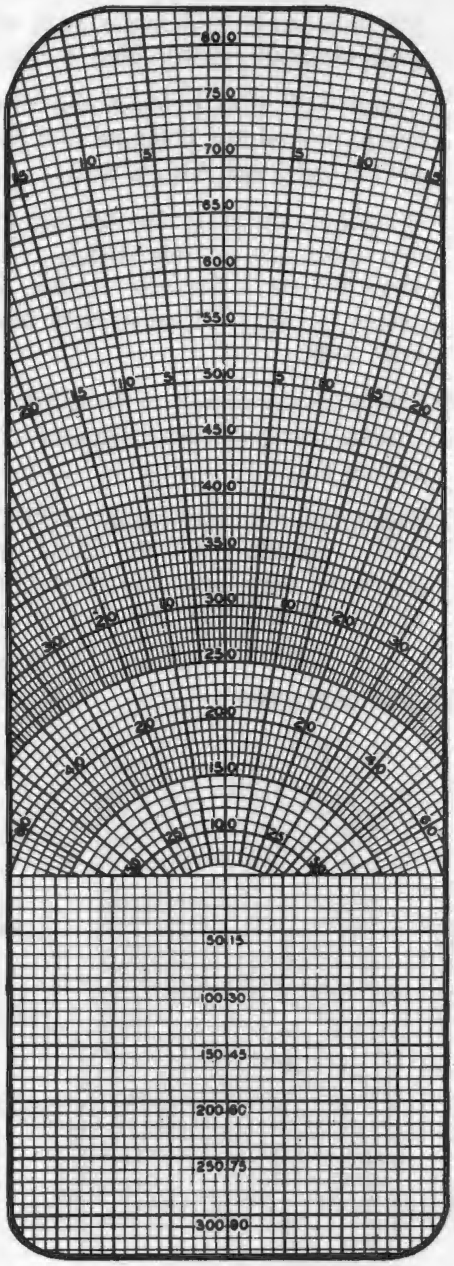


Figure 8–23. Reverse side of sliding grid.

concentric arcs and the point at which all converging lines meet is located at the lower end of the slide. On one side of the sliding grid the speed arcs are numbered from 0 to 270; on the reverse side, from 70 to 800. The low range of speeds on the sliding grid is especially helpful in solving navigational problems for aircraft having slow-speed flight characteristics.

Note. Some computers are equipped with speed scales ranging from 80 to 350 on one side of the sliding grid. These computers were designed for high performance aircraft, but have been issued in limited quantities for Army use. Computation of airspeed or groundspeed on these computers is discussed in paragraph 8–29.

a. Rectangular Grid. The rectangular grid on the reverse side of the sliding grid (fig. 8–23) is designed so that the left half can be used for calculations on the 70 to 800 side of the sliding grid and the right half can be used with the 0 to 270 side of the sliding grid. On the left half, each small division has a value of 10 units; each large division has a value of 50 units. On the right half, the small squares have a value of 3 units; the large squares, a value of 15 units. This grid is used for solving problems, such as off-course correction, air plot, and radius of action, and for correcting reported wind (par. 9–30).

b. Correction Factors. The F correction factors on the front side of the sliding grid are used for calculating TAS caused by compressibility of air at high airspeeds and altitudes. Army aircraft do not require the application of these correction factors to their TAS.

Section IV. WIND TRIANGLES

8–23. Wind Triangle Construction

a. Problems involving wind can be solved by constructing a wind triangle. In its simple form, this triangle is made up of three vectors (six vector quantities) whose elements are always the same. The vectors (fig. 8–24) are—

(1) A wind vector, consisting of the wind direction and speed.

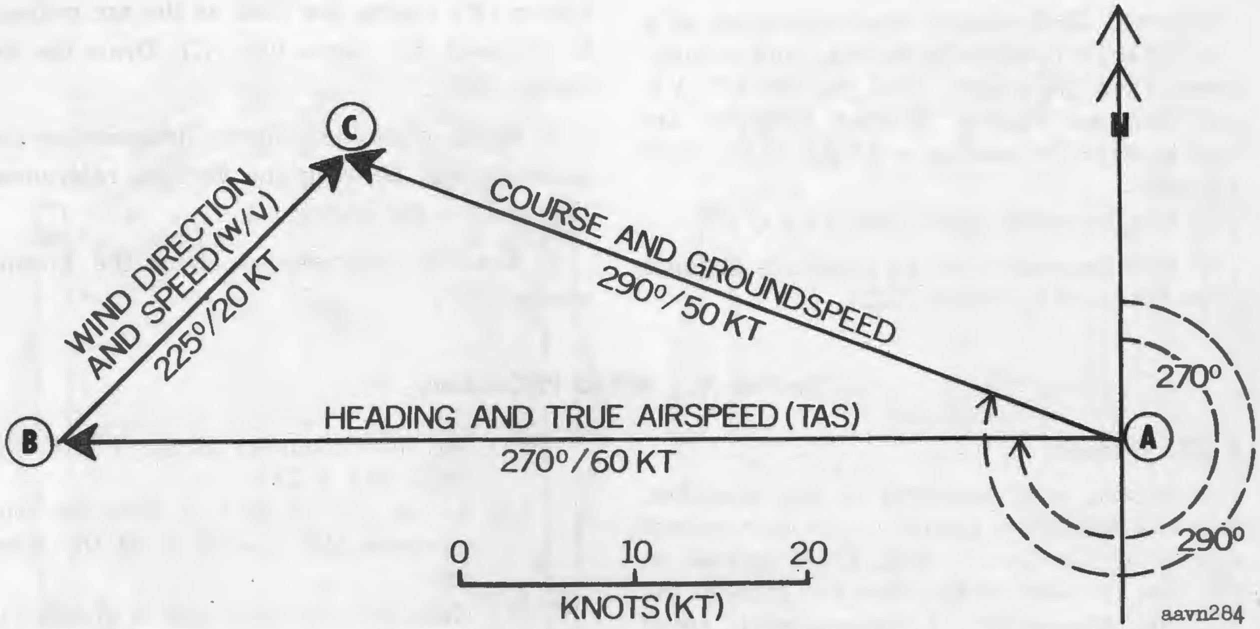


Figure 8–24. Representing the six vector quantities in a wind triangle.

(2) A ground vector, representing the movement of the aircraft with respect to the ground, and consisting of the course (or track) and the groundspeed.

(3) An air vector, representing the movement of the aircraft with respect to the airmass, and consisting of the heading and the true airspeed.

b. The direction of such vectors is shown by the bearing of a line with reference to north. The magnitude of the vector is shown by comparing the length of a line with an arbitrary scale. For example, if 1 inch represents 10 knots, then a velocity of 50 knots would be shown by a line 5 inches long (fig. 8–24).

c. Necessary steps for drawing the wind triangle are—

(1) Draw a vertical reference line with an arrow at the top indicating north.

(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 (*a* above).

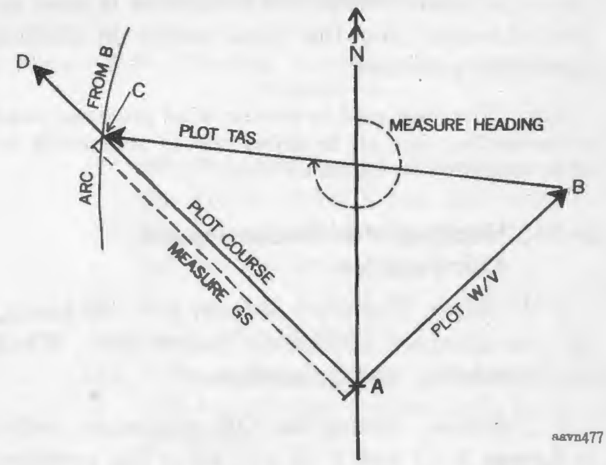


Figure 8–25. Solving for heading and groundspeed.

(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.)

8–24. Wind Triangle Solution

Figure 8–25 illustrates the construction of a wind triangle to solve for heading and groundspeed when the course, wind velocity (W/V), and TAS are known. Similar triangles are used to solve for heading and TAS or for wind velocity.

a. Plot the wind vector first (AB).

b. Plot the course for an indefinite distance from the point of origin (AD).

c. Swing an arc from the end of the wind vector (B) (using the TAS as the arc radius) to intersect the course line (C). Draw the air vector (BC).

d. Measure the heading by determining the angle formed between the vertical referenced line and the air vector.

e. Measure groundspeed along the ground vector (AC).

Section V. WIND PROBLEMS

8–25. General

In solving wind problems on the computer, part of a triangle is plotted on the transparent surface of the circular disc. Lines printed on the slide are used for the other two sides of the triangle. The center of the concentric speed circles (fig. 8–26) 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.

Note: Directions used in solving wind problems *must* be compatible; i.e., all in references to true north or all in references to magnetic north.

8–26. Heading and Groundspeed Computation

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

b. Solution. Using the DR computer, refer to figures 8–27 and 8–28 and solve the problem as follows:

(1) Set 160° (direction *from* which the wind is blowing) to the TRUE INDEX (fig. 8–27).

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

(3) Set 090° (course) at the TRUE INDEX (fig. 8–28).

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

(5) Note that the wind dot is at the 14°

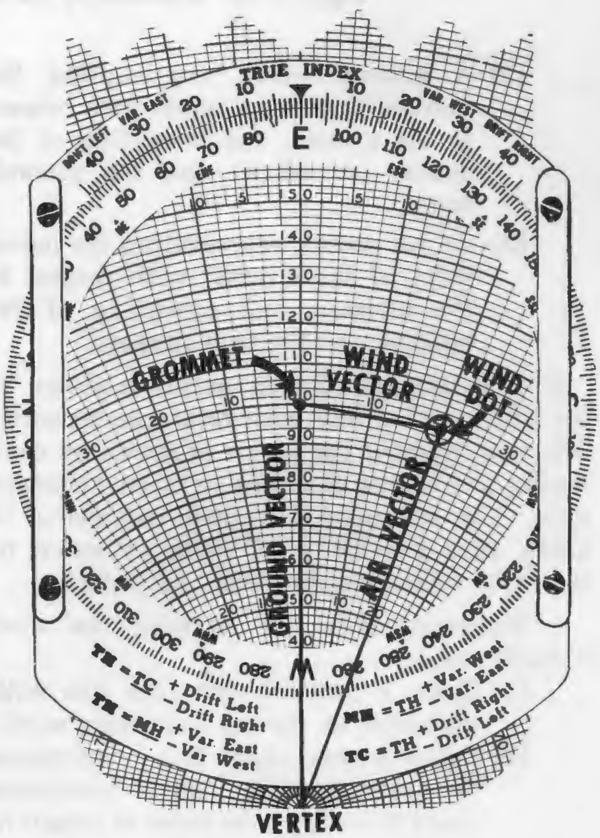


Figure 8–26. Wind triangle on DR computer.

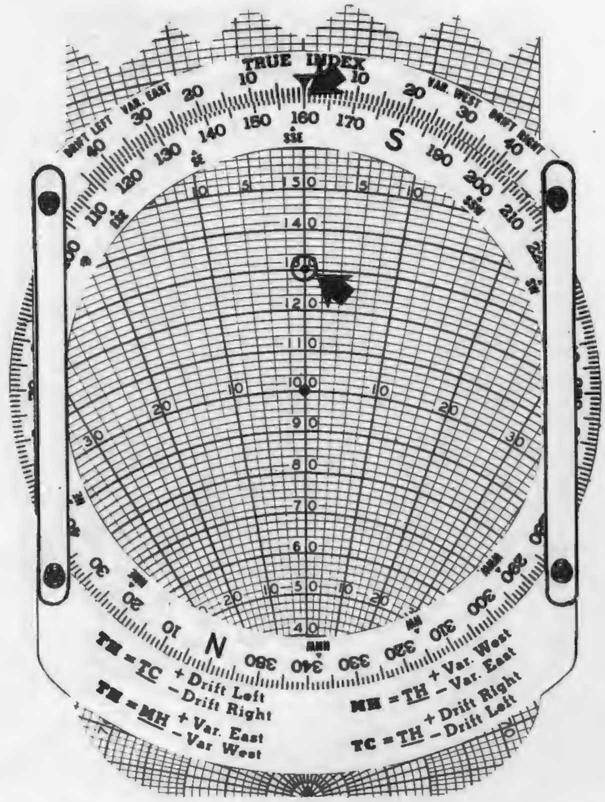


Figure 8–27. Plotting the wind vector to solve for heading and groundspeed.

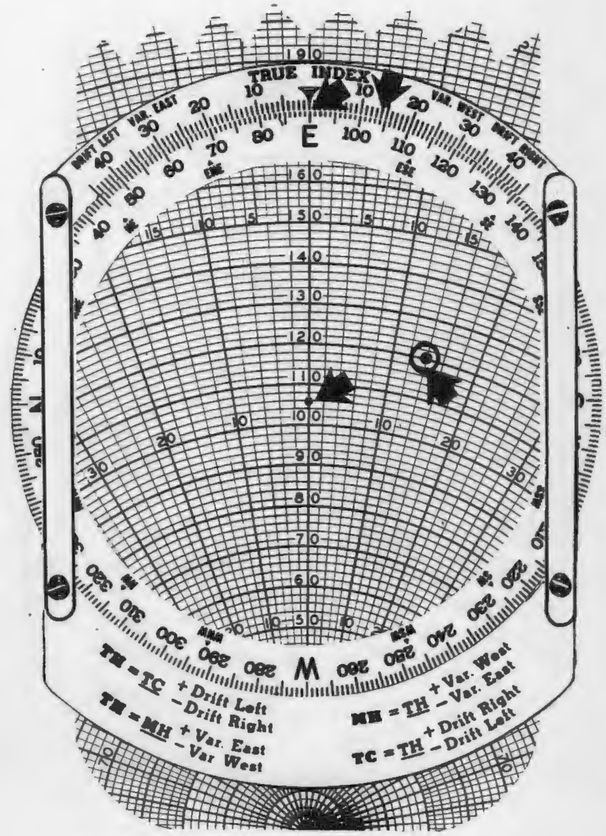


Figure 8–28. Reading heading, wind correction, and groundspeed.

converging line to the right of centerline.

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

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

8–27. Heading and True Airspeed Computation

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

b. Solution. Using the DR computer, refer to figures 8–29 and 8–30 and solve as follows:

b. Solution. Using the DR computer, refer to figures 8–29 and 8–30 and solve as follows:

(1) Set 90 (090° wind direction) under the TRUE INDEX and plot wind vector 20 units above the grommet using dot within circle (fig. 8–29).

(2) Set course (120°3 to the TRUE INDEX (fig. 8–30).

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

(4) The wind dot is now on the converging line 5° to the left of centerline. Read the heading (115°) 5° left of TRUE INDEX on correction scale.

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

8–28. Wind Velocity Computation

a. Problem. Heading 130°, true airspeed 100

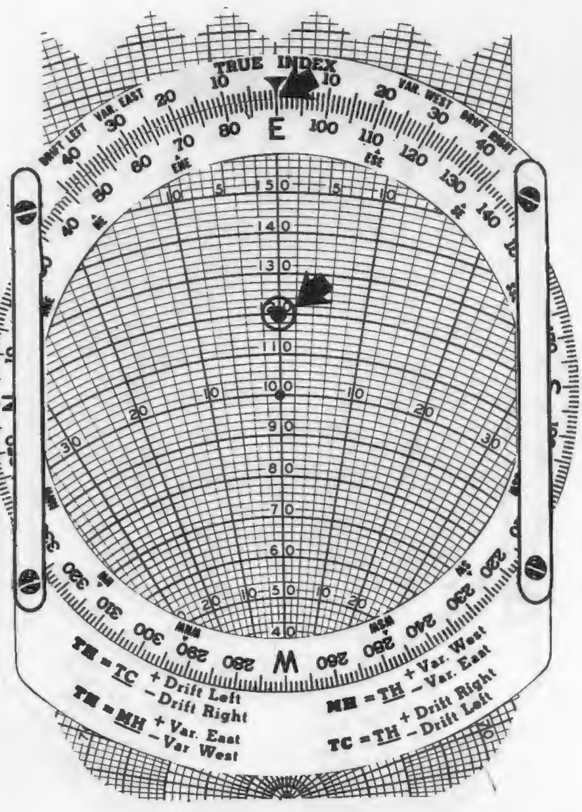


Figure 8-29. Plotting the wind vector to solve for heading and true airspeed.

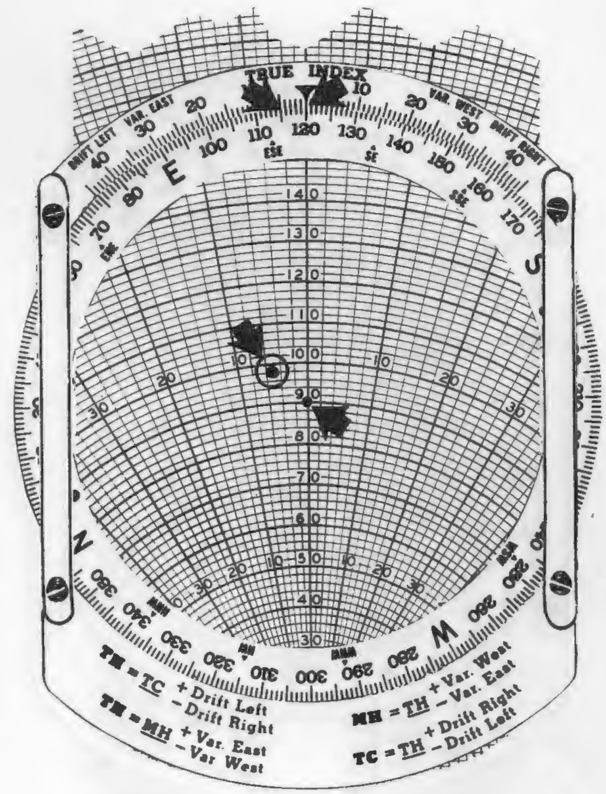


Figure 8-30. Reading heading, drift correction, and true airspeed.

knots, track 140°, groundspeed 90 knots. What is the wind velocity?

b. Solution. Using the DR computer, refer to figures 8-31 and 8-32 and solve as follows:

(1) Set track (140°) at TRUE INDEX and grommet over the groundspeed (90 knots).

(2) Since the 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. 8-31).

(3) Turn circular grid until the dot is directly *above* the grommet (fig. 8-32).

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

8-29. The 80 to 350 Type Sliding Grid

a. General. To use the 80 to 350 type sliding grid while solving problems in which airspeeds and/or groundspeeds are less than 80, plot the problem for 2 hours by doubling the known values for windspeed, airspeed, and groundspeed. Magnitudes indicated in figure 8-33 are for periods of ½ hour, 1 hour, and 2 hours. Although the vector magnitudes change, the angular relationship between the vectors is constant. The following example will further clarify this method.

b. Example Using 80 To 350 Sliding Grid. Find the heading and groundspeed where the course is 030°, true airspeed 70 knots, wind velocity 010°/20 knots. If this problem were

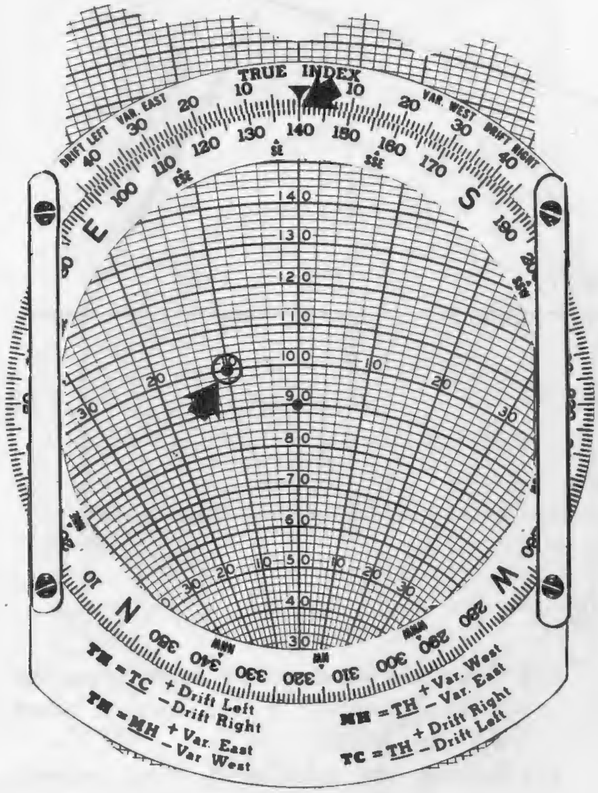


Figure 8-31. Solving for wind velocity.

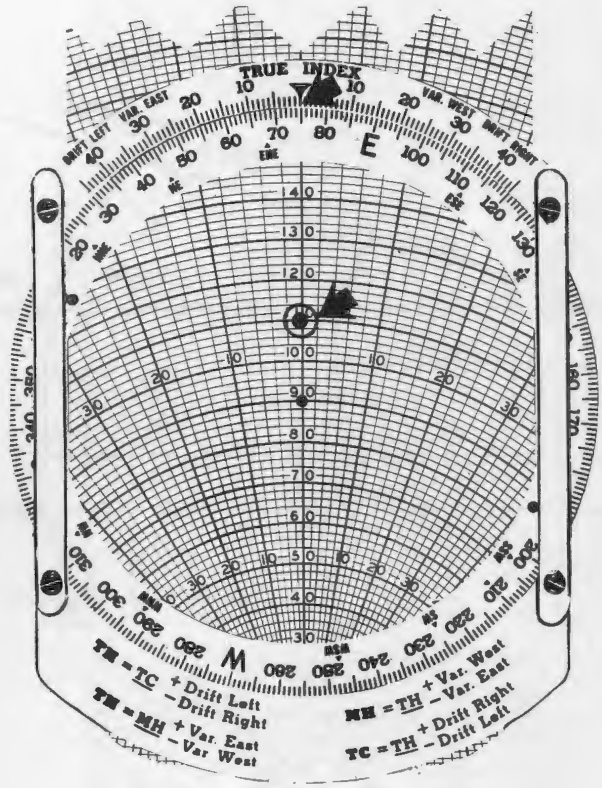


Figure 8-32. Reading wind velocity.

computed using the 80 to 350 sliding grid, certain points necessary for computation would be missing on the computer. Doubling the magnitudes, the computer would be adjusted as follows:

(1) Set wind direction (010°) to. the TRUE INDEX.

(2) Place a dot within a circle 40 units above the grommet. (This represents wind effect for 2 hrs.)

(3) Place the course (030°) at the TRUE INDEX.

(4) Move the sliding grid until the dot made in (2) above is at the 140 speed arc. (140 represents the true airspeed for 2 hrs.)

(5) Read drift correction 6° to the left of centerline. Below the 6° drift correction scale at top of disc, read the heading (024°).

(6) Under the grommet, read 102. Since this is the ground covered in 2 hours, the value for 1 hour is 51 knots.

8-30. Correcting the Reported Wind

A pilotage fix, furnishing information on track and groundspeed, can be used for correcting the reported wind using the rectangular grid portion of the sliding grid.

a. Problem. After flying for 30 minutes, an aviator establishes a fix on a navigational chart and finds he is 6 miles north of his on-course dead reckoning position. The reported wind for the flight was 30 knots from 125°. What is the actual wind condition?

b. Solution. Place the rectangular grid of the slide under the transparent disc.

(1) Rotate the compass rose until the wind direction (125°) is under the TRUE INDEX (fig. 8-34).

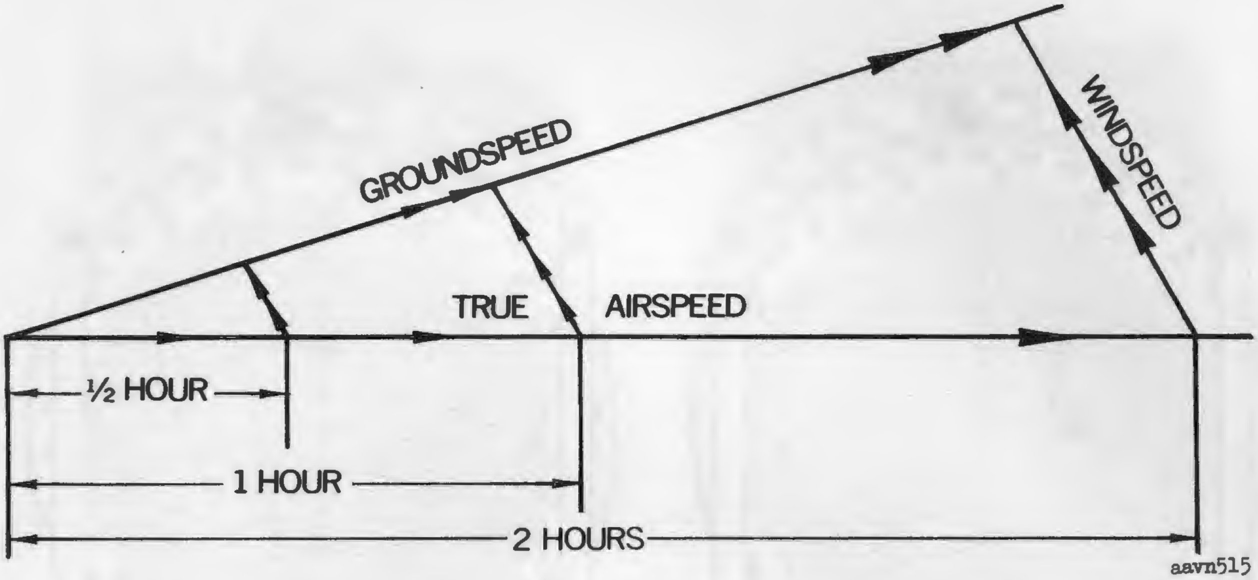


Figure 8-33. One-half, one, and two-hour plot.

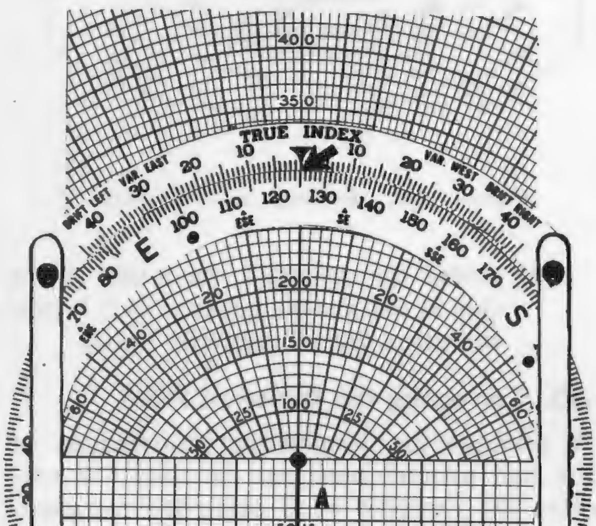


Figure 8-34. Plotting the reported wind.

(2) Draw the wind vector down from the grommet (at 0) to the 30-knot point (A, fig. 8-34).

(3) Reason the additional wind component; i.e., since the aircraft is 6 miles north of the desired position after 30 minutes flying time, the wind component is 12 knots (the aircraft would blow off course twice as far in 1 hour), and since the aircraft is drifting to the north, the wind is from the south.

(4) Rotate the compass rose until S appears under the TRUE INDEX (fig. 8-35).

(5) From the end of the first wind vector ((2) above), plot the additional wind component vertically downward 12 knots to scale (B, fig. 8-35).

(6) Connect the end of this second wind vector with the point of origin of the first wind vector (the center of the disc) (C, fig. 8-35).

(7) Rotate the compass rose until the corrected wind vector (C) lies along the centerline downward from the center of the disc (fig. 8-36). Read the actual wind direction (140°) under

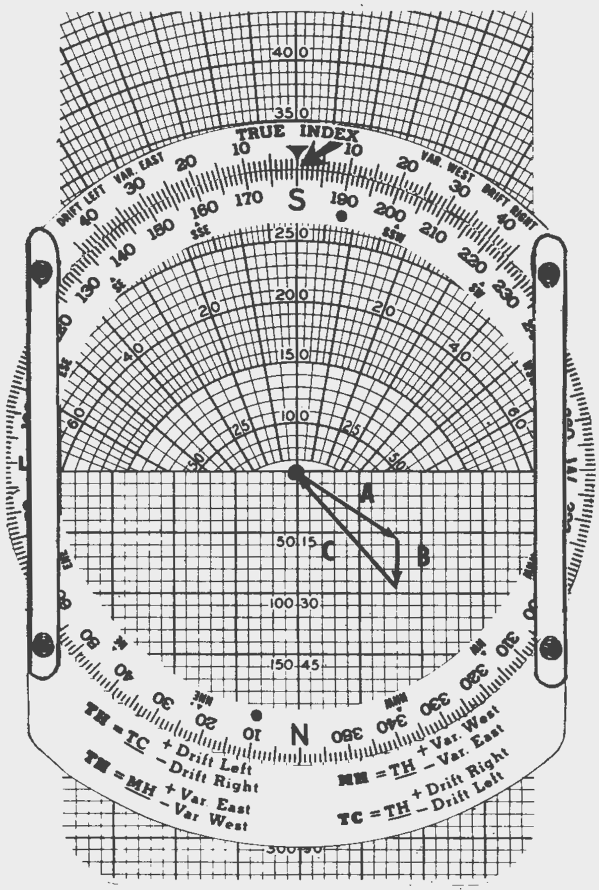


Figure 8–35. Plotting the assumed wind.

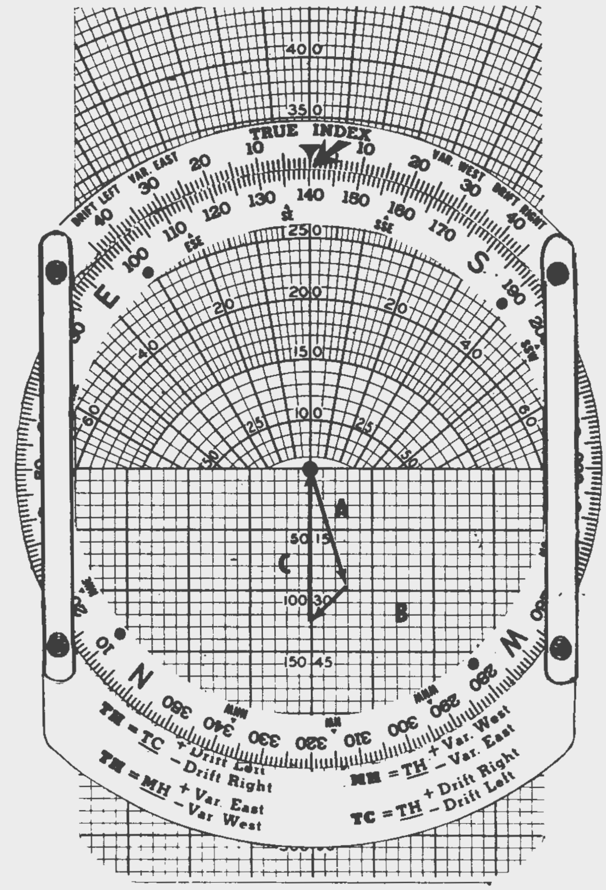


Figure 8–36. Plotting the actual wind.

the TRUE INDEX, and read the actual windspeed (38 knots) as the length of the vector (C) along the centerline.

8–31. Wind Triangle Variations

a. Many other wind problems can be solved using the grid face of the MB-4A computer, including track and groundspeed, wind and groundspeed from double or multiple drift, wind from groundspeed and drift, and correction for reported wind. Wind triangles may also be plotted on the computer, using the centerline as the air vector, by plotting the wind vector below the grommet.

b. Since the mastery of the wind triangle problems discussed in this section is adequate for flight planning with Army aircraft, a complete discussion of the variations mentioned in *a* above is not essential or within the scope of this manual. A complete discussion of the potential of the DR computer is presented in AFM–51–12 (see app. I).

PART TWO

RADIO NAVIGATION

CHAPTER 9

RADIO PRINCIPLES

9-1. General

Radio communication and radio navigation usually are necessary during instrument flight. The aviator should be familiar with radio principles and the capabilities and employment of Army aircraft radio equipment.

9-2. Wave Transmission

According to the wave theory of radiation, sound, light, and electrical energy are transmitted by waves.

a. Wave. Energy traveling through a substance or space by vibrations or impulse moves in waves. For example, when a stone is dropped into a pond, the energy of motion from the stone causes ripples on the water surface. The ripples (waves of energy) travel outward from the place where the stone struck the water, but the water itself does not move outward. The rise and fall above and below the normal undisturbed water level can be graphed as a curved line.

b. Cycle. A cycle is an *alternation* of a wave from a specific amplitude through a complete series of movement back to the same amplitude (*e* below); i.e., one complete wave vibration. A cycle (fig. 9-1) is represented by the portion of the wave from A to E, from B to F, from C to G, or between any other two points encompassing exactly one complete amplitude variation. For example, a cork floating on calm water is subjected to cyclic wave movement when a stone is dropped into the water. One wave cycle occurs as the cork (1) rises from the calm water level (normal position) up to the wave crest, (2) drops back to normal, (3) falls into the wave trough, and (4) rises back to normal. A cycle is also completed when the cork moves from the crest of the wave down to the normal position, falls into the wave crest, rises back to normal, and continues rising to the top of the wave crest. Thus a *cycle* is any complete sequence of amplitude variation in a repetitive series of wave movements.

c. Frequency. The frequency of a wave is measured by the number of cycles completed in 1 second. If two cycles are completed in 1 second, the wave frequency is two cycles per second. Since the number of cycles per second

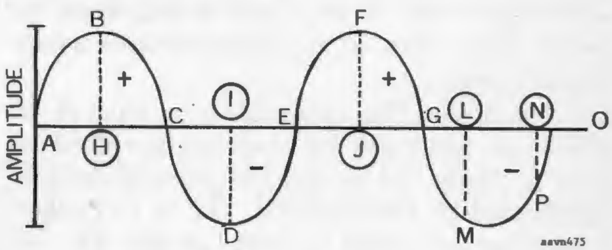


Figure 9-1. Wave representation (alternating current).

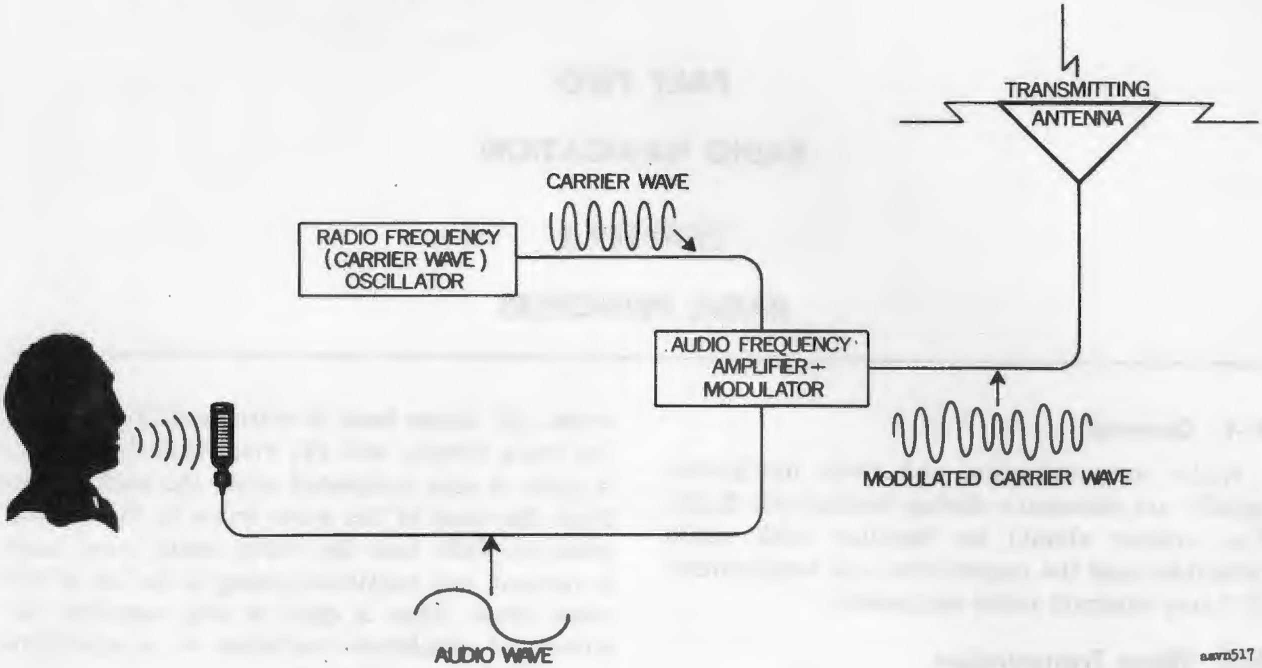


Figure 9-2. Radiotelephone transmitter schematic.

(*cps*) runs into high figures, radio frequencies are commonly expressed as kilocycles (1,000 cycles) or megacycles (1,000,000 cycles). The "per second" time period is dropped but understood.

d. Wavelength. The linear distance of a cycle is known as the *wavelength.* In figure 9-1 the wavelength from A to E can be expressed in meters, feet, miles, or any other suitable linear measurement.

e. Amplitude. The *amplitude* of a wave is its magnitude measured from a specific reference level. In figure 9-1 the peak wave amplitude is represented by the lines BH, ID, or FJ; other amplitudes are shown as lines LM and NP. All representations were measured in linear distance above (+) or below (-) reference line AO.

9-3. Dc and Ac Current

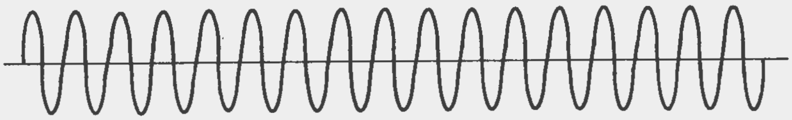
An electrical current flows by the movement of electrons through a conductor. Direct current (dc) flows in only one direction. An alternating current (ac) flows in one direction for a time and then flows in the opposite direction for the same length of time, with a continuous movement. An alternating current (fig. 9-1) can be represented as a continuous flow of electrons with half of each cycle being negative and the other half being positive.

9-4. Radio Waves

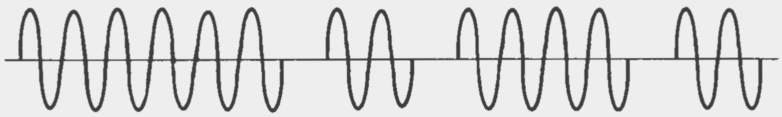
An electrical current builds up a magnetic field around the conductor through which it flows. When alternating current flows through a wire, the magnetic field around the wire alternately builds up and collapses. An alternating current of high frequency is used to generate radio waves which are emitted during the build-up and collapse of the magnetic field around a conductor (the antenna). Radio frequencies extend from 10 kilocycles to above 300,000 megacycles.

9-5. Principles of the Transmitter

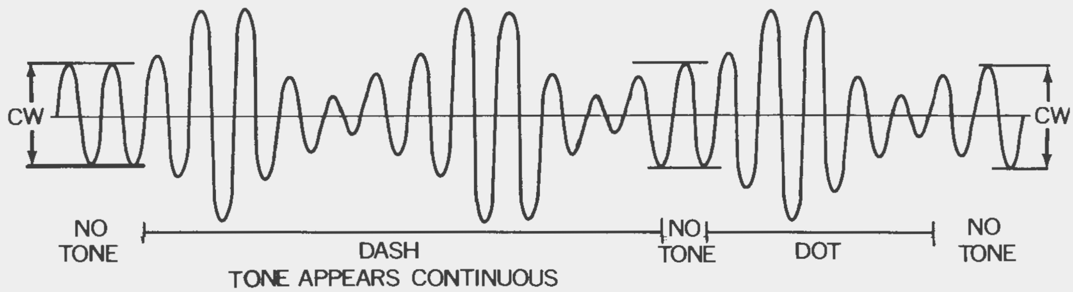
a. Generating and Transmitting a Radio Signal. Fundamentally, a radio signal is transmitted by generating an alternating electric current of the desired frequency and connecting it to an antenna suitable for radiating that



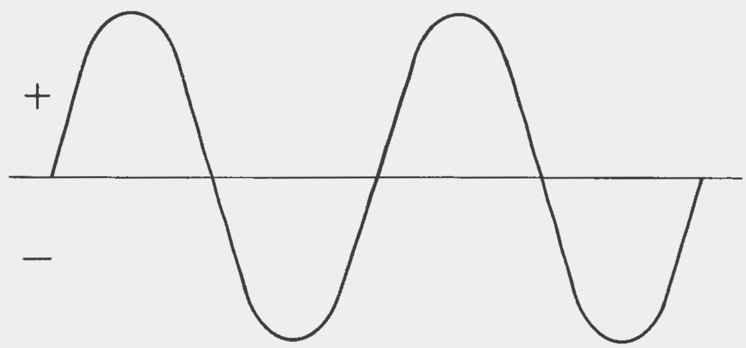
A. CARRIER WAVE - continuous and unmodulated.



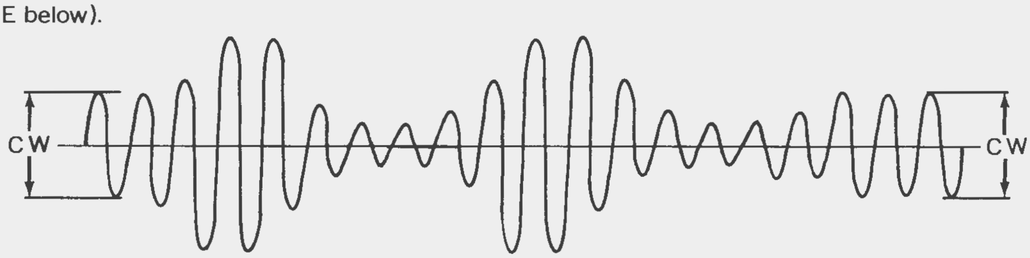
B. INTERRUPTED CARRIER WAVE - for transmitting code.



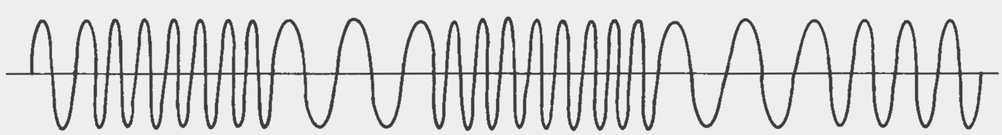
C. CONTINUOUS WAVE MODULATED WITH TONE SIGNAL - modulation is interrupted to create code.



D. AUDIO WAVE - continuous audible tone signal. When superimposed on carrier wave, the positive 180° increases the carrier wave amplitude and the negative 180° decreases the carrier wave amplitude (E below).



E. CARRIER WAVE (A above) with audio wave (D above) superimposed by amplitude modulation (AM).



F. CARRIER WAVE (A above) with audio wave (D above) superimposed by frequency modulation (FM).

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Figure 9–3. Radio waves.

particular wavelength (fig. 9-2). The current frequency is determined by the number of times per second that the alternating current changes direction of flow in the antenna.

b. Altering the Radiated Signal. To transmit intelligible data, the radiated carrier wave (A, fig. 9-3) is altered in some manner and these alterations are decoded at the receiver. Code is transmitted either by interrupting the carrier wave (B, fig. 9-3) into a series of dots and dashes or by modulating the carrier wave with another steady tone (C, fig. 9-3) which is interrupted to produce the desired code. Voice is transmitter by molding or modulating the carrier wave signal with audio wave transmissions (D, fig. 9-3) generated through the radio microphone. The combined carrier wave and audio wave appear as in E, figure 9-3 if the audio wave is superimposed by amplitude modulation (AM) of the carrier wave. If the audio wave is superimposed by frequency modulation (FM), the combined wave will appear as shown in F of figure 9-3. Both AM and FM are used in transmitting voice to Army aircraft, but AM is the most common method. A modulated signal is commonly called a modulated carrier wave (mcw) when either voice or tone signals are used in the modulation process (C, E, and F of fig. 9-3 represent modulated carrier waves). Figure 9-2 illustrates voice modulation of a carrier wave.

9-6. Principles of the Receiver

a. Tuning. Radio waves induce minute electrical currents in receiving antennas. This process is the same as inducing an alternating current in one conductor by placing it near another conductor carrying alternating current. The method of selecting the desired signal from the many induced 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. The selected frequency is unintelligible at this receiving stage since it is still a combination of the radio wave (carrier wave) and the audio wave (voice).

b. Demodulating. Another stage of the receiver called a demodulator or detector is used to separate the audio wave from the carrier wave. The audio portion of the wave is amplified and used to vibrate the diaphragm of the

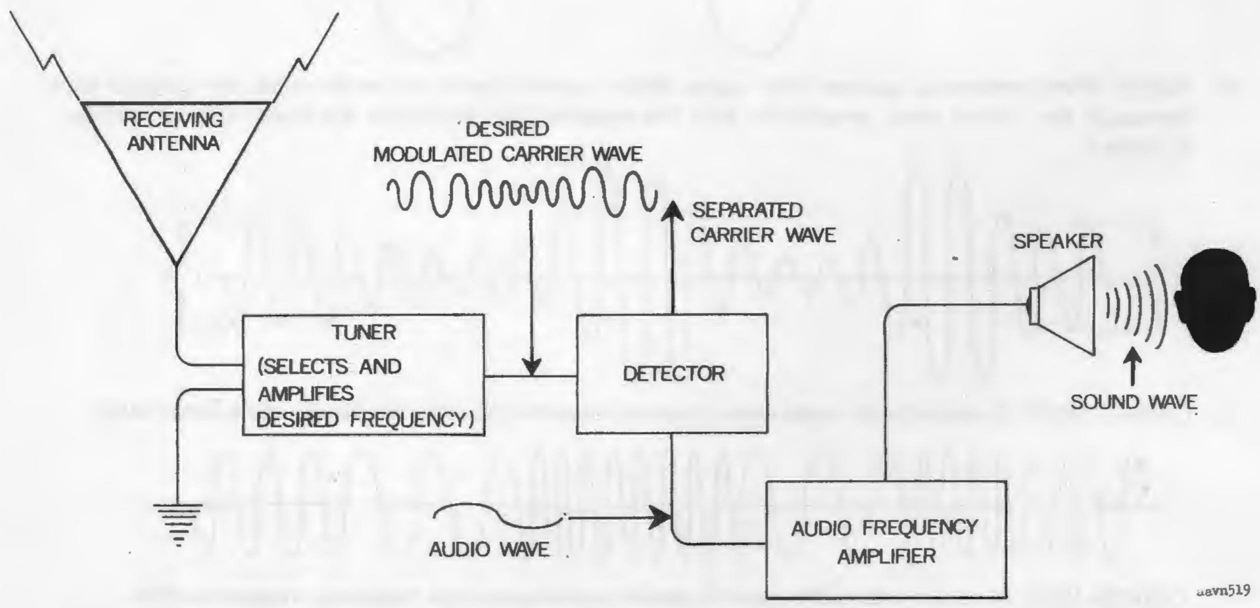

Figure 9-4. Radiotelephone receiver schematic.

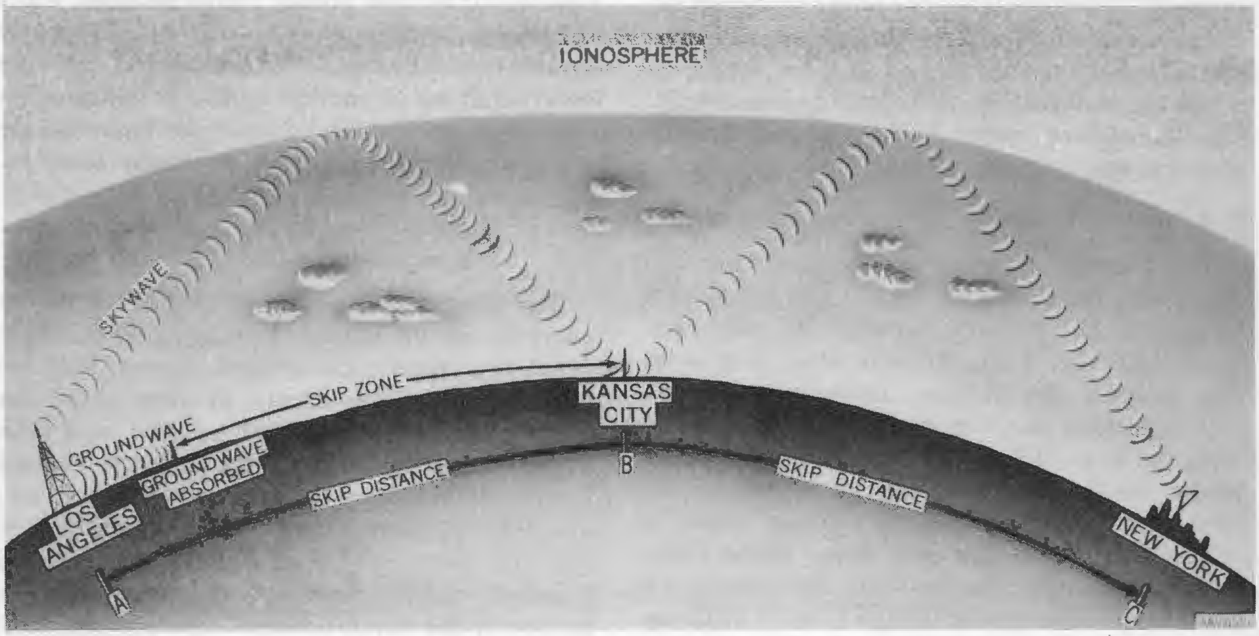

Figure 9-5. Radio wave transmission.

headset or a speaker. This vibrating surface causes audible sound waves, reproducing those which entered the microphone at the transmitter (fig. 9-2).

Note. Since the frequency of a carrier wave is above the audible sound range, a beat frequency oscillator (BFO) (par. 11-3*d*) is used to convert coded interrupted carrier wave signals into audible, intelligible sound.

9-7. Classification of Frequencies

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

b. Radio Frequency (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.

Note. Although the Federal Communications Commission (FCC) designates 300 to 3,000 mc as UHF, the UHF radio frequency band in aviation communication begins at 200 mc.

9-8. Low Frequency Radio Wave Propagation (Nondirectional)

A radio wave leaves the transmitting antenna in all directions. That portion of the radiated wave following the ground is called the *ground wave* (fig. 9-5). The ground wave is conducted along the earth until its energy is absorbed (depleted by the attenuation process, par. 9-10). The remainder of the radiated energy is called the *sky wave* (fig. 9-5). The sky wave is radiated into space and would be lost were it not for the refracting layers in the atmosphere. These layers are in the region of the atmosphere called the *ionosphere* (region where air is ionized by radiation of the sun). The refracting effect on the waves returns them to earth and permits signals to be received at distant points. The effect on reception distance is determined by the height and density of the ionosphere and by 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.

9-9. 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* (AB, fig. 9-5). By extension, this term also includes the distance between each surface reflection point in multihop transmission (BC, fig. 9-5). The distance between the point where the ground wave can no longer be received and the point where the sky wave is returned is called the *skip zone*. Since solar radiation changes the position and density of the ionosphere, a great change in skip distance occurs at dawn and dusk, causing the fading of signals to be more prevalent than usual.

9-10. 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. Therefore, the ground wave is attenuated (decreased in strength) as its distance from the antenna increases. The molecules of air, water, and dust in the atmosphere and matter at the earth's surface — such as trees, buildings, and mineral deposits — also absorb radiation energy in varying amounts.

9-11. Effect of Static Upon Low and Medium Frequency Reception

Static disturbance is either manmade or natural interference. Manmade interference is caused, for example, 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 0 to approximately 50 mc are transmitted from each spark and, consequently, add their energy to any radio reception within this frequency range. Natural static may be divided into two types. Interference which originates from natural sources away from the aircraft is called *atmospheric static*. Interference resulting from aero-logical conditions and caused by electrostatic discharges from the aircraft is called *precipitaion* or *canopy static*.

9-12. General Nature of High Frequency Propagation (3,000 Kc to 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 used, and since it reflects back and forth from sky to ground, communication can be maintained over long distance (12,000 miles, for example). Frequencies between LF and VHF produce the greatest radio transmission range between points on the earth because they are refracted by layers of the ionosphere and follow the curvature of the earth. The range of low frequencies (LF) is reduced by attenuation and atmospheric absorption, and VHF or higher frequencies penetrate the ionosphere and escape to outer space.

9-13. General Nature of Very High Frequency (VHF) and Ultra High Frequency (UHF) Propagation (30 to 3,000 Mc)

Practically no ground wave propagation occurs at frequencies above approximately 30 mc. Ordinarily there is little refraction from the ionosphere, so that communication is possible only if the transmitting and receiving antennas are raised far enough above the earth's surface 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 aviator to be aware of the factors limiting his communication range.

9-14. Range of VHF and UHF Transmission

The range of VHF and UHF transmission

is limited primarily by the altitude of the aircraft and the power of the station. Both VHF and UHF are line-of-sight transmission, and at 1,000 feet above level terrain are usable for approximately 39 nautical miles. At higher altitudes, VHF and UHF transmissions can be received at greater distances as indicated below.

Altitude above ground station (feet)	Reception distance (nautical miles)
1,000	39
3,000	69
5,000	87
10,000	122
15,000	152
20,000	174

CHAPTER 10

VHF OMNIDIRECTIONAL RADIO RANGE SYSTEM (VOR)

Section I. COMPONENTS AND OPERATION

10-1. General

The VHF omnidirectional radio range system (VOR) is the major navigational system used by Army aviators in the United States. The VOR is a VHF facility which eliminates atmospheric static problems and provides the aviator with 360 usable courses to or from any *omni* (*omni*directional) range station. The terms *omni* and *VOR* are used interchangeably with reference to the VHF omnidirectional range.

10-2. Transmitter and Receiver Fundamentals

The omnirange transmitter emits two signals — the *variable signal* and the *reference signal.* The variable signal is transmitted in only one direction at any given time; however, the direction of its transmission varies so rapidly that the signal appears to be a continuous signal rotating clockwise around the station at approximately 1,800 rpm. Receivers which are correctly tuned to a station will receive both

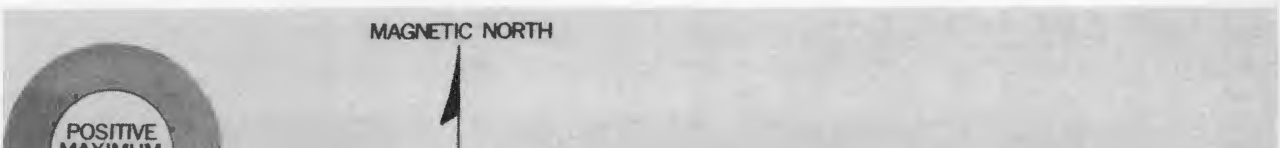

Figure 10-1. Omni signal phase differences.

signals. The two signals are in phase *only* at magnetic north. At all other points around the station there is a definite difference between the signals (fig. 10-1). Receivers in the aircraft detect the phase difference and present the information to the aviator either by centering an indicator needle representing an on-course position or by deflecting the needle to the right or left of center representing an off-course position. The signals may also be fed to a compass-type indicator (ch. 12) to show direction to the transmitting station.

10-3. Army Receivers

The standard omni receiver set is the ARN-30. The control panel for the ARN-30A is illustrated in figure 10-2. This set can receive VHF signals from 108 mc to 136 mc. The lower part of this band (108 to 118 mc) is used for reception of voice and navigational signals from omni stations and the localizer transmitter of the instrument landing system (ILS). Since omni stations do not operate above 118 mc, the upper part of the receiver band is used only for voice reception of various radio facilities operating on these channels. Some Army aircraft are equipped with the ARN-30D receiver. This receiver is basically the same as the ARN-30A but has a different tuning mechanism (fig. 10-3). The ARN-30A control panel has a continuous tuning crank, whereas the ARN-30D has two digital tuning knobs. The left knob changes the whole-megacycle frequency and the right knob changes the decimal values. The tuned frequency appears in the window on the receiver control panel. This digital tuning feature of the ARN-30D is far more efficient and convenient in flight, especially when the aviator's attention must be devoted to several things simutaneously. Another type receiver (ARN-30E) is similar to the ARN-30D but is coupled with a glideslope receiver to allow simultaneous tuning of the ILS localizer frequency and the glideslope. The frequency span for the ARN-30D and 30E is 108.00 to 126.90 mc. The glideslope feature of the ARN-30E is discussed in chapter 15.

Figure 10-2. ARN-30A receiver control panel.

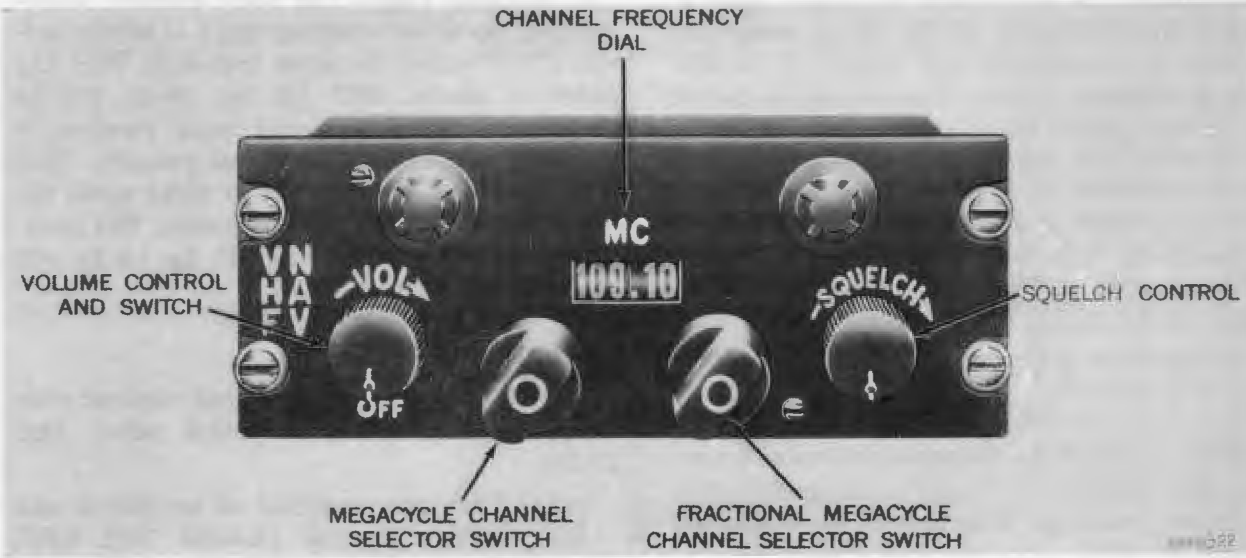

Figure 10-3. ARN-30D or 30E receiver control panel.

10-4. VOR Course Indicator Components (ID-453)

The omni navigation signal is displayed to the aviator in most Army aircraft on an instrument called the *course indicator* (ID-453) (fig. 10-4).

a. Components. This instrument consists of—

(1) A course selector (omni bearing selector) (A and A[1], fig. 10-4).

(2) A course deviation indicator (usually called the *needle*) (B, fig. 10-4).

(3) A to-from indicator (sense indicator) (C, fig. 10-4).

(4) A glideslope deviation indicator (D, fig. 10-4).

Note. The glideslope indicator is not shown in other figures of this chapter because it is not used for the procedures discussed herein. (See chapter 15 for a complete discussion.)

(5) An omni receiver warning flag (localizer warning flag) (E, fig. 10-4).

(6) A glideslope receiver warning flag (F, fig. 10-4).

b. Course Selector. The aviator operates the course selector manually with the course selector knob labeled ARC (fig. 10-4). The arrow end of the course selector (A, fig. 10-4) is set to any course the aviator desires; the course reciprocal then appears opposite the course arrow under the ball (A[1], fig. 10-4). The to-from indicator (sense indicator) will respond

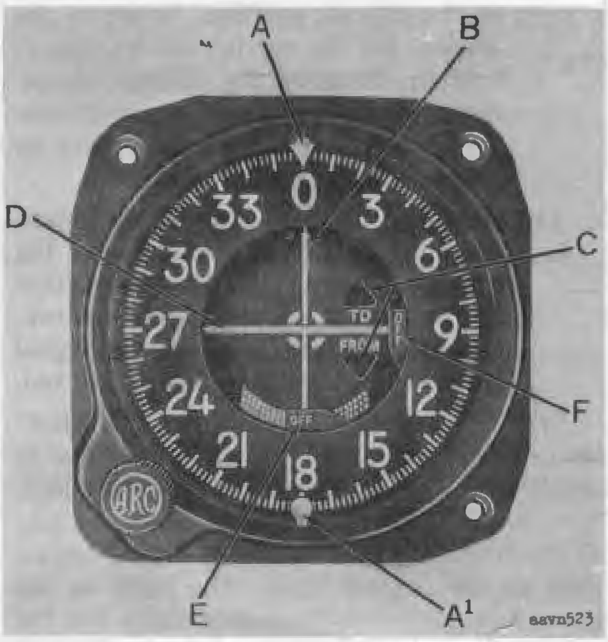

Figure 10-4. ID-453 course indicator.

automatically to any course the aviator selects. The to-from indicator (C, fig. 10-4) senses the position of the aircraft with respect to the station. It indicates *TO* any time a selected course (if flown) would bring the aircraft closer to the station. For example, if an aircraft is located southeast of a station and the aviator selects a course of 270°, the to-from indicator immediately responds with a *TO* indication. If the aircraft flies the 270° course it will move closer *to* the station (fig. 10-5).

c. Deviation Indicator. The course deviation indicator (needle) (B, fig. 10-4) will indicate whether the aircraft is presently located on the selected course or its reciprocal indicated under the ball. Figure 10-6 shows course deviation indicator readings with respect to a selected course of 300°.

(1) *Centered.* When the aircraft is actually located on the selected course (aircraft A, B, and C, fig. 10-6), the deviation needle is centered regardless of the aircraft's heading.

(2) *Full-scale deflection.* If the aircraft is off the selected course by 10° or more (dashed radials, fig. 10-6), the needle deflects full-scale to one side (aircraft D, fig. 10-6). The indicator face is graduated in 2° increments, with the edge of the small center circle representing 2° and each dot (alined horizontally) representing 2°.

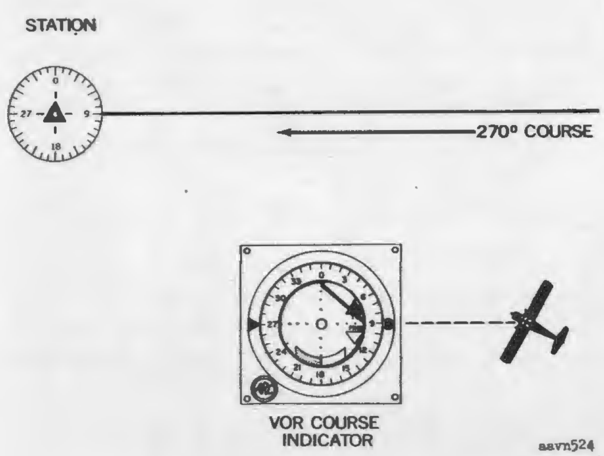

Figure 10-5. Course selector operation.

d. Warning Flags. The omni receiver warning flag (localizer warning flag) is at the bottom of the course deviation indicator. This flag which is labeled OFF (E, fig. 10-4) will be visible any time the signal being received is too weak to operate the receiver properly. This flag must be completely out of sight while the receiver is being used for navigation. The glide-slope receiver warning flag (F, fig. 10-4) will be discussed in chapter 15.

10-5. Tuning

a. ARN-30A. To tune the omni receiver with the ARN-30A receiver control panel (fig. 10-2)—

(1) Turn the combined off-on switch and volume control (labeled VOL/OFF, fig. 10-2) clockwise.

(2) Place the selector switch (labeled OMNI/VAR-LOC, fig. 10-2) in the OMNI position. (The VAR-LOC position will be discussed in chapter 15.)

(3) Determine the frequency to be used and "crank in" this frequency on the dial (MC, fig. 10-2) with the tuning crank.

(4) When the dial (MC, fig. 10-2) is set to the correct position, listen in the headset for the correct station identification. Increase the volume temporarily if necessary. After identification is completed, the volume may be reduced to the desired level.

(5) Observe the behavior of the omni warning flag (OFF flag) on the course indicator (E, fig. 10-4). This flag will drop out of sight as the correct frequency is tuned and the signal from the station is reliably received.

b. ARN-30D or 30E. Tuning with the ARN-30D or 30E receiver (fig. 10-3) is similar to the ARN-30A except for *a*(2) and *a*(3) above. There is no OMNI/VAR-LOC select switch, and the frequency is set with the digital tuning knobs on the control panel. The knob on the left controls the whole-frequency digits and the knob on the right is used to set the tenths and hundredths of megacycles. Other procedures

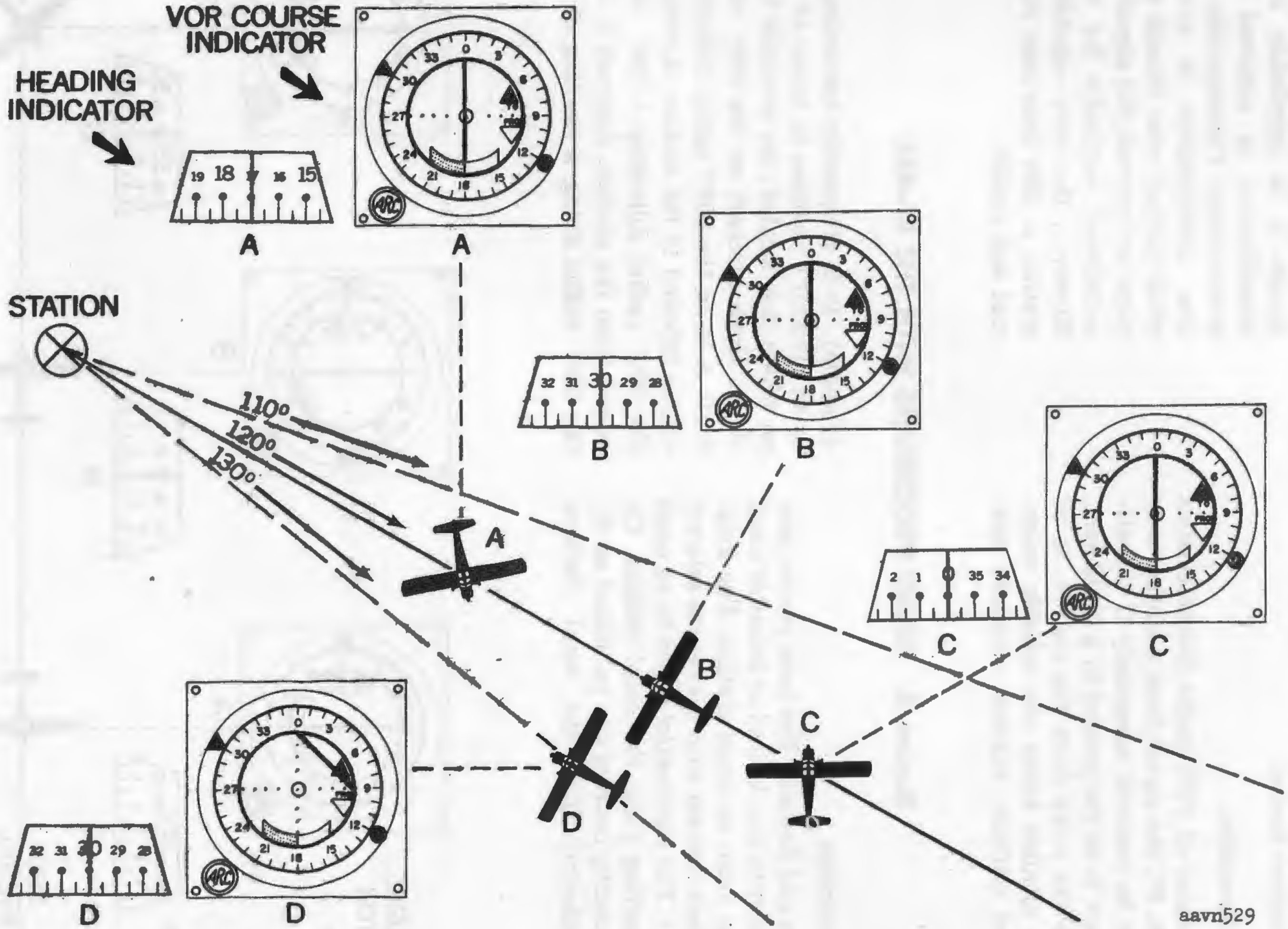

Figure 10-6. Deviation indicator operation.

involved in tuning are the same as described for the ARN-30A.

Note. The squelch knob is used to reduce background noise in the receiver headset.

c. Signal Reception.

(1) Because of VHF radio characteristics (ch. 9), the signal from a station may not be received adequately if the aircraft is on the ground in a blind spot, too far away from the station, or at an altitude below the reliable reception altitude. Station monitors normally detect irregularities in the transmission of the signal from the station.

(2) If the station is transmitting a signal known to be unreliable, the station identification is removed from the transmission. Consequently, if the station identification is not received while tuning, even though other reactions are normal, the signal should be considered unreliable for navigation. However, the voice capability of the station at this time may still be normal and usable.

Section II. FLIGHT PROCEDURES WITH THE ID-453

10-6. Orientation

a. Courses and Radials. The term *course* may be used to refer to any desired or intended track into or away from an omni station. The aviator selects such courses with the course selector (par. 10-4*b*). The term *radial* refers to an omni course emanating *from* the omni station. On navigation charts, courses are published as directions outbound from the omni stations (radials). It is frequently convenient to refer to an aircraft's position in terms of the radial on which it is located; for example figure 10-7 shows three aircraft on the 090° radial. Aircraft A is on the 090° radial following a 270° course inbound to the station. Aircraft B is on the 090° radial following a 090° course outbound from the station. Aircraft C is crossing the 090° radial flying a heading of 320°.

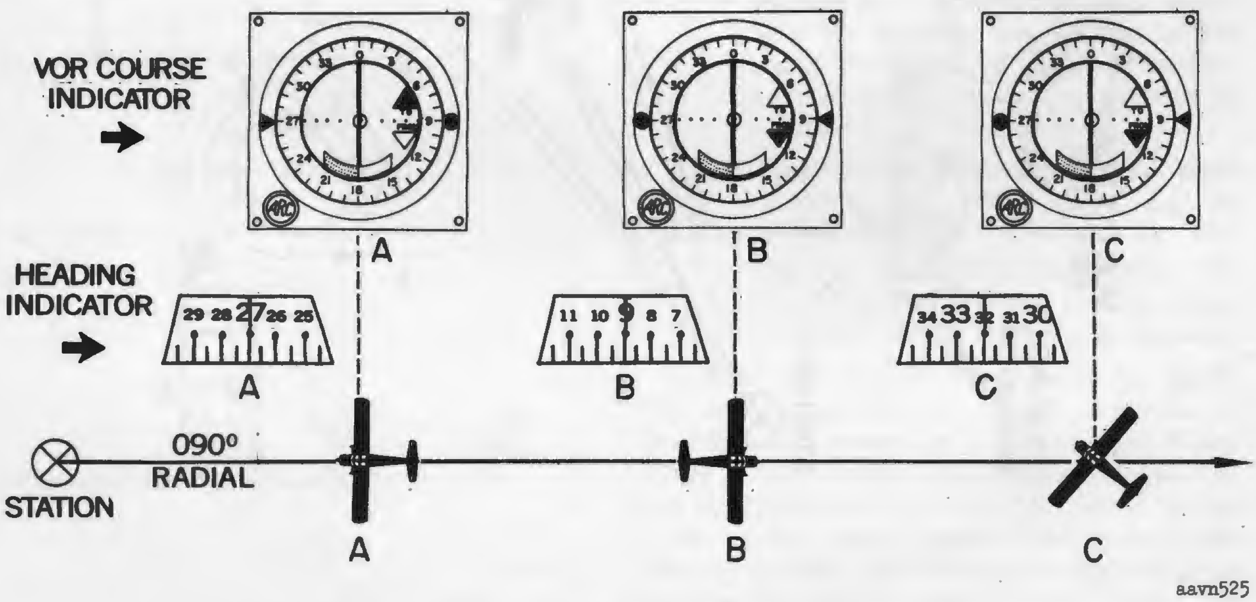

Figure 10-7. Aircraft positions described by radial and heading.

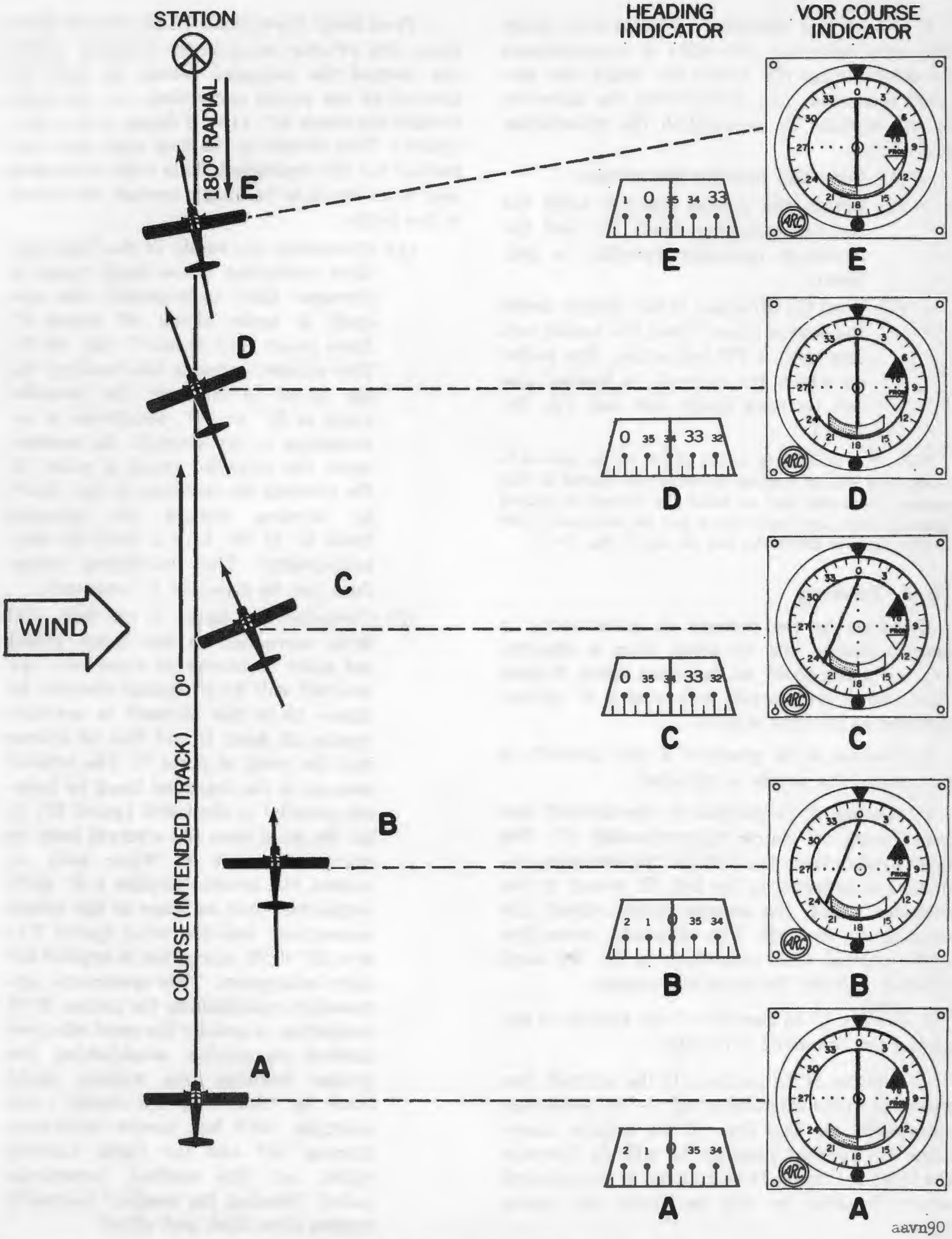

Figure 10–8. Tracking inbound (VOR).

b. Orientation Procedure. Orientation using the omni indicator (ID-453) is accomplished by determining the radial on which the aircraft is located; i.e., determining the direction to the station. To accomplish the orientation procedure—

(1) Tune and identify the station.

(2) Rotate the course selector until the to-from indicator reads TO and the deviation indicator (needle) is centered.

(3) Read the direction to the station under the course arrow when the needle centers with a TO indication. The radial on which the aircraft is located also can be read under the ball (A, fig. 10-7).

Note. The procedures in (2) above can be altered to result in a FROM reading if desired. If altered in this manner, the radial dial on which the aircraft is located appears under the course arrow and the direction to the station appears under the ball (B and C, fig. 10-7).

10-7. Tracking

Tracking is the process of maintaining a specific course into or away from a station; i.e., to "make good" an intended track. Figure 10-8 shows an aircraft following a 0° course inbound to an omni station.

a. Position A. In position A the aircraft is on course; the needle is centered.

b. Position B. In position B the aircraft has been blown off course approximately 5°. The crosswind is from the left and the deviation indicator is deflected to the left. To return to the intended track, the aviator must correct his heading to the left. The standard correction under normal wind conditions is 20° for most aircraft and 30° for slow helicopters.

c. Pattern C. In position C the aviator is applying the standard correction.

d. Position D. In position D the aircraft has returned to the intended track — the needle has recentered. At this time if the aviator maintains his present heading he will fly through the intended track. If he returns to the original course heading he will be blown off course again.

e. Trial Drift Correction. To avoid both situations, the aviator corrects the heading (turning toward the intended track) by half the amount of the initial correction; i.e., he turns toward the track 10° (15° if flying a slow helicopter). This results in the first trial drift correction for the crosswind. This drift correction may later prove to be either correct, too small, or too large.

(1) *Correction too small.* If the first trial drift correction is too small (wind is stronger than anticipated), the aircraft is again blown off course 5° from point E to point F (fig. 10-9). The aviator corrects his heading (G, fig. 10-9) to intercept the intended track at 20° or 30°, whichever is appropriate to his aircraft. He reintercepts the intended track at point H. He corrects his heading (I, fig. 10-9) by turning toward the intended track 5° (a 10° turn is used for slow helicopters). This bracketing procedure can be repeated if necessary.

(2) *Correction too large.* If the first trial drift correction is too large (wind not quite as strong as expected), the aircraft will fly off course upwind. In figure 10-10 the aircraft is overcorrecting at point U and flies off course into the wind at point V. The aviator returns to the intended track by turning parallel to the track (point W) to let the wind blow the aircraft back on course at point X. When back on course, the aviator applies a 5° drift correction (not as large as the initial correction) into the wind (point Y); or a 10° drift correction is applied for slow helicopters. This systematic approach to establishing the proper drift correction is usually the most effective method of quickly establishing the proper heading. An aviator *could* track by "following the needle"; for example, with left needle deflection, turning left and for right, turning right; but this method, sometimes called "chasing the needle," normally wastes time, fuel, and effort.

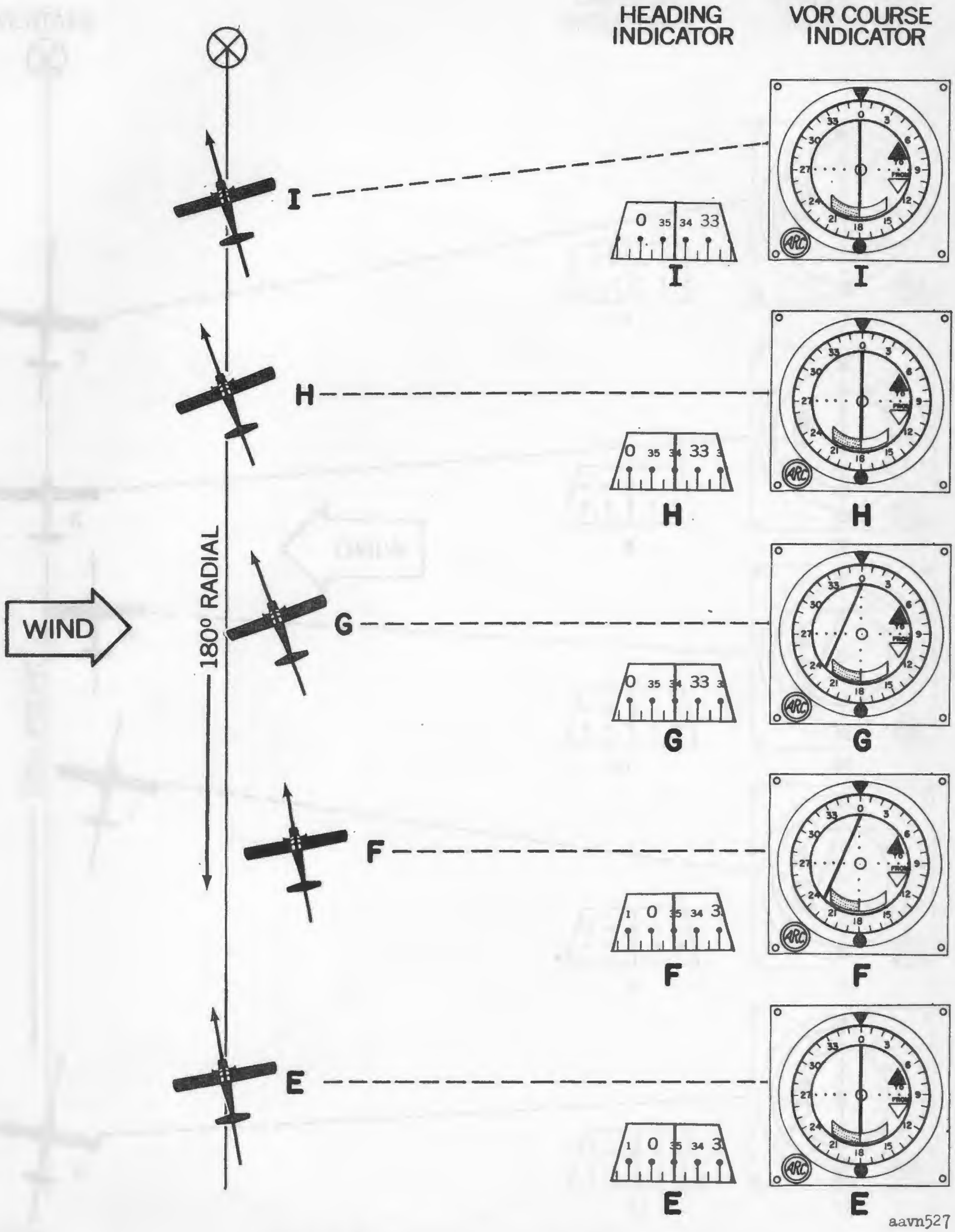

Figure 10-9. Trial drift correction too small (VOR).

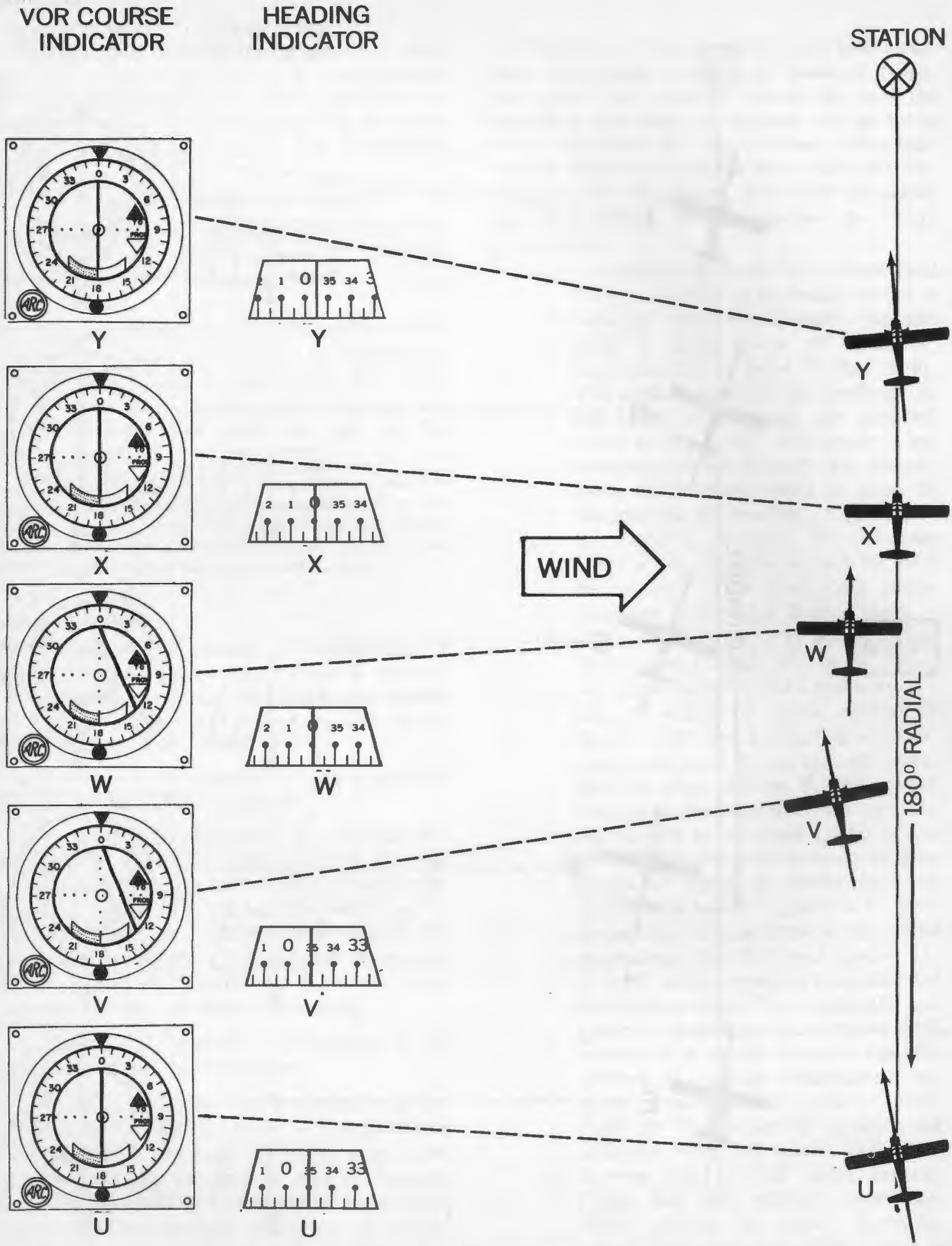

Figure 10-10. Trial drift correction too large (VOR).

(3) *Correction for unusually strong wind.* On some occasions unusually strong winds will prevent the aircraft from returning to the intended track even when a 20° or 30° correction is used. If, after applying a 20° or 30° correction, the aviator sees that the needle is still not recentering in a reasonable amount of time, he may have to apply a correction of 40° or more to return to the course. The aviator must assume that if 40° is required to return to the intended track, approximately half of the correction (in this example 20°) will be required to stay on course.

Note. Tracking procedures discussed here are for guidance only; in flight these procedures are refined by the aviator to suit specific flight conditions.

10-8. Station Passage

Recognition of station passage is very important because aviators use omni stations to fix their exact position. These stations are also used as holding points for air traffic control and are often the destination point of an IFR flight to be used during the instrument approach to the airfield. Station passage is determined as follows:

a. Since the aviator usually knows his approximate arrival time over a station, he watches the clock and, as this time approaches, observes the to-from indicator reaction:

(1) While inbound to the station, the indicator will read *TO*.

(2) As the aircraft passes over the station, the to-from indicator will fluctuate momentarily, then drop to *FROM*. The time that this occurs is station passage time. While flying over the station, the aviator may also notice fluctuations of the deviation needle and the momentary appearance of the warning flag.

b. If the aviator intends to continue his flight along the same course, he continues to track outbound. The only indicator change is the reversal of the to-from indicator. If there is a

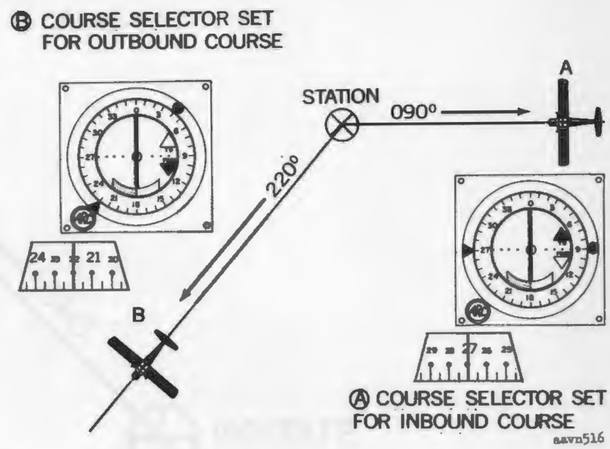

Figure 10-11. Course selector reset to track outbound on a different course.

course change (fig. 10-11), the aviator resets the course selector and turns the aircraft to the new reading.

c. Figure 10-11 illustrates another important consideration when the to-from indicator reading changes. The aircraft is flying toward the station (point A) but is *not* inbound on the selected course. The aircraft continues on the same heading and flies past the station (point B). At the time the aircraft is abeam the station, the to-from indicator will change to read *FROM*. This *FROM* reading will remain in the indicator as the aircraft flies away from the station (point C).

10-9. Position Fixing

a. The Victor (V) airways system (see *note* below) is based upon the operation of several hundred omni stations and has, in addition to the stations themselves, numerous other flight checkpoints (intersections). An *intersection* is a point where two or more radials from different omni stations intersect. Checkpoints can be established at these intersections for position fixing. The procedure for fixing position over intersections by using one omni receiver (course selector reading FROM) is illustrated in figure 10-13.

Note. Airways are routes through navigable airspace on which air route traffic control is maintained over en route IFR traffic. Airways are labeled along their

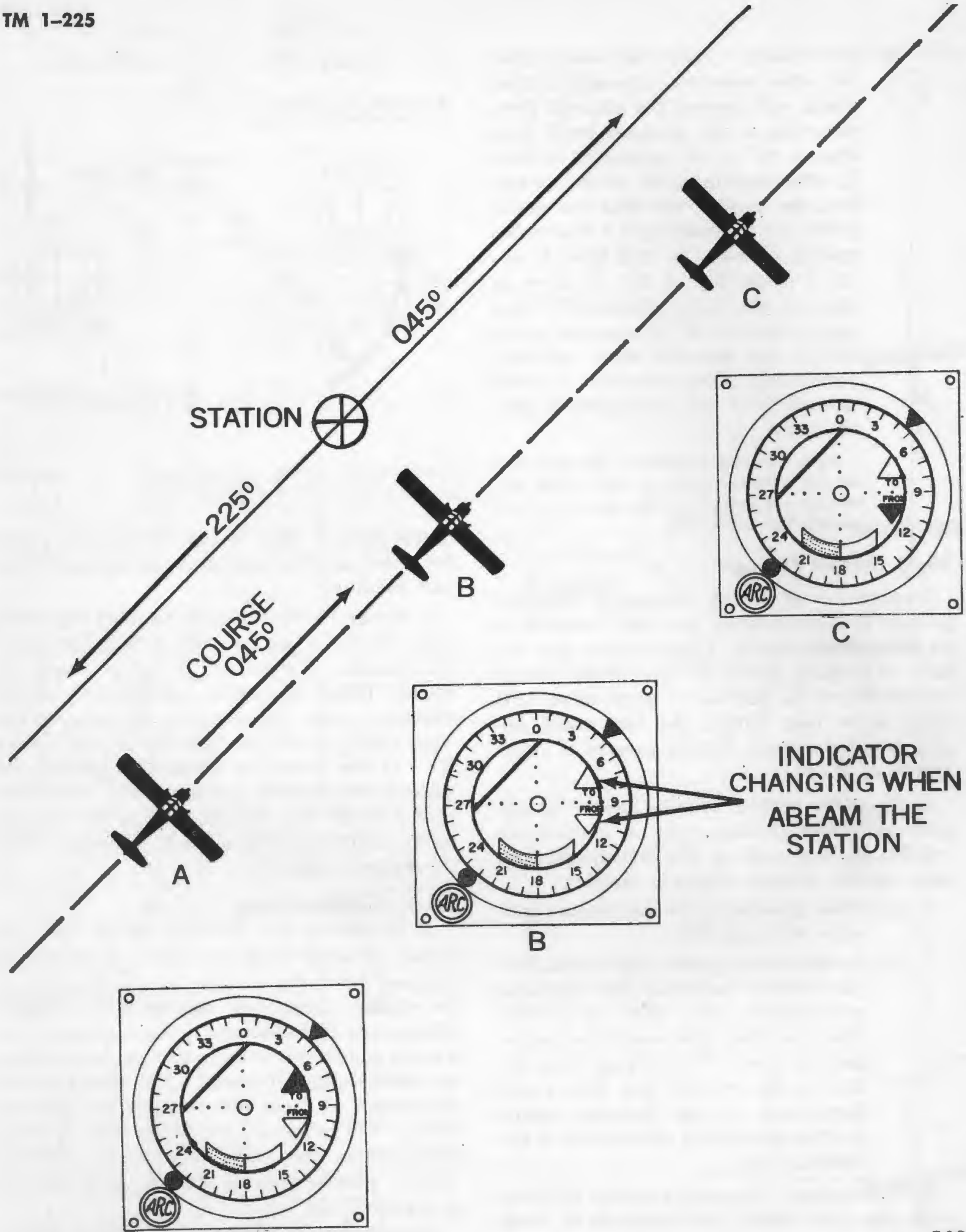

Figure 10–12. To-from indicator changes abeam the station.

centerlines point-to-point, and are comprised of the airspace charted on either side of the designated centerline and within the designated upper and lower limits. Airways established with VOR facilities in the low altitude route structure (position determined by radials from VOR stations) are called Victor airways and are labeled with a V and a number; e.g., V-111. The north-south airways have odd numbers and the east-west airways even numbers. Airways in the high altitude route structure are labeled with a J and a number, and are called jet routes.

(1) The aircraft proceeds outbound (W, fig. 10-13) from station A with the receiver tuned to station A. During this outbound flight the aviator establishes the correct heading for remaining on the course (090°) by the tracking procedure outlined in paragraph 10-7.

(2) After establishing the desired heading to remain on a 090° course, the aviator tunes and identifies station B.

(3) The 130° radial from station B crosses the 090° radial from station A to establish the intersection (open triangle symbol). The aviator sets the

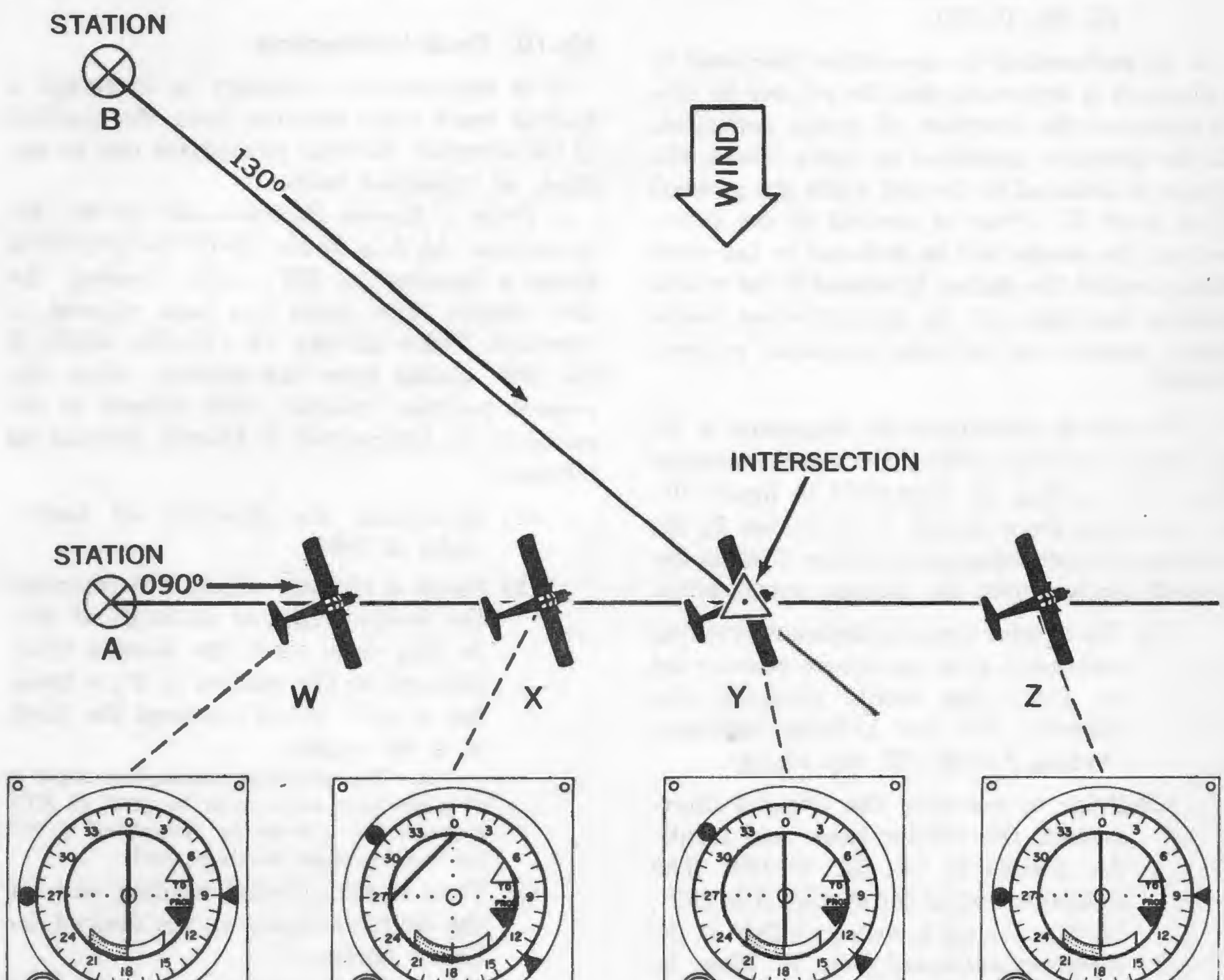

Figure 10-13. Position fixing at an intersection, course selector reading FROM.

course selector on 130° and, since this is the radial from the station, the to-from indicator will read *FROM* (X, fig. 10–13).

(4) At the time the aircraft is exactly over the intersection (Y, fig. 10–13), the deviation indicator will center since the aircraft's position will then be on the 130° radial from station B. Having fixed his position over the intersection, the aviator then resets the course selector to 090°, retunes and identifies station A, and checks for the centering of the needle to remain on course outbound from station A (Z, fig. 10–13).

b. In performing the procedure discussed in *a* above, it is important that the aviator be able to interpret the direction of needle deflection. In the situation described in figure 10–13, the needle is deflected to the left while the aircraft is at point X. Prior to arrival at the intersection, the needle will be deflected to the same side on which the station is located if the course selector has been set on the published *radial* which causes the to-from indicator to read *FROM.*

c. It may be convenient or necessary to fix an intersection by setting the course selector for a *TO* reading, as illustrated in figure 10–14. In flying from station A to station B, the aviator will turn inbound to station B when the aircraft arrives over the Gamma intersection.

(1) The aviator departs station A tracking outbound, with the course selector set on 010°, the needle centered (on course), and the to-from indicator reading *FROM* (W, fig. 10–14).

(2) Prior to reaching the Gamma intersection, the aviator tunes and identifies station B (X, fig. 10–14). The published radial for station B is 250°, but the aviator knows that 250° is the direction *outbound* from B. Since he desires to go *inbound,* he sets the course selector to 070°, the reciprocal of 250°. The resultant reading on the to-from indicator is *TO* because a course of 070° will take the aircraft *to* station B. Station B is to the aviator's right from point X to Gamma intersection, but the needle deflects to the left. Since the course selector is set on the reciprocal of the published radial to produce the *TO* reading in the to-from indicator, the needle deflects to the side opposite the station (compare with the deflection described in *b* above).

(3) The needle centers when the aircraft arrives over Gamma intersection (Y, fig. 10–14), and remains centered inbound to station B (Z, fig. 10–14).

10–10. Track Interception

It is occasionally necessary to intercept a desired track some distance from the position of the aircraft. Several procedures can be applied, as explained below.

a. From a Known Position—45° or 90° Interception. At A in figure 10–15 the aircraft is flying a heading of 350° while crossing the 200° radial. The flight has been cleared to intercept Victor airway 13 (V–13), which is the 180° radial from the station. Since the present position (radial) with respect to the radial to be intercepted is known, proceed as follows:

(1) Determine the direction of turn—right or left.

(2) Select a reading which will intercept the desired track at an angle of 45°. In this case, since the desired track inbound to the station is 0°, a heading of 045° would intercept the track at a 45° angle.

Note. The standard interception angle is 45°; however, others may be used. If ATC requests the aviator to "expedite," a 90° interception angle should be used.

(3) Turn to the selected heading and set the course selector on the desired inbound track—0°.

(4) Turn to the inbound heading of 0° when the needle centers (B, fig. 10–15); i.e., when the aircraft has reached the track.

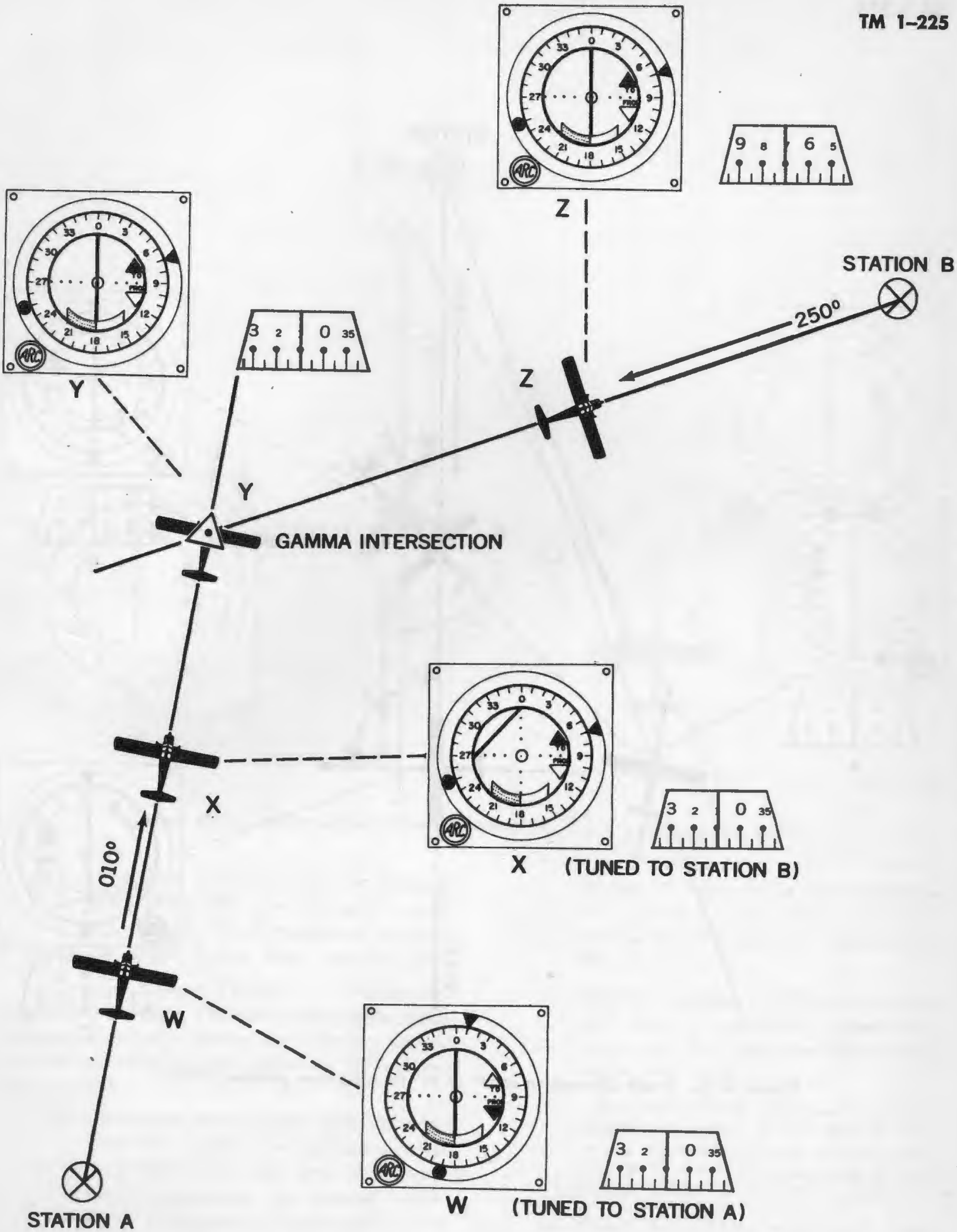

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Figure 10–14. Position fixing at an intersection, course selector reading TO.

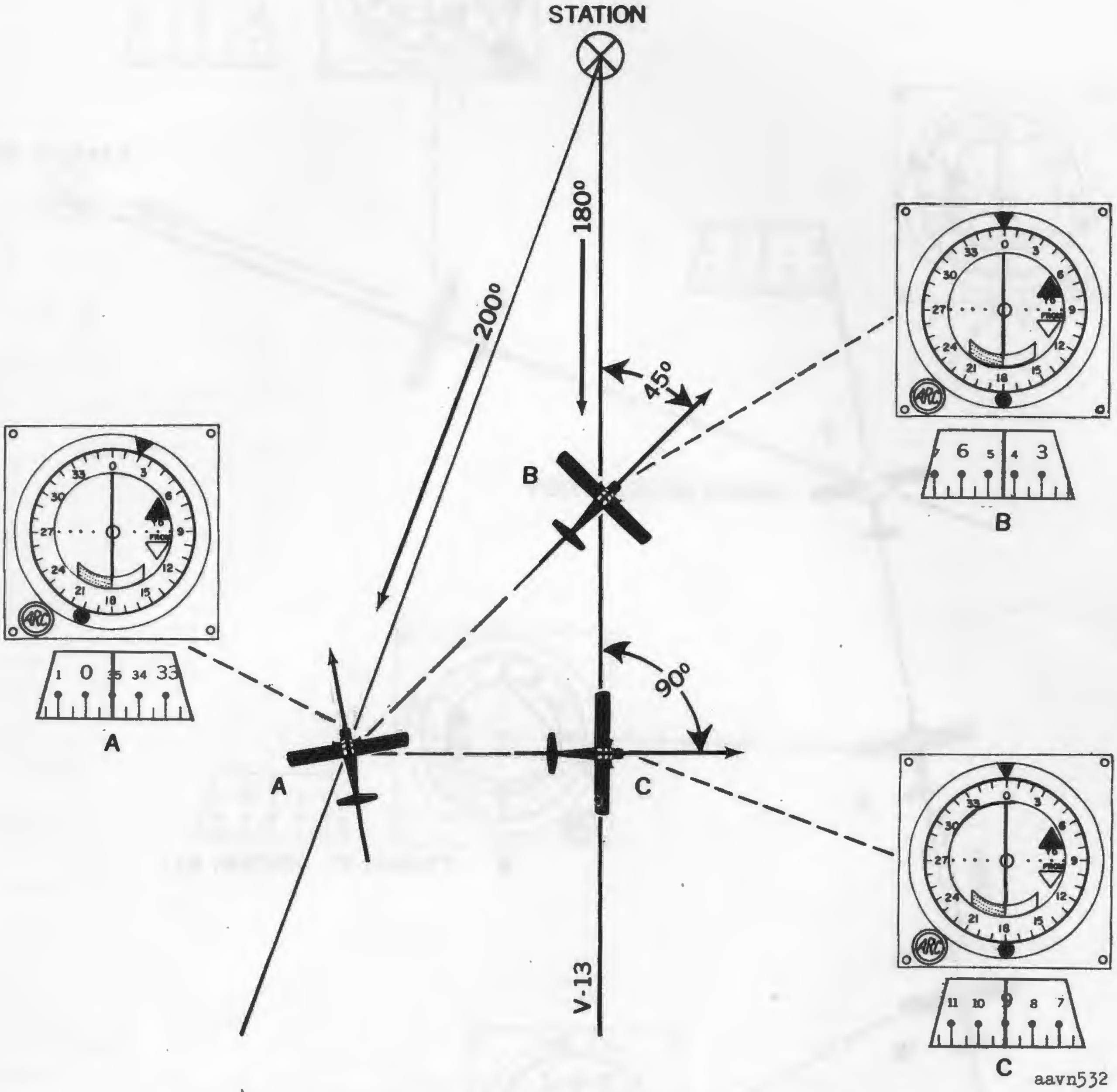

Figure 10-15. Track interception at 45° or 90° from a known position (VOR).

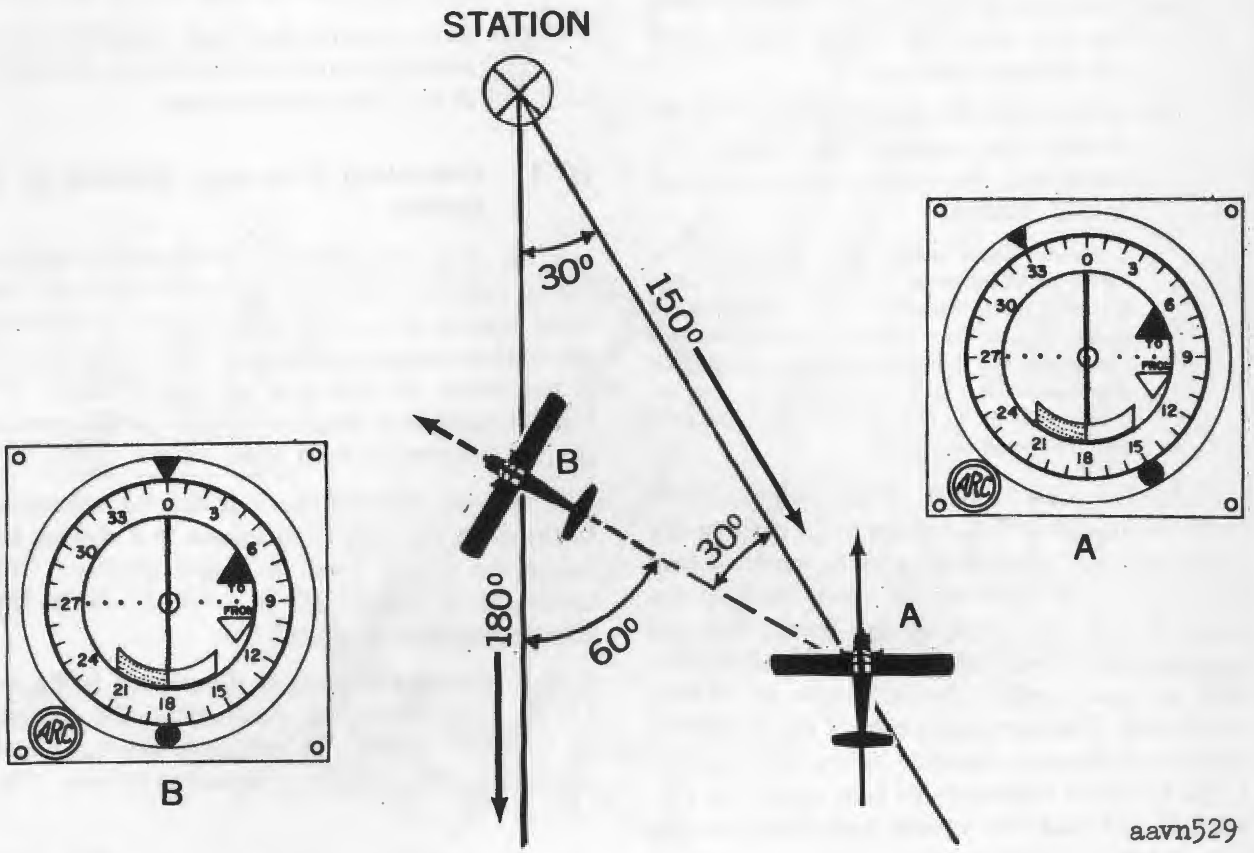

Figure 10-16. Double-the-angle track interception from a known position (VOR).

(5) Procedure (2) above can be changed to intercept the track at a 90° angle (C, fig. 10-15) if necessary to reach the track in the least possible time.

b. From a Known Position — Double-the-Angle Interception. The double-the-angle method of intercepting a desired track from a known position consists of the following procedures (fig. 10-16):

(1) Determine the angular difference between the radial on which the aircraft is presently located and the radial which represents the desired track. At A of figure 10-16 the aircraft is on the 150° radial and the aviator wishes to intercept the inbound course of 0° to the station. (This is the 180° radial, so the angular difference is 30°.)

(2) Double the angular difference and this will give a desirable interception angle. In this case the interception angle will be 60°.

Note. When using this procedure, initial interception angles of less than 20° are usually not practical. Also, an interception angle of 90° is the maximum; thus, an angle greater than 40° would not be doubled.

(3) Select the heading which will cause the aircraft to interecpt the desired

track at the desired interception angle. In this case, a heading of 300° will intercept the inbound track of 0° at the desired 60° angle.

(4) Turn the aircraft to the selected heading and reset the course selector for the inbound track of 0°.

(5) At the time the needle centers (B, fig. 10-16), the aircraft has reached the track and the aviator turns inbound to the station.

Note. When using this technique, the leg flown to intercept (from point A to point B) is equal in length to the leg remaining to the station from point B to the station). Consequently, the time required to fly the interception leg is the approximate time remaining to fly to the station, from the time that interception occurs.

c. Leading the Needle. If the aviator waits until the needle is fully centered to turn to the track heading, he runs the risk of overshooting the track; if he turns to the track heading too soon, he will roll short of the track. For use during initial track interception or reinterception, he must perfect the technique of leading the needle. The movement rate of the deviation needle and the size (degree) of the interception angle are good indicators of how much the aviator should lead the needle just prior to the actual track interception.

d. Interception of a Given Track From an Unknown Position. An aviator may be directed to intercept a specific track, and at a time when he is uncertain of the track location. He may not know if it is to his right, left, front, or rear. One simple method of quickly orienting the aircraft with respect to a desired track is as follows:

(1) From the present heading of the aircraft, turn the shortest way to a heading which is parallel to the desired track. (The station has previously been tuned and identified.)

(2) While turning ((1) above), set the course selector to the desired track.

(3) After rolling out of the turn ((1) above), observe the deflection of the needle. The track lies to the same side as the needle deflection. The to-from indicator will now indicate if the station is ahead or behind the aircraft.

(4) Turn toward the track (needle), to a heading which will intercept the track at an appropriate angle.

10-11. Estimating Time and Distance to a Station

a. In most situations an aviator will be flying in regions where two omni stations, or one omni station and some other type of station, are within reception distance. The aviator can, if necessary, fix his position and estimate the time and distance to either station by determining the bearing to each (par. 10-6).

b. In some isolated cases, it may be necessary to estimate the time or distance to a station by using the signal from a single station. One technique of doing this is pointed out in the note to paragraph 10-10*b*(5).

c. A different method is illustrated in figure 10-17. The aircraft is inbound to the station on the 200° radial. To estimate the time and distance to this station, proceed as follows (fig. 10-17):

(1) Turn the aircraft through 80° (left in fig. 10-17).

(2) Move the course selector 10° (from 020° at point A to 030° at point B) to a known radial ahead of the aircraft.

(3) Wait for the needle to recenter and take a time check (e.g., 1412:50).

(4) Move the course selector an additional 10° (from 30° at point B to 40° at point C).

(5) Wait for the needle to recenter and take a second time check (e.g., 1414:55, or 2 minutes and 5 seconds elapsed during the 10° bearing change).

(6) Turn inbound to the station (D) and

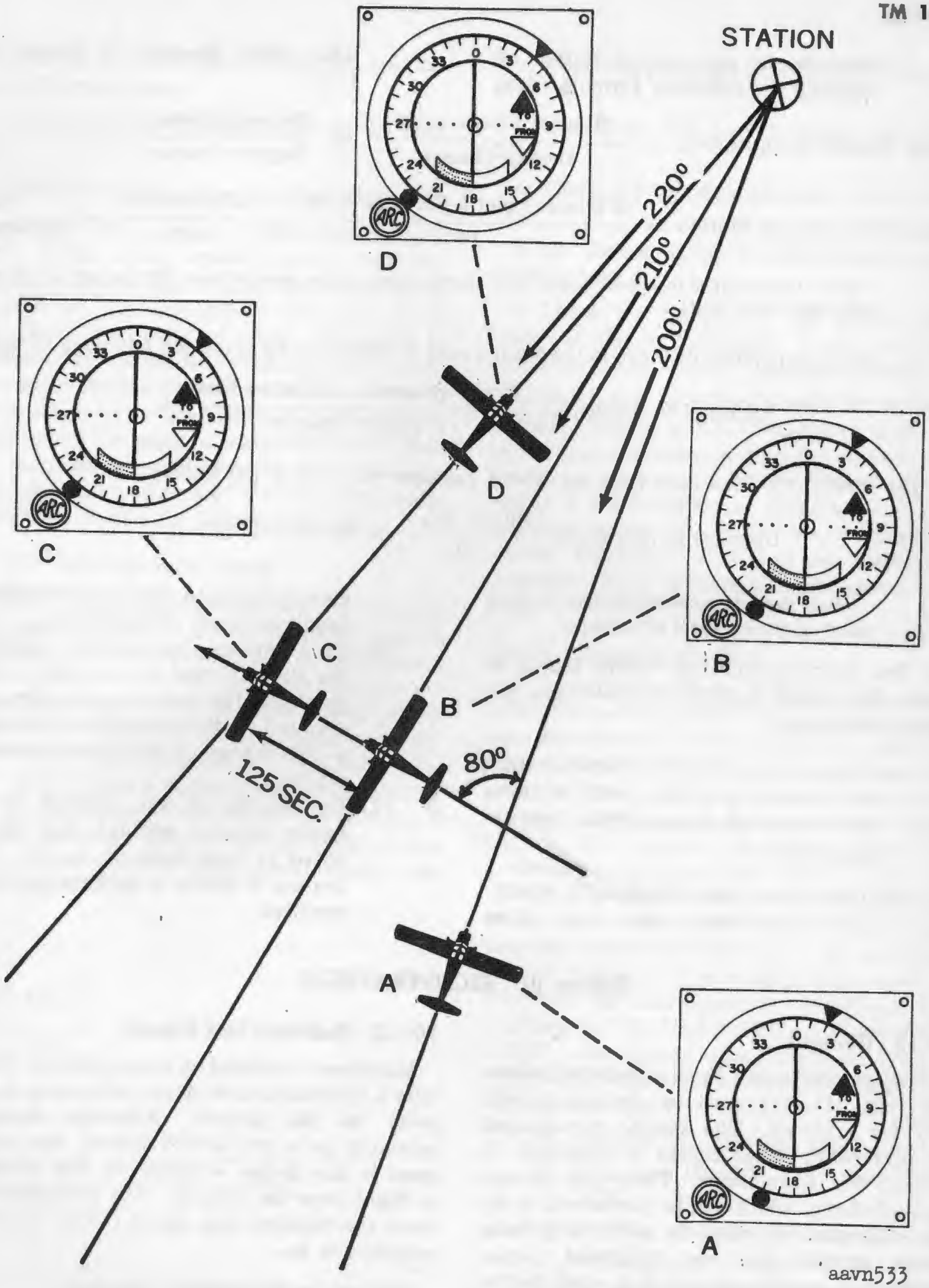

Figure 10–17. Estimating time and distance (VOR).

estimate the time to the station by applying the following formula (data taken from situation in figure 10-17.):

$$\text{Time Remaining to Station} = \frac{\text{Minutes Flown} \times 60}{\text{Degree Change}} = \frac{\text{Seconds Flown}}{\text{Degree Change}}.$$

$$\text{Time Remaining to Station} = \frac{\text{2 Minutes and 5 Seconds} \times 60}{10^\circ} = \frac{\text{125 Seconds}}{10^\circ} = \text{12.5 Minutes.}$$

Note. If aircraft is turned 80° right ((1) above), move course selector from 020° to 010° in (2) and from 010° to 0° in (4).

(7) The approximate distance to the station may be estimated by using the following formula:

$$\text{Distance to Station} = \frac{\text{True Airspeed} \times \text{Minutes Flown}}{\text{Degree Change}}$$

(8) Substituting the data from fig. 10-17 (assume the TAS is 120 knots)—

$$\text{Distance to Station} = \frac{120 \times 2\frac{1}{2}}{10} = \text{25 Nautical Miles.}$$

Note. Seconds must be changes to fractional or decimal parts of a minute.

d. The following limiting factors should be kept in mind when applying the above time and distance formulas:

(1) They are based on the assumption that a 1° angle is 1 mile wide 60 miles away from the vertex. This is an approximation.

(2) They do not take into account adverse wind conditions that may cause groundspeeds to vary considerably on headings which differ by 90°.

(3) To determine time-distance required, the aircraft must turn so that it will fly abeam the station during the time required for the aircraft to fly through a 10° change in the course selector reading.

(4) The bearing change (change in the course selector setting) may be allowed to vary from 5° to 15°. Ten degrees is used as a mathematical convenience.

Section III. RECEIVER CHECKS

10-12. General

Omni receivers and their associated indicators (e.g., ID-453) must be checked periodically for accuracy. The specific requirement for performing these checks is contained in Federal Air Regulations. There are several types of checks which can be performed to insure equipment accuracy. In performing these checks, current data for designated station frequencies, specific omni radials, and station identification are contained in current navigational publications.

10-13. Radiated Test Signal

Equipment installed at many airports transmits a continuous test signal receivable at any point on the airport. Although designed primarily as a ground test system, this equipment is also usable at relatively low altitudes in flight over the airport. The procedure for using the radiated test signal (VOT) to check receivers is to—

a. Tune the designated frequency.

b. Listen for the proper identification; i.e., either a continuous series of dots or a continuous 1,020-cycle tone.

c. Check for the disappearance of the *OFF* flag.

d. Set the course arrow to either 180° or 0°.

e. Check the reaction of the to-from indicator. If the course arrow is set on 180°, the indicator should read *TO.* If the course arrow is set on 0°, the indicator should read *FROM.*

f. Check the deviation needle. It should be centered. If the needle is not centered, rotate the coarse selector until the needle centers. If the coarse selector does not have to be rotated more than 4° in order to center the needle, then the equipment is within tolerance. If the needle will not center within a 4° tolerance, the equipment is unreliable for instrument flight.

10–14. Other Ground Check

Not all airports have equipment for radiated test signals (VOT). However, many airports have omni stations situated nearby from which selected radials can be used for checkpoints. Data pertaining to the certified ground check radial is published in current navigation publications. In the illustration (fig. 10–18), the 120° radial from a station passes directly over the end of runway 9. An exact spot is marked on this runway. The aircraft is taxied to this spot and the receiver check is performed in the following manner:

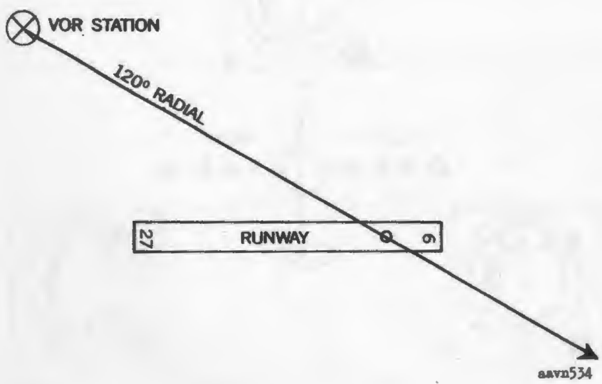

Figure 10–18. Ground receiver check (VOR).

a. Tune the designated frequency of the station.

b. Listen for the correct station identification.

c. Check for the disappearance of the *OFF* flag.

d. Set the course arrow on the specific radial for the check.

e. Check the reaction of the to-from indicator. If the correct radial is set under the course arrow, it should indicate *FROM.*

f. Check the deviation needle for centered position. Plus or minus 4° tolerance is allowed on the course selector setting for centering the needle. If movement of the course selector within 4° of the published radial will cause the deviation needle to center, the equipment is usable. Equipment that does not meet these tolerance limits is unreliable for instrument flight.

10–15. Airborne Check

a. At airports where radiated test signals (VOT's) or other ground check radials have not been established, an airborne check radial may exist. Airborne checks are performed like ground checks except that an air checkpoint is specified instead of a designated spot at the airport. For example, if a prominent water tower exists within a few miles of the omni station, a certain radial can be selected which passes over this tower. As the aircraft flies over the tower, the accuracy of the equipment can be checked. A published airborne check over the tower may appear in navigational publications as: "DALLAS, TEXAS (Love Field) —213°, over striped water tower on Loop 12 (Highway) approximately 2.6 miles east-northeast of Love Field."

b. To perform the airborne check—

(1) Tune and identify the Dallas, Texas VOR.

(2) Set the course arrow on 213° and check for a *FROM* reading.

(3) Fly over the water tower described.

(4) When over the water tower, check the deviation needle for centered position.

If the needle is within 6° of center, or if a course selector movement of 6° or less from the published radial will cause the needle to center, the equipment is within tolerance. Equipment that does not meet these tolerance limits should not be used for instrument flight.

10-16. Dual VOR Receivers

If an aircraft is equipped with dual receivers, one receiver may be checked against the other. If receivers are within 4° of each other, both may be considered reliable. To perform this check—

a. Tune and identify one omni station with both omni receivers.

b. Using dual course indicators (ID-453 or equivalent), rotate the course selectors of each until the needles are centered.

c. Check to determine that the to-from indicators on each instrument are in agreement.

d. Check the course arrow readings. These readings must be within 4° of each other. If receivers do not meet these limits, one or both are unreliable. Each will have to be checked independently to determine if one is within allowable tolerance.

10-17. Unpublished Receiver Check

An aviator in a location where no receiver checks are published may establish a checkpoint from a nearby omni station. To accomplish an unpublished receiver check—

a. Select a VOR radial that lies along the centerline of an established VOR airway.

b. Select a prominent ground point along the selected radial preferably more than 20 miles from the VOR ground facility, and maneuver the aircraft directly over the checkpoint at a reasonably low altitude.

c. Note the VOR bearing indicated by the receiver when over the ground point (the maximum permissible variation between the published radial and the indicatd bearing is 6°).

10-18. Needle Sensitivity

At the same time that the omni receiver is checked for accuracy, the indicator can be checked for needle sensitivity. The face of the indicator (ID-453) (fig. 10-19) is graduated in 2° intervals. Moving from center to either side, the edge of the small circle is 2° and each dot (alined horizontally) represents 2°. When the needle is fully deflected to one side, the aircraft is off the selected course by at least 10°. Consequently, if the receiver is checked for a centered needle with the course selector set on a given radial—for example 140° (A, fig. 10-19)—a full swing of the needle can be checked by setting the course selector on 130° (B, fig. 10-19) and then on 150° (C, fig. 10-19). If the needle swings full scale to each side as the course selector is displaced ± 10° from a published check radial, the needle reaction is correct. Full scale needle swing can vary between approximately 8° and 12° when the receiver is within the reliable accuracy tolerances discussed in paragraph 10-15*a* through *e* above.

Note. The sensitivity tolerance of the needle is different if the receiver is used in conjunction with the ILS (ch. 15).

Warning: **Pertinent information for omni receiver checks should be verified from current navigational publications and regulations. This information is subject to change.**

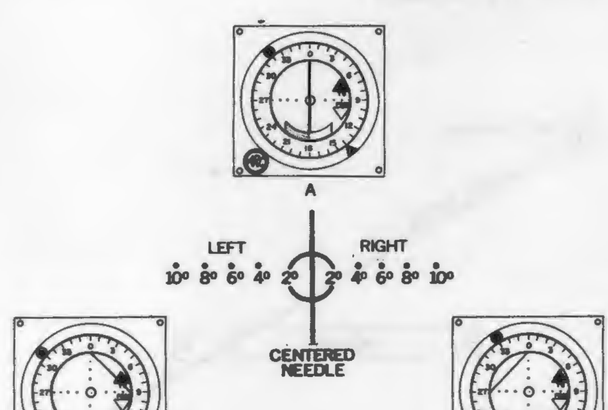

Figure 10-19. Needle sensitivity check.

Section IV. VOR STATION CLASSIFICATION

10-19. Classification by General Types

The general types of omni stations are—

a. VOR—This is a VHF omni range.

b. TVOR—A T in front of the VOR signifies that it is a terminal omni. It is located either on the air terminal or very near it.

c. VORTAC—This signifies a dual facility (VOR and TACAN). TACAN is a system of navigation which, although similar to the VOR, operates in the UHF frequency band. TACAN is not being used in Army aircraft at present. The VOR and TACAN are collocated and have some common components, but either facility may be used independently.

10-20. Classification by Reception Capabilities

Stations are also classified by their interference-free reception capabilities with respect to distance and altitude. This classification is the basis for establishing the interference-free reception range of transmitter frequencies. The following data shows station classification with maximum reliable distances and altitudes.

Station Classification	*Maximum Reliable Distance*	*Reliable Maximum Altitude*
T—VOR	25 nautical miles	12,000 ft. msl
L—VOR	40 nautical miles	18,000 ft. msl
H—VOR	130 nautical miles	up to 45,000 ft. msl
	100 nautical miles	above 45,000 ft. msl

Note. Classification of stations is subject to change. Current operational publications should be consulted for the latest information.

CHAPTER 11

RADIO DIRECTION FINDER

11-1. General

The *radio direction finder* is a radio receiver set used to determine the bearing to the radio transmitting station from the aircraft. When a loop antenna of a radio receiver is placed in a radio transmitter signal pattern, the signal is heard *except* when the plane of the loop is perpendicular to the line from the aircraft to the station. The loop position at which no audible signal is received is called the *null*. Navigation by means of the radio direction finder uses the null for determining direction to the transmitting station. Automatic direction finding (ADF) equipment in Army aircraft is constructed so that the aviator can either manually rotate the loop and its indicator needle as he listens for a null or operate the receiver in the automatic position and read the instrument indicator needle as the loop automatically determines the null position. A bearing to the transmitting station can be read from the indicator face by either method.

Note. The bearing to the station measured clockwise from the aircraft heading is the *relative bearing* (the bearing is relative to the aircraft heading). Relative bearing can be converted to a magnetic bearing (par. 11-4), or the indicator can be set so as to read the magnetic bearing directly (par. 11-7*a*(4)).

11-2. Components of the ARN-59 Automatic Direction Finder (ADF)

The ARN-59 is the standard automatic direction finder receiver set in most Army aircraft. The components of this set (fig. 11-1 ① and ②) are—

a. The receiver, which is an LF/MF radio receiver.

b. The loop antenna, which is directional (par. 11-1) and consists of an iron-core loop housed in a sealed container.

c. The sensing antenna, which usually is a length of wire running parallel to the fuselage of the aircraft.

Figure 11-1①. ARN-59 components.

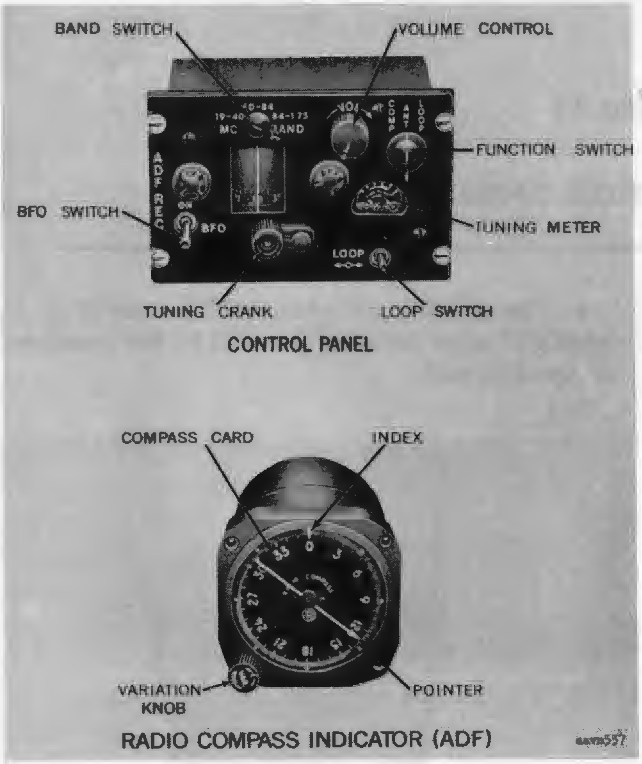

Figure 11-1(2)——Continued.

d. The control panel, which is used for tuning the receiver and for selecting the mode of operation.

e. The radio compass indicator (also called the ADF indicator), which consists of a compass card, an azimuth indicator needle (pointer), and a card rotation knob (labeled VAR). The indicator is used to determine the bearing to the station.

Note. Another type of indicator (the radio magnetic indicator, ch. 12) has a compass card that moves automatically to show the aircraft heading.

11-3. Receiver Operation

a. Frequency Range. The ARN-59 can receive signals transmitted between .19 mc (190 kc) and 1.75 mc (1,750 kc). To facilitate rapid tuning, this range is divided into three separate bands on the control panel from .19 mc to .40 mc, from .40 mc to .84 mc, and from .84 mc to 1.75 mc.

b. Receivable Stations.

(1) *Homing beacon transmitter.* The primary radio navigational transmitting station used with the ARN-59 receiver is the *homing beacon.* The LF/MF homing beacon is also called a nondirectional beacon, radio beacon, compass locator, or a homer, and is classified by power output, as follows:

Radio class	*Power output (watts)*	*Minimum usable distance (statute miles)*
L	Less than 25.	15
MH	25 to less than 50.	25
H	50 to less than 2,000.	50
HH	2,000 or more.	75

(2) *Other transmitters.* In addition to homing beacon transmitters, other stations usable with the ARN-59 receiver are commercial broadcasting stations, radio marine beacons, and low or medium frequency transmitters operating in control towers or in other communications installations.

c. Tuning. Inaccurate tuning to a station frequency may cause the azimuth needle to fluctuate, making accurate interpretations of bearing difficult. The procedure for accurate tuning is as follows (refer to the control panel, fig. 11-1 (2)):

(1) Turn on the set by rotating the VOL (volume) switch to the right (clockwise) and adjust the volume to the desired level.

(2) Place the function selector knob in the *ANT* (antenna) position.

(3) Select the correct radio frequency band. For example, if the transmitting station broadcasts on 310 kc (.31 mc), set the band selector on .19 mc to .40 mc.

(4) Operate the tuning crank until the desired radio frequency appears on the dial. At this time the station identification code should be audible. Make slight adjustments with the crank until the strongest signal is heard.

(5) Reset the function selector knob to the *COMP* (compass) position and make

further slight adjustments with the crank to obtain the maximum deflection on the *TUNE TO MAX* meter.

(6) Adjust volume to desirable level.

d. Beat Frequency Oscillator (BFO).

(1) *Function.* Certain types of radio stations transmit an interrupted but unmodulated radio carrier wave which is inaudible unless the BFO switch is turned on. The beat frequency oscillator converts the inaudible keyed (interrupted) carrier wave into an audible, intelligible sound. (On some ADF receivers the BFO switch is labeled CW.) Stations transmitting a carrier wave signal are common in Europe and other oversea regions. The overseas navigation publications indicate these stations with the classification "A-1 emission."

(2) *Tuning.* While tuning with the BFO switch, a continuous monotone is heard until the station frequency is approximately tuned. At this point, the monotone fades to a null. A peak tone exists on each side of the null, but the strongest signal is received from the peak on the lower frequency side of the null (as indicated in the dial window). After the set is tuned, the BFO switch is turned off for normal operation in the COMP position. For operation of the set in the LOOP position (sec. III), the BFO switch is left on so that the signal can be heard.

Section II. AUTOMATIC DIRECTION FINDER FLIGHT PROCEDURES

11-4. Orientation

a. ADF Indicator (Radio Compass). The radio compass indicator (fig. 11-1②) usually is used with the ADF receiver to determine direction to the transmittting station. The compass card (indicator face) can be rotated manually with the VAR knob on the indicator head to facilitate postition fixing on airways (par. 11-7*a*(4)). Normally, however, the card is set with 0° at the index (the small mark at the top center of the indicator head which represents the nose of the aircraft).

b. Relative Bearing. Standard ADF flight procedures are based upon setting 0° on the compass card under the index representing the nose of the aircraft. Therefore, the bearing read directly from the ADF indicator is measured from 0°. For this reason, the bearing is called the *relative bearing,* and is the bearing to the station as measured clockwise from the nose of the aircraft. Although measured clockwise, the relative bearing may be read from the ADF indicator as degrees left or right of the nose; i.e., a relative bearing of 270° clockwise is equivalent to a bearing of 90° left of the nose.

(1) In figure 11-2 the relative bearing to the station is 060° regardless of the aircraft heading; i.e., the station is 60° right of the actual aircraft heading. To determine the magnetic direction to the station, add 60° to the magnetic heading; i.e., at point A, figure 11-2, the magnetic heading is 030°, the station is 60° right; the magnetic direction to the station is 090°. The magnetic directions at points B and C in figure 11-2 are 160° and 350°, respectively. Once the direction to the station is known, the aviator can orient his aircraft with respect to this station.

(2) Figure 11-3 depicts a station 330° right of the aircraft heading (060°). In this situation it is more practical to interpret the indication as 30° left of the nose, although the relative bearing is 330° right of the nose. Since the magnetic heading of the aircraft is 060°, the magnetic direction to the station is computed as 030° by subtracting 30° (left of the nsoe) from the magnetic heading of 060°.

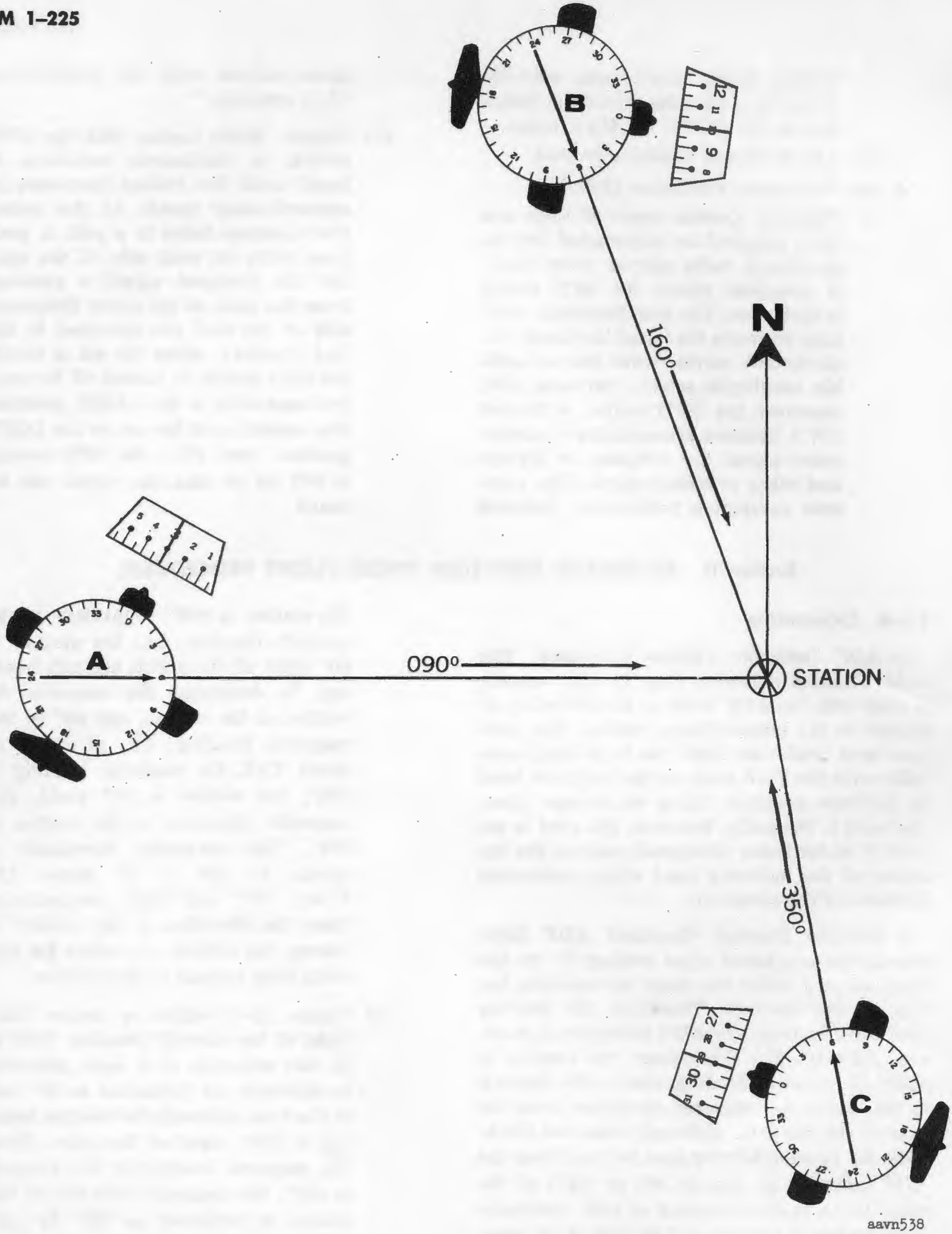

Figure 11-2. Relative bearing of 060° on three different aircraft headings.

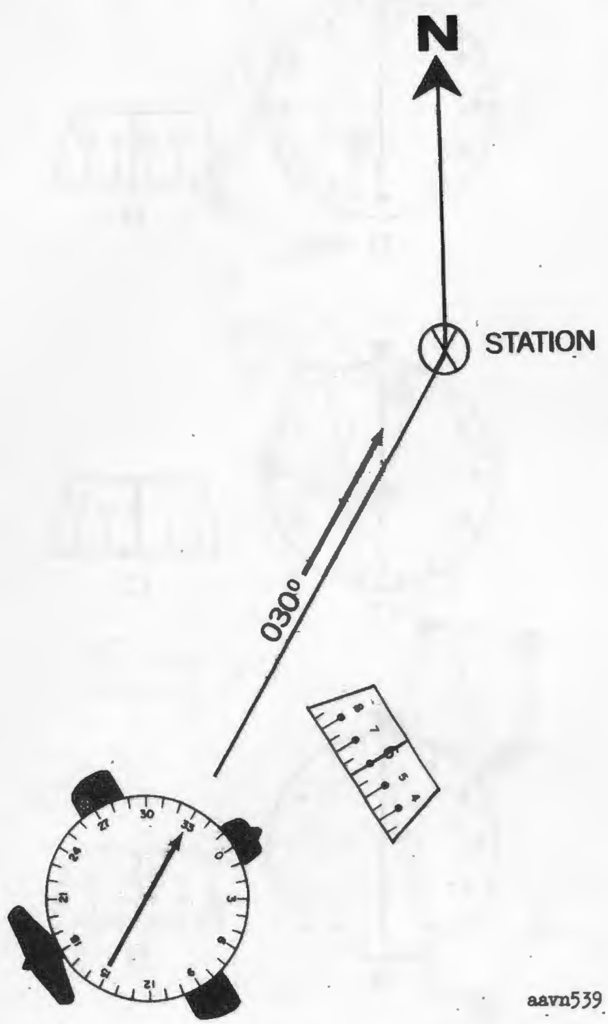

Figure 11-3. Relative bearing read left of nose position.

c. Summary. The procedure for ADF orientation is summarized as follows:

(1) Tune and identify the station.

(2) From the ADF indicator, determine the number of degrees left or right between the station and the aircraft heading.

(3) Add the number of degrees right to the heading or subtract the number of degrees left from the heading to determine the magnetic course to the station.

11-5. Homing

Flying toward a station by keeping the nose of the aircraft oriented toward the station at all times is called homing (fig. 11-4); i.e., maintaining a constant relative bearing of 0°. After the aviator determines the direction to the station (par. 11-4), he homes to the station by turning toward it until the ADF indicator reads 0° (A, fig. 11-4). If the azimuth indicator needle drifts off zero, the aviator turns the aircraft toward the arrow (the station) until the needle returns to zero. With a crosswind, the path flown (*track*) will curve (B to C, fig. 11-4). As the aircraft approaches the station, the ADF indicator tends to fluctuate because of the strong signal. The aviator should estimate his close proximity to the transmitting station and not "chase the needle." Arrival at the station and station passage is indicated when the needle swings through 180° (to 180° in D, fig. 11-4).

11-6. Tracking

Tracking is the technique of flying a definite path (track) into or away from a station. The correction for wind must be determined and applied to remain on track. The method for applying drift correction varies slightly for slow-speed helicopters because with slower airspeeds the wind correction must be greater. Both the usual tracking technique and the technique used on slow helicopters are illustrated in figure 11-5.

a. Tracking Inbound. ((A), fig. 11-5).

(1) *Point A.* Aircraft is inbound on a track of 350°, heading is 350°, and ADF indicator reads 0°.

(2) *Point B.* Crosswind from the left has caused the aircraft to drift off course to the right. The ADF indicator reads 355°, so the intended track is 5° to the left. Normally, a correction in heading to return to track is applied when the aircraft moves 5° or more off track. However, a 5° deflection of the ADF needle is not significant close to the station.

(3) *Point C.* The aviator applies 20° of

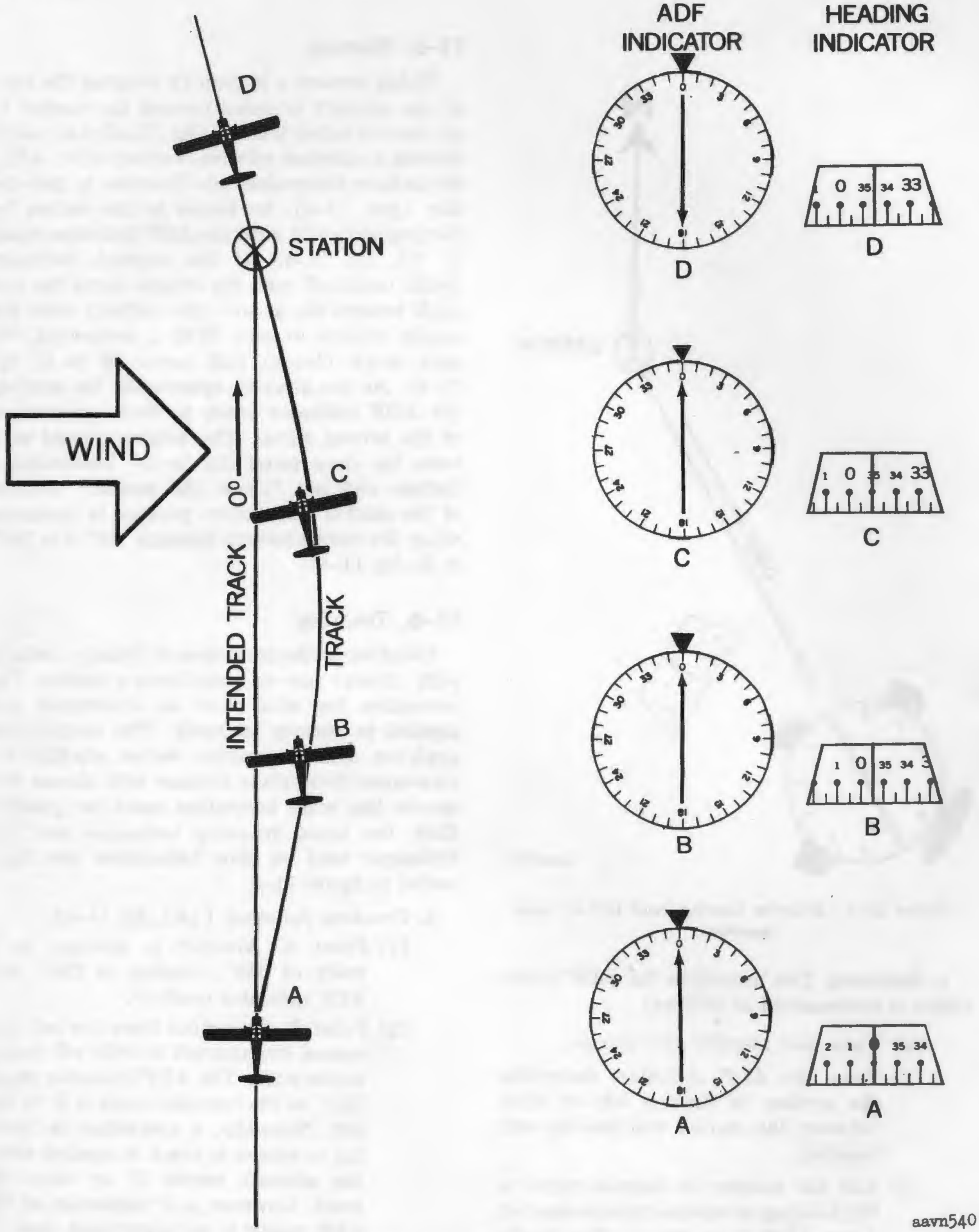

Figure 11-4. Homing (ADF).

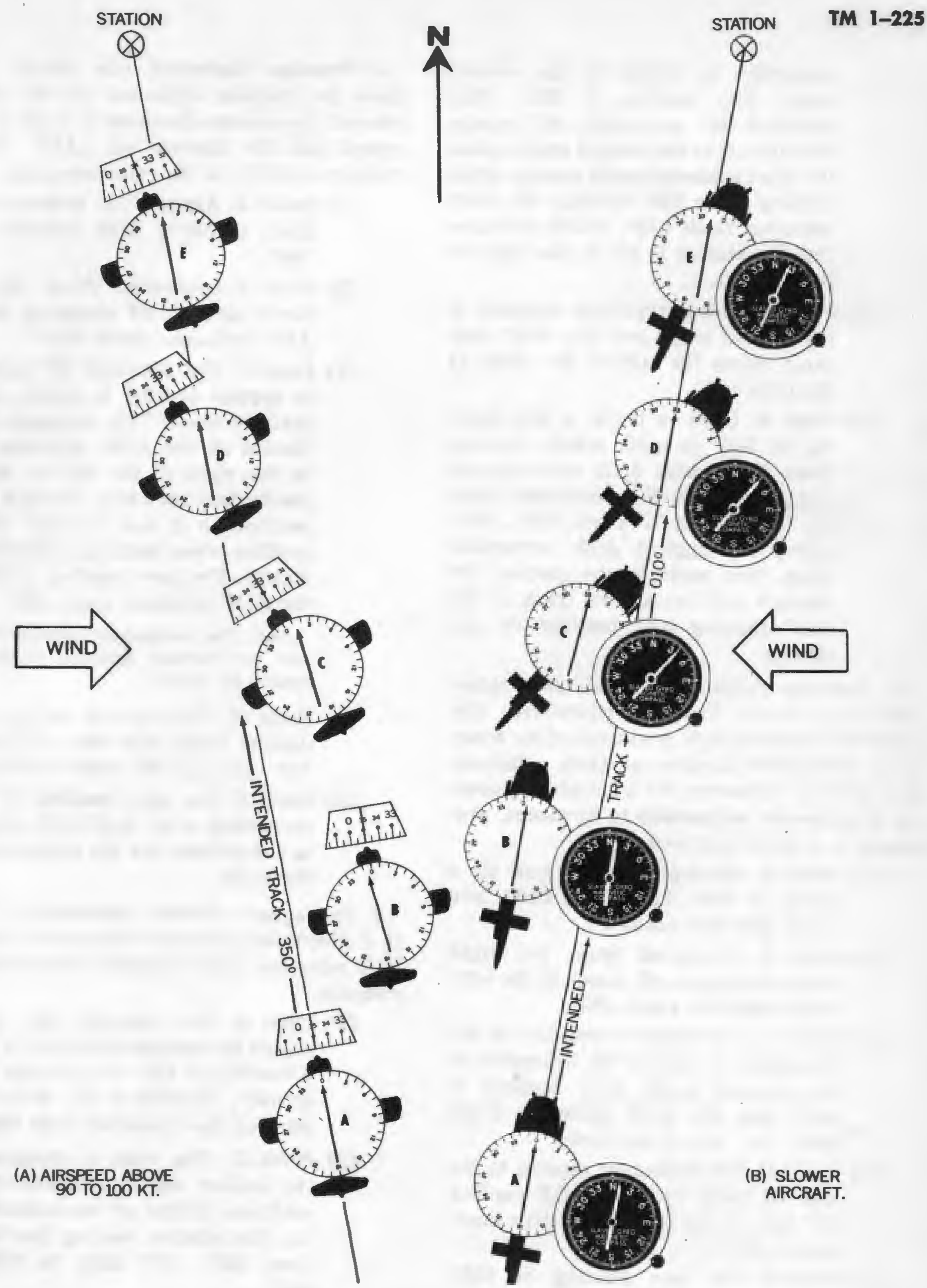

Figure 11–5. Tracking inbound (ADF).

correction to return to the desired track. The heading is 330°. This standard 20° correction will return the aircraft to the desired track unless the wind is exceptionally strong. After turning to the 330° heading, the ADF indicator reads 015°, which indicates that the station is 15° to the right of the aircraft.

(4) *Point D.* The aircraft has returned to the desired track and the ADF indicator shows the station 20° right of the nose.

(5) *Point E.* Once on track, a new heading of 340° is used, which incorporates a 10° trial drift correction to compensate for the crosswind from the left. The ADF reads 010°, indicating the applied drift correction. From this point to the station, the aircraft will remain on track if the ADF reading and heading do not change.

b. Tracking Inbound — Slow Helicopters ((B), fig. 11–5). Tracking procedures discussed in this paragraph are standard for many Army helicopters because of their relatively slow airspeed. However, for helicopters operating at airspeeds comparable to airplanes, procedures in *a* above are used.

(1) *Point A.* Helicopter is inbound on a track of 010°, heading is 010°, and ADF indicator reads 0°.

(2) *Point B.* Crosswind from the right blows helicopter off course to the left; ADF indicator reads 005°.

(3) *Point C.* A standard correction of 30° is applied to return the helicopter to the desired track. New heading is 040° and the ADF indicator reads 335° (25° left of the nose).

(4) *Point D.* The helicopter returns to the desired track with the ADF reading 30° left of the nose (a relative bearing of 330°).

(5) *Point E.* The new heading of 025° incorporates a 15° trial drift correction to compensate for the crosswind from the right.

c. Tracking Outbound (fig. 11–6). Procedures for tracking outbound are the same as inbound procedures discussed in *a* and *b* above, except that the aircraft tail (ADF indicator reading of 180°) is the reference point.

(1) *Point A.* Aircraft is outbound on a track of 350°; ADF indicator reads 180°.

(2) *Point B.* Crosswind from the right blows aircraft off course to the left; ADF indicator reads 175°.

(3) *Point C.* The standard 20° correction is applied upwind to return the aircraft to track. This increases the deviation of the ADF indicator needle to the right of the tail by 20°. The needle does not swing through the tail position as it does through the nose position when tracking inbound (*a*(3) above). The new heading is 010° and the ADF indicator reads 155°.

Note. The standard 30° correction value is used for tracking outbound in slow helicopters (*b* above).

(4) *Point D.* The aircraft returns to the desired track with the ADF reading 160° (station 20° right of tail).

(5) *Point E.* The new heading of 0° incorporates a 10° trial drift correction to compensate for the crosswind from the right.

d. Inadequate Initial Corrections. Figure 11–7 illustrates procedures to correct for wind drift when the initial applied correction is inadequate.

(1) *Point A.* An aircraft has reintercepted the desired track and is holding a heading of 100° to maintain a track of 090°, allowing a 10° drift correction for the crosswind from the right.

(2) *Point B.* The wind is stronger than the aviator anticipated and the aircraft has drifted off the desired track; i.e., the relative bearing has changed from 350° (10° left) to 355° (5° left).

(3) *Point C.* The aviator turns to a heading of 110° (ADF indicator reads

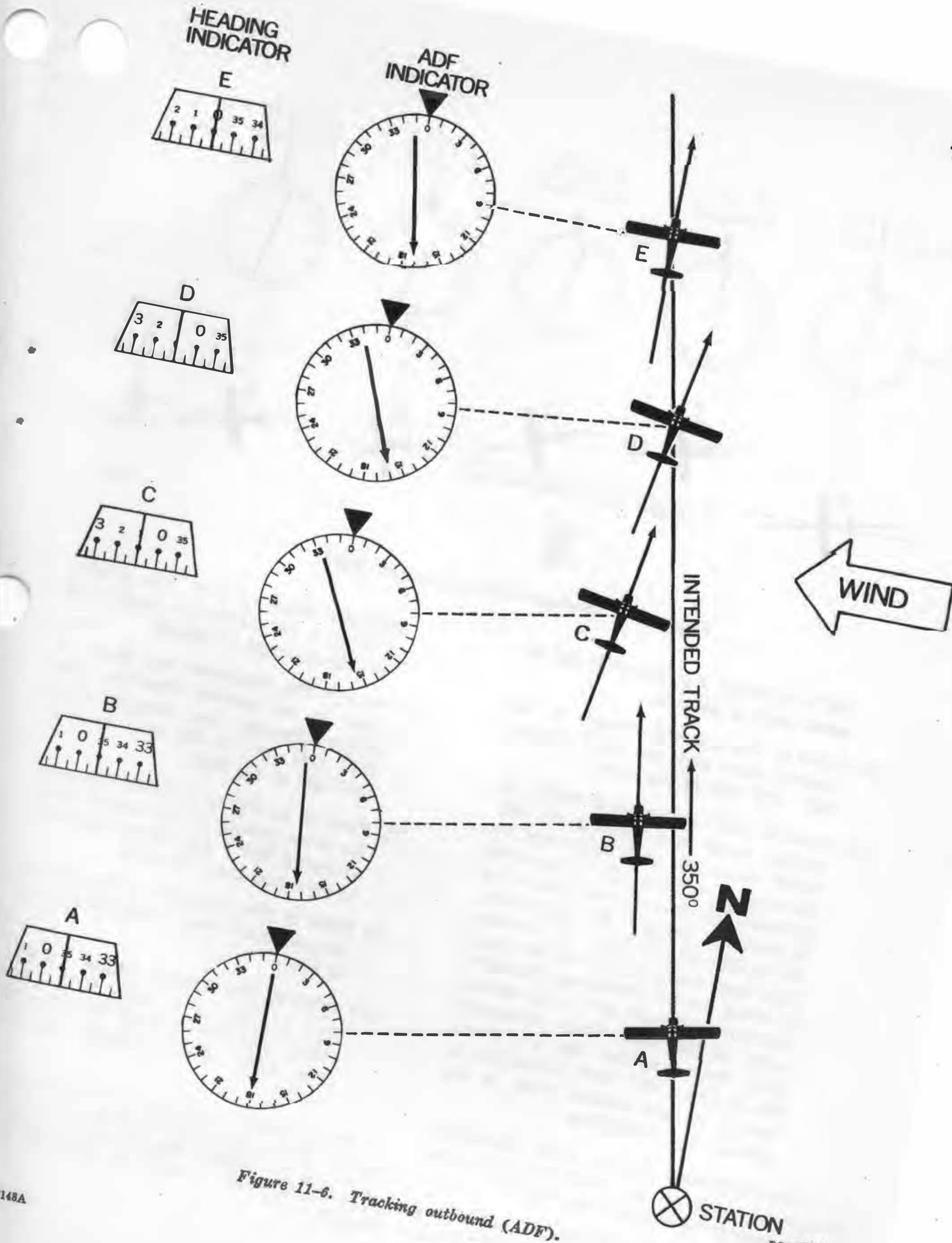

Figure 11-6. Tracking outbound (ADF).

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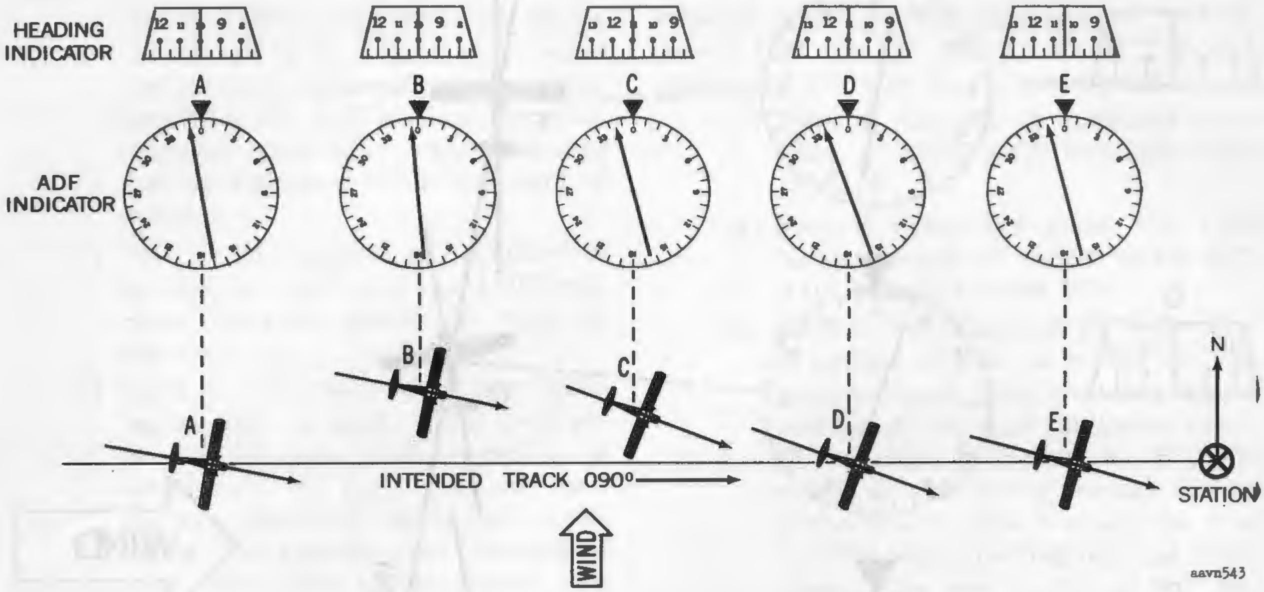


Figure 11-7. Inadequate initial correction (ADF).

345°) to return the aircraft to the desired track at point D.

(4) *Point D.* The aircraft returns to the desired track with the ADF reading 340° (20° left of the nose).

(5) *Point E.* After returning to track, the aviator turns to a heading of 105° which allows 15° drift correction for the wind. If an unusually strong wind prevents the aircraft from returning to track by using a 20° correction, the aviator should try a 40° correction. Upon reinterception of the track by using the 40° correction, the ADF indicator will read 40° to the left or right of the nose. Upon successful track reinterception, the aviator should try a 20° drift correction to remain on the desired track in the strong wind conditions.

e. Overcorrection. Figure 11-8 illustrates procedures to correct for wind drift when the initial applied correction is too great.

(1) *Point A.* The helicopter is holding a 15° left correction to remain on an outbound track of 270°. The aviator is using a 15° correction because of his slow airspeed (*b* above).

(2) *Point B.* The helicopter has flown off track in an upwind direction. The relative bearing has changed from 195° (15° left of the tail) to 190° (10° left of the tail).

(3) *Point C.* To return to track, the aviator turns parallel to the desired track (heading 270°) and allows the wind to blow him back on track.

(4) *Point D.* The helicopter is back on the desired track with a relative bearing of 180°.

(5) *Point E.* The aviator selects a heading of 260° (10° left drift correction) since the original 15° left drift correction (255° heading) was too great.

Note. The system of trial-and-error drift correction described above (bracketing) illustrates the tracking principle, but in practice each aviator much refine the bracketing procedure to satisfy his particular flight technique.

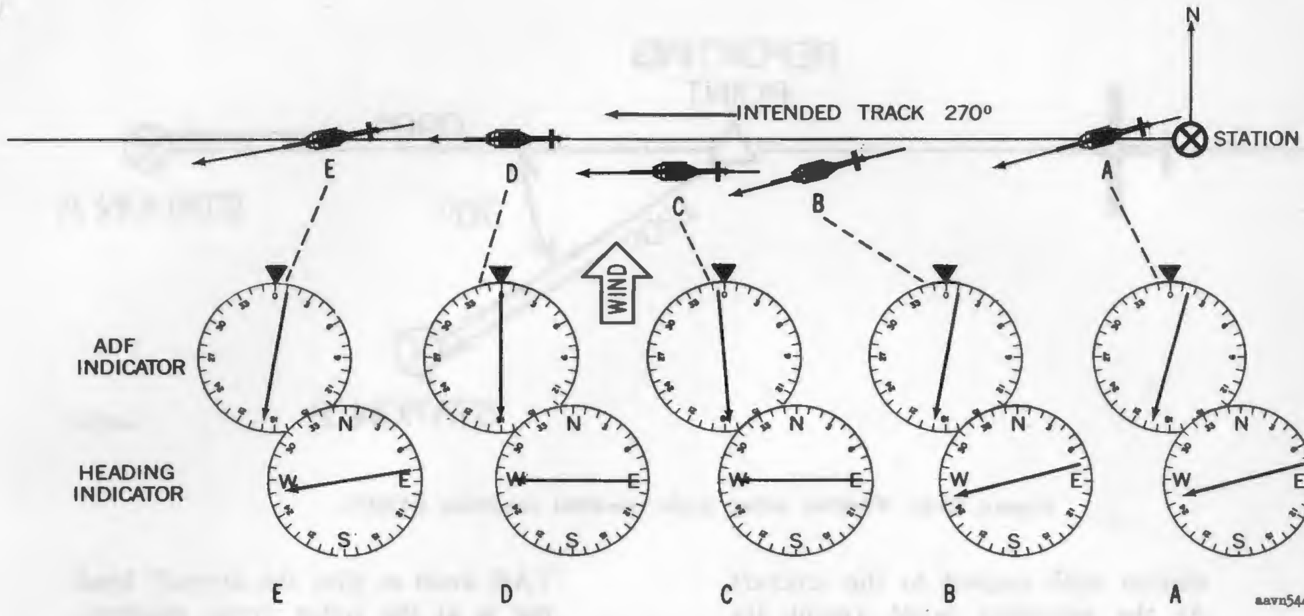


Figure 11–8. Overcorrection (ADF).

11–7. Position Fixing (Fixes)

a. Position Fixing at Airway Reporting Points. If an aircraft has flown a known track from a station, the track can be represented by a course line or airway on a navigation chart. At any point along this course the aviator can take a radio bearing to a second station with the ADF receiver and plot this bearing as a second line on the chart. The intersection of these two chart lines fixes the approximate location of the aircraft. This method of position fixing can be used in flight training without drawing any lines on the chart; for example—

(1) In figure 11–9 an aircraft is tracking inbound to station A on a track of 090°. The aircraft has been maintaining the track in a no-wind condition. Ahead of the aircraft is a reporting point (the triangle) at which the aviator must fix his position and report to air traffic control. A check of the navigation chart shows the direction to station B is 120° from the reporting point. Since the direction to station A is 090°, there will be a 30° difference between the heading to station A (090°) and the radio bearing to station B over the reporting point (120°); i.e., at the time the aircraft arrives over the mandatory reporting point, station B will be 30° to the right of the nose of the aircraft. If the aviator tunes station B on the ADF receiver, he will be over the reporting point when the ADF indicator shows a relative bearing of 30°. Prior to arriving over the reporting point, the relative bearing on the indicator will be less than 30°.

(2) In a similar situation (fig. 11–10), the aircraft is holding a heading of 080° to track inbound on 090° (applied drift correction of 10° left). When the aircraft reaches the reporting point, the relative bearing on the ADF indicator will be 040° (the difference between the heading and the bearing to station B).

(3) Figure 11–11 illustrates three other situations involving the principles discussed in (1) and (2) above, but with changes in the position of the

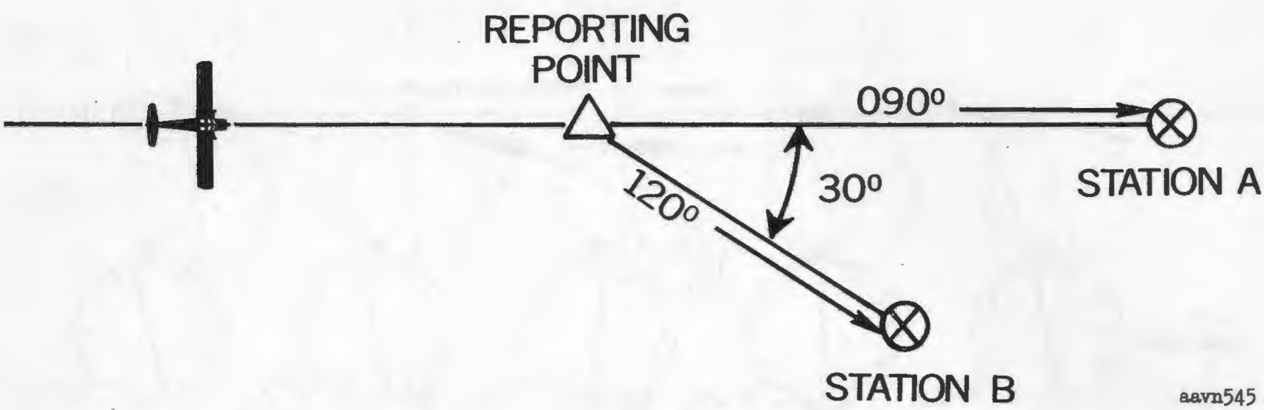


Figure 11-9. Position fixing under no-wind condition (ADF).

station with respect to the aircraft. At the reporting point (point B), figure 11-11① depicts the instrument readings when the station is 45° left of the nose; figure 11-11② depicts the station 40° left of the tail; and figure 11-11③ depicts the station 60° right of the tail.

(4) The position of the aircraft over a reporting point may also be fixed by rotating the compass card with the VAR knob so that the aircraft heading is at the index (nose position). As illustrated in figure 11-12, the aircraft will be over the intersection (point B) when the ADF needle indicates the published bearing (120°) to station C. This method eliminates the need for computing the angle between the heading and the station (relative bearing) ((1), (2), and (3) above).

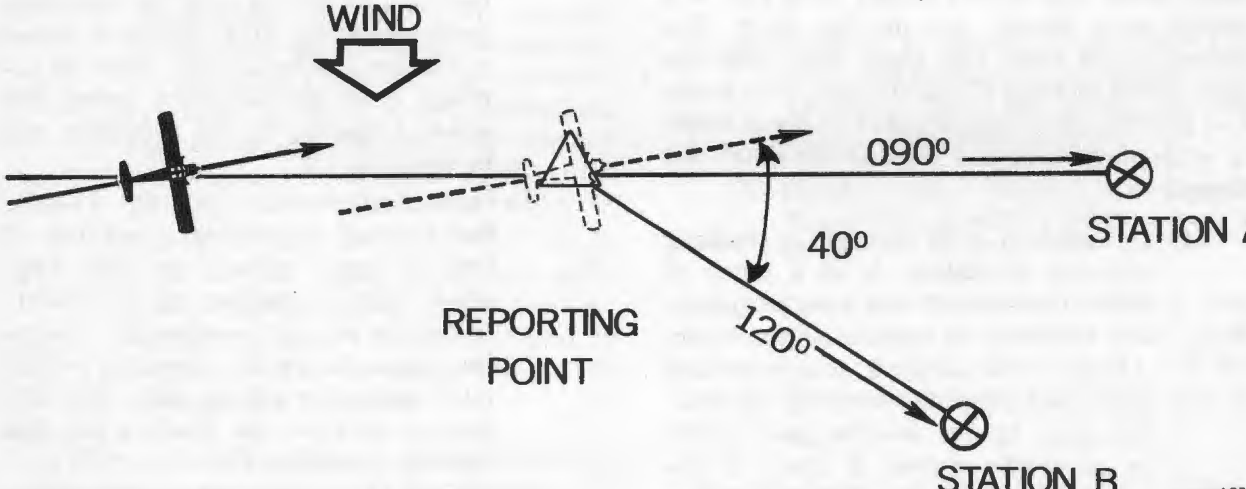


Figure 11-10. Position fixing with drift correction (ADF).

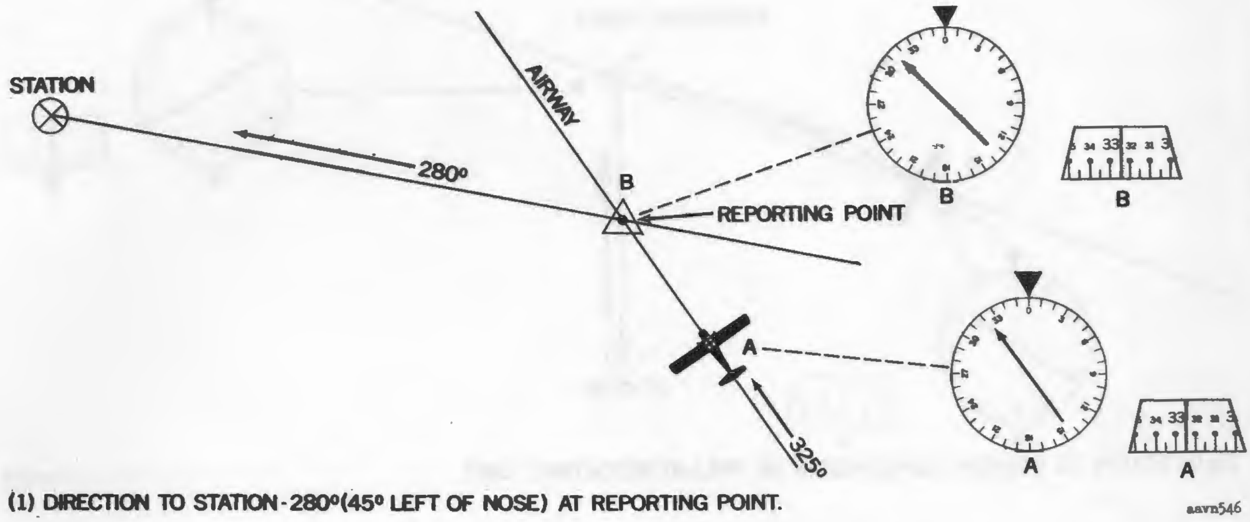


Figure 11-11①. Typical position fixes (ADF).

b. Position Fixing When Lost or Disoriented. If an aviator is lost or disoriented, he can quickly determine his position on a navigational chart when there are at least two LW/MF radio transmitting stations within reception distance of the ADF receiver. The relative bearing to one station is determined by orientation (par. 11-4) and plotted on the chart as a line of position (direction from the station to the aircraft). The relative bearing to a second station is determined by the same method and plotted. The intersection of the two lines is the approximate location of the aircraft. An angular difference of 30° between the two lines of position usually is large enough for a fix, but the closer this angle is to 90° the more accurate is the fix. The relative bearing to a third station may be used to form a more accurate fix.

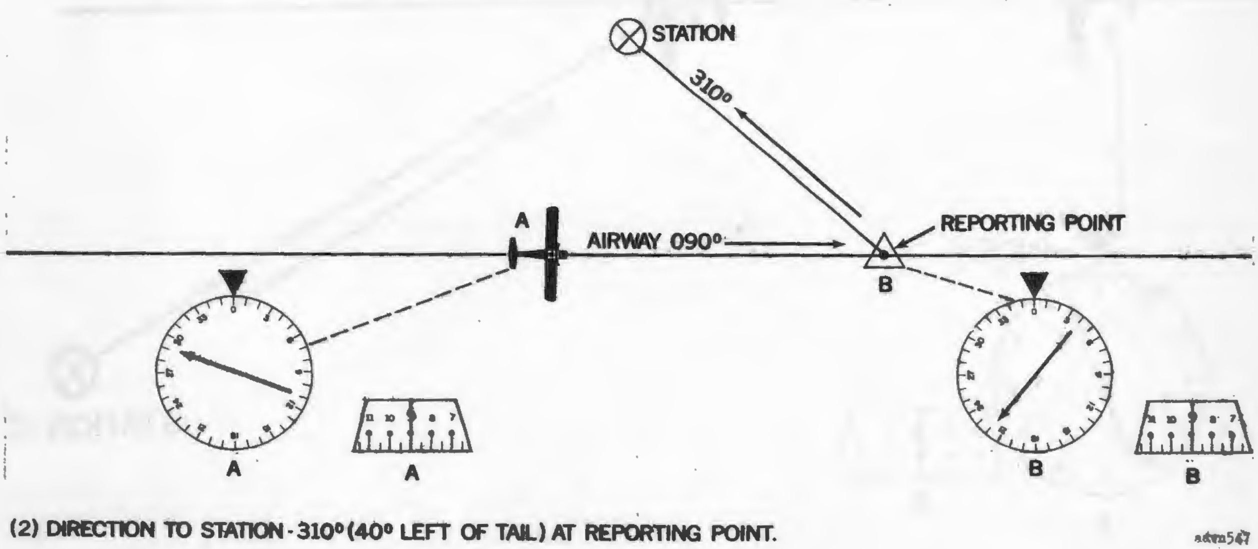
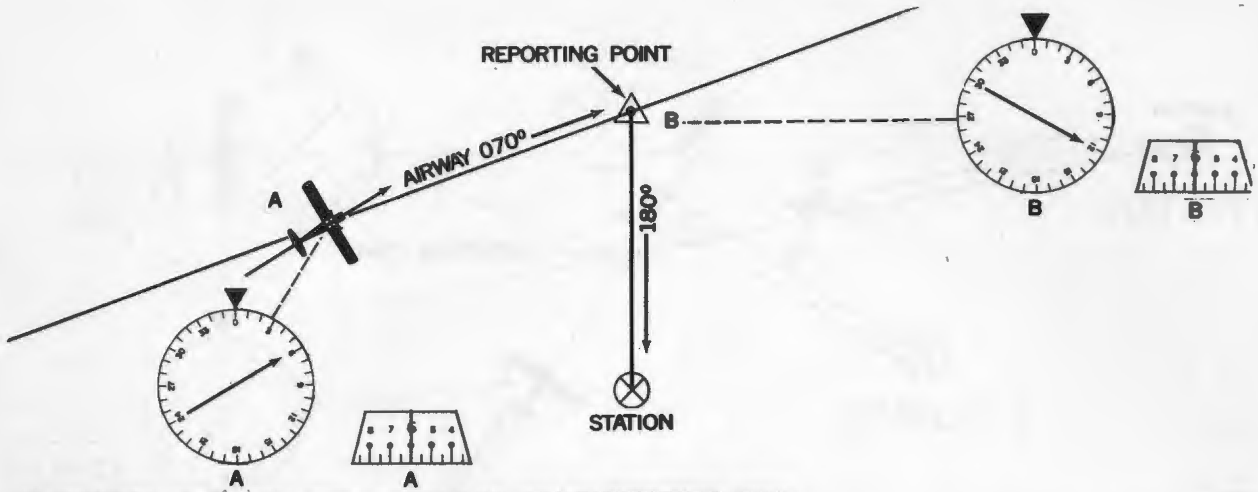


Figure 11-11②—Continued.



(3) DIRECTION TO STATION-180° (60° RIGHT OF TAIL) AT REPORTING POINT.

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Figure 11-11(3)—Continued.

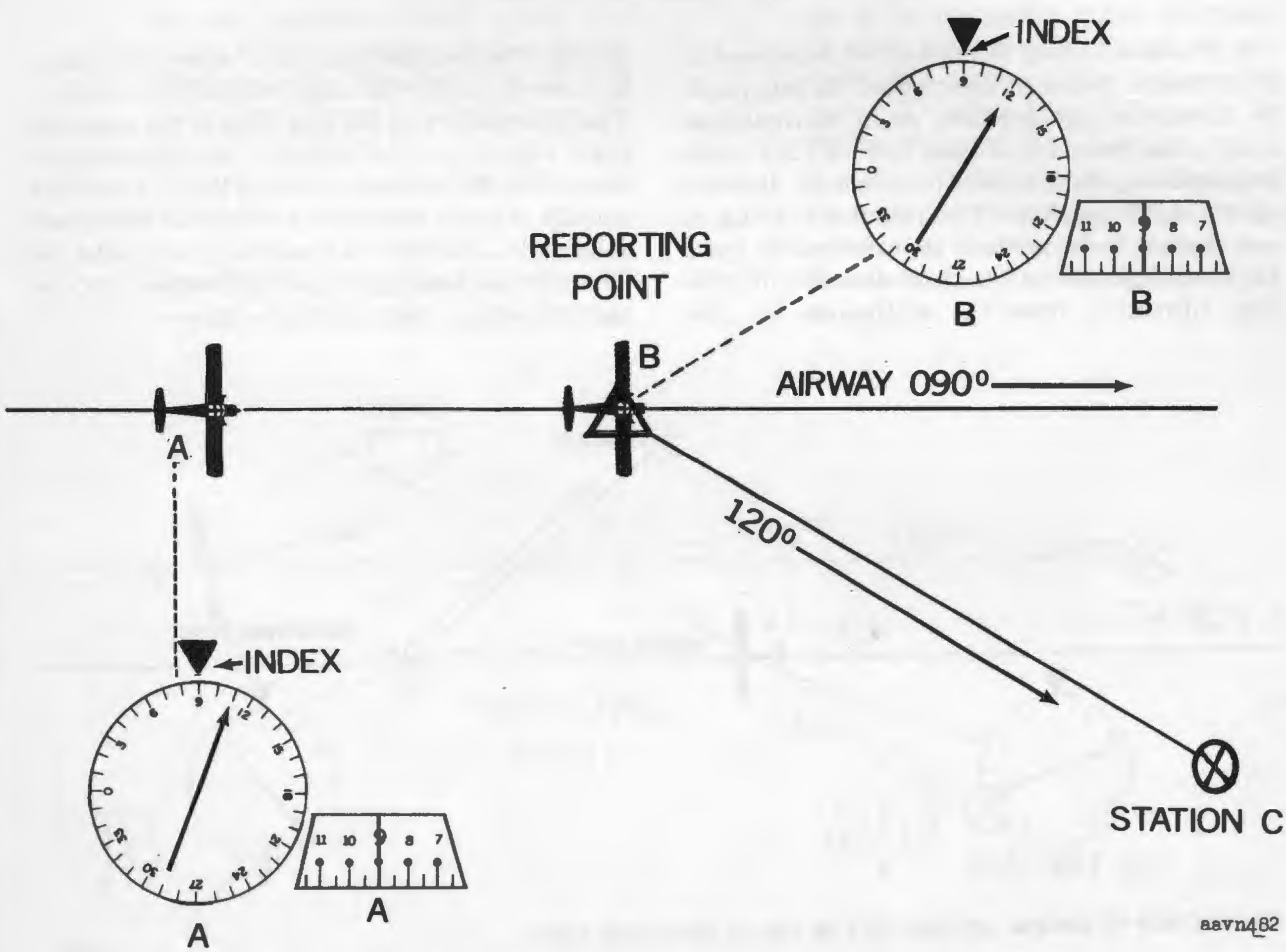

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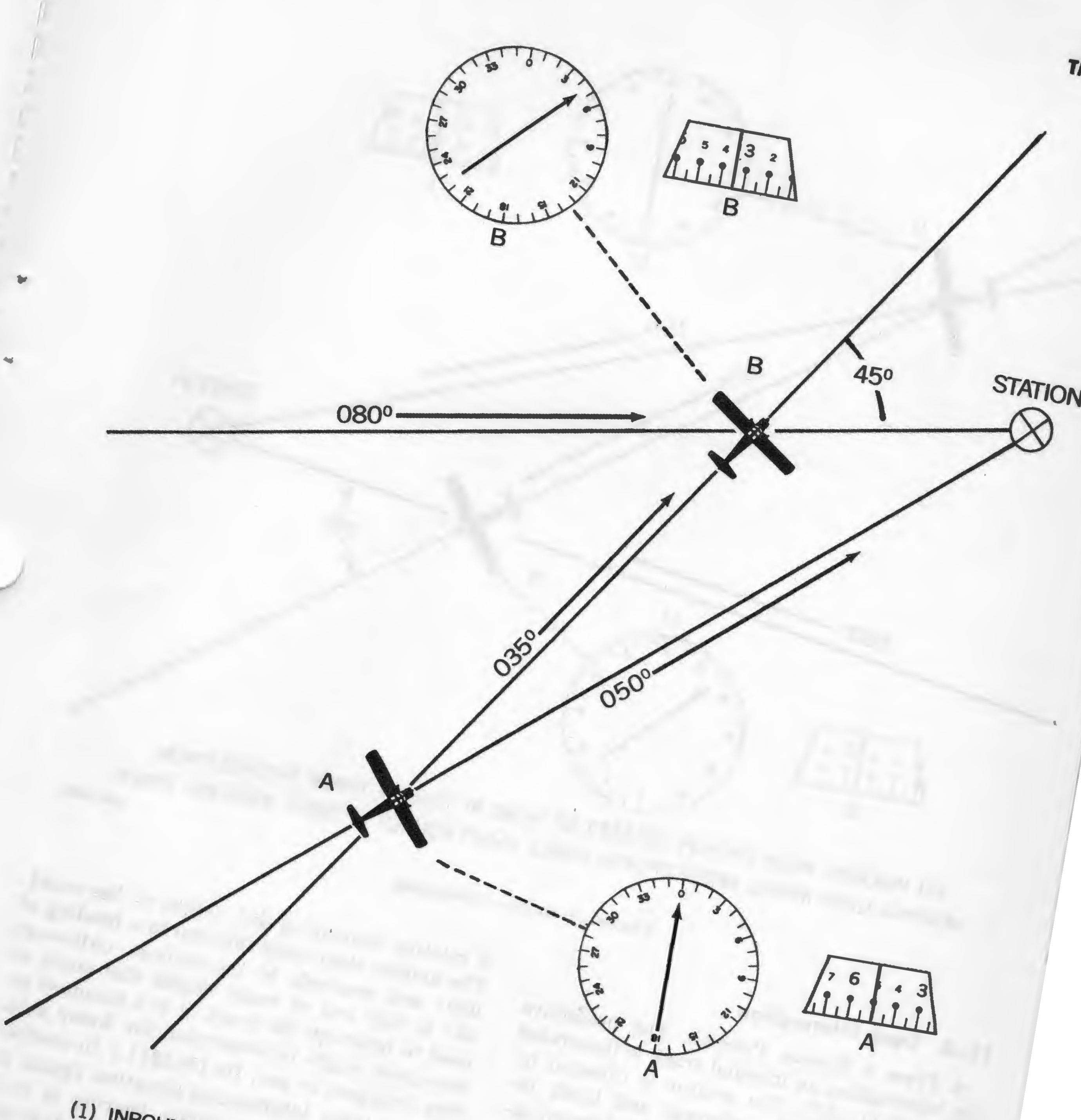
Figure 11-12. Position fixing with heading set under index (ADF).



(1) INBOUND WITH STATION 45° RIGHT OF NOSE AT TIME OF TRACK INTERCEPTION.
HEADING (035°) PLUS INTERCEPTION ANGLE (045°) EQUALS DESIRED INBOUND TRACK (080°).

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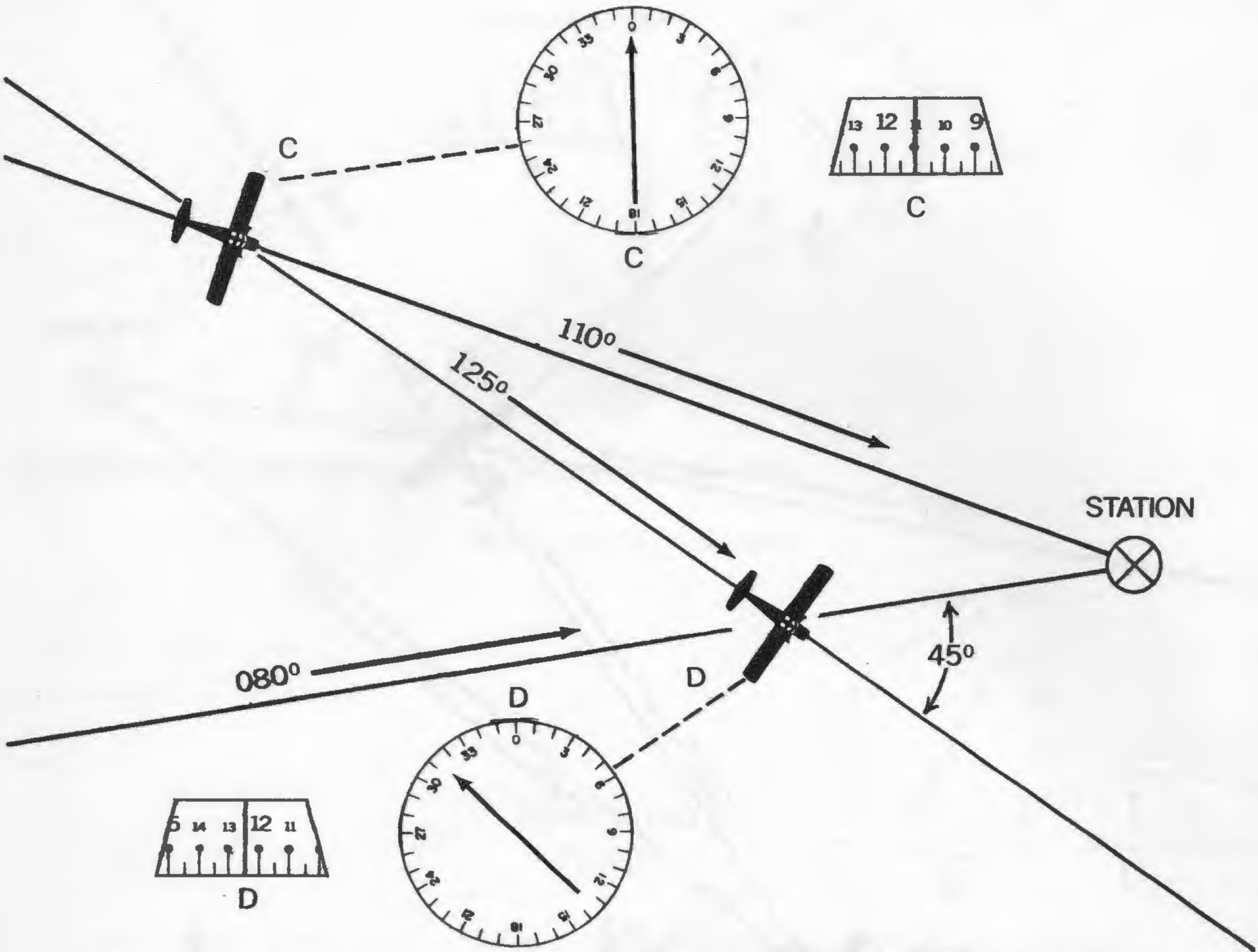
Figure 11–13①. Track interception from a known position (ADF).



(2) INBOUND WITH STATION 45° LEFT OF NOSE AT TIME OF TRACK INTERCEPTION.
HEADING (125°) MINUS INTERCEPTION ANGLE (045°) EQUALS DESIRED INBOUND TRACK.

Figure 11-13②—Continued.

11-8. Track Interception

a. From a Known Position. The procedure for intercepting an inbound track is illustrated in figure 11-13①. The aviator is directed by air traffic control to intercept and track inbound on a track of 080°. From his present inbound track of 050° (point A), he knows that he must turn left to intercept the new track at the desired angle of 45°. In this situation, the aviator turns left to a heading of 035° and flies to intercept the desired track (080°) at a 45° angle (point B). The desired interception is accomplished when the ADF indicator shows a relative bearing of 45° (right of the nose). The aviator then turns inbound to a heading of 080° and proceeds to the station. (Although 45° is only one of many angles that could be used to intercept the track, it is a standard interception angle recommended for Army aviation (see note to par. 10-10*a*(2)).) In another inbound track interception situation (point D, figure 11-13②), the relative bearing is 315° (45° left of the nose) when the station is to the left of the nose of the aircraft at the time of interception. When intercepting an outbound track (fig. 11-13③), the 45° interception angle

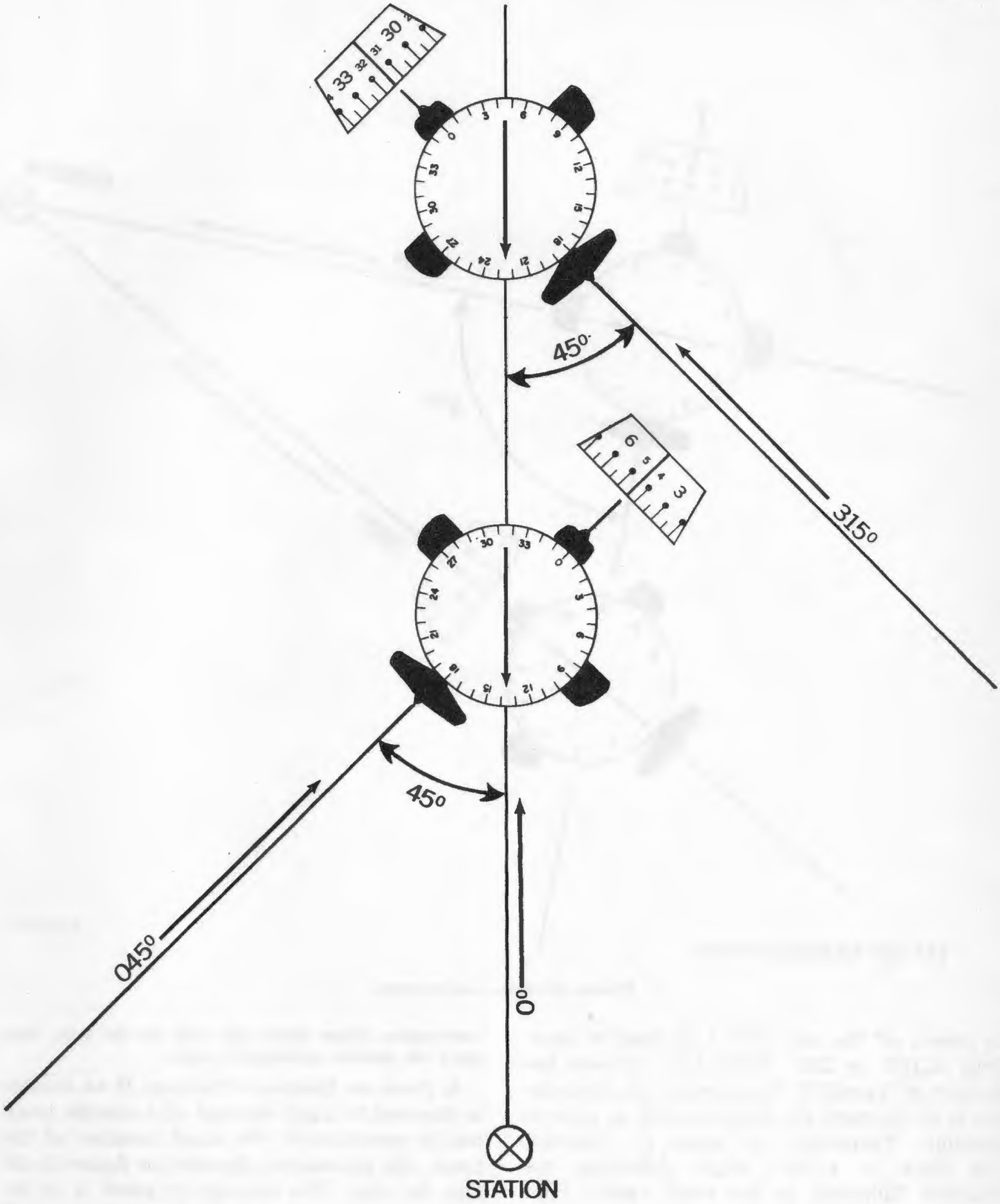


Figure 11-13(3)—Continued.

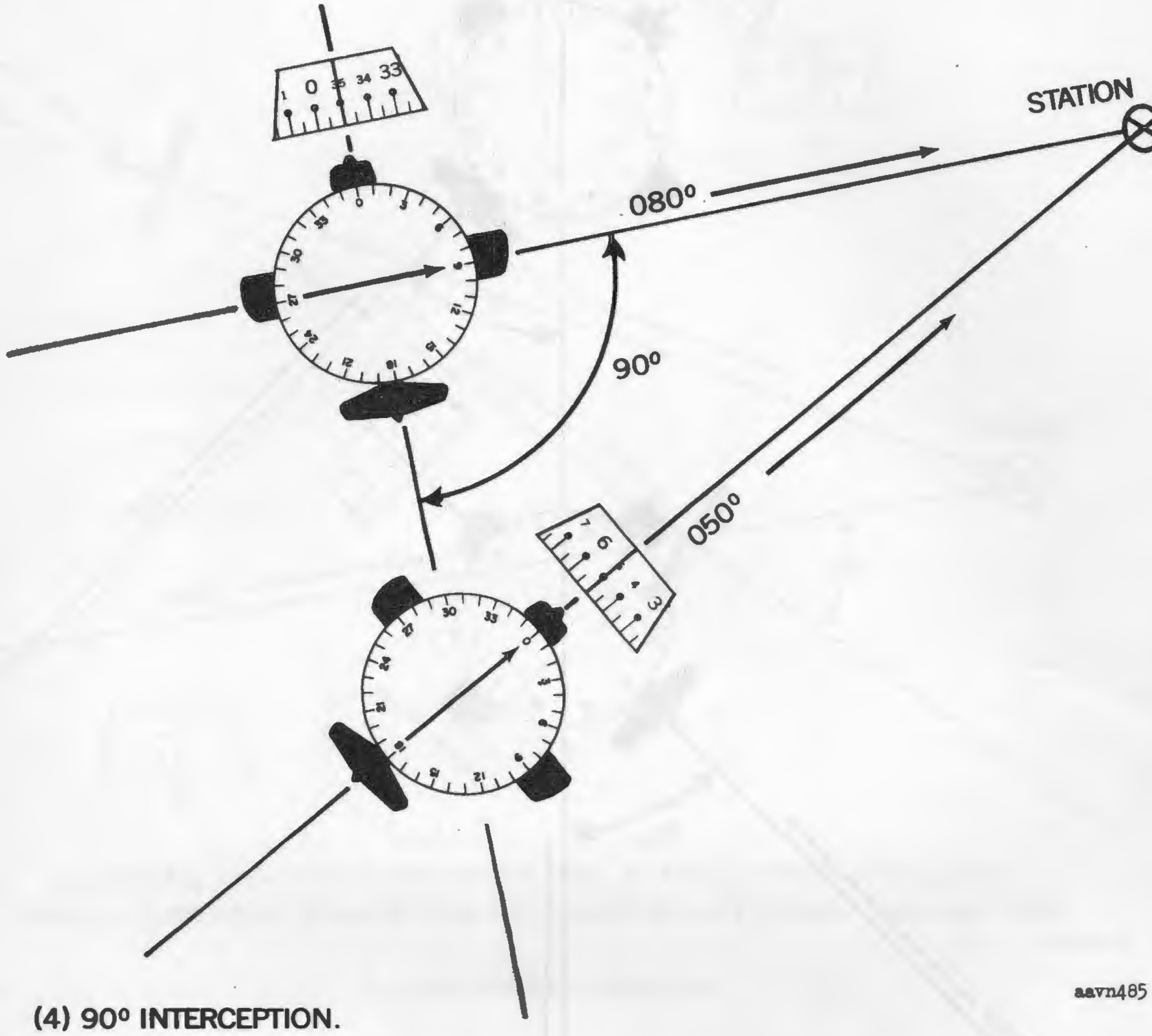


Figure 11-13④—Continued.

is shown off the tail (180°) as relative bearings of 135° or 225°. When ATC requests the aviator to "expedite" the interception, the aviator is to intercept the desired track as soon as possible. Therefore, he turns to intercept the track at a 90° angle, following the shortest flightpath to the track rather than using the standard 45° interception angle (fig. 11-13④).

Note. In all interception problems, the relative bearing read on the ADF indicator at the time of track interception (from either the nose or the tail) must equal the desired interception angle.

b. From an Unknown Position. If an aviator is directed to track inbound on a specific track but is uncertain of the exact location of the track, the procedures depicted in figure 11-14 may be used. The aircraft at point A is inbound to station X on a track of 010° according to the flight instruments. ATC directs the aviator to track inbound on a track of 075° to station Y. Although he is uncertain of his present position with respect to station Y, he can orient himself by first turning parallel to the desired track (075°) while tuning his ADF receiver to station Y. After paralleling the desired track (point B), he observes the ADF indicator is deflected to the right, he knows that the station and track are located to the right of the aircraft; if to the left, the track and station are to the left. In figure 11–14 at point C, the track is to the right. The aviator turns to a heading of 120° to intercept the desired track at the standard 45° angle.

c. Double-the-Angle Method. This procedure (fig. 11–15) for intercepting a definite track is as follows:

(1) With the ADF receiver tuned to station Z, determine the angular difference between the aircraft and the desired track. If necessary, turn parallel to the desired track to determine the angular difference. When the present position of the aircraft and the desired track are known, a turn to parallel the track may not be required.

(2) Double the angle derived in (1) above and use the product as an interception angle. At point X of figure 11–15, the angular difference of 30° produces an interception angle of 60°.

(3) Turn to a heading which will give the desired interception angle. A heading of 135° intercepts the inbound track (point Y, fig. 11–15) of 075° at the desired 60° angle.

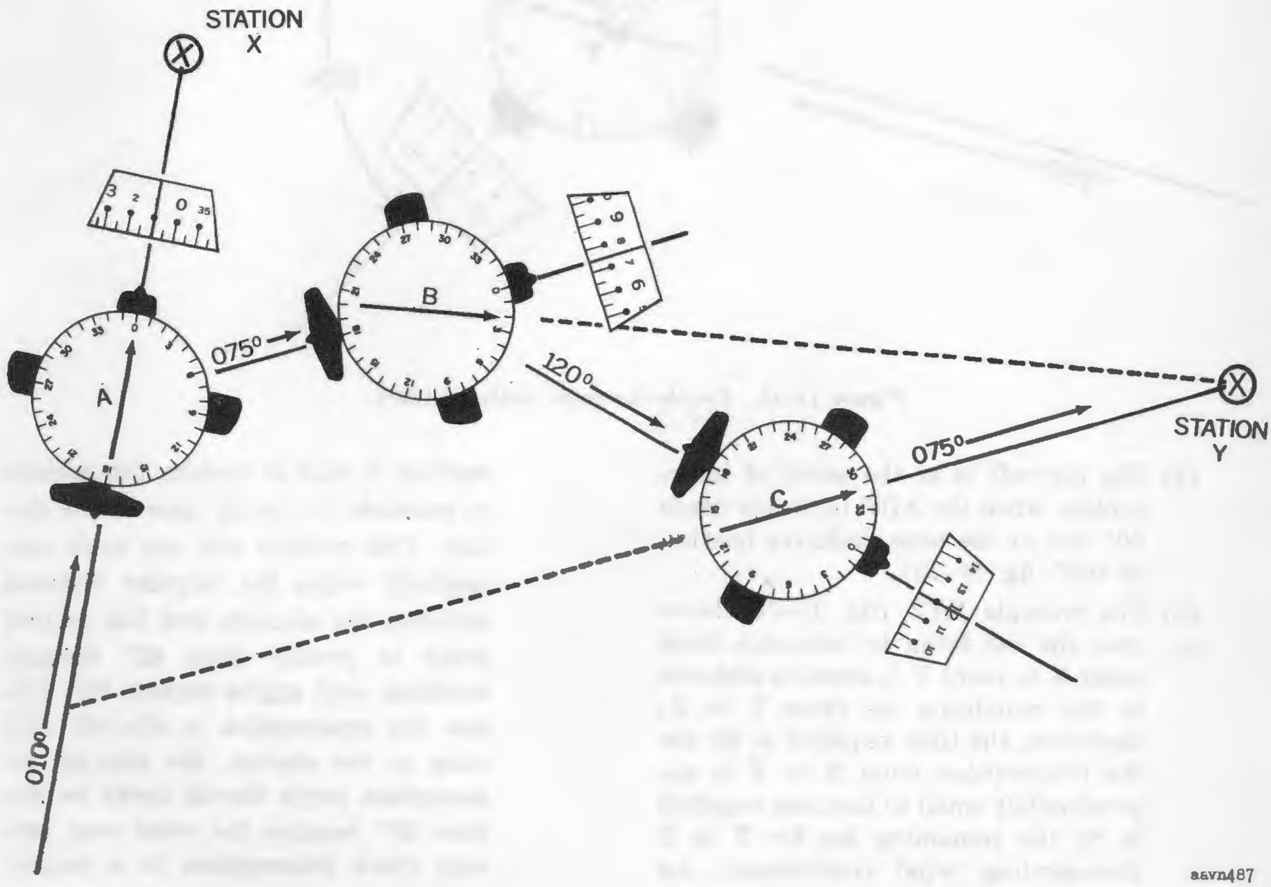


Figure 11–14. Track interception from an unknown position (ADF).

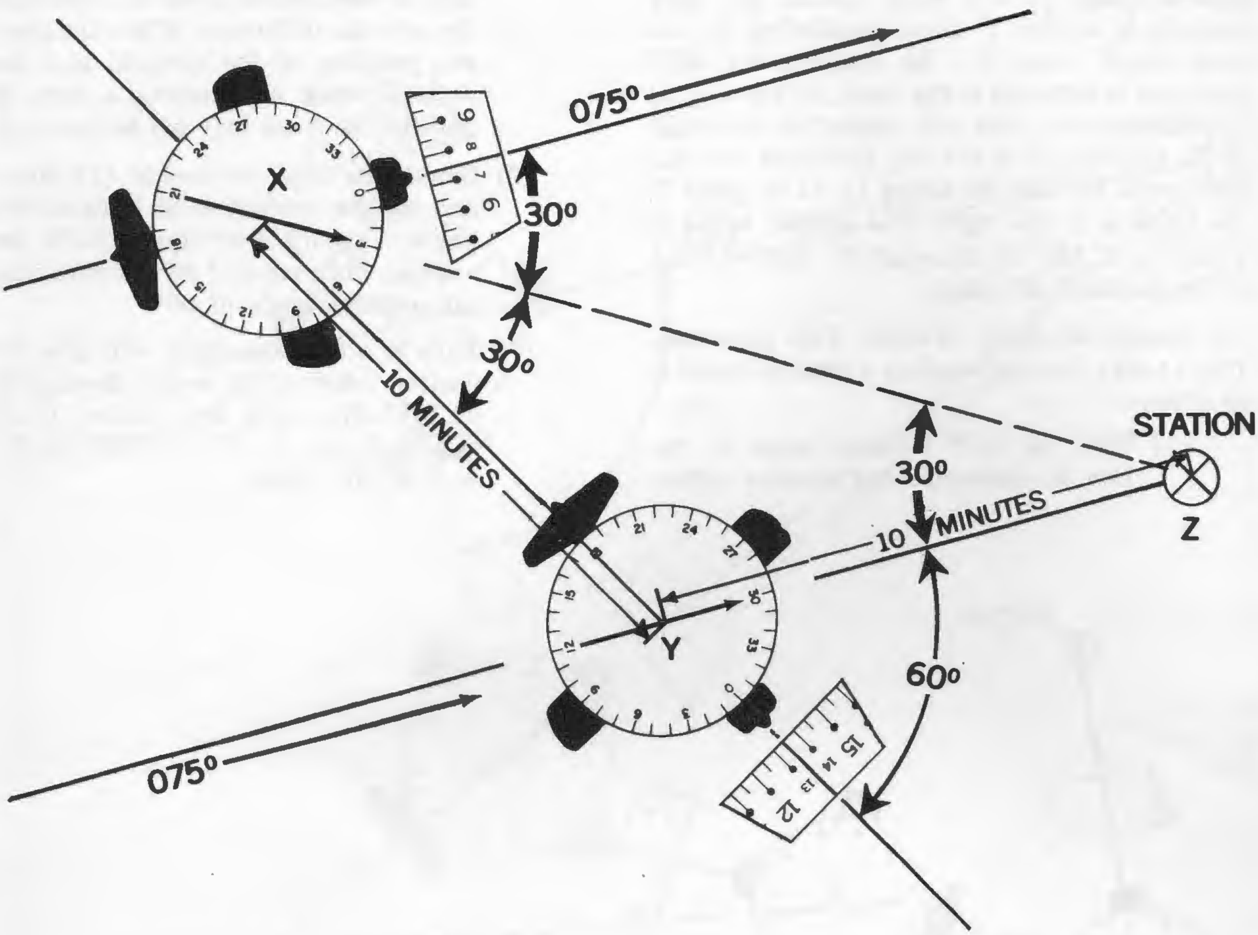


Figure 11-15. Double-the-angle method (ADF).

(4) The aircraft is at the point of interception when the ADF indicator reads 60° left of the nose (relative bearing of 300°, fig. 11-15).

(5) The triangle XYZ (fig. 11-15 shows that the leg flown to intercept from point X to point Y is equal in distance to the remaining leg from Y to Z; therefore, the time required to fly the the interception from X to Y is opproximately equal to the time required to fly the remaining leg for Y to Z disregarding wind conditions). An advantage of the double-the-angle method is that it enables the aviator to estimate his flying time to the station. This method will not work successfully when the angular distance between the aircraft and the desired track is greater than 45° because doubling such angles exceeds 90°. Unless the interception is effected very close to the station, the selected interception angle should never be less than 20° because the wind may prevent track interception in a reasonable time.

Section III. MANUAL (LOOP) OPERATION OF THE ARN-59

11-9. General

The radio compass (ARN-59) may be operated manually for navigational use with the selector switch in the LOOP position. Manual operation may be necessary when the signal or indicator readings received in the COMP position are unreliable. Navigation procedures are the same in the LOOP position as when using the COMP position; however, the azimuth needle is positioned manually by the loop drive switch to locate the null by sound. If the switch is moved to the right, the indicator arrow moves to the right (clockwise); if the switch is moved to the left, the indicator moves to the left (counterclockwise). An aural null (minimum reception) results when the plane of the loop antenna is perpendicular to a line from the station.

11-10. Orientation

Orientation procedures used in determining direction to the transmitting station are explained below.

a. Tune and identify the station in the ANT position.

b. Move the selector switch to the LOOP position.

c. Move the loop drive switch and listen to the signal. At some point the signal will fade; this is the null position. As the aviator rotates the azimuth indicator, the signal will build on each side of the null position. Ideally, the null should be no more than 5° wide on the face of the ADF indicator. For example, if the signal begins to fade when the indicator reaches 120° and immediately builds up again at 125°, the null is reasonably narrow. Normally, a well defined null can be obtained by increasing the volume. After the null is definitely located, the azimuth indicator needle points toward the station but the indication is ambiguous; i.e., the correct relative bearing may be at either end of the indicator needle. For example, when the arrow points to 120° the relative bearing to the station may be at either 120° or its reciprocal, 300°.

d. To resolve the ambiguity, rotate the loop manually until the azimuth indicator needle points to 090° or 270°. Turn the aircraft right or left until the signal, which increased in strength as the azimuth indicator needle was rotated again fades to a null. The station is then either to the left or to the right of the aircraft. Maintain a constant heading until the aircraft flies out of the null; depress the loop drive switch again and relocate the null. If the loop is rotated to the right to relocate the null, the station is to the right (clockwise) of the aircraft; if rotated to the left to relocate the null, the station is to the left of the aircraft. Procedures for resolving ambiguity are illustrated in figure 11-16.

(1) At point A, the aviator has located an aural null on a heading of 270°, with the azimuth indicator in the 0°-180° position. The station is either directly ahead of or behind the aircraft.

(2) At point B, the aviator rotates the azimuth indicator needle (loop) to the 090°-270° (wingtip) position, which causes the signal to rebuild.

(3) At point C, the aircraft is turned until the null reappears at the wingtip position (heading 0°), indicating the station is either to the left or right of the aircraft. The aviator flies this heading for a short time and the signal rebuilds. This indicates that the aircraft has flown out of the wingtip null.

(4) The null is relocated at point D by rotating the azimuth indicator (loop) 10° clockwise to 100°. Therefore, the station is at point X 100° right of the aircraft heading of 0°.

11-11. Homing

a. Homing to a station with the ARN-59 set operating in the LOOP position is accomplished by first locating the station (par. 11-10) and then turning the aircraft until the null is on the nose position. If the aircraft drifts out of the null position, the aviator determines the direction of drift by rotating the loop left or right

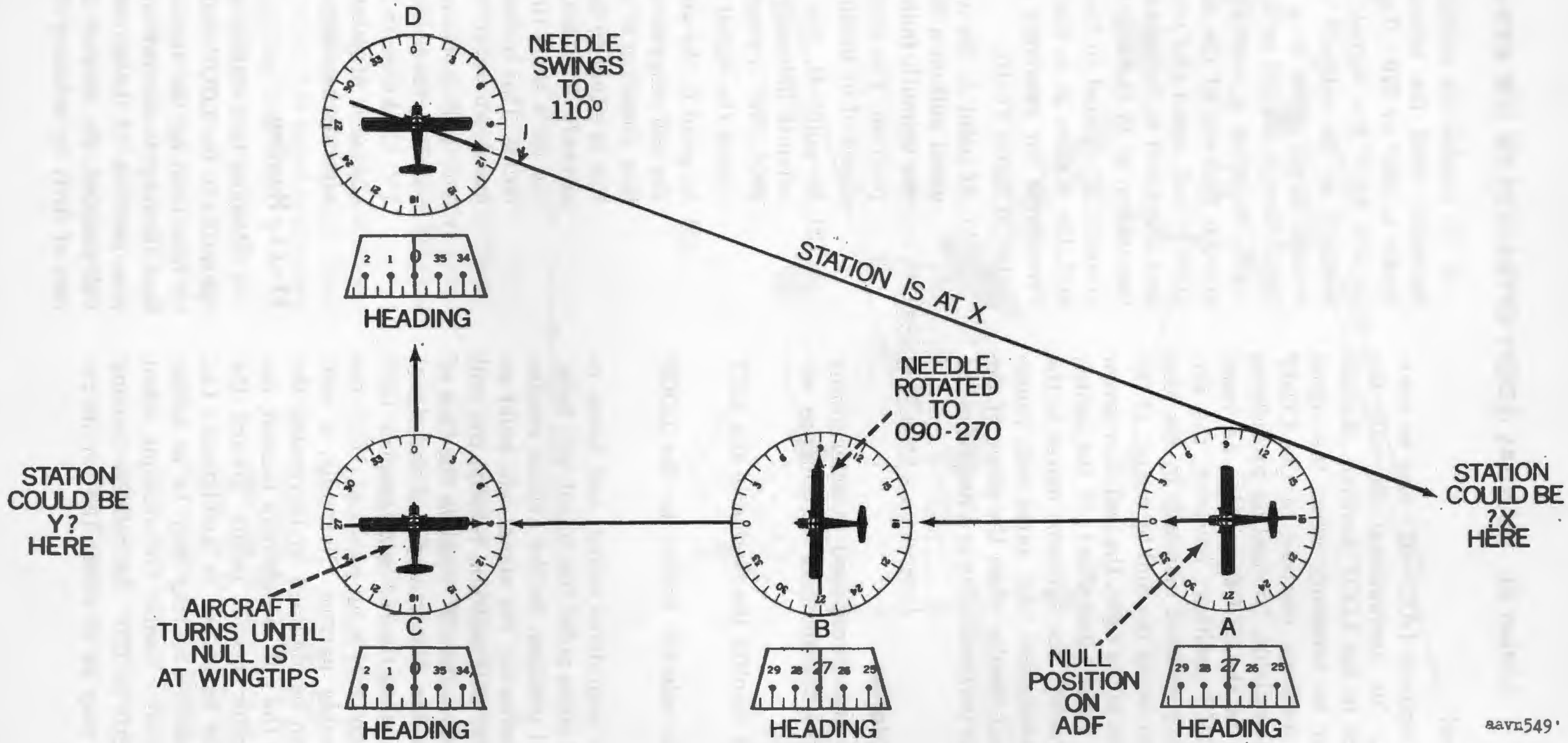


Figure 11-16. Resolving ambiguity (loop).

to relocate the null (par. 11–10*d*). The aviator then turns the aircraft until the null is again on the nose position and repeats the procedure until in the immediate vicinity of the station.

b. To determine arrival over the station—

(1) Estimate the time of arrival accurately.

(2) Prior to arrival, set the azimuth indicator on the wingtip position (090°–270°) with the loop drive switch to receive a strong signal.

(3) As the aircraft flies over the station (or abeam the station), a sharp null of short duration will be detected. The time that this null occurs is the station passage time.

11–12. Tracking

Aural null tracking procedures are identical with those used for ADF tracking except that the aviator must manually rotate the loop to determine the null position and relative bearing. In tracking toward or away from a station (null at 0° or 180°), drift is indicated by movement of the null from the nose or tail position. For example, if the aircraft drifts off course to the left, a 20° correction may be made to reintercept the track. Procedures are as follows:

a. Using the heading indicator, turn 20° right to intercept the track. Set the indicator (loop) to 20° left of the nose.

b. Continue on the same heading until the null reappears at this new setting (20° left of nose). Aircraft is back on desired track.

c. Turn back toward original heading by 10° and relocate the null (10° left of nose).

d. If original correction of 10° is excessive or inadequate, make additional corrections of 5° (par. 11–6).

11–13. Time and Distance

In remote areas, the aviator may, if necessary, estimate the time or distance to a radio beacon with the ARN–59 by following the procedure described in paragraph 10–11*c*. The bearing change during flight is observed on the ADF indicator. Time and distance estimates with the ARN–59 are less reliable than with the ARN–30.

Section IV. DIRECTION FINDING (DF) STATIONS

11–14. General

A wide network of DF stations exists in this country and overseas. Many control towers are equipped with DF radios operating in the VHF and UHF frequency bands. When navigational radios are inoperative or the aviator is lost, a nearby DF station can be requested to provide the aviator with a DF steer.

11–15. Station Capabilities

DF stations provide steers for aircraft on selected VHF and UHF channels. Equipment is available for operation during normal working hours at most stations and usually on a 5-minute notice at other times. (Consult current navigation publications for this data.) This equipment has an effective line-of-sight range of approximately 100 miles, although greater distances can be obtained when the signal strength of the aircraft's radio transmitter and its altitude are ideal. The emergency frequencies of 121.5 and 243.0 mc can be used when an emergency occurs.

11–16. Typical DF Steer

The following is a typical DF homing procedure:

a. Aviator tunes a specific DF frequency using the ARC–55 or equivalent radio.

b. Aviator transmits (for example), "Cairns tower, Army 75088, requests practice steer (or emergency steer) over."

c. DF station replies, "Army 75088, Cairns tower, transmit for steer, over."

d. Aviator replies, "Army 088, Roger." (Aviator then depresses the microphone button for about 10 seconds.)

e. DF station replies, "Army 088, steer 180° to Cairns, over."

f. Aviator acknowledges, "Army 088, Roger, out."

g. Subsequent corrections to the DF steer can be provided as necessary.

CHAPTER 12

RADIO MAGNETIC INDICATOR (RMI)

12-1. Components

A radio magnetic indicator (RMI) (fig. 12-1) consists of a compass card, heading index, and two arrow pointers. Indicator readings enable the aviator to determine simultaneously (1) the present magnetic heading of the aircraft, (2) the direction to and from the station to which the number 1 pointer receiver is tuned, and (3) the direction to and from the station to which the number 2 pointer receiver is tuned.

a. Compass Card. The compass card is actuated by the aircraft's compass system; it is a remote indicator for a compass system (explained in TM 1-215). When working properly, the card shows the correct magnetic heading under the index at all times.

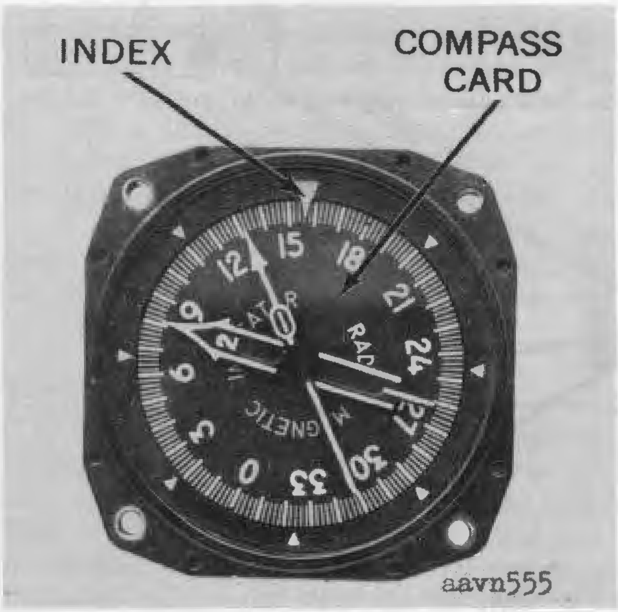


Figure 12-1. RMI components.

Note. Failure to synchronize the compass card correctly with the magnetic compass has been a contributing factor in several aircraft accidents.

b. Number 1 and 2 Arrow Pointers. These two indicator arrows are actuated by VOR or ADF radio receivers. Each arrow is capable of indicating the direction to a VOR station or to a low/medium frequency (L/MF) nondirectional beacon, depending on which receiver has been coupled with the indicator. In Army aircraft there are several possible coupling arrangements. By using selector switches, either the number 1 or number 2 arrow may be coupled to the VOR or the ADF receiver. Some aircraft have dual VOR or dual ADF receivers which permit tuning of two VOR's or nondirectional beacons simultaneously, with directions of both stations shown simultaneously on the RMI. Information on coupling arrangements for specific aircraft types and models can be found on each aircraft operator's manual. In this chapter, reference to *station number 1* and *station number 2* applies equally to the VOR or the L/MF station. RMI flight procedures are the same for either type facility (except during a compass system failure (par. 12-6)).

12-2. Orientation

a. Using the RMI an aviator can orient himself instantly with respect to a station. When the receiver is properly tuned to a station, the head of the arrow indicates the magnetic direction to the station. The tail of the arrow shows the radial on which the aircraft is located. The readings on the RMI face ((A), fig. 12-2) show an aircraft on a heading of 280° located on the 120° radial from station number 1 and the 240° radial of station number 2. The aviator uses a navigation chart to visualize a specific radial from a station. (B) of figure

12-2 presents graphically the readings shown on the RMI face in (A) of figure 12-2. The orientation consists of two procedures:

(1) Tune and identify a station.

(2) Under the tail of the appropriate arrow, read the radial on which the aircraft is located.

Note. For convenience, the concept of a radial used for VOR flight procedures (ch. 10) may be applied to ADF flight procedures. That is, a radial may be considered as a magnetic bearing *from* the station.

b. To fly directly to a station, the aviator turns the aircraft toward the indicator arrow pointer. As the aircraft turns, both the compass card and the pointer rotate toward the heading index. When the head of the pointer reaches the heading index, the aircraft is headed directly toward the station. The RMI,

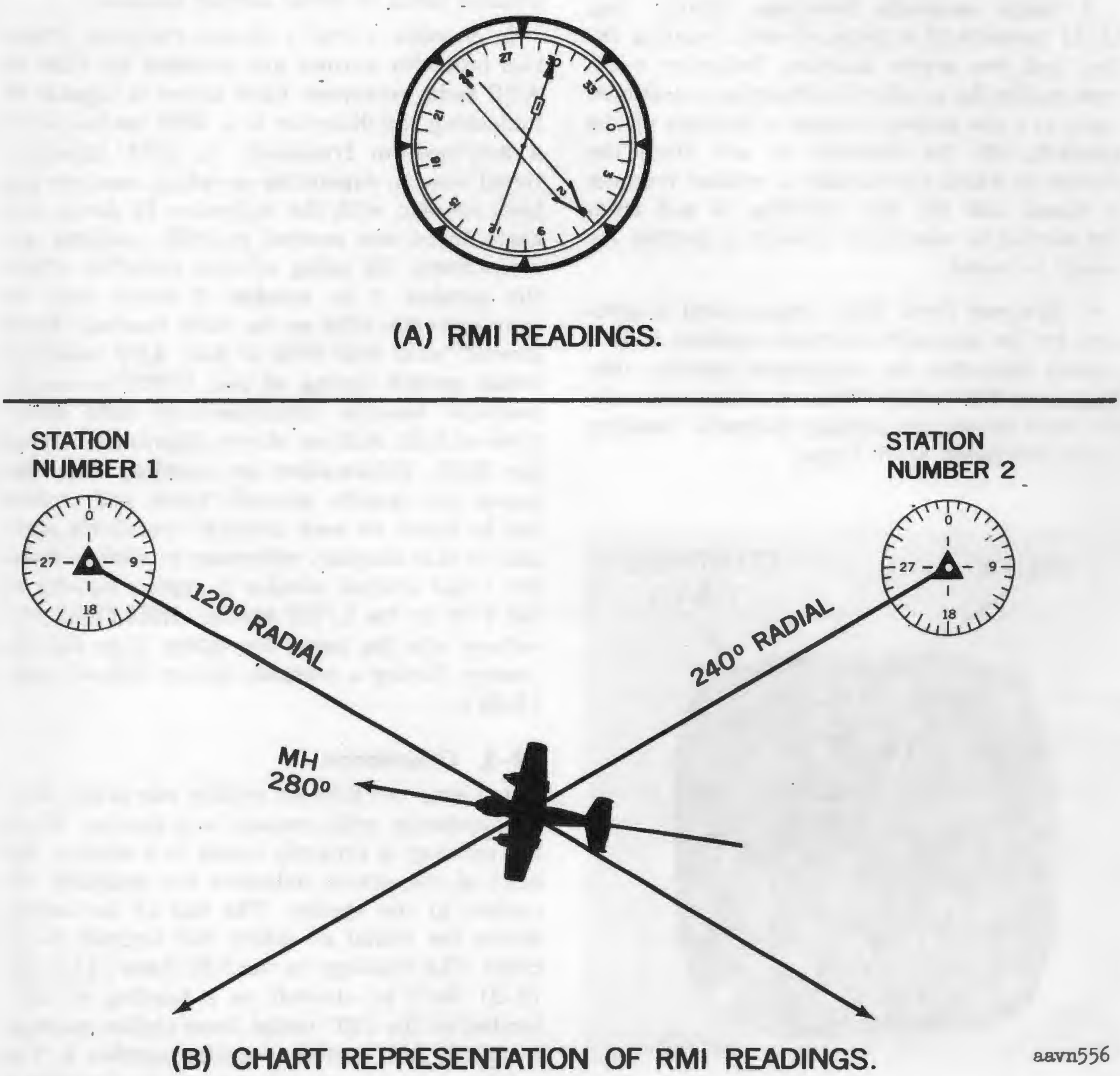


Figure 12-2. Orientation (RMI).

when operating properly, always shows the magnetic direction to a station.

12-3. Tracking

a. Inbound. When tracking inbound with the RMI, the desired magnetic course to a station should appear under the appropriate arrowhead. Figure 12-3 illustrates a tracking sequence using the same tracking techniques discussed in chapters 10 and 11.

(1) *Point A.* Aircraft is on course with no drift correction. Heading is 0°, RMI indicates 0° (180° radial).

(2) *Point B.* Left crosswind blows aircraft off course 5° to the right. Heading is still 0°, but RMI is now indicating 355° (175° radial).

(3) *Point C.* Aircraft turns left 20° toward the intended course (heading 340°). This heading is held until back on course (point D), at which time the RMI indicates 0° (180° radial).

(4) *Point E.* After returning to intended track, aircraft turns 10° right to a heading of 350°, allowing 10° drift correction for wind effect. RMI still indicates the course of 0° (180° radial).

b. Outbound. While tracking outbound the aviator observes the tail of the arrow to determine whether he is on the correct radial or has drifted off course. When using either type of facility the aviator can consider the tail of the RMI needle as indicating the radial on which the aircraft is located. Figure 12-4 illustrates an outbound tracking sequence employing the initial correction of 30° used for slow helicopters (chs. 10 and 11).

12-4. Position Fixing

a. (A) of figure 12-5 illustrates a navigation chart presentation of a VOR intersection as it normally is published. Intersections using VOR radials are published with the radial passing through the intersection. Arrival over these intersections is easily identified with the RMI. (B) of figure 12-5 illustrates the RMI reading using the VOR intersection as a position fix.

(1) The number 1 arrow is pointing to the VOR station ahead of the aircraft (station 1). This station is being used to maintain the airway track.

(2) The aircraft heading necessary to maintain this airway track is read under the RMI index.

(3) The number 2 arrow is pointing to an off-airways station (station 2) used to fix the intersection. Since the navigation chart shows the radial from the station, this radial (305°) appears under the tail of the number 2 arrow when the aircraft arrives at the intersection.

Note. If both station number 1 and number 2 are VOR stations, and if the aircraft is equipped with only one VOR receiver, then the aviator maintains the airway track by flying a predetermined heading and tunes the receiver to the off-airways station to fix the intersection.

b. Figure 12-6 illustrates a situation similar to the one in figure 12-5, but the intersection is based on an L/MF facility. Therefore, the bearing from the intersection to the station, rather than a radial (direction from the station), is shown. The arrowhead is read to determine the magnetic bearing to the station. The aircraft is maintaining a heading of 305° to make good a track of 295°. Regardless of the aircraft heading, arrival at the intersection occurs when the number 2 arrow points to the desired bearing (235° in fig. 12-6).

12-5. Track Interception

a. If an aviator, using the RMI, is directed to intercept a track other than the one he is presently following or crossing, he visualizes the position of the desired track with reference to the radial on which the aircraft is presently located.

b. A of figure 12-7 shows the RMI indication with the aircraft located on the 300° radial on a heading of 020°. If the aviator is instructed to intercept and track outbound on the 270° radial, he will—

(1) Determine his present location from the RMI face (300° radial).

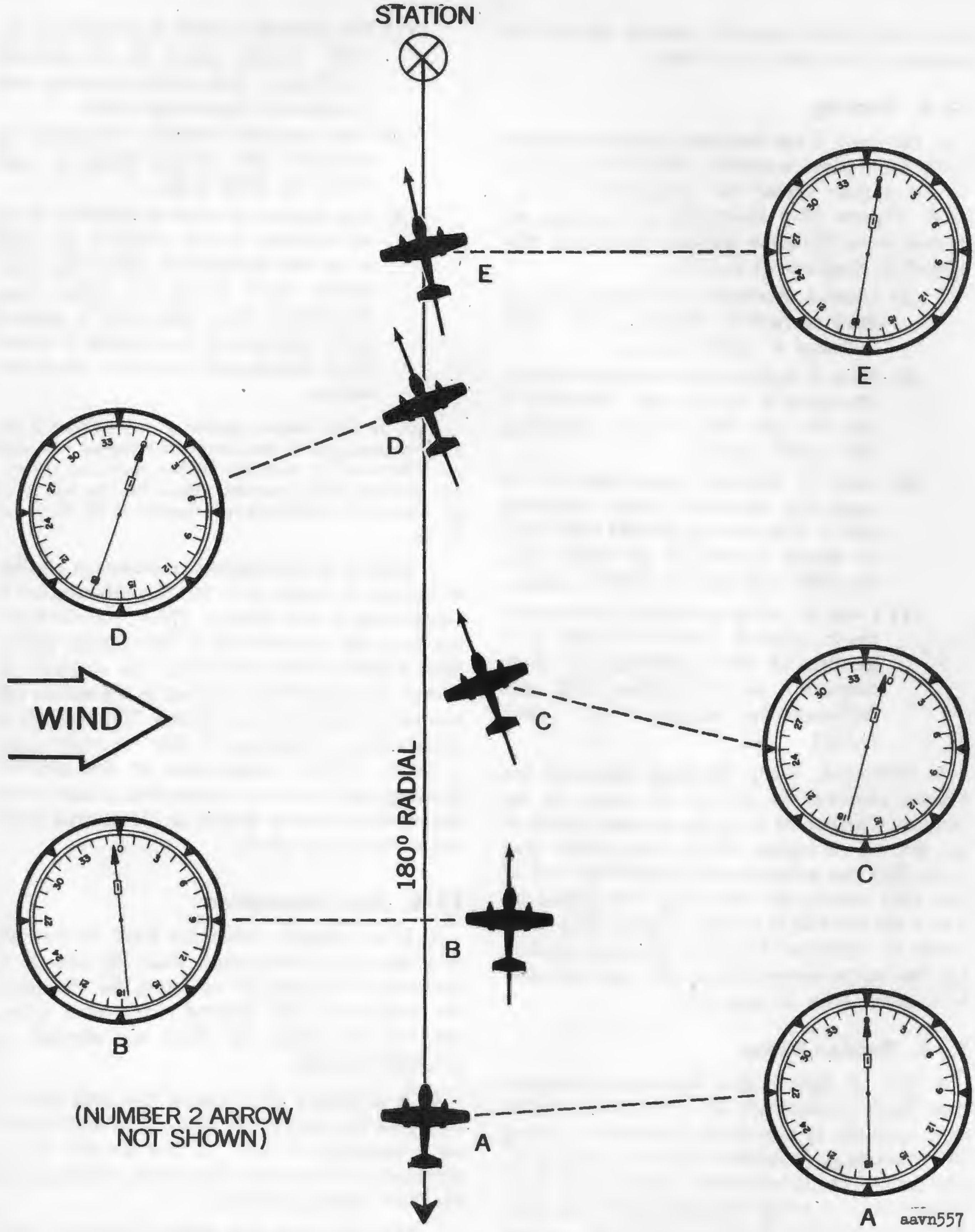


Figure 12-3. Tracking inbound (RMI).

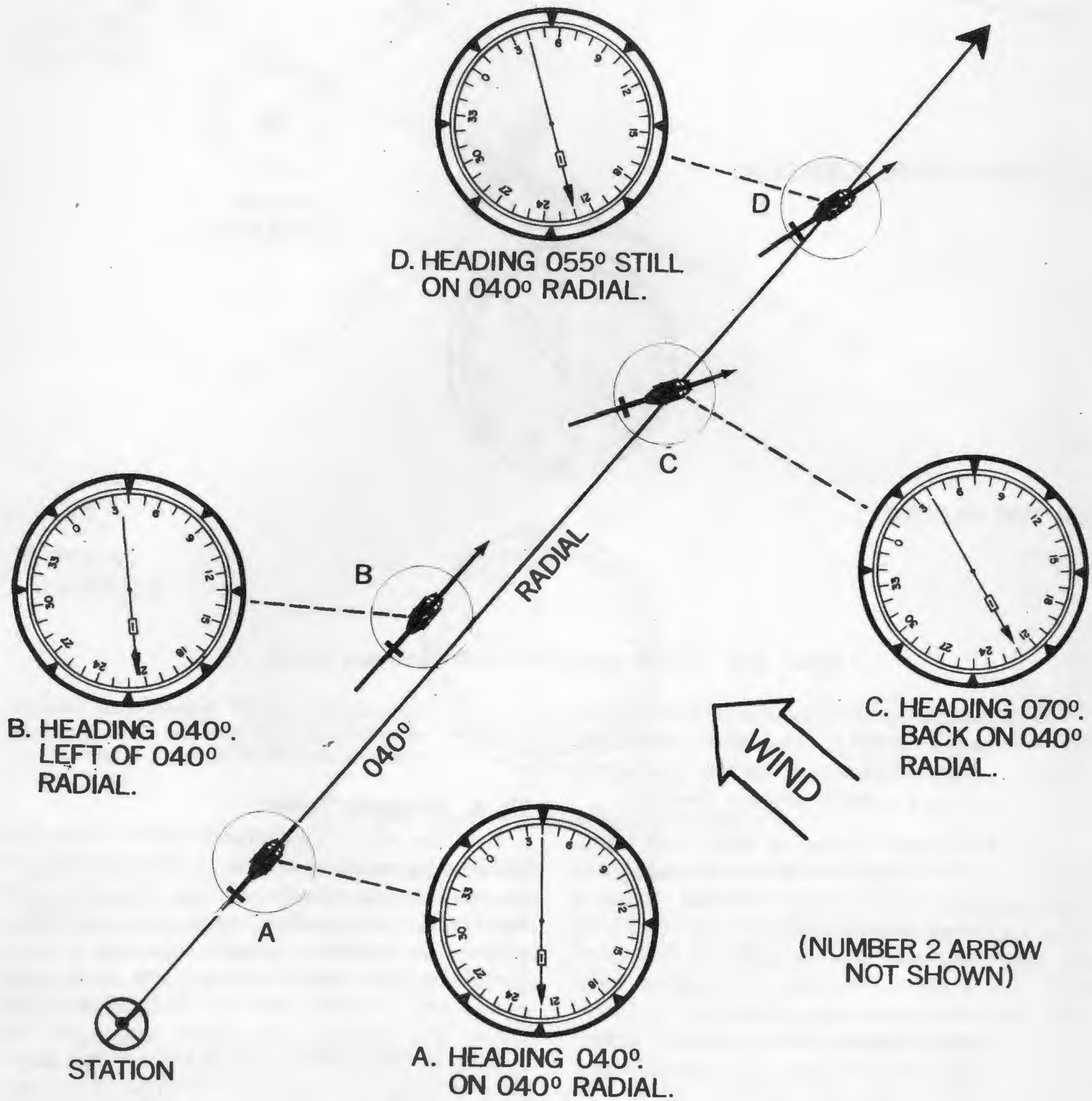


Figure 12-4. Tracking outbound (RMI).

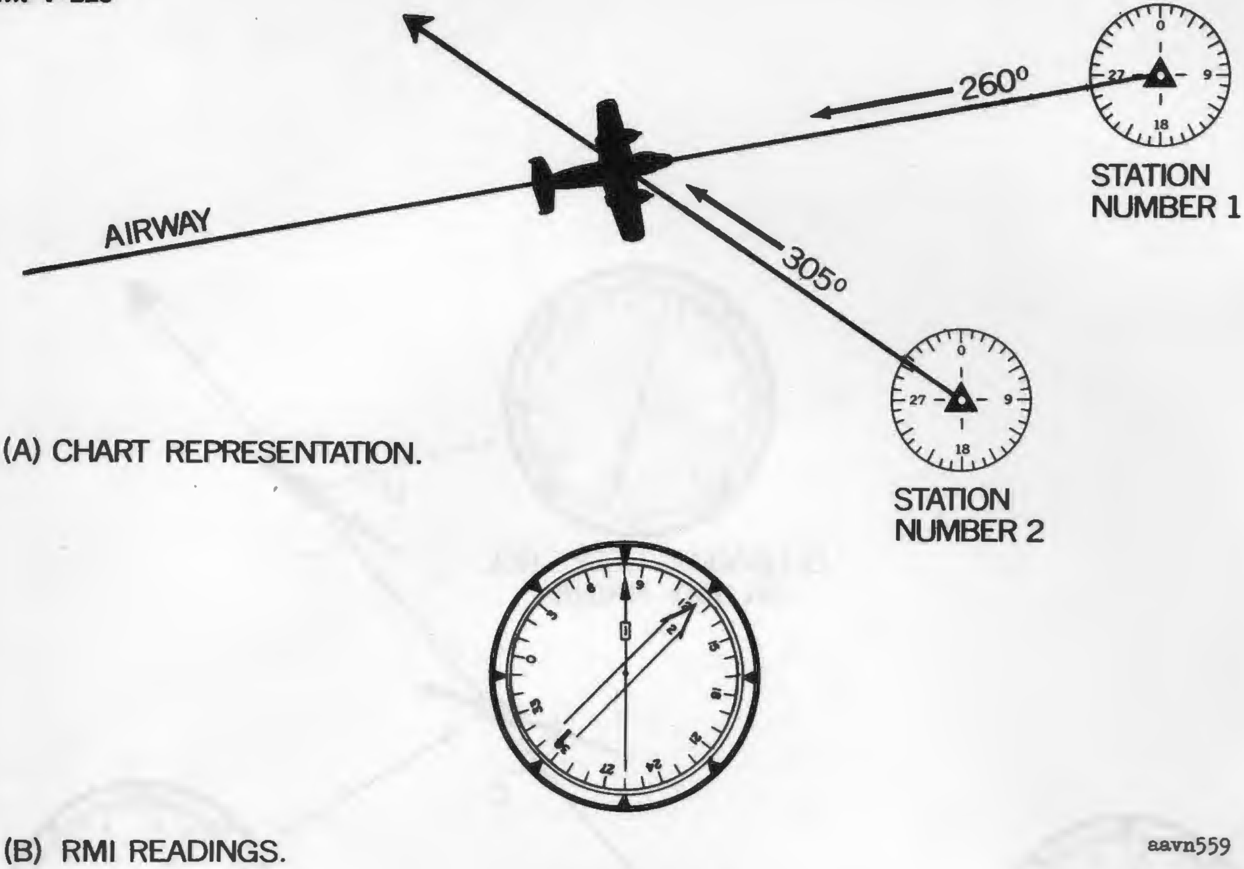


Figure 12-5. Position fixing using VOR intersection (RMI).

(2) Determine the location of the desired radial (270°). The 270° radial is counterclockwise from 300° and south of the aircraft's present position.

(3) Determine a heading which will intercept the desired radial at a reasonable angle while flying outbound. Using a standard interception angle of 45°, he will turn to a heading of 225° and maintain the desired heading until interception (B, figure 12-7). Interception occurs when the RMI arrow (tail end) indicates the desired radial (270°) (C, fig. 12-7).

Note. Surrounding the face of the RMI compass card are tick marks at 45° intervals. These marks assist the aviator in determining 45° and 90° interceptions (inbound or outbound), and also aid in determining when the aircraft is abeam a station.

12-6. Compass Failure

a. If the aircraft's compass system fails, the heading information shown under the RMI index will be unreliable. If the compass card stops and remains fixed on a given heading, subsequent heading changes will not be reflected by the card. Another type of failure causes the compass card to drift (float). In either type failure, the aviator must rely on supplementary directional gyros or the magnetic compass (depending on type of equipment installed in the aircraft) for heading information.

b. The RMI arrows will continue to operate

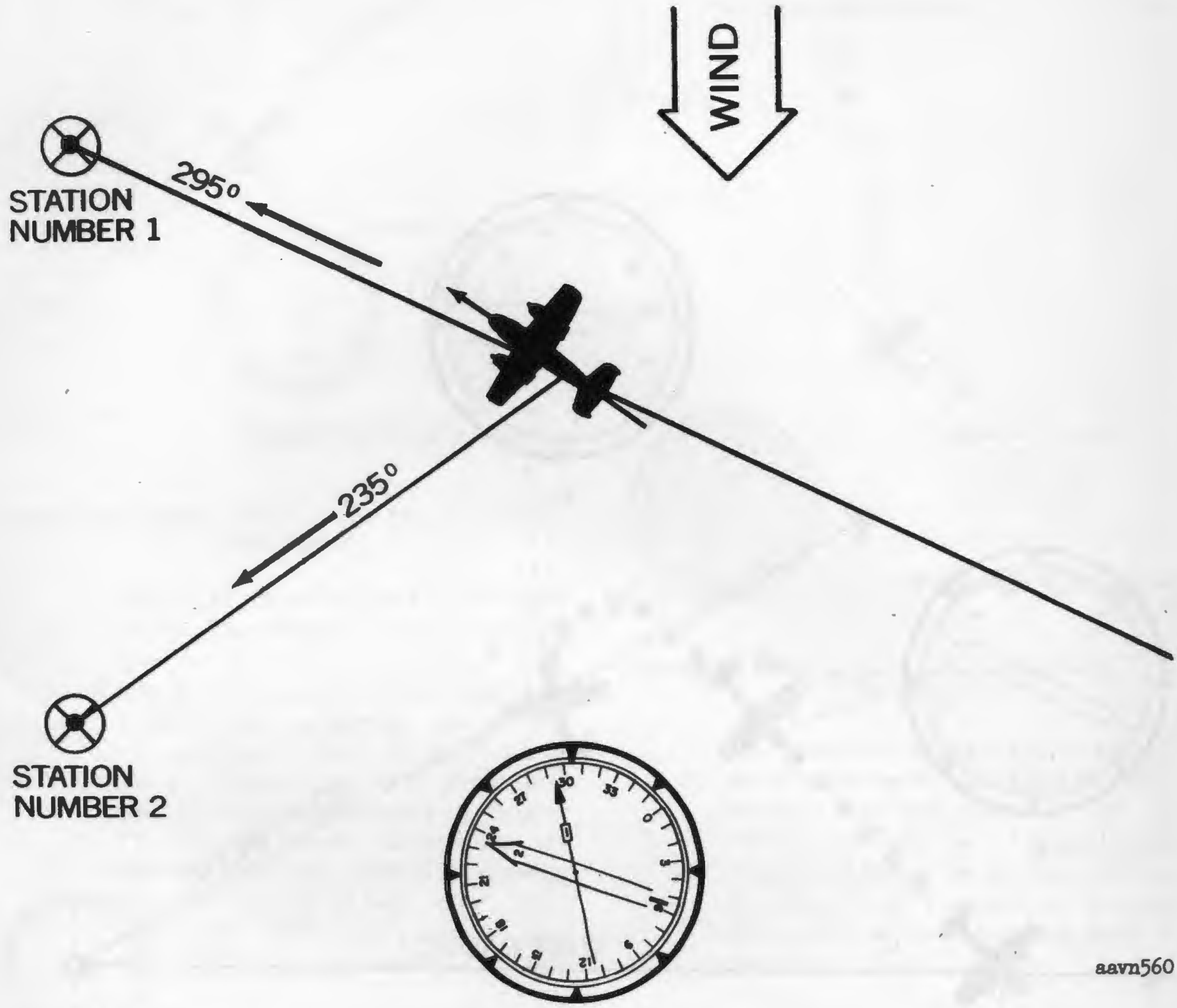


Figure 12-6. Position fixing using ADF station (RMI).

regardless of compass failure as long as the radio signals and instrument relay circuits are operating properly. However, the arrow reaction when coupled with a VOR receiver is different from the reaction when coupled with an ADF receiver.

(1) If the pointer arrow (number 1 or 2) is coupled with a VOR receiver, the arrow continues to indicate the correct magnetic bearing to the VOR station, but an incorrect heading appears under the index. The aviator can continue to read the correct radial under the tail of the arrow and the correct direction to the station under the head of the arrow (fig. 12-8). The magnetic compass can be used to determine the correct heading.

(2) If either arrow is coupled with the ADF receiver, that arrow will point to the L/MF station and indicate a bearing relative to the heading under the

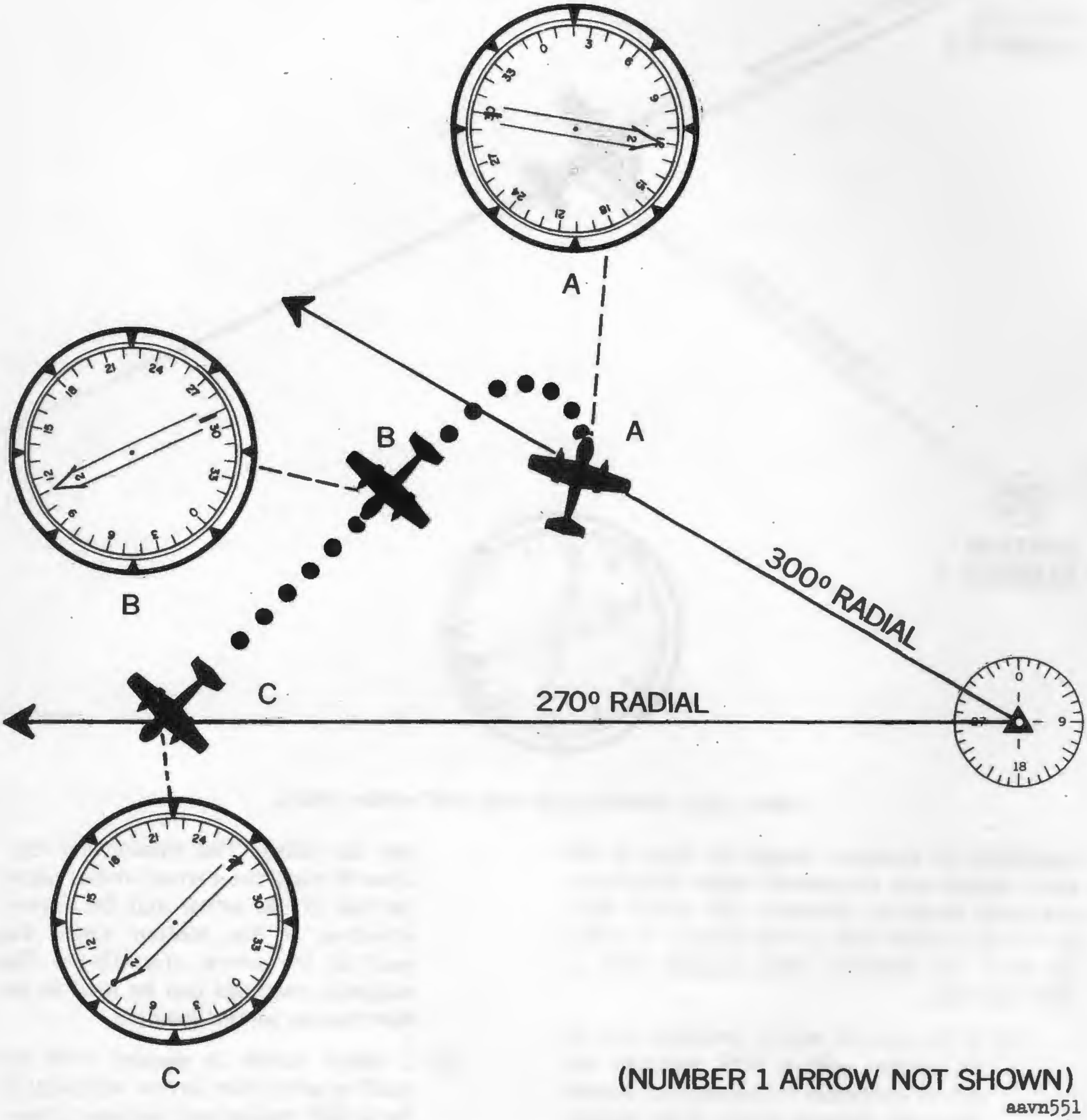


Figure 12-7. RMI readings during track interception.

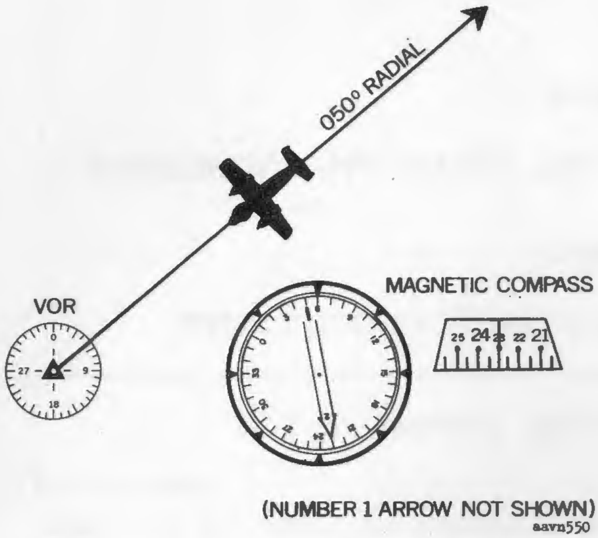


Figure 12-8. RMI compass failure (receiver tuned to VOR station).

index (30° right of heading in figure 12-9). The magnetic compass can be used to determine the correct heading. If the compass failure results in a fixed card (*a* above), the aviator can continue to read the ADF arrow using relative bearing procedures similar to those discussed in chapter 11. The tick marks surrounding the RMI face are very useful in showing relative bearings of 045°, 090°, 135°, 180°, 225°, 270°, 315°, and 0° (fig. 12-9). If the compass card is drifting

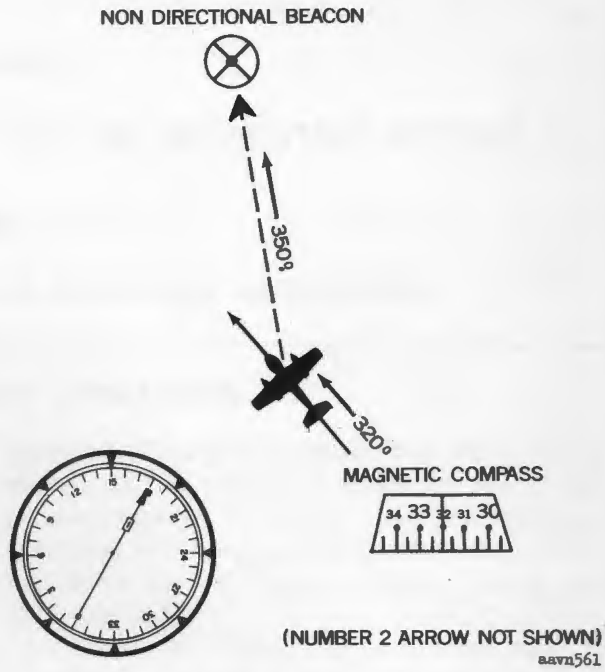


Figure 12-9. RMI compass failure (receiver tuned to L/MF station).

as a result of compass failure, it will be of little use as an ADF reference; however, the tick marks at 45° intervals can still be of considerable help. In addition, the aviator can turn the aircraft as necessary to position the needle at the index and home to the station (par. 11-5).

PART THREE

INSTRUMENT APPROACHES AND ASSOCIATED NAVIGATION SYSTEMS

CHAPTER 13

INTRODUCTION TO INSTRUMENT APPROACH PROCEDURES

Section I. INSTRUMENT APPROACHES

13–1. Purpose

Instrument approaches are designed to assist the aviator in landing during low ceiling and low visibility conditions by—

a. Allowing movement from en route courses and altitudes to a position and altitude at which the final descent on a final approach course can be started.

b. Providing for safe descent on the final approach course with accurate directional guidance.

c. Guiding the aircraft down on the approach path to a minimum altitude from which a safe landing can be made if the aviator has visual reference to the runway.

13–2. Instrument Approach Procedure Employing a Procedure Turn

A typical instrument approach procedure consists of four phases: *transition, outbound leg, procedure turn,* and *final approach.* These are illustrated in figure 13–1.

a. Transition. The aircraft arrives over station A via an airway from the west at a 5,000-foot altitude. Since station A is not properly located to serve as an instrument approach aid to the runway, the aircraft is cleared to station B to execute the instrument approach. The flight from station A to station B is called the *transition* (initial approach) (par. 13–4). During this transition phase, the aircraft is cleared to descend to 3,000 feet.

b. Outbound Leg. The outbound leg from station B to point C is the second phase of the approach. This leg normally requires about 1 minute, but it can be extended as long as the aviator remains within the distance limitations published for the approach. Descent from 3,000 feet down to 1,800 feet is begun during this outbound leg.

c. Procedure Turn. The turn from point C to point D is called a *procedure turn.* Several types of procedure turns are discussed in section III.

d. Final Approach. The final approach phase is accomplished from point D through point E to point F. The final approach consists of two parts: (1) from the completion of procedure turn (point D) to the station (point E), and (2) from the station (point E) to the runway (point F). It is divided into these two parts because descent is limited to a certain minimum altitude (1,300 feet in fig. 13–1) until passing the station. After passing the station, further descent to a lower altitude normally is authorized. In figure 13–1 the approach minimum is 400 feet above the airport and, since the airport elevation is 200 feet, the aircraft can descend to 600 feet as indicated on the altimeter.

Note. The altitudes used in figure 13–1 are examples only. Actual altitudes authorized on instrument approaches are published in navigation publications; they vary considerably for each installation.

13–3. Straight-In Approaches

Figure 13–2 illustrates an aircraft approaching from the east inbound to a station. This station is ideally located as an approach aid to the runway. Because of the station location and

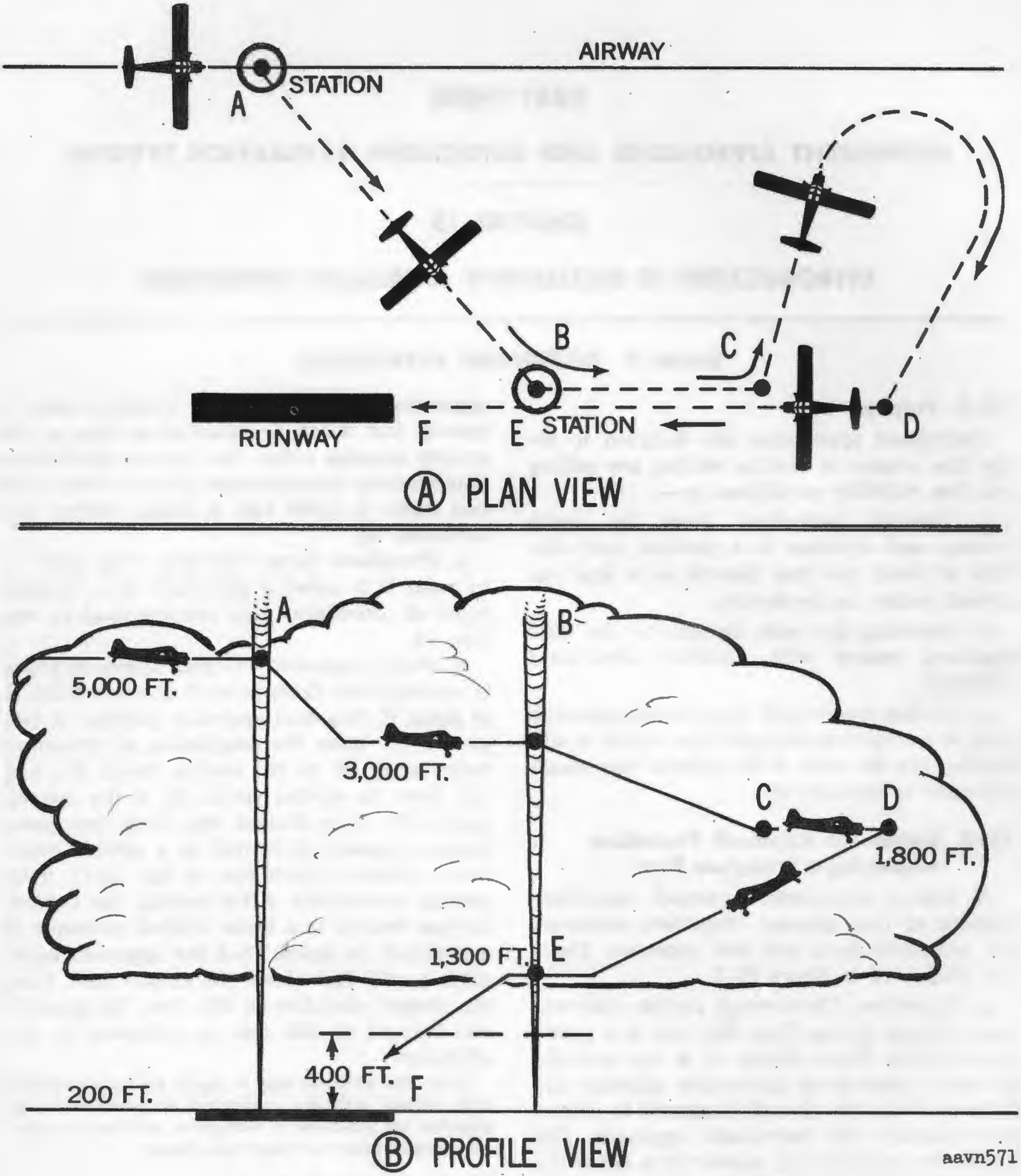


Figure 13–1. Instrument approach procedure employing a procedure turn.

the direction from which the aircraft is arriving, the approach can be completed straight in if traffic conditions will allow it and if the controller clears the aircraft for a straight-in

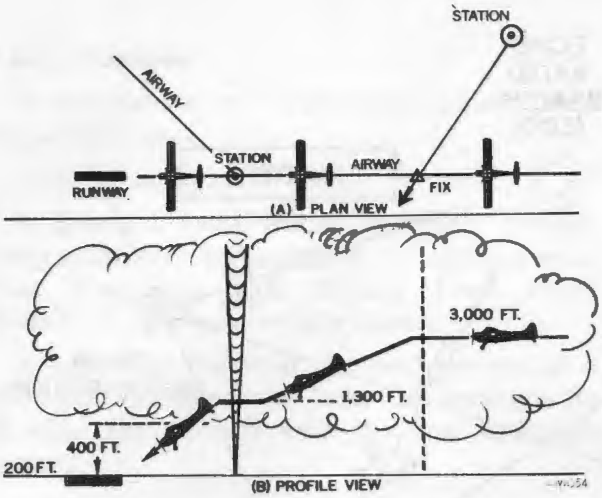


Figure 13-2. Straight-in approach.

approach. The straight-in approach is divided into two phases—final transition and final approach.

a. Final Transition. The aviator determines his position at the intersection (fix) and begins descent along the course alined with the final approach. This phase of the approach is a transition because the aircraft is flying and descending from an *outer fix* (the airway intersection) to the *approach fix* (the station). Since the course is alined with the final approach and since the aircraft continues inbound on final approach after reaching the station, this is called a *final transition* (par. 13-5).

b. Final Approach. The final approach phase (fig. 13-2) is the descent from 1,300 feet at the station to the authorized minimum altitude along the final approach course. The aircraft can descend to 600 feet as indicated on the altimeter because the diagram shows the authorized minimum as 400 feet (above the airport) and the airport elevation as 200 feet (above mean sea level). During the descent from 1,300 feet to 600 feet, the aircraft normally will establish visual contact and be in a position to complete the landing visually. If visual contact with the ground has not been established by the time the aircraft has reached the minimum authorized altitude, the aviator executes a *missed approach* (par. 13-12) at the point specified.

Note. The term *straight-in approach* as used in this paragraph refers to the completion of the *approach* without executing a procedure turn. It should not be confused with *straight-in landing.* An aircraft lands *straight in* at any time the landing runway is alined within 30° of the final approach course. An aircraft may execute a *straight-in approach* and then circle to land. Conversely, the aircraft may execute a conventional approach, including a procedure turn, and then land *straight in.*

Section II. TRANSITIONS

13-4. Definition and Purpose

Note. Format, symbols, and abbreviations on figure 13-3 parallel those used in current navigation publications.

The term *transition* as applied to instrument approaches refers to the procedure whereby an aircraft departs one facility or fix (usually an outer fix) and proceeds along a specified course to a nearby facility or fix (usually the approach fix). Figure 13-3 shows three stations in a terminal area. Two of these (BVO and CHA) are not suitably located to serve as approach aids; the other (ECO) is conveniently located to serve the airport. Air traffic arriving at stations BVO and CHA must transition to the ECO beacon to make an instrument approach to the airport.

13-5. Publication

Information on course, distance, and minimum altitude, which is necessary for the aviator to execute a transition, is published on instrument approach charts in navigation publications. In establishing an instrument approach to an airport, the agency having jurisdiction normally is required to publish transitions from any fix or facility in the area which is within 20 miles of the approach fix, unless such information (including minimum altitude) is

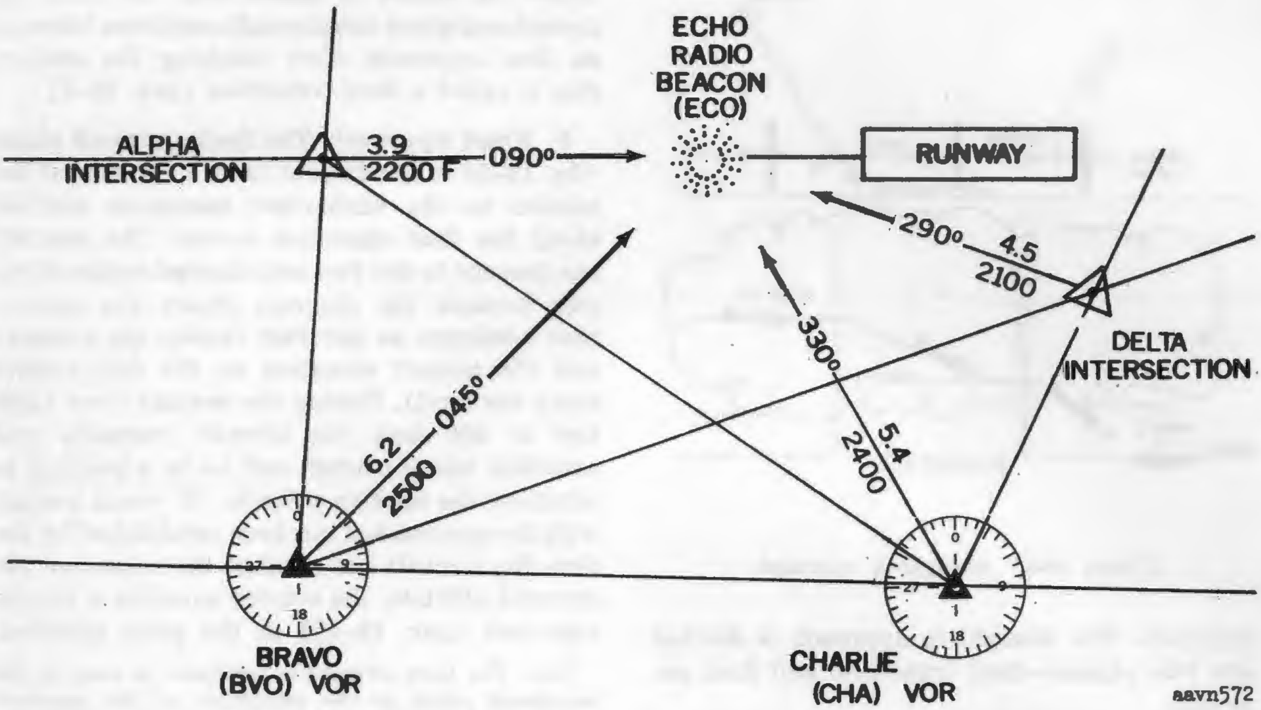


Figure 13-3. Typical transition information as published on navigation charts.

duplicated on existing area and en route charts. Figure 13–3 shows an area with several transitions published from VOR stations and intersections to a radio beacon approach facility (ECO) for the nearby airport. In each case, the information published for the transition consists of—

a. Course, with the magnetic direction printed and indicated with an arrow.

b. Distance, shown to the nearest tenth of a mile.

c. Minimum authorized altitude, which is usually based upon a standard obstruction clearance of 1,000 feet above obstacles within 4.34 nautical miles of the transition course. The letter *F* is printed following the minimum authorized altitude (at Alpha intersection on figure 13–3) to indicate a final transition—meaning that, because of the close alinement of the transition course with the final approach course to the airport, the aviator can expect to be cleared straight in.

13–6. Execution

A transition from an outer fix to the approach fix is executed in accordance with the clearance delivered by the air traffic controller. This clearance may authorize either of the following transitions:

a. Transition to the approach fix or facility without authority to execute an approach. In this event, the controller is unable to give the actual approach clearance (because of traffic). The clearance for a transition in this situation will include a specific altitude assignment and holding instructions.

b. Transition to the approach fix with clearance to execute the approach; e.g., "Army 12345 is cleared to the Cairns VOR, and is cleared for a VOR approach." In this situation the recommended procedure is to descend to the published minimum altitude authorized for the transition, unless the procedure turn altitude is higher (par. 13–10).

Section III. PROCEDURE TURNS

13-7. Purpose

A *procedure turn* is a maneuver which allows the aviator to—

a. Reverse flight direction.

b. Descend from initial approach (transition) altitude or last assigned altitude to a specified procedure turn altitude from which descent on final approach is begun.

c. Intercept the final approach course at a sufficient distance away from the approach fix to aline the aircraft with the final approach course.

13-8. Typical Patterns

Typical procedure turn flight patterns are illustrated in figures 13-4 through 13-6. A description is given for each illustration.

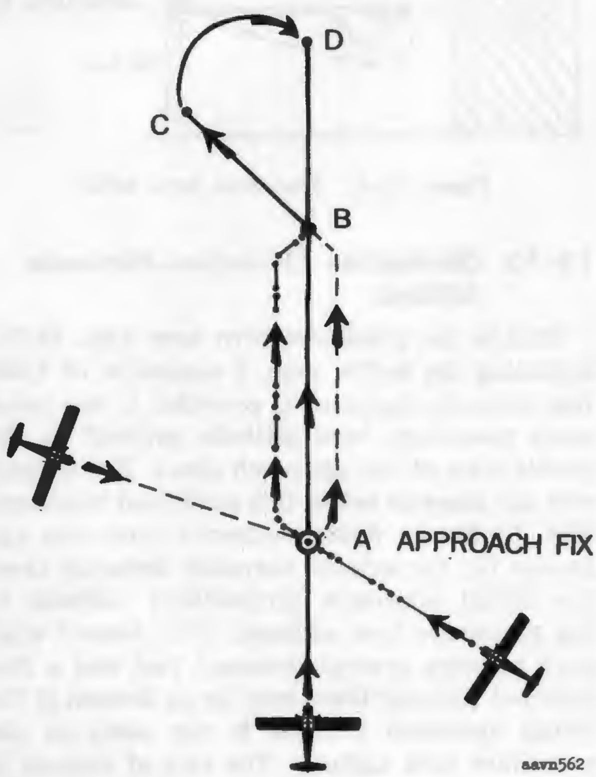


Figure 13-4. Standard 45° turn.

a. Standard 45° Turn (fig. 13-4).

(1) The aircraft may approach station A from any direction (fig. 13-4). Upon arrival over the station the aircraft flies outbound to point B, either on the reciprocal of the approach course or parallel to it.

(2) At point B the aircraft turns to a heading which is 45° left of the reciprocal of the approach course. After turning to this heading, the aircraft flies for 40 seconds to point C. To compensate for known headwinds or tailwinds, the aviator may either increase or decrease the 40 seconds flying time (par. 13-11).

(3) At point C the aviator turns right to intercept the final approach course going inbound at point D. At point D the aviator proceeds inbound and alines the aircraft on final approach.

b. Nonstandard 45° Turn. A nonstandard procedure turn (fig. 13-5) is executed on the right side of the reciprocal of the approach course. The procedure for using the nonstandard 45° turn is executed in a manner similar to the standard 45° turn (*a* above), except that the nonstandard 45° turn is made to the right and the turn to intercept the final approach course is made to the left.

c. Teardrop Turn (Standard and Nonstandard). A teardrop turn (fig. 13-6) may be executed at the aviator's discretion in lieu of the more conventional 45° type turn.

(1) Upon arrival over approach fix B from point A, the aviator follows a track outbound not to exceed 30° left of the reciprocal of the approach course. (A nonstandard turn ((B), fig. 13-6) is executed to the right.)

(2) At point C, which is about 1 minute from the approach fix, the aviator starts a turn inbound. He continues the turn until intercepting the approach course inbound at point D.

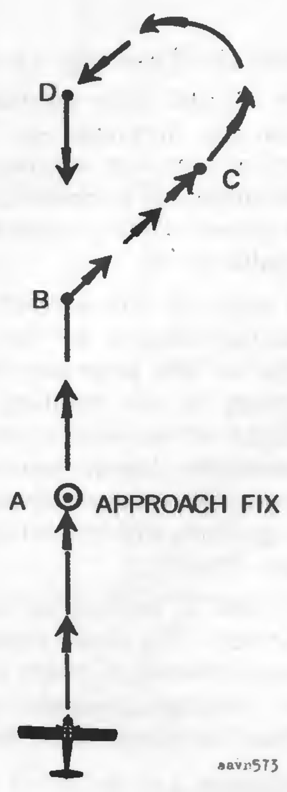


Figure 13-5. Nonstandard 45° turn.

(3) The aviator alines the aircraft with final approach and tracks inbound to the station.

13-9. Procedure Turn Area

a. Figure 13-7 shows the airspace area within which obstruction clearance is provided for procedure turn maneuvering.

b. The limiting distance for procedure turns is published on the profile view of approach charts. It is normally 10 nautical miles. Variations from normal will be clearly depicted on the approach charts (fig. 13-8).

c. In flying outbound from the approach fix to execute the procedure turn, the aviator normally flies a minimum of 1 minute. This outbound leg may be extended, if necessary, to lose additional altitude or compensate for adverse wind effects. However, in no event may the distance outbound from the station exceed the one published on the approach chart.

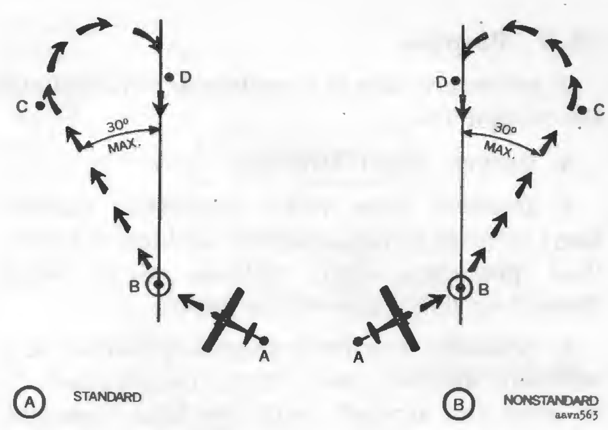


Figure 13-6. Teardrop turn.

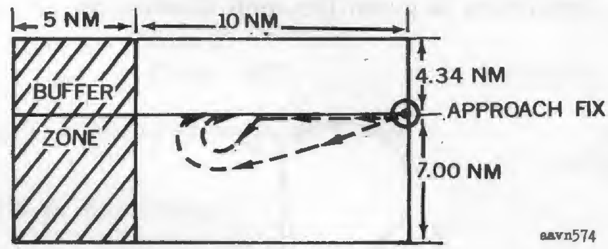


Figure 13-7. Procedure turn area.

13-10. Obstruction Clearance—Minimum Altitude

Within the procedure turn area (fig. 13-7), including the buffer zone, a minimum of 1,000 feet obstacle clearance is provided in the minimum procedure turn altitude printed on the profile view of the approach chart. The aviator will not descend below this published minimum (fig. 13-8). In flying outbound from the approach fix, the aviator normally descends from the initial approach (transition) altitude to the procedure turn altitude. This descent may vary between several thousand feet and a few hundred feet—or there may be no descent if the initial approach altitude is the same as the procedure turn altitude. The rate of descent is a matter of aviator judgment; however, it should not exceed a maximum reasonable rate

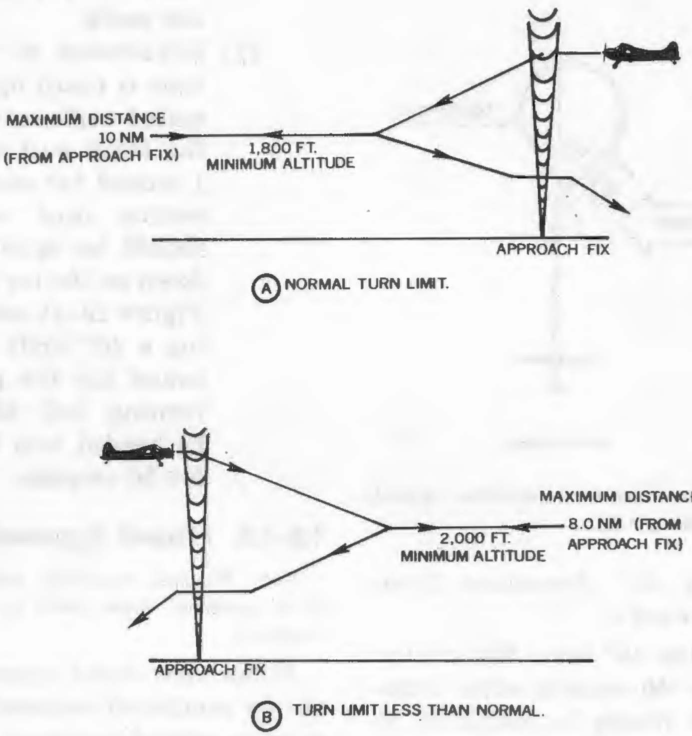


Figure 13-8. Procedure turn limits and minimum altitudes.

at which the aviator can fully control the aircraft. A descent rate of 500 feet per minute is recommended for the last 1,000 feet of altitude change. If the aircraft has not arrived at the minimum procedure turn altitude at the time the turn starts, the descent is continued during the turn until the minimum altitude is reached. If the initial approach altitude is unusually high, the aircraft may not reach minimum procedure turn altitude during the turn and must continue to lose altitude during the descent on final approach.

13-11. Turning Rate

The procedure turn is made at the standard rate of 3° per second; however, the bank angle should not exceed 30°. In aircraft equipped with an integrated flight system which uses a steering pointer (ch. 17), the turn is executed with a centered steering pointer (approximately a 25° bank angle).

a. Flying Outbound to the Procedure Turn.

(1) If the aircraft encounters unusually strong headwinds while flying outbound to execute a 45° procedure turn, the groundspeed may be less than 1 mile per minute, especially with slower helicopters (TAS 75 knots or less). If such headwinds are expected, the outbound leg should be lengthened, providing for approximately 1 minute of inbound flight after the procedure turn is completed (par. 13-15).

(2) The outbound leg of the teardrop turn is subject to the same adjustment for wind as in (1) above. In executing the teardrop turn, the aviator should fly outbound long enough for the 180° turn to be completed as the aircraft intercepts the final approach inbound.

(3) In either case, the aviator should complete the procedure turn with enough inbound time for alinement of the aircraft on the final approach course.

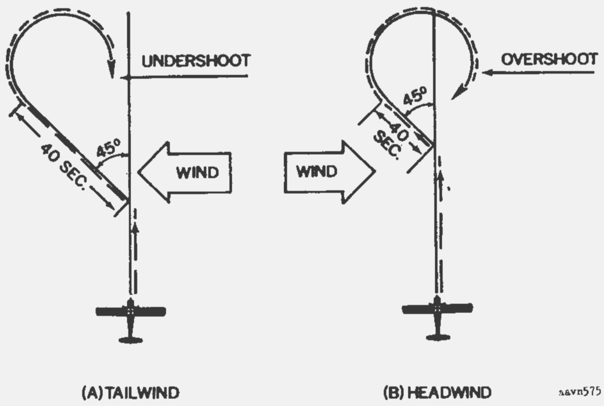


Figure 13-9. Improper procedure turn patterns caused by wind effects.

b. After Making a 45° Procedure Turn (Standard or Nonstandard).

(1) In executing the 45° turn, the aviator should fly for 40 seconds after turning 45°. This timing is calculated so that the subsequent turn to the inbound course will be completed when the final approach course is intercepted. However, the 40 seconds flying time must be adjusted if adverse headwinds or tailwinds are encountered. Figure 13-9 illustrates the results when suitable adjustments are not made.

(2) Adjustment to the 40 seconds flying time is based upon the known or estimated drift correction required to fly the track outbound. An allowance of 1 second for each degree of drift correction used on the outbound leg should be applied to the 40 seconds flown on the leg of the procedure turn. Figure 13-10 shows the aircraft holding a 10° drift correction flying outbound for the procedure turn. After turning left 45°, the aircraft will be headed into the wind and will fly for 50 seconds.

13-12. Missed Approaches

Note. Format, symbols, and abbreviations in figure 13-11 parallel those used in current navigation publications.

If the instrument approach and landing cannot be completed successfully, the aviator executes a *missed approach* procedure. This procedure is published on the approach chart and normally is supplemented by further instructions and clearances from the controller.

a. Typical Procedure. The procedure normally directs the aircraft to proceed on a specified course to or from a designated facility,

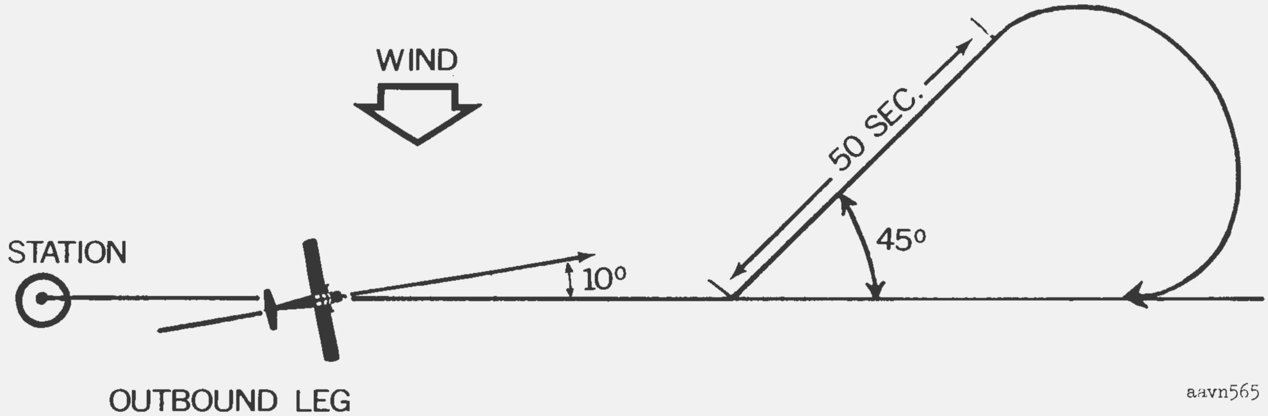


Figure 13-10. Adjusting procedure turn for wind effects.

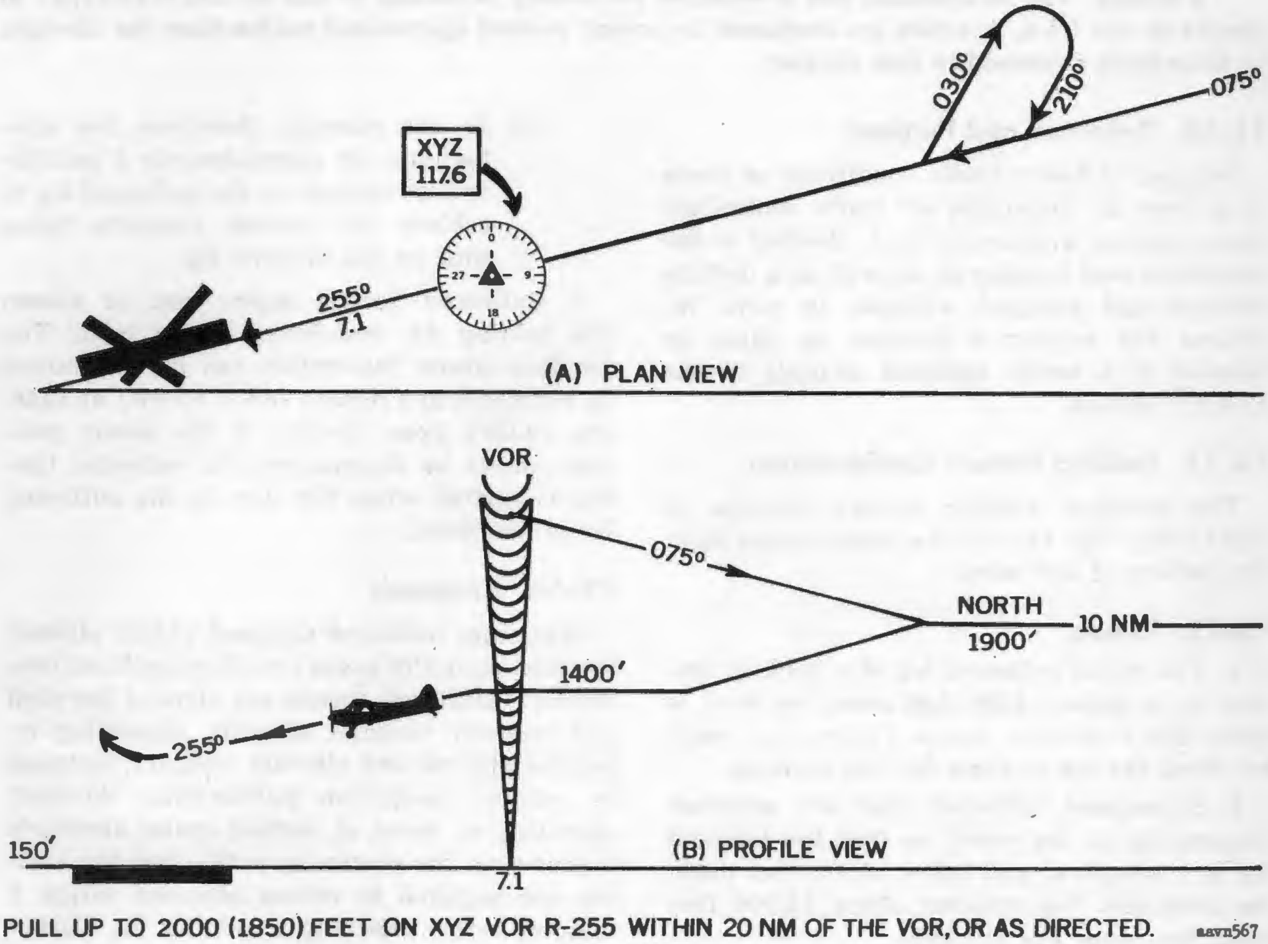


Figure 13–11. Missed approach pattern.

and to climb to a specified minimum altitude. Figure 13–11 shows plan and profile views of an instrument approach procedure, with the missed approach procedure printed beneath the profile view. The aircraft is making the final approach on the 255° radial from the station and is unable to complete the landing. The aviator pulls the aircraft up on the same course, climbing to 2,000 feet indicated on the altimeter (1,850 feet above the airport). The procedure is based upon the use of the 255° radial of XYZ VOR; the minimum altitude guarantees 1,000 feet obstacle clearance within 4.34 miles on each side of the course within 20 miles of the VOR.

b. Report. The aviator must report a missed approach to the controller as soon as practical after he has started the procedure. The report states the time the missed approach began and includes a request for further clearance. The aviator may request clearance to execute another approach (if feasible), or he may request clearance to an alternate airport if conditions warrant it.

Section IV. HOLDING

***Warning:* The information and procedures pertaining to holding in this section are subject to change by the FAA. Aviators are cautioned to consult current operational publications for changes to procedures discussed in this chapter.**

13-13. Definition and Purpose

Because of heavy traffic conditions en route or at busy air terminals, air traffic controllers often instruct aviators to *hold*. *Holding* is the procedure used to delay an aircraft at a definite position and assigned altitude. In some instances the aviator is directed to climb or descend to a newly assigned altitude in the holding pattern.

13-14. Holding Pattern Configuration

The *standard* holding pattern consists of *right* turns (fig. 13-12); the *nonstandard* holding pattern of *left* turns.

13-15. Timing

a. The initial outbound leg of a holding pattern at or below 14,000 feet mean sea level is flown for 1 minute. Above 14,000 feet mean sea level, the leg is flown for 1½ minutes.

b. Subsequent outbound legs are adjusted (depending on the wind) so that the inbound leg is 1 minute at and below 14,000 feet mean sea level and 1½ minutes above 14,000 feet mean sea level. For example:

(1) A helicopter flying a true airspeed of 75 knots experiences a 30-knot headwind on the outbound leg and a 30-knot tailwind on the inbound leg. The following tabular data shows the comparative times flown on the outbound and inbound legs to compensate for this wind (no allowance is made for drift during the inbound turn):

Outbound time	*Inbound time*
1 minute	26 seconds
1 minute and 20 seconds	34.5 seconds
1 minute and 40 seconds	43 seconds
2 minutes	51.5 seconds
3 minutes	1 minute and 17 seconds

(2) In this example, therefore, the aviator must fly approximately 2 minutes and 20 seconds on the outbound leg to achieve the desired 1-minute flying time on the inbound leg.

c. Outbound timing begins over or abeam the holding fix, whichever occurs later. The position abeam the station can be determined by reference to a certain radial (VOR) or bearing (ADF) (par. 13-18). If the abeam position cannot be determined, the outbound timing is started when the turn to the outbound leg is completed.

13-16. Airspeeds

Maximum indicated airspeed (IAS) allowed for holding is 175 knots for all propeller-driven aircraft. Different speeds are allowed for civil and military turbojet aircraft, depending on holding altitude and aircraft category, as listed in current navigation publications. Aircraft operating en route at normal cruise airspeeds higher than the maximum authorized for holding are required to reduce airspeed within 3 minutes before reaching a holding fix. Turboprop aircraft may operate at normal climb indicated airspeed while climbing in a holding pattern, and turbojet aircraft may operate at 310 knots IAS or less while climbing in the holding pattern.

13-17. Turns

Turns made during entry and while holding are to be made at (1) 3° per second, (2) in a 30° bank angle, or (3) with the steering pointer of an integrated flight system (ch. 17).

13-18. Entry

The manuvering required for entry into a holding pattern is determined by the direction from which the aircraft approaches the holding fix (the aircraft heading). The area around the holding fix is divided into three sectors to aid in

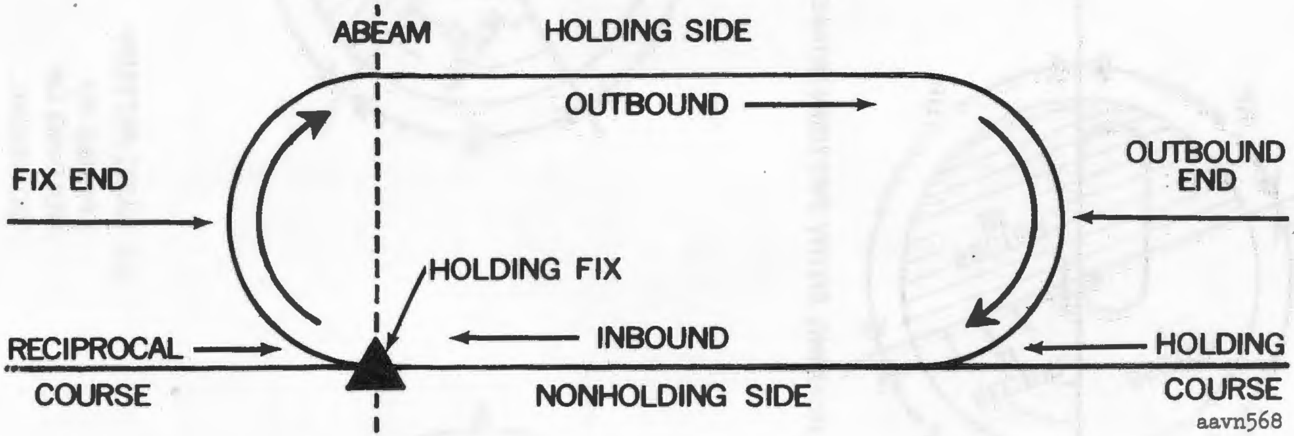
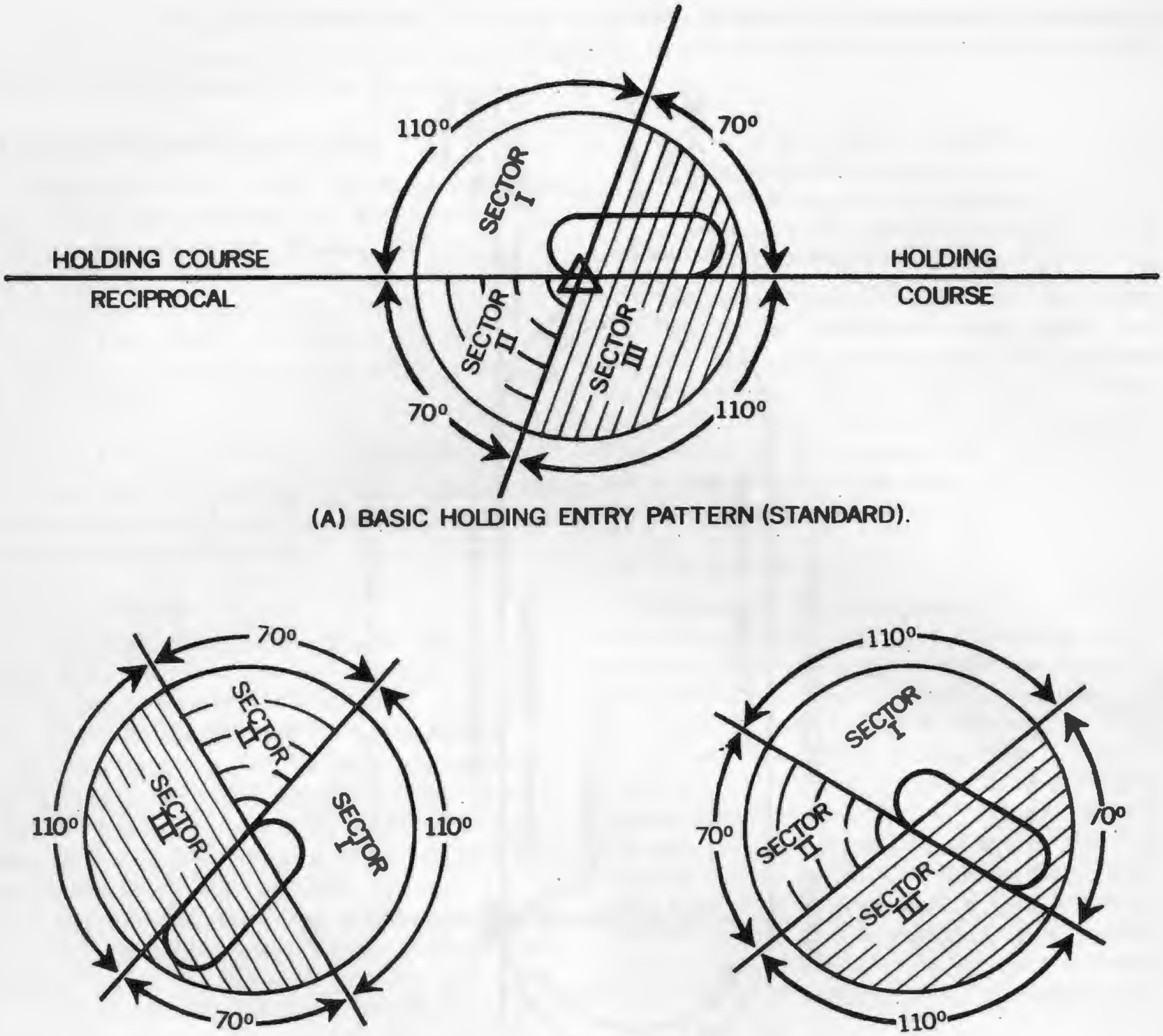


Figure 13–12. Standard holding pattern.



(A) BASIC HOLDING ENTRY PATTERN (STANDARD).

(B) BASIC PATTERN APPLIED TO HOLDING ON 220° RADIAL.

(C) BASIC PATTERN APPLIED TO HOLDING ON 120° RADIAL.

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Figure 13–13. Standard holding pattern entry.

establishing standard entry patterns. Sector III includes both the area 70° from the holding course on the holding side and the area 110° from the holding course on the nonholding side. Sector II is the area 70° left of the holding course reciprocal; sector I is the area 110° right of the holding course reciprocal ((A), fig. 13-13). This standard pattern is applicable to any standard holding course ((B) and (C), fig. 13-13). The FAA requires use of the following entry patterns:

a. Approaching the Fix From Sector I (fig. 13-14). Upon passing the fix the aviator turns parallel to the holding course (on the nonholding side), flies for approximately 1 minute, then turns left and returns to the holding fix or intercepts the holding course.

b. Approaching Fix From Sector II (fig. 13-15). Upon passing the fix the aviator flies for approximately 1 minute outbound on a track 30° (or less) to the left of the reciprocal of the holding course, and then turns right to intercept the holding course inbound. This is essentially the same as the teardrop procedure turn described in paragraph 13-8*c*.

c. Approaching Fix From Sector III. Sector III includes 70° on the holding side and 110° on the nonholding side. After arriving at the fix from any direction within this sector, the aviator turns right to the outbound leg of the holding pattern (fig. 13-16). In (A) of figure 13-16 the outbound timing of 1 minute starts from over the fix, but in (B) of figure 13-16 it begins from abeam the fix.

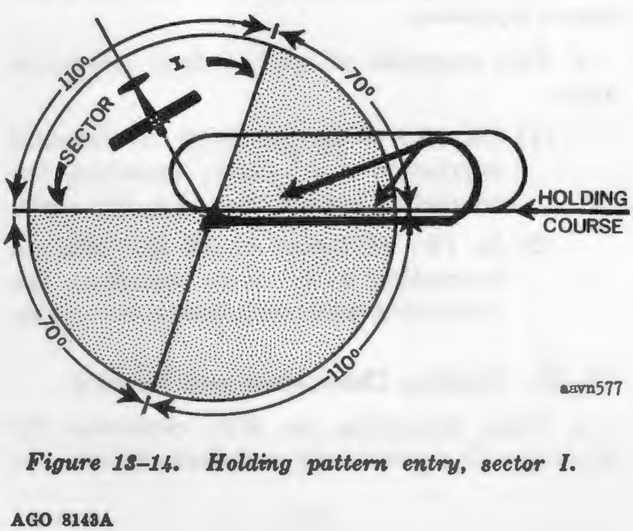


Figure 13-14. Holding pattern entry, sector I.

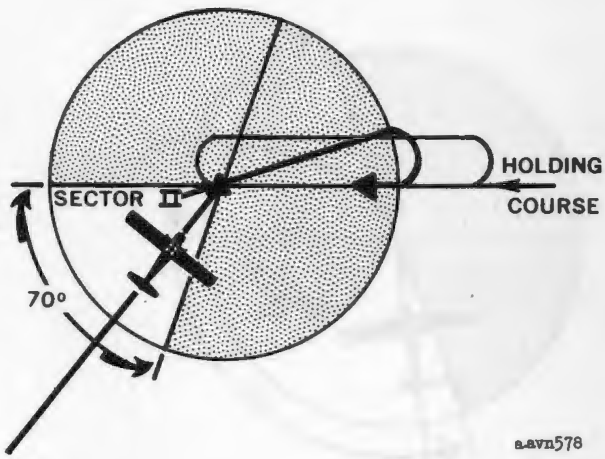


Figure 13-15. Holding pattern entry, sector II.

d. Entry Into Nonstandard Pattern. If the holding pattern is nonstandard (left turns), the entry patterns are reversed (fig. 13-17).

13-19. Departing the Holding Pattern

When cleared by the controller to leave the holding fix, the aviator normally departs the pattern from over the fix. An exception to this occurs when the controller specifically states ". . . cleared from your present position . . . ." If the controller has specified a departure time, the aviator must adjust the holding pattern so that the aircraft is over the holding fix ready to depart at the specified time. If an aircraft is holding on the published final approach course at an approach fix and receives clearance for the approach, the aviator normally begins the final approach from the holding pattern without executing the conventional procedure turn.

Note. At some locations beginning the final approach from the holding pattern may be prohibited by notes published on the approach chart.

13-20. Drift Correction in the Holding Pattern

a. If no attempt is made to correct for adverse affects of crosswinds while holding, the aircraft will fly a wide arc in one turn and a tight arc in the opposite turn (fig. 13-18).

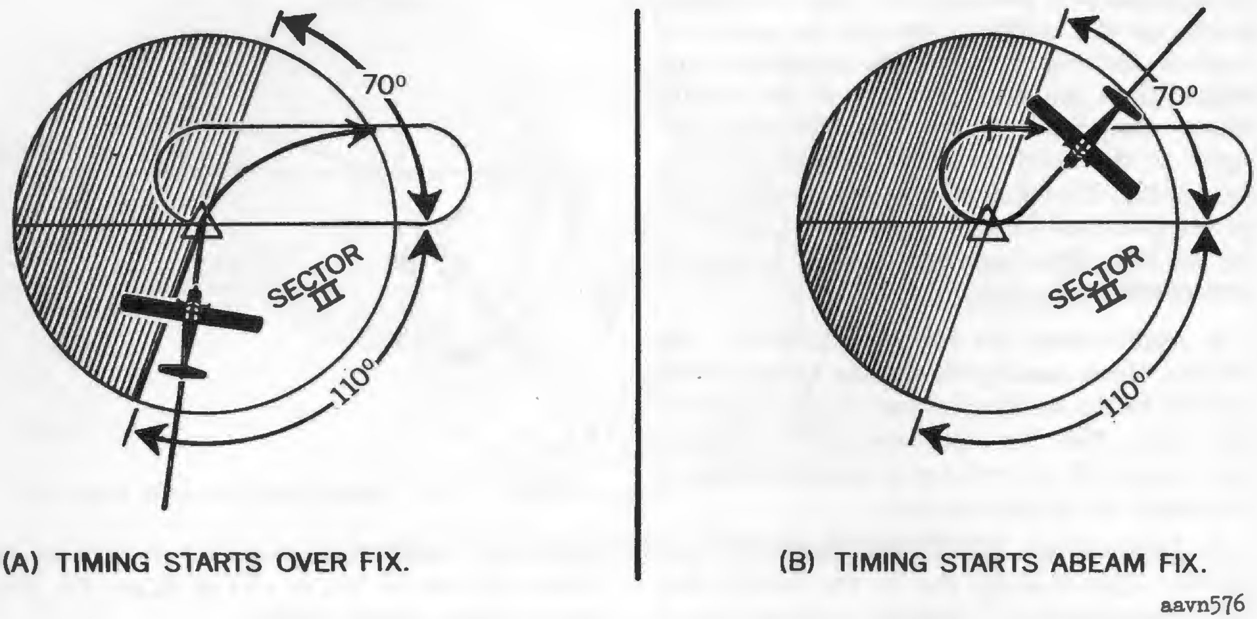


Figure 13-16. Holding pattern entry, sector III.

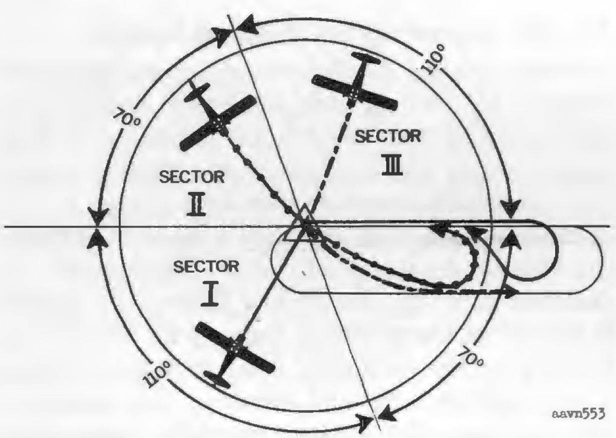


Figure 13-17. Nonstandard holding pattern entry.

b. If the same amount of drift correction is flown for both inbound and outbound legs (but applied in opposite directions), the outbound leg will parallel the inbound leg; however, the turns will still be wide and tight, respectively. Since the aviator has little control over the aircraft's track while turning, he must adjust the track of the outbound leg to avoid turning short of or overshooting the inbound leg.

c. For holding pattern drift correction—

(1) Determine the correction necessary to maintain the track inbound.

(2) While flying the outbound leg, double the inbound correction and apply it in the opposite direction; or if the inbound correction is over 10°, use an outbound correction of 10° plus the inbound correction.

Note. **This guide must be adjusted to fit each situation. Analysis of the initial inbound turn (overshooting or undershooting) should be used as a basis for a subsequent adjustment.**

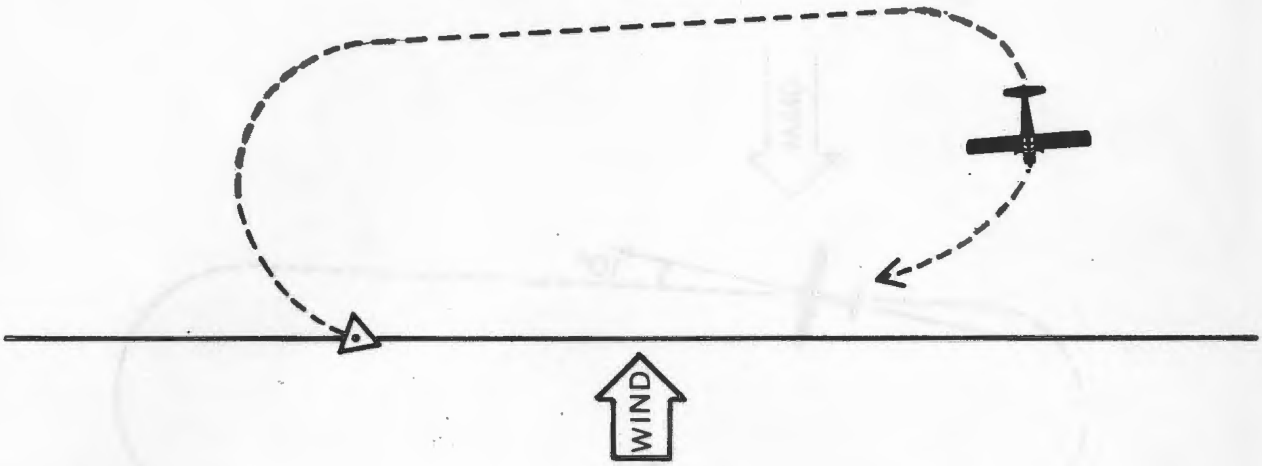
d. Two examples of applied drift correction are—

(1) On (A) of figure 13-19 the inbound correction is 5° right; therefore, the correction used outbound is 25° right.

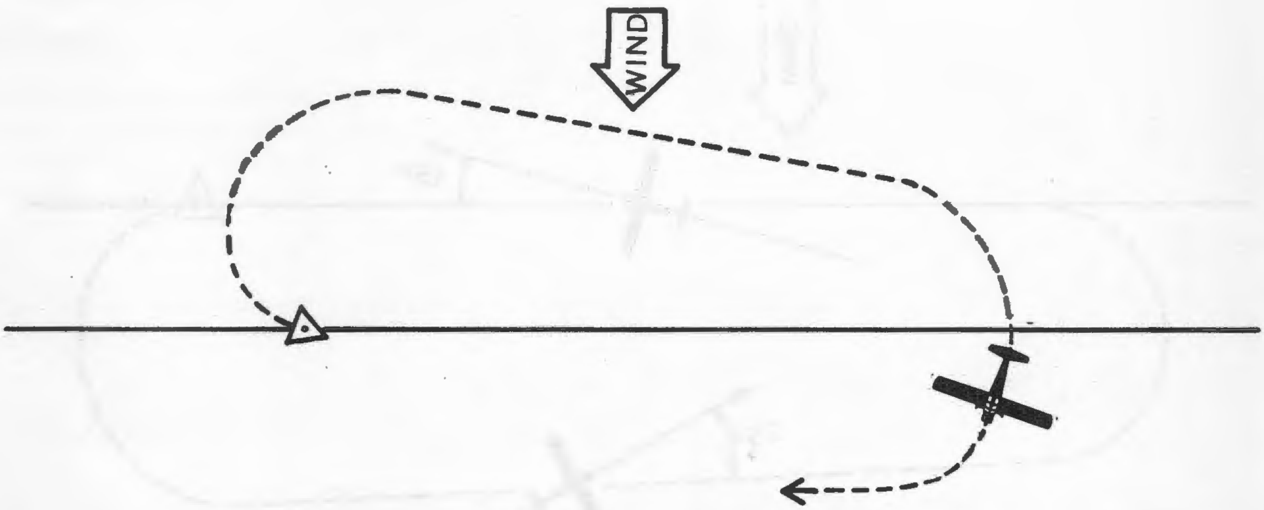
(2) In (B) of figure 13-19 the inbound correction is 15° left; therefore, the correction used outbound is 25° right.

13-21. Holding Clearances and Reports

a. When delivering an ATC clearance for holding with a previously assigned altitude, the



(A) RIGHT CROSSWIND OUTBOUND



(B) LEFT CROSSWIND OUTBOUND

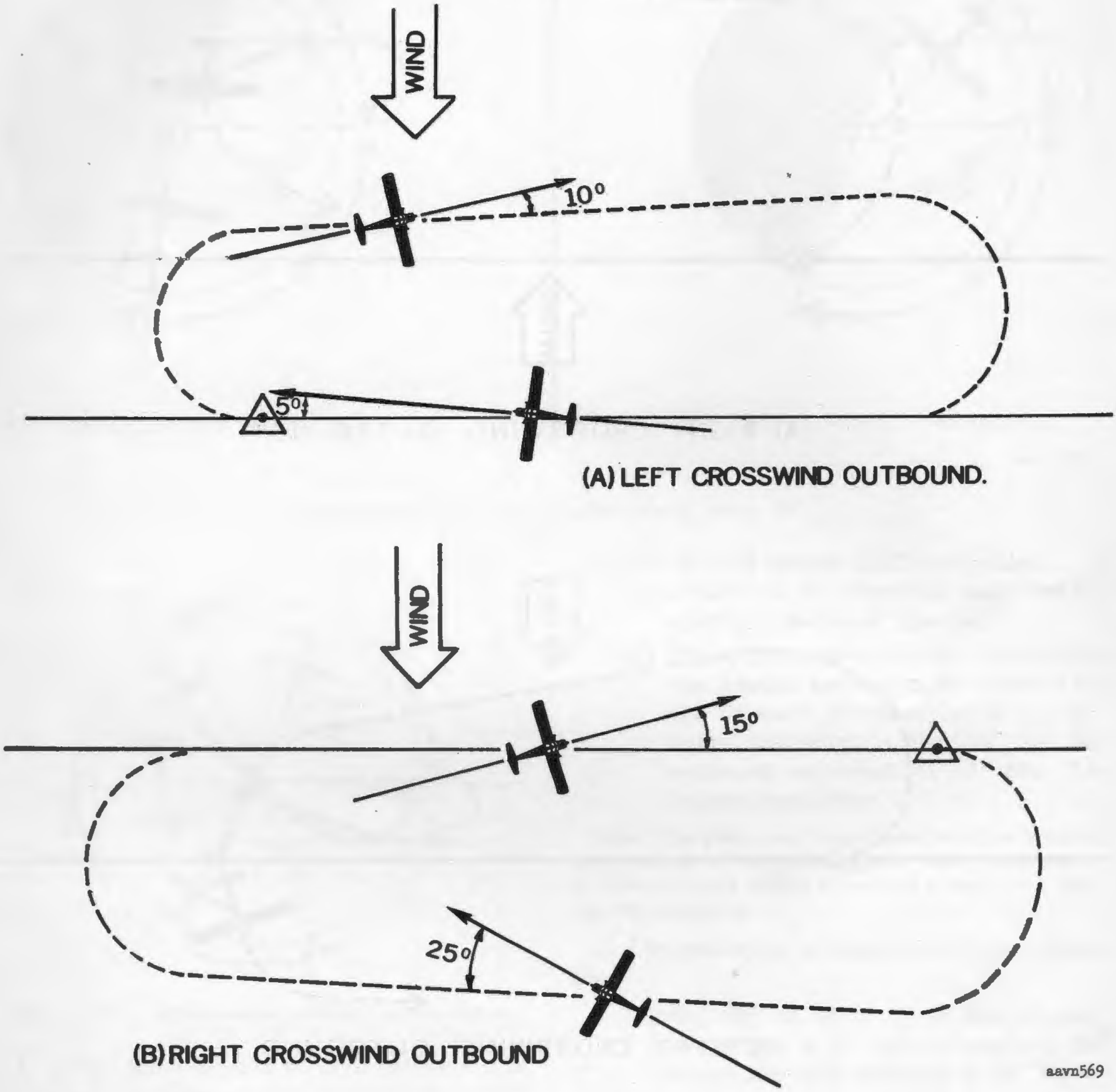


Figure 13-19. Adjusting holding pattern for wind effects.

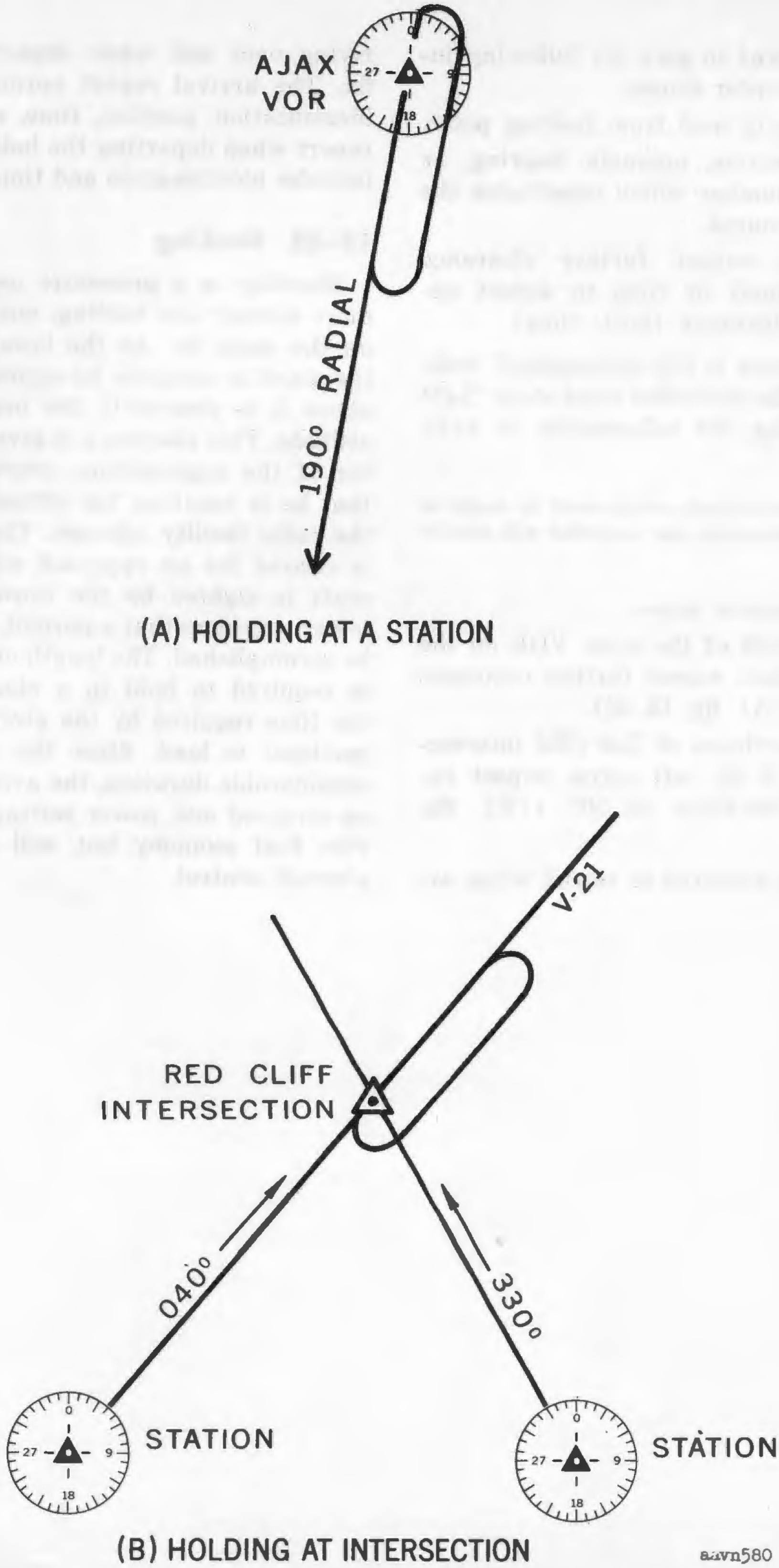


Figure 13-20. Holding patterns flown for typical clearances.

controller is required to give the following information, in the order shown:

(1) Direction to hold from holding point.

(2) Radial, course, magnetic bearing, or airway number which constitutes the holding course.

(3) Time to expect further clearance (EFC time) or time to expect approach clearance (EAC time).

b. If the clearance is for nonstandard holding (left turns), the controller must state "Left turns" after giving the information in *a*(2) above.

Note. When a new altitude assignment is made as part of the holding clearance, the controller will specify the altitude.

c. Typical clearances are—

(1) "Hold south of the Ajax VOR on the 190° radial; expect further clearance at 30" ((A), fig. 13–20).

(2) "Hold northeast of Red Cliff intersection on V-21, left turns, expect approach clearance at 50" ((B), fig. 13–20).

d. Aviators are required to report when arriving over and when departing the holding fix. The arrival report normally will include identification, position, time, and altitude. The report when departing the holding fix normally includes identification and time of departure.

13–22. Stacking

Stacking is a procedure used when two or more aircraft are holding, one above the other, on the same fix. As the lower aircraft leaves the stack to complete its approach, the aircraft above it is cleared to the next lower holding altitude. This clearance is given after the aviator of the approaching aircraft has reported that he is vacating his altitude and is leaving the radio facility inbound. The second aircraft is cleared for an approach when the first aircraft is sighted by the tower and when the tower considers that a normal, safe landing will be accomplished. The length of time an aircraft is required to hold in a stack depends upon the time required by the aircraft in the lower positions to land. Since the delay may be of considerable duration, the aviator should fly at an airspeed and power setting which will provide fuel economy but still permit adequate aircraft control.

CHAPTER 14

VOR AND ADF APPROACHES

Section I. APPROACH CHARTS

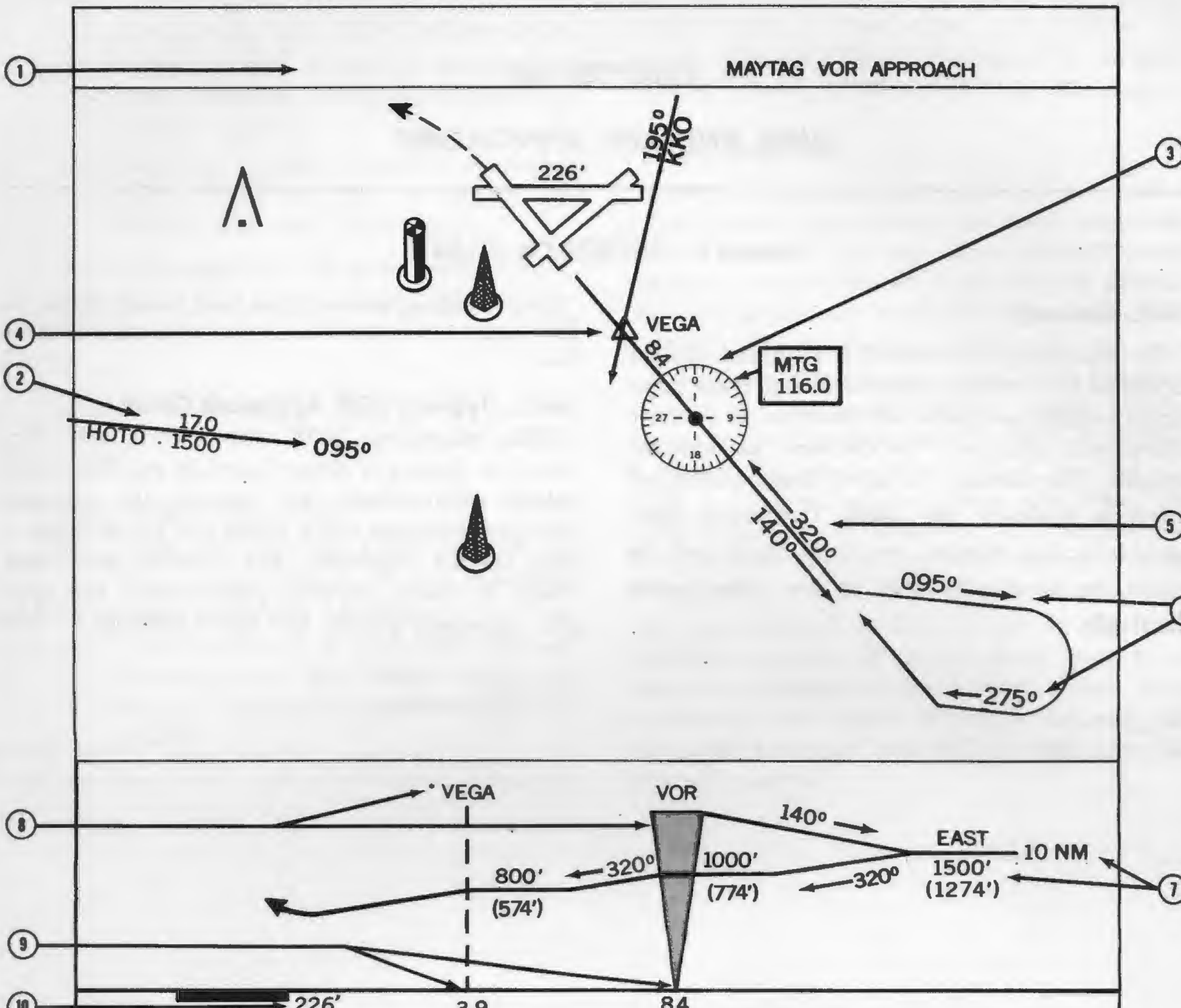
14-1. General

The separate omni and ADF approach charts published by Federal agencies and private companies contain complete information on current instrument approach procedures at specific airfields. The format for all of these published charts is basically the same. Therefore, once the aviator has studied one type chart and its legend, he is usually able to use other types effectively.

Note. Symbols, abbreviations, and format in figure 14-1 parallel those used in current navigation publications.

14-2. Typical VOR Approach Chart

This simplified VOR approach chart (fig. 14-1) is typical of those found in current navigation publications. Its format and general data presentation are a guide for the aviator—they do not represent any specific published chart. (Consult current publications for specific approach charts and their legends.)



(11) PULL UP: turn LEFT to 1800(1574) feet outbound on MTG VOR, R 310 within 20 NM, or as directed.

(12)

	ST-IN RWY 32		CIRCLING	
AUTHORIZED MINIMUMS	DAY	NIGHT	DAY	NIGHT
	*400-1	*500-1	*500-1	*500-1

(13) * Descent below 800 (574) feet not authorized if aircraft not equipped with dual VOR receivers and Vega intersection not established.

(14)

Ground speed-knots	60	80	100	120	140	160	180	Ceiling/Altitude Conv.		
								QFE	400	500
VOR to Pull up 8.4	8:25	6:20	5:03	4:12	3:36	3:10	2:48	QNH	626	726

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Figure 14-1. Typical VOR approach chart.

Explanatory Data for Figure 14-1

1 Chart heading (data incomplete). Includes name of city, state, and airport; type of approach (VOR, ADF, RADAR, ILS, etc.); and radio communications data.

2 Transition data from Hoto intersection. (Minimum transition altitude (1,500 feet) may be lower than MEA on airway.)

3 Approach facility location with distance to airfield (8.4 nautical miles).

4 Supplementary final approach fix established by the intersection of the MTG radial (320°) and KKO radial (195°).

5 Final approach course and radial.

6 Conventional procedure turn headings.

7 Procedure turn data:

a. Direction of turn is east of final approach course.

b. Maximum turn distance from the approach fix is 10 nautical miles.

c. Minimum indicated altitude during the turn is 1,500 feet (1,274 feet absolute altitude).

8 Minimum indicated altitude over VOR station on final approach (1,000 feet) and over Vega intersection (800 feet).

9 Distances from VOR station and Vega intersection to the airport.

10 Field elevation (226 feet).

11 Missed approach procedure.

12 Authorized ceiling and visibility minimums.

13 Note concerning procedure restrictions.

14 Pull-up time. To assist in prompt execution of missed approaches, travel time in minutes and seconds between the VOR station and the airport is listed for several average groundspeeds.

Section II. TYPICAL VOR APPROACH

14-3. VOR Station Location

VOR stations used in VOR approaches may either be located near the approach end of the runway, making supplementary fixes unnecessary, or they may be located so that additional approach aids or fixes are necessary to reduce the landing minimums. The latter type is shown in figure 14-1 to depict the typical VOR approach procedure.

14-4. Initial Contact and Arrival

Note. Symbols, abbreviations, and format in figure 14-2 parallel those used in current navigation publications.

An aviator is flying eastbound on V-44 at 5,000 feet with Maytag as his destination (fig. 14-2). In compliance with ATC instructions, he establishes radio contact with Maytag approach control over the Hoto intersection. Maytag clears him to hold southeast of Maytag VOR on the 140° radial at 4,000 feet; his expected approach clearance time is 1425 hours. Upon arrival at Maytag VOR, the aviator—

a. Checks the time.

b. Turns outbound to execute a teardrop entry into the holding pattern.

c. Reduces airspeed to prescribed holding pattern airspeed.

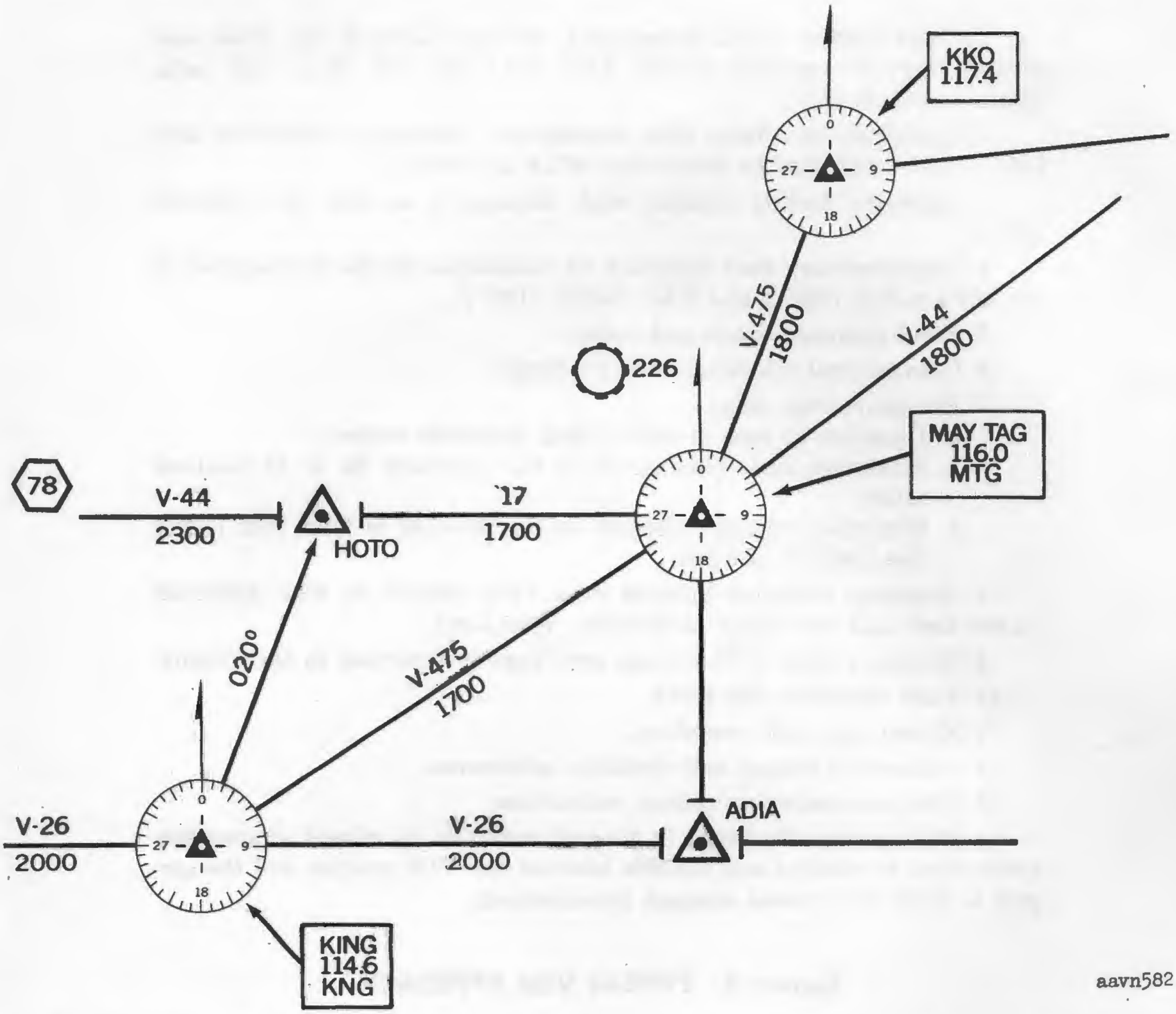


Figure 14-2. Typical VOR station location.

d. Begins descent to 4,000 feet.

e. Reports station passage and leaving 5,000 feet.

Note. Actions *a* through *d* above are performed almost simultaneously. The report is not made until the aircraft leaves the 5,000-foot altitude.

14-5. VOR Holding

a. Initial passage of Maytag VOR occurs when the to-from indicator reverses readings (*TO* to *FROM*). The aviator then turns outbound to enter the teardrop pattern used for intercepting the holding course inbound (320°, fig. 14-3). The aviator may fly any radial within 30° of the holding radial when entering the teardrop turn. Use of the course selector and deviation needle to track outbound on the teardrop turn is optional, but this procedure will aid the aviator in orienting himself with respect to the VOR station and to the holding radial. He may either set the course selector on the desired outbound radial or fly a heading

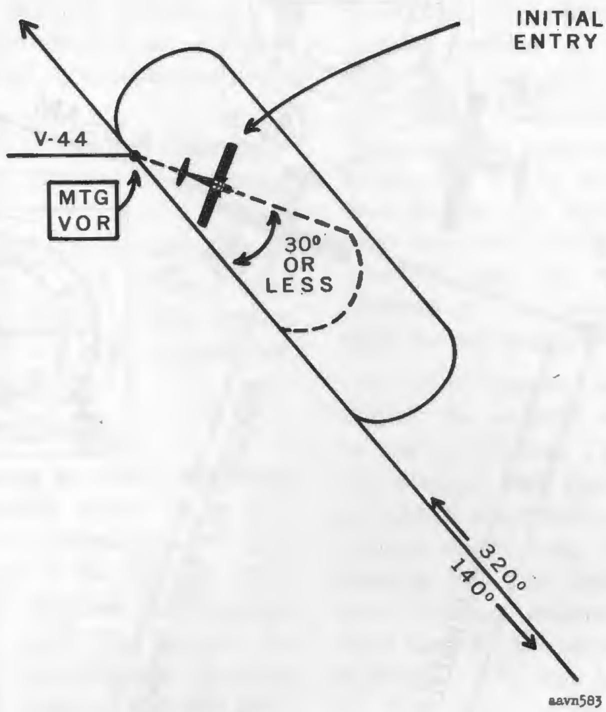


Figure 14-3. Teardrop entry.

outbound with the course selector set for tracking inbound on the holding course.

b. After flying 1 minute on the outbound leg of the teardrop turn, the aviator turns right to intercept the holding course inbound (320°, fig. 14-3). Prior to turning, the course selector is set on 320° and the to-from indicator reads *TO*. The teardrop turn ends when the indicator needle centers, showing that the aircraft has intercepted the desired holding course.

c. During the initial inbound leg of the holding course, the aviator should determine (1) the drift correction necessary to remain on the desired track, and (2) the time flown on the inbound leg. Subsequent outbound legs of the holding pattern are adjusted so that each inbound leg requires 1 minute. Drift corrections in the holding pattern are discussed in chapter 13.

d. After flying over the VOR station, the aviator makes a 180° turn to the outbound heading of the holding course. Timing for the outbound leg should begin when the aircraft is abeam the station. One accurate method for determining his position abeam the station is by rotating the course selector 90° to fix the aircraft position abeam the station (fig. 14-4). This technique permits the aviator to time the outbound leg accurately from a position abeam the station.

(1) *Point A.* During the right turn outbound, the aviator rotates the course selector 90° to the right (reading of 050°), thereby enabling him to fix his position abeam the station. During the turn, the deviation needle deflects full right.

(2) *Point B.* Needle centers abeam the station. Begin outbound timing at this time.

(3) *Point C.* After passing point B, reset course selector to 320° to intercept the holding course inbound. The needle deflects to the side away from the

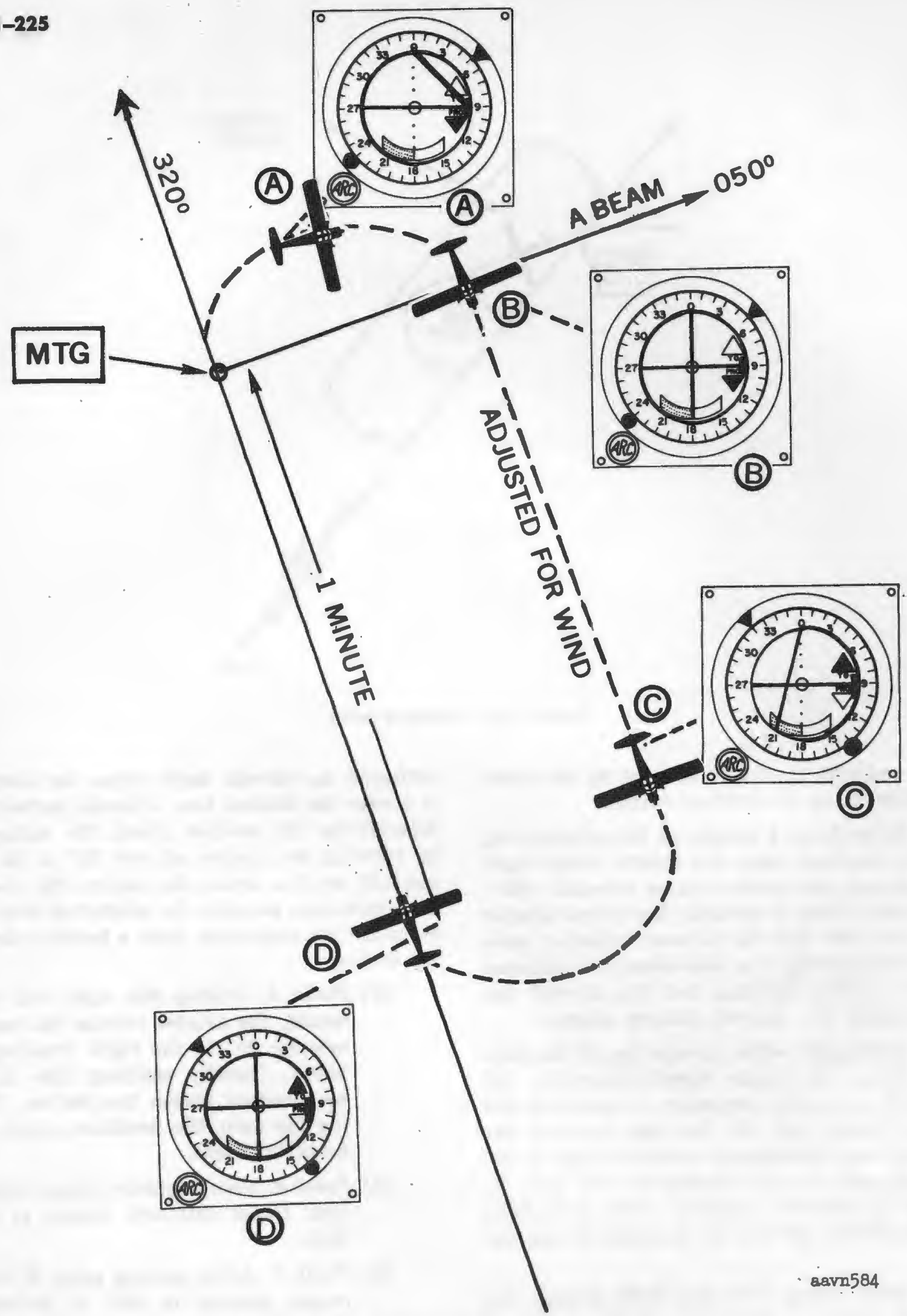


Figure 14-4. Flying a holding pattern (VOR).

holding course during the outbound portion of the holding pattern.

(4) *Point D.* Needle centers as aircraft turns inbound and intercepts the holding course.

e. Another method of accurately determining position abeam the station is by using RMI indications (ch. 12).

f. When holding at a fix where methods described in subparagraphs *d* and *e* above cannot be used, the aviator should begin timing the outbound leg immediately after rolling out of the 180° standard rate turn.

14-6. Descent While Holding

a. The aviator is holding at 4,000 feet over Maytag VOR. The approach chart ((7), fig. 14-1) shows the minimum procedure turn altitude for the VOR approach to the field as 1,500 feet. As lower air traffic departs the holding pattern, the controller clears the aviator to descend to a lower holding altitude. In this situation, the clearance is received to 3,000 feet. The aviator continues the established holding pattern and establishes a 500-foot-per-minute rate of descent. When the aviator reports leaving 4,000 feet, the controller can assign this holding altitude to another aircraft. (The 500-foot-per-minute rate of descent is used for 1,000-foot descents in the holding pattern.)

b. If the aircraft had been at a higher altitude (e.g., 9,000 feet) and were cleared to a low altitude (e.g., 3,000 feet), the aviator could have established the maximum rate of descent at which he could still fully control the aircraft. He could have used this steep rate to within 1,000 feet above the newly assigned holding altitude; he would then have to reduce the rate to 500-feet-per-minute for the last 1,000 feet of the descent.

14-7. Final Approach

a. The aviator has been advised of his expected approach clearance time (1425 hours, par. 14-4). As air traffic conditions change, the controller revises the expected approach clearance time and advises the aviator accordingly. When the aviator is cleared for the approach, he may immediately begin the descent from the 3,000-foot holding altitude to the 1,500-foot procedure turn altitude, regardless of his position in the holding pattern. The final turn inbound from the holding pattern serves as the procedure turn, so the aviator may use the maximum distance allowed (10 miles, fig. 14-1) for losing altitude prior to and during the turn. After intercepting the final approach course inbound, the aviator may descend from the authorized procedure turn altitude to the minimum altitude authorized over the station (1,000 feet; (8), fig. 14-1).

b. Upon passing over the VOR station inbound, the aviator notes the time and reports to the controller. The altitude flown between the station and the runway is controlled by published approach chart minimums. The approach chart (fig. 14-1) authorizes descent only to 800 feet indicated altitude after station passage, unless the aircraft is equipped with dual VOR receivers and Vega intersection is fixed ((13), fig. 14-1). Descent restrictions of this type, using supplementary final approach fixes, are common where the facility-to-field distance exceeds 6 miles.

(1) Lower approach altitudes are authorized for aircraft with dual VOR's because the aviator can establish supplementary fixes without tuning the receiver away from the primary navigation aid. An aviator using dual VOR's can fix Vega intersection (195° radial from KKO VOR, fig. 14-1) and descend below the 800 foot minimum during the approach. The authorized ceiling and visibility minimums (12, fig. 14-1) are shown as absolute altitudes (height above the field elevation). Therefore, the published 400 foot authorized minimum for dual VOR equipped aircraft is added to the field elevation (226 feet) to determine the minimum indicated altitude of 626 feet.

(2) Supplementary fixes which can be established without dual VOR receivers are sometimes authorized. However, this procedure requires tuning away from the primary navigation aid and

may be inconvenient at this stage of the approach.

c. Visual contact with the ground usually is established at some point along the final approach path. The ceiling data in the current weather report for the field indicates the absolute altitude at which the aviator *should* be able to see the ground. If visual contact has not been established upon reaching the VOR station, the aviator may fly past the station at the minimum authorized altitude for the distance specified on the approach chart. If the aviator following the Maytag VOR approach procedure (fig. 14-1) is flying an average groundspeed of 80 knots, he may continue for 6 minutes and 20 seconds, without establishing visual contact, before executing the missed approach procedure.

14-8. Landing

Clearance to land on a specified runway is issued when the aviator is on final approach. If the aviator is cleared to land on runway 32 (fig. 14-1), he will land straight in. Clearance to land on other runways will require circling to land. Landing minimums are usually higher for circling-type landings. However, for aircraft with a single VOR receiver, the approach chart for Maytag VOR (fig. 14-1) restricts the approach minimum to 800 feet mean sea level regardless of the landing runway.

14-9. Missed Approach

If, for any reason, the landing is not accomplished, the aviator executes the missed approach procedure. To accomplish the procedure as specified in figure 14-1, the aviator—

a. Adjusts power and attitude, as necessary, to begin an immediate climb.

b. Turns left to intercept the 310° radial of Maytag VOR.

c. Sets the course selector to 310°. (This results in a *FROM* indication and a left needle deflection on the course indicator.)

d. Reports a missed approach to the controller and requests further clearance, either for another approach or to his alternate airport, as appropriate. (If he requests clearance to the alternate, flight plan data must be given to the controller.)

e. Checks for centered needle at the 310° radial.

f. Continues climb to missed approach altitude (1,800 feet).

g. Complies with subsequent ATC instructions.

Section III. TYPICAL ADF (NONDIRECTIONAL BEACON) APPROACH

14-10. General

ADF approach charts are similar in appearance and format to VOR approach charts. The approach procedures are essentially the same as those for VOR. The significant difference between VOR and ADF approaches is the aircraft instrumentation; i.e., the ADF procedure is accomplished by reading bearings from the ADF indicator or the RMI (see RMI techniques, ch. 12).

14-11. Transition

Figure 14-5 shows the ADF transition procedure and instrument readings during the transition. The aircraft is making a transition from RPT VOR to HUP radio beacon to execute an ADF approach. The aviator has been cleared to hold at HUP and await an approach clearance.

14-12. Holding

a. Figure 14-6 shows the ADF holding pattern entry procedure and instrument readings in the entry pattern. The aviator arrives at HUP and accomplishes the normal entry into a standard holding pattern by turning outbound on the nonholding side.

b. Figure 14-7 shows the ADF holding pattern procedure and instrument readings in the holding pattern.

(1) *Point A.* After passing HUP inbound from the entry pattern, the aviator ob-

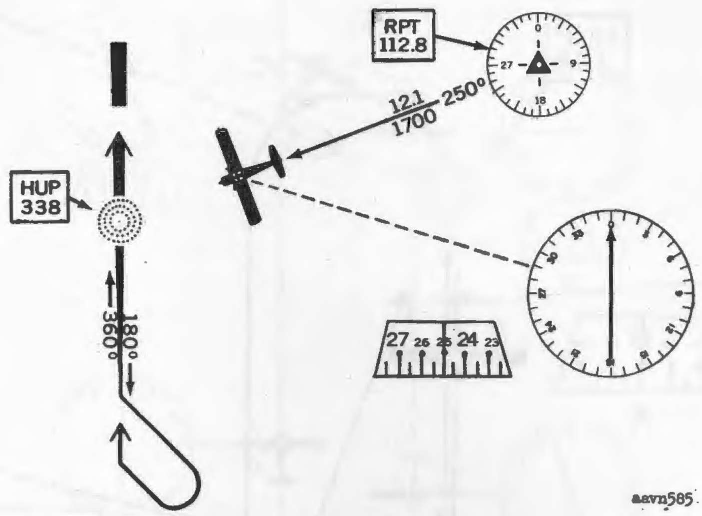


Figure 14-5. ADF transition.

serves station passage (indicator arrow reverses from 0° to 180°) and turns right. At point A, the aircraft has completed 30° of the right turn.

(2) *Point B.* The aircraft is abeam the station; relative bearing is 090° on a heading of 180°.

(3) *Point C.* On the first outbound leg the aviator flies for 1 minute. Subsequent outbound legs are adjusted for wind to make the inbound leg flight time 1 minute.

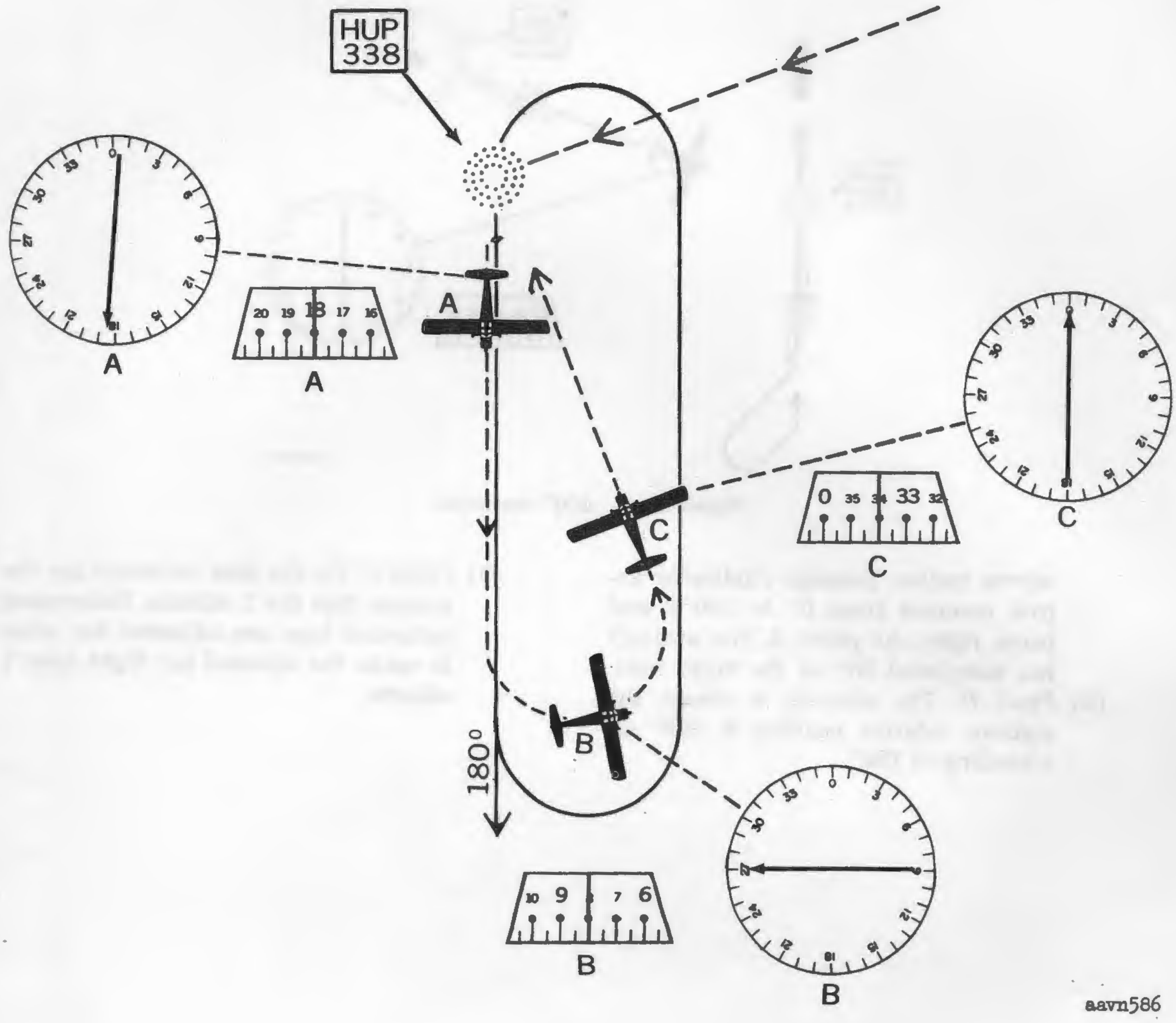


Figure 14-6. ADF holding pattern entry.

(4) *Point D.* The aircraft is inbound to the station with a relative bearing of 0° on a heading of 0°. The aviator checks the inbound drift correction and flight time accurately for adjusting subsequent outbound legs.

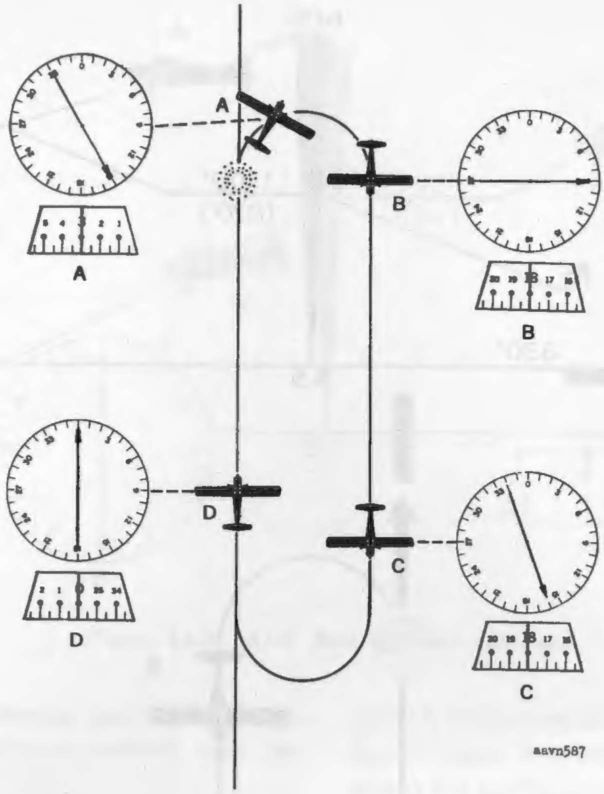


Figure 14-7. ADF holding pattern procedure.

14-13. Descent

Note. Symbols, abbreviations, and format in figure 14-8 parallel those used in current navigation publications.

Figure 14-8 shows the ADF descent procedure from the holding pattern. While in the holding pattern (point A), the aviator receives the ADF approach clearance and immediately begins descent to procedure turn altitudes.

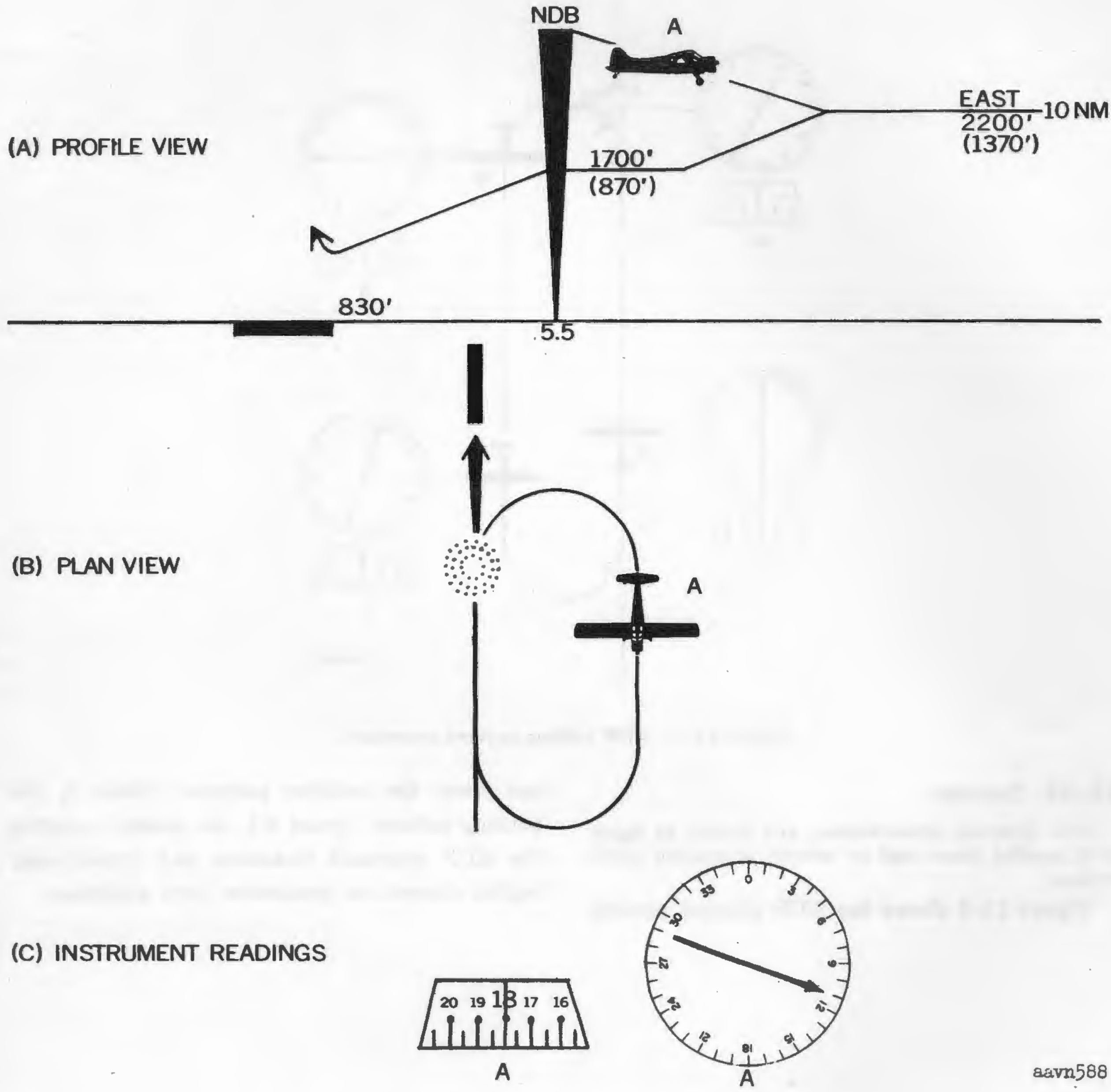


Figure 14-8. ADF descent in the holding pattern.

14–14. Final Approach

Note. Symbols, abbreviations, and format in figure 14–9 parallel those used in current navigation publications.

a. Figure 14–9 shows the ADF final approach procedure and instrument readings during the approach. After completing the procedure turn, the aviator intercepts the final approach course inbound and begins descent to the minimum altitude authorized over the nondirectional radio beacon (1,700 feet).

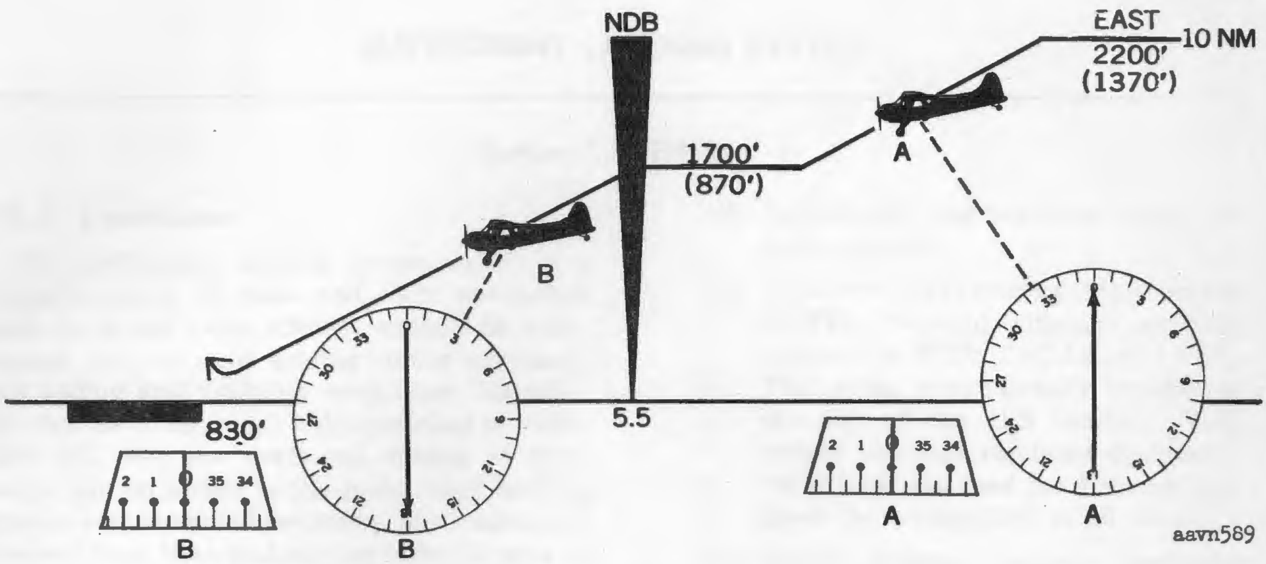


Figure 14-9. ADF final approach inbound.

b. The aviator determines station passage by reversal of the indicator needle, and reports to the controller.

c. Descent continues to the authorized approach minimum altitude. If the aviator establishes visual contact with the ground, he completes the landing; if not, he executes the missed approach procedure.

CHAPTER 15

INSTRUMENT LANDING SYSTEM

Section I. GENERAL

15–1. Introduction

The instrument landing system (ILS) is a complex array of radio and light navigation aids. It is the most efficient system in widespread use for safe landing under extremely low ceiling and visibility conditions. Its effectiveness as an approach aid is matched by radar (ch. 16), but the preferred system at most major air terminals is the instrument landing system supplemented by radar. More advanced systems have been undergoing tests for several years, but several factors have prevented placing these systems operational status.

15–2. Ground Components

a. Required Components. For a complete ILS to be commissioned operational at an airport, the following ground components must be installed and operating within specified tolerances as determined by flight checks:

(1) Local transmitter (par. 15–3).

(2) Glideslope transmitter (par. 15–4).

(3) Outer marker beacon (par. 15–5*b*).

(4) Middle marker beacon (par. 15–5*c*).

(5) Approach lights (par. 15–6).

Note. Airports use several types of transmitting equipment, but the design differences are relatively minor.

b. Supplementary Components. The ILS is frequently supplemented by installing one or more of the following approach aids:

(1) *Compass locators* (par. 15–5*d*).

(2) *Transmissometers.* This device "looks" electronically down the instrument runway in the landing direction and either determines the runway visibility by reference to ordinary runway lights or computes the runway visual range (RVR) (par. 15–9) by reference to high-intensity runway lights.

(3) *Surveillance and precision radar systems* (ch. 16).

(4) *Distance measuring equipment (DME).* This aid, although normally installed at VOR, TACAN, and VORTAC sites, is occasionally installed at the site of the ILS localizer. With proper airborne receiving equipment, the aviator can read the distance to or from the transmitter at all times.

(5) *Visual approach slope indicator (VASI).* This aid provides by visual reference the same information that the glideslope unit of the ILS provides electronically. It provides a visual light path within the approach zone which the aviator can use for descent guidance during an approach to a landing. The basic principle of the VASI is that of color differentiation between red and white. The light units are arranged so that the aviator during approach will see the following colors:

(*a*) Above glideslope—all white lights.

(*b*) On glideslope—red above white lights (combination).

(*c*) Below glideslope—all red lights.

Note. The element of course guidance during the VASI-guided approach is obtained by reference to the runway lights.

(6) *Condenser-discharge sequenced flashing light system.* This system consists of a series of brilliant blue-white bursts of light flashing in sequence along the approach path in the approach light system (par. 15–6). This creates the illusion of one high-intensity light moving rapidly down the approach path toward the runway touchdown point.

(7) *High-intensity runway lights.* Special lights of high brilliancy used to outline the sides of the active runway.

(8) *In-runway lighting aids.*

(*a*) *Touchdown zone lighting* — two rows of transverse light bars placed symmetrically about the runway centerline in the runway touchdown zone.

(*b*) *Runway centerline lighting* — bidirectional lights recessed almost exactly in the center of the runway along most of its extent.

(*c*) *Taxiway turnoff lights* — flush lights defining the curved path of aircraft travel from the runway centerline to a point on the taxiway.

(9) *Runway and identifier lights* (*REIL*). These flashing light pairs provide rapid positive identification of the approach end of a particular runway.

Note. Consult current navigation publications to determine the exact supplementary ILS components available for specific airfields and airports.

Section II. OPERATION AND FLIGHT USE

15-3. Localizer

a. Location and Signal Pattern (fig. 15-1). The localizer transmitter is located near the end of the primary instrument runway opposite the approach end. It produces two signal patterns which overlap along the runway centerline and extend in both directions from the transmitter. One side of the signal pattern is referred to as the *blue* sector, the other as the *yellow* sector. The "beam" produced by the overlap of the sectors is usually from 4° to 5° wide. The portion of the beam extending from the transmitter to the right (fig. 15-1) is called the *front course.* The sectors are arranged so that, when flying inbound toward the runway on the front course, the blue sector is to the right of the aircraft and the yellow sector to the left. While flying inbound on the *back course* (extending from the transmitter to the left, (fig. 15-1), the blue sector is to the left of the aircraft and the yellow sector is to the right. Both the front course and the back course may be approved for instrument approaches; however, only the front course will be equipped with a glideslope and associated marker beacons and lighting aids. (Some major airports are equipped with two complete ILS installations (par. 15-2*a*), thus providing a front course for each end of the runway.)

b. Transmission Frequencies.

(1) Localizer transmitters are assigned 1 of 20 VHF channels, from 108.1 mc to 111.9 mc, as indicated below.

Localizer frequency	Corresponding glideslope frequency
108.1 mc	334.7 mc
108.3 mc	331.4 mc
108.5 mc	329.9 mc
103.7 mc	330.5 mc
108.9 mc	329.3 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	331.7 mc
111.3 mc	332.3 mc
111.5 mc	332.9 mc
111.7 mc	333.5 mc
111.9 mc	331.1 mc

(2) Only frequencies ending with an odd digit are assigned as localizer frequencies. Those within the same frequency band ending with even digits are assigned to VOR stations. The use of this frequency band provides the typical reception advantages of VHF, but also imposes the usual line-of-sight limitation (ch. 9). Since localizers and VOR stations have overlapping frequency bands, the same VHF navigation receiver is used with both types of stations.

c. Tuning. To tune a localizer transmitter

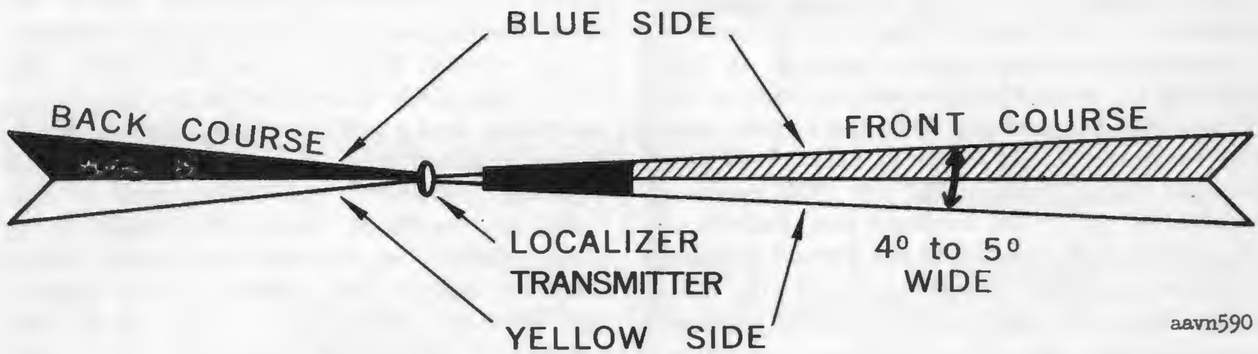


Figure 15-1. ILS localizer location and signal pattern.

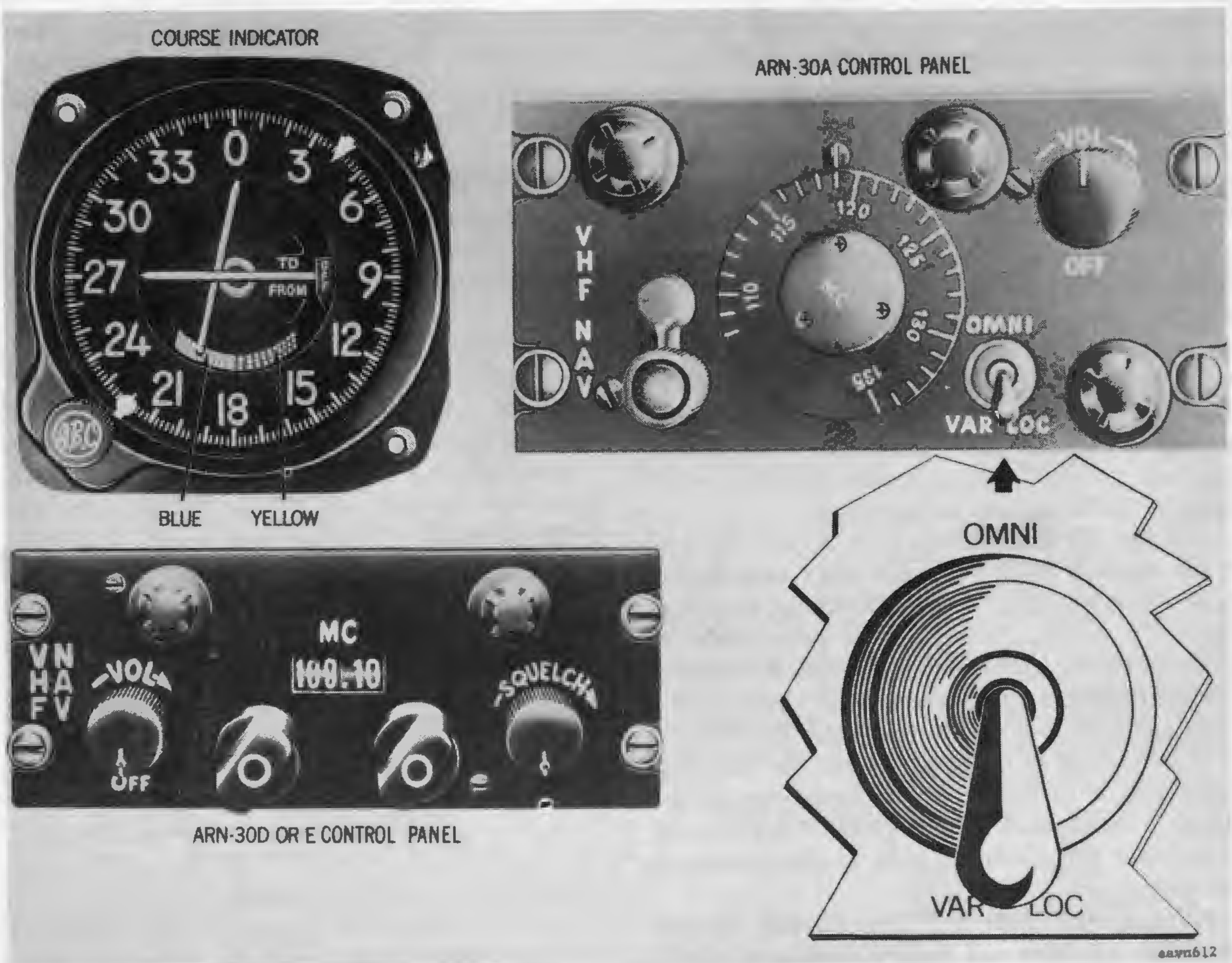


Figure 15-2. ID-453 course deviation indicator and control panels.

with the ARN-30A receiver, the selector switch (OMNI – VAR LOC) on the control panel (fig. 15-2) is placed in the VAR LOC position. This changes the functioning of the receiver to make it operate by signals from a localizer. In this function the course selector and the to-from indicator are disconnected from the circuit. Also the needle sensitivity of the deviation indicator changes from a total of 20° for VOR use to a total of 4° to 5° for localizer use. Failure to place the selector switch in the correct position will give unreliable results on the course indicator. The ARN-30D and ARN-30E receiver control panels (fig. 15-2) provide digital tuning of the station and eliminate the OMNI-VAR LOC selector switch. On these models the change in function to localizer is automatic when a localizer frequency is selected.

d. Flight Checks. Flight checks of the localizer will insure that it has a usable distance of at least 25 miles in a sector extending 30° on each side of the course line, from 1,000 feet above the highest terrain on the localizer course to 6,250 feet above site elevation. When reception at greater altitudes and distances is needed, appropriate flight checks must be made and the facility approved for use as required.

e. Identification and Voice. Localizer transmitters identify themselves continuously in code with the three-letter identifier assigned to the airport; however, the basic identification is preceded by the letter I; e.g., IOZR identifies the Cairns AAF localizer. The localizer channel usually is capable of simultaneous voice transmissions and is frequently used for transmitting air traffic control instructions.

f. Signal Failure. If there is a malfunction in the receiver or if, for some other reason, the localizer signal is not received reliably, the *OFF* flag will appear in the ID-453 course indicator at the bottom of the vertical needle. Automatic ground monitors are situated to provide a continuous check on ground equipment. If a failure or malfunction is detected, either the standby equipment is turned on or the broadcast of the signal is terminated. Alarm systems immediately indicate functional trouble to controllers at the airport.

g. Localizer Tracking. The ID-453 course indicator has blue and yellow markings on its face. The colors are arranged so that when the aircraft is proceeding inbound on the front course or outbound on the back course, the needle indications are directional. For example, if the aircraft flies into the blue sector (fig. 15-3), the needle is deflected to the blue (left), indicating that a left turn is required to return to the localizer track. However, if the aircraft is flying inbound on the back course or outbound on the front course, the needle is no longer directional although the color indications are correct. For example, if the aircraft flies into the yellow sector (fig. 15-3), the needle will indicate yellow (right), but the aircraft must turn left (away from the needle) to return to the localizer track. The amount of correction required depends on the distance between the aircraft and the transmitter. Corrections of 20° or more to return to the localizer may be necessary if the aircraft is following a track 25 miles away from the airport. However, during the latter part of final approach, corrections larger than 2 °to 5° are seldom required to remain on the localizer track.

15-4. Glideslope

a. Transmitter Location. The glideslope transmitter is located near the touchdown end of the runway, but is placed to one side so it will not cause a final approach hazard. Figure 15-4 shows a typical installation. These transmitters are located to produce a glideslope on the front course of the localizer. At some major airports there may be two complete ILS installations offering a front course approach with glideslope to each end of the primary instrument runway.

b. Signal Pattern.

(1) The normal elevation of the glideslope is 2½°, but this may be raised to 3° to provide adequate obstacle clearance. The absolute elevation of the 2½° glideslope above the base line at various distances is as follows:

¼ mile	65.5′
½ mile	131′
1 mile	262′
2 miles	525′
4½ miles	1,180′

(2) The thickness of the glideslope may

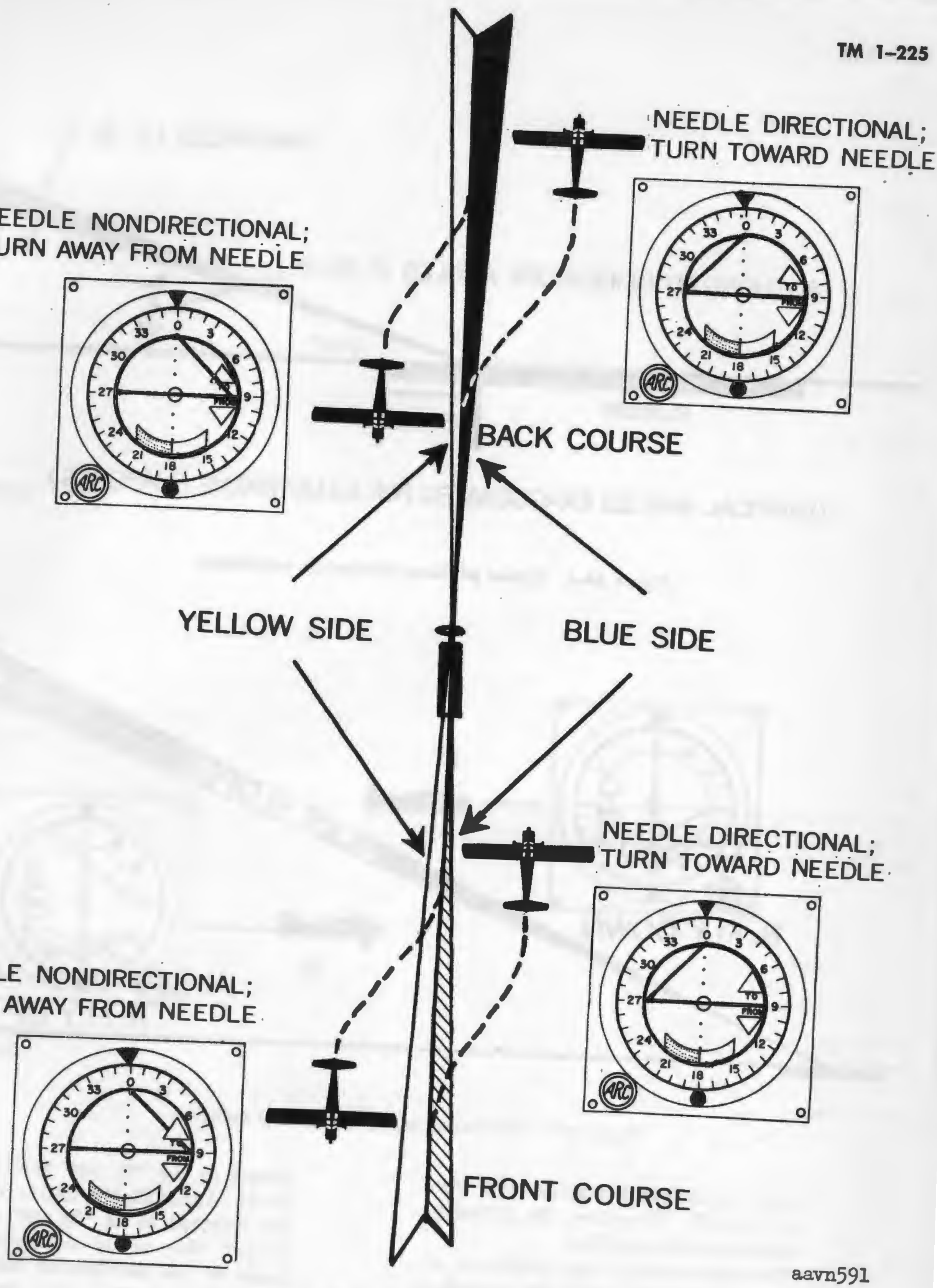


Figure 15–3. Localizer tracking.

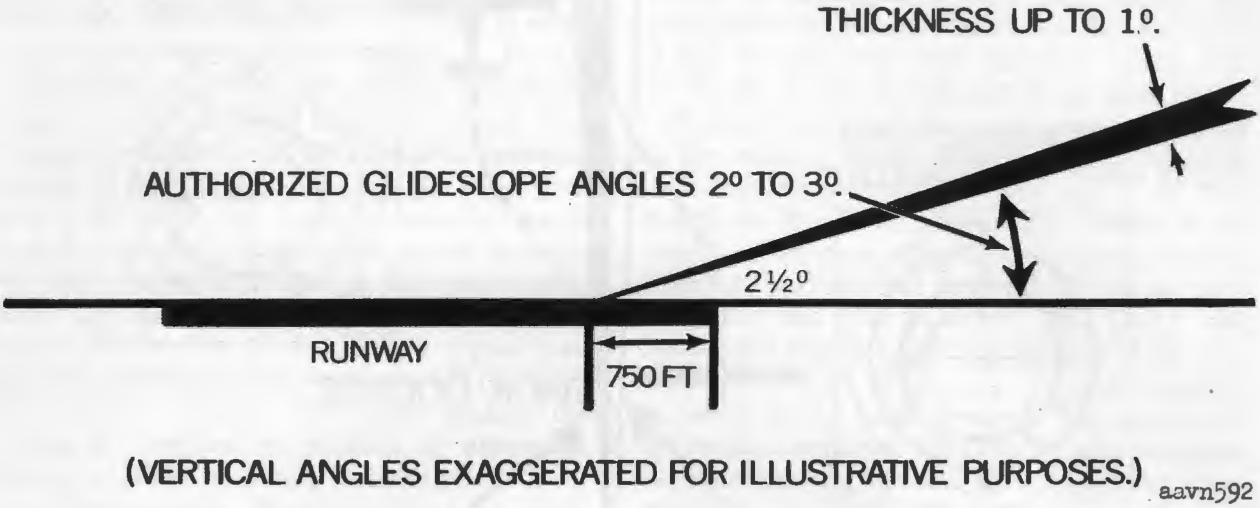


Figure 15–4. Typical glideslope transmitter installation.

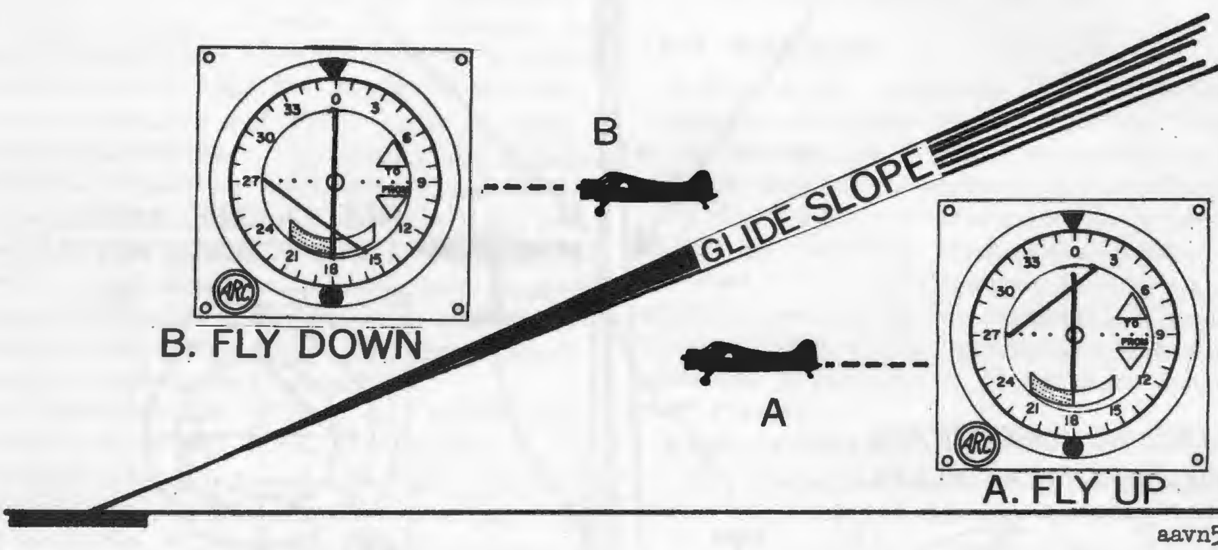
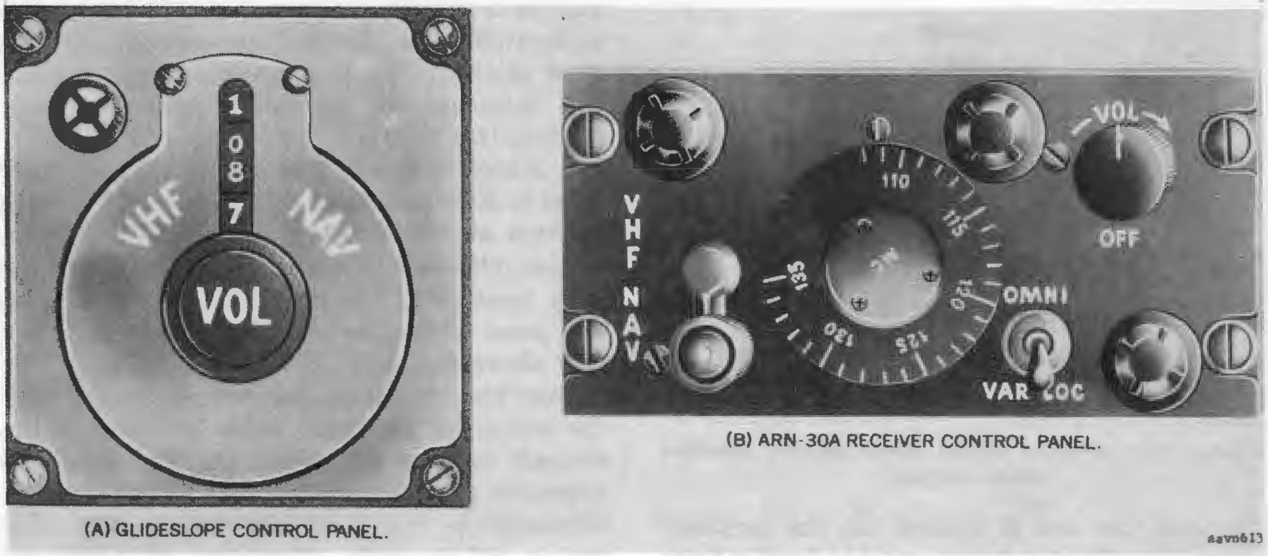


Figure 15–5. Directional aspect of glideslope indicator.

vary at different installations from 0.5° to 0.9°. Therefore, the glideslope needle is very sensitive.

(3) The indications of the needle are always directional; i.e., if the aircraft is below the glideslope, the needle is deflected to the "fly up" position (fig. 15–5). Although the needle reactions are referred to as "fly up" and "fly down," the actual corrections are made by the coordinated use of aircraft pitch controls and power set-



(A) GLIDESLOPE CONTROL PANEL.

(B) ARN-30A RECEIVER CONTROL PANEL.

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Figure 15-6. Coordinated tuning of glideslope receiver and VOR receiver (ARN-30A).

tings to adjust the attitude and rate of descent of the aircraft.

c. Tuning. Since glideslope and localizer frequencies are paired in predesignated combinations (see tabular data par. 15-3*b*), tuning of the glideslope transmitter is accomplished automatically and simultaneously with the tuning of the localizer on certain receiver sets. The Army receiver control panel ARN-30E provides for this arrangement. When the frequency of 108.7 mc is tuned on the ARN-30E, the corresponding frequency of 330.5 mc is automatically tuned on the glideslope receiver. On some aircraft there is a separate control panel for the glideslope receiver. However, instead of being graduated with the actual glideslope frequencies ranging from 329.6 mc to 335.0 mc, the control panel is graduated with the corresponding localizer channel. Therefore, to tune both receivers the aviator would set 108.7 mc on each control panel (fig. 15-6).

d. Signal Reception. Prior to tuning the glideslope receiver, the glideslope *OFF* flag is visible at the right end of the horizontal needle of the ID-453 course indicator. When the flag disappears, the signal is being reliably received. At any time the signal fails, the OFF flag will reappear. Interception and tracking of the glideslope signal is discussed in paragraph 15-8*c*.

15-5. Marker Beacons and Compass Locators

a. Marker Beacons. A *marker beacon* is a radio facility capable of transmitting a signal in a vertical direction only. Its signal is received only while flying directly over the facility (fig. 15-7). The primary purpose of the marker beacon is to provide the aviator with a definite radio position fix. The horizontal cross section of the vertical radiation pattern of a marker beacon resembles either an ellipse or a bone (fig. 15-8). The type used with ILS is the elliptical pattern. It is quite narrow so that an aircraft will pass through the pattern rapidly, thereby insuring the accuracy of the fix. Since all marker beacons transmit on a frequency of 75 mc, the receiver is preset to a 75 mc frequency to receive signals from any beacon. The marker beacon signal is modulated with a coded (or continuous) audio frequency for identification purposes. The marker beacon receiver is arranged so that the signal can be either heard in the headset or seen as a marker beacon light on the aircraft's instrument panel, or both.

b. Outer Marker. The outer marker is the

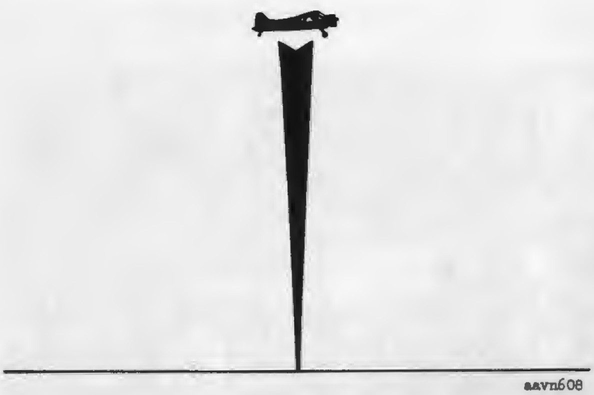


Figure 15-7. Marker beacon signal pattern (vertical cross section).

approach fix and is located on the localizer course, usually at a distance of 4 to 7 miles from the end of the runway. The ideal distance is approximately 4.5 miles (fig. 15-9). The outer marker transmits a signal of continuous dashes modulated at an audio frequency of 400 cps (low pitched). On final approach the aircraft will intercept the glideslope near the outer marker (fig. 15-9).

c. Middle Marker. The middle marker is located to provide a fix at approximately the same location at which the aircraft will reach approach minimum. Under typical conditions, the ideal location of the middle marker would be at a point where the glideslope elevation is 200 feet above the field elevation. Usually if the aviator has not established visual contact with the ground or approach lights by the time the aircraft reaches the middle marker, a missed approach will be executed. The middle marker transmits a signal of alternating dots and dashes on an audio frequency of 1,300 cps (medium pitched).

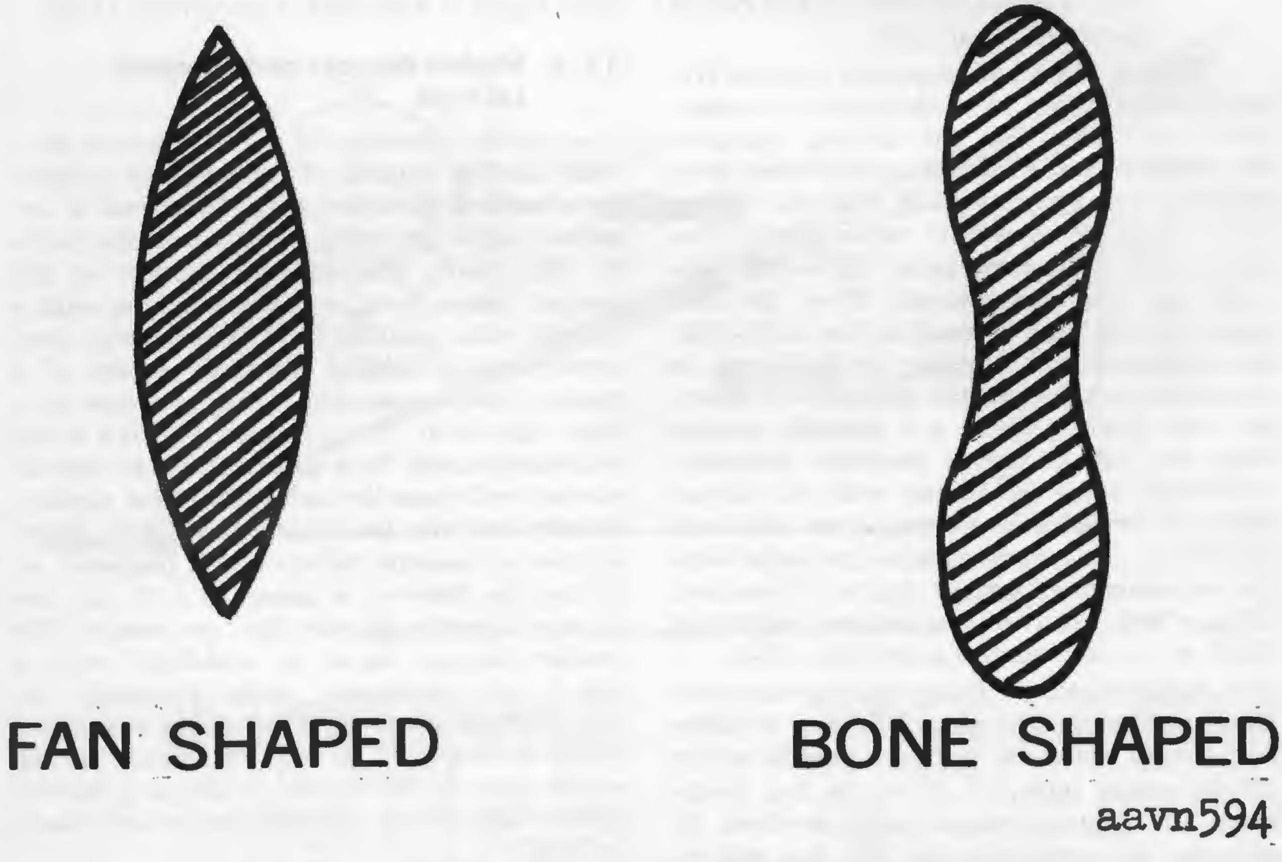


Figure 15-8. Marker beacon signal patterns (horizontal cross section).

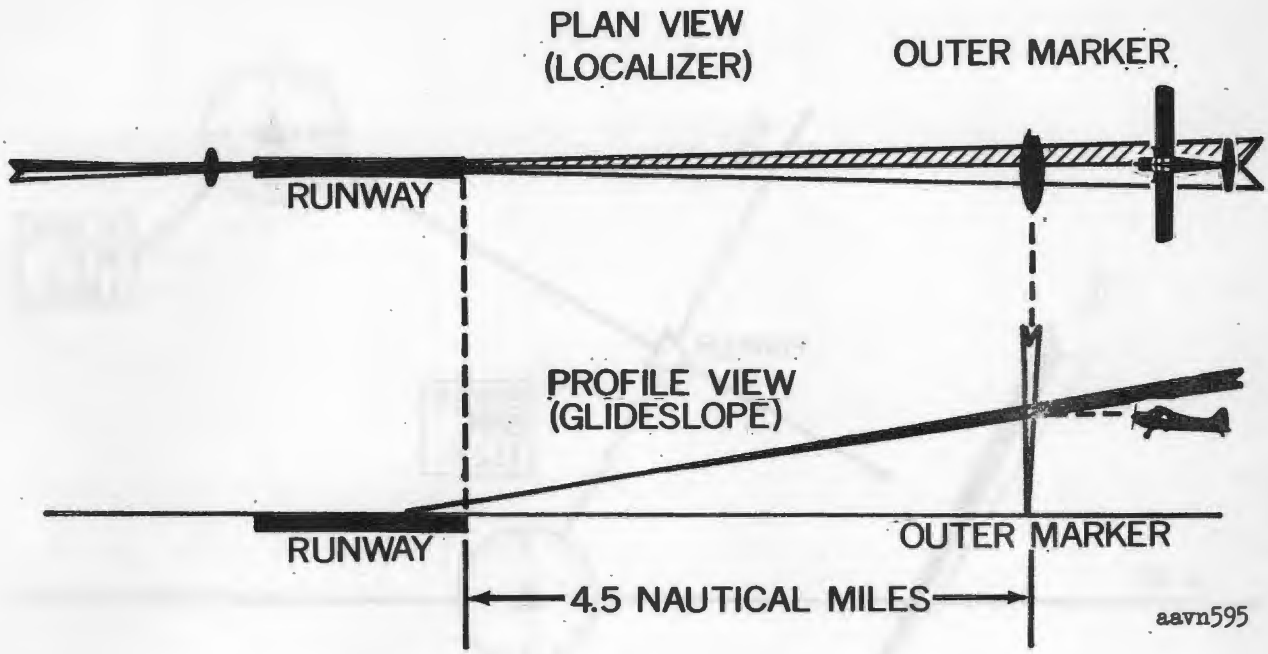


Figure 15-9. Outer marker location and signal pattern.

Note. Missed approach procedures vary, so instrument approach charts must be consulted for exact procedures at a particular airport.

d. Compass Locators. A *compass locator* is a nondirectional homing beacon (ch. 11). It is used with the ARN-59 ADF receiver and is a supplementary component of the ILS. Two normally are used — one at the outer marker site and another at the middle marker site (fig. 15-10). The combination of a marker beacon and compass locator at the outer marker site is referred to in navigation publications as an *LOM;* i.e., *L* — compass locator and *OM* — outer marker. *LMM* refers to a compass locator and middle marker beacon situated together at the middle marker site. Compass locators are low-powered facilities which normally have a reliable range of 15 miles. These locators are used in two ways: (1) they aid the aviator in transitioning to the outer marker from other fix or facility in the area, and (2) the compass locator feature may be used as a final approach fix if the marker beacon or marker beacon receiver fails. Compass locators transmit identification in code. The outer compass locator transmits the first and second letters of the basic airport identification (e.g., the outer) compass locator at Cairns AAF (OZR) would transmit OZ as its identification). The middle compass locator transmits the second and third letters of the basic airport identification (e.g., ZR is the middle compass locator identification for Cairns AAF).

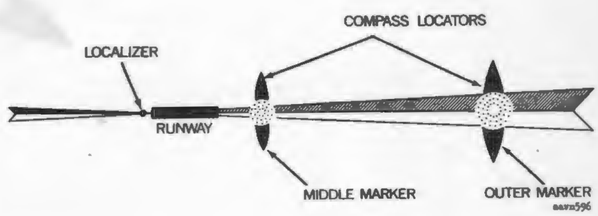


Figure 15-10. Compass locator positions.

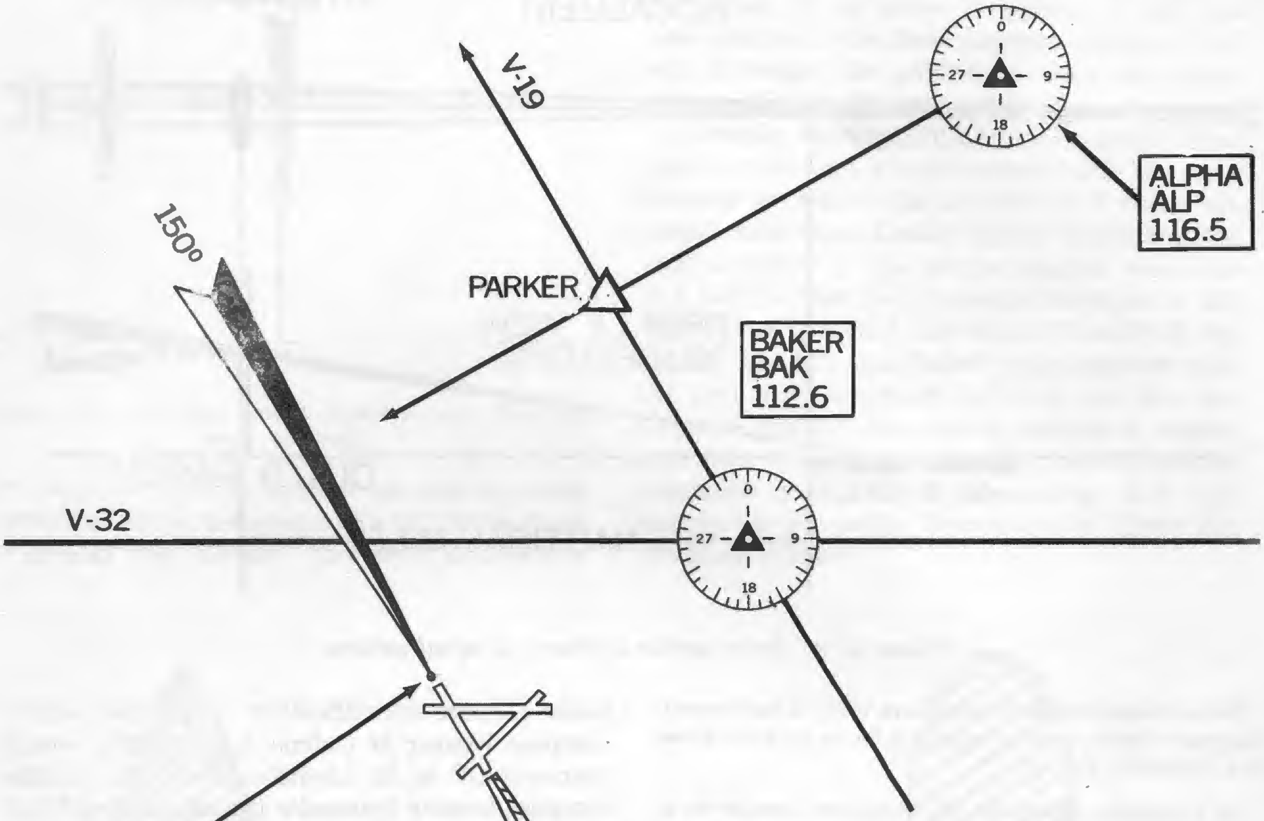


Figure 15-11. Typical area chart representation.

15-6. Approach Lights

Several different approach lighting systems are used at airports as an integral part of the ILS. Current navigation publications contain characteristic features of specific systems, e.g., approach lights and high-intensity approach lights. However, all approach lighting systems are designed for the same purpose — to provide the aviator with a visual aid in completing the last phase of his approach. The electronic aids are designed to guide the aircraft to reasonably low ceiling and visibility minimums; e.g., 200 feet and ½ mile. The lighting aids assist the aviator in establishing visual contact with the runway and in completing the approach visually. Approach lights are situated in the final approach path within the last ¼ to ½ mile of the final approach. When the approach lighting system fails, the ceiling and visibility minimums for the instrument approach are normally increased. (Consult approach charts and their legends for specific airport approach lighting data.)

15-7. Transition

Figure 15-11 shows an airport with the localizer course and LOM in relation to the airways network, and the related facilities in a given area. The sequence of arrival in the area, transition to the ILS, and the ILS approach (without the use of radar) might typically proceed as follows:

a. Army aircraft 64264 is inbound to Baker VOR (BAK) from the northwest on airway V-19. The aviator has been instructed to establish contact with Baker approach control over Parker intersection:

(1) Aviator: "Baker approach control, Army 64264 — estimating Baker VOR at 30 at 3,000, over."

(2) Approach control: "Roger Army 64264, you are cleared from Baker VOR to the Baker LOM direct; maintain 3,000 feet; no delay expected. Current weather: measured ceiling 300, visibility ¾, light rain, fog, altimeter 29.98."

(3) Aviator: "Army 64264, Roger, out.".

b. The aviator analyzes the clearance and observes that he has not been cleared to hold. The controller is expecting to clear him for the approach with no delay just 2 minutes after his ETA for the VOR. He also notes that he has been cleared to continue at 3,000 feet and, by referring to the approach chart (fig. 15-12), that the procedure turn altitude is 2,000 feet. The approach chart also shows the distance and direction from the VOR to the LOM (8.1 miles and 195°). The aviator knows he will be able to receive the compass locator signal at least 7 miles before arriving at the VOR.

c. The aviator tunes the ADF receiver (ARN-59) to the outer compass locator (279 kc) and attempts to get an accurate, positive identification (BA). The aircraft (Army 64264) is equipped with only one VHF navigation receiver (ARN-30A) which remains tuned to Baker VOR until arrival at the station. However, this aircraft has a glideslope receiver and, although the aviator is not in a position to use it yet, he tunes the glideslope receiver by turning it on and setting the 109.5 mc frequency in the window. The actual glideslope frequency of 332.6 mc is paired with the localizer channel of 109.5 mc (par. 15-3*b*). The glideslope warning flag will not disappear until the aircraft is in position to receive a reliable signal from the glideslope transmitter.

d. Upon arrival at the VOR the aviator observes station passage, turns to 195°, and reports:

(1) Aviator: "Army 64264 Baker VOR 30, over."

(2) Approach control: "Roger Army 264, you are cleared for an ILS approach to runway 33, wind north-northwest, 6 knots, over."

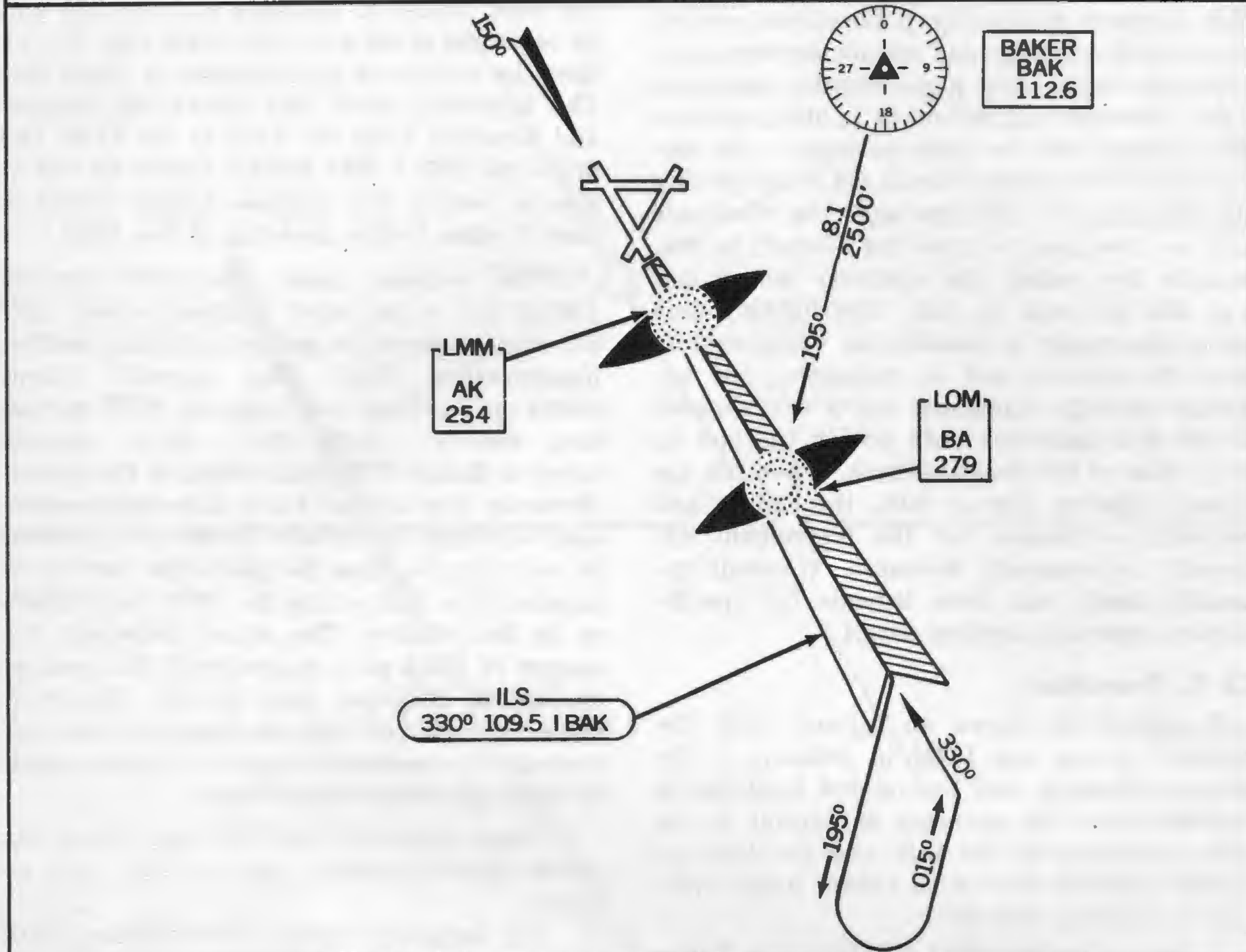
(3) Aviator: "Army 264, Roger, out."

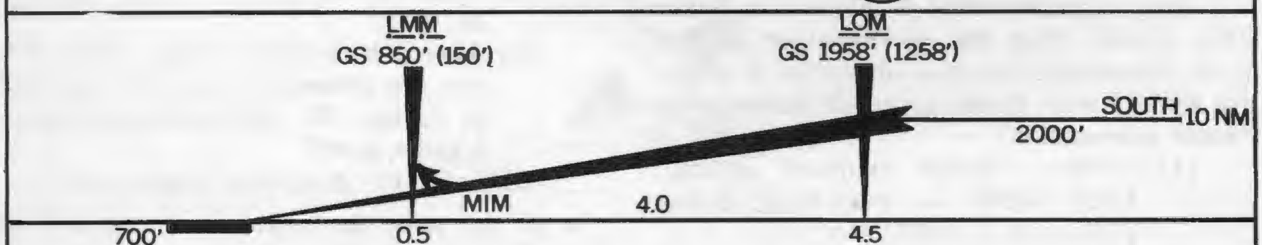
e. At this point the aviator performs each of the following actions:

(1) Cross-checks heading (195°) and ADF relative bearing (0°) to verify that aircraft is proceeding directly to the LOM.

(2) Tunes VHF navigation receiver (ARN-30A) to 109.5 mc, setting the selector switch to VAR LOC position. Verifies identification IBAK, checks for disappearance of OFF flag, and

RADIO FREQUENCIES	APT. ELEV. 700 FEET GS 332.6	BAKER, USA BAKER MUN. ILS/NDB (ADF) 33 LOC 109.5 I BAK





PULL UP: TO 3000 (2300) FEET ON NORTWEST COURSE ILS OR 330° FROM BA LOM WITHIN 15NM.

FAA MINIMA LANDING	STRAIGHT IN RWY 33				CIRCLING	
	ILS	w/o glide slope	LOC+OM	NDB		
PROP 1 & 2 ENG TO 65K	200-½ OR RVR 24	400-¾	400-1	500-1		

GROUND SPEED-KNOTS	60	80	100	120	140	160	CEILING/ALTITUDE CONV.			
GS DESCEND 2° 31'	267	356	445	534	623	712	QFE	200	300	400
LOM TO PULL UP	4:30	3:23	2:42	2:15	1:56	1:41	QNH	900	1000	1100

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Figure 15-12. Typical approach chart (data incomplete).

observes that the needle is deflected to blue side of instrument.

(3) Checks minimum authorized transition altitude (2,500 feet (fig. 15-12)), reports leaving 3,000 feet, and descends to 2,500 feet. This is the recommended procedure because the aviator is already cleared for the approach and can lose an additional 500 feet prior to executing the procedure turn.

(4) Checks the indications of the localizer needle. It should be in the blue sector (full left deflection) and should move rapidly when the aircraft gets within 2½° (5° localizer) of the localizer course.

(5) Cross-checks power switch on marker beacon receiver to verify that it is turned on with appropriate volume setting. The marker beacon signal (continuous dashes — low pitched) will be detected as the aircraft flies over the LOM.

(6) Cross-checks the glideslope warning flag. As the aircraft flies into a good reception position with the receiver tuned, the flag will disappear (*c* above).

(7) Checks the instrument approach chart, noting the direction, limiting distance, and minimum altitude for the procedure turn. (The aviator has previously studied the approach and is familiar with it.) In this situation, the procedure turn is nonstandard, within 10 miles of the LOM, and at a minimum altitude of 2,000 feet. Also, the aviator has previously determined that his minimums for this approach are 200 feet and ½ mile and, since the current weather is 300 feet and ¾ mile, he does not expect any difficulty in completing the approach visually.

f. After flying the 8.1 miles from the VOR, the aviator detects passage of the LOM by reversal of the ADF indicator and simultaneous reception of the marker beacon signal (light and tone). Also, the localizer needle has centered, or if the aviator's reaction is delayed, the localizer needle may pass slightly through the center position.

15-8. Approach

With the transition to the ILS complete, the aviator flies outbound for the procedure turn.

a. During this phase the aviator —

(1) Turns to the outbound heading (150°) and checks the position of the localizer needle and ADF indicator. The color indication of the needle is correct, but while flying outbound on the front course, track corrections are made by turning away from the needle. If the needle deflects to the yellow (right), the aviator turns left. The ADF needle will be approximately on the tail (180°) but will deflect if the aircraft flies off track. If the aircraft drifts into the yellow sector while maintaining the outbound heading of the front course, the ADF will show a relative bearing greater than 180° (left of tail).

(2) Flies outbound approximately 1 minute. The actual limiting distance (usually 10 miles) is shown on the profile of the instrument approach chart.

(3) Begins descent to the procedure turn altitude — in this case, 2,000 feet. Since only 500 feet is to be lost, the maximum rate of 500 fpm may be used.

(4) Executes the procedure turn by turning (in this case) to the right 45° to a heading of 195°. Holds this heading for approximately 40 seconds (ch. 13), and then completes the procedure turn by turning left to intercept the localizer course inbound.

(5) Upon intercepting the localizer inbound, continues inbound on the final approach course (330°).

(6) Checks the localizer needle (centered) and ADF indicator (relative bearing 0°). If the aircraft flies off track, corrects by turning toward the localizer and ADF needle.

(7) Checks the position of the glideslope needle. It should be above center ("fly up" position), indicating that the actual glideslope is above the procedure turn altitude. Notes that the profile view on the approach chart (fig. 15-12) indicates that the glideslope will be intercepted just prior to passing the LOM inbound. Rechecks to verify that the glideslope OFF flag is out of sight. Begins descent on glidepath.

b. Upon reaching the LOM inbound, the aviator observes the marker beacon signal, ADF reversal, checks for centered glideslope needle at 1,958 feet indicated altitude, and reports —

(1) Aviator: "Baker approach control, Army 64264 outer marker inbound at 38, over."

(2) Approach control: "Roger Army 264, cleared to land runway 33. Wind: north-northwest 8 knots, altimeter 29.97, over."

(3) Aviator: "Army 264, Roger, out."

c. During this final phase of the approach, the aviator —

(1) Sets up the proper rate of descent on the glideslope after lowering the landing gear and setting flaps for final approach. In this case, assume that the final approach groundspeed is 80 knots. The approach chart (fig. 15-12) indicates the rate of descent as 356 feet per minute. This rate can be achieved by proper coordination of aircraft controls and power.

(2) Checks the glideslope pointer. Makes glideslope corrections by following the needle (i.e., "fly up" and "fly down"). Corrections are made by varying the rate of descent through the coordinated use of aircraft controls and power.

(3) Checks the deviations of the localizer needle. Only minor corrections should be necessary to keep the needle in the centered position.

(4) Observes the altimeter. The approach chart (fig. 15-12) shows the approach minimums to be 200 feet and ½ mile. The field elevation is 700 feet. The lowest *indicated* altitude to which the aircraft may descend on the glidepath is 900 feet.

(*a*) When making an ILS approach with a glideslope receiver, the aviator initiates a missed approach when the minimum authorized altitude is reached and visual contact with the runway is still not established.

(*b*) When making an ILS approach without a glideslope receiver, the aviator must time his progress on the final approach course by using the aircraft clock (e.g., according to the approach chart (fig. 15-12), the time to fly from the LOM at a groundspeed of 80 knots is 3:23 (3 min. and 23 sec.)).

(5) Checks for visual contact with approach lights. At the time definite visual contact is established, the approach can be completed without further reference to localizer and glideslope instruments.

(6) Observes LMM passage. The marker beacon signal will be medium-pitched alternating dots and dashes. If the ADF receiver has been retuned to the locator at the middle marker (254 kc), the ADF needle will reverse as the aircraft passes the LMM.

Note. If the aircraft has been equipped with dual ADF receivers, one receiver would have been tuned to each of the compass locators.

(7) If visual contact is established, completes the approach.

(8) If visual contact is not established, or if for other reasons the approach cannot be completed, executes the missed approach procedure as published on the approach plate (fig. 15-12). In this event the aviator would report, "Baker approach control, Army 64264 missed approach at 41 . . . . " This

report would be followed by a request for another approach or a clearance to the alternate airfield. If requesting clearance to the alternate airfield, the aviator would give the necessary flight plan data.

15-9. Runway Visual Range (RVR)

a. A number of airports are equipped with transmissometers and related equipment for determining the distance that can be seen down the runway from the approach end. If the determination is based on *high-intensity* runway lights, this distance is known as the *runway visual range* (RVR). RVR values have proven to be accurate and reliable; consequently approach minimums, in some cases, are based on RVR.

b. Figure 15-12 shows published approach minimums for a straight-in ILS of 200 feet and ½ mile, RVR 24. This means that an RVR value of 2,400 feet is authorized as a minimum for beginning the approach in lieu of the 200-foot ceiling and ½ mile visibility. To apply the 2,400 feet as a minimum in a particular case, the aviator must be sure that all required ground equipment and airborne receivers are operating. This includes VHF navigation (localizer) receiver, glideslope receiver, marker beacon receiver, ADF receiver, and adequate two-way voice communications. Army aviators must also insure that appropriate Army and Federal regulations authorize the application of RVR minimums for their particular situations. Assuming that all required equipment is operating and that the aviator is authorized to use RVR minimums, he could *start* the approach regardless of the reported ceiling and visibility if the reported RVR was at least 2,400 feet. However, after starting the approach the aviator must establish visual contact with the approach lights or be clear of clouds before descending below 200 feet. Where the aviator can approach to within 200 feet of the lights, he usually will have little difficulty in establishing visual contact if the reported RVR is equal to or better than the published RVR minimum.

Note. Refer to current navigational publications and regulations for additional information on RVR. As improved equipment becomes operational, changes in procedures and regulations will occur.

15-10. Use of the Back Course

a. The localizer transmitter produces a front and a back course; the front course is usually equipped with all required components for a complete ILS (par. 15-2*a*). The back course is frequently used as an additional approach course, but it provides azimuth guidance only. Altitude on the final approach is controlled with reference to the altimenter, as in VOR and ADF approaches (ch. 14). An approach fix must be established at some suitable location on the back course. Such a fix is necessary to establish minimums for the procedure turn and the descent on final approach. Figure 15-3 illustrates a back course with a fix established by a radial from a nearby VOR station. Since the localizer and the VOR are both received on the same receiver, the procedure of tuning first one facility and then another may become a problem. Use of dual VHF navigation receivers solves this problem; in some instances, the back course approach procedure is restricted to aircraft equipped with these dual receivers. Notations on the approach chart indicate such restrictions.

b. A back course approach can be useful in situations similar to the one which follows (fig. 15-13): Army 12126 is approaching Zulu VOR on V-22 from the west. Current weather reports indicate that the ceiling and visibility at the airport are 900 feet and 2 miles. The wind is southeast at 15 knots. A back course approach is authorized and published for the airport; it shows back course approach minimums at 400 feet and 1 mile. Since the aircraft is approaching the RIX intersection from the west, it is in an ideal position for a back course approach. Since the wind is southeast, the active runway will be number 15. The current ceiling and visibility is well above authorized back course minimums. All things considered, there would be no advantage in executing a front course approach. Therefore, the aviator requests and receives clearance for a back course approach. He executes the approach as follows:

(1) Maintains a previously determined

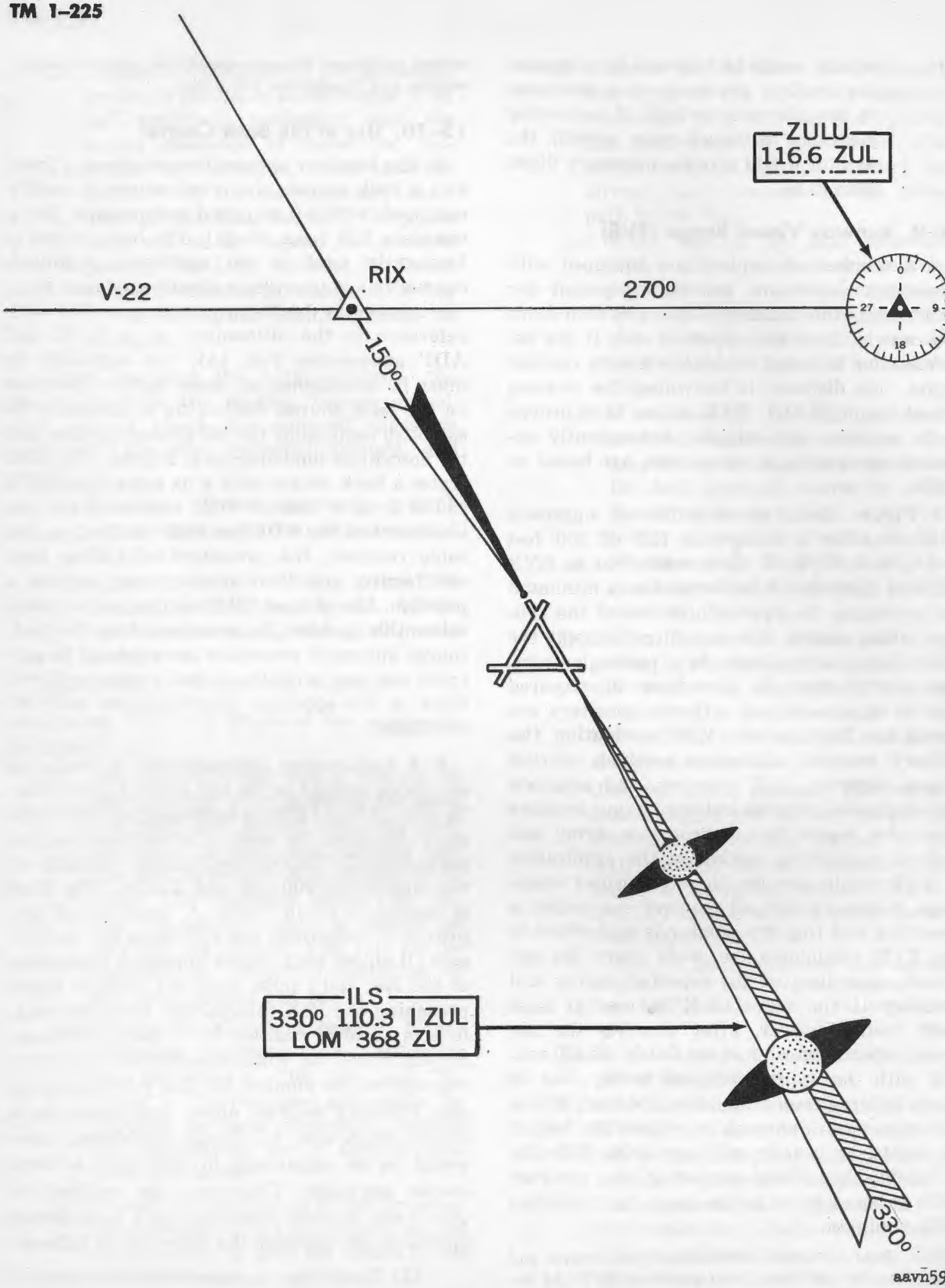

Figure 15-18. Typical back course approach (ILS).

heading which will keep the aircraft on V-22.

(2) Tunes the VHF navigation receiver to the localizer (110.3 mc) and identifies the station (IZUL). Checks the disappearance of the *OFF* flag.

(3) Checks the indication of the localizer needle. Since the aircraft is west of RIX in the yellow sector, the needle will be deflected to the yellow side (right deflection).

(4) For backup information, tunes the ADF receiver to the compass locator at the middle marker.

Note. The outer compass locator may be used if the signal is reliable. The middle locator is closer and may give a better signal.

(5) Determines arrival at RIX by observing the centered localizer needle and cross-checking the ADF for a relative bearing of 060°.

(6) Turns outbound on the localizer course to execute the procedure turn. Completes the procedure turn as published.

(7) Tracks inbound to RIX, descending to appropriate minimums.

Note. While tracking inbound on the back course, make tracking corrections away from the needle; e.g., if the needle deflects to the yellow (right), a left turn is necessary to correct. Cross-check course indicator deflections with the relative bearing changes on the ADF.

(8) Prior to reaching RIX, tunes the VHF navigation receiver to the VOR in order to establish the 270° radial at the intersection.

Note. To allow sufficient time for establishing a tracking heading inbound, the procedure turn can be executed at a distance up to 10 miles. The outbound leg can be extended at the discretion of the aviator if the published limitations are not violated.

(9) Fixes the RIX intersection, reports, and begins the descent on final approach.

(10) Retunes the VHF navigation receiver to the localizer. Checks for a centered localizer needle. Cross-checks with the ADF indications and makes minor corrections as necessary. Continues descent to approach minimums.

(11) When visual contact is established with the ground, completes the approach visually.

Caution: **In cross-tuning the ARN-30A VHF navigation receiver from the VOR to the localizer, the aviator must place the selector switch (OMNI - VAR LOC) in the correct position.**

CHAPTER 16

RADAR

Section I. PRINCIPLES

16-1. Radar Distance

Radar (radar detection and ranging) operates through the timed reflection of ultra high frequency radio waves. A radar transmitting antenna sends out a powerful burst of radio energy which travels essentially in a straight line. Some of this energy is reflected back to the antenna from the surface of the target. This reflected energy is fed into the radar receiver, where it is amplified to produce an image (blip) on a special cathode-ray tube (scope). Since the speed of the transmitted radio energy is a constant 186,000 miles per second, the time interval between the sent impulse and the returning reflected energy can be automatically computed into a value of distance between the transmitter-receiver and the target. For example, in approximately 10.75 millionths of a second (microseconds), radar waves travel 1 radar mile (fig. 16-1). A radar mile is a round trip of 2 miles — transmitter to target tnd target to receiver. Therefore, any target returning an echo in 10.75 microseconds shows up on the calibrated radar scope as a target which is 1 mile from the radar transmitter.

Note. The term *radar*, as used in this chapter, refers to *primary radar* except as explained in section IV.

16-2. Radar Azimuth

To be useful in controlling air traffic, radar must provide target azimuth information in addition to distance. The radar antenna can be rotated through its 360° horizon, or through any desired arc of its horizon, to obtain the azimuth data needed. As the antenna rotates, a narrow beam of transmitted radar energy sweeps the selected area. When these radar waves strike a target and return, a "blip" forms on the radar scope. Since the scope is graduated in degrees of azimuth and with range markings, the radar operator can simultaneously estimate the range and azimuth of a target according to its image in the scope.

16-3. Transmitter-Receiver Operation

a. The Duplexer. When the radar waves strike a target and return, the same antenna

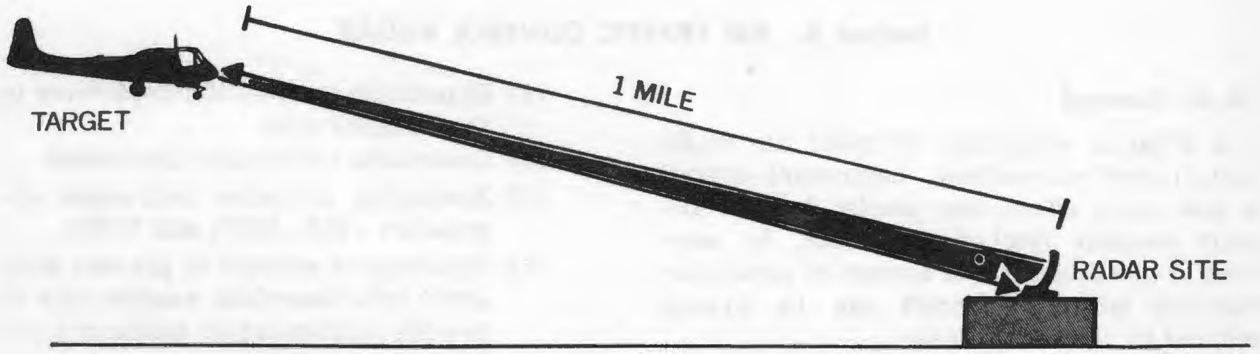

Figure 16-1. The radar mile.

that was used to transmit them is used to receive them. This dual antenna function is made possible by the *duplexer,* a transmit-receive (T-R) box. This device separates the receiver and the transmitter actions, alternately, as each is put into operation.

b. The Plan Position Indicator (*PPI*). The reflected signal echo is fed to the radar scope to present target information in usable form. The type indicator (scope) used is based on the information desired. The plan position indicator (fig. 16-2) is used when both azimuth (bearing and range (distance) information are desired simultaneously. The PPI is a cathode-ray tube (CRT) similar to a television picture tube. It presents a mapping of the area surrounding the antenna by variations in light intensity on the face of the tube. The electron gun of the CRT sends out a beam of electrons which strike the sensitized surface of the scope. A yoke deflects this beam from the center of the scope to the edge. This recurring deflection toward the edge is called a *sweep;* The sweep traces a fine light line on the face of the scope. To eliminate the need for a semidark scope environment, many recent radar indicators use a TV-type picture tube.

c. Antenna Synchronization. For accurate azimuth information, the antenna position with respect to magnetic north must be known at all times. In the PPI this orientation is accomplished by rotating the sweep through 360° in synchronization with the antenna. The electron beam starts its sweep at the exact time the transmitter pulse is sent out from the antenna. The sweep moves outward at a rate proportional to the radar pulse movement. When a reflected signal is received, it is fed to the electron gun of the CRT. The beam of electrons is intensified for that instant of the sweep, so that a blip appears on the face of the scope. This distance of the blip from the starting point of the sweep is, therefore, a measure of the distance the radio pulse traveled out to the target and back. Thus, the range and azimuth of any target in the area of radar coverage is presented to the radar operator.

Note. Permanent objects such as buildings, trees, and mountains also appear on the scope. To eliminate these undesirable targets, a device called a moving target indicator (MTI) is used to prevent scope display of stationary targets.

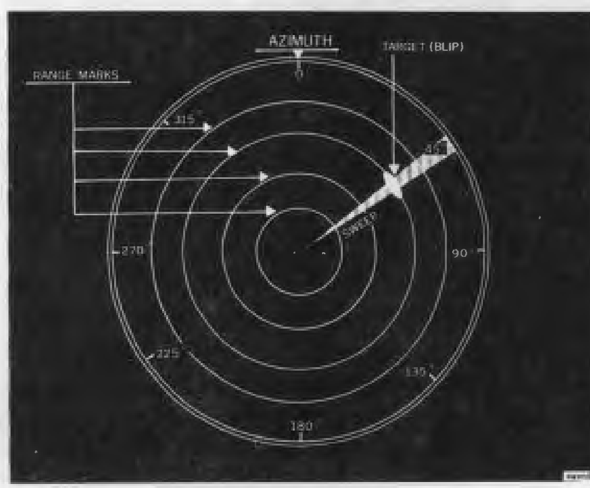

Figure 16-2. The plan position indicator (*PPI*).

Section II. AIR TRAFFIC CONTROL RADAR

16-4. General

a. A great advantage of radar air traffic control over conventional (nonradar) control is that radar offers very precise data on aircraft location (including altitude, in some cases); consequently, the amount of separation required between aircraft can be greatly reduced by the use of radar.

b. Major air traffic control uses of radar include—

(1) Resolving en route traffic conflicts.

(2) Expediting arrivals and departures in the terminal area.

(3) Controlling instrument approaches.

(4) Monitoring nonradar instrument approaches (ILS, ADF, and VOR).

(5) Vectoring of aircraft to prevent their entry into hazardous weather and to provide supplementary means of navigation.

(6) Providing radar weather and traffic advisories.

c. Virtually all radar air traffic control relies on one of the types of surveillance radar discussed below.

16-5. Air Route Surveillance Radar (ARSR)

The use of long range radar for control of traffic by the Air Route Traffic Control Centers (ARTCC's) is standard procedure. The range of this type radar is approximately 200 miles, with altitude coverage to 40,000 feet. Since the area of control of an ARTCC normally is more than 200 miles, more than one radar is required to give complete coverage.

a. ARSR indicators normally are centrally located in the air traffic control center. However, the antennas are remotely located at outlying sites selected to produce the best radar coverage of the area. An outlying radar unit can serve two or more centers simultaneously.

b. Either transparent map overlays or electronically displayed video maps are normal for use on the controller's scope to indicate the location of radio navigational aids, airways, and reporting points. In effect the controller can see all of the air traffic within his area of responsibility (fig. 16-3).

16-6. Airport Surveillance Radar (ASR)

The normal radar equipment for airport surveillance is the PPI type discussed in section I. The range of ASR is usually a 30 to 50 mile radius from the antenna site. An overlay on the scope or a video map (par. 16-5*b*) shows facilities and landmarks in the area. The two basic purposes of ASR are (1) for radar approaches (sec. III) and (2) for radar control of air traffic in the terminal area by approach control facilities.

16-7. Airport Surface Detection Equipment (ASDE)

Improved instrument landing facilities, combined with high intensity lighting aids, make continued aircraft operations possible during extremely adverse weather conditions. It is possible, however, to complete an instrument approach only to find visibility too restricted to taxi the aircraft from the runway. Since the runway must be clear for each landing aircraft, the rate of landings depends on the time of runway occupancy by the aircraft. The ASDE is used to alleviate runway congestion; it is basically a short range radar designed to scan the ground rather than the sky. The normal 1-mile area of coverage is displayed on the same size scope as the ASR. This offers the ground controller a magnified, detailed view of the entire airport. With this advantage the controller can direct the movement of ground traffic efficiently, day or night, in any weather condition (fig. 16-4).

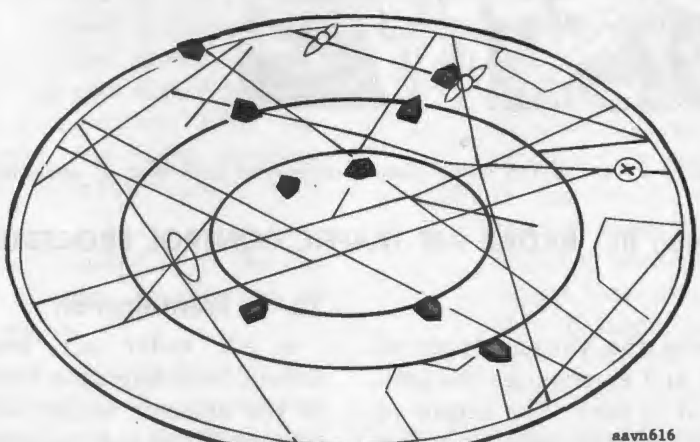

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Figure 16-3. Air traffic control radar.

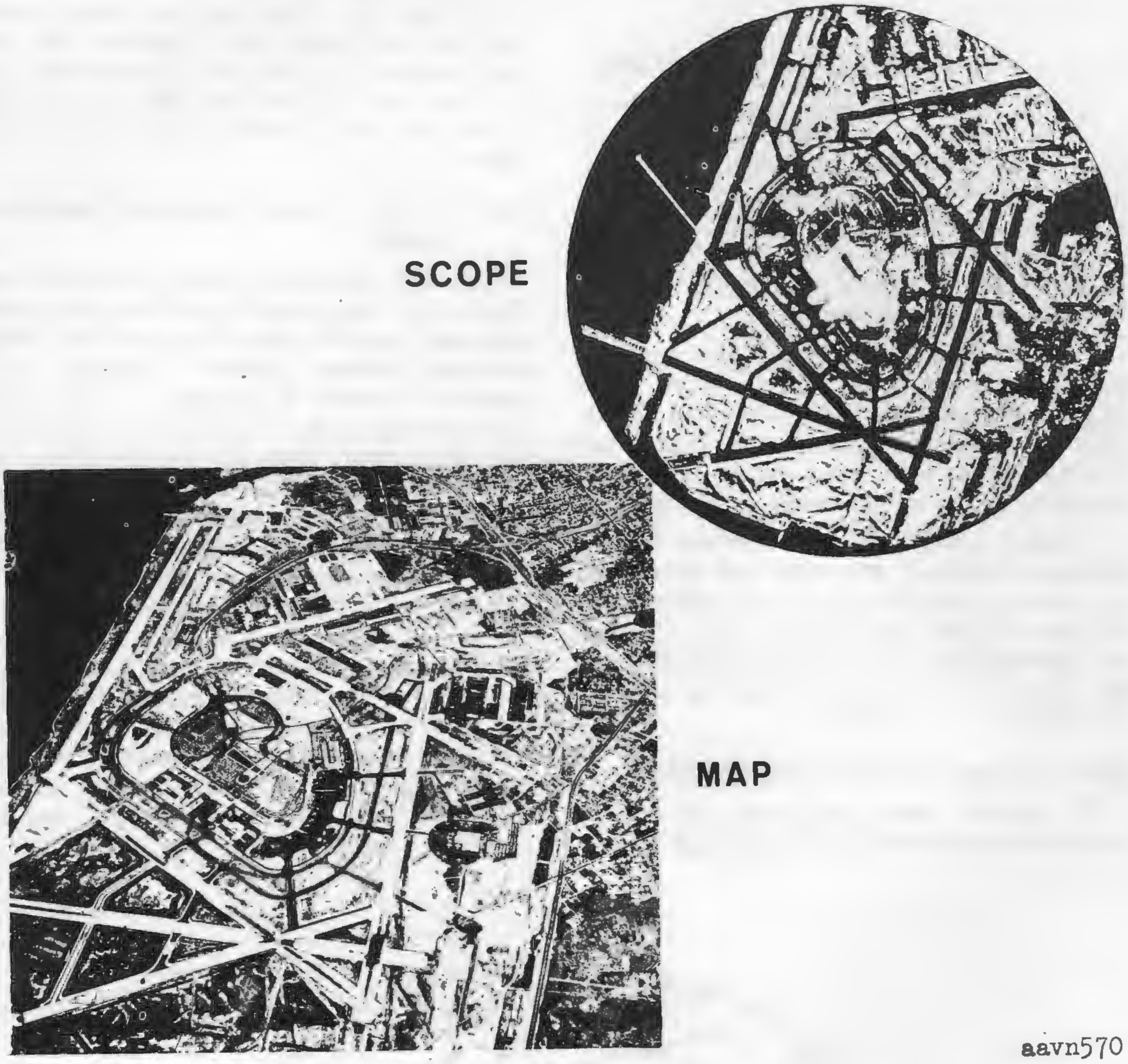


Figure 16-4. ASDE scope picture compared with map of same area.

Section III. RADAR AIR TRAFFIC CONTROL PROCEDURES

16-8. General

This section discusses the various types of radar control services and emphasizes the general principles involved in each. For details of the techniques and procedures used by radar controllers, see TM 11-2557-27 (FAA publication, ATP 7110.1B).

16-9. Identification

a. All radar air traffic control services depend basically upon the positive identification of the aricraft target being controlled. Radar control is lost the moment identification is lost. Positive target identification can be accomplished in several ways. For example—

(1) A departing aircraft is observed on the radar scope within 1 mile of the takeoff runway.

(2) A single aircraft target is observed on the scope at a definite radio fix over which that aircraft has just reported.

(3) An aricraft is required to execute one or more turns of at least 30°. The target which responds to the controller's turning instructions is thereby identified.

(4) A coded transmission is received from a radar beacon transponder in the controlled aircraft (sec. IV).

b. If radar identification is lost, the radar controller, immediately advises the aviator. He then issues instructions and clearances to the aviator to permit resumption of conventional control.

16-10. Transfer of Radar Control (Handoff)

a. If aircraft under radar control are being transferred from one controller to the radar controller of an adjacent sector, the *handoff* must be accomplished without loss of identification. Several methods for transferring control are discussed below.

(1) One controller provides another, in an adjacent sector, with the observed distance and azimuth of the aircraft from a definite fix or transfer point. The receiving controller advises the other controller when he has positive identification. Control of the aircraft is held by the original controller until the other one has established positive identification and control. (For this type of transfer, the radar coverage areas of the adjacent sectors must overlap.)

(2) Another handoff method is by the use of the radar beacon transponder, as explained in section IV.

(3) If radar control is being transferred to a nonradar sector, the aviator can be given appropriate communications instructions and clearance which permits the nonradar controller to assume control through a positive position report of the aircraft at a predesignated fix.

(4) Handoff from a nonradar controller to a radar controller is completed when positive radar identification has been established.

b. Radar handoff from en route control to approach (arrival) control is accomplished at an outer fix. Since the area of surveillance coverage at a terminal may vary from 25 to 50 miles, the outer fix established as the release point can be a considerable distance from the destination radio facility. Normally each radar controller uses from two to four outer fixes for traffic release to his control. These outer fixes are established conveniently along arrival routes to assure efficient use of transition routes and altitudes for feeding the traffic to the various final approach courses established for the airport.

16-11. En Route Control Procedures

a. Separation. Within 40 miles of the radar site, aircraft positive radar control are provided a minimum of 3 miles horizontal separation. This separation is between all identified targets. Aircraft normally are kept a minmum of 1.5 miles away from the boundary of the radar sector. Horizontal separation is provided between aircraft flying at the same altitudes. The radar controller has under his jurisdiction a number of different altitudes and flight levels. Separation can also be effected by assignment of different altitudes or flight levels.

(1) Radar as compared to nonradar separation allows for greater density of air traffic and, consequently, more efficiency in using available airspace.

(2) If the controlled aircraft are more than 40 miles from the radar site, the required separation is 5 miles because target resolution is not as precise. At this distance, two targets which are close together (e.g., 3 miles) can appear as one on the radar scope.

b. Routing. Established airways are used by radar controllers for en route traffic. However, if required minimums of separation and obstacle clearances are met, controllers have the option of alleviating traffic conflicts by using radar vectors which depart from established routes. Aviators may request deviation from established routes to avoid hazardous weather conditions (par. 16-25*d*). When the controller vectors the aircraft off the assigned route, the aviator is expected to return to the previously assigned route immediately if communications fail. He will continue on this route in accordance with standard procedures, as given in current navigation publications.

c. Altitude. In some cases, en route radar provides the controller with target altitude data; in other cases, the controller must rely on the aviator's reported altitude. In either case, altitude assignments are made in a manner similar to those of nonradar traffic control.

(1) In certain cases, the radar controller may assign an altitude below the minimum en route altitude (MEA) for the airway. However, an altitude assignment below the minimum obstruction clearance altitude (MOCA) will not be made.

(2) If the controller assigns an altitude below the MEA, he will realize that the aircraft may be unable to navigate because of the possibility of passing below the minimum reception altitude of the radio facility. Therefore, the radar controller navigates the controlled aircraft past all obstacles by offering the aviator radar vectoring service.

16-12. Departure and Arrival Control Procedures

a. Handoffs. Handoffs of departing and arriving aircraft are carried out as described in paragraph 16-10 above.

b. Departures. Radar departure routes are established as *standard instrument departures* (SID's) wherever practicable. Channelized altitudes are placed under the jurisdiction of radar departure control. The use of standard departure routes and altitudes reduces the amount of coordination between departure/arrival control and tower (local VFR control) facilities.

(1) Departure routes normally are based on the use of available radio facilities and thus do not require radar service for navigation. However, for an operational advantage, the controller may provide vectoring service for navigation; for example, to achieve adequate separation, noise abatement, avoidance of hazardous weather, or for other reasons. If an aviator is given a radar departure which deviates from established SID's or routes, he will be advised by the controller of the route or SID to which the aircraft is being vectored.

(2) Radar separation for departures is maintained as required by traffic conditions and within the saturation limits of the radar facility. Handoff to en route radar, or transition to nonradar separation, is accomplished as traffic conditions permit. In all cases, the transition to nonradar separation is completed well within the limits of radar coverage.

c. Arrivals.

(1) Transition to nonradar facilities, such as ILS, ADF, and VOR, can be accomplished with radar control of arriving aircraft. Radar transitions may be established to "feed" the traffic to the final approach fixes as required.

(*a*) A radar transition is similar to a conventional nonradar transition described in chapter 13. The nonradar transition is usually a straight course from an outer fix to an approach fix with bearing, distance, and minimum altitude published. However, a radar transition may employ several "legs" with different courses and different minimum altitudes on the legs. This multilegged transition is also referred to as the *radar traffic pattern.* In some cases it may resemble a conventional VFR traffic pattern with downwind and base legs.

(*b*) The radar transition area and required obstacle clearance is different than that required for nonradar transitions. In general, radar transitions allow greater airspace utilization because (1) known obstacles can be plotted on the overlay map of the radar scope and (2) identified aircraft targets can easily be provided with adequate obstacle clearance.

(*c*) Standard radar transitions are established but usually not published unless they happen to coincide with conventional nonradar transitions. The radar controller can vary radar traffic patterns to resolve conflicting traffic conditions, provided he complies with the minimum separation and obstacle clearance standards required by the Air Traffic Control Procedures manual. If a radar transition to a nonradar final approach is being used, the controller can use radar vectoring for navigation when necessary. If the radar transition coincides with a conventional transition the radar may be employed solely for separation of traffic and the aviator navigates using conventional radio facilities. Since the demands on the controller are less if radar vectoring for navigation is not necessary, an operational advantage is usually achieved by establishing radar transitions to coincide with nonradar transitions.

(2) If the final approach of the aircraft is to be controlled by radar (GCA) the transition to the final approach course is the preliminary part of the GCA. The transition—or traffic pattern—leading up to the final approach course can assume any configuration which takes into account the location of landing and navigation facilities, arrival routes, and the airport.

(*a*) The GCA final approach may be one of two types, as described in paragraph 16-13 below. The type of GCA approach has little effect on the traffic pattern leading to final, except perhaps at the point where the final approach course is intercepted.

(*b*) Patterns are established from outer fixes to intercept the final approach course. Typical patterns are illustrated in figure 16-5. While the aircraft is in the radar traffic pattern, prior to the time it is turned on final approach, the radar controller issues appropriate advisories to assure effective completion of the radar approach. These are discussed in paragraph 16-13 below.

16-13. Radar Approaches

a. General. The two types of radar final approaches are *airport surveillance radar* (ASR) *precision approach radar* (PAR). The type employed is dependent on the equipment available, landing, runway, weather, and traffic conditions. ASR equipment provides the controller with positive data on range and azimuth of the aircraft target. With the additional equipment of PAR available, however, the final approach can be more precisely controlled. The basic difference to the controller between ASR and PAR is that he is able to determine the exact aircraft elevation in relation to the glidepath with PAR and, secondarily, the range and azimuth can be determined with greater accuracy. In general, where PAR is employed approach minimums are lower.

b. Prior to Final Approach (ASR and PAR). Prior to the start of the radar final approach, the controller issues the following advisory information to the aviator:

(1) Altimeter setting and current weather (if appropriate).

(2) Cockpit check. (This is given on the downwind leg or its equivalent.)

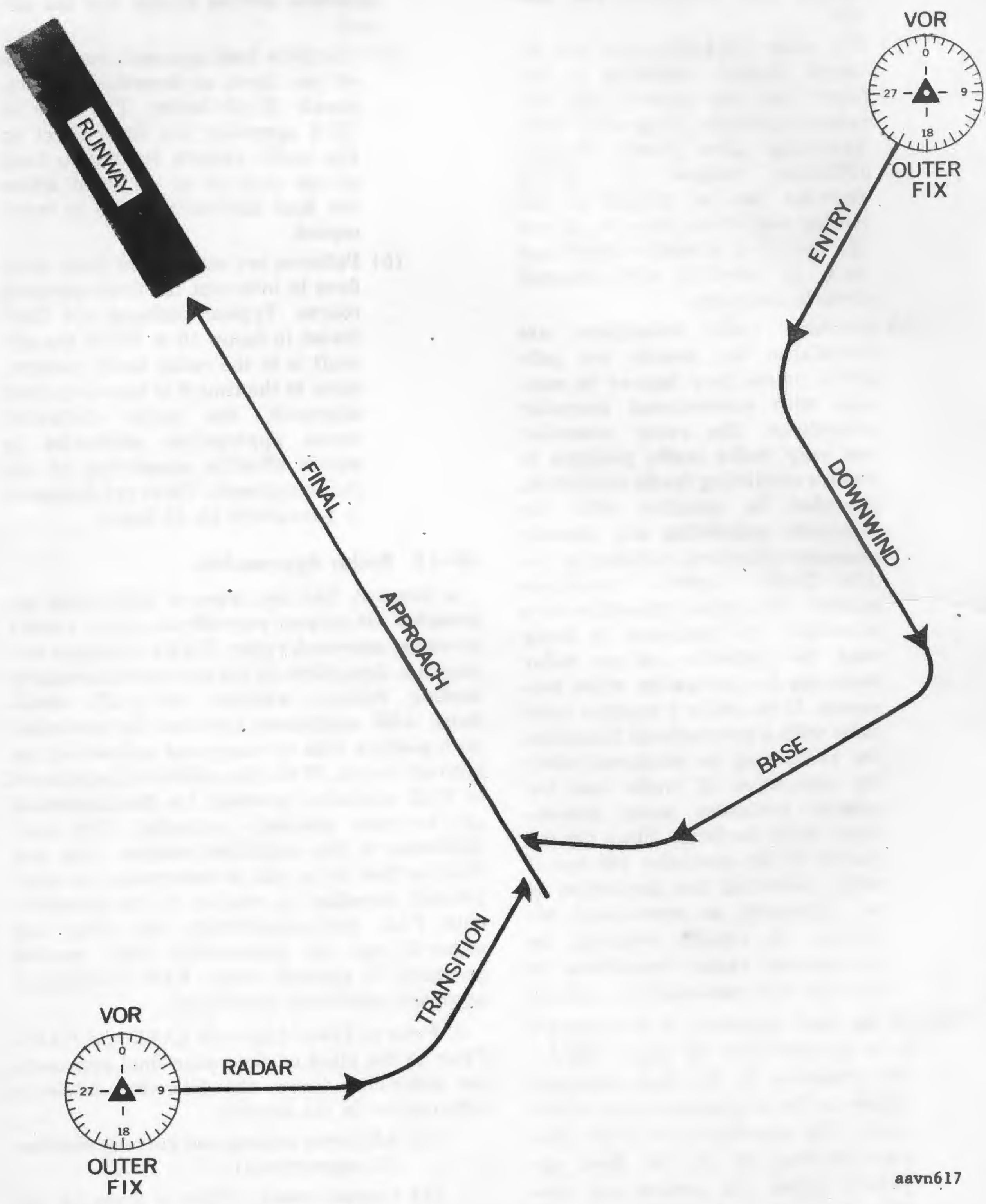


Figure 16-5. Radar transitions to GCA final approach.

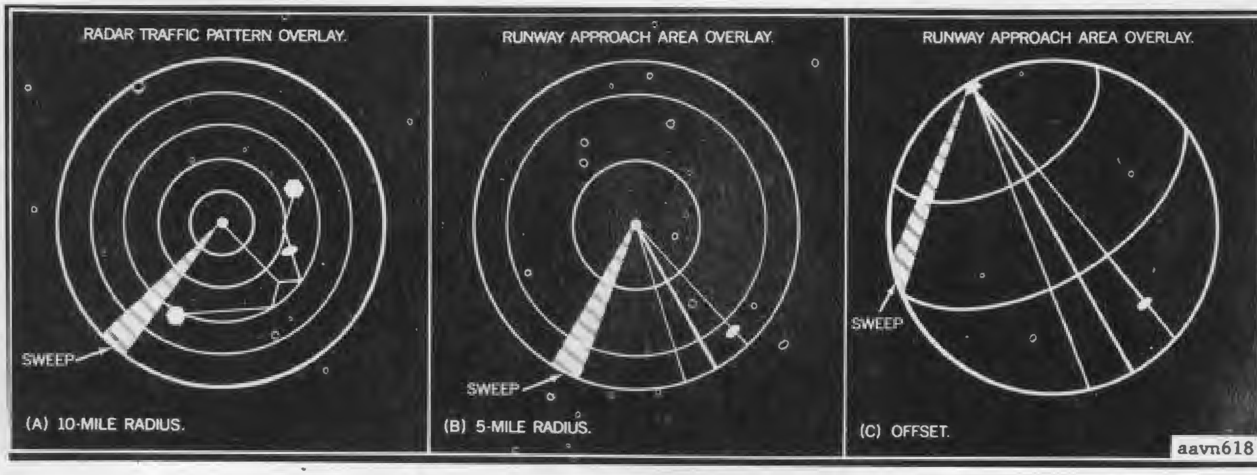


Figure 16–6. ASR scope presentations.

(3) Aircraft position.

(4) Alternate instructions to follow if radar or communications fail.

(5) Rate of descent on final. The aviator may be requested to advise the controller of the final approach airspeed. This airspeed is used to determine groundspeed, which in turn governs the rate of descent.

(6) Approach runway.

(7) Radio frequency for use on final approach, if different from the frequency used in the pattern.

c. *On Final Approach* (*ASR*).

(1) *Scope data.* ASR approaches are controlled by reference to a PPI scope. The range of this scope can be changed to represent a radius of 5 miles, 10 miles, or more. As an example, part (A) of figure 16–6 shows the scope set for a 10-mile radius, with the radar traffic pattern and area map superimposed. Part (B) of figure 16–6 shows the scope set with a 5-mile radius. This radius offers good final approach area coverage and target resolution. Most radar equipment is capable of offset presentation, which electronically moves the center of the scope to the edge. This offset results in spreading of the last 5 miles of the final approach area over the face of the scope (part (C) of fig. 16–6).

(2) *Approach area.* The ASR final approach area extends 5 miles from the runway. The actual final approach course can vary from 5 to 10 miles, depending on the point at which the aircraft is turned on final. However, final descent normally is not begun until the aircraft is within the final approach area—the last 5 miles. The rate of descent which the controller advises the aviator to use will approximate a 3° glidepath. This can be adjusted by the controller to provide a minimum 300-foot obstacle clearance in the final approach area.

(3) *Approach instructions.*

(*a*) *Radio contact.* If necessary, the controller will complete a radio check immediately after the aircraft turns on final. He will then advise the aviator not to acknowledge further transmissions. The controller must transmit at least once each 30 seconds since the aviator has been instructed to execute a missed approach if a transmission is not received on the ASR final for a period of 30 seconds or more.

(*b*) *Range, azimuth, and elevation.* The controller transmits the range of the aircraft and heading corrections at frequent intervals, giving small heading corrections of 2° to 5° to maintain the aircraft on the extended centerline of the runway. Since he cannot determine the exact altitude of the aircraft with ASR, he establishes a precise altitude at which the approach is to be started and a rate of descent which fits the given groundspeed to obtain the glidepath desired. In addition, he transmits the desired altitude that corresponds with a given distance from the runway. For example, if the field elevation is 200 feet, the desired altitude at a range of 4 miles is 1,400 feet. The controller transmits: ". . . . 4 miles from runway, altitude should be 1,400 . . . ." If there is a water tower located at 3 miles and the aircraft must maintain 1,200 feet to clear it, the controller can transmit: ". . . . 3.5 miles from runway, maintain 1,200 feet . . . ." Later he would transmit: ". . . . Now past water tower, continue descent . . . ."

(*c*) *Visual contact* (*termination of surveillance*). The controller requests the aviator to report when he has the runway in sight. If the runway is sighted prior to the 1-mile point, the controller discontinues approach guidance and issues the landing clearance. If the aviator fails to report the runway in sight by the time he has reached the 1-mile point, the controller tells him to execute a missed approach if the runway is not in sight at the landing minimums. In either case, the controller discontinues approach guidance 1 mile from the end of the runway.

d. On Final Approach (*PAR*).

(1) *Approach area.* PAR approaches can be made in extremely poor weather since this radar equipment is accurate enough to detect range variations of 300 feet, and at 1 mile can detect variations in elevation of 10 feet and in azimuth of 20 feet. Only the final approach area, to a maximum range of 10 miles, is covered by PAR equipment. Within this area, 20° of azimuth coverage and 7° of elevation coverage is possible.

(2) *Scope data.* Precision approach radar provides the controller data on range and elevation, and on displacement from the extended runway centerline (azimuth). The display scanned by the controller is from two scopes mounted in one console (fig. 16–7). One scope has a range of 10 miles and the other a magnified display of 3 miles. This two-scope arrangement provides a high degree of accuracy at the most critical stage of the approach.

(3) *Approach instructions.*

(*a*) *Radio contact.* The aircraft target is detected on the PAR scope by the final controller prior to release by the area controller. The final controller then completes a radio check and advises the aviator not to acknowledge further transmissions. From this point on the controller transmits almost continuously because the aviator has been instructed to execute a missed approach if a transmission is not received for 5 seconds or more.

(*b*) *Range, azimuth, and elevation.* The controller turns the aircraft on final approach prior to the point at which the glideslope is intercepted. He instructs the aviator to maintain altitude until intercepting the glideslope, at which time he tells him to start his descent. After the aviator starts his descent, the controller transmits almost constant advisories as to his position in relation to the glideslope and centerline. He gives the range at each mile on

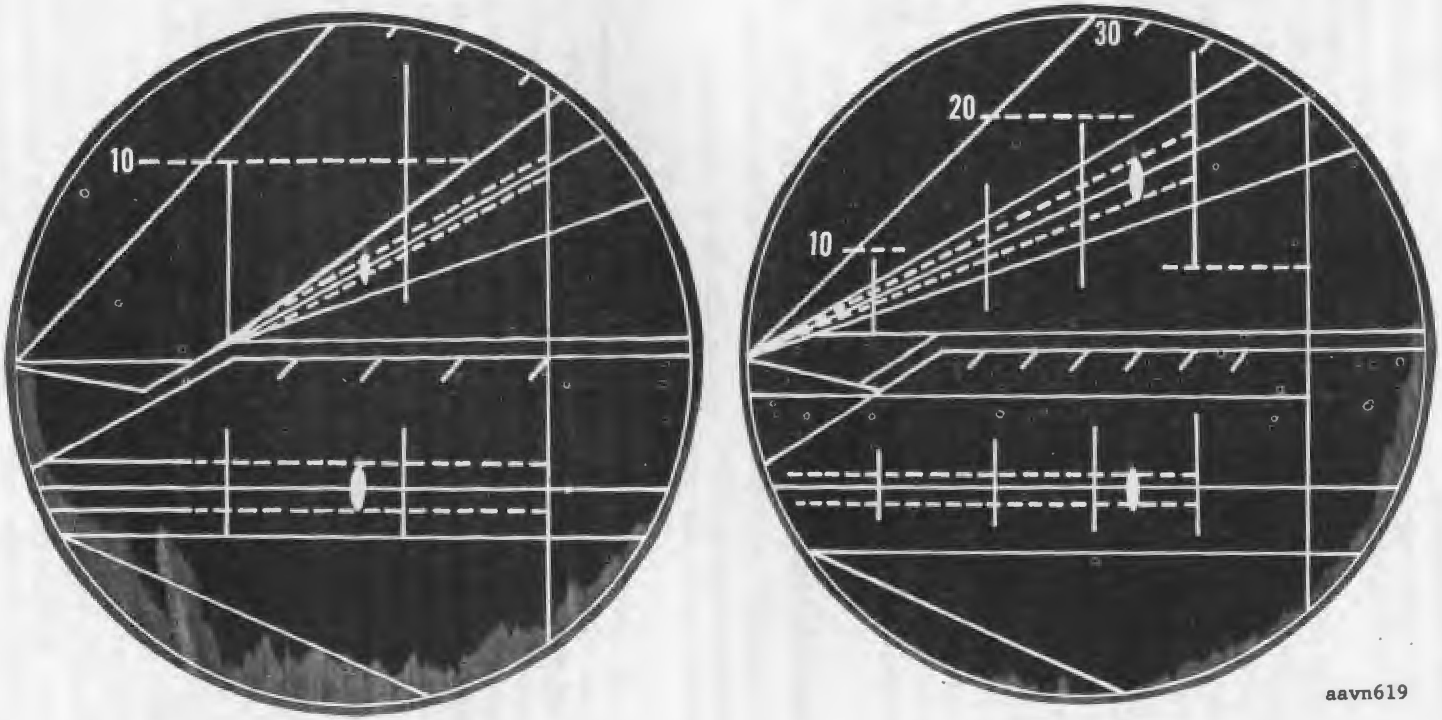


Figure 16-7. PAR scope presentations.

final, and again over the approach lights and the end of the runway.

Note. Normally advance warning of glideslope interception is given either in time or in distance.

(*c*) *Visual contact.* At the time the aircraft is observed over the end of the runway, the controller advises the aviator of his position in relation to the runway centerline and instructs him to take over visually. If the aircraft is observed exceeding the lower and/or lateral limits of a prescribed safety zone, the controller instructs the aviator to climb to a specified altitude on a specified course. (Compliance with authorized minimums for the approach is the responsibility of the aviator.)

16-14. Monitoring of Nonradar Approaches

a. The final portion of a nonradar instrument approach should be monitored by the radar final controller from the approach fix to the runway, provided—

(1) The final approach course coincides with PAR coverage, and

(2) Currently reported weather conditions are below VFR minimums. If weather conditions are higher than these minimums, the controller monitors the approach at his option.

b. Surveillance radar is *not* use to monitor nonradar approaches from the approach fix inbound to the runway.

c. After advising the aviator that his approach will be monitored and of the frequency on which advisories will be issued, the controller immediately notifies the aviator of any situation affecting flight safety. In addition, he issues the following advisories:

(1) Passage of the approach fix inbound.

(2) The distance form touchdown (for ILS approaches) or the distance from the end of the runway (for other approaches). This advisory is transmitted each mile on final.

(3) Glidepath and course-line deviation when the aircraft proceeds beyond a prescribed safety zone.

(4) Passage of major obstructions.

d. The controller ends monitor service when the aviator reports runway visual contact or when the aircraft reaches the end of the prescribed azimuth safety zone.

16-15. Expanded Radar Service for VFR Traffic

As IFR traffic volume and radar capability permits, future radar service will increase assistance to VFR traffic. As more airports and control centers become equipped with modern radar, this expanded service will become widespread. For the types of service and the existing procedures to employ them, see current navigation publications. Among these services to VFR traffic are the following:

a. Sequencing of arriving traffic.

b. Radar control of "special" VFR flight in marginal weather conditions.

c. Traffic advisories.

d. Weather advisories.

16-16. Radar Assistance—Loss of Communications

Aviators who have lost radio communications can alert radar stations and receive assistance by flying a specified triangular pattern. This procedure can be used in situations where the radar station might otherwise be unaware of the communications failure. If, however, the aircraft is operating on an IFR flight plan in controlled airspace, standard loss-of-communications procedures, as prescribed in current navigation publications, should be used. If the aviator elects to alert a radar station by flying a triangular pattern (fig. 16-8), the following rules apply:

a. If receiver only is operating: The aviator flies a triangular pattern to the right ((A), fig. 16-8) and holds each heading for 2 minutes (1 min. for jet aircraft). A minimum of two such patterns must be completed before resuming original course, then the pattern is repeated at 20-minute intervals. When the triangular pattern is observed by a radar controller and

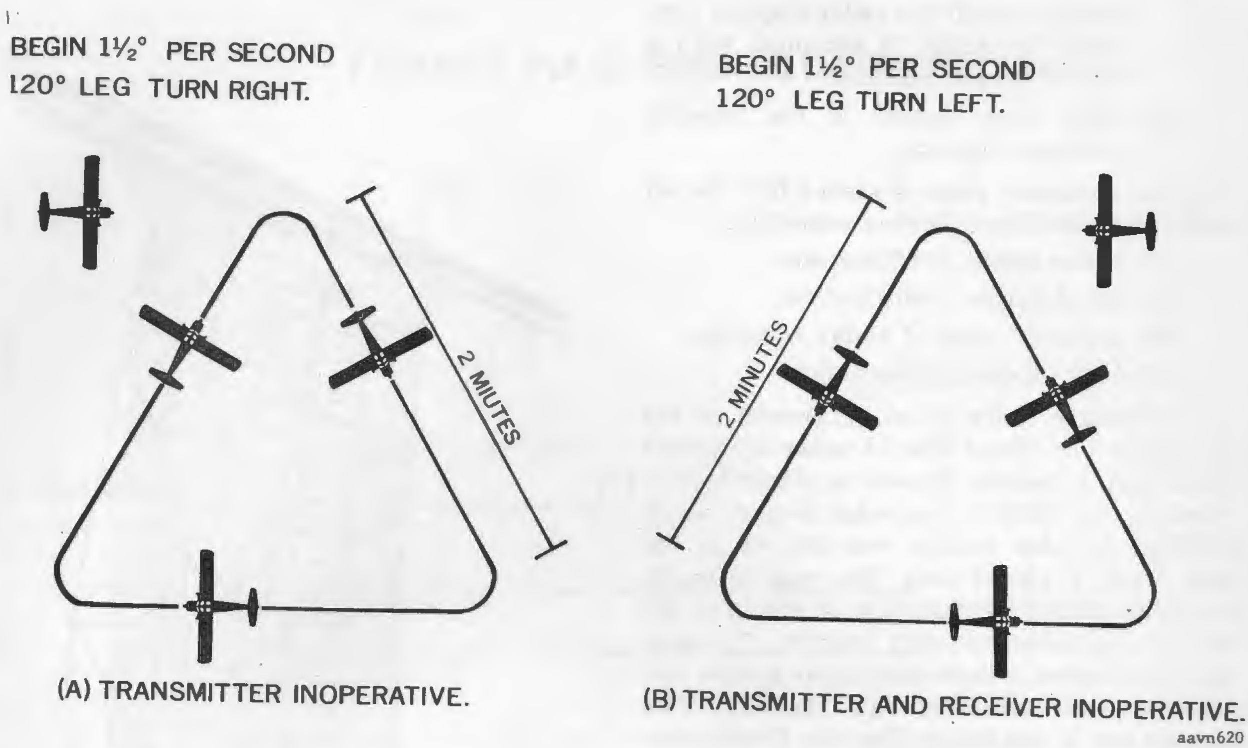


Figure 16–8. Triangular pattern to indicate loss of communications.

positive identification has been made, the controller follows normal procedures except that his instructions are given in a way that will enable the pilot to answer with aircraft turns.

b. If transmitter and receiver are both inoperative: The aviator fiies a triangular pattern to the left ((B), fig. 16–8) as in *a* above. When this pattern is observed by a radar controller, the controller dispatches an escort aircraft to intercept the flight if possible.

Note. Emergency procedures for alerting ground controllers with the transponder are discussed in section IV.

Section V. SECONDARY SURVEILLANCE RADAR (AIR TRAFFIC CONTROL RADAR BEACON SYSTEM)

16–17. Secondary Radar

a. Secondary radar differs from primary radar in that its scope display is transmitted from an airborne radar transmitter (a transponder) instead of being a reflected signal from a ground transmitter. Secondary surveillance radar is a separate air traffic control radar system, capable of independent operation; however, when used in normal air traffic control, it is slaved with primary surveillance radar. A combined display of both the primary and secondary radar targets is presented on the radar set PPI. As used with secondary radar, the term *radar beacon* refers to a secondary surveillance radar system using a functioning interrogator on the ground, a functioning transponder in the aircraft, and a display on an air traffic control radar scope.

b. Secondary surveillance radar effectively counteracts the following shortcomings of primary radar:

(1) Radar echoes alone give no clue to aircraft identity.

(2) Aircraft targets (blips) vary in size and configuration.

(3) Ground clutter and other undesirable

returns impair the radar display, even when the radar is equipped with a moving target indicator.

(4) Blind spots appear in the antenna coverage pattern.

c. The secondary radar system offers the air traffic controller the following advantages:

(1) Radar target reinforcement.

(2) Rapid target identification.

(3) Extended area of radar coverage.

(4) Altitude data transmission.

d. Secondary radar is an outgrowth of the development of World War II radar equipment which had a feature known as *identification friend or foe* (IFF). The radar beacon which provided for this feature was known as the basic *Mark X* (*Mark ten*). The need in traffic control is not for identification of friend or foe but for individual aircraft identity. To meet this requirement, a secondary radar system was developed under the direction of the FAA. Two systems are in use today. The Air Traffic Control Radar Beacon System (ATCRBS) is a completely new system designed specifically for air traffic control. The basic Mark X system for military tactical use, modified with a selective identification feature (SIF), is the second system. Both of these systems provide for coded replies to be presented on the radar scope. In most cases, the two systems are compatible with both civil and military secondary radar ground equipment.

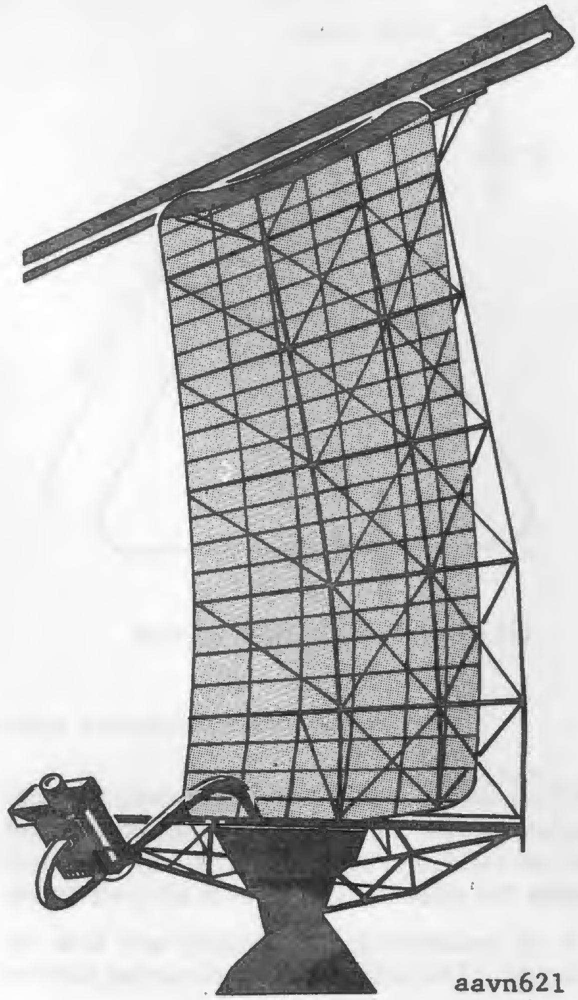


Figure 16-9. Secondary surveillance radar antenna mounted on ASR antenna.

16-18. Secondary Radar—Basic Functions

The secondary radar system is based upon four distinct functions jointly carried out by ground and airborne components.

a. Interrogation. A ground component sends out two closely spaced radar pulses from a bar antenna mounted on top of, and synchronized with, the conventional sweep antenna of a surveillance radar (fig. 16-9). The spacing between these two pulses (in microseconds) can be changed by the ground operator. This spacing between pulses determines the *mode* of operation (par. 16-19).

b. Transponder Triggering. The transponder is an airborne component, which is set by control knobs to receive only certain modes. If set for the same mode being transmitted by the ground interrogator unit, the transponder is triggered and a special return signal (called a *reply*) is transmitted to the ground interrogator unit.

c. Reply. The reply signal which the transponder sends to the ground receiver unit adds other pulses (information pulses) to the mode pulses. The exact reply is referred to as the *code.* A specific code normally is set on the transponder control panel by the aviator to comply with instructions given by the con-

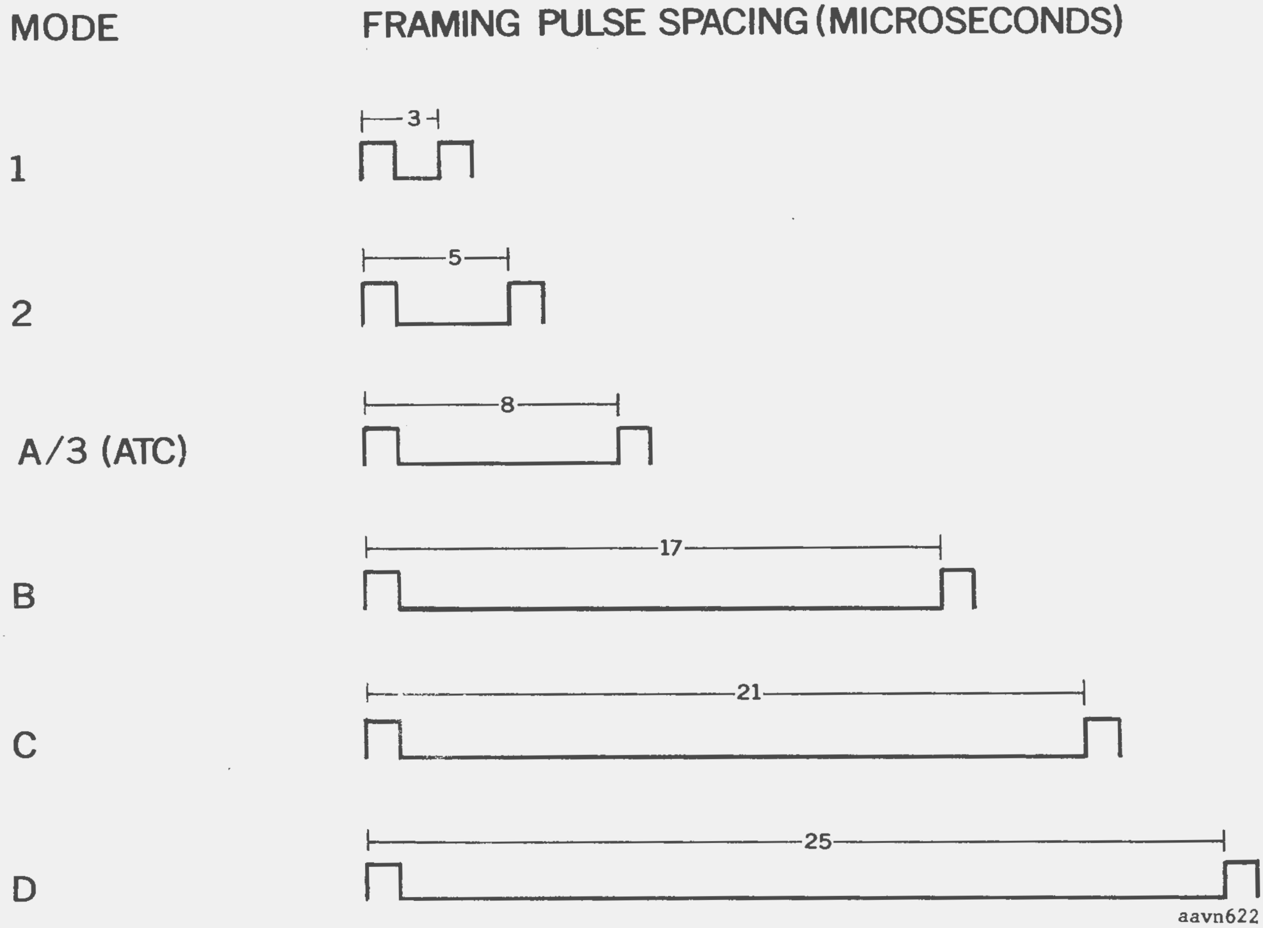


Figure 16–10. Mode and pulse spacing.

troller. (For certain tactical modes of operation, codes are preset in the transponder by technicians prior to flight.) The coded reply set in the transponder determines the spacing (in microseconds) of the pulses transmitted from the transponder to the ground component.

d. Reception and Decoding. The reply transmitted from the transponder is automatically decoded by the ground receiver. The microsecond spacing between pulses is presented on the radar scope as spacing between light slashes (arc segments) which represent the radar beacon target on the scope (par. 16–20).

16–19. Modes and Codes

a. Modes. The mode is the microsecond spacing between two radar pulses transmitted by the ground component. Spacings used to establish modes are illustrated in figure 16–10. Present equipment of the secondary radar system provides for operation on six distinct modes, allocated as follows:

(1) Mode 1—Military tactical use.

(2) Mode 2—Military tactical use.

(3) Mode 3 and mode A (usually written as mode A/3)—these two modes are identical. The civil designation is A and the military designation is 3. These are the common military/civil modes for air traffic control use in the United States.

(4) Mode B—Civil air traffic use; but not used in the United States.

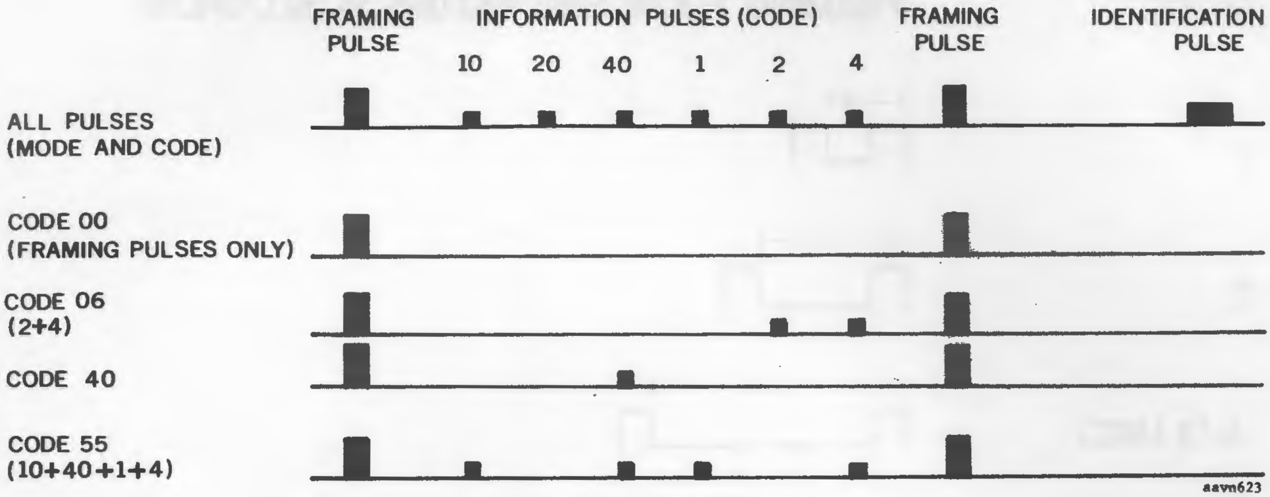


Figure 16-11. Radar beacon code pulses for mode A/3.

(5) Mode C—Automatic altitude data (proposed).

(6) Mode D—Individual airframe identity (proposed).

b. Codes. An airborne transponder set for the proper mode is triggered when that mode pulse combination is received from the ground component. The triggering causes the transponder to transmit a series of return pulses. The spacing between the reply pulses can be varied and is called the *code.* Each reply consists of two framing pulses; and combinations of pulses within these frames (called information pulses) create a code.

(1) *Code capability in mode A/3.*

Framing pulses—20.3 microseconds apart.

Information pulses (6)—2.9 microseconds apart.

Possible codes—64 (see below).

A reply from a transponder may consist of the framing pulses alone, or of the framing pulses plus any combination of the information pulses. Each information pulse is assigned a numerical value (fig. 16-11). The numerical values of the information pulses are added to the framing pulses to produce 64 possible codes. These codes may be set by the aviator on the transponder control panel.

(2) *Code capability in other modes.* The principle of operation described for mode A/3 above is the same for all other modes. The number of possible codes, however, differs.

Mode	*Codes*	*How set*
1	32	By aviator
2	4,096	On transponder

Mode 2 cannot be changed in flight by the aviator. Civil mode C, when installed, is connected to an altitude measuring instrument for automatic code readout.

16-20. Basic Scope Display and Target Identification

Ground surveillance radars, equipped with radar beacon decoders, can display a normal (primary) radar echo from any detected target within the surveillance area. By operation of the beacon decoder, the controller can also display coded replies from aircraft equipped with transponders which are operating on the proper mode and code. In addition, the controller can set the decoder equipment to display only those aircraft equipped with transponders or, in some cases, only those transponder-equipped aircraft which reply to specified codes. The two basic scope displays used are called *raw video* and *select*.

a. Raw Video. In the raw video position, the PPI scope will display aircraft having or not having a transponder. Figure 16–12 illustrates a scope with different type target displays. Target A is the normal primary radar echo (blip) received from any target within range. Target B shows a beacon return. The beacon return appears as a series of arc segments of concentric circles, called *slashes*. A slash will appear for each of the framing pulses, as well as for each of the information pulses. The spacing of the information pulses between the framing pulses corresponds to the spacing between pulses illustrated in figure 16–11. The entire beacon display is called a *code train*. With the code train display, the controller, by very close inspection, can determine the reply code by adding the numerical values of the information pulses. Target B in figure 16–12 represents the code train for code 01; target C indicates code 40. Figure 16–13 shows several echo targets with other beacon targets as appearing on the scope with the decoder set to raw video. With raw video displays the scope becomes too cluttered for efficient aircraft control, and the

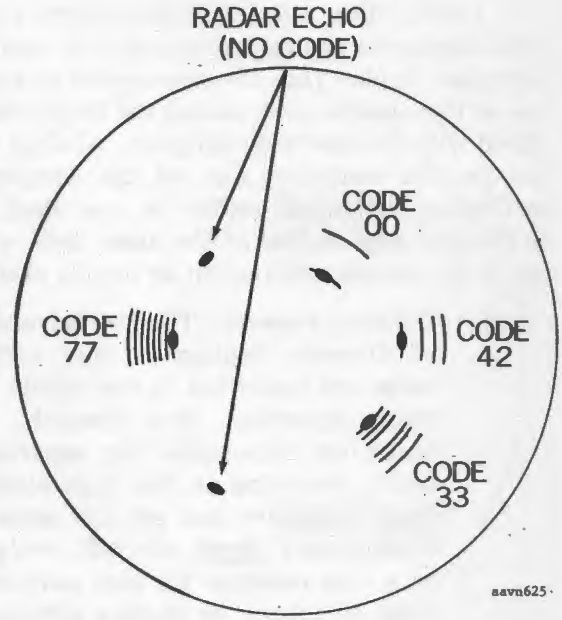
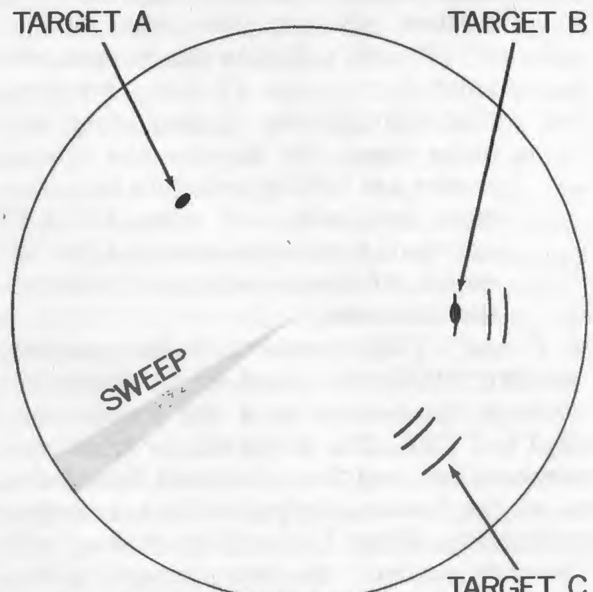


Figure 16–13. Type code trains (raw video).



TARGET A-PRIMARY RADAR ECHO (NO BEACON)
TARGET B-PRIMARY RADAR ECHO COMBINED WITH CODE TRAIN (CODE 01)
TARGET C-BEACON REPLY (CODE 40)
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Figure 16–12. Basic display differences.

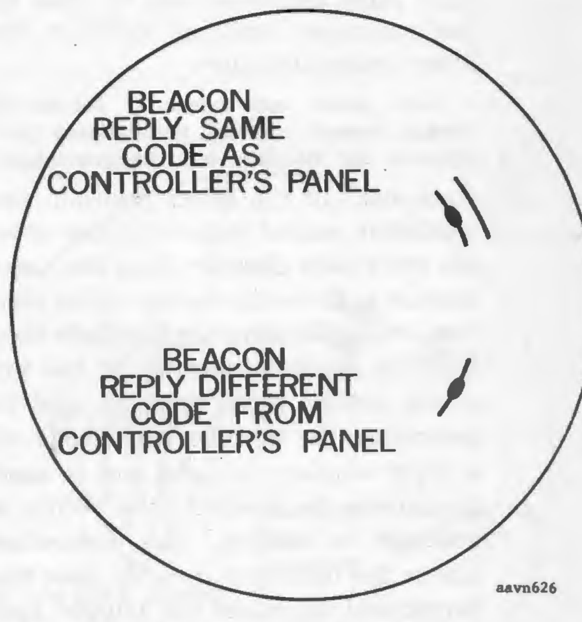


Figure 16–14. Type code trains (select).

controller cannot easily determine the code of a given code train.

b. Select. The select position offers a discrete display to the controller. In this position the radar display (fig. 16-14) consists of either one or two slashes, eliminating the clutter associated with the raw video display. Also, in this position the controller can set the equipment to display all beacon replies as one slash, or to display only replies of the same code when set on the decoder equipment as double slashes.

(1) *Discrete displays.* The real advantage of discrete displays is that certain codes are restricted to use within one route structure. For example, the controller responsible for separating traffic operating in the high altitude route structure can set his scope to display only those aircraft replying on a code reserved for that particular route structure, he thereby eliminates the clutter which would be present on his scope if the display included all aircraft within the range of the radar. This same technique can be used by the controller handling traffic in the lower route structure.

Note. Since code usage is subject to change, consult current navigational publications for standard code assignments.

(2) *Readouts.* In the select position, the controller cannot determine the specific reply code directly from the scope display as he can in the raw video position, which displays the complete code train. A readout indicator at the top of the control panel must be used to determine the specific reply code of a scope display. A light gun is used to activate the readout tube. When a readout is desired, the controller places the light gun directly over the target and depresses the trigger just prior to the time the radar sweep passes over the target. The code number of the transponder is displayed on the readout tube as soon as the sweep passes the target.

c. Other Target Identification Methods. Another method for rapid target identification is the identification (ident) display. This display appears on the scope (fig. 16-15) when an identification-position (I/P) switch is engaged on the aircraft transponder. The method used to create an identification reply, and the type display seen on the scope by the controller, is dependent on the type transponder used and the decoder setting employed (i.e., RAW VIDEO or SELECT). When the identification switch is activated on the ATCRBS transponders, an extra pulse (the *caboose* pulse) is transmitted 4.35 microseconds after the last framing pulse. On the selective identification feature (SIF) transponder, a second complete code train is transmitted 4.35 microseconds after the first.

(1) When the controller's scope is set to RAW VIDEO, the identification display has an extra slash .3 of a mile behind the code train (away from the center of the scope) (fig. 16-15). The SIF reply appears as two identical code trains, with the second one .3 of a mile behind the first.

(2) When the controller's scope is operated in SELECT, the identification feature changes the two slashes ( ))) to a filled in bar or stretched pulse ( ) (fig. 16-15). However, this identification display only appears when the decoder and transponder are both operated on the same mode and code, and when the I/P switch of the transponder and the ID switch of the decoder are engaged simultaneously.

d. Use of STBY Position. Another method of positive identification used by the controller is to have the aviator place the transponder control to STBY. This turns off the transponder transmitter, and the subsequent disappearance of the beacon reply slash(es) provides identification. When the aviator is then told to "squawk normal," the reappearance of the beacon reply further verifies the identification.

e. Emergency Identification. Both the ATCRBS and military SIF transponders are capable of transmitting an emergency signal. How-

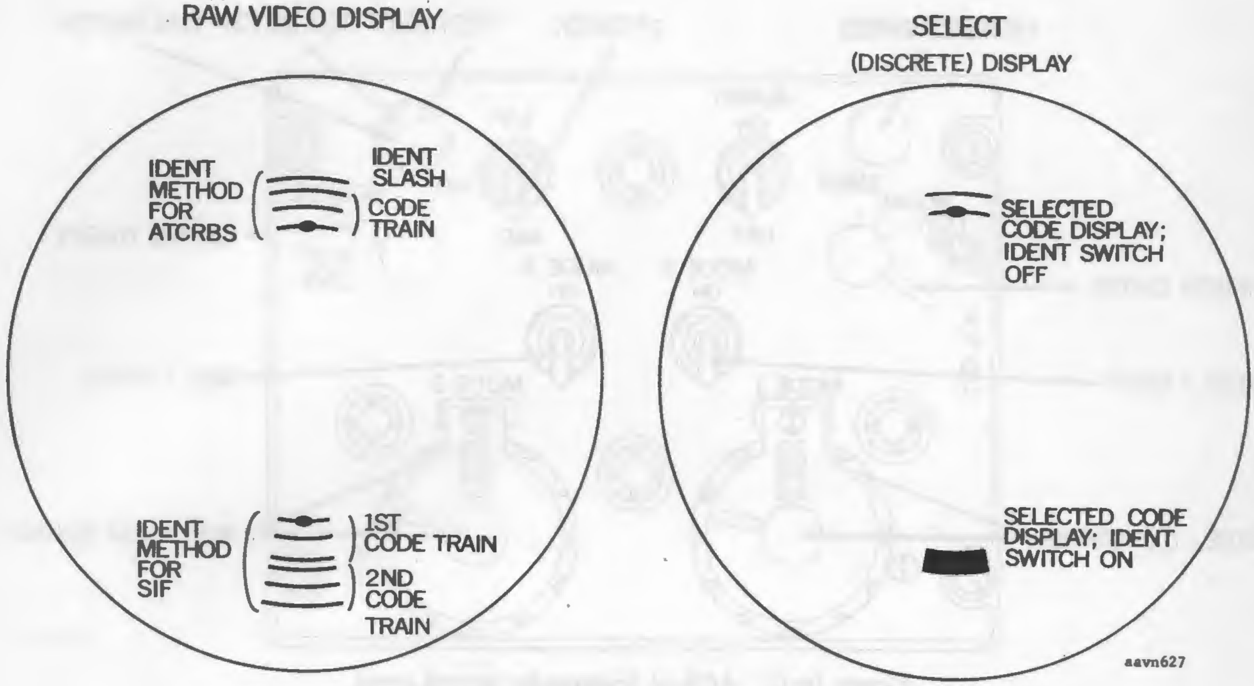


Figure 16–15. Identification pulse, raw video and select.

ever, the civil and military methods used, and the associated displays, differ. When placed in the emergency position, the civil transponders automatically transmit code 77. The military SIF transmits a series of four code trains when the emergency position is selected, but this type reply is not recognized as an emergency signal by ATCRBS decoders in the SELECT position. To overcome this difference, code 77 has been set aside as an emergency code, and the military services have agreed to use code 77 in conjunction with the emergency position on the SIF transponder. Code 77 is continuously interrogated by all ATCRBS decoders. When this code is received, an emergency alarm consisting of a flashing red light and a buzzer is activated. Figure 16–16 shows the type emergency display as seen by the controller in both the RAW VIDEO and SELECT positions.

16–21. APX–44 Transponder Description

The APX–44 transponder is the type most commonly used in Army aircraft. Its three

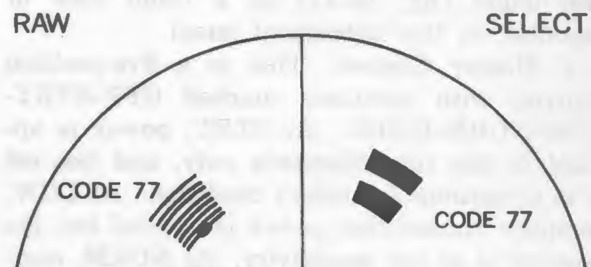


Figure 16–16. Emergency signal display.

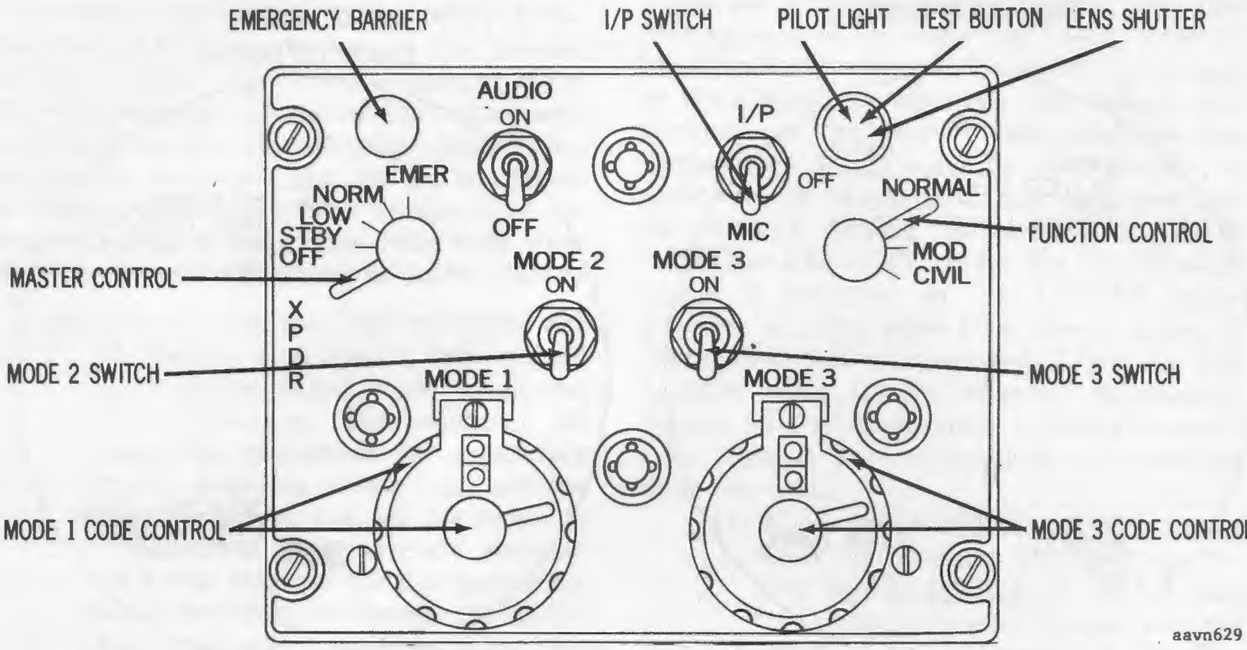


Figure 16–17. APX–44 transponder control panel.

operational modes (coded interrogation patterns) can be operated independently or simultaneously. The transponder is usually mounted at a remote part of the aircraft, with the control panel (fig. 16–17) in a radio rack or mounted on the instrument panel.

a. Master Control. This is a five-position control, with positions marked OFF-STBY-LOW-NORM-EMER. At STBY, power is applied to the tube filaments only, and the set is in a warmup (standby) condition. At LOW, complete transmitter power is applied but the receiver is at low sensitivity. At NORM, complete power is applied and the receiver is at maximum sensitivity. At EMER, complete transmitter power is applied and a special reply code is transmitted to ground-based interrogations.

b. Audio Switch. This is a two-position toggle switch labeled ON and OFF. In the ON position, transmitted reply pulses may be monitored through the headset. In most APX–44 installations, this feature is inoperative.

c. Identification Position Switch. This is a three-position switch labeled I/P-OFF-MIC and is spring-loaded to OFF from the I/P position. In the I/P position, special identification reply pulses (codes) are transmitted. When set to MIC, the identification pulses are transmitted when the microphone switch is depressed.

d. Functional Control. The function control is a three-position rotary control with positions marked NORMAL-MOD-CIVIL. At NORMAL, the set responds to the basic Mark X IFF system interrogations (modes) (par. 16–17*d*); only standard replies to mode are transmitted, and all preset code combinations are disabled. At MOD, the set responds to the basic IFF system interrogations, supplemented by selective identification feature (par. 16–17*d*). At CIVIL, the set responds to civil ground radar interrogations.

Note. At either the MOD or CIVIL position, any preset code for any mode is included in the reply pulse.

e. Mode 1 and Mode 3 Code Controls. These two rotary controls are marked mode 1 and mode 3. A knurled knob control is used to select the first code digit, with a wing-type control for selecting the second digit. The selected code appears in a vertical opening on each selector.

Caution: **Use of excessive force on the wing-type code selector, at its extreme clockwise and counterclockwise position, can cause damage to the switching mechanism.**

f. Mode 2 and Mode 3 Switches. Modes 2 and 3 have two-position ON-OFF switches. For detailed instructions for setting mode 2 code combinations on the transponder, see TM 11-5895-217-12. The mode 3 switch turns the mode 3 reply circuit on or off.

16-22. APX-44 Transponder Operation

a. Starting Procedures.

(1) Check preliminary settings — all switches OFF, function control to NORMAL, code control to 00.

(2) Place master power ON—check that circuit breakers are set.

(3) Place the master control in the STBY position. The pilot light should light; if it does not light, press the test button. If the pilot light still fails to light, either the bulb is burned out or power is not reaching the set.

(4) Allow the transponder 3 to 5 minutes to warm up.

b. In-Flight Operation. In the following procedure the function switch is in the MOD or CIVIL position. The NORMAL position is not used for air traffic control. When ready for use, set up the equipment as instructed by the controller. For example, if the Atlanta center transmits, "Army 12345, squawk mode 3 code 10," select code 10 in the mode 3 window and place the mode 3 toggle switch to ON. Place the master control switch to NORM unless otherwise instructed.

Note. When the aircraft is located very near the radar antenna site, the transponder may reply to spurious interrogation signals. This causes the beacon slashes to be displayed completely around the scope, which is referred to as "ring-around." When this condition is observed by the controller, he advises the aviator to set the transponder to LOW. This reduces the transponder receiver sensitivity, thereby eliminating the "ring-around" condition.

c. Position Identification. When requested to "Ident" (identify) by the controller, activate the I/P by momentarily depressing the spring-loaded I/P switch to the I/P position. *It is not necessary to hold this switch on.* Do not place the switch to MIC position unless desiring to "Ident" each time the microphone switch is depressed. The use of the MOD and CIVIL positions of the function control differs only for the identification feature of the transponder. The CIVIL position should be used with ARTCC's and the MOD position with joint military-FAA installations, such as RAPCON.

d. Emergency. In an emergency, depress the red barrier button and place the switch in EMER position. Set code 77 in mode 3 window. This sets up the emergency code, and the ground radar units interrogating this code are alerted by an alarm signal. The combined use of the standard emergency call word "Mayday" on 243.0 megacycles is recommended.

16-23. Miscellaneous Instructions

a. Operate transponders in STBY while taxiing for takeoff and after landing.

b. When filing flight plans, indicate that the aircraft is equipped with a coded transponder by adding a slant and a letter *T* to the radio call (e.g., R-12345/T) on the flight plan. *When making position reports, etc., the slant T is not stated.*

c. Check current navigation publications for the standard code for various route structures and for special use; e.g., *mode 3 code 06* for VFR traffic below FL-240 (flight level 24,000 feet) and *mode 3 code 00 and 50* for Air Defense Command aircraft only.

d. Know phraseology used both by civil and by military air traffic controllers when referring to the operation of the transponder; i.e.—

Squawk alpha/three code (number). Operate radar beacon transponder on designated mode and code (transponder has not been operating on mode A/3).

Section V. GROUND WEATHER RADAR

16-24. General

In addition to the application of radar to traffic control, there are other applications of radar which contribute to efficient aviation operations. The U.S. Weather Bureau, the USAF, and the USN operate radar storm detection sites. Some ARTC centers have access to radar sets designed for weather observation. As a result of these efforts, a large part of the continental United States and some oversea areas provide radar weather service.

16-25. Metro Service

Direct communication service between aviators and forecasters is provided at many locations by the USAF. At locations where the service is available, the aviator can call METRO on a frequency of 344.6 megacycles. The forecaster will reply to the call and can furnish the aviator an inflight weather advisory by a qualified weather forecaster who has access to weather radar coverage of the flight area. While operating on an IFR flight plan, the aviator must obtain permission from the controller to leave the control frequency long enough to obtain a weather advisory. Subsequent vectoring, which may be necessary to avoid hazardous storm areas, can be coordinated between forecaster, aviator, and controller. For METRO service listings, consult current navigation publications.

16-26. FAA Weather Radar Advisories

In some cases, FAA facilities obtain weather information from weather radar sets of the individual facility. This information is subsequently relayed to the control center or flight service station for broadcast to aviators as a weather advisory. In other cases, the traffic controller's facility may have a weather radar set, or the controller may issue a weather advisory to the aviator based on weather data obtained from the air traffic control radar set. Traffic control radar sets, however, deemphasize weather phenomena since the image of storm areas and precipitation tends to obscure aircraft targets; consequently, the sets are designed to "filter out" echoes from storms and precipitation. The resulting display on these sets thus does not portray, in great detail, the existing weather phenomena. Therefore the aviator should obtain weather data from a weather radar source if possible.

Section VI. AIRBORNE WEATHER RADAR (APN-158)

16-27. General

Some Army aircraft are equipped with airborne radar set APN-158 for detecting weather phenomena in flight. This radar set operates on the same principles as other primary radars discussed in section I. It is relatively simple to use and reliable, presenting scope display from which aviators can detect and avoid such hazardous weather conditions as severe turbulence, tornadoes, and hail. The APN-158 is also capable of ground mapping when the antenna is directed toward the terrain below the aircraft.

16-28. Airborne Weather Radar Control Panel

(fig. 16-18)

a. Master Control Switch Settings (A, fig. 16-18).

OFF —Equipment is inoperative.

STBY—Filament voltage is applied in STANDBY position, but set does not transmit radar energy. System holds in warm-up condition after a 4-minute time delay.

OPR —Equipment is operative after 4-minute time delay. In NORMAL OPERATION position, radar echoes from all targets are displayed on the indicator as bright spots or areas. Contour circuit (par. 16-30*h*) is operative.

CTR —In the CONTOUR OPERATION

Figure 16–18. Airborne weather radar control panel.

position, radar echoes from intense rainfall areas appear as dark areas or as black holes within the brighter echo areas of lighter rainfall. The contour circuit is operative.

b. RF GAIN (B, fig. 16–18). The RF GAIN regulates receiver sensitivity and performs a function similar to the volume control on a conventional radio.

c. ANTENNA TILT (C, fig. 16–18). The antenna tilt control knob adjusts the antenna 15° above or below the nose position of the aircraft. The tilt scale is calibrated in 1° increments. The antenna is automatically stabilized within these tilt limits to compensate for pitch and roll of the aircraft.

16–29. Daylight Display Scope (fig. 16–19)

The *daylight display scope* permits the aviator to view radar targets during both day and night conditions without using a viewing hood. It also provides for retention of the target image on the scope for easier interpretation.

a. The BACKGROUND control knob (A, fig. 16–19) adjusts the level of background "noise" and enables very weak signals to be viewed.

b. The RANGE control knob (B, fig. 16–19) permits the selection of either a 30-mile range with three 10-mile range marks; a 60-mile range with four 15-mile range marks; or a 150-mile range with six 25-mile range marks.

c. The DIM tab (C, fig. 16–19) permits the dimming of the scope for night viewing.

d. The RED tab (D, fig. 16–19) varies the display color from a normal yellow green to deep red for protection of the aviators night vision.

16–30. Operating Procedures

a. Start the equipment with the master control switch. To prevent damage to the radar transmitter circuit, the built-in time delay of

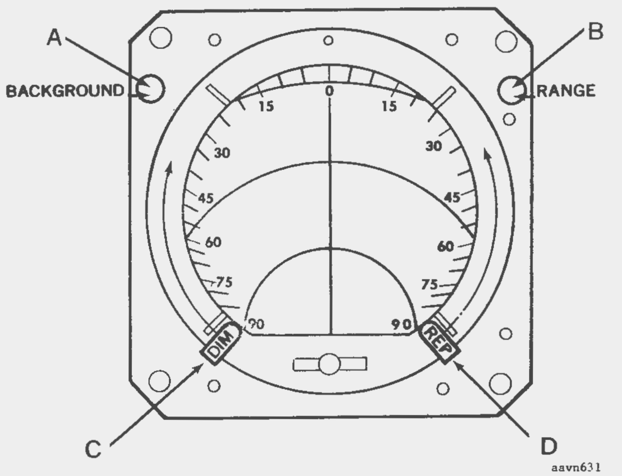


Figure 16-19. Daylight display scope.

4 minutes prevents the application of full power until the tube filaments are heated. With the master control switch in the OPR position, the set will begin transmitting after the 4-minute delay. The set should never be operated when a reflecting surface such as another aircraft or a building is near the radar transmitter since the intense energy returns may damage the set. The intense radiation may also cause small metal particles of certain length (a multiple of the radar transmitter wavelength) to heat and ignite. This can be very hazardous, especially near refueling operations. To prevent inadvertent damage to the set or to ground facilities, a STBY position is provided which allows the set to warm up without transmitting.

b. Set RANGE switch to the desired setting Initial use of the 60- or 150-mile range permits inspection of the greatest weather area.

c. Set RF GAIN at lowest gain (fully counterclockwise).

d. Turn BACKGROUND control fully counterclockwise, then turn BACKGROUND control clockwise until sweep line is barely visible. (The sweep line is the line from bottom center to the edge of the indicator face.)

e. Turn RF GAIN to the maximum clockwise position. For weather analysis, the gain control should not be changed from this position.

f. Reset BACKGROUND control for desirable background level. A marked contrast between echoes and the scope background is desirable. Excess background will produce excessive brightness on the scope face.

g. Rotate ANT TILT control to obtain desired scope presentation. Although ground target returns on the scope (ground clutter) usually appear as curved replies (arcs), the congested ground clutter is virtually impossible to distinguish from weather targets on the scope. To eliminate ground clutter in the weather target area, the aviator must tilt the antenna upward in small increments. This will cause the ground clutter to disappear while the weather target remains on the scope. At the 150-mile range setting, the aviator usually must adjust the tilt so that about two-thirds of the scope presentation near the aircraft is ground clutter, with the outer limits of the scope showing only precipitation areas beyond and above the horizon. This low tilt setting is necessary because storms near the 150-mile range are beyond the earth's horizon. The curvature of the earth between the aircraft and the storms is depicted on two-thirds of the scope nearest the aircraft as ground clutter; the last one-third of the scope then shows precipitation echoes of storms whose tops tower above the horizon.

Note: Adjust antenna tilt position in small increments; (½°-1°) allow sufficient time between adjustments for scope presentation to develop. Scan the storm areas both above and below the rainfall areas.

h. Turn master control switch to CTR (CONTOUR) position. If the weather target ((A), fig. 16-20) contains heavy precipitation areas, they will appear as black holes or cores ((B), fig. 16-20) in the target area. This contour circuit feature of the radar equipment makes it possible to distinguish areas of severe turbulence without the complex adjustment of gain control and background settings necessary with most radar equipment. See paragraph 16-32*d* for contour analysis.

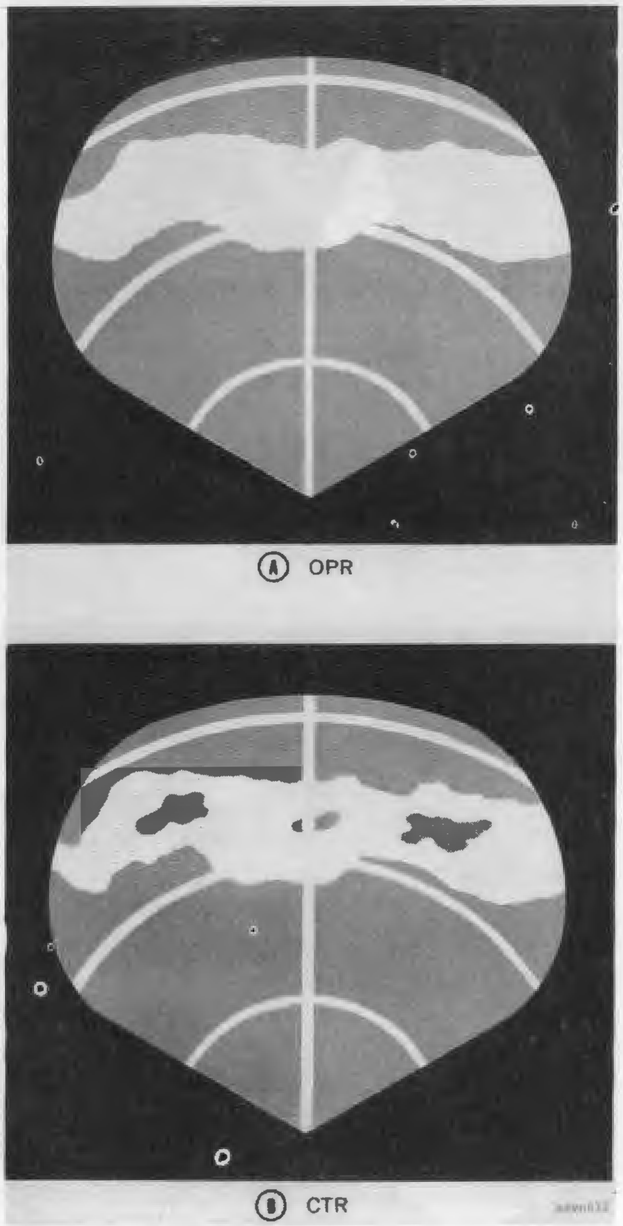


Figure 16-20. Scope display of precipitation areas.

16-31. Range and Azimuth Determination

a. General. For both range and azimuth determination, the bottom center of the screen represents the position of the aircraft. The 0° calibration on the indicator face represents the heading of the aircraft. Therefore, all echo returns displayed to the left or right of the 0° reference denote objects which are located to the left or right, respectively, of the aircraft.

b. Range Determination. To determine the distance between the aircraft and targets—

(1) Note the position of echo returns which are displayed on the screen.

(2) Determine the distance between the bottom center of the screen and echo returns, using the known range marks (circles). If targets are between range marks, use simple interpolation to obtain distance.

c. Azimuth Determination. The periphery of the indicator screen is graduated in 5° increments which extend 90° to the left and right of the 0° reference mark. Determine the azimuth bearing of targets with respect to the heading of aircraft as follows:

(1) Note the position of echo return which is displayed on the screen.

(2) Note the angle between the 0° reference and the sweep trace as the trace passes the echo return.

(3) Determine the azimuth bearing of targets, using the calibrated azimuth scale.

16-32. Radar Weather Observation

The principal function of the APN-158 airborne Weather Radar System is the detection and presentation of weather hazards as a radar scope weather map. This weather map, particularly helpful during severe weather conditions, enables an aviator to select a flightpath which will assure a safe flight around scattered storms or even through lines of storms.

a. In order for the aviator to travel safely through lines of thunderstorms, information regarding turbulence, rain, hail, and long conditions must be obtained. Such information is based upon rainfall *gradients* (varying rainfall densities with respect to distance) which are displayed on the radar indicator.

b. Conversion of rain densities to video presentations on the radar indicator are based on the principle that radio-energy pulses transmitted by a radar are returned by precipitation; i.e., rain drops, hail (when covered by a thin layer of water), and wet snow (when greater than 1 mm). (Variation in rainfall gradient is detected by the use of the contour circuit, which is controlled in the APN-158 with the master control switch. When this switch is in the CTR position, the contour circuit is operative and areas of heavy rainfall are presented as dark areas or black cores within the brighter returns. The bright returns are areas of lighter precipitation.

c. Studies of thunderstorms indicate that sharp sheer (producing violent turbulence) is associated with steep rainfall gradients, i.e., where the change from no rain to heavy rain occurs in the shortest distance.

d. Steep gradients are displayed on the radar indicator as black cores surrounded by a narrow ring of bright returns. Conversely, if cores are not displayed, or if they appear surrounded by a wide ring of light returns, relatively little turbulence exists. The intensity of the bright returns surrounding the black areas also indicates the approximate rainfall rate (the more intense the rainfall, the brighter the echo).

e. When entering a storm area, the aviator should enter and pass through areas where no cores are displayed or where core separation is greatest. It is more important to avoid regions which display narrow contour separation than avoiding areas of heavy rainfall which, in themselves, may not be dangerous to flight. Although a thunderstorm may look like a single storm cell, the typical large thunderstorm cloud contains a collection of several individual storm cells in varying stages of development and dissipation. Thus, the aviator should rely on the radar presentation to determine the storm conditions within a storm mass, and monitor the scope continuously for new cell development and old cell decay.

f. Studies have indicated that the average life of a storm cell in a thunderstorm cloud is approximately 1 hour. Since a thunderstorm will usually have more than one storm cell, the characteristics of the storm undergo constant change. Thereafter, the aviator approaching a storm should make his own decision. A flight 30 minutes earlier would encounter completely different conditions, and a flight at 20,000 feet would probably encounter a different weather situation from one at 10,000 feet.

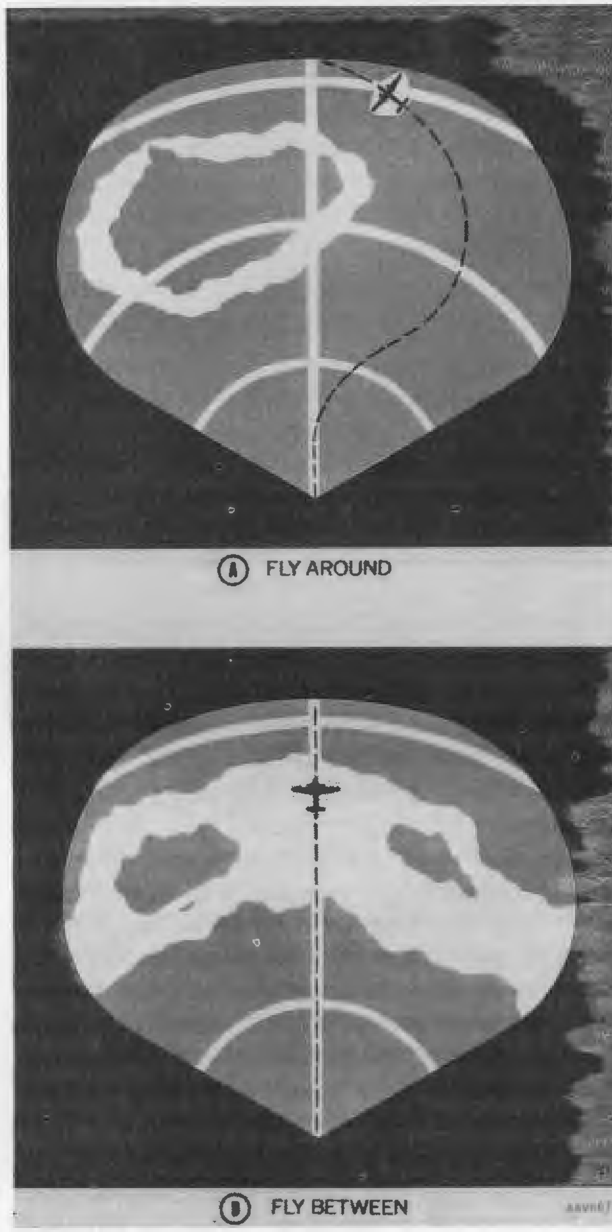


Figure 16-21. Scope display of turbulent areas.

g. Hail in a thunderstorm is associated with either strong updrafts and downdrafts, or it is pushed upward and outward from the cell of the thunderstorm by wind. Damaging hail and turbulence are usually indicated on the radar as fingers, hooked fingers, scalloped edges, or U-shaped projections extending from areas of intense echoes. These presentations are due to hail fallout and/or tornadoes. Avoid these dangerous projections. Also, avoid flights beneath the overhang of a thunderstorm since this overhang may be a hail-shaft formation.

h. In summary, when entering a thunderstorm area, the aviator should fly around the area, which produces intense, bright returns ((A), fig. 16-21). If penetration of a storm area is necessary, the aviator should enter and pass through areas where no cores are displayed or where separation between cores is the greatest ((B), fig. 16-21). If, for example, the radar indicator has a display of two large cores separated by a narrow strip of bright returns, the narrow bright strip usually denotes an extremely turbulent area, which must be avoided. If a wide area of light or fuzzy returns separates the black holes, turbulence in this area is generally mild. If sufficient separation is indicated (par. 16-34*b*), the aircraft can be flown through these light or fuzzy returns, midway between the black holes, with relatively little difficulty.

16-33. Radar Weather Interpretation

a. Precipitation density and distance from the transmitter will affect the size of the indicator presentation. Precipitation areas near the transmitter will appear large; identical precipitation areas located some distance from the transmitter will appear small due to the loss of energy.

Note. **Any weather echo appearing at a range of 50 miles or more warrants continued attention.**

b. A rule of thumb for avoiding areas of sharp shear (strong turbulence) is to bypass them by at least 5 miles when flight level temperatures are above freezing and by 10 miles when flight level temperatures are below freezing. Since the ice crystals present at cold temperatures do not return distinct, strong signals as do liquid water drops, these areas should be given a greater clearance distance.

c. When the antenna is set too high on a storm target, the return from the cloud top may be weak even though the storm is intense. Ice crystal formations are poor radar targets.

d. In addition to the main "bang" (beam), the APN-158 transmitter emits side lobes of radar energy (leakage). These side lobes can produce deceptive images on the scope. The ANT TILT should be used to keep the main bang pointed at the target.

e. Prolonged use of a short RANGE setting is dangerous. While studying the immediate vicinity in minute detail, the aviator may fly into a large area of storms without noticing their presence. Close range should be used to obtain a large, detailed picture of suspect storms located at longer range settings. The range should then be returned to the longer range setting.

f. Electronic equipment has mechanical limitations. Weather radar is a supplement to the weather briefing, but the aviator should not depend entirely on the radar for storm information since the set may become inoperative during a flight.

PART FOUR
ADVANCED NAVIGATION SYSTEMS

CHAPTER 17
THE INTEGRATED FLIGHT SYSTEM

Section I. DESCRIPTION AND OPERATION

17-1. Introduction

a. The integrated flight system installed in some Army aircraft is the ASN-33 navigational computer. This system and other similar systems obtain flight data from multiple sources and present this data visually to the aviator on two relatively large instrument indicators. The two integrated flight system instruments have been carefully designed to present navigational and attitude data as simple, easy-to-interpret indications.

b. The integrated flight system instruments are the *approach horizon-ID-882* (fig. 17-1) and the *course indicator-ID-883* (fig. 17-2). The flight information they show consists of—

(1) Pitch and bank attitude indications.

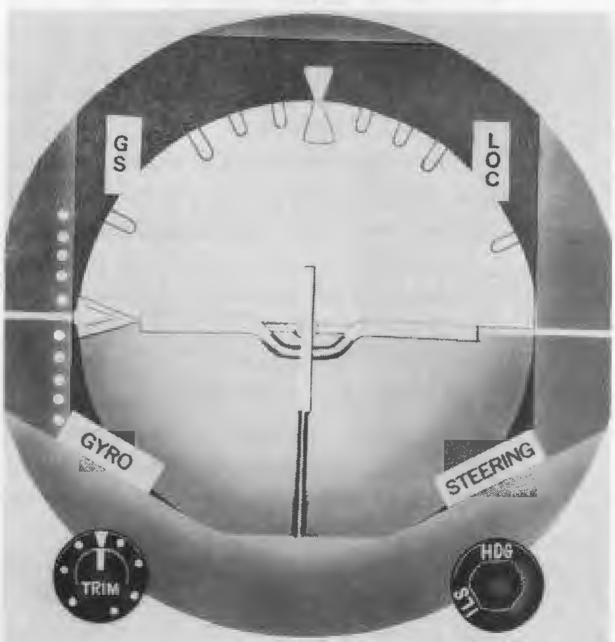


Figure 17-1. Approach horizon—ID-882.

Figure 17-2. Course indicator—ID-883.

(2) Steering and turning commands.
(3) Magnetic heading.
(4) VOR track deviation and to-from data.
(5) ILS localizer deviation data.
(6) ILS glideslope deviation data.
(7) Warnings for component or signal failure.

17-2. Approach Horizon—ID-882

a. General. The approach horizon—ID-882 (fig. 17-1) is a primary attitude and steering instrument. It also provides glidescope data during a front course ILS approach when the glidescope receiver and ground equipment are operational.

b. Mode. A mode selection knob labeled HDG (heading) and ILS (instrument landing system) is located on the bottom right side of the approach horizon indicator (fig. 17-1). The aviator selects the mode of operation by placing this knob in one of the two positions. The HDG mode of operation is used in all cases *except* when the aviator is executing the final approach on the front course of an ILS.

c. Bank Pointer and Horizon Bar. The bank pointer and horizon bar (fig. 17-3) work together. The bank pointer indicates the amount of bank read from the 10°, 20°, 30° and 60° graduations at the edge of the horizon disc; the horizon bar correctly indicates the bank attitude of the aircraft throughout all, or any portion, of a 360° roll. Under ordinary cruise conditions a coordinated turn is accomplished at approximately a 25° bank angle (*e*(3) below).

d. Pitch Bar and Pitch Trim Knob (fig. 17-4).

(1) *Pitch bar.* The pitch bar correctly indicates the pitch of the aircraft to plus or minus 85°. The bar moves independently in front of the horizon disc in contrast to conventional attitude indicators on which the disc and bar move as a unit.

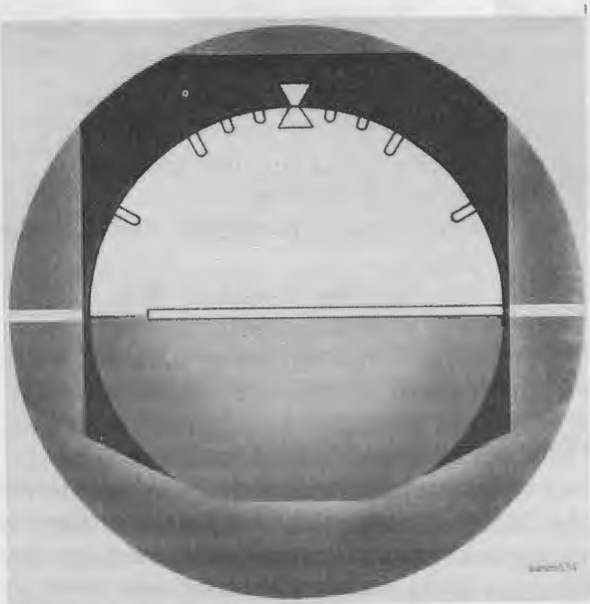


Figure 17-3. Bank pointer and horizon bar.

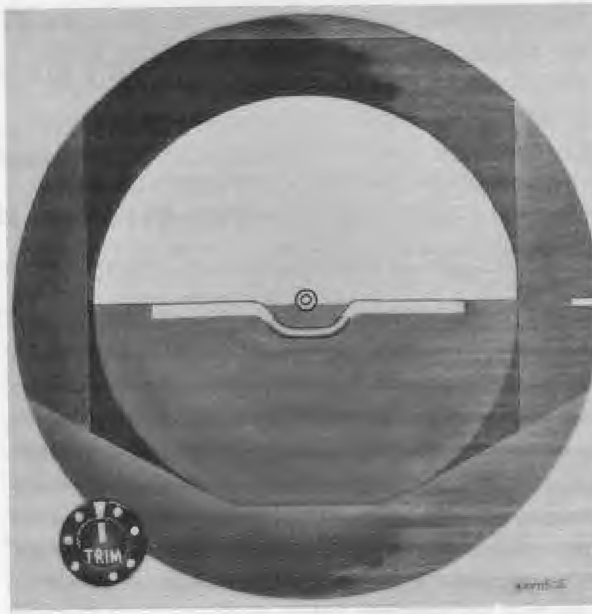


Figure 17-4. Pitch bar and pitch trim knob.

(2) *Pitch trim knob—HDG mode.* In the HDG mode, the pitch trim knob (bottom left side of indicator) allows the aviator to adjust the pitch bar with reference to the horizon bar for pitch attitudes up to plus 20° and down to minus 15°. The knob is marked with dots at 5° intervals.

(3) *Pitch trim knob—ILS mode.* When the equipment is placed in the ILS mode, the pitch bar is automatically adjusted for the correct pitch attitude of the aircraft on final approach. The pitch trim knob has no control over the pitch bar.

e. Steering Pointer (fig. 17-5).

(1) *HDG Mode.* In the HDG mode, the steering pointer is activated by data from two sources—heading and bank attitude. If the aircraft is maintaining the heading set under the heading marker (par. 17-3*c*) and 0° of bank, the steering pointer is vertically centered. If the aircraft tends to deviate

from the selected heading or to bank (which normally results in a turn), the steering pointer reacts immediately and commands the aviator to take corrective action. For example, if the aircraft tends to turn or bank toward the left, the steering pointer deflects to the *right*, commanding the aviator to correct to the *right*.

(2) *ILS mode*. In the ILS mode, the steering is fed data from the ILS localizer signal (ch. 15) in addition to heading and bank data. Consequently, the pointer becomes a localizer steering command indicator. By following the indicator commands, the aviator turns to a heading which will either keep the aircraft on, or return it to, the ILS final approach course.

(3) *Coordinated turns*. To turn from one heading to another with the pointer to the HDG mode, the aviator first selects the new heading with the heading marker (par. 17-3*c*). The steering pointer immediately deflects in the direction (right or left) of the

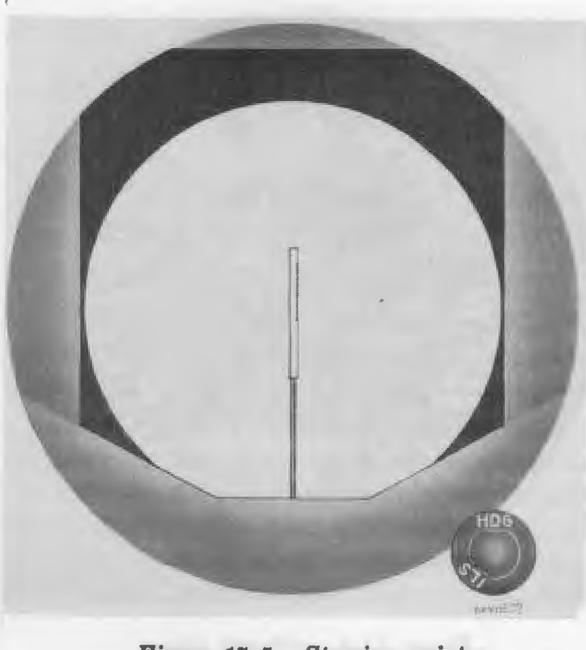


Figure 17-5. Steering pointer.

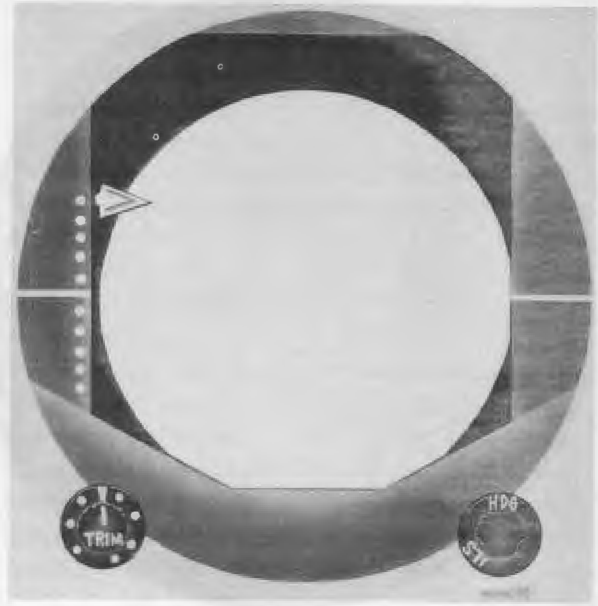


Figure 17-6. Glideslope pointer.

necessary turn. The aviator follows the command of the steering pointer by beginning the turn and bank toward the steering pointer. When the correct amount of bank (approximately 25°) to execute a coordinated turn has been established, the steering pointer will center. The aircraft has not yet reached the new heading, but is turning correctly to do so. As the aricraft approaches the new heading, the steering pointer tends to deflect in the direction opposite the turn. This commands the aviator to reduce the amount of bank (to roll out). With very slight aircraft control movements, the aviator can keep the pointer centered and cause the aircraft to roll out on the new heading with little probability of overshooting or rolling out short. The pointer also commands coordinated turns while operating in the ILS mode, but the heading marker (par. 17-3*c*) is not used.

f. Glideslope Pointer. The glideslope pointer (fig. 17-6) shows the displacement of the air-

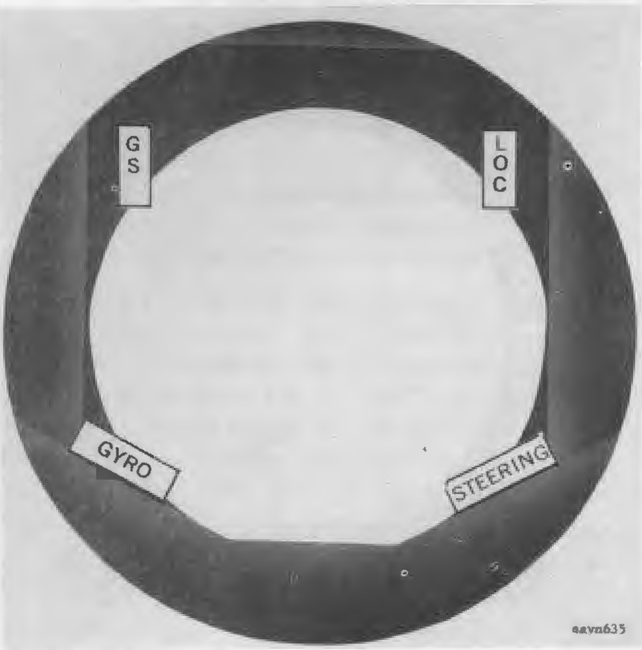


Figure 17-7. Warning flags.

craft above or below the glidepath by reference to a standard 5-dot vertical scale at the left of the instrument face. A pointer deflection above center commands the aviator to "fly up"; a pointer deflection below center indicates a "fly-down" command. Corrections are made (1) by "flying" the pitch bar up or down to meet the glideslope pointer and then (2) by keeping them together as they simultaneously approach the glideslope center line (indicated when the glideslope pointer is at the center mark of the scale on the left side of the indicator).

g. Warning Flags. The approach horizon has four warning flags (fig. 17-7). Their meaning and the corrective action required by the aviator are as follows:

(1) *LOC flag.* The LOC flag appears if the VOR/localizer (ARN 30) receiver is off (or has a malfunction) or if the received signal is unreliable. If the LOC flag appears when the aircraft is within range of the transmitter and the receiver is tuned properly, then the aviator should switch to another VOR receiver (if available) or to a secondary navigation system (e.g., ADF).

(2) *GS flag.* The GS flag appears when the glideslope receiver is not tuned or when the glideslope signal is not being reliably received. If the GS flag appears on final approach when the glideslope signal should be received, the aviator disregards the glideslope data and continues the approach using other navigation equipment. This occurrence may change the authorized approach minimums.

(3) *Steering flag.* Indications of the steering pointer should be disregarded when the steering warning flag appears, indicating that power is not being supplied to the steering computer.

(4) *Gyro flag.* If the gyro warning flag appears, attitude information (pitch and bank) is unreliable. The aviator disregards pitch and bank information from the ID-882 and relies on a supplementary attitude indicator or uses partial panel procedures as appropriate for his aircraft equipment.

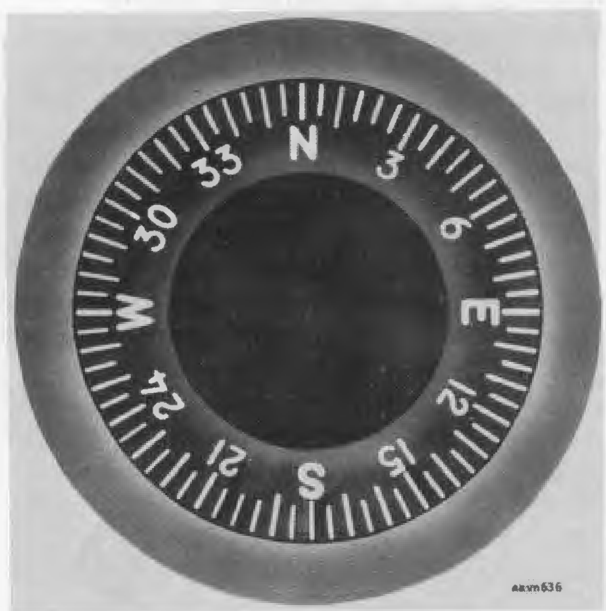


Figure 17-8. Azimuth ring.

Note. The ID-882 gyro does not furnish bank information to the steering pointer.

17-3. Course Indicator—ID-883

a. General. The course indicator ID-883 (fig. 17-2) shows the magnetic heading of the aircraft and a pictorial presentation of the aircraft with respect to a selected VOR radial and station or localizer course.

b. Azimuth Ring. The azimuth ring (fig. 17-8) is driven by the aircraft compass system. It is almost a duplicate of the azimuth ring of the RMI (ch. 12). As long as the compass system of the aircraft is operating properly, the correct magnetic heading of the aircraft appears under the lubber line and index at the top of the course indicator.

Note. Failure to synchronize the aircraft compass system with the correct magnetic direction causes significant heading errors (TM 1-215).

c. Heading Marker and Heading Knob (fig. 17-9). The aviator turns the heading knob to move the heading marker. The heading marker is used in conjunction with the steering pointer (par. 17-2*e*). The heading which the aviator desires to fly is selected with the marker, and the steering pointer reacts instantly. The aviator follows the commands of the steering pointer to reach, and roll out on, the desired heading, with the heading marker under the lubber line. As long as the aviator keeps the steering pointer centered, on recenters it, the heading marker remains under the lubber line until the aviator selects a new heading.

(1) In turning right to a new heading, the aviator should turn the heading knob to the right, causing a right deflection of the steering pointer. The opposite procedure is used for left turns. A turn of the knob in excess of 180° should be avoided since this will cause a steering pointer reaction opposite to that desired. If the aircraft is to be turned in excess of 180° (e.g., for completing a procedure turn), the heading marker should be moved in increments less than 180° until the full turn is achieved.

(2) The heading marker should be used in

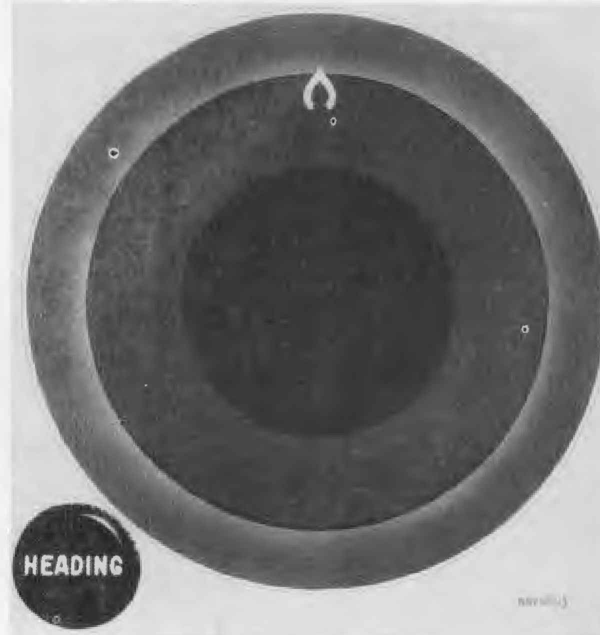


Figure 17-9. Heading marker and heading knob.

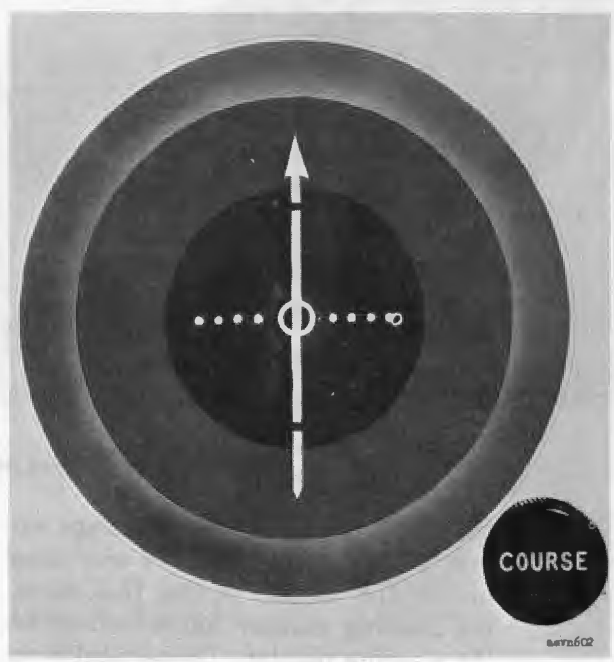


Figure 17-10. Course bar, arrow, and course knob.

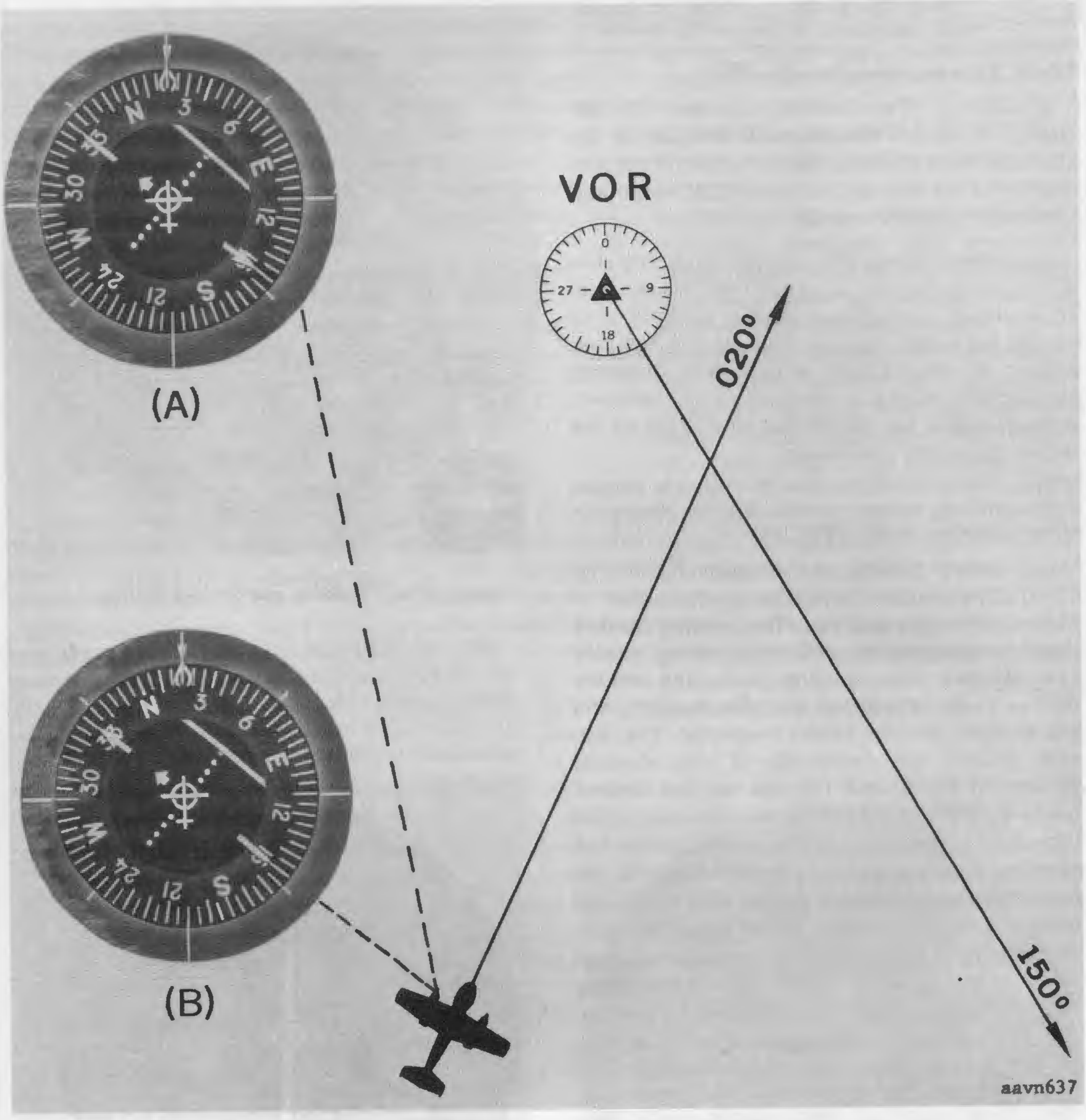


Figure 17-11. Course arrow tuned to VOR station.

making turns to all new headings except when the equipment is operating in the ILS mode. In the ILS mode, the heading marker has no effect on the steering pointer. Consequently, in exceeding the final front course approach of the ILS, the aviator sets the heading marker on the missed approach heading. If a missed approach is executed, the aviator changes the mode back to HDG and the steering pointer then reacts to the

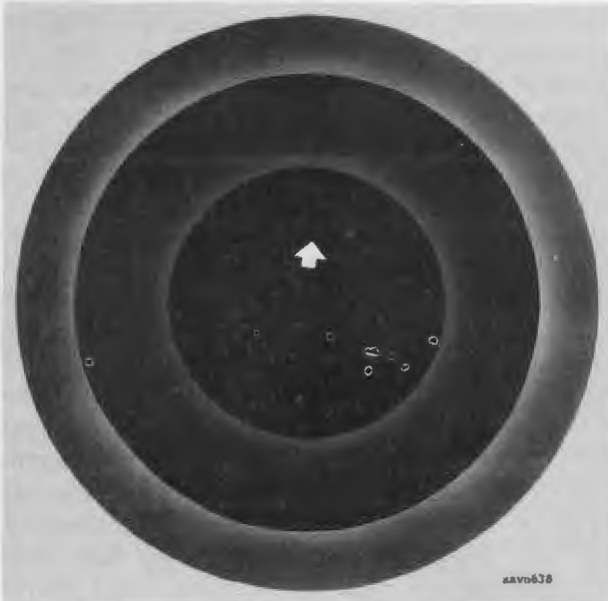


Figure 17–12. To-from arrow.

heading marker setting. This feature can be especially helpful when the missed approach course differs from the final approach course.

d. Course Bar, Arrow, and Course Knob (fig. 17–10). The course arrow is similar to the course selector used with the ID–453 (ch. 10). With the course knob, the aviator moves the course arrow to select any VOR course or radial, *or* any *localizer course*. The course bar indicates the position of the selected course or radial with respect to the aircraft. The entire course bar moves laterally across the inner disc of the course indicator on a standard scale consisting of a small inner circle and four dots. Two important differences between the functioning of the ID–883 course indicator and the more conventional course indicator (ID–453, ch. 10) are—

(1) When a VOR station is tuned, the course arrow may be set on either the course or the course reciprocal; i.e., if the aviator wishes to use the 240° course, the course arrow may be set to 240° or to 060°. The resulting pictorial display will be identical. For example, the aircraft (fig. 17–11) is flying a heading of 020° to intercept the 150° radial (330° course) in-bound to the VOR. In (A), figure 17–11 the course arrow is set on 150°; in (B), figure 17–11 it is set on 330°. The course bar indication is identical in both cases; it depicts the desired course to the right-front of the aircraft in a map-like display.

(2) When the localizer transmitter of an ILS is tuned, the *course arrow must be set on the inbound front course* for the indicator to display the correct pictorial relationship between the aircraft and the localizer course.

Note. This applies to operation in both modes whenever a localizer is tuned, regardless of the flight situation (e.g., inbound, outbound, transition, or intersection).

e. To-From Arrow. The to-from arrow (fig. 17–12) is aligned with the course arrow; it may appear at the head of the course arrow pointing in the same direction as the course arrow

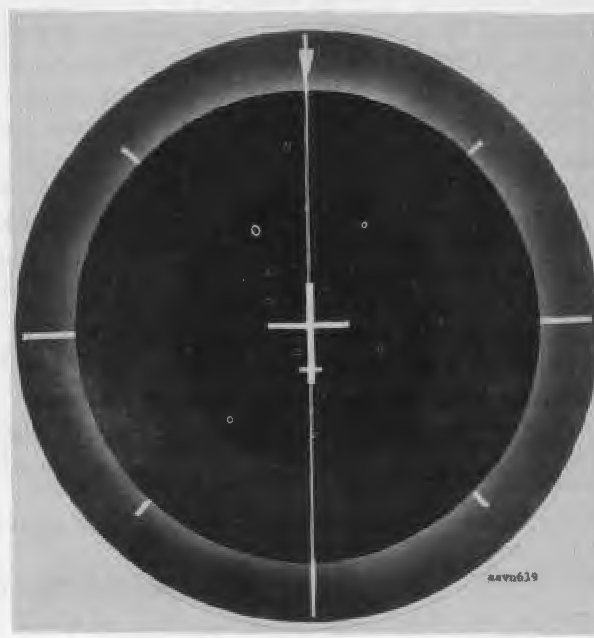


Figure 17–13. Miniature airplane and lubber line.

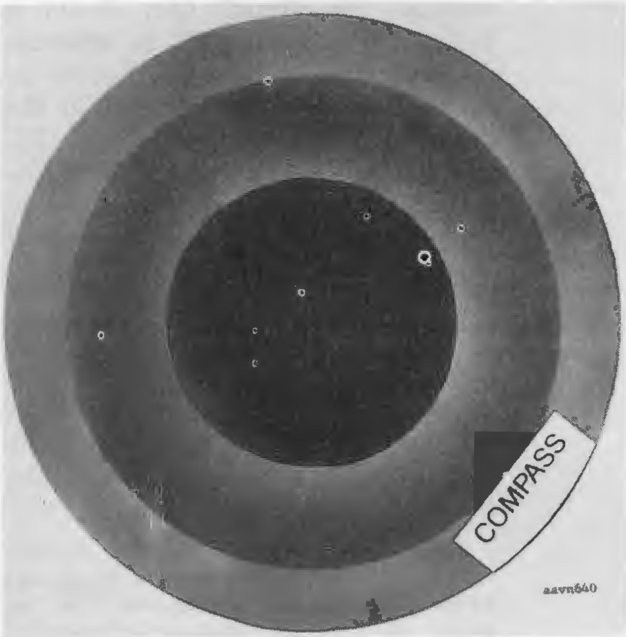


Figure 17-14. COMPASS warning flag.

((B), fig. 17-11), or at the tail of the course arrow ((A), fig. 17-11). It does *not* show the *flight direction* of the aircraft but shows the location of the station with respect to the aircraft along the selected course. For example, in (A) and (B) of figure 17-11 the to-from arrow indicates that the station is to the left-front of the aircraft; i.e., it is at the western extremity of the 150°-330° course line with respect to the aircraft. The to-from arrow shows the correct indication regardless of the course arrow setting. In (A) and (B) of figure 17-11, the position of the to-from arrow is the same although the course arrow setting is for 150° in (A) and 330° in (B). The to-from arrow is not visible when the receiver is tuned to an ILS localizer.

f. Miniature Airplane and Lubber Line (fig. 17-13). The miniature airplane is mounted at the center of the instrument face. The lubber line is marked at the top of the face along the vertical centerline. The lubber line indicates the aircraft heading. The miniature airplane indicates the position of the aircraft with respect to the selected course. When the miniature airplane is pointed toward the course bar, the aircraft is approaching the selected course.

g. COMPASS Warning Flag.

(1) The COMPASS warning flag (fig. 17-14) appears when there has been a failure in the compass system. In some cases the compass may fail only in the slaved-gyro mode and may continue to function in the free-gyro mode. The aviator should follow the procedures for slaved-gyro compass failure recommended in the appropriate aircraft operator's manual. The appearance of the COMPASS warning flag also means that the aviator must disregard indications of the steering pointer, since steering pointer indications are based in part on heading data obtained from the compass system.

(2) Although a compass system failure occurs, the VOR information presented by the course bar and to-from arrow is still reliable and usable unless the LOC flag appears. However, to interpret indications of the course bar the aviator must make adjustments for improper headings that might appear under the lubber line. For example, the aircraft (fig. 17-15) is tracking inbound on the 180° radial maintaining a heading of 0°. The azimuth ring of the course indicator shows 040° as a result of compass system failure. However, the course bar is centered under the miniature airplane indicating the aircraft is on course.

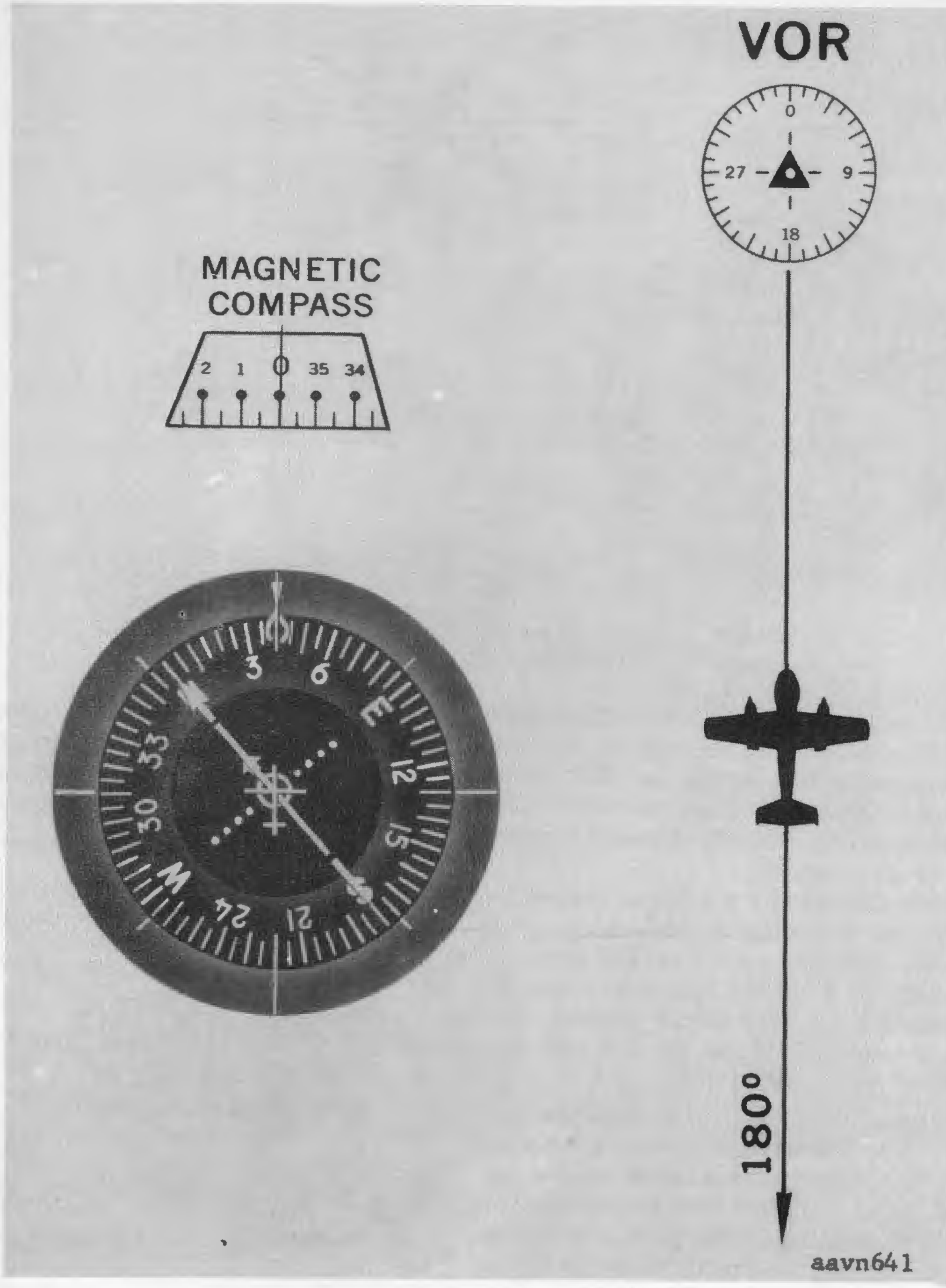


Figure 17–15. Improper heading information because of compass system failure.

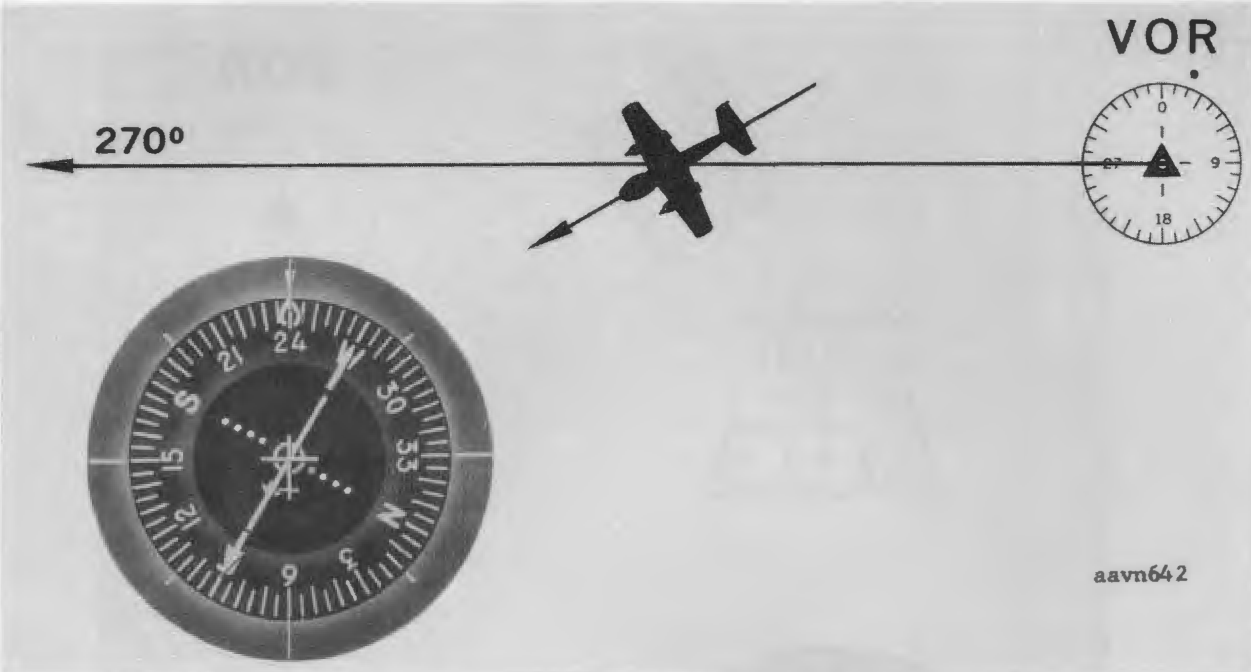
Section II. FLIGHT OPERATION

17–4. Before Takeoff

The aviator should make the following preflight checks:

a. Check appropriate items on the aircraft circuit breaker panel.

b. Turn on aircraft power. After a slight de-



Aircraft is oriented on the 270° radial flying a heading of 240°.
Figure 17-16. Orientation using the integrated flight system.

lay, check to see that the GYRO, COMPASS, and STEERING flags are masked.

c. Set the ILS-HDG switch to HDG. Move the heading marker 90° from the lubber line. The steering pointer should deflect in a corresponding direction.

d. Return the heading marker to the lubber line. The steering pointer should center.

e. Set the ILS-HDG switch to ILS. Move the course arrow 5° from the lubber line and return it quickly to its original position. The steering pointer should deflect abruptly and return to center slowly.

f. If ground VOR and ILS facilities are available, tune the navigation and glide-slope receivers to the proper channels. Check to see that the GS and LOC flags disappear, the glide-slope pointer deflects in the proper direction, the course bar centers correctly when the course arrow is alined with the omni radial on which the aircraft is located, and that the to-from arrow displays properly.

g. Check the course indicator azimuth ring for proper followup to the magnetic compass during taxiing, and cross-check against RMI azimuth ring.

h. Check the pitch bar and horizon line for correct indication of aircraft ground attitude.

i. Before takeoff, check to see that the ILS-HDG knob is in the HDG position.

17-5. Orientation

Orientation using the integrated flight system course indicator is accomplished as follows (fig. 17-16):

a. Tune and identify the station.

b. Rotate the course arrow until the course bar centers and the to-from arrow appears at the head of the course arrow.

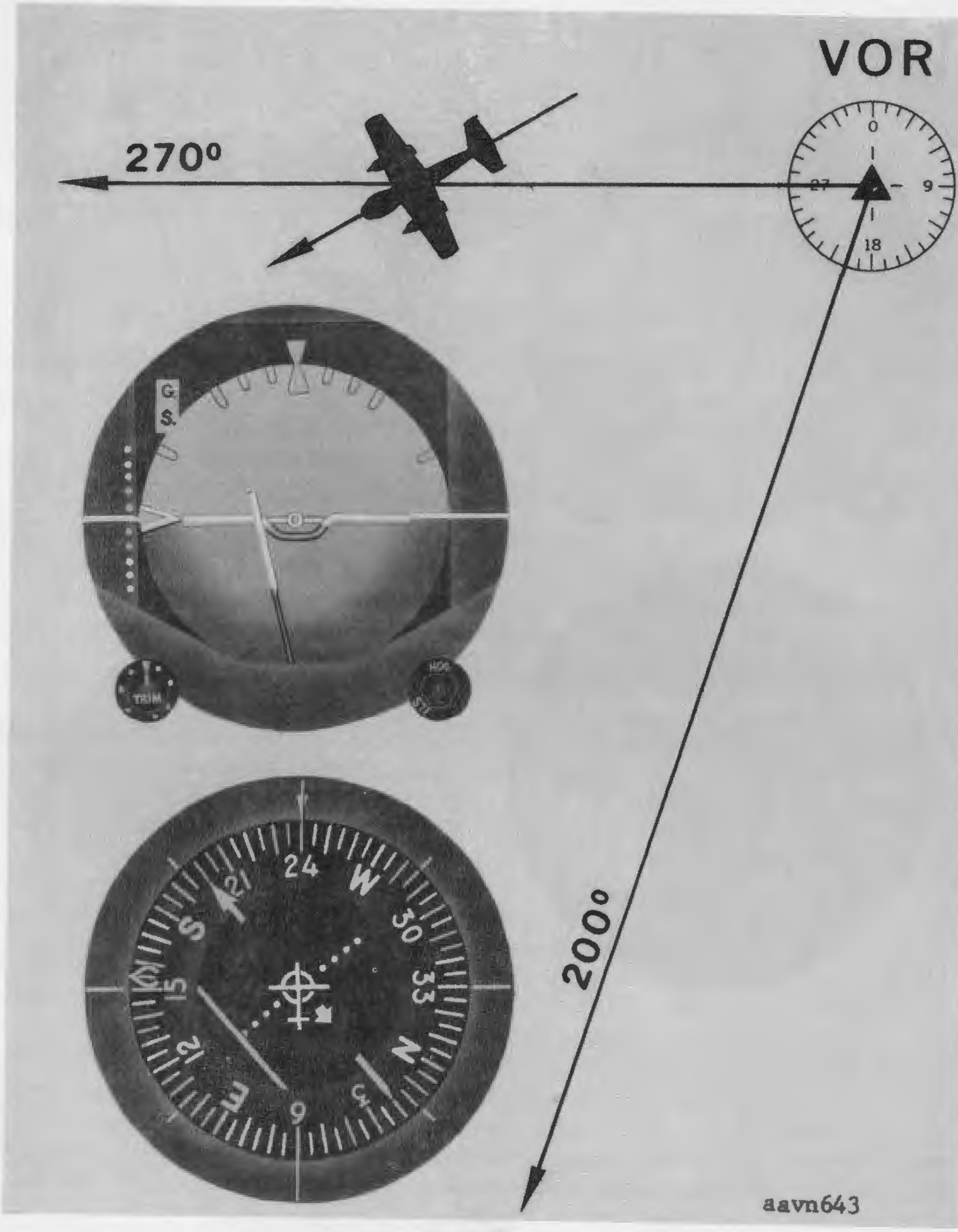
c. Read the radial on which the aircraft is located under the tail of the course arrow; the direction to the station is under the course arrow.

d. Read the aircraft heading under the lubber line.

17-6. VOR Track Interception

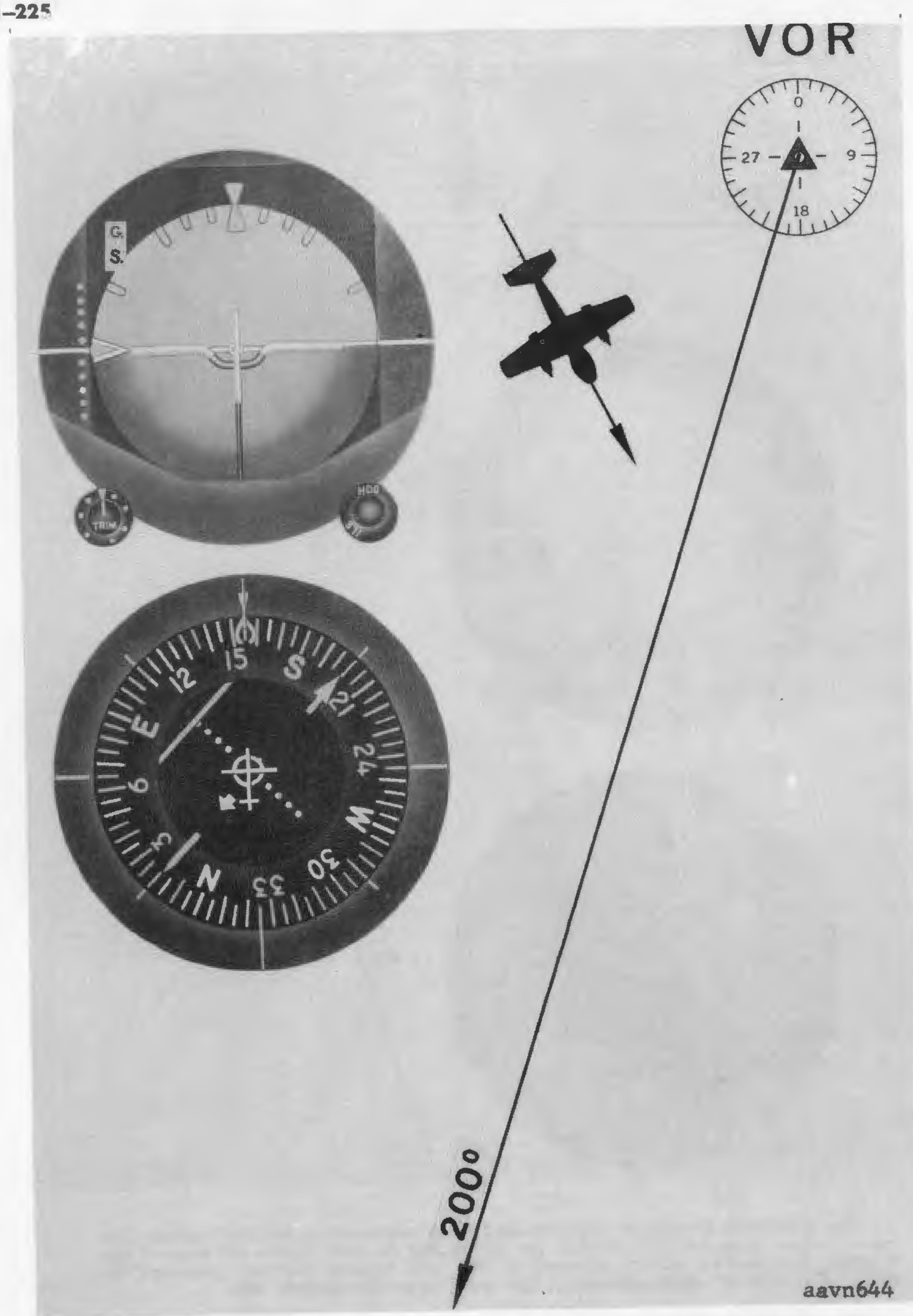
VOR track interception using the integrated flight system is accomplished as follows:

a. With the course knob, set the course arrow on the desired course (or its reciprocal) (fig. 17-17 ①).



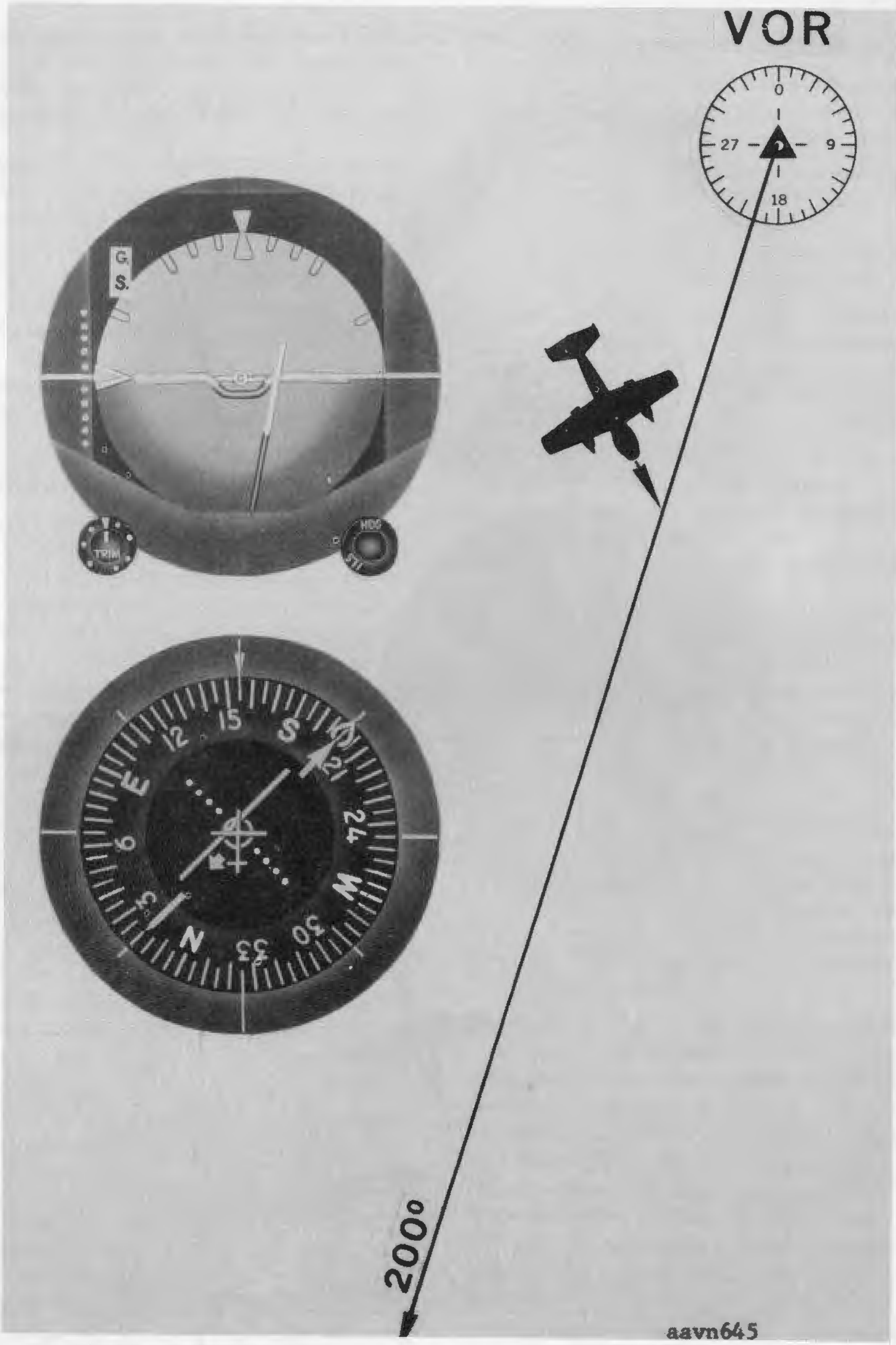
The aviator is directed to intercept and track outbound on the 200° radial. The course arrow is set to 200°, causing the course bar to move to the left-rear of the aircraft. The heading marker is moved to 155° (the heading that will intercept the 200° radial at a 45° angle outbound). The steering pointer deflects left.

Figure 17-17①. VOR track interception using the integrated flight system.



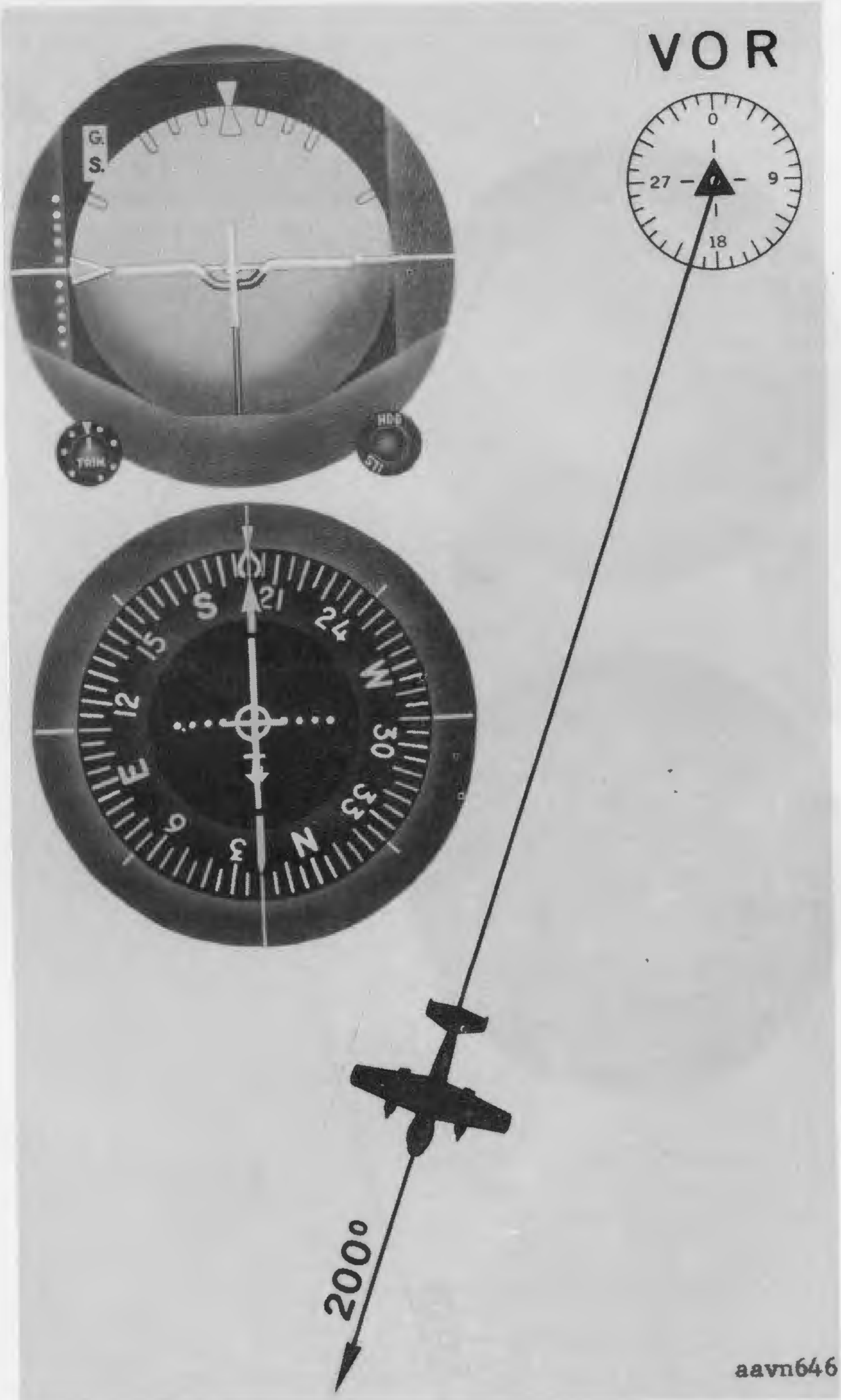
The aviator has followed the command of the steering pointer to the new heading of 155° to intercept the 200° radial. The radial and the course bar are to the left-front of the aircraft. The aviator holds the new heading until just prior to the interception.

Figure 17–17(2)——Continued.



The aviator has observed the closure rate of the course bar and course arrow. Just before interception, he resets the heading marker to the outbound track. The aviator follows the command of the steering pointer by turning right to the outbound heading.

Figure 17-17(3)—Continued.



The aviator has completed the turn outbound to 200°. The course bar and the steering pointer are centered. The to-from arrow shows the station behind the aircraft.

*Figure 17-17*④——Continued.

b. With the heading knob, set the heading marker to the heading which will intercept the course at the desired angle (fig. 17–17 ①).

Note. Interception of 45° and 90° are standard (par. 11–8*a*).

c. Follow the turning command of the steering pointer to the new heading (fig. 17–17 ①).

d. Maintain the interception heading and observe the closure rate between the miniature airplane and the course bar. Just prior to interception, reset the heading marker to the desired course heading (figs. 17–17 ② and 17–17 ③).

e. Follow the commands of the steering pointer to roll out on course and on heading (fig. 17–17 ④).

17–7. VOR Tracking

Figure 17–17 ④ shows the aircraft on track using a 0° drift correction. The course bar is centered and the heading marker and course arrow are both on the same setting under the lubber line. When a crosswind produces a significant deviation of the aircraft from the course bar (fig. 17–18 ①), execute the tracking procedure as follows:

a. Offset the heading marker 20° toward the direction of the course bar deflection (17–18 ①).

b. Follow the command of the steering pointer to the new heading for reintercepting the course.

c. Observe the rate of closure between the miniature aircraft and the course bar. Just prior to interception, reset the heading marker to a heading which provides a 10° drift correction into the wind (fig. 17–18 ②).

d. Follow the command of the steering pointer to the new heading. On the new heading the course bar should be approximately centered under the miniature aircraft. The heading marker is under the lubber line, the steering pointer is centered, the course arrow is offset 10° from the lubber line, and the 10° crab angle is pictured between the course bar and the minature aircraft (fig. 17–18 ③).

Note. Make subsequent tracking corrections (if necessary) using the standard bracketing procedure (ch. 10). Use the heading marker and steering pointer for turning to and maintaining new headings.

17–8. VOR Intersections Using the ID–883

a. Establish the drift correction and heading necessary to maintain the present aircraft track inbound to or outbound from the station.

Note. Supplementary radio receivers may be used to maintain this track if the aircraft is appropriately equipped.

b. Retune the VOR receiver to the off-track facility used to establish the intersection.

c. Set the course arrow to the radial (or its reciprocal) passing through the intersection. This will cause the course bar to assume the same position in relation to the miniature airplane as the actual radial is in relation to the aircraft (point X, fig. 17–19).

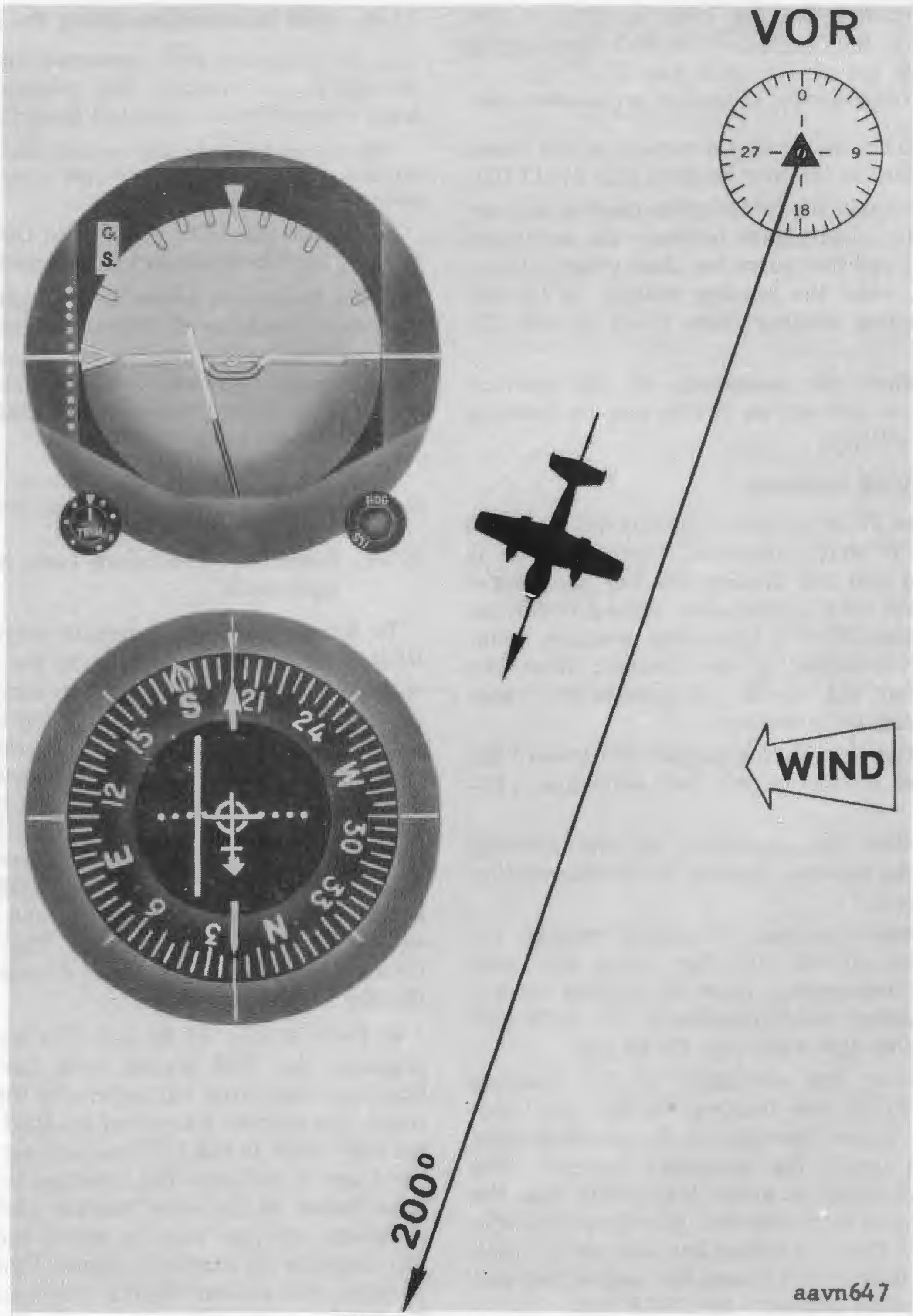
d. When the course bar centers (point Y, fig. 17–19), the aircraft is over the intersection.

17–9. Transition, Procedure Turn, and ILS Approach

In figure 17–20, the aircraft arriving at a VOR station must transition to the LOM, fly outbound for a procedure turn, and complete the final apprach on the front course of an ILS. The aircraft is equipped with a marker beacon receiver, dual VOR's, and ADF receiver, the RMI (ID–250, ch. 12), and the integrated flight system (ID–882 and ID–883). One VOR receiver is tuned to the ILS localizer and displayed on the ID–883. The second VOR receiver is tuned to the local omni station and displayed on the ID–250 (No. 2 arrow). The ADF receiver is tuned to the LOM and displayed on the ID–250 (No. 1 arrow).

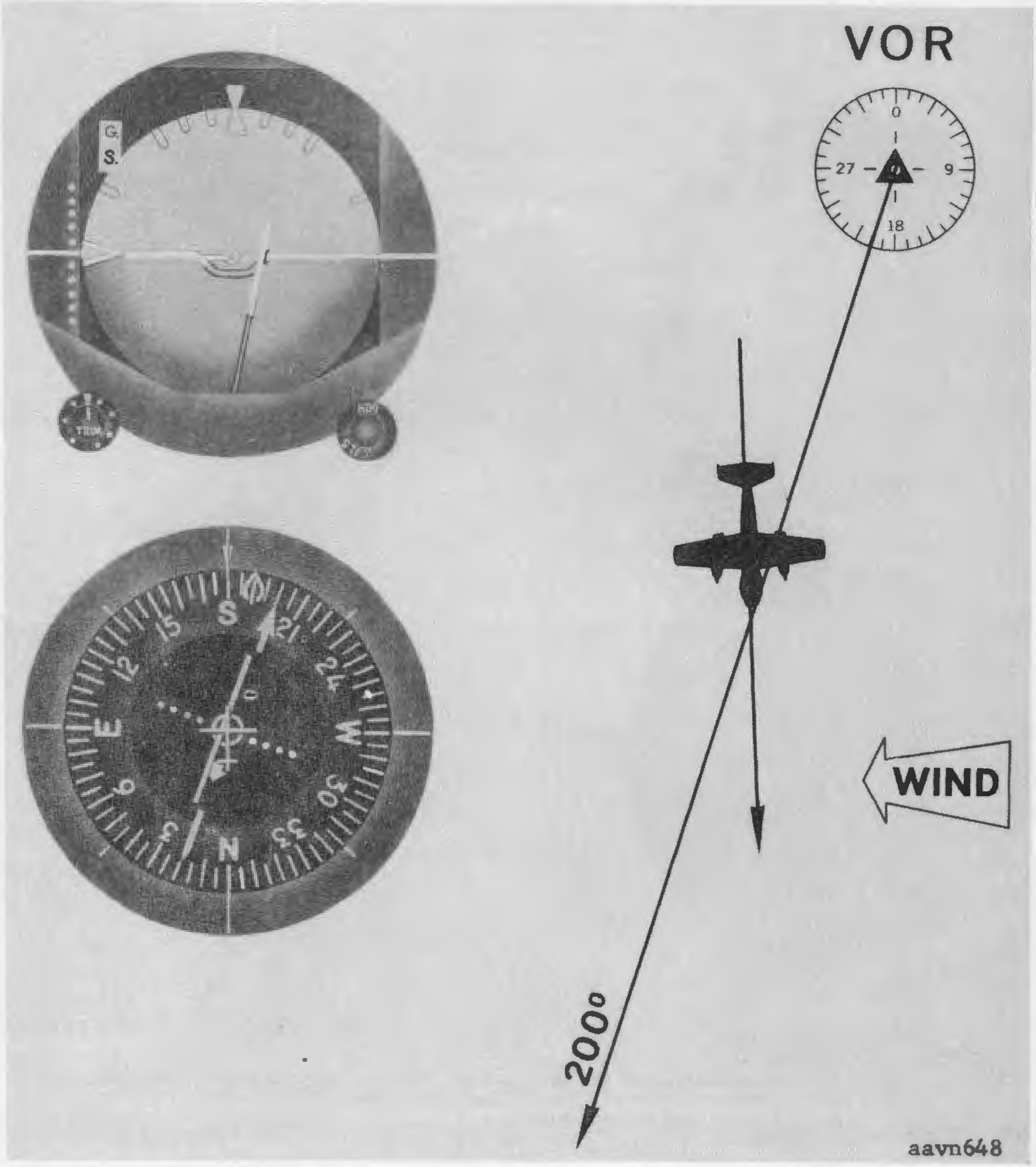
a. Point A (fig. 17–20 ①). The aircraft approaches the VOR station with the localizer tuned and the course bar indicating the localizer track. The number 2 arrow of the RMI indicates the 200° track to the VOR station and the number 1 arrow indicates the direction to the compass locator at the outer marker (LOM). The glideslope receiver may be tuned, but the GS flag indicates an unreliable signal. Upon station passage, the aviator begins the transition to the LOM.

Note. The course arrow must be set for the inbound front course (090°). The to-from arrow does not appear when the system is tuned to a localizer signal.



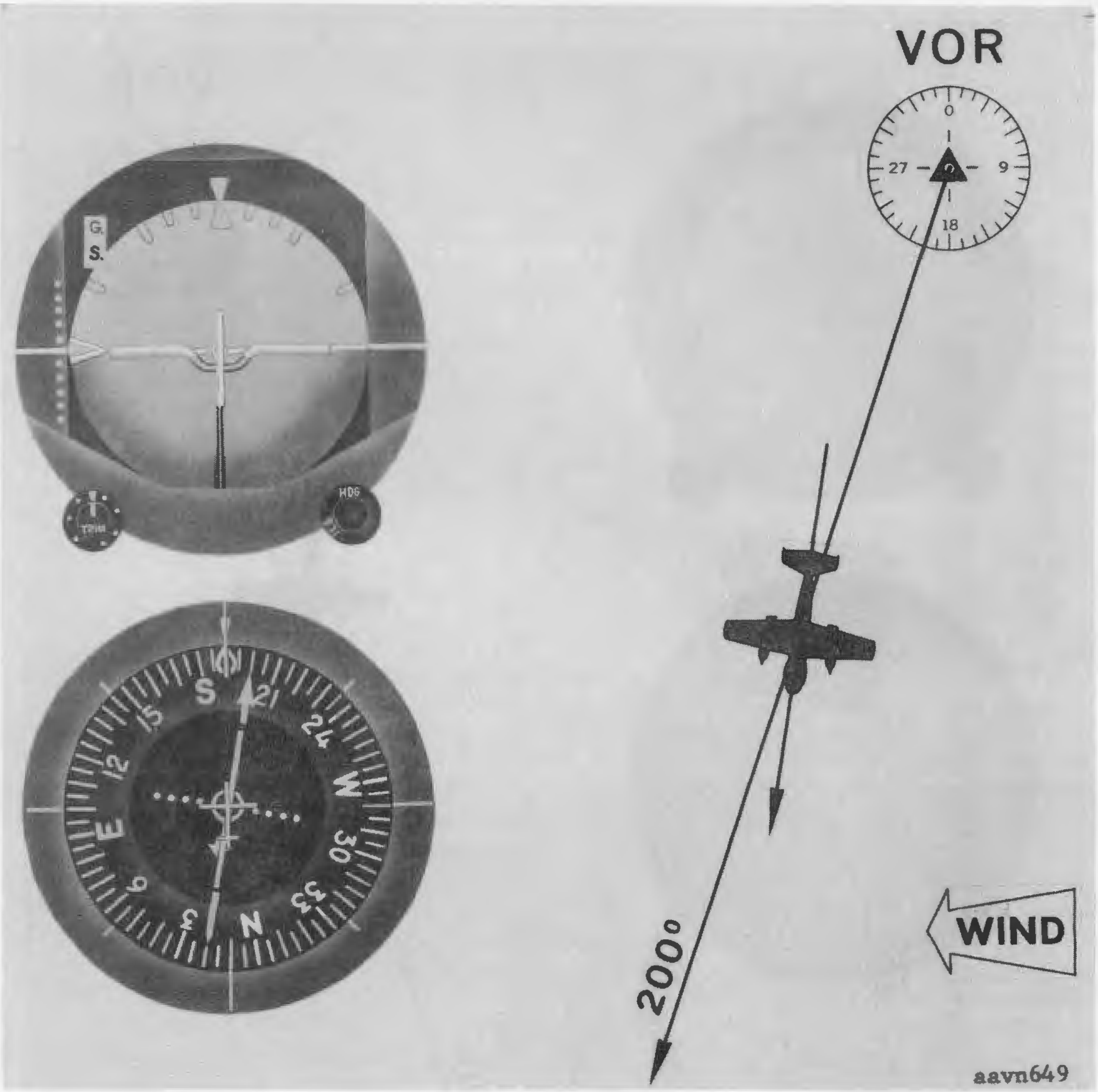
The aviator observes a significant deviation of the course bar caused by a crosswind. The heading marker is set 20° left. The steering pointer deflects and the aviator follows the command, turning left to center the steering pointer.

Figure 17-18①. VOR tracking using the integrated flight system.



Just before reinterception, the aviator sets the heading marker to a heading (190°) which provides a 10° drift correction into the left crosswind. The steering pointer deflects to the right, commanding the aviator to turn right to a 190° heading.

*Figure 17-18*②—Continued.



The aviator has completed the turn to 190°. The heading marker is under the lubber line, the course arrow is offset 10°, and the crab angle is pictured between the miniature airplane and the course bar.

*Figure 17-18*③—Continued.

b. Point B (fig. 17-20 ①). The aviator is executing the transition. The number 2 RMI arrow indicates the direction to the VOR (080°) and the number 1 arrow indicates the direction to the LOM (260°). The course bar shows the localizer course just to the left of the aircraft.

c. Point C (fig. 17-20 ②). The aviator turns outbound after passing the LOM. He ro-

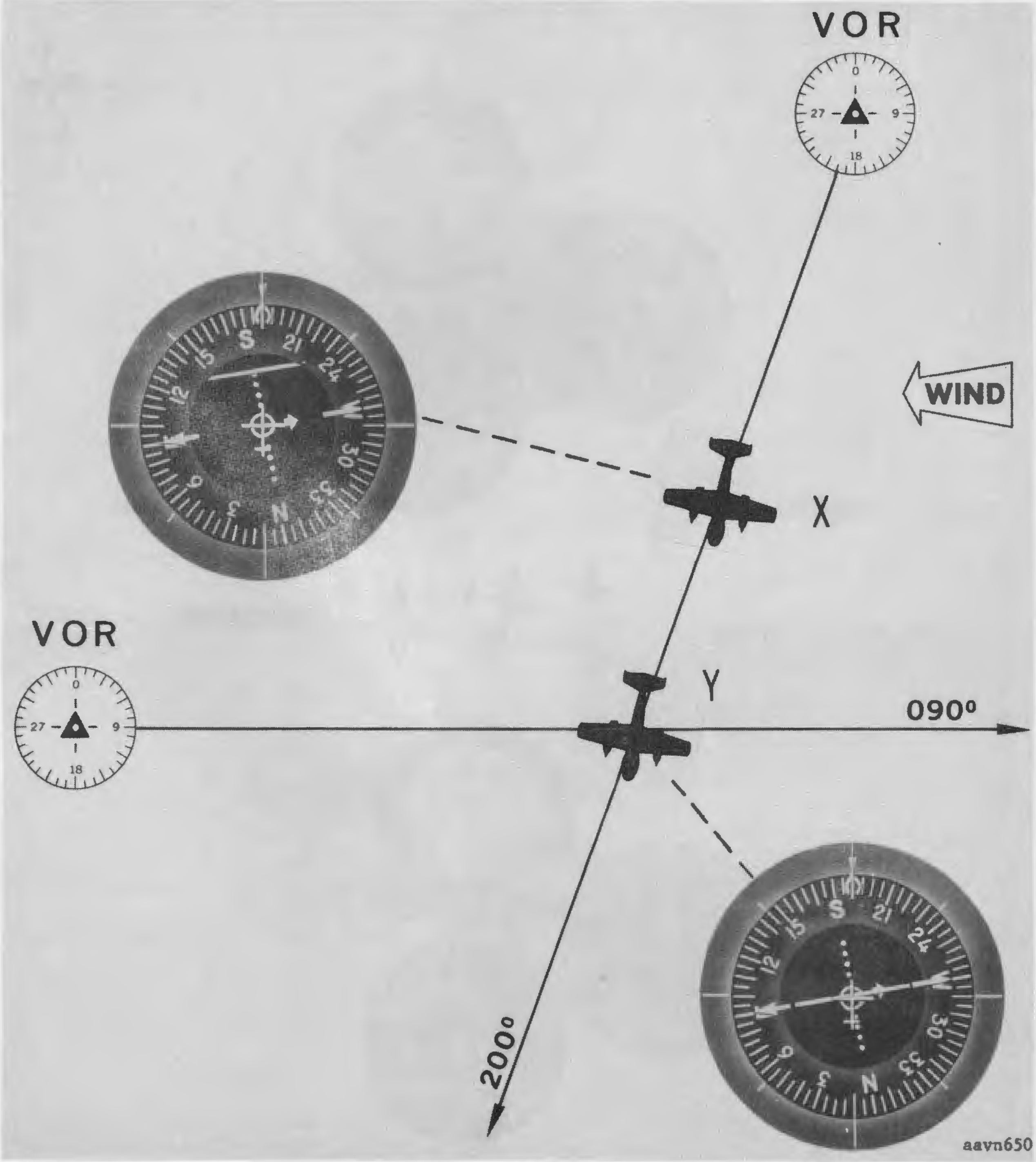


Figure 17-19. VOR intersections using the ID-883.

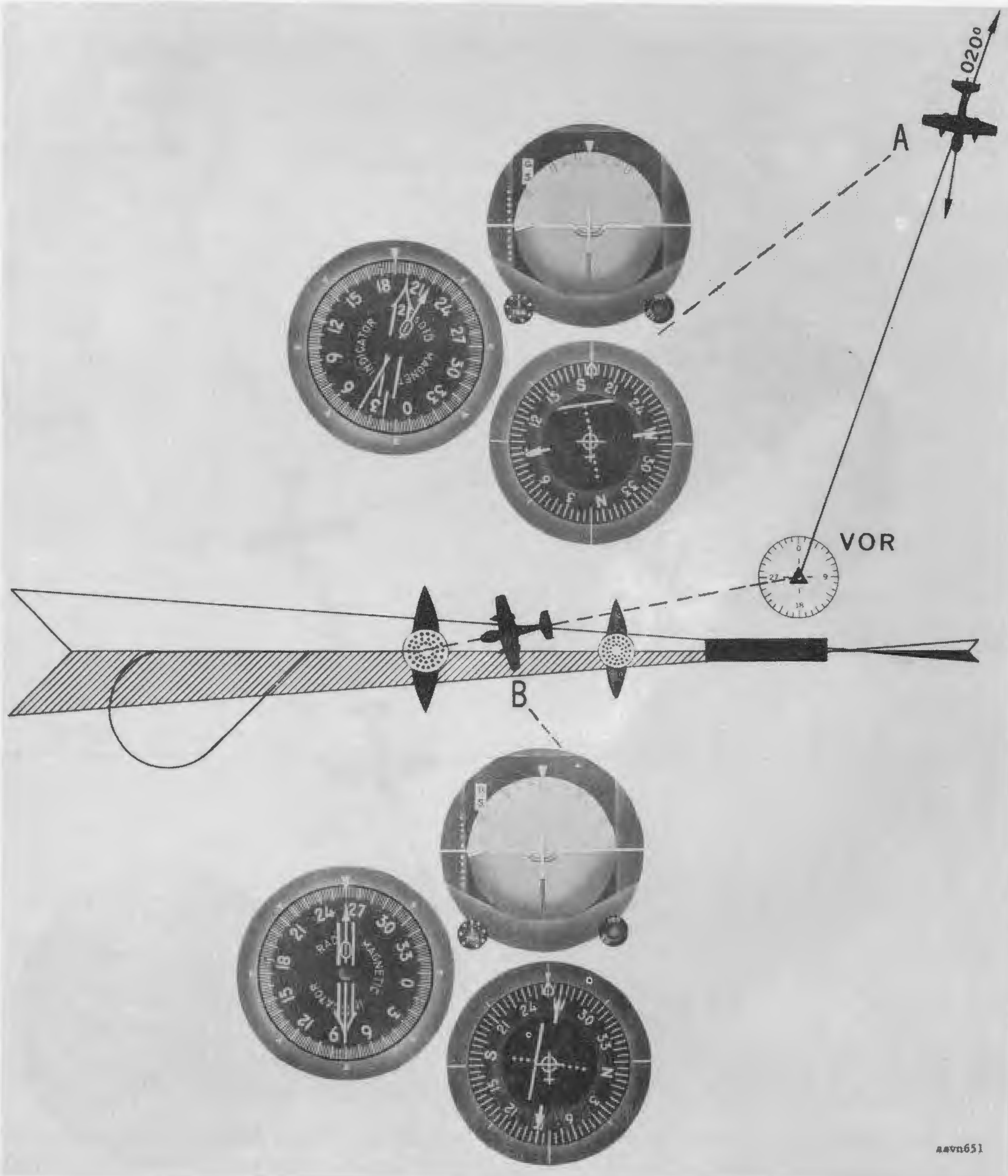


Figure 17-20①. Transition procedure, turn, and ILS approach using the integrated flight system.

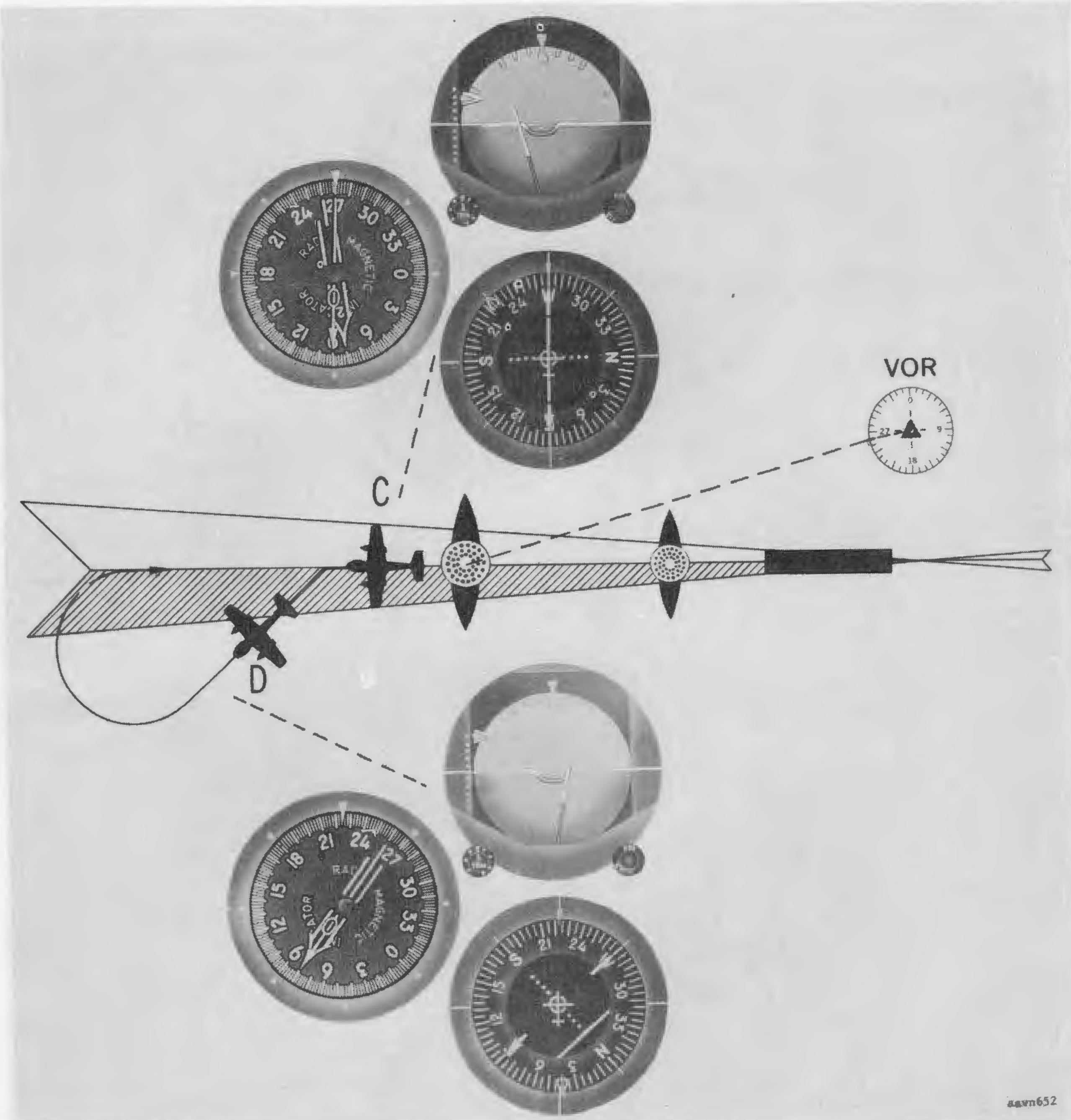


Figure 17-20 ② —Continued.

tates the heading marker 45° left before starting the procedure turn and follows the commands of the steering pointer.

d. Point D (fig. 17-20 ②). The aviator flies away from the localizer course for 40 seconds (the course bar moves off the tail position of the miniature aircraft). He rotates the heading marker clockwise (in increments less than 180°) to the inbound ILS heading, causing the steering pointer to deflect to the right.

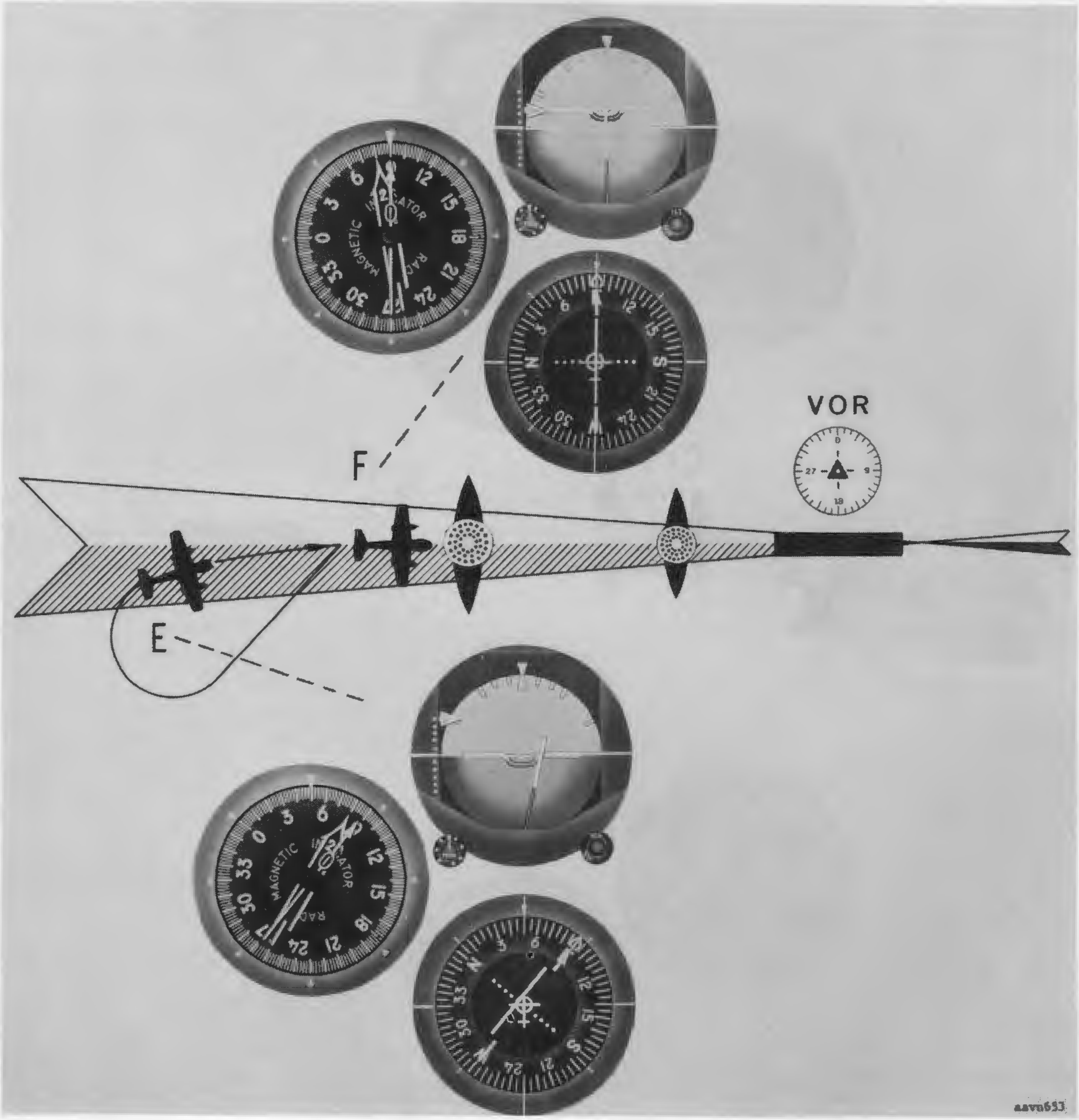


*Figure 17-20*③——Continued.

Note. The heading marker should not be rotated more than 180° at one time.

e. Point E (fig. 17-20 ③). As the aviator nears the completion of the procedure turn, he observes that the course bar is about to center. He rotates the heading marker to the inbound course (090°) and follows the commands of the steering pointer to roll out inbound on course.

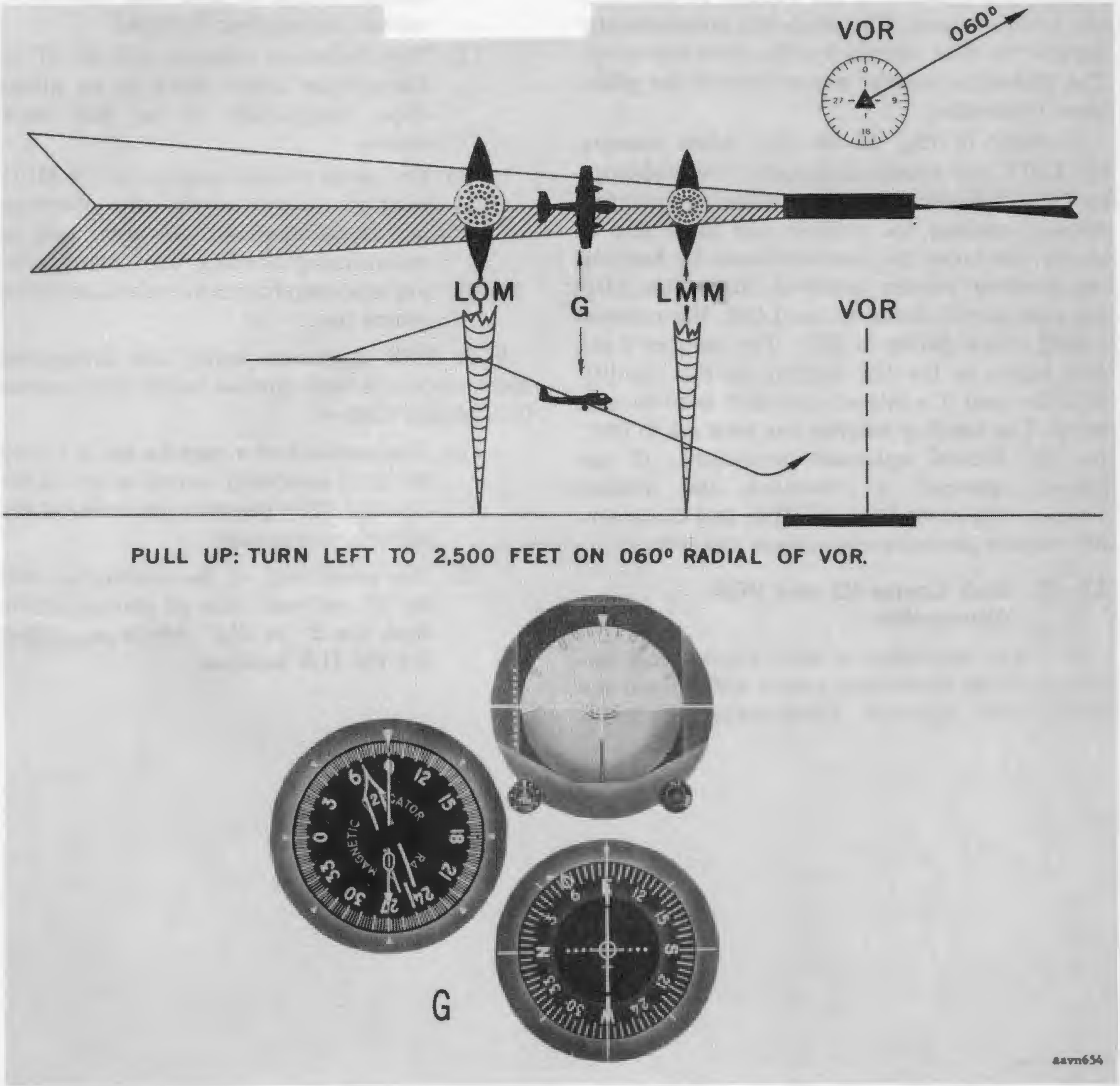


*Figure 17–20*④——Continued.

If the course bar had been several degrees away from center at this point, the aviator would have held a heading of 045° until the course bar indicated a position near the point of interception.

Note. At point E, the glideslope pointer is above center, indicating proper reception of the glideslope signal. The mode knob is still in the HDG position.

f. Point F (fig. 17–20 ③). After completing the procedure turn and before passing the LOM, the aviator changes the mode knob to the ILS position. With the equipment in the ILS mode, the steering pointer is sensitive to the localizer signals and commands the aviator to maintain the localizer track. The pitch bar automatically adjusts for final approach attitude in this mode. The glideslope pointer moves toward the glideslope centerline.

g. Point G (fig. 17–20 ④). After passing the LOM, the aviator maintains the glideslope by flying the pitch bar to the glideslope pointer, thereby causing the pointer and pitch bar to center. He holds the localizer beam by keeping the steering pointer centered. Since the ADF receiver is still tuned to the LOM, the number 1 RMI arrow points to 270°. The number 2 arrow points to the OR station, as this facility must be used if a missed approach is to be executed. The heading marker has been set to 060° for the missed approach procedure. If the missed approach is executed, the aviator swtiches the mode back to HDG and the steering pointer immediately deflects the left.

17–10. Back Course ILS and VOR Approaches

a. When executing a back course ILS approach, three significant points differ from the front course approach. These differences are—

(1) The course arrow is set to the inbound front course instead of the final approach course. The inbound front course setting is used *any* time a localizer transmitter is tuned.

(2) The glideslope receiver will be off or disregarded since there is no glideslope transmitter on an ILS back course.

(3) The mode switch remains in the HDG position; consequently, the steering pointer is used only in turns and in maintaining heading. Localizer tracking is accomplished by reference to the course bar.

b. A VOR approach using the integrated flight system is very similar to the back course ILS, except that—

(1) The course arrow may be set to either the final approach course or to its reciprocal. The presentation will be the same in either case.

(2) The sensitivity of the course bar will be 10° on each side of center rather than the 2° or 2½° which is normal for the ILS localizer.

CHAPTER 18

AUTOMATIC FLIGHT CONTROL SYSTEM (ASW-12(V))

18-1. General

a. The automatic flight control system (ASW-12(V)) installed in some Army aircraft is similar in principle and operation to other autopilot systems that have been used on aircraft for several years. This chapter is primarily concerned with the operating techniques and limitations of the system.

b. The system provides for basic aircraft control and automatic navigation by the operation

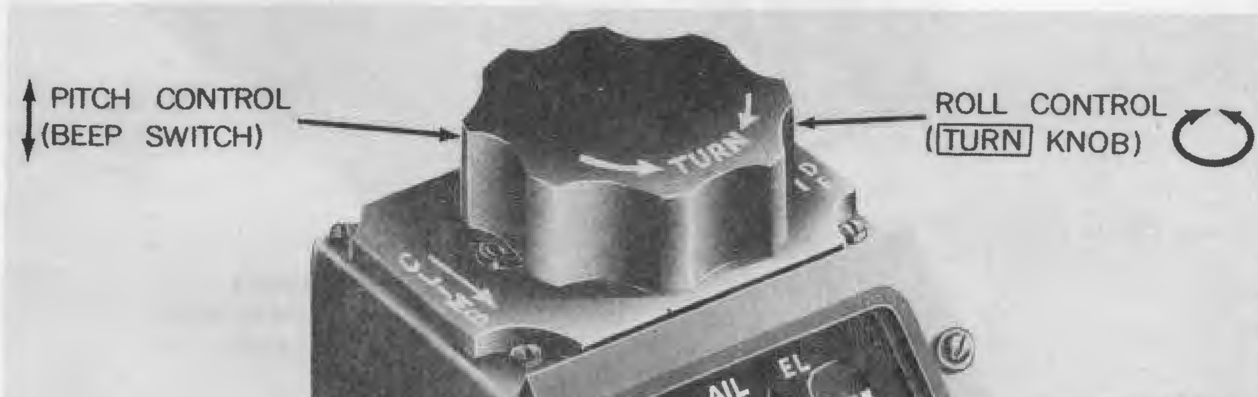


Figure 18-1. Flight control panel.

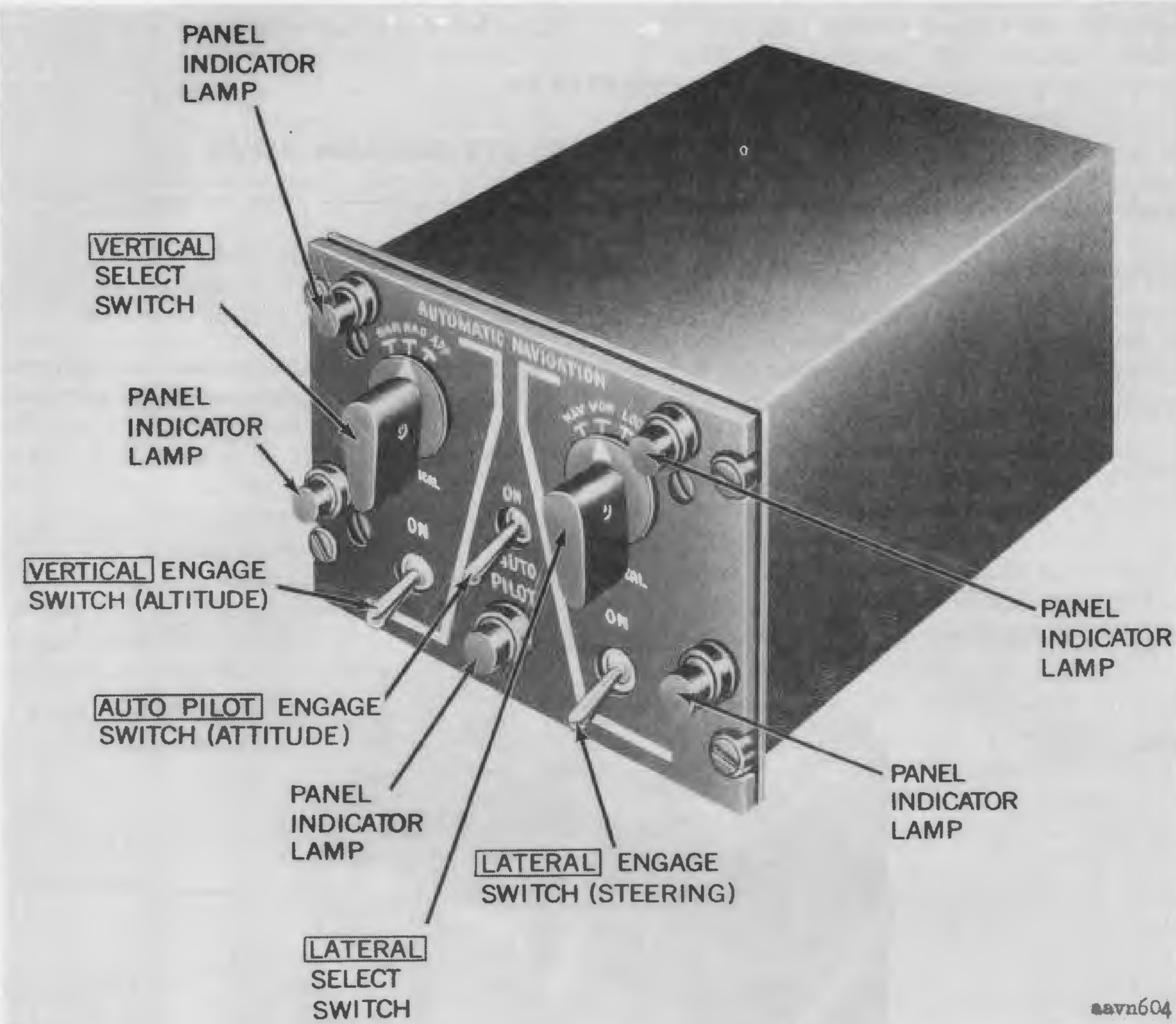


Figure 18-2. Navigational coupler control panel.

of two cockpit controls—(1) the flight control panel (fig. 18-1), and (2) the navigational coupler control panel (fig. 18-2).

c. By moving the combination TURN knob and beep switch on the top of the flight controller, the aviator can climb, descend, or turn the aircraft. The navigational coupler may be engaged in the vertical mode to maintain a constant altitude or to maintain proper descent on an ILS glideslope; it may be engaged in the lateral mode to maintain a magnetic heading, a selected omni radial, or a localizer course.

18-2. Preflight Checks

Prior to flight in an aircraft equipped with an operational autopilot, the aviator should perform the following preflight check (figs. 18-1 and 18-2):

a. Check the aircraft controls for free movement.

b. Check the control panel knobs and switches. The TURN knob and ROLL TRIM knobs on the flight controller should be centered. On the navigational coupler, the switch in the center labeled AUTO PILOT is the master switch; it should be turned OFF. The VERTICAL and LATERAL engage switches should be OFF. The VERTICAL and LATERAL select switches can be in any position.

c. Apply basic aircraft electrical power.

d. Check the servo effort indicators on the flight controller. After applying power, the indicators should be centered as they appear in fig. 18–1. If they fail to center, the system is malfunctioning. Stop the procedure and report the malfunction.

e. The gyroscope used as a data source for the system requires about 2½ to 3½ minutes for erection after power is applied. During this period, attempt to engage the AUTO PILOT (master) switch. *It should not engage* during the 2½- 3½-minute period required for gyro erection.

f. After gyro erection, engage the AUTO PILOT switch.

g. Operate the pilot release switch located on the control stick (or wheel) and see that the AUTO PILOT switch disengages.

h. Reengage the AUTO PILOT switch and rotate the roll control (TURN knob) to the right. Note that the control stick (or wheel) moves to the right. Rotate the roll control to the left and note that the control stick or wheel moves to the left. Recenter the roll control.

i. Rotate the ROLL TRIM control to the right and left and note that the control stick (or wheel) moves right and left in response. Recenter the ROLL TRIM control.

j. In addition to turning, the TURN knob can be depressed (tilted) forward or aft. This movement corresponds to fore and aft stick (or wheel) movement. When used as a pitch control, the TURN knob is called a *beep switch.* Push the pitch control (beep switch) forward and note that the control stick (or wheel) moves forward. Pull the pitch control aft and note that the control stick (or wheel) moves aft. Retrim the control stick or wheel to netural, using the pitch control.

18–3. Inflight Operation Procedure

***Caution:* Do not engage the equipment unless all three servo effort indicators (RUD, AIL, and EL) are centered (fig. 18–1).**

a. Engagement. Perform the starting procedure for engagement of the automatic flight control system as described in paragraph 18–2*a* through *f*. If the AUTO PILOT engage switch (fig. 18–2) is engaged during a climb or glide, the aircraft will continue to climb or glide at the prevailing pitch attitude. If the system is engaged while the aircraft is executing a banked maneuver, the aircraft will roll out level and maintain the heading established at the time of engagement. The automatic flight control system will aline itself with the existing pitch attitude at the time of engagement, but will level the aircraft from a turning bank and maintain the existing heading. The system may be engaged in any pitch attitude of the aircraft up to ±30° and in roll attitudes up to ±60°.

b. Command Operation.

(1) *Pitch attitude.* To set the rate of aircraft climb and descent, use the pitch control (beep switch) on the flight controller (fig. 18–1). Pushing the pitch control forward will produce a fixed nosedown pitch rate; pulling the pitch control aft will produce a fixed noseup pitch rate. When the pitch control is released, the system will maintain the aircraft in the established pitch attitude.

(2) *Turns.* To establish a coordinated turn, rotate the roll control (TURN knob) of the flight controller (fig. 18–1) out of detent to the right for a right turn or to the left for a left turn. Return to a level attitude by rotating the TURN knob back into its detent position.

(3) *Roll trim.* To trim the aircraft roll attitude without a heading change, adjust the ROLL TRIM control (fig. 18–1) to the right or left in proportion to the amount of roll trim needed.

c. Vertical Navigational Coupler Operation. To operate the vertical coupler functions, the AUTO PILOT switch must be turned to ON (fig. 18–2). Also, the applicable navigation aid must be operating properly.

(1) *Barometric altitude control.*

(*a*) Set the VERTICAL select switch to BAR.

(*b*) Turn the VERTICAL engage switch to ON. The aircraft will now be automatically stabilized to a constant indicated altitude based on the existing altimeter setting at the time of engagement.

(*c*) Make altitude changes by disengaging the VERTICAL engage switch, executing the change in altitude with the pitch control (fig. 18-1), and reengaging the VERTICAL engage switch (fig. 18-2) upon reaching the desired altitude.

(2) *Radar altitude control.*

(*a*) Set the VERTICAL select switch to RAD.

(*b*) Switch the VERTICAL engage switch to ON. The aircraft will now be stabilized to a constant absolute altitude based on the radar altimeter. Altitude changes are made as described in (1)(*c*) above.

***Caution:* Over a period of time, if the barometric altitude of the aircraft changes more than 400 feet (plus or minus), disengage the VERTICAL engage switch, correct altitude, and then reengage.**

(3) *Glideslope altitude (APP) control.*

(*a*) Set the VERTICAL select switch to APP.

(*b*) On final approach when the aircraft ILS glidepath is intercepted (centered needle), turn the VERTICAL engage switch to ON. The aircraft will now automatically descend on the glidepath.

d. Lateral Navigational Coupler Operation. In (1) through (4) below, assume that the aircraft is under cruise conditions with the AUTO PILOT engage switch ON, and that the associated navigation receivers have been tuned.

(1) *Heading select.* Heading is maintained automatically by the following procedure—

(*a*) Set the LATERAL select switch on HDG.

(*b*) Set the heading marker to the desired heading (par. 17-3*c*).

(*c*) Turn the LATERAL engage switch to ON. The aircraft will now automatically perform coordinated turns to maintain the selected heading.

(*d*) Make changes in aircraft heading by rotating the heading marker.

(2) *VOR select.* Automatic tracking on a VOR course is accomplished by—

(*a*) Setting the LATERAL select switch to VOR.

(*b*) Engaging the LATERAL control switch when the aircraft is within a half-scale (5° on the VOR course indicator) of the desired course and on an intercept heading within 20° of the desired course. From this position the system will automatically intercept and maintain the selected VOR course.

(3) *Localizer select.* Automatic tracking of an ILS localizer is accomplished as follows:

***Caution:* Do not engage the lateral LOC mode on a back course ILS or when outbound on a front course ILS.**

(*a*) Set the LATERAL select switch to LOC.

(*b*) Fly the aircraft to intercept the ILS localizer beam at a 45° angle. When the aircraft localizer indicator needle first begins to move away from the stops, turn the LATERAL engage switch to ON. The aircraft will now automatically perform coordinated turns to fly the localizer beam.

(4) *Navigation select.* If the aircraft equipment includes a Doppler navigational coupler, the LATERAL control, when in the NAV position, will automatically maintain a selected Doppler track. The select switch is placed in NAV and the LATERAL engage switch is turned ON at the time the

aircraft has intercepted and has turned to maintain the selected Doppler course.

Note. At the present time (August 1964) there are no Army aircraft equipped with navigational couplers for the Doppler system.

18-4. Stopping Procedure

The autopilot system may be turned off by either disengaging the AUTO PILOT switch or by operating the pilot's autopilot release switch on the stick (or wheel).

Note. The AUTO PILOT engage switch (attitude) (fig. 18-2) will automatically be turned off when either ac or dc power is lost. In all cases of AUTO PILOT disengagement, the standby light (a steady amber light) will show. If the disengagement is due to a power failure, operation of the power failure test switch located adjacent to the standby light will extinguish the light. If the light does not go out, the system is ready to be reengaged.

18-5. Operation With Malfunction

a. Overpowering the System. The automatic flight control system can be overpowered by applying pressure to the aircraft controls. If the system must be overpowered because of a malfunction, disengage the system by pressing the pilot release switch on the control stick (or wheel).

b. Command Mode Malfunction. If the action of the flight controller is lost, the system can still be used for stabilization.

(1) Center the roll control (TURN knob) into detent (fig. 18-1).

(2) Center the ROLL TRIM control.

(3) Manually establish the attitude of the pitch, roll, and yaw axes.

(4) Set the AUTO PILOT engage switch to ON (fig. 18-2).

(5) Make changes in attitude by disengaging the AUTO PILOT engage switch.

(6) Manually position the aircraft to the new attitude.

(7) Set the AUTO PILOT engage switch to ON to hold the new attitude.

c. Navigational Coupler Malfunction. If a system malfunction occurs while the system is operating in the VERTICAL or LATERAL modes, select another position if possible; (e.g., if failure occurs in the VOR position, switch to HDG position to maintain the predetermined heading for tracking the desired course). If operation in another position is not possible or appropriate, continue to operate the flight controller system for automatic stabilization of heading and attitude, and for turning, climbing, and descending.

18-6. Operation Under Adverse Conditions

The automatic flight control system is designed to operate under extreme climatic conditions. It will operate under temperature conditions from —67° to +131° F. It is not affected by extremely humid conditions. The protection afforded by the normal aircraft enclosure usually is adequate for dust protection; however, in arid regions where dust concentrations are abnormally high, extra care should be taken to keep the system free of dust.

Note. This autopilot system can be installed for operation in helicopters, but at the present time (August 1964) this system is not used in conjunction with navigation systems in Army helicopters. For a discussion of installation and operation of the ASW 12(V) in helicopters, see TM 11-6615-204-12.

Chapter 19

THE DOPPLER SYSTEM (APN-129(V)1)

19-1. General

The *Doppler system* used in some Army aircraft is an airborne groundspeed and drift-angle computer and display system. The operating frequency is 13.5 kilomegacycles per second (kmc). The Doppler system uses continuous wave Doppler radar to provide the aviator with a continuous visual indication of aircraft groundspeed in knots and drift angle in degrees (without the aid of ground stations, wind estimates, or true airspeed data).

a. Transmitter. The transmitter radiates two beams, left and right of the aircraft, with an angular width of 4°, an outward projection of 11°, and a downward projection of 22° aft of the vertical axis through the mounting (fig. 19-1).

b. Antennas. The antenna system consists of a parabolic reflector with dual antennas for each beam—one antenna for transmitting and the other for receiving. The ground-reflected signals are picked up by the receiving antennas, which are isolated from the transmitting antennas by a dividing wall called a *septum.*

c. Doppler Frequency Shift. The frequency difference between the transmitter reference signal and the ground-reflected signal is called the *Doppler frequency shift.* This difference in frequency is proportional to the aircraft velocity; it is analyzed as forward or sideward movement by the system components. The difference between the left and right frequency shifts indicates the amount of drift. The sense (direction) of drift is identified by the beam that registers the lesser frequency. Visual drift and speed indications are displayed on the drift angle-groundspeed indicator (fig. 19-2).

d. Controls. Controls for the Doppler system are located on the NAV control panel (fig. 19-3).

19-2. Drift Angle-Groundspeed Indicator

The drift angle-groundspeed indicator displays groundspeed and drift angle right or left of the aircraft heading. An electrically operated red signal flag, marked *OFF,* is located at the lower left edge of the dial. For operating procedures, consult the appropriate aircraft operator's manual.

19-3. Coupling With a Navigation Computer

The Doppler system used in Army aircraft provides the aviator with groundspeed and drift information only. This system, when coupled with a navigation computer, enables the aviator to maintain any predetermined track by Doppler navigation. When so coupled, the system also provides the aviator with a continuous indication of the actual distance flown along the track.

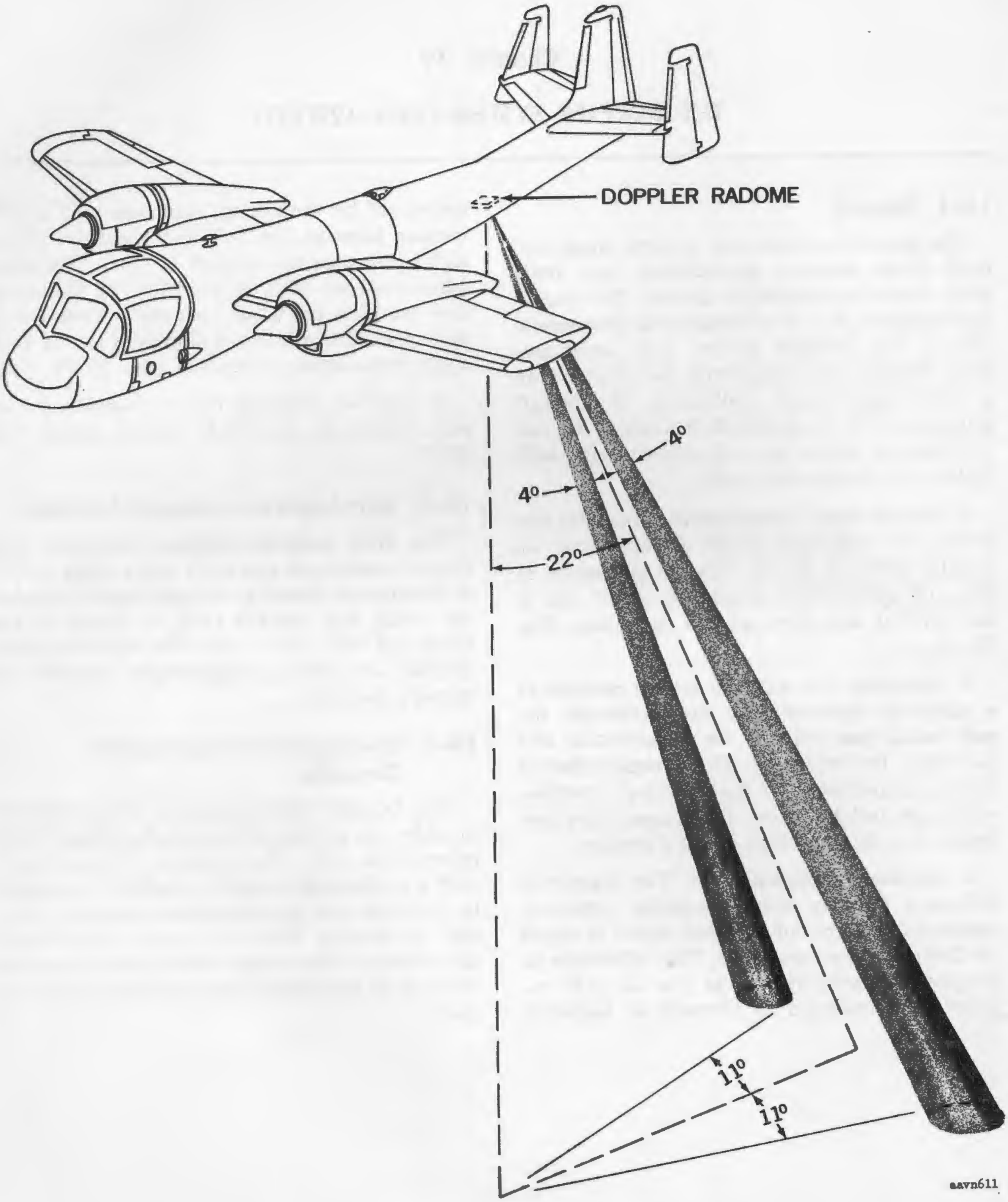


Figure 19-1. Doppler radar beam pattern.

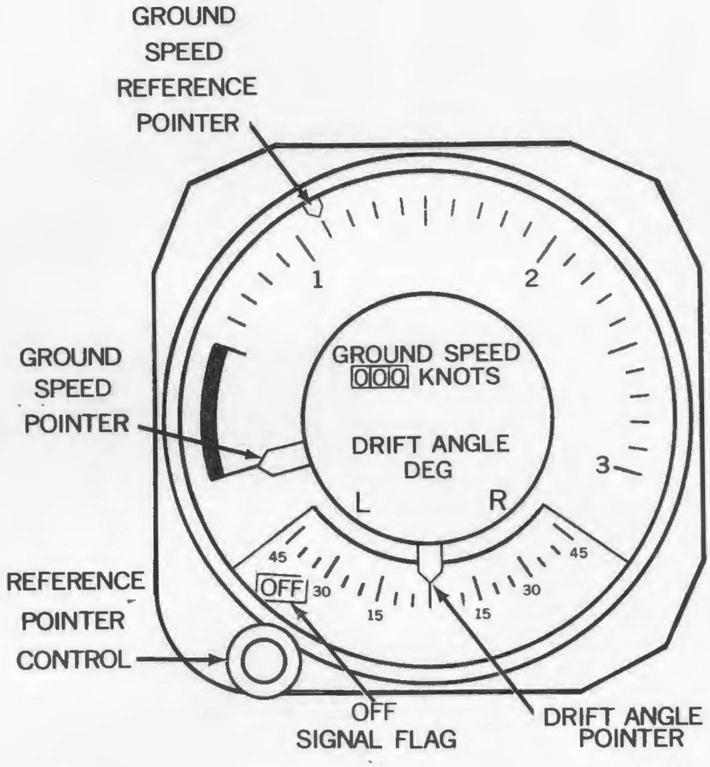


Figure 19-2. Drift angle-groundspeed indicator.

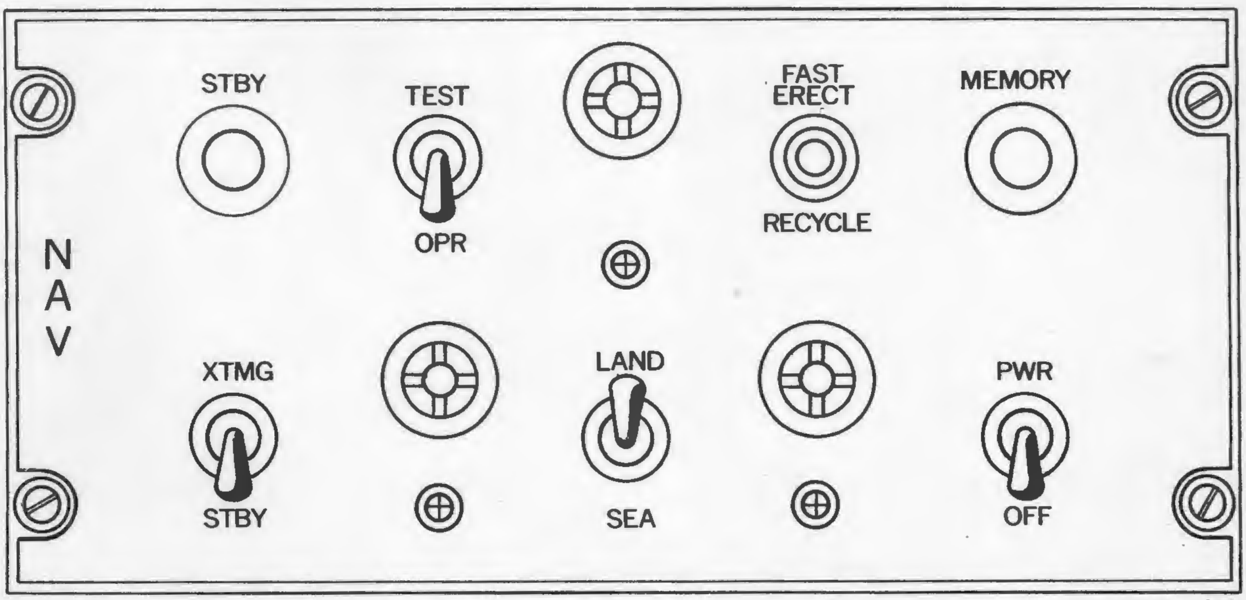


Figure 19-3. NAV control panel.

APPENDIX I

REFERENCES

AR 95-series	(Aviation.)
TM 1-215	Attitude Instrument Flying.
TM 1-300	Meteorology for Army Aviation.
TM 11-2557-27 (ATP 7110.1B)	Air Traffic Control Procedures. (Washington, D.C.: Government Printing Office, 12 November 1964.)
TM 11-5895-217-12	Transponder Set AN/APX-44, Operator and Organizational Maintenance Manual.
TM 11-6615-204-12	Automatic Flight Control System AN/ASW-12(V), Operator and Organizational Maintenance Manual.
AFM 51-12	Dead Reckoning Computers. (Department of the Air Force, Air Training Command, May 1959.)

APPENDIX II

ATC SHORTHAND SYMBOLS

1. General

The number of flight clearances which must be delivered by ATC does not permit excessive repetitions of a clearance. Also the speaking rate is too rapid for longhand copying of the clearance. Occasionally ATC will issue a clearance which differs from the original flight plan. In such cases the aviator must be particularly alert to receive and understand the clearance given. Clarification should be requested if any doubt exists. As an aid in copying ATC clearances, a series of symbols has been devised and standardized for use as clearance shorthand.

2. Common ATC Shorthand Symbols

Words and Phrases	*Symbol*
Above (e.g., 5,000 feet altitude)	$\underline{50}$
Advise	ADV
After Passing	>
Airways	G-5, V-7
All Turns Left	↶
Alternate Instructions	( )
Altitude 6,000-17,000	60-170
And	&
Approach	AP
Automatic Direction Finder	ADF
Approach Control	APC
At	@
ATC Clears	C
As a Fix	FX
Before Passing	<
Below, e.g., 5,000 feet altitude	$\overline{50}$
Climb to (Altitude)	↑
Contact	CT
Contact (Chicago) Approach Control	CHI
Contact (Chicago) Center	CHI
Course	CR
Cross	X
Cruise	→
Delay Indefinite	DLI
Depart	DP

Words and Phrases	*Symbol*
Descend to (Altitude	↓
Direct	DR
Directions (Bound):	
Eastbound	EB
Westbound	WB
Northbound	NB
Southbound	SB
Inbound	IB
Outbound	OB
Each	EA
Enter Control Area	△
Estimated Time of Arrival	ETA
Expected Approach Clearance	EAC
Expect Further Clearance	EFC
Fan Marker	FM
Final	F
For Further Clearance	FFC
For Further Headings	FFH
Ground Control Approach	GCA
Heading	HDG
Hold (East)	H—E
If Not Possible	or
Instrument Landing System	ILS
Initial	I
Intersection	△ (Small)
Left Turn After Takeoff	LT

Words and Phrases	*Symbol*
Localizer	L
Maintain	M
Middle Compass Locator	ML
Middle Marker	MM
Nonstandard Pattern (Left Turn)	
No Delay Expected	
Outer Marker	OM
Out of Control Area	
Over (Identification)	DHN
Outer Compass Locator	OL
On Course	OC
Plan Position Indicator	PPI
Procedure Turn	PT
Radar Vector	RV
Radial (270°)	270°R
Range (LF/MF)	R
Remain Well to Left Side	LS
Remain Well to Right Side	RS
Report Departing	RD
Report Leaving	RL
Report Over	RO
Report Passing	RP
Report Reaching	RR
Request Further Altitude Changes En Route	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
Traffic Is	TFC
Track	TR
Terminal VHF Omnirange	TVOR
Until	U
Until Advised (By)	UA
Until Further Advised	UFA
VFR Condition on TOP	VFR
Via	VIA
Victor	V
VHF Omnidirectional Range	VOR
While in Control Areas	△ (Large)

3. Examples

a. "ATC Clears Army 72888 for an ILS approach to Dannelly Field, runway 9, circle land runway 27, maintain 3,000 until reaching the locator outer marker. Report departing the Montgomery VOR. Dannely Field weather 600 feet overcast, 2 miles visibility in light rain and fog, wind 270° at 6 knots, altimeter setting 29.38, over."

C R 72888 ILS AP DAN FLD RY 9 ○. LD RY
27 M 30 UR LOM RD MGM WX 6 ⊕ 2–RF 2706 29.38

b. "ATC Clears Army 72813 to Muscogee County Airport, via direct Skipperville intersection, V–7 to Banks intersection, V–454 Columbus, maintain VFR on top. Takeoff southwest, turn right, climb to 3,000 on the 270 degrees radial of Cairns VOR, reverse course and climb to 5,000, if not on top at 5,000 maintain 5,000 and advise. Contact Cairns departure control on 237.5 immediately after takeoff, over."

C R 72813 MUS CO A VIA DR SKP △ V–7 BKS △
V–454 CSG M VER T/O SW RT 3 ON 270° R OZR VOR RC
50 (VFR 50 M 50 & ADV) CT OR DC 237.5 AFT T/O.

APPENDIX III

IFR FLIGHT PLANNING

1. General

a. Planning for an IFR flight can be a simple operation requiring 10 minutes or it can be a complex operation requriing many hours. The extent of planning necessary is dependent on the nature of the mission, the type and number of aircraft on the mission, the distance to be flown, selected route, weather conditions, and available navigational facilities. The checklist items presented in this appendix provide general guidance for the individual aviator; they are especially applicable to instrument flight planning with the United States. The aviator's proficiency and judgment will dictate necessary modifications to these procedures and techniques.

b. An aviator assigned a specific mission usually must plan the flight for arrival at a fixed destination at a definite time. The type aircraft, the load, and the personnel on board are often predetermined by the mission. However, an aviator planning a proficiency flight can often choose the aircraft, the destination, route, time, and other factors which have a bearing on the flight. Where possible the aviator attempts to control the variable factors affecting his mission to produce optimum flight conditions.

2. Flight Planning Checklist

a. Weather Briefing Sources. A weather briefing can be obtained from the following persons or agencies:

(1) A military or civilian forecaster—in person.

(2) A forecaster—by local telephone.

(3) A recorded forecast—by local telephone.

(4) Flight Service Stations—in person.

(5) Flight Service Stations—by local or exchange telephone.

(6) Military or Weather Bureau forecasters—by long-distance collect telephone.

Note. Check current operational publications for procedures and listings.

b. Weather Data Briefing. The weather briefing should include—

(1) A forecast for destination and alternate airfields at estimated time of arrival to include—

(*a*) Ceiling and visibility. Check for compliance with regulations. The destination forecast will determine the reqiurement for selecting an alternate. If the minimum conditions specified by AR 95-2 exist at the destination, an alternate airport is not required.

(*b*) Weather phenomena producing low ceilings and visibility.

(*c*) Hazards to flight, including thunderstorms, icing, gusty winds, and high density altitude.

(*d*) Height of cloud tops.

(2) An en route forecast to destination and alternate airfields to include—

(*a*) Hazards to flight.

(*b*) Height of the freezing level.

(*c*) Height of cloud tops and bases.

(*d*) Flight level winds and temperatures.

(3) An overall weather picture. The aviator, with the aid of a forecaster if possible, should obtain a clear mental picture of the synoptic weather situation including location of highs, lows,

and frontal systems. The rate and direction of their movement, and the weather conditions associated with them, should be clearly understood by the aviator.

c. Route Selection. Select the best route based on—

(1) Weather conditions.

(2) Preferred routes. Check current operational publications for listings. Deviate from preferred routes when safety or the mission requires it.

(3) Direct routing. File for direct flight only if the mission requires it or, considerable savings of fuel or time can be realized. If the flight penetrates noncontrolled airspace, ATC will not provide for traffic separation.

d. Route Survey. Conduct a route survey to the destination and alternate airfields, using navigational charts to determine—

(1) Primray radio aids for en route navigation. List frequencies, station identifiers, courses, and radials on the flight log.

(2) Supplementary radio aids to be used for position fixing and secondary navigation.

(3) Availability of air traffic control and weather radar en route.

(4) Distance between reporting points and total flight distance. Total distance is computed from takeoff to the destination radio facility.

(5) Minimum en route altitudes (MEA's), minimum reception altitudes (MRA's), and minimum crossing altitudes (MCA's).

Note. Check NOTAMS and chart revision notices for latest changes in the status of navigational aids. Check listing of VOR shutdown information for alternate routing where appropriate.

e. Altitude Selection. Select the best altitude(s) for the flight based on—

(1) *Weather conditions.* Avoid altitudes where icing and turbulence will be hazardous.

(2) *Direction.* Direction of flight based on hemispherical rule (below 29,000 feet).

(*a*) Odd altitudes are requested on magnetic courses from 0° to 179°.

(*b*) Even altitudes are requested on magnetic courses from 180° to 359°.

Note. Request altitudes which deviate from the direction rule if the safety of flight, aircraft characteristics, or mission requires it.

(3) *MEA's, MRA's, MCA's.*

(*a*) Select altitudes that comply with published minimum altitudes applicable to the flight.

(*b*) On direct flights, determine minimum altitude based on charted obstacles and the requirements of the regulations.

(*c*) Do not plan a flight at the MEA if the flight level temperature will be significantly below standard. Lowering of pressure levels in air significantly colder than standard will result in the true altitude being significantly lower than the indicated altitude (TM 1-300). Request an altitude assignment above the MEA under these cold-air-temperature conditions.

(4) *Aircraft performance and equipment.* In selecting a flight altitude consider—

(*a*) Optimum operating conditions for the aircraft.

(*b*) Availability of oxygen.

(*c*) Radio equipment limitations (range, altitude, etc.).

(5) *Traffic conditions.*

(*a*) Avoid relatively low altitudes which may conflict with approach control service in complex terminal areas.

(*b*) Do not request unnecessary altitude changes.

f. Departure.

(1) Plan the departure to comply with standard instrument departures (SID's) at airports for which they have been established since ATC normally will employ SID's if available.

Be familiar with all SID's since the controller may not authorize the particular one requested.

(2) Check for availability of departure control (conventional or radar). Note appropriate frequencies.

(3) Study the local area chart if one is published, or study the departure area on the en route chart. Become familiar with the radio facilities and intersections within the departure area.

Note. Aviators departing their home airfield normally will be familiar with its departure procedures. Additional study is necessary when departing an unfamiliar airport.

g. True Airspeed.

(1) Compute and file the true airspeed accurately. Recompute the TAS later in flight to verify preflight calculation. If the actual TAS varies more than 10 knots from the filed TAS, notify ATC of the difference.

(2) Base true airspeed computation on the known indicated airspeed for normal cruise and the forecast flight level temperature, *OR* consult the aircraft operator's manual for true airspeeds based on gross weight, altitude, temperature, and desired cruise conditions (e.g., maximum range, maximum endurance, and short range).

Note. True airspeeds of a given aircraft can vary considerably depending on weight, altitude, and desired cruise condition. Don't guess—consult the aircraft operator's manual.

h. Groundspeed. Compute groundspeed for each leg of the flight by combining the forecast winds with planned courses and the true airspeed (ch. 8). Apply magnetic variation to wind direction when using magnetic courses published on radio navigation charts.

i. Estimated Time En Route (ETE).

(1) Based on groundspeed and distance, compute the ETE for each leg of the flight between reporting points.

(*a*) On the initial leg allow sufficient additional time for the planned departure and climb to flight altitude.

(*b*) If en route climbs are made at reduced airspeed, allow additional time for *significant* changes on the leg.

(2) Compute the total ETE for the flight. This will be the estimated time required to reach the destination radio facility. Subsequent time required for transition, holding, and approach at the destination is not included in the ETE on an IFR flight.

(3) Compute the ETE to the alternate airfield from the destination or other critical position along the flight path.

j. Fuel.

(1) Compute the "fuel-on-board" flight plan entry by subtracting the warmup and takeoff fuel allowance (see the aircraft operator's manual) from the total fuel on board and dividing this quantity by the cruise consumption rate. The cruise consumption rate is determined by the cruise conditions and aircraft gross weight, as explained in the aircraft operator's manual.

(2) Compute total fuel required for the flight based on the appropriate consumption rate specified in the operator's manual, and including allowance for—

(*a*) Warmup and takeoff.

(*b*) Initial climb (consult aircraft operator's manual for extended climbs).

(*c*) En route cruise to destination and alternate. Allow time in addition to ETE's for *known* en route delays required by the mission. En route ATC delays usually *cannot* be anticipated.

(*d*) Fuel reserves required for IFR flight (see AR 95-2).

(3) Compute surplus fuel by subtracting total fuel required from total fuel capacity.

Note. Surplus fuel is important since en route traffic delays, holding at the destination, and the instrument approach are not provided for in the fuel requirements specified in paragraph 2*j*(2)(*a*) through (*d*) above. Reserve fuel is for UNFORESEEN circumstances. Do not plan to use reserves for routine delays.

k. Terminal Area.

(1) If an area chart is published for the destination, study it carefully to become familiar with—

(*a*) Radio facilities and intersections.

(*b*) Published transitions.

(2) Study all published destination approaches which the aircraft is equipped to make. Become familiar with—

(*a*) Transitions.

(*b*) Final approach courses.

(*c*) Procedure turns.

(*d*) Approach minimums.

(*e*) Restriction, warning, and caution notes.

l. Aircraft Clearance Form (Flight Plan). Army aviators may use either the standard military form (DD Form 175) for filing a flight plan or the FAA Form 398. A standard procedure for entries has not been established. Clarity is the basic essential in completing either form. Any entry subject to misinterpretation should be avoided.

m. Flight Log. The use of the flight log (DA Form 2283) is recommended. This provides for a concise summary of data required to execute the flight, allows for inflight revision of data, and provides an accurate record of the flight. The flight log normally is supplemented by reference to the appropriate radio navigation chart.

APPENDIX IV

FM HOMING

1. Characteristics of the ARA–31 Homing Antenna

The homing antenna system enables the aviator to home to any radio transmitter which transmits in a frequency range of 24.0 to 49.0 mc. When homing on stations which do not emit a continuous signal, it will be necessary for the aviator to—

a. Establish contact with the station.

b. Have station operator depress transmitter switch for a period of 15 seconds with 10-second pauses between transmissions.

c. Use the 15-second transmission periods to determine station direction and home. (Homing switch must be in the homing position during these periods.)

Note. Aviator and operator may use the 10-second pauses to monitor or send voice transmissions. (Homing switch must be in the COMM position during these periods.)

2. Operation of the ARA–31

The operation of the FM homing system is based upon the phase of the incoming FM signal as it reaches the ARA–31 antennas. When this system is used with the ARC–44 type radio receiver, the aviator determines his position relative to the transmitting antenna by interpreting the aural signal received.

a. If the signal reaches the left antenna first, the aviator will hear the Morse code letter D (– · ·). This signal indicates the station is to the left of the aircraft on its present heading.

b. If the signal reaches the right antenna first, the aviator will hear Morse code letter U (· · –). This signal indicates the station is to the right of the aircraft on its present heading.

c. If the signal reaches both antennas at the same time the aviator will hear the on-course, solid tone. This signal indicates the station is directly in front of or behind the aircraft.

Note. The ARC–54 type radio receiver employs a visual FM homing capability. This set uses an OMNI course indicator (such as the ID 453, ch. 10) to show position relative to the FM homing transmitter. An on-course heading is indicated by centered horizontal and vertical needles. Station passage is indicated when the horizontal needle falls. Turns to remain on course are made by reference to the directional vertical needle; i.e., left deflection, turn left—right deflection, turn right.

3. Orientation

(fig. IV–1)

a. If the on-course signal is heard, the aircraft must be turned (either right or left) until a U or D signal is heard. Then, the aircraft must be turned in the direction the signal indicates until the on-course signal is heard again. The station will now be directly in front of the aircraft.

b. If the letter D is heard, the aircraft must be turned left until the on-course signal is heard. The station will now be directly in front of the aircraft.

c. If the letter U is heard, the aircraft must be turned right until the on-course signal is heard. The station will now be directly in front of the aircraft.

4. Homing and Station Passage

While homing on the station, small turns should be made every 1 or 2 minutes (always in the same direction) to identify the signal. Then, the aircraft will be turned back on course. When a reversal of the signal is heard, the aircraft has passed the station.

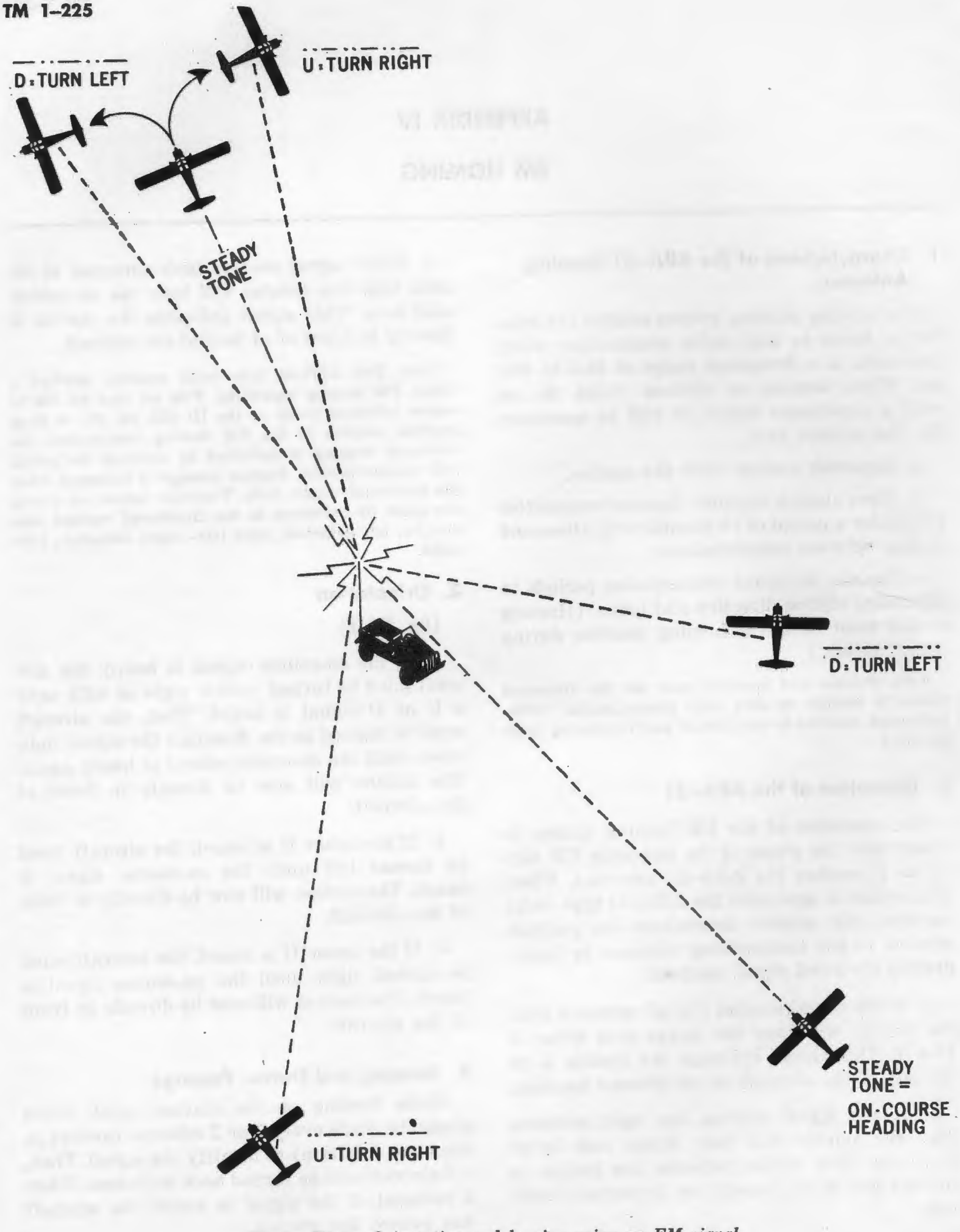


Figure IV-1. Orientation and homing using an FM signal.

INDEX

AGO 8143A

By Order of the Secretary of the Army:

HAROLD K. JOHNSON,
General, United States Army,
Chief of Staff.

Official:

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