U. S. DEPARTMENT OF COMMERCE
CIVIL AERONAUTICS ADMINISTRATION
WASHINGTON, D. C.

Practical Air Navigation

By Thoburn C. Lyon
U. S. Coast and Geodetic Survey

Civil Aeronautics Bulletin No. 24
SEPTEMBER 1940

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This publication supersedes U. S. Coast and Geodetic Survey Special Publication No. 197, *Practical Air Navigation and the Use of the Aeronautical Charts of the U. S. Coast and Geodetic Survey,* which has been discontinued

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PREFACE

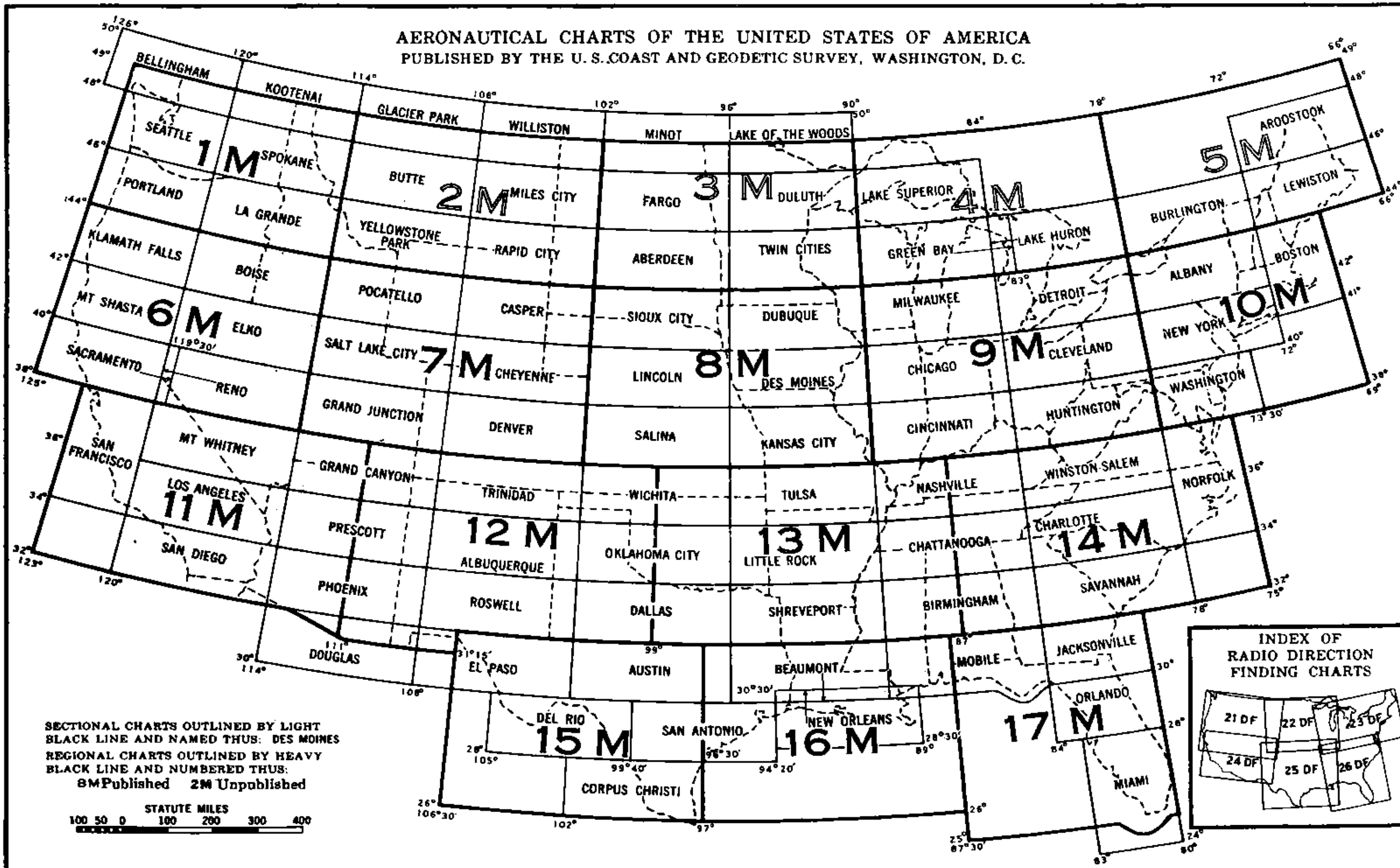
This book, written by Thoburn C. Lyon, Cartographic Engineer, United States Coast and Geodetic Survey, supersedes Special Publication No. 197, PRACTICAL AIR NAVIGATION AND THE USE OF THE AERONAUTICAL CHARTS OF THE U. S. COAST AND GEODETIC SURVEY, by the same author. It is, in effect, the fourth edition of that publication.

Since this book is designed for use as a text on air navigation in the controlled private ground course of the Civilian Pilot Training Program, the form and arrangement of former Special Publication No. 197 have been changed somewhat to provide for greater ease of reading and improved methods of instruction. Several chapters have been added which were not in the old publication, and all the material, insofar as possible, has been brought abreast of recent developments. Technical and semitechnical terms, sometimes not formally defined in the main text, have been collected into a fairly complete glossary. A chapter which appeared in Special Publication No. 197 on meteorology has been deleted, since this subject is now comprehensively covered in Civil Aeronautics Bulletin No. 25, METEOROLOGY FOR PILOTS.

It is felt that the book will continue to serve the purpose of Special Publication No. 197 as an important auxiliary to the aeronautical charts issued by the Coast and Geodetic Survey. In this way it will, as did the three editions of its predecessor, enable pilots to make full and efficient use of the charts provided for them.

The first three editions of Special Publication No. 197 enjoyed a wide circulation. It is hoped that this book may also continue to contribute something to the development of practical air navigation.

The Civil Aeronautics Administration is deeply grateful to the Coast and Geodetic Survey and to Mr. Lyon for preparing the material contained in the text, and to the Survey for consenting to its issuance as a Civil Aeronautics Bulletin.



III

Frontispiece. Index of aeronautical Charts.

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PRACTICAL AIR NAVIGATION

Chapter I.—THE PROBLEMS OF AIR NAVIGATION

THE PROBLEM OF FLIGHT

Learning to fly has occupied the minds of men almost from the beginning of time. Legend has brought us accounts of magic carpets and winged sandals; history brings us stories of flying machines that might have succeeded with proper powerplants or other refinements; but the first powered flight in a heavier-than-air machine was made at Kitty Hawk, N. C., by Orville Wright, on December 17, 1903.

That first flight lasted for 12 seconds, and covered a distance over the ground of only 540 feet. The maximum altitude attained was 12 feet above the ground. Today, light airplanes, refueled in flight, have remained in the air an entire month; the long-distance record is in excess of 6,000 miles; and commercial transportation has reached into the lower layers of the stratosphere.

THE PROBLEM OF THE AIRCRAFT

In the early days of flying, serious accidents often occurred because men were not thoroughly familiar with this new medium of transportation. Its mechanical limitations were sometimes not realized, and maneuvers were attempted which were beyond its structural strength and performance. The functioning of controls under unusual conditions had to be learned the hard way, and recovery from spins and stalls could be learned only by trial and error.

Today, pilots are expected to be thoroughly familiar with the construction of the aircraft, its controls, and its limitations. Competent instructors are available to impart this information, as well as to give actual flight instruction. Manuals treating of the airplane, its powerplant, and the various flight maneuvers, have been prepared by the Civil Aeronautics Administration. These manuals are based not only on sound theory, but also on long experience. They should be obtained and carefully studied.

THE PROBLEM OF AIDS TO NAVIGATION

The achievement of flight, notable as it was, satisfied only half of the age-old dream. To satisfy the other half, it was necessary that men learn to fly expeditiously from *here* to *there*, cutting across all barriers and surface limitations. The directing of aircraft from one place to another by various methods is the science of air navigation.

In bad weather and in the hours of darkness, the usual landmarks are often lost to view. If air transportation is to function safely at such times, some artificial aids to navigation must be made available.

To supply this need, rotating beacon lights have been established at frequent intervals along the Nation's airways. Most of these lights have their own characteristic signals, by means of which pilots may definitely identify them and determine their positions. Figure 1 is a photograph of a typical airway beacon light; figure 2 shows the complete beacon installation. The power shed at the base of the tower is air marked with the site number of the beacon, for identification from the air by day. Landing fields have been con-

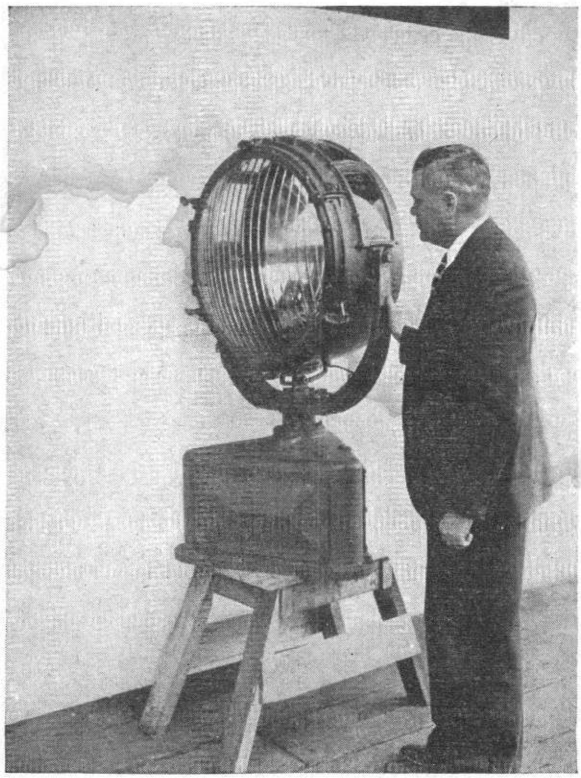


Figure 1.—Rotating aeronautical beacon light.

structed at intervals of about 50 miles along the airways for use in case of emergency.

In very thick weather, all visual aids become useless, and for this condition the various radio aids have been developed. Radio range stations transmit directional signals along the airways, while radio marker beacons indicate critical points along the routes marked out by the range stations. At scheduled intervals weather information and other data of importance to those flying the airways are broadcast from the radio range stations. Figure 3 shows a typical radio range station.

With the installation of instrument landing systems at the principal terminals, and with other instruments now in process of development, we may confidently expect that in the near future air transportation will become entirely independent of all but the most severe weather conditions.

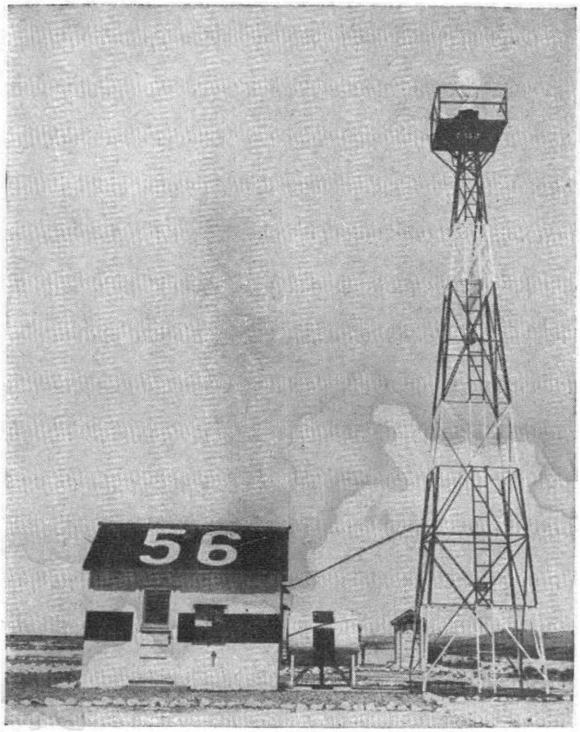


Figure 2.—Rotating beacon installation.

Figure 3.—Radio range station.

THE PROBLEM OF TRAFFIC CONTROL

With the ever-increasing number of planes aloft, it is obvious that some system of traffic control must be set up and enforced, for the safety of all concerned.

At each airport there are local traffic rules governing the method of taking off and landing. In some cases, traffic lights signal that all is clear; in other cases, colored flags are used. At some of the busier airports, pilots are forbidden

Figure 4.—Airway traffic control center.

to fly unless their airplanes are equipped with radio, in order to receive the instructions directly from the airport traffic control tower.

Other rules have to do with such matters as the right-of-way; altitude of flight; minimum weather conditions for flight by day and by night; requirements for instrument flying; the designation of civil airways; flight along or across a civil airway; and the filing of flight plans. Control in such matters is administered by the airway traffic control centers of the Civil Aeronautics Administration. Figure 4 illustrates some of the varied equipment and activities at these centers.

Before a pilot is permitted to make his first solo flight he must become familiar with the Civil Air Regulations, which are commonly referred to as the "C. A. R." For convenient reference and study, a separate manual, known as "Digest of the Civil Air Regulations," has been prepared for student and private pilots by the Civil Aeronautics Administration.

THE PROBLEM OF CHARTS

The most elaborate system of aids to navigation is of little value unless the navigator is provided with charts showing the location of the various aids with reference to other features of the surface.

In the early days of surface navigation, mariners soon learned the value and importance of charts; even in the barnstorming days of aviation, pilots began to realize this same need. Because of the basic similarity between nautical and aeronautical charts, the task of charting the airways was assigned to the United States Coast and Geodetic Survey, with instructions "to provide as adequate charts for air navigation as it now provides for ocean navigation."

With only normal head winds, some of the light airplanes make good over the ground speeds as low as 50 or 60 miles an hour. On the other hand, the speed of some of the faster military ships approaches 500 miles an hour. The pilot of the light airplane flies mostly by reference to visible landmarks; he therefore requires a large scale chart showing landmarks in all possible detail. At 500 miles an hour pilots have no time to look for any but the most prominent landmarks, and a small-scale chart showing few details is desired.

To meet the needs of pilots flying these widely different types of airplanes, three principal series of aeronautical charts are now being published by the Coast and Geodetic Survey. The limits of these charts, and their relative size and extent, are shown in the frontispiece. The series are as follows:

Sectional charts, of the entire United States, in 87 sheets, at a scale of 1:500,000, or about 8 miles to the inch.

Regional charts, to cover the whole country, in 17 sheets, at a scale of 1:1,000,000, or about 16 miles to the inch.

Radio direction-finding charts, of the entire United States, in 6 sheets, at a scale of 1:2,000,000, cr about 32 miles to the inch.

In addition to the above, the following special charts are also available:

Aeronautical planning chart of the United States (chart No. 3060 b), at a scale of 1:5,000,000, or about 80 miles to the inch.

Great-circle chart of the United States (chart No. 3074) at approximately the same scale as chart No. 3060 b.

Magnetic chart of the United States (chart No. 3077), showing lines of equal magnetic variation, at a scale of approximately 1 : 7,500,000, or about 115 miles to the inch.

Kenai, and **St. Elias,** Alaska, at a scale of 1 : 1,000,000, or about 16 miles to the inch. These are the first two of a series of charts intended to cover the entire Territory of Alaska.

The Kenai chart extends approximately from latitude 57°30′ to latitude 62°, and in longitude from 144°30′ to 157°30′.

The St. Elias chart extends from latitude 57°30′ to latitude 62°45′, and in longitude from 133° to 147°.

To illustrate further the effect of airplane speeds on the scale of charts, the average sectional chart is about 20 by 42 inches in size. With some allowance for margins, then, a sectional chart covers an area of about 140 miles from north to south, and 320 miles from east to west. At 70 miles an hour, it would take 2 hours to fly from north to south over the area represented on the chart, and about 4½ hours to cross it from east to west. At 200 miles an hour these are reduced, respectively, to 40 minutes and 1½ hours; for a flight of considerable distance, this would require the carrying of a great number of charts, with frequent changes from one chart to the next. At 400 miles an hour, the time intervals are further reduced to 20 minutes and 45 minutes. For a regional chart, at 200 miles an hour the corresponding time intervals are 2 hours and 3 hours respectively.

The sectional charts are entirely suitable for all forms of navigation, but are intended primarily for use in piloting.

The regional charts are designed particularly for air navigation, as contrasted with piloting. They are more convenient than the sectional charts for comparatively long flights, with faster planes, since pilots do not need to change charts as often while in the air. They are also convenient for planning routes which extend beyond the limits of a sectional chart, one regional chart often covering a route which would require two or three sectional charts.

Because of the larger scale and the more complete information of the sectional charts they are necessary supplements to the regional series. They will always be required for detailed studies of an area, and should generally be used whenever piloting is employed. Most of the landmark data appearing on the sectional charts have been eliminated from the regional charts, since, for their intended purpose, clarity is more essential than completeness of detail.

The radio direction finding charts have been designed especially for use in the plotting of radio bearings. Their smaller scale and wider extent make it possible to plot bearings from radio stations that would frequently be outside the limits of the local chart when using either of the larger-scale series.

The Aeronautical Planning Chart of the United States is very useful in planning routes between distant points.

The Great-circle Chart is of value for one special purpose only, namely, the easy determination of the exact great circle route between any two points. It cannot be used directly for the scaling of courses or distances. Its use is limited, then, to the most exacting record flights, and to comparative studies.

Plates I and II represent portions of a sectional chart and a regional chart, respectively. The special features and uses of the charts are treated more fully in later chapters.

Any of the charts described may be obtained from the Director, United States Coast and Geodetic Survey, Washington, D. C. Most of these charts are also carried in stock by the "Recognized Dealers" listed on p. 234. This list, of course, is revised from time to time, and the current list of such dealers may be obtained from the Director. Many of the charts may also be obtained from other dealers at principal airports.

QUESTIONS

1. Why is it important that private pilots be familiar with the construction of aircraft?

2. To what extent do the Civil Air Regulations affect private pilots?

3. Define navigation.

4. What use might be made of the various aids to navigation when flying by reference to visible landmarks?

5. Name the three principal series of aeronautical charts published by the United States Coast and Geodetic Survey.

6. Name three additional charts, and state the special purpose of each.

7. With a cruising speed of 100 miles an hour, how long would it take to cross the area covered by an average sectional chart: (*a*) From north to south? (*b*) From east to west? How long for a regional chart?

8. Under what circumstances should a sectional aeronautical chart be used? For what purpose should a regional chart normally be used?

9. State two important reasons why the sectional charts for a route should also be at hand, even though a regional chart is being used in navigation.

Chapter II.—THE EARTH: ITS FORM, COORDINATES, AND REPRESENTATION

SURFACE NAVIGATION AND AIR NAVIGATION

Learning to fly, if only for the sake of flying, is well worth while. As already suggested, however, there still remains the problem of learning to fly from here to there—that is, of learning to navigate.

Through the centuries there have evolved four principal or basic methods of surface navigation. Air navigation, of course, has profited by these centuries of experience. The evolution in this case has been much more rapid, but essentially the same four methods are used. They may be briefly stated, as follows:

Piloting, or directing the airplane with respect to visible landmarks;

Dead reckoning, in which the distance and direction are determined between two known positions, or position is determined by keeping a record of distance and direction from a known position;

Radio navigation, or the determination of position by means of observed radio bearings; and

Celestial navigation, in which position is determined by means of sextant observations of the sun, moon, planets, or stars, together with the exact time of the observations.

THE EARTH AS A PLANET

In all forms of navigation, some elementary knowledge of the earth, upon the surface of which the navigator works his problems, is important.

The earth is one of the family of nine planets which revolve about the sun. It is third in order from the sun, at an average distance from it of about 93,000,000 miles.

The sun is our nearest star. It is a great mass of flaming gas, some 864,000 miles in diameter. It is our chief source of light and heat, the amount received from any other source being negligible by comparison.

The earth rotates on its axis once in 24 hours, with reference to the sun, causing day and night for us, according as our part of the earth is toward the sun or away from its light. The direction of rotation is from west to east (fig. 5), and it therefore seems as though the sun, moon, planets, and stars rise in the east and pass across the sky to set in the west.

At the same time that the earth rotates on its axis, it is also revolving in its orbit, or traveling in its path around the sun. Throughout its yearly journey, the direction of its axis (about 23½° from a perpendicular to the plane of the earth's orbit) remains practically unchanged. As a result, the temperate regions of the earth receive the sun's rays in more nearly perpendicular direction in summer than in winter, causing the seasons, with their varying degrees of heat and cold.

The intersection of the plane of the earth's orbit with the surface of the earth marks out an imaginary line on the earth known as the ecliptic. Since the sun, moon, and other planets all lie very nearly in the same plane as the earth's orbit, they are always seen in the sky somewhere directly above this imaginary line.

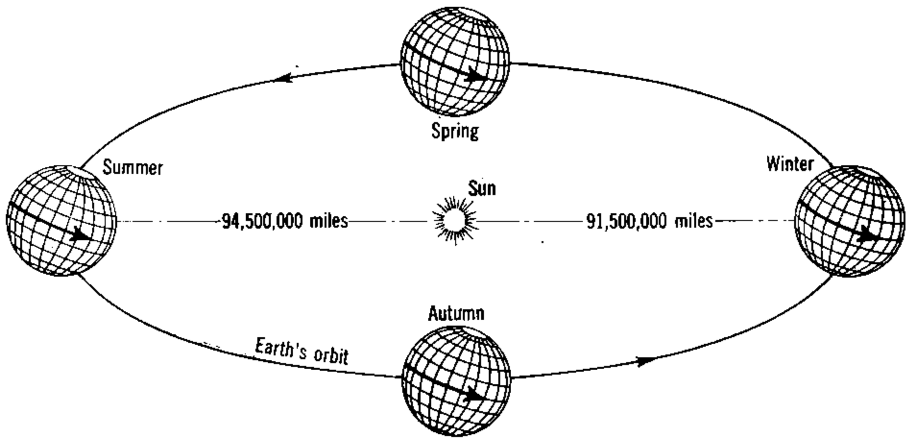


Figure 5.—The earth as a planet.

NAVIGATION ON A SPHERICAL EARTH

Navigation on a flat earth would be very simple indeed. There is a common saying, however, that "the earth is round." One of the most convincing and practical proofs that the earth is a sphere is the fact that, for centuries, navigators have plotted and sailed their courses on that assumption, and have consistently arrived at the most distant destinations.

Strictly speaking, the earth is not a sphere, but a "spheroid." It is slightly flattened at the poles, the polar diameter (7,900 miles) being about 27 miles shorter than the diameter at the equator (7,927 miles).

In practice, navigation even on a spherical earth can be made quite simple, and the earth is regarded as a perfect sphere.

COORDINATES OF THE EARTH

On a plane surface it is customary to locate points with respect to two reference lines at right angles to each other. For example, in figure 6 the point P may be definitely located when its distance from XX', and from YY', is known.

On the surface of a stationary sphere all points are exactly alike, and there is no definite point to serve as the origin of a system of reference lines. As soon as rotation of the sphere is introduced (as in the case of the earth), this is no longer true.

The axis on which the earth rotates is a definite line within the sphere, different from any other diameter. The ends of this diameter, where they meet the surface of the earth, are called the poles. With these as starting points, the sphere is supposed to be divided into two equal parts by a plane perpendicular to the axis and midway between the poles. The circle formed by the intersection of this plane with the surface of the earth is also a definite line upon the earth, and is called the equator.

Any number of circles can be drawn which will pass through both poles. These circles are known as meridians. In most countries they are considered to be divided into 360°, and there will be 90° between the equator and each pole, on each side.

Let us now take a point along one of the meridians 30° north of the Equator. Through this point pass a plane perpendicular to the axis and *parallel* to the plane of the equator. The intersection of this plane with the surface of the earth is called a *parallel* of latitude, this particular one being the parallel of 30° north latitude. In the same way other circles may be determined to rep-

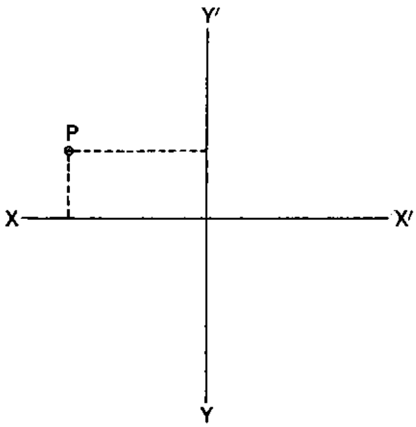


Figure 6.—The location of a point from known reference lines.

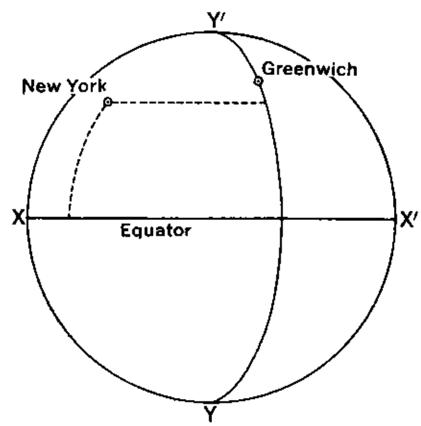


Figure 7.—Reference lines on the earth.

resent other degrees of latitude north or south of the Equator. The position of any point on the sphere with respect to latitude may now be definitely given as "so many degrees north or south of the Equator."

The Equator may also be divided into 360°, for the measurement of longitude, but first we must determine upon some starting point. A great many places have been used for this purpose by different nations; but the English adopted the meridian passing through their principal observatory at Greenwich as the origin for reckoning longitude, and this has since been adopted by many other countries.

The longitude of a place may be defined in several different ways. It is:

(*a*) the distance along the Equator, measured in degrees, minutes, and seconds, between the meridian of Greenwich and the meridian passing through the place; or,

(*b*) the distance from the meridian of Greenwich, measured along the parallel passing through the place in degrees, minutes, and seconds; or

(*c*) the angle at the pole between the meridian of Greenwich and the meridian passing through the place.

Longitude is measured up to 180° east or west from the meridian of Greenwich. With reference to the sun, the earth makes one complete rotation of

360° in 24 hours. The circumference (or Equator) could therefore be divided into 24 hours as logically as into 360°; for some purposes it is so divided, and longitude may be expressed, therefore, either in degrees, minutes, and seconds of arc, or in hours, minutes, and seconds of time. The longitude of a place may be given, for example, either as 75° or as 5 hours west of Greenwich.

Having now established two reference lines—the Equator for latitude, and the meridian of Greenwich for longitude—New York (or any other point) may be located on the sphere in much the same way that a point is located on a plane surface. See figure 7.

DISTANCE ON A SPHERE

In plane geometry a straight line is defined as "the shortest distance between two points." It is on this principle that a carpenter stretches a chalked

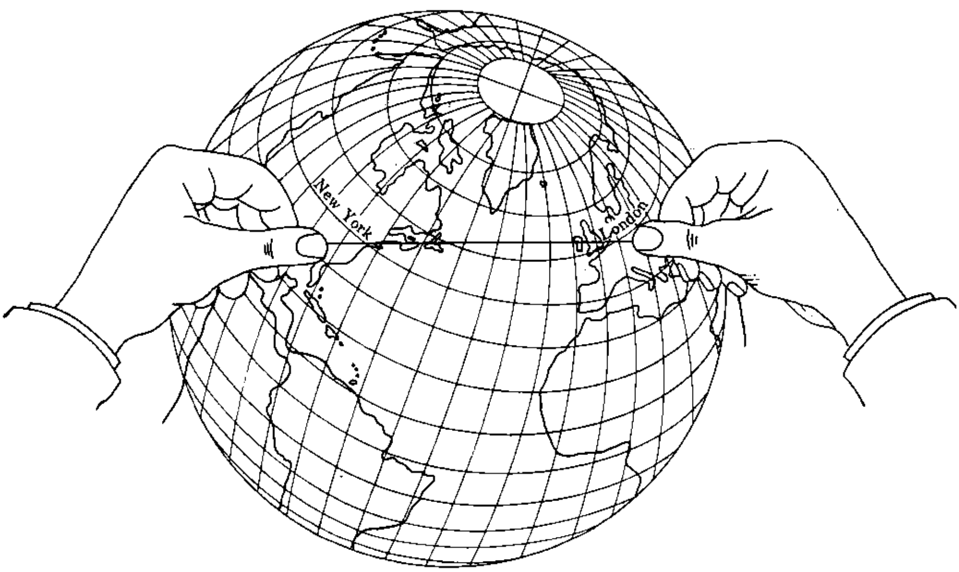


Figure 8.—Great circle illustrated by a taut string.

line between two points and snaps it lightly against the floor to obtain, in a faint chalk impression, a straight line.

On the surface of a sphere, the shortest distance between two points lies along the arc of a great circle. This does not mean, of course, that the shortest distance is not along the most direct route, for a great circle may be popularly defined as "the straight line of the sphere." This is illustrated in figure 8, where a string is stretched over the globe, from New York to London, to obtain the great circle route (shortest distance) between the two points.

More exactly, a great circle on the earth is a line marked out by the intersection with its surface of any plane passing through the center of the earth. Stated another way, all circles upon the earth which divide it into two equal parts are called great circles. The Equator is a great circle, and so are all meridians. The plane of a great circle, of course, may be at any angle to the plane of the Equator or to the earth's axis. Figure 9 illustrates these definitions.

From the definition of a parallel of latitude, it is clear that a parallel divides the sphere into two unequal parts. A parallel is therefore not a great circle, but a small circle. Any circle, the plane of which does not pass through the center of a sphere is known as a "small circle," regardless of its size.

Distance along a great circle is measured in the same way that latitude and longitude are measured along the meridians and the Equator—that is, in degrees, minutes, and seconds of arc. For most purposes, the distance is then converted into the ordinary distance units of nautical miles, statute miles, or meters. For all practical purposes, a minute of latitude, or a minute of any other great circle, may be considered as a nautical mile. Because of the flattening of the earth near the poles, the length of a minute of latitude varies somewhat, increasing with the latitude, from the Equator to the poles.

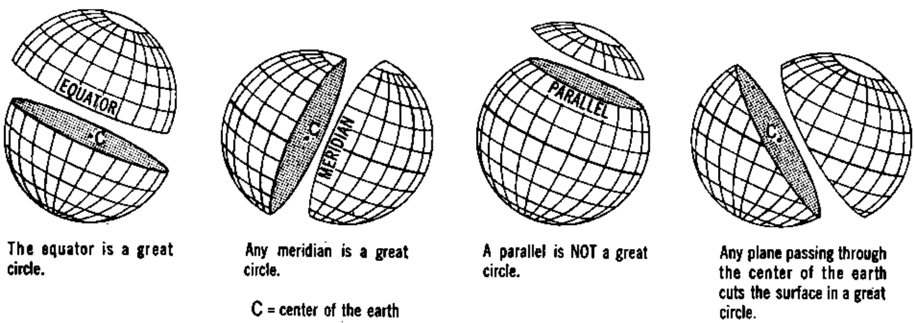


Figure 9.—Great circles on the earth.

In the United States, however, the length of a nautical mile is definitely fixed at 6,080.20 feet.

The statute mile is more commonly used on land, and also for air navigation. The graphic scales printed on the various series of aeronautical charts are all based on the statute mile of 5,280 feet.

TIME

Due to the 23½° tilt of the earth's axis, the eccentricity of its orbit, and other irregularities, the length of a day is not constant, and the sun is at times ahead of the clock; at other times it is slower. Time measured by the irregular motion of the sun itself is known as "apparent time," or as "true solar time."

For many purposes this variable time is not satisfactory, and it is supposed that a "mean sun" moves uniformly around the heavens. A day is defined as the time required for one complete rotation of the earth with respect to this mean sun. Mean solar time is the time ordinarily kept by our clocks and watches.

It is considered that the day begins at any given place when the sun is on the opposite side of the earth, directly over a point 180° of longitude distant from the place. Something like 6 hours later the sun comes over the eastern horizon; at 12 noon it is directly over head; about 6 p. m. it sinks below the western horizon, and at 12 midnight it is again directly over the meridian from which it started 24 hours before, and a day is completed.

When it is noon at any point, it is past noon at all places to the east of the point, for the sun has already passed over them; it is not yet noon for places to the west, for the sun has not yet reached them. The earth rotates through 360° in 24 hours, or 15° every hour. To people on the earth, it seems as though the earth is motionless and the sun moves, so we say that the sun moves 15° in one hour, or 1° in four minutes. For places 15° toward the east the time is one hour later; 15° toward the west the time is one hour earlier.

Not many years ago every city had its own local time. In railroad centers there were occasionally as many as six different kinds of time. To avoid the confusion that naturally followed, zone time, or "standard time" was adopted. Originally each standard time zone was 15° of longitude in width, with the first zone centered on the meridian of Greenwich. Eventually many irregularities crept in, as communities decided to keep the standard time of some large city

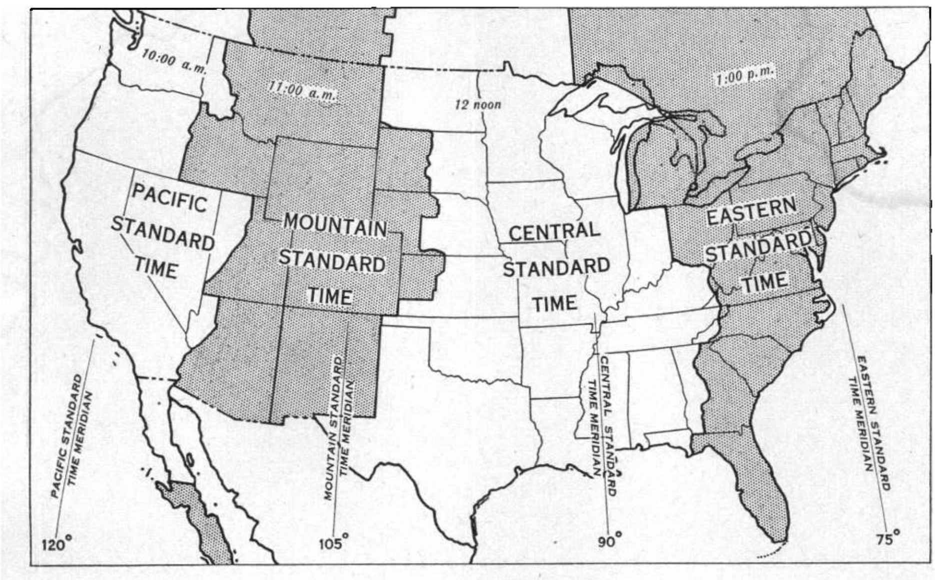


Figure 10.—Standard time zones of the United States.

farther east or west. Daylight saving time has introduced further complications.

Figure 10 shows a very generalized picture of the four standard time zones of the United States.

In reporting estimated time of arrival to an airway traffic control center, pilots sometimes become confused and add an hour when it should have been subtracted, or vice versa. The best practice is to report according to the watch time actually being kept by the pilot. The estimated time of arrival, for example, should be given as "5:30 p. m., central standard time," leaving no doubt in the mind of either the pilot or the control tower operator concerning the time referred to.

REPRESENTATION OF A SPHERE

No considerable part of the surface of a sphere can be spread out in a plane without some stretching or tearing. In attempting to flatten out a portion of a hollow rubber ball, as under glass, the outer part must be stretched or torn before the central part can be pressed into the same plane with it.

If only a small portion of the earth's surface is to be shown, it may be represented on a plane surface with negligible distortion. When a large number of such maps have been made, it will be found that they cannot be joined together

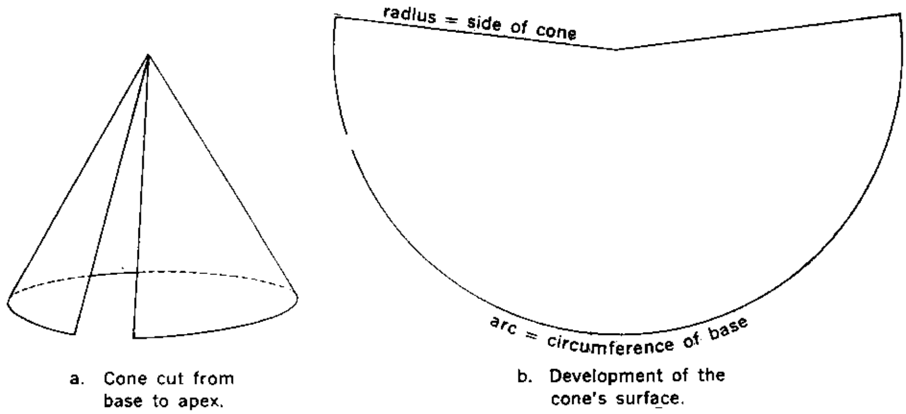


Figure 11.—Development of a conical surface.

so as to lie flat. If they are carefully joined along the edges it will be found that they naturally adapt themselves to the shape of the globe.

While it is impossible to represent a sphere upon a plane accurately, there are some surfaces that can be spread out in a plane without any stretching or tearing. Such surfaces are called developable surfaces; those like the sphere

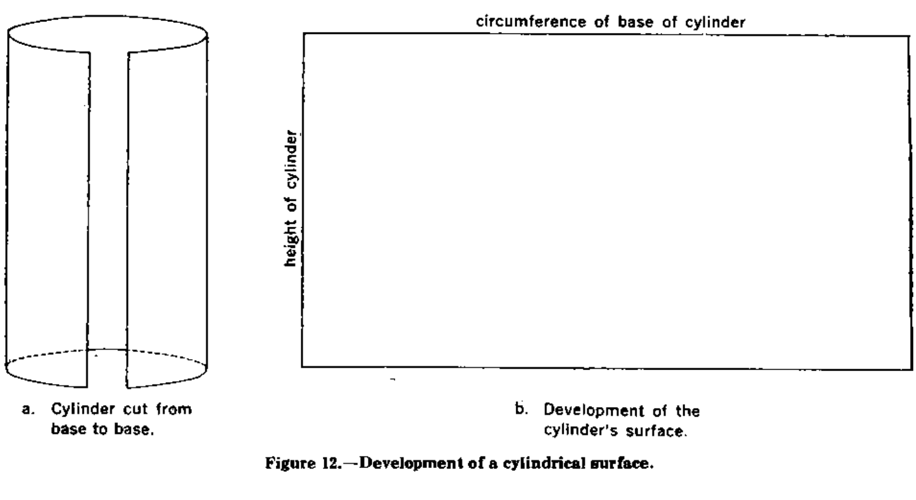


Figure 12.—Development of a cylindrical surface.

are called nondevelopable. The cone and the cylinder are two well known surfaces that are developable.

If a paper cone is cut in a straight line from base to apex (fig. 11), the surface of the cone can be spread out in a plane with no stretching or tearing. Any curve drawn on the surface will have exactly the same length after development that it had before.

In the same way, if a cylindrical surface is cut from base to base the whole surface can be rolled out in a plane. See figure 12. In this case, also, there is no stretching or tearing of any part of the surface.

Since the sphere cannot be directly developed into a plane surface, it is customary first to project the reference lines of the sphere upon some developable surface, as a cone or cylinder. This is done by mathematical analysis, but the process may be visualized by supposing a tiny light at the center of a transparent sphere, projecting a shadow network of meridians and parallels upon a tangent cone or cylinder (fig. 15). When this developable surface has been unrolled into a plane, we have a more or less satisfactory representation of the reference lines of the sphere upon a plane surface. The system of lines representing the meridians and parallels of the sphere is known as a chart projection. It is the foundation upon which the chart or map is built.

PROPERTIES OBTAINABLE IN A PROJECTION

A great many systems of projection have been devised, each intended to serve some particular purpose, or to preserve some special property of the sphere. Some of the properties which it would be desirable to preserve in a chart are:

(1) The true shape of physical features, including correct angular relationships;

(2) Equal areas, or the representation of areas in their correct relative proportions; and

(3) True scale values, for measuring distances.

Other properties often desired and obtained are:

(1) The representation of great circles as straight lines;

(2) The representation of rhumb lines (see p. 16) as straight lines; and

(3) A compromise between several desirable properties, sacrificing a little of one in order to obtain a little more of some other, yet without too much violence to either.

It is possible to obtain any one of these properties, sometimes more than one, on a flat map; it is possible to obtain ALL of them in one map only on a globe. It is necessary, then, to consider what purpose the chart is to fulfill, and to select the projection that most nearly affords the properties desired. For all the ordinary methods of navigation in the United States only two projections are of real importance: the Mercator, and the Lambert conformal conic.

THE MERCATOR PROJECTION

This projection was introduced by Gerhard Krämer, better known as Mercator, nearly 400 years ago. Today it is used almost exclusively for the nautical charts of the world. It is of the cylindrical type illustrated in figure 12, and its meridians and parallels are represented by two sets of parallel lines at right angles to each other. Figure 13 shows a map of the world on the Mercator projection.

On the earth itself, the meridians converge toward the poles. On this projection the meridians do not converge, but are everywhere the same distance apart. This means that as we approach the poles the meridians of the projection are too far apart; to compensate for this, and to retain true angular relationships, the parallels of latitude are also spaced at proportionately greater intervals, so that the shape of each rectangle of the projection is kept proportional to the shape of the same rectangle on the earth.

Since both meridians and parallels are spaced too far apart in the northerly parts of a chart on this projection, it is clear that those areas are distorted and are shown too large with reference to the more southerly areas; that is, the scale of the northerly part is larger.

The change of scale between the most northerly point of the United States and the most southerly, amounts to about 40%. That is, if we adopt a scale of 8 miles to the inch at the southernmost part of the United States, the scale at the northernmost part of the chart will be 4.8 miles to the inch. As a result,

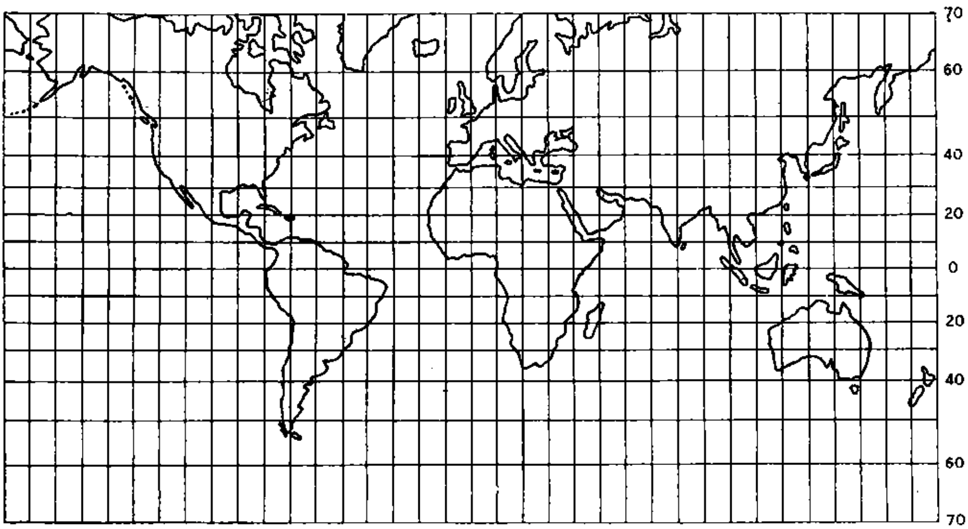


Figure 13.—Mercator projection of the world.

no graphic scale of miles can be used even for one chart with satisfactory accuracy. Instead, a different scale of miles, based on the mean latitude between the two points in question, must be used in each case. Since measurements of distance are necessarily frequent in air navigation, this presents a real difficulty.

Because of the distortion of areas already referred to, and the rapidly changing scale, the Mercator projection is not suitable for many purposes. It was designed for one special purpose, namely, the representation of a rhumb line as a straight line.

A rhumb line between any two points crosses all meridians of the earth at a constant angle. A ship or an airplane that holds to a constant course is making good a rhumb line over the ground. Mercator wished to be able to plot the rhumb line as a straight line, and this projection was designed accordingly.

As already pointed out, a great circle represents the shortest route between two points; the rhumb line is somewhat circuitous, and is always longer. Figure 14 shows the great circle route from New York to London (from figure 8), together with the rhumb line between the same two points. Note that in this case the rhumb line is 141 statute miles longer. For distances of less than 1,000 miles the saving in distance by way of the great circle is not great enough to be of practical importance.

If it is desired to follow a great circle, the route must first be drawn on a great circle chart (gnomonic projection) as a straight line. In the gnomonic projection the sphere is projected upon a tangent plane, and all great circles appear as straight lines. The route plotted on the great circle chart is then transferred to the Mercator chart, point by point, by latitude and longitude. The distortion of the Mercator projection is such that the great circle appears as a curved line on the chart, as though it were longer than the rhumb; this is

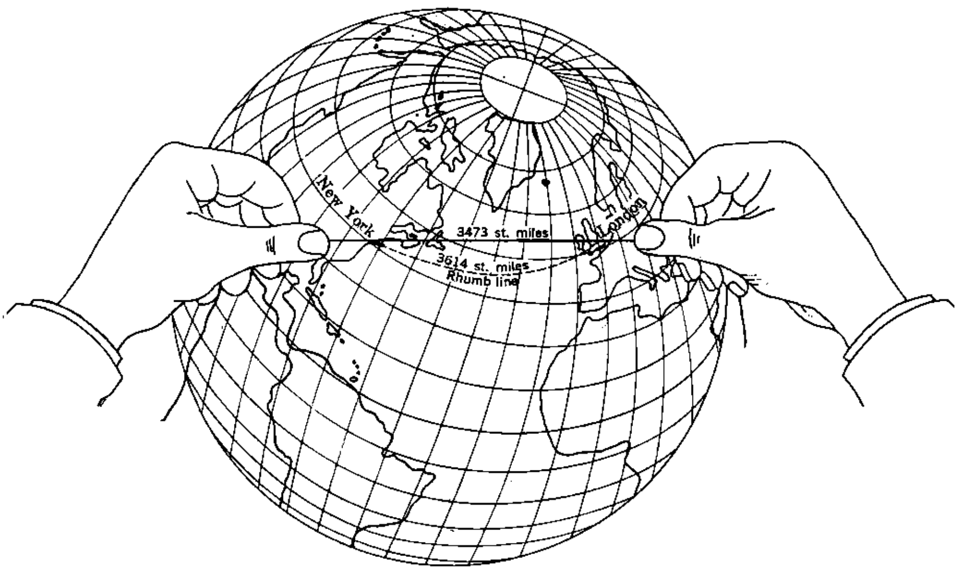


Figure 14.—Great circle versus rhumb line.

not the case on the earth, of course. The curved line on the Mercator is next broken down into a number of sections of convenient length, and the rhumb line course for each section is followed. In this way the great circle route is approximated by a series of rhumb line courses.

In the days of slowly moving surface vessels, a constant compass course might be followed for a full day's run. It was a distinct advantage to be able to plot this as a straight line. In air navigation the situation is quite different. As a result of changing magnetic variation (see p. 70) and changing winds, the swifter aircraft seldom hold to one course more than an hour. The track over the ground must therefore be plotted as a series of short lines, and the one important advantage of the constant compass course (rhumb line) disappears.

For reasons already suggested, the Mercator projection has not been generally adopted for use in air navigation. It is of interest in the United States chiefly to naval pilots, who must be familiar not only with air navigation methods and charts, but also with the methods and charts of the fleet.

The only Mercator charts for air navigation available in the United States consist of a series of narrow strip charts along our coasts, published by the Hydrographic Office of the United States Navy.

THE LAMBERT PROJECTION

To avoid any confusion with other projections devised by Lambert, this projection is properly known as the Lambert conformal conic projection. It is his best known projection, however, and for the sake of brevity it is commonly referred to as "the Lambert."

The projection was introduced in 1772, but was little known until, during the first World War, it was adopted by the Allies for their military maps because it afforded maximum accuracy of directions and distances.

These are the two basic problems of all navigation, since these two factors definitely determine position; consequently, when the Coast and Geodetic Survey was assigned the task of preparing charts for air navigation the Lambert projection was given serious consideration. It was selected, however, only after a thorough investigation had indicated that it afforded a very desirable combination of properties and advantages. Two properties, both of which are vital in air navigation, are the speed and accuracy with which solutions of navigational problems may be obtained.

Like the Mercator, the Lambert projection is mathematically derived; however, its derivation is well illustrated in figure 15.

In the figure the meridians and parallels of the earth are projected upon a cone which intersects the surface of the earth along two standard parallels. The standard parallels on the earth and on the cone coincide and along them the scale is therefore exact. Between the standard parallels the earth is projected *inward* upon the cone, and the scale of the cone is somewhat smaller than the scale of the larger earth. Outside the parallels the earth's surface is projected *outward*, and the scale of the cone is slightly larger than that of the earth.

The standard parallels of true scale adopted for all aeronautical charts of the United States are latitudes 33° and 45°. For aeronautical charts of Alaska, the standard parallels are latitudes 55° and 65°.

Figure 16 shows a portion of the developed Lambert cone, with the outline of the United States. Note that the meridians of the earth are represented by straight lines converging toward a common point (the apex of the cone) outside the borders of the chart. They may be considered as radii of the parallels, which are represented by arcs of concentric circles; the common center of the parallels, of course, is at the point of intersection of the meridians. Meridians and parallels intersect at right angles, and the angles formed by any two lines on the earth's surface are correctly represented.

The excellent scale properties of the projection are also illustrated in figure 16, where it is seen that for about 90 percent of the area of the United States the maximum error is about one-half of 1 percent—that is, one-half mile for every 100 miles. The scale error of any single chart is so small that distances may be measured as if the scale of the chart were constant.

A straight line on the Lambert chart is a close approximation to the path of a great circle, and for all practical purposes may be regarded as the shortest route between two points. In order to plot a great-circle route on this projection, a gnomonic chart is not required. It is only necessary to draw a straight line on the chart, break it down into sections of convenient length, and determine the rhumb-line course for each section, as described on page 67.

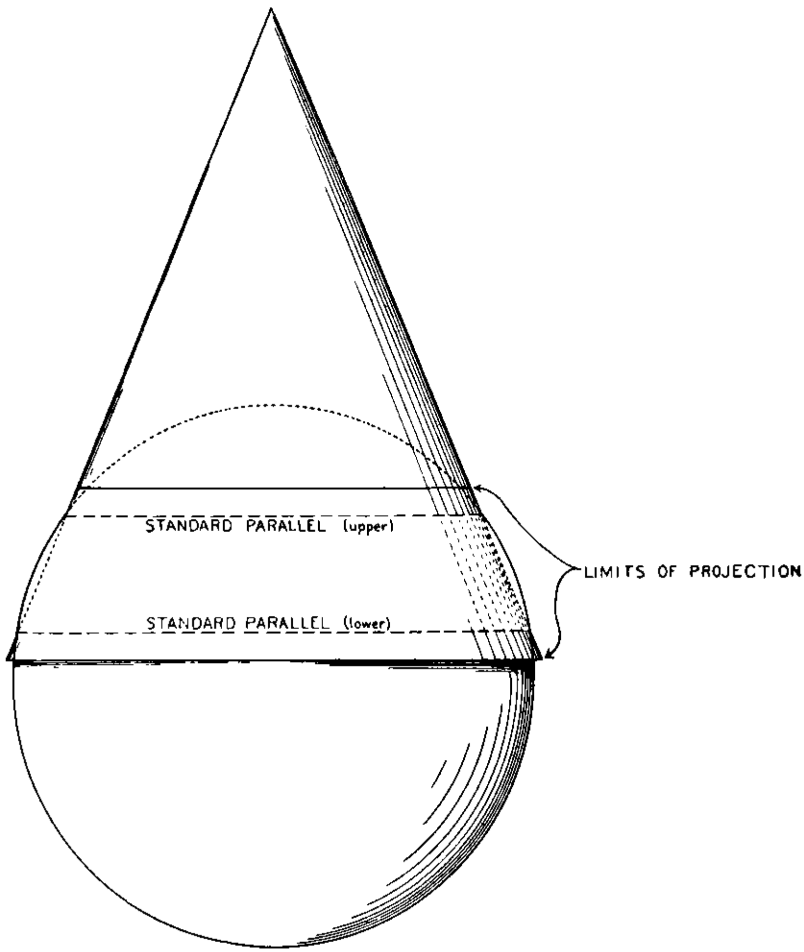


Figure 15.—The Lambert conformal conic projection.

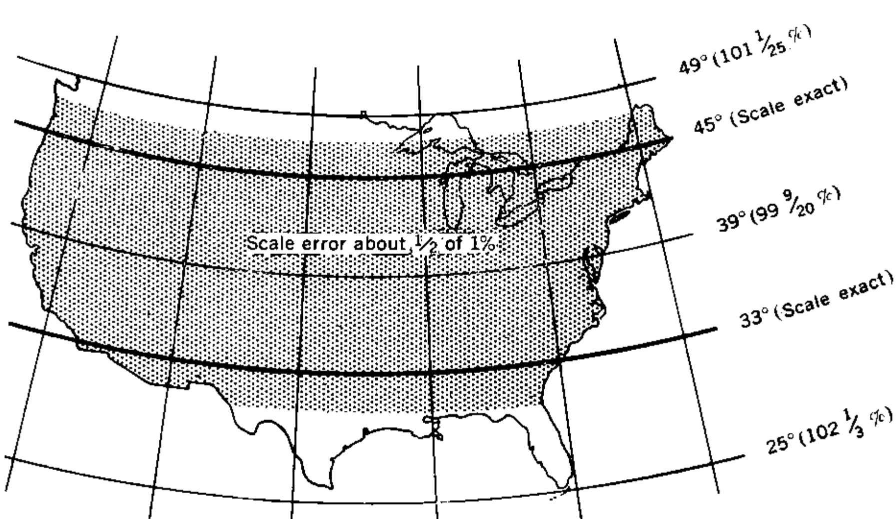
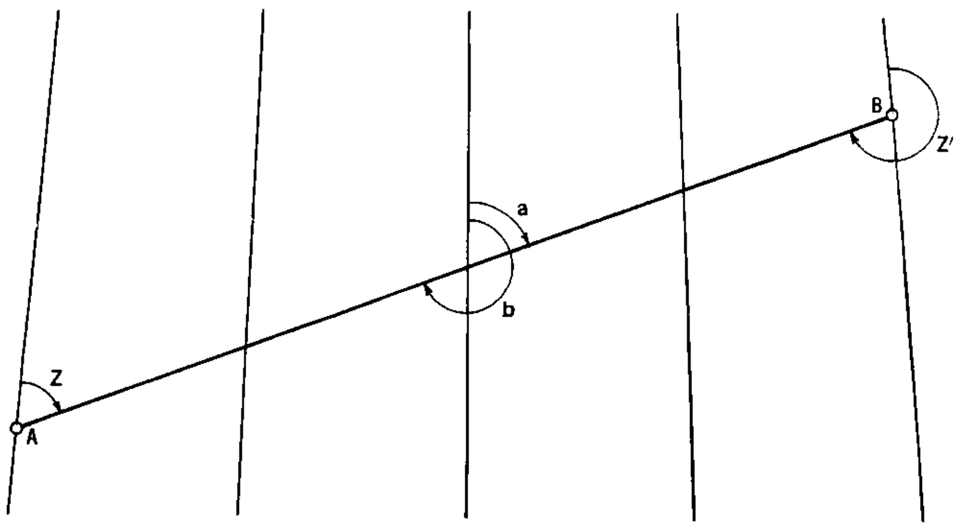


Figure 16.—A portion of the developed cone, Lambert conformal conic projection, showing scale properties.

It has been stated that a straight line on the Lambert *approximates* the path of a great circle. It should be remembered that this is only an approximation; on the gnomonic projection alone can a straight line exactly represent a great circle.

Through the central part of the Lambert projection for the United States a straight line so closely approximates a great circle that for all practical purposes it may be so considered. The same is true for a line from low latitudes to high latitudes, or vice versa, however great the distance (for example, from Seattle to Miami). For a long line east and west, along the Canadian border or across the Gulf (as Miami to Brownsville), the straight line on the Lambert departs appreciably from the true great-circle track. Even in these areas,



Angle **a** is the course to be followed from A to B;
Angle **b** is the course to be followed from B to A;
Angle **Z** is the bearing, or azimuth, of B as measured at the point **A,**
Angle **Z′** is the bearing, or azimuth, of A as measured at the point **B.**

Figure 17.—Courses and bearings.

however, the distance represented by the straight line differs very little from the true great-circle distance; but for any purpose in which the precise great circle track is of interest, the Great-circle Chart (No. 3074) should be used.

At this point it may be well to distinguish carefully between two different kinds of direction and the methods of measuring each on the Lambert projection. In air navigation the two kinds of directions are known as courses and bearings, and are illustrated in figure 17.

A bearing is the direction of the great circle; a course is the direction of the rhumb line.

A bearing is measured at the meridian passing through the place at which the bearing is determined; a course is always measured at the meridian nearest halfway between the two points in question.[1] Failure to follow this rule intro-

[1] For theoretical precision, long courses should be measured with the meridian of middle longitude between the two points in question, rather than the meridian nearest halfway. This applies only to very long distances, however, and is an unwarranted refinement, the maximum course error from this cause being too small for practical consideration.

duces an error of about 0°.3 for each degree of longitude between the two points.

Courses and bearings are both measured clockwise from the north, from 0° up to 360°.

A bearing is constantly changing as we progress along the route and is different at every point along the great circle (except for the special cases in which the two points are both on the same meridian, or are both on the equator); a course is the average of the changing directions of the great circle, and may be followed without change for the entire distance between the two points (if, for the moment, we disregard magnetic variation, compass deviation, and wind).

The course from *A* to *B* is the exact reciprocal of the course from *B* to *A* (that is, exactly 180° different); the bearing of *A* from *B* is never the exact

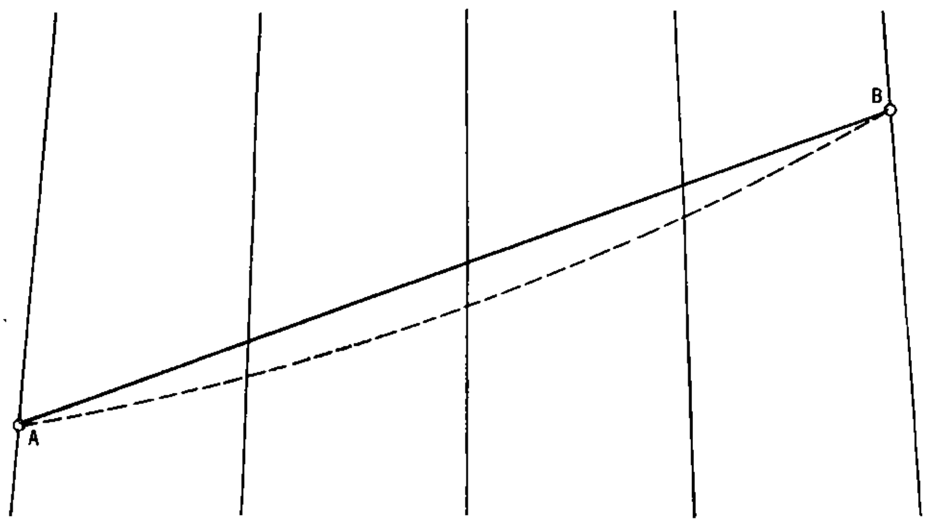


Figure 18.—Course and track.

reciprocal of the bearing of *B* from *A*, but differs therefrom by an amount equal to the angular convergence between the meridians through the two places.

Courses are used continually in all problems of dead reckoning; the use of bearings (azimuths) is confined to radio navigation and celestial navigation almost exclusively.

The terms "bearing" and "azimuth," as used in air navigation, are identical, but the former term is generally used in radio navigation, the latter in celestial navigation.

To clear up any confusion that may yet remain, it should be explained that when the course is measured with the meridian nearest halfway (as the angle *a*, fig. 17), an airplane following that course will not exactly follow the straight line *AB* (great circle) on the chart, but will slightly depart from it near the middle of the route, as indicated by the light, broken line (rhumb line, greatly exaggerated) in figure 18. When courses are measured as recommended on page 67, however, the departure is so slight that it may be considered that the airplane does exactly track the straight line throughout its entire length.

These properties of the Lambert projection provide for very simple methods of air navigation. They are developed more completely in later chapters, but are briefly summarized here. It may be said of the Lambert projection that:

1. It permits a perfect junction between any number of charts in any direction.

2. It is unexcelled for scaling distances in all directions in the United States.

3. Its directions conform very closely to directions on the earth.

4. It affords a simple and satisfactory solution for all problems of dead reckoning, not excepting the rhumb line.

5. It affords the simplest possible method of great circle navigation.

6. It is unsurpassed for all types of radio navigation.

7. It is well suited to all problems requiring the plotting of positions, and for celestial navigation.

QUESTIONS

1. Define navigation.

2. Name the four principal methods of navigation.

3. What is the difference between a planet and a star?

4. Name the nearest star.

5. How many planets are there?

6. The earth is closer to the sun in winter than in summer (see fig. 5); why are our winters colder?

7. What is the diameter of the earth?

8. Define latitude and longitude.

9. Express longitude 77°30′ in terms of time; longitude 6 hours 30 minutes in terms of arc.

10. What is a great circle? a small circle? a rhumb line?

11. What is a nautical mile?

12. How long is a statute mile?

13. What is meant by the "mean sun"?

14. What is meant by "apparent time"?

15. What is standard time? Name the standard time zones of the United States.

16. When it is noon in Chicago, what time is it in New York? Los Angeles? Portland, Maine? Denver?

17. How should the estimated time of arrival at an airway traffic control center be reported?

18. Define a chart projection.

19. What two projections are of interest in air navigation?

20. Describe the Mercator projection.

21. Describe the Lambert conformal conic projection.

22 Compare the advantages and disadvantages of these two projections.

23. What standard parallels have been adopted by the Coast and Geodetic Survey for the aeronautical charts of the United States? Alaska?

24. How should a great circle route be plotted on a Lambert chart (a) for practical purposes? (b) for precise results?

25. How should a great circle route be plotted on a Mercator chart?

26. Distinguish between a course and a bearing, and describe how each is measured.

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Chapter III.—INSTRUMENTS

THE FIVE FUNDAMENTAL INSTRUMENTS

It has already been stated that distance and direction are the two basic problems in all navigation. Before taking up the various methods of navigation it will be well to become familiar with the instruments for measuring these quantities while in flight, and with their limitations.

The pilot of a modern transport airplane faces an array of something like 100 different instruments and gadgets. The great majority of these, however, have nothing to do with navigation. There are instruments which furnish information with regard to the functioning of each engine, such as fuel gages, oil-temperature gages, and manifold pressure gages; there are other instruments having to do with the mechanical handling of the aircraft, such as rudder, elevator, and aileron-tab controls, and the flaps-position indicator; there are also switches for landing lights, running lights, cabin lights, and for numerous other purposes.

There are a number of interesting instruments in process of development, and some of the standard ones appear in various forms. Those essential for navigation, however, may be reduced to the following five fundamental instruments:

(1) clock or watch;
(2) altimeter;
(4) compass;
(3) air speed indicator; and
(5) drift sight.

It is not expected that pilots should know the mechanical details of construction, nor that they should attempt their own aircraft-instrument repairs. It is desirable, however, that they should be familiar with the underlying principles of each instrument, in order that they may know its limitations, and what corrections (if any) must be applied.

THE CLOCK

The clock or watch is included here, since time plays an important part in many of the steps of navigation. For example, fuel consumption is reckoned in time, rather than miles, and the distance flown is the product of speed and time. Also, progress along the charted route is often plotted directly in units of time, when the ground speed is accurately known.

For all ordinary navigation, any good timekeeper is quite satisfactory, and it is unnecessary to obtain clocks or chronometers of elaborate or expensive design. For many purposes, however, a clock that indicates both the time of day and the elapsed time in flight is a convenience. A dollar watch, set to 12 o'clock at the time of take-off, will indicate the elapsed time quite satisfactorily.

THE ALTIMETER

Surface travel is limited to two dimensions; in air transportation, vertical movement is added. The altimeter is essential to indicate the movement of the aircraft in this third direction—that is, to indicate the altitude of flight. More exactly, the altimeter is an aneroid barometer, registering atmospheric pressure on a scale which has been calibrated to read directly in feet, instead of inches of mercury.

Figure 19 shows an altimeter of conventional type. The small hand registers thousands, and the large hand hundreds of feet of altitude. The altitude indicated in the figure is 4,080 feet. At one side of the dial there is a barometric scale which can be set to correspond to the barometric pressure existing at the time in the vicinity of flight. The altimeter setting may be obtained from the latest available hourly teletype sequence weather report, before taking off; or, better, it may be obtained by radio in flight, from the broadcast by the local range station. It is broadcast as the altimeter setting, and is given in inches of mercury; it should not be confused with the barometric pressure, which is reported in millibars. When the altimeter setting has been applied, the instrument will indicate very closely the field elevation above sea level when the wheels of the airplane touch the ground.

Figure 19.—Altimeter.

The altimeter consists of a small, airtight chamber, from which most of the air has been removed. The pressure, or weight, of the outside air tends to collapse the chamber, but this tendency is resisted by a spring. As the atmospheric pressure increases, the chamber is compressed; as it decreases, it is again expanded by the spring. This slight motion is magnified mechanically, and registered in terms of the altitude that would produce a corresponding change in pressure under standard conditions.

As "standard conditions," it is assumed that the temperature at sea level is 59° F. (15° C.), and that it decreases with altitude at the uniform rate of 3.6° F. (2° C.) for each 1,000 feet. Actually, of course, temperatures differing widely from this standard are experienced.

If the existing temperature is **higher** than standard, the air has expanded, and is lighter per unit volume. The *change of pressure* recorded now will be less than with standard conditions, and the altimeter will not read 1,000 feet until the airplane is higher than 1,000 feet. That is, the true altitude will be **higher** than the indicated altitude.

Conversely, if the existing temperature is lower, the density of the air is greater. The *change of pressure* per 1,000 feet will be greater than normal, and an elevation of 1,000 feet will be indicated before the airplane has actually reached that height. That is, the true altitude will be lower than the indicated altitude.

The latter condition, of course, is usually the more dangerous. When temperatures are very low the true altitude may be as much as 20 percent lower than the indicated altitude. Under these conditions the altimeter registers 8,000 feet when the altitude of the airplane is only 6,400 feet—and in mountainous country this could prove disastrous.

For rather similar reasons the altimeter also indicates an altitude higher than the true when flying from an area of high barometric pressure into a low pressure area. The same is true, of course, if the pressure falls during flight, before the airplane returns to the point of departure.

In the absence of more accurate information, a good general rule for arriving at the amount of the altimeter error is that the correction is equal to 2 percent of the indicated altitude for each 10° F. (5.5° C.) that the temperature differs from the standard temperature.

The altimeter is also subject to "lag." By this it is meant that after a change in altitude some time interval (as much as 6 or 8 seconds) may elapse before the change is registered by the instrument. For this reason, it is well for pilots not to depend too much on altimeter readings when landing.

The chief mechanical sources of inaccuracy of the altimeter are friction in the mechanism and failure of the parts because of vibration. The latter condition may result from loose mounting of the case or excessive vibration of the instrument panel.

The interior is susceptible to corrosion, and rust in the mechanism will result in erratic readings. Frequent flights to high altitudes tend to strain the diaphragm so that it expands and does not return to normal. This action also affects the lever system.

Calibration is accomplished by placing the instrument in a bell jar connected with a vacuum pump, varying the pressure, and comparing the readings with those of an attached mercury barometer or an altimeter of known accuracy. The hole in the case must be unobstructed so the internal pressure will be equal to that of the air in which the airplane is operating.

For some purposes use is made of the "pressure altitude." This may be defined as the indicated altitude above sea level when the barometric scale is set to the standard sea level pressure of 29.92 inches.

THE MAGNETIC COMPASS

This is the primary instrument for indicating the direction of flight. It is designed to indicate magnetic directions by utilizing the directive force of the earth's magnetic field.

The compass appears in a variety of forms, figure 20 illustrating, perhaps, its most common one. The markings on the card are in reverse, the *N* appearing on the south side of the card, for convenience in reading when it is mounted in front of the pilot. The compass card is suspended in liquid, which serves to damp out, or minimize, oscillations and to reduce the weight on the pivot.

The earth may be considered as a large magnet, with two magnetic poles at some little distance from the geographic poles. Along the magnetic Equator (that is, about halfway between the magnetic poles) the lines of force of the earth's magnetic field are parallel to the surface of the earth. As the distance from the Equator increases, the lines of force become more and more inclined until, at the magnetic poles, they are vertical. These inclined lines of force may be considered as made up of a horizontal component and a vertical component.

The magnetic compass takes its directive force from the horizontal component of the earth's magnetic field. As long as the airplane is kept horizontal, in straight and level flight, the compass is fairly stable and reliable; with any appreciable degree of bank, the compass card is affected by the vertical component, and no longer indicates directions correctly. When the airplane is turned, the compass may even indicate a turn in the opposite direction, and may turn completely around before taking up the correct direction again. For

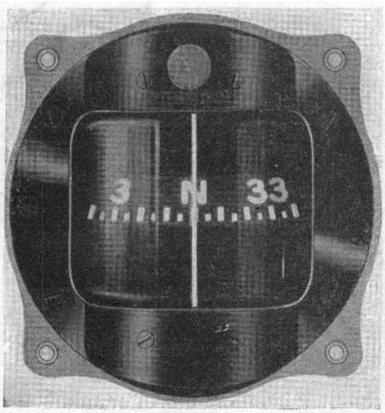

Figure 20.—Magnetic compass.

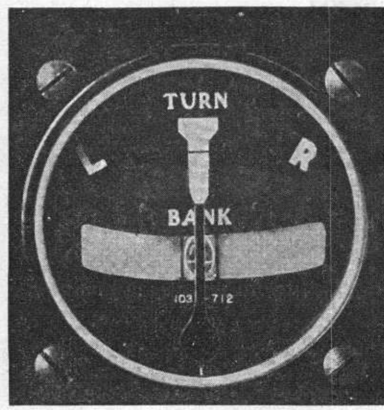

Figure 21.—Bank-and turn-indicator.

this reason a bank-and-turn indicator (fig. 21) is commonly used in conjunction with the compass.

Any turn toward the left or right is indicated by a corresponding deflection of the hand of the turn indicator. If the turn is properly executed, the steel ball remains centered in its tube; if the controls are not properly coordinated for the turn, the ball skids outward from the turn, or falls inward.

During construction the iron and steel parts of the airplane acquire a certain amount of magnetism. The ignition system and other electric circuits also may be surrounded by magnetic fields when in operation. These influences affect the magnetic elements of the compass, with the result that the card does not indicate the magnetic directions correctly on most headings. This error is known as the deviation of the compass. It is different, of course, for each compass installation, for each airplane, and for different headings of the same airplane.

The compass direction may be in error on any particular heading, but the error on that heading remains the same, except for changes in the ship's magnetism with the passage of time or from severe landing shocks. The important thing is to know the amount of deviation on the various headings, and to allow for it in navigation (see p. 74). This is accomplished by first compensating the compass, to make the deviation as small as possible; and then "swinging ship," to determine the deviation on headings for at least every 30°.

Before compensating the compass the following tests should be made:

1. See that the bowl is completely filled with liquid.

2. Check the mounting of the compass card for excessive friction by causing it to deflect through a small angle, with a magnet, and noting if it returns freely to its original position.

3. Make sure that the lubber line (reference, or index line) is parallel with the longitudinal axis of the airplane.

4. See that all tools and other equipment are placed in flying position.

5. Raise the tail of the airplane to flying position and see that the wings are level.

6. Have the engine running.

By means of plumb bobs suspended from the propeller hub and from the rudder post, head the airplane toward magnetic north. Adjust the N-S screw of the compensating device with a nonmagnetic screw driver as necessary, until the compass reads north.

The airplane is then turned toward magnetic west, and the E-W screw adjusted until the reading of the compass is west.

Next, the airplane is turned toward magnetic south, and the N-S screw adjusted to remove *half* of the observed error; and

Finally, it is turned toward the east and half of the remaining error removed.

The above procedure distributes the error fairly evenly between the four cardinal points, and avoids deviation of excessive magnitude in any one direction.

At some airports, magnetic stations and compass-testing platforms are available, which greatly simplifies the problem of determining the correct magnetic directions. In the absence of such facilities, magnetic directions must first be determined by reference to a master compass of known deviation; by determining the direction of true north from observations on the sun or stars, and correcting for the magnetic variation of the place; or by other available means.

Magnetic variation is the angle between true north and magnetic north at any given place. In engineering and scientific work it is known as magnetic declination.

After compensating the compass as just described, the airplane is again headed toward magnetic north, and the compass reading noted. The airplane is then turned to magnetic headings for every 30°, completely around the compass-testing platform, and the compass reading for each heading noted. With these data, a deviation card similar to figure 22 is prepared, and fastened up near the compass to which it applies.

If the compass reading is less than it should be, it is clear that compass north lies to the east of magnetic north, and the deviation is known as easterly deviation. If the compass reading is greater than it should be, the deviation is westerly.

In swinging ship, as just outlined, the engine should be kept running. Navigation lights and radio should both be turned on at intervals, if not continuously, to see if their operation affects the deviation. If the compass card moves when lights are turned on, the wires are too close to the compass. The electrical field surrounding the wires may be destroyed by twisting them tightly together in the form of a twisted pair—being careful, of course, not to break the connections.

A recent report from the Naval Aircraft Factory, Philadelphia,[1] states that having compensated the compass on the ground, the deviation can be determined more accurately in flight than by swinging ship on the ground.

For this method it is recommended that the airplane be flown in different directions over a straight section of railroad track or highway, the magnetic

For	N	330	300	W	240	210
Steer	3	334	298	270	241	209
For	S	150	120	E	60	30
Steer	179	147	122	90	61	31

Figure 22.—Typical deviation card.

bearing of which is known. The compass should be watched, and the readings on each particular course written down, to be averaged later. At the instant the track is crossed, the relative bearing (that is, the angle between the longitudinal axis of the airplane and the railroad) is measured with a drift sight. (See p. 30.)

The following rules for obtaining deviation in flight should be observed:

1. A large number of compass readings on each heading should be made and averaged.

2. The airplane should be flown for at least 3 minutes on each heading.

3. At least two complete swings in the air should be made, and the deviations for the same headings averaged.

The bearing, or direction, of the road or railroad used for this purpose should be accurately determined on the ground. Bearings measured from a chart are not likely to be exact enough for the purpose because of the small scale of the charts and the shortness of the section of railroad or highway on the chart.

Swinging ship in the air, of course, should not be attempted except when the air is smooth.

As already suggested, deviation is subject to change from time to time. It is also subject to change from place to place, especially where any considerable difference of latitude is involved. It is particularly likely to be affected by severe electrical storms or heavy shock, and should be checked at least several times a year—certainly before beginning any important flight.

THE AIR SPEED INDICATOR

This instrument is closely related in principle to the altimeter, and in reality measures pressure calibrated in terms of air speed at sea level and at standard atmospheric pressure. A common type of air speed indicator is shown in figure 23.

[1] Report No. IDS—2—40, May 10, 1940.

Since its indications are based on pressure, its accuracy is limited by conditions affecting the density of the atmosphere. Obviously, the atmospheric pressure varies with temperature and altitude, and a correction should be applied for these factors.

Roughly, the correction amounts to about 2 percent per 1,000 feet of altitude, the true air speed being always greater than the indicated air speed (except for extremely low temperatures at low altitudes).

Figure 99, page 151, gives this correction more accurately, for any ordinary range of temperature, and altitudes to 20,000 feet. The correction may also be found by means of the computer which is to be assembled from the prints facing page 138. With the computer it is only necessary to rotate the upper disk (disk *B*) until the observed temperature is opposite the pressure altitude (see p. 141) in the cut-out opening; the true air speed may then be read from the outer scale (on disk *A*) opposite the indicated air speed on disk *B*.

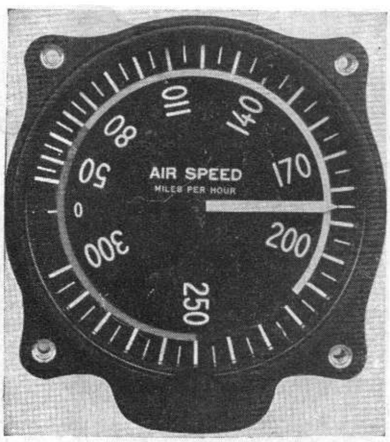

Figure 23.—Air speed indicator.

The air speed indicator also affords information regarding departures from level flights. If the throttle remains unchanged and the air speed increases, it is noticed that the nose has dropped and the airplane is in a dive; if the air speed falls off, the nose has come up and the airplane is in a climb.

It is important to realize that, while the air speed indicator is in error at any appreciable altitude, its indications are still a trustworthy guide to safe flying speed, regardless of altitude. For example, if the stalling speed of an airplane is 40 miles an hour at sea level, the same pressure, and hence the same indicated air speed, will be necessary to keep it from stalling at any higher altitude.

With regard to the care of this instrument, it is important not to attempt to test it by blowing or sucking on the tubes. It is possible to exert a pressure in this way that is many times greater than the normal operating pressure, and the indicator may be damaged beyond repair.

Faulty readings are usually due to leaks or obstructions in the tubes leading to the instrument. They should be repaired only by a competent repair man. The sensitivity of the indicator may be lessened by vibration, and the indicated air speed may eventually become 5 or 10 miles an hour too slow. This may be checked by comparing with a master gage, or by timed flight over a measured course on the ground when there is no wind blowing, or when the wind and its effect on the speed of the airplane are accurately known.

THE DRIFT SIGHT

Wind is the principal complicating factor in all forms of air navigation. It varies with time, place, and altitude, and the wind reported at the airport Weather Bureau station may be appreciably different from the wind actually encountered only a few miles away. Unless there is at hand some means for knowing with reasonable accuracy the direction and velocity of the wind at different altitudes, accurate navigation is almost impossible.

Drift sights have not come into general use for several reasons. Not the least of these is that, in bad weather, when drift corrections are most important, often the ground cannot be seen and the air is too turbulent to obtain satisfactory drift observations. Nevertheless, it is very desirible to learn to use a drift indicator; whenever it can be used it makes accurate navigation possible, and in an emergency it may prove invaluable.

There are a number of drift sights available, some of them rather elaborate, with auxiliary devices for the determination of ground speed also. For most purposes a simple drift sight of the type illustrated in figure 24 is entirely satisfactory.

The drift sight is installed in an opening in the floor, making sure that the line of zero drift is lined up with the longitudinal axis of the airplane.

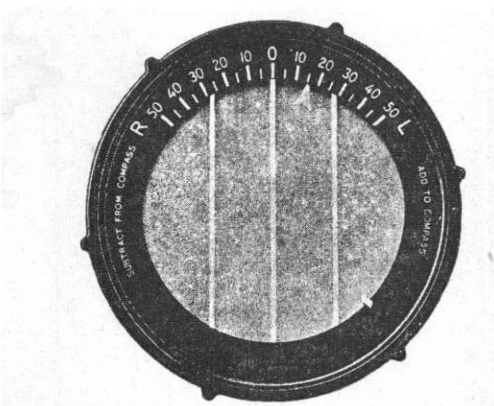

Figure 24.—Drift sight (floor type).

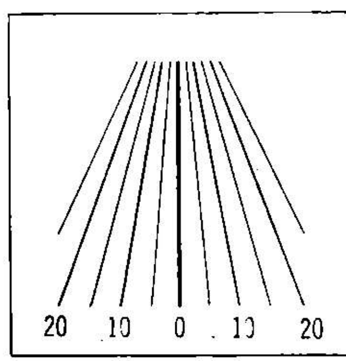

Figure 25.—A simple drift sight (floor type).

In flight, the grid ring is rotated until the grid wires are lined up with the apparent motion of the ground. The drift angle may then be read from the grid ring.

Drift angles on more than one heading are required before wind direction and velocity can be determined. However, by applying one observed drift angle as a correction to the course being flown, and rechecking, the desired correction may be obtained after two or three trials.

A very simple and satisfactory drift sight may be made by drawing drift lines on a piece of glass, as illustrated in figure 25. This drift sight, also, is to be installed in the floor of the airplane, and the drift angle is determined by noting the drift grid line along which the surface of the ground appears to move.

OTHER INSTRUMENTS

In addition to the five fundamental instruments already treated, several others are sufficiently important to demand at least a brief mention.

The **directional gyro** (fig. 26) is much the same in appearance as the magnetic compass. It has no directional properties of its own, but contains a small gyroscope driven by suction from a venturi tube. The gyro will maintain any direction to which it is set, for a short time. It changes direction because of precession, at the rate of about 3° in 15 minutes time, and must therefore be reset at frequent intervals.

Within this limitation, it accurately measures the amount of any turn, and provides the pilot a steady indication of direction, without lag or oscillation.

In flight, the instrument may be set on any arbitrary heading and used as a turn indicator until the magnetic compass has come to rest. It may then be set to agree with the observed compass heading. Another method is to use the gyro as a turn indicator until the compass card indicates the desired course, then set the gyro to zero. It is easier to hold the airplane's head on zero than on some heading requiring the frequent reading of a particular number of degrees, as 205°.

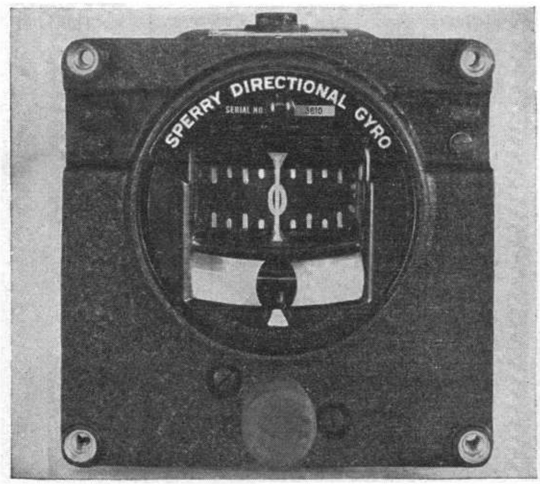

Figure 26.—Directional gyro.

When performing acrobatics or other maneuvers requiring any extreme degree of tilt, the knob should be pushed in, and the gyro "caged" until normal flight is resumed. It may then be checked against the compass again, and reset.

A novel combination of the directional gyro and magnetic compass in one instrument is under development, in which the gyro is continuously and automatically reset by the compass. In this way, the pilot will be provided with a stable and continuously accurate indication of direction, without the necessity of frequent checking and resetting.

The **artificial horizon** consists of a horizon bar maintained in horizontal position by an air-driven gyroscope, and a tiny silhouette of an airplane which is in reality a part of the airplane structure, and therefore tilts in the same manner as the actual airplane. If the airplane climbs or descends, the horizon bar seems to fall or rise in the same way that the actual horizon seems to move when viewed by the pilot. Figure 27 shows the artificial horizon as it indicates varied positions of an airplane in flight.

Radio is of ever-increasing importance in air navigation, and there are a number of radio instruments suited to the needs of all types of flying.

A simple **radio receiver** has become almost a necessity, even in the light airplane. With it, radio range signals and weather reports may be received while in flight, and instructions may be received from the traffic control tower at the airport, upon taking off or upon completion of the flight. There are already a number of airports where aircraft not equipped with radio are forbidden.

A two-way radio makes it possible for the pilot to communicate with the various ground stations while in flight, requesting weather reports or other essential information, reporting his estimated time of arrival, or requesting permission to alter his flight plan.

The **radio compass** makes use of the directional properties of a loop antenna. The loop in this case is fixed (nonrotatable), and as long as the airplane is headed directly toward the radio station to which it is tuned, the indicator hand remains centered. Any turning away, toward the right or the left from

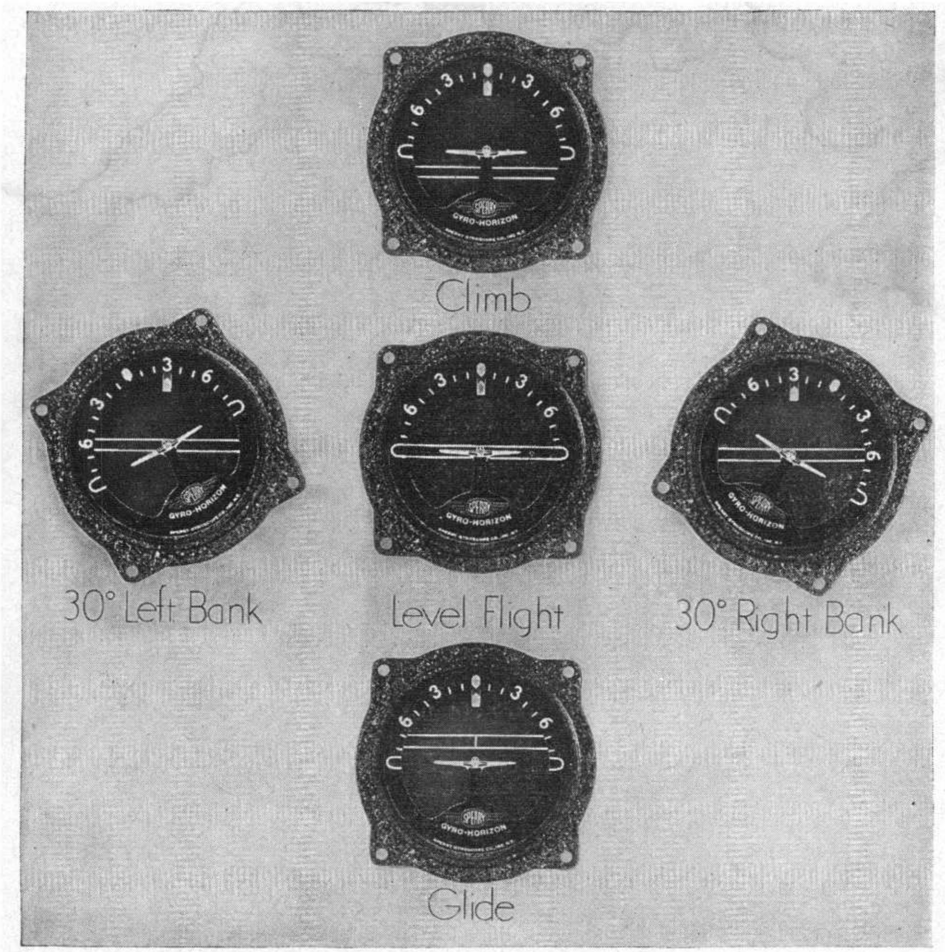

Figure 27.—Artificial horizon.

the station, results in a corresponding deflection of the indicator hand. The radio compass is chiefly used for "homing flight" toward or away from a radio station. Figure 28 shows the dial of a radio compass.

The **radio direction finder** makes use of a rotatable loop, which is rotated until an aural null (absence of signal) is obtained. In this position, a movable hand indicates on an azimuth scale the angle between the heading of the airplane and the direction to the radio station. This angle is known as the "relative bearing" of the station. The same information for two or more radio stations, when plotted on a suitable chart, determines the position of the airplane. For the method of plotting radio bearings, see pages 113 to 118.

With the **automatic direction finder** it is only necessary to tune in the desired radio station; the loop then rotates automatically to the null position, and the hand on the dial points continuously toward the station. The scales on the dial are movable, and may be set so that (1) the relative bearing, (2) the magnetic bearing, or (3) the true bearing of the station is read directly. Figure 29 shows the indicator of an automatic direction finder.

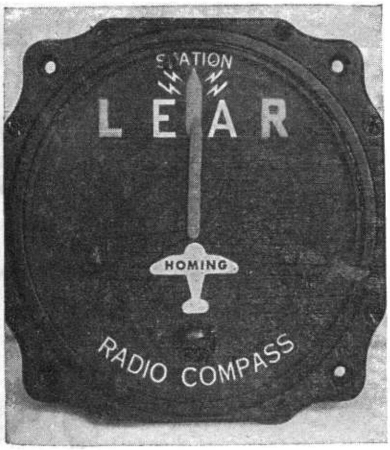

Figure 28.—Radio compass indicator.

The **radio altimeter** measures the actual height of the airplane above the ground level, rather than the height above sea level. It is also known as the "absolute altimeter," or "terrain clearance indicator." It is very accurate and offers many possibilities, but further development will probably be necessary before it becomes of interest to pilots of the smaller aircraft.

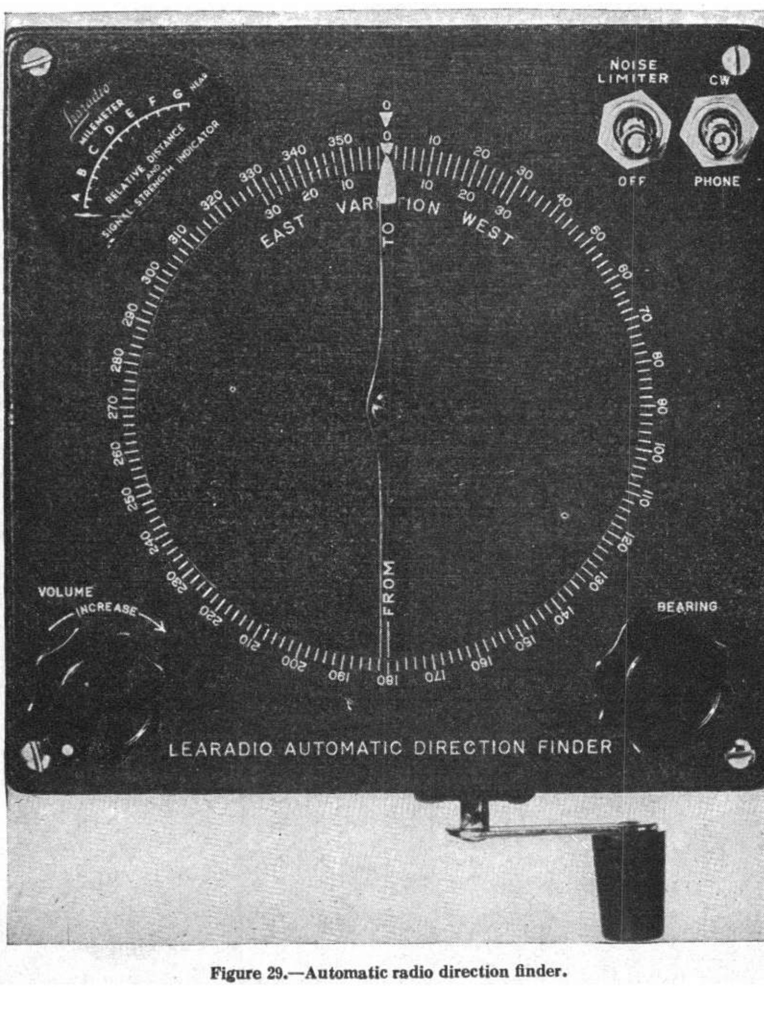

Figure 29.—Automatic radio direction finder.

QUESTIONS

1. Name the five fundamental navigation instruments.

2. To what errors is an altimeter subject? Explain the corrections to be applied.

3. What is meant by a "standard atmosphere?"

4. Under what conditions will an altimeter indicate altitudes higher than the true altitude? Altitudes lower than the true?

5. State the rule for the approximate altitude error.

6. What is meant by the "lag" of an altimeter?

7. Define pressure altitude.

8. How is a bank-and-turn indicator of importance in the use of the magnetic compass?

9. What is meant by deviation of the compass?

10. Does the deviation of the same compass ever change? Why?

11. Describe the method of compensating a compass.

12. What is meant by "swinging ship?"

13. Why should the engine be running, and lights and radio be on, while swinging ship?

14. How would you swing ship in flight?

15. Using a compass with deviations as shown in figure 22, what compass course should be flown in order to make good a magnetic course of 130°? 215°? 315°?

16. Define magnetic variation.

17. State the rule for the approximate error of the airspeed indicator per 1,000 feet of altitude.

18. Even if the indicated air speed is in error because of altitude, what important information does it afford?

19. Of what importance is a drift sight?

20. Discuss the value of a directional gyro in conjunction with the magnetic compass.

21. What accuracy may be expected of the gyro?

22. Of what value is radio to the pilot of a light airplane?

23. Distinguish between a radio compass, a radio direction finder, and an automatic radio direction finder.

Chapter IV.—CHART READING

DISTINCTIVE PROPERTIES OF CHARTS

The distinction usually made between maps and charts is that a chart is a representation of an area consisting chiefly of water; a map represents an area that is predominantly land. It is easy to see how this distinction arose, in the days when there was no navigation over land, but a truer distinction is that charts are specially designed for use in navigation, whether at sea or in the air.

Charts are intended not only to furnish an accurate representation of an area, but also to serve as a suitable base for the plotting of the problems of navigation in order to arrive at an accurate solution. The safety of life and property demands the greatest care and accuracy in all details.

In the preparation of maps definite conventions have developed, evaluating the relative importance of features to be mapped and the emphasis to be given each. On the aeronautical charts, items which would normally be included in any ordinary map are often omitted in order not to obscure details of greater importance to the navigator; other features are sometimes exaggerated beyond topographic justification, because of their landmark value.

The aeronautical charts include more than 25,000 miles of airways equipped with beacon lights, radio ranges, teletype service, weather reporting stations, and other related features. Over such an extensive system it is clear that many changes must occur: New airways are being established and old routes rebuilt for more efficient operation; aids are even being provided for the navigation of air routes across the oceans, and for the extension of routes into Alaska. Once the information on a chart has become obsolete, its further use is a definite hazard. The frequent correction of its charts, to show the changes in information as they occur, is a most important function of the Government, and is imperative for safety in all forms of air transportation.

THE IMPORTANCE OF CHART READING

An aeronautical chart, then, may be defined as a small-scale representation of a portion of the earth and its culture, presenting to the trained eye a description of the charted region more nearly perfect than could be obtained from the pages of a book. It depicts the landmarks and other information found of value by pilots long familiar with the region, and provides a base suitable for the solution of the problems of air navigation. Consequently, any time spent in learning to read and interpret its detailed information will be well repaid.

In charting the details of the terrain and the system of aids to navigation, many conventional symbols are employed. Some of these have been in use for many years, and their significance is generally understood; others have been adopted more recently and are of more specialized use, and therefore are not as well known. The following description of these symbols and their significance has been prepared as an aid to chart reading. It applies primarily to the sectional charts, since the scale of that series permits the charting of fairly complete information. On the smaller scale charts many details must be omitted, but with few exceptions those that can be included are shown by the same symbols.

The features shown on these charts may be divided into two groups:

1. **Topographic information** necessary to a clear and accurate representation of the region.

2. **Aeronautical data** and information of interest chiefly for air navigation.

The topographic features may in turn be subdivided into three groups:

a. Water, including streams, lakes, canals, swamps, and other bodies of water.

b. Culture, such as towns, cities, roads, railroads, and other works of man.

c. Relief, including mountains, hills, valleys, and other inequalities of the land surface.

TOPOGRAPHIC INFORMATION

WATER FEATURES

[See fig. 30]

Water features are represented on the aeronautical charts in blue, the smaller streams and canals by single blue lines, the larger streams and other bodies of water by blue tint within the solid blue lines outlining their extent.

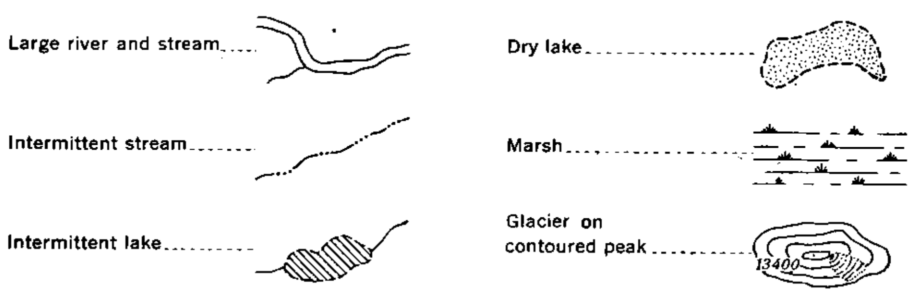

Figure 30.—Water features.

Intermittent streams are shown by a series of long dashes separated by groups of three dots, suggesting the scattered pools into which the diminished streams sink during the dry season.

Intermittent lakes and ponds are shown with broken shore line and cross ruling in blue.

In some sections of the country, the beds of dry lakes and ponds are conspicuous landmarks. Such features are indicated by brown dots within the broken "shore line" of blue.

Marsh areas are shown by horizontal blue lines, with scattered groups of short vertical dashes suggesting the clumps of marsh grass common in such areas.

Glaciers are indicated by blue shading, representing the form and the flow lines of the glacial area.

CULTURAL FEATURES

[See fig. 31]

Cultural features are generally indicated in black. Towns with a population of less than 1,000 are indicated by a conventional black circle. Towns having a population between 1,000 and 5,000 are shown by a yellow square outlined by purple, while the actual shapes of larger cities are shown in yellow within a purple outline.

Railroads are represented by fairly heavy black lines with crossties at 5-mile intervals, electric railways (trolleys) by lighter black lines with crossties at 2½-mile intervals.

Single-track railroads are shown with single crossties, while for railroads of two or more tracks the crossties are in pairs.

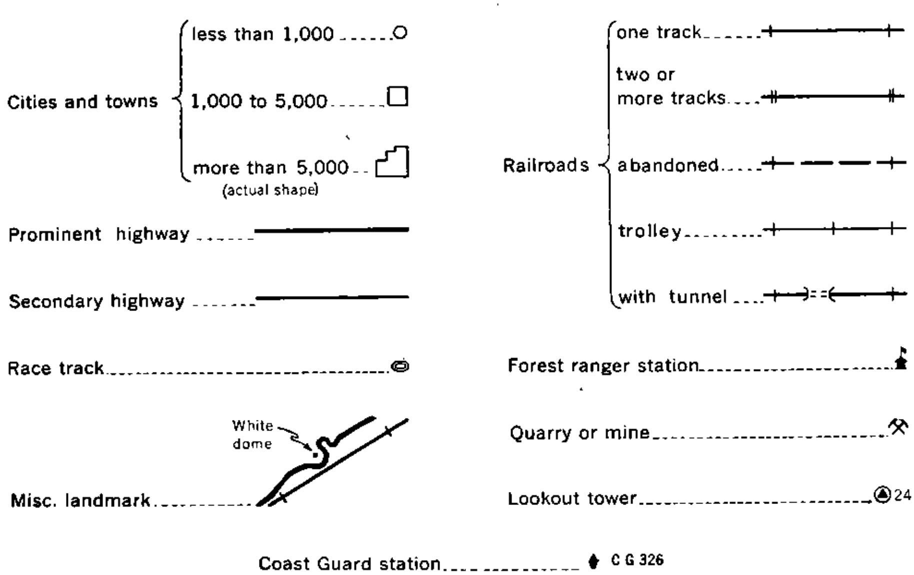

Figure 31.—Cultural features.

Even if a railroad has been abandoned or torn up, the old roadbed is sometimes a prominent feature when viewed from the air; when this is the case, it is indicated on the chart by a broken black line.

Tunnels are indicated not only because they serve as landmarks, but also because they are a source of potential danger. If a pilot is following a railroad through territory with which he is not familiar, and the railroad enters a tunnel, he may find himself suddenly deprived of the one landmark upon which he was relying, or even confronted by a mountainside, without sufficient space either to turn or to climb above it. This difficulty is seldom encountered in the case of highways, but any highway tunnels are shown by the same symbol.

Prominent highways are indicated by a heavy purple line, secondary highways by lighter lines in purple. The highway route number, centered within a shield, is shown at intervals along the principal Federal highways. In some states the main roads are air marked with the same numbers, as an aid to identification from the air. In a few instances, in sparsely settled country where there are few other landmarks, very poor roads are charted because of their unusual landmark value, and such roads are shown by a broken purple line (the conventional symbol for a trail).

"Prominent highways" and "secondary highways" must be understood as only relative terms. In some of the thinly settled western districts, roads are so few that practically all of them are shown; the most important through

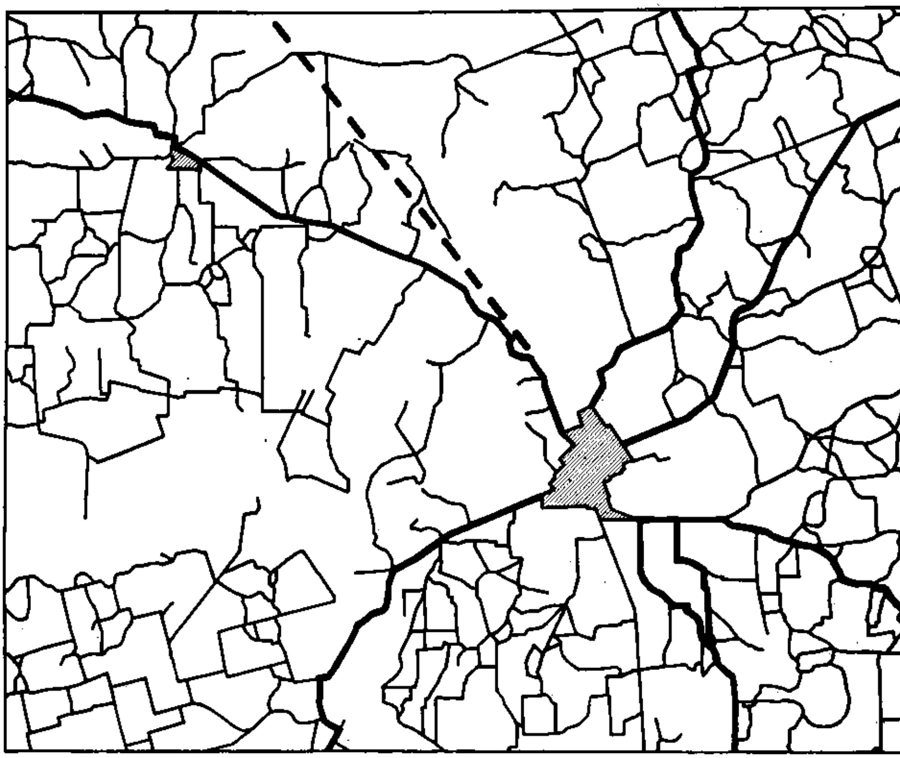

Figure 32.—Highways in vicinity of Navasota, Tex. (1912).

highway may be only a well-graded dirt or gravel road, yet it is so prominent in its own vicinity that it is charted with a heavy line. On the other hand, in the more thickly settled sections there are so many roads that it is impossible even to include all the highly improved roads.

For example, figure 32 shows all the roads in the vicinity of Navasota, Tex., according to a survey made in 1912. Only those shown by heavy lines were included on the Austin sectional chart; the road shown by a heavy broken line was constructed after the survey was made, and was added from later sources.

The treatment of highways, then, varies with the region under consideration, but in each case an attempt is made to delineate the distinctive road pattern as it would be seen from the air.

Race tracks are prominent landmarks, and whenever possible their characteristic oval shapes are indicated in black. In congested areas where the actual shape cannot be shown, the location is sometimes indicated by a heavy dot, and the words "Race track," or the letters "R. T." are printed in the nearest open space, with an arrow leading to the dot.

Lookout towers in the state and national forests are located on the highest ground in the vicinity, and are usually quite prominent. In some cases they have been air marked with a number, and these numbers appear on the chart adjacent to the symbols, in vertical black figures. Elevations of the ground at the towers are added in black italics.

Forest ranger stations are shown by small symbols suggestive of the ranger station and its flag.

A quarry, or a mine, is represented by a symbol suggesting the pick and hammer of the miner.

A Coast Guard station is indicated by a small black "boat," accompanied by the number with which it has been marked for identification from the air.

In addition to the foregoing, there are in many localities a number of unclassified distinctive landmarks which are of great assistance in identifying position. These are usually indicated on the sectional charts with a dot and descriptive note.

It should be understood that, even on the larger-scale charts, certain features must be exaggerated in size. For example, if a prominent highway is measured by the scale of statute miles on a sectional chart, the highway appears to be about an eighth of a mile, or 650 feet in width, but this exaggeration is necessary for the sake of clarity and emphasis. Again, in a narrow canyon it may be required to show a stream with a railroad on one side and a highway on the other. On the ground the three features may occupy a space no more than 75 feet in width, yet on the chart, showing the three symbols as close together as possible, they appear to occupy more than a third of a mile, or about 2,000 feet. In the case of water features, a small lake 300 feet wide and 2,000 feet long may be an outstanding landmark; at the actual scale of the chart 300 feet would be reduced to a fine single line; it must be exaggerated in width enough to show a small area of blue tint between two limiting shore lines of solid blue, and in length enough to preserve in a general way, at least, the shape of the lake. Whenever possible, symbols are centered on their true locations and exaggerated only as much as may be essential to a clear representation.

RELIEF

[See fig. 33]

Relief is shown by contour lines in brown, and is emphasized by a series of gradient tints ranging from green at sea level to a dark brown above 9,000 feet. On a few charts in the west, extensive areas below sea level are indicated by a faint purple tint.

Some prominent peaks, or steep cliffs, are also accentuated by hachuring, or shading, with the elevations in black italic figures.

Many other critical elevations—mountain passes and high points—are shown on the charts with a dot to designate the location. The elevations of a number of cities and towns are also shown.

A contour represents an imaginary line on the ground, every point of which is at the same height above sea level, and the varied curves of the contour show the ridges valleys, canyons, bluffs, and other details. With a little practice, one may read from the contours not only the elevations, but also the shape of the terrain, almost as easily as from a relief map and much more accurately.

Any contour is the intersection of an imaginary horizontal plane with the surface of the terrain. To illustrate, figure 34 represents a pile of sand from the

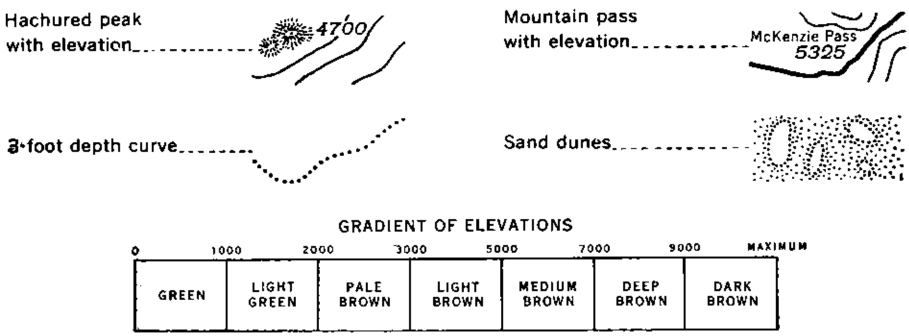

Figure 33.—Relief (elevation).

nearer side of which sand has been carried away until a "valley" has been formed. The top of the sand pile is 5 feet above the pavement, and an imaginary plane is passed through the pile at a height of 2 feet. In the lower part of the figure is shown the "contour," or the trace of the intersection of the plane with the sand. The trace of the lower edge of the pile of sand on the pavement may be considered as the "shore line," or the line of zero elevation.

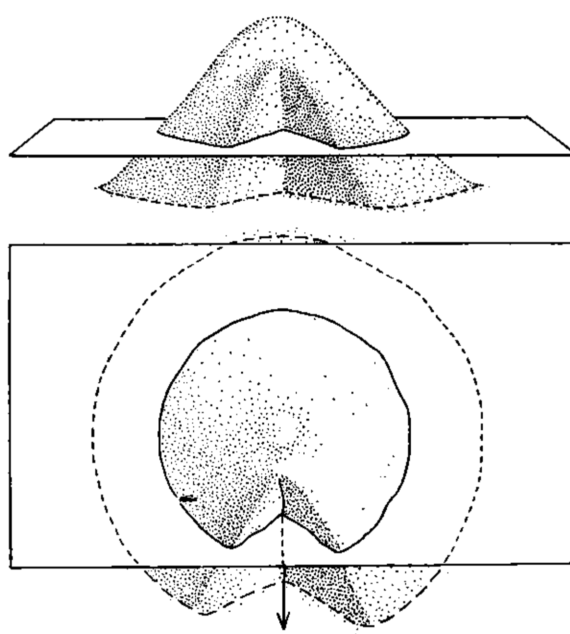

Figure 34.—Contours illustrated by a sand pile.

If it were raining, water would flow down the "valley" in the direction indicated by the arrow, which may be considered as a "stream." Thus, we see that when contours cross a stream they bend toward the source of the stream which is, of course, on higher ground; conversely, when crossing a ridge the contours bend away from the higher ground.

In figure 35 the curves at *V*, *V*, *V*, represent valleys of varying width and depth, while *R*, *R*, *R*, represent ridges or hills.

One way of visualizing more readily the significance of the contours is to think of them as successive shore lines if the sea should rise to the levels indicated by the respective contours. The line of the seacoast itself is a contour, every point thereon having the same elevation (zero) with respect to mean high water. Any valleys running down to the shore line are represented by a curve or indentation landward; any ridges result in a curve seaward (fig. 36). Now if the sea should rise 1,000 feet, the 1,000-foot contour would become the

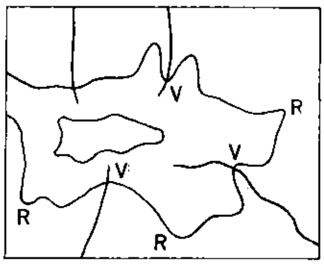

Figure 35.—Ridges and valleys shown by contours.

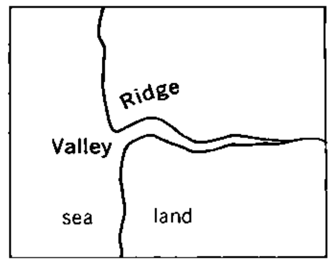

Figure 6.—The seashore as a contour.

shore line; valleys would still be indicated by a curve toward the higher ground (which could now be called "landward"), and ridges would be indicated by a curve toward the lower ground ("seaward").

If a cliff should rise almost vertically above the shore line for 1,000 feet, the 1,000-foot contour would appear on the chart very close to the shore.

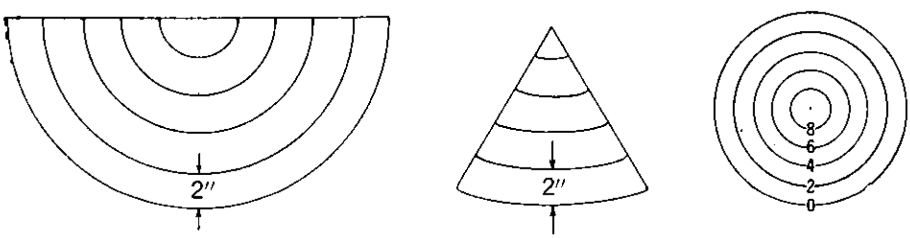

Figure 37.—Contours illustrated by a dunce cap.

When the terrain slopes gently upward from the coast, the 1,000-foot contour is a considerable distance inland. Thus, contour lines that are far apart on the chart indicate a gentle slope, while lines that are close together indicate a steep slope; contours that run together indicate a cliff. Many people believe that contours can never cross, but this would occur in the case of an overhanging cliff.

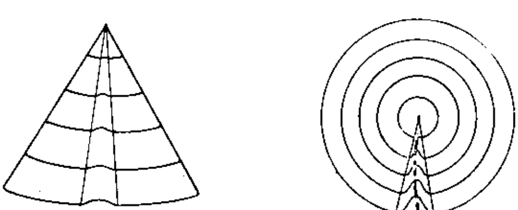

Figure 38.—The dunce cap with "valley" and "stream."

To clear up any confusion about contours, on a semicircular piece of paper draw a series of semicircles at intervals of about 2 inches, as illustrated at the left of figure 37. Now roll the paper into an ordinary "dunce cap," and pin it so it will not come undone. It will appear as in the center of the figure, with the horizontal lines representing contours having successive differences in elevation of about 2 inches.

If we set the dunce cap on the floor and look straight down upon it (which is the way the earth's surface is represented on a chart), the system of "contours" will appear as at the right of the same figure.

Now, if we crease a "valley" into one side of the dunce cap, the two views will appear as in figure 38. If this were a real valley, a stream would probably be flowing down it, as represented by the broken line. Note, again, that where contours cross the stream they bend toward the source of the stream, which is, of course, on higher ground. Where contours cross a ridge, the opposite is true, and they bend away from the higher ground.

The manner in which contours express elevation, form, and degree of slope is shown in figure 39. The sketch in the upper part of the figure represents a

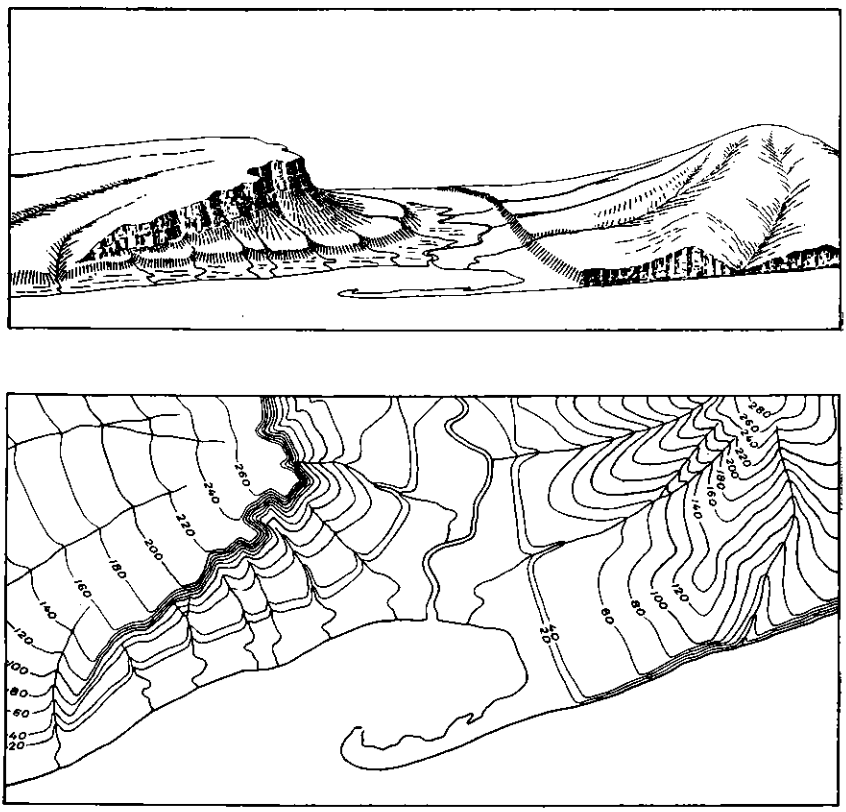

Figure 39.—Altitude, form, and slope expressed by contours.

river valley that lies between two hills. In the foreground is the sea, with a bay that is partly enclosed by a hooked sand bar. On each side of the valley is a terrace into which small streams have cut narrow gullies. The hill on the right has a rounded summit and gently sloping spurs separated by ravines. The spurs are cut-off sharply at their lower ends by a sea cliff. The hill at the left terminates abruptly at the valley in a steep and almost vertical bluff, from which it slopes gradually away and forms an inclined tableland that is traversed by a few shallow gullies. In the lower part of the figure, each of these features is represented, directly beneath its position in the sketch, by contour lines.

In figure 39 the contours represent successive differences in elevation of 20 feet—that is, the "contour interval" is 20 feet. For the sectional and regional aeronautical charts a contour interval of 1,000 feet [1] has been adopted.

[1] On a few of the charts, because of unusual local conditions, intermediate contours at 500-foot intervals are shown.

In order to maintain a safe flying altitude, unless the elevation of the top of a ridge or peak is given in figures, it should be assumed that the elevation is a full thousand feet above the highest contour shown. For example, the highest charted contour along a ridge may be only 2,000 feet, yet the ridge may be topped by minor summits rising to 2,800 feet or more. Assuming trees approximately 100 feet in height, the extreme elevation of the ridge may be almost 3,000 feet, yet the information available to the cartographer does not warrant the addition of the 3,000-foot contour. It should be noted that the gradient tint used in this case, pale brown (see fig. 33), indicates not merely an elevation of 2,000 feet, but includes any elevation short of 3,000 feet. Unless absolutely certain of their position, whenever visibility is poor, pilots should be careful to fly at a safe margin above the highest ground in the entire region.

The 3-foot depth curve, in water areas (fig. 33), may be thought of as an under-water contour, and every point along the curve is 3 feet below low water. It is shown by a row of black dots, and serves as a sort of danger line within which seaplanes should not attempt to land. Three feet of water is not sufficient for large flying boats, and on new editions the 3-foot curve is being replaced by a 6-foot curve.

Sand and sand dunes are indicated by brown dots (fig. 33).

All the foregoing features are combined by the cartographer in such a manner as to reproduce the characteristic details of the region accurately, but without confusion. Then to this basic topographic representation are added those features of special interest for air navigation.

AERONAUTICAL DATA

DATE OF INFORMATION

Aeronautical information and features of interest chiefly for air navigation—such as airports, beacon lights, radio ranges, radio call letters, and identification signals—are ordinarily shown in red.[2] These data are subject to constant change, and it is well to remember that charts are safe only as long as their data are correct. The elimination of certain airports, with changes in beacon lights or radio aids to navigation, makes the use of an obsolete chart as dangerous in the air as at sea. For this reason, new editions are frequently printed, showing the latest information available, with the date of the edition printed in red in the lower left corner of each chart.

The same date also appears in small red italic figures, immediately under the black border in the same corner, this being known as the "print date." When the chart is printed again, if only minor changes are made the edition date (in large type) is not changed, but a second print date is added, and so on. The aeronautical information may therefore be considered as corrected for reports received to the latest print date indicated. Whenever an extensive revision is made, all previous dates are removed, and a "new edition" is issued, with new edition date and new print date. The pilot's own interests and the safety of the public make it imperative that obsolete charts be discarded and replaced by new editions as they are issued.

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[2] On the radio direction-finding charts these features have been shown in black, but are being changed to red in future editions for greater legibility, and to avoid confusion.

At principal airports and other carefully selected centers, the Coast and Geodetic Survey has appointed recognized dealers in aeronautical charts, who have contracted to stock the most recent editions. Such dealers are required to display a printed "List of Latest Editions," which may be used as a check list to insure that only the latest available charts are used. A copy of this list may also be obtained from the Director, United States Coast and Geodetic Survey, Washington, D. C., on request.

Airport and airway changes subsequent to the date of printing are listed in the WEEKLY NOTICE TO AIRMEN which is posted at the principal airports. A pilot should note such changes on his own copies of the charts affected. Even then, whenever possible, he should obtain local information as to continued availability of facilities shown upon the chart. Notice of the issuance of new charts is carried in the CIVIL AERONAUTICS JOURNAL, which is published twice a month by the Civil Aeronautics Administration at $1 a year.

AIRPORTS

[See fig. 40]

Airports are classified as to their operation (whether commercial, municipal, Army, etc.), and are shown in accordance with the accompanying legend (fig. 40). It is important to consider the classification of a field before landing, as frequently civilians cannot obtain supplies or service at an Army or Navy field.

In the absence of other suitable airports, the intermediate fields of the Civil Aeronautics Administration are established at intervals of about 50 miles.

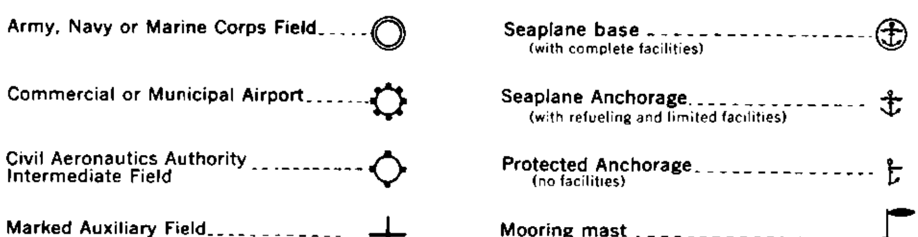

Figure 40.—Airport classification.

They are intended primarily for emergency use, but are also available for noncommercial flying activities; under certain conditions they are even available for occasional commercial use.

Under a program jointly sponsored by the Civil Aeronautics Administration and the National Youth Administration, approximately 300 seaplane bases have now been established, providing for practical and economical seaplane operations from coast to coast, and from border to border.

With the growth of international air traffic, information regarding airports of entry (customs airports) is becoming increasingly important. Accordingly, when an airport has been designated as a port of entry, this fact is noted near the airport name. A complete list of airports of entry is included in the Appendix.

Elevations of airports above sea level are indicated by inclined numerals adjacent to the airport.

The Letters *LF* adjacent to an airport symbol indicate that the field is equipped with lighting facilities for landing at night. Sometimes these facilities are operated only at certain hours, or on request. The same is true of certain other beacon lights and aids, and for complete information on these points pilots should refer to Civil Aeronautics Bulletin No. 11, or obtain local information.

OTHER AERONAUTICAL DATA (MISCELLANEOUS)

[See fig. 41]

A rotating beacon is indicated by a star with open center. Arrows in conjunction with the beacon symbol indicate that the beacon is equipped with course lights, and show the direction in which they are pointed. Course lights

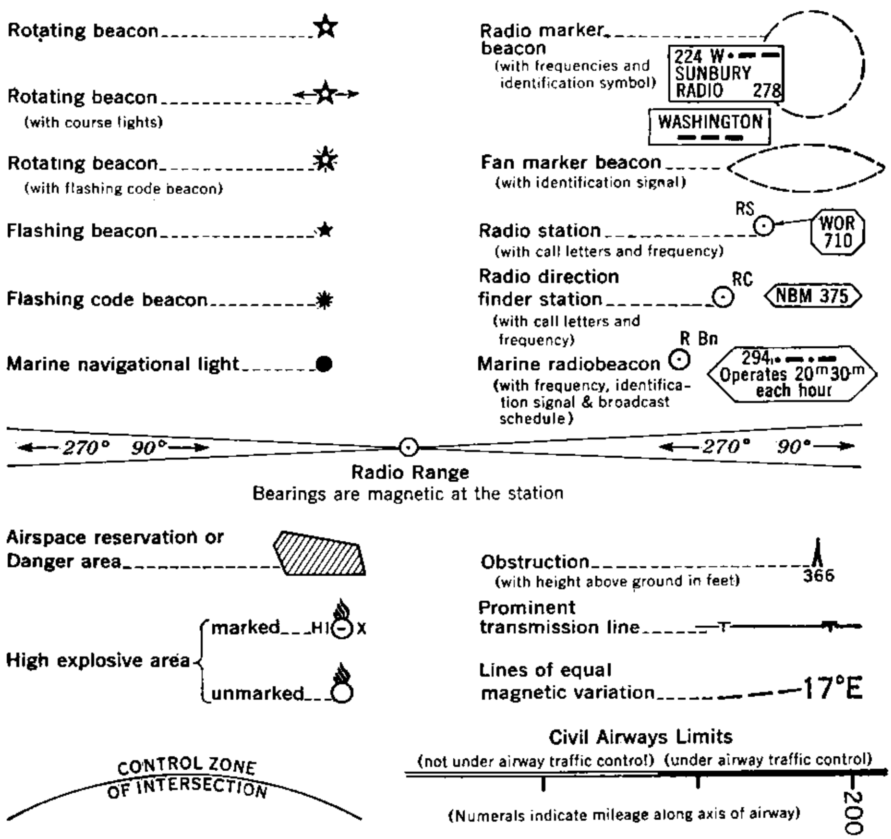

Figure 41.—Aeronautical data (miscellaneous).

are aviation green in color when adjacent to a lighted field; aviation yellow when adjacent to a day field (unlighted); and red when there is no field nearby. Beside the beacon symbol are placed the number of the beacon, and the corresponding code signal which is flashed by the course lights for identification at night. When there is a power shed at the beacon, the site number is also painted on the shed roof for daylight identification. (See fig. 2.)

The number of any intermediate field or beacon is obtained by dropping the final digit of the mileage from the origin of the airway on which it is located. For example, beacon No. 19 on any airway is approximately 190 miles from the origin of the airway. The course lights flash the code for only the last figure of the beacon number, the code signals being the same for beacons numbered 9, 19, 29, etc. Beacons having the same signal are approximately 100 miles apart, and a pilot should know on which 100-mile section of the airway he is flying. For convenient identification, the code used along the airways is shown in table 7, page 231.

At some places the rotating beacon is supplemented by an auxiliary beacon which flashes an identifying code signal. In this case, rays are added to the rotating beacon symbol and the code signal flashed by the auxiliary beacon is placed nearby.

A flashing beacon, or other nonrotating beacon, is indicated by a solid star, smaller than the rotating beacon symbol; for a beacon flashing in code, rays are added around the star.

If an airport is equipped with beacon light, the proper beacon symbol is placed in the center of the airport symbol.

A light for marine navigation is shown by a large dot. It should be noted that a powerful light of this kind is often inconspicuous from the air, because its light is directed along the surface, for the benefit of surface navigation.

A landmark beacon, operated by private interests or by a commercial establishment for advertising purposes as well as for the benefit of airmen, is represented by the proper beacon symbol (rotating or flashing), as described above. As a rule these beacons are located neither on an established air route nor at an airport, but they serve to identify a point from which a pilot may proceed to his destination. A rotating landmark beacon [3] usually rotates at two revolutions per minute, in order to distinguish it from an airway beacon, which makes six revolutions per minute. An arrow in conjunction with this symbol indicates that the beacon is equipped with a course light; on the chart the arrow is placed so that it points to the airport toward which the course light is directed.

Air space reservations and danger areas are indicated by prominent cross ruling and appropriate notes. The former have been designated by Executive order, and may not be flown over at any altitude. Danger areas are shown by request of the Army and Navy. They should never be flown over at altitudes below 5,000 feet, and preferably not at any altitude.

High explosive areas should not be flown over except at such altitude as to permit landing outside the area in case of complete power failure—in no case less than 1,000 feet above the ground. "Marked" areas are ground-marked with the same symbol used on the charts.

Flying is also prohibited in other limited areas for special reasons—for example, in the vicinity of the White House and Capitol, in Washington. In such localities the charts are already too congested to indicate the restricted area, and pilots should keep informed of such matters through the CIVIL AERONAUTICS JOURNAL, WEEKLY NOTICE TO AIRMEN, Civil Air Regulations, and through local sources.

Isolated obstructions are shown as indicated in the figure, together with numerals indicating the height of the obstruction above the ground, in feet. The center of the symbol marks the location of the obstruction.

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[3] Formerly this feature was indicated by a heavy asterisk, and is still so represented on some of the charts.

Prominent transmission lines are shown by a symbol representing the poles or towers, with wires between. These lines may be considered either as landmarks or as obstructions, and because of their importance to air traffic they are shown in red. Usually, only steel tower lines are shown on the aeronautical charts, but occasionally pole lines are shown, if they are particularly prominent when viewed from the air.

A radio range station is indicated by a dot within a small circle, and the positions of the range courses are shown by a pink tint. Magnetic bearings

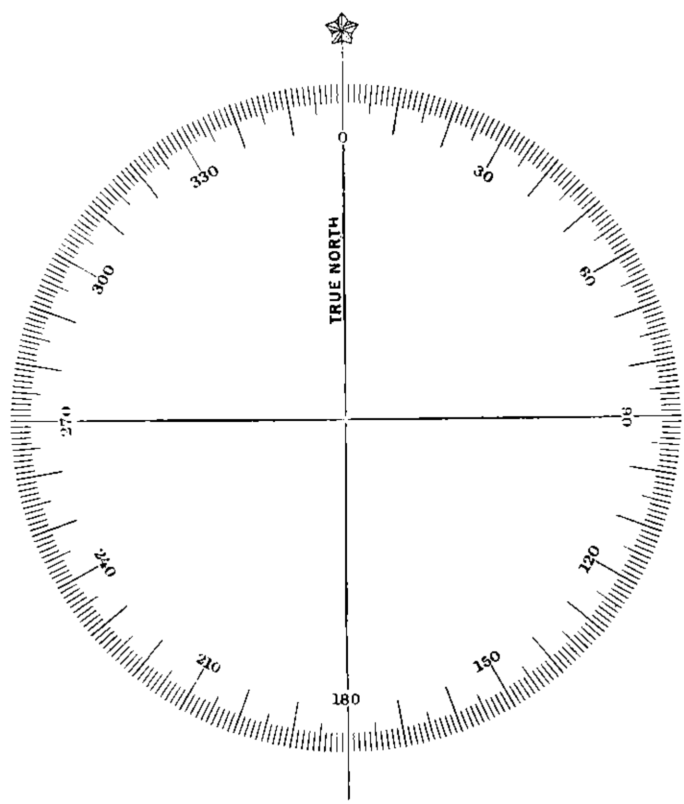


Figure 42.—True compass rose (sectional and regional charts).

toward or away from the station are indicated, and the *A* and *N* quadrants of the system are marked at intervals along the range courses, to avoid any confusion as to quadrant designation. The method of flying the radio ranges is treated in detail in a later section.

A radio marker beacon is indicated by a broken circle around the location of the station, the diameter of the circle representing the normal range of the beacon. The fan-type marker beacons are shown by a broken ellipse, suggesting the space pattern and also the range of these stations.

Weather broadcast schedules, as well as the names, identifying signals, and frequencies of the various radio stations, are shown adjacent to the stations to which they apply. For aeronautical radio stations the data are shown within a rectangle; for other radio stations the corners of the rectangle are cut off.

A number of commercial broadcasting stations are shown on the charts. Originally, they were included chiefly because they were dangerous as obstructions; with the development of the aircraft radio compass and direction finder, however, these stations have also become of navigational importance. Radio stations suitable for this purpose are shown by the conventional circle-and-dot symbol, the initials *RS*, the frequency, and call letters. Stations operating at less than 500 watts are not charted. For stations with power between 500 and 1,000 watts, the power is indicated on the chart as some guide to the distance at which satisfactory reception may be expected. For stations of 1 kilowatt or more, the power is omitted.

Radio direction finder stations are seldom used by aircraft today; however, these stations are indicated by a circle-and-dot symbol and the initials *RC* (from their former designation as "Radio Compass" stations). Marine radio beacon stations are indicated by the same symbol and the initials *R Bn*.

Places at which the magnetic variation is the same in direction and magnitude, are connected on the charts by broken lines known as lines of equal magnetic variation, or isogonic lines. The amount and direction of variation are also shown. In some areas unusual magnetic variation exists, and a warning note to that effect is printed in red in the area affected.

Compass roses (fig. 42), oriented to true north, are printed on the sectional and regional charts. If a protractor is not available, these roses may be used for the approximate measurement of courses and bearings. Because of the convergence of meridians in the Lambert projection, some inaccuracy is introduced if a compass rose is used for the measurement of direction at a point more than 1° or 2° of longitude away. Therefore, compass roses are printed at intervals sufficiently close that courses may be measured from them with practical accuracy, and one is usually available no matter how the chart is folded. On some charts, the direction and amount of magnetic variation are indicated on the compass roses, in addition to their representation by isogonic lines.

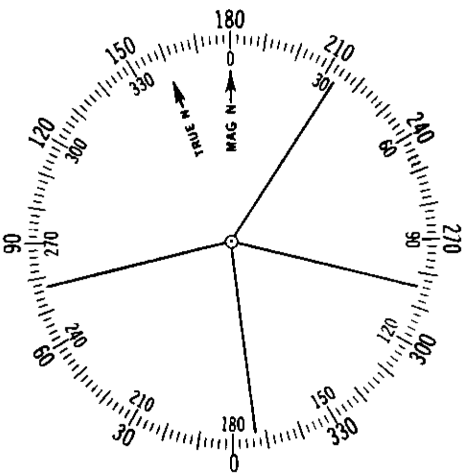


Figure 43.—Magnetic compass rose (radio direction finding charts).

Specially designed compass roses (fig. 43), oriented to magnetic north, are used on the radio direction finding charts. These roses are graduated to read both from magnetic south and from magnetic north. The outer figures are ordinarily used, and are therefore larger; they are intended for use in plotting reciprocal bearings (the radio compass bearing observed at the airplane plus or minus 180°), and for that reason read from 0 at magnetic south. For certain other problems a rose reading from 0 at magnetic north is more convenient, and for such problems the inner (smaller) figures are also available. These roses should not be confused with the conventional compass roses appearing on the sectional and regional charts, nor used in the same manner; their special use is explained in detail in a later section.

CIVIL AIRWAYS

[See fig. 41

A civil airway has been defined as "a route in the navigable airspace designated as a route suitable for interstate or foreign air commerce and includes the airspace located vertically above an area on the horizontal plane contained within lines encircling each terminal airport, and other intermediate points, specified on such airway within a radius of 10 miles from the center of such airport or other specified intermediate point and also contained within two parallel lines located 10 miles from the center line connecting the terminal airports by way of each intermediate point specified to designate the route of such airway."

In more general terms it may be defined as a strip of land, together with the navigable airspace above it, 10 miles on either side of the center line connecting the terminals and intermediate points of the airway, and extending 10 miles in all directions beyond the terminal airports.

A civil airway also includes the aids to navigation described above and other facilities which have been constructed along it: Rotating beacons at intervals of about 15 miles; intermediate fields at 50-mile intervals; radio range and broadcast stations; teletype communications; hundreds of weather reporting stations; and airway traffic control centers.

An airway traffic control center is operated by the Civil Aeronautics Administration for the control of traffic on the civil airways.

An airport control tower is operated by the local airport management for the control of traffic in the immediate vicinity of the airport. The designation and frequency of the airport radio station are shown near the airport symbol, to facilitate calling the control tower. A number of airports have been designated by the Administrator of Civil Aeronautics as "control airports," and traffic within a radius of 3 miles of such airports is subject to the local airport control tower. If a radio range station designed to direct traffic to the control airport is more than 3 miles distant, then the control zone is extended over an area one-half mile on either side of a line from the airport to the radio range station.

The airport control tower should not be confused with the airway traffic control center of the Civil Aeronautics Administration. It is the function of the latter to keep continual check on the flight plans and movements of all aircraft on the airways under its control; to avoid any possibility of collision; and to bring the aircraft safely and expeditiously to the point where they can be turned over to the airport control tower for actual landing instructions.

At the present time not all the airways are under the control of a traffic control center, although it is expected that this control will have been extended to all Federal airways during 1941. On the aeronautical charts the limits of the civil airways are shown. Airways under control of a traffic control center are outlined by a heavy red line; airways not so controlled are outlined in red by a fine double line.

On some of the regional charts, the limits of the civil airways have been subdivided into 10-mile intervals, as measured along the center line of the airway. Sometimes, at sharp bends in an airway, some of the subdivisions are omitted in order to avoid confusion. Under these conditions, the mileage is indicated at the first subdivision beyond the bend. These 10-mile intervals are being added to the remaining charts as opportunity is afforded.

In areas not at present served by a traffic control center, "control zones of intersection" have been established at the intersections of principal airways. These zones are of 25-mile radius, usually centered at a radio range station, the intersection of two range courses, or other such designated point. Except in contact flying, pilots may not enter a control zone of intersection without permission from the local airway communication station. Within the control zone, traffic rules very similar to those on the controlled airways are in effect. The limits of such a zone are indicated on the chart by a red circle and appropriate note.

Certain restrictions regarding flying within these zones, and on the civil airways themselves, have been made necessary to promote safety in flying. These have been published in the Regulations, a special digest of which has been prepared by the Civil Aeronautics Administration (Civil Aeronautics Bulletin No. 22).

PROJECTION AND SCALES

All aeronautical charts of the United States Coast and Geodetic Survey [4] are on the Lambert conformal projection. In this projection, it has already been pointed out that variations in scale are extremely small; therefore, in the borders of these charts there are conveniently graduated scales of statute miles by means of which distances may be scaled anywhere on the chart with a high degree of accuracy.

There are slight variations in scale between adjacent charts to the north or south, as may be seen from the scale of statute miles on chart No. 3060b; however, as already stated, this difference in scale is so slight as to be negligible in practice. The scale of miles appearing on any particular chart is the average scale for that chart, but it could be used even on the adjoining charts with very satisfactory results.

The expressions 1:500,000 and 1:1,000,000, used to denote the scale of a chart, are read as "one to five hundred thousand" and "one to one million." They represent the proportion existing between the chart and the portion of the earth represented thereon. Thus, in the first case, 1 inch on the chart represents 500,000 inches on the ground; similarly, any other unit, as 1 foot, 1 yard, or 1 centimeter, represents 500,000 of the same units on the ground. Such a proportion is sometimes written as a fraction, as $1/500,000$, and is occasionally referred to as the fractional scale, or representative fraction of the chart to which it applies.

In the margins of some of the sectional charts (1:500,000) there are scales subdivided into minutes of latitude, and into minutes of longitude. These scales are convenient for plotting points when their geographic coordinates (latitude and longitude) are known, or for determining the geographic coordinates of points from their positions on the charts. On many charts these scales have been omitted, and the meridians and parallels are subdivided into minutes of latitude and longitude. Eventually all charts will be changed to this form.

[4] Except the Great-circle Chart (No. 3074), and the magnetic chart (No. 3077).

Entirely around each of the regional charts (1:1,000,000) are border scales subdivided into minutes of latitude and longitude. Meridians and parallels are drawn across the entire chart at intervals of 30 minutes each way; those representing whole degrees are subdivided into minutes. Any point to be plotted will never be very far from one of the meridians and parallels and in many cases it can be plotted with sufficient accuracy by referring to the subdivided lines and estimating by eye the distance from the nearest meridian and parallel.[5]

To illustrate the plotting of points, the following examples are given:

Example 1.—In Notices to Airmen there is reported the erection of a high radio tower which is considered an obstruction to air navigation. The position of the tower is given as latitude 47°04′.5, longitude 120°38′.

Required: To plot the position of the tower on the Seattle sectional chart (pl. I).

By means of the graduated meridians showing minutes of latitude, on the adjacent meridians (120°30′ and 121°) lay off northward from latitude 47° a distance equal to 4.5 minutes of latitude and draw a straight line through the points so obtained. This line represents the latitude of the radio station.

Lay off along the graduated parallels of latitude (46°30′ and 47°30′) a distance of 8 minutes, westward from longitude 120°30′, and draw a straight line between the points so obtained. This line represents the longitude of the radio station (120°30′+8′=120°38′), and its intersection with the line representing the latitude is the position of the tower.

Example 2.—After an extended period of flying above fog, it is desired to check the position of an airplane by celestial observations, and the latitude and longitude of the dead reckoning position are required.

On the regional charts (pl. II) the meridians and parallels corresponding to whole degrees are subdivided into minutes of latitude and longitude. It is therefore necessary only to draw a north-and-south line through the dead reckoning position to the nearest subdivided parallel and read the longitude, while a straight line east and west permits reading the latitude from the nearest subdivided meridian. The slight curvature of the parallel within the limits of 1° is entirely negligible for all practical purposes.

As already stated, if a scale of nautical miles should be desired, the scale of minutes of latitude—that is, the subdivisions along the meridians—will serve, since a minute of latitude may be considered as a nautical mile for all practical purposes.

THE FLIGHT CHECK

The last and not the least important step in the preparation of the sectional charts is known as the "flight check." The entire area covered by a new chart (or by the new drawing for a new edition of an old chart) is inspected from the air by a trained observer, and the details of the chart are compared with the details seen on the ground below. Numerous corrections and improvements are made in this way, especially in areas where only poor source material is available. Also, many distinctive landmarks, which are of great value in identifying position, are added to the charts from the flight check notes.

In order to keep pace with new construction in the charted areas and to keep the charts of maximum usefulness to pilots, the program calls for new flight checks of all charts at intervals of 3 or 4 years. These flight checks also provide the means for testing new instruments and new methods of air naviga-

[5] On early charts of this series the projection interval was 15 minutes each way; some have not yet been changed to the 30-minute interval.

tion, providing in this way a real contribution to the advancement of practical air navigation.

QUESTIONS

1. What are some of the distinguishing characteristics of a chart?

2. Name the various types of information to be found on an aeronautical chart.

3. What is meant by culture? topography?

4. How is relief indicated on aeronautical charts?

5. Discuss the relative importance of highways on aeronautical charts.

6. What is a contour?

7. On plate I, point out the following:
(*a*) At least three instances of exaggeration of scale.
(*b*) Contours which indicate a valley, but in which no stream is shown.
(*c*) A steep slope.
(*d*) A gradual ascent.

8. What is meant by the contour interval?

9. From the information on plate I, arrange the following cities in order of population: Easton; Wenatchee; Yakima; Ellensburg.

10. What is the highest elevation between Mount Rainier and Yakima?

11. Estimate the elevation of Ellensburg; Cle Elum; Tieton Reservoir.

12. What is the significance of the blue shading on Mount Rainier?

13. How can one tell the date of the aeronautical information on a chart?

14. From what sources might a pilot learn of any corrections that should be made to his chart?

15. How might he tell if there is a later edition of an aeronautical chart?

16. Is seaplane operation over land areas safe or practicable?

17. Referring to plate I again, if a pilot were flying from some point in Canada to the Seattle-Tacoma area, at what airport should he land?

18. What is the difference between an air space reservation and a danger area?

19. In general terms, define a civil airway.

20. Distinguish between an airway traffic control center and an airport control tower, and state the functions of each.

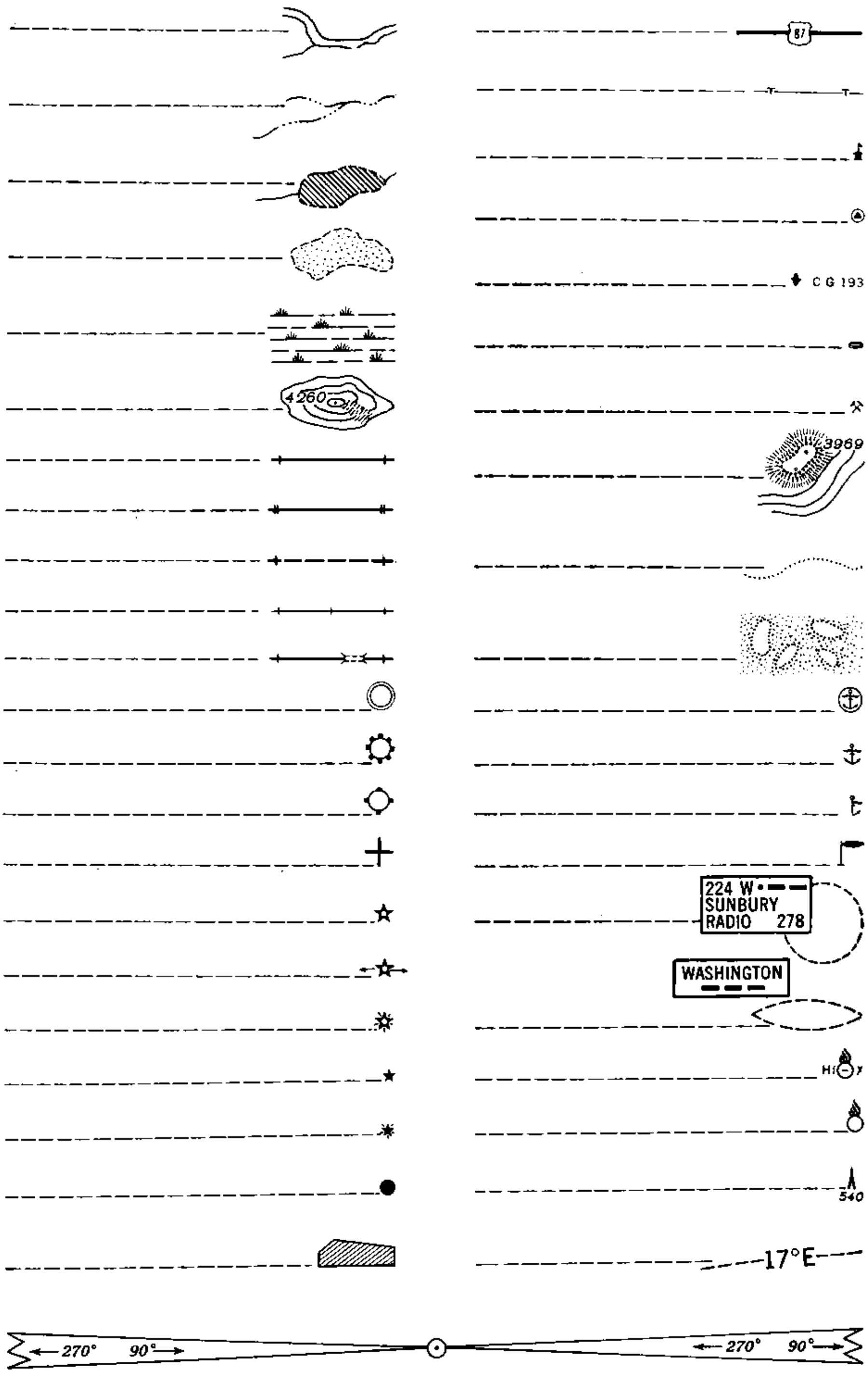
21. What is meant by a control zone of intersection?

22. What is meant by the phrase 1 : 1,000,000, as an expression of scale?

23. On plate I, scale the distance between Boeing Field (Seattle), and Yakima Airport; between Yakima Airport and Fancher Airport (Wenatchee).

24. What is meant by a flight check? Select, from plate I, landmarks that were probably added from this source.

25. Write in the blank spaces below what each of the symbols following represents.



Chapter V.—CROSS-COUNTRY FLYING—PILOTING

PROCEDURE

Air navigation is a subject to which much study can be given, but ordinary cross-country flying may be satisfactorily accomplished over land areas and in clear weather, by very simple methods. If the pilot has a thorough knowledge of chart reading, few instruments will be required other than reliable charts of the route to be flown; the use of a compass is highly desirable (see p. 57), but is not absolutely essential.

When flying between points on the same aeronautical chart, the following steps are necessary for this type of flying:

1. Draw a straight line on the chart between the points in question.
2. Make a careful study of the intervening country, in order to decide whether to fly the direct route, or whether some detour may be desirable in order to avoid flying over large bodies of water, mountains, or other hazardous terrain.
3. Note any characteristic landmarks along the route (such as prominent hills, or the pattern of stream, railroad, and highway crossings).
4. Shape the course in the air with reference to the landmarks noted.

Obviously, there are other factors to be taken into consideration: the route must be laid out so that a field with refueling facilities is available within the safe cruising radius of the plane, even allowing for unexpected head winds; it should also be laid out to take advantage of established airways and intervening airports for emergency landings; weather conditions along the route and at the destination, as well as at the starting point, must be taken into account; the time required for the trip must be checked against the number of hours of daylight yet remaining; and, of course, the air traffic rules pertaining to contact flying must be observed at all times. These factors, however, have to do with the safe operation of the airplane, while the four steps noted above deal with flying from place to place by reference to visible landmarks which can be identified on the chart.

Flying an airplane from one place to another solely by reference to visible landmarks is known as **piloting.** It is also known as pilotage, although this is a less desirable term, since it is sometimes used with a very different meaning.

LANDMARKS

The cultural features of the terrain constitute a most important class of landmarks. For example (pl. I), compare the distinctive pattern of railroads and highways at Yakima, with that at Ellensburg. Similarly, the pattern of roads, railroads, and other cultural features gives to each locality its own distinguishing marks.

Many other distinctive landmarks have been included on the sectional charts as an aid to identifying ground position. Referring again to plate I, note the race track at Yakima; the athletic field at Eatonville (about 25 miles south-southeast of Tacoma); the flume west of the Nisqually River (southwest of Eatonville); the powerhouse at La Grande; the race track at Puyallup (east of Tacoma); the silver water tank east of the southern part of Seattle; and many others.

Often a combination of landmarks affords a most definite identification. For example, it may be noted on the chart that there is a grain elevator at a certain town. If there are also grain elevators at a number of other towns in the same vicinity this fact loses any significance. But if it can be seen from the chart that the town has a grain elevator, is on a double-track railroad, and is near the fork of a river, this combination of landmarks is not likely to be duplicated within a hundred miles, and identification is quick and positive.

Intermediate fields and most of the beacons of the Civil Aeronautics Administration are air marked with their site numbers, to facilitate their use in landmark flying by day; however, beacon sites are of necessity so small that from any considerable altitude they are often very inconspicuous.

The topographic features are frequently of outstanding importance in flying a course by landmarks. For example, in flying from Winchester, Va., to Washington, D. C., it is only necessary to head the airplane for the prominent notch in the Blue Ridge Mountains toward the east; Washington may be reached by continuing on approximately the same course after passing the notch. This notch is apparent on the sectional chart because of the highway passing through it, and also because of the diminished width of the contoured ridge at that point. Other typical and better known landmarks of this kind are the Delaware Water Gap, Stone Mountain, El Capitan, Sugarloaf Mountain, and so on. Such features may be readily selected from the chart by pilots experienced in chart reading and the interpretation of relief.

Landmark flying is so generally understood and practiced that it is scarcely necessary to give an example; however, suppose that it is desired to fly from Yakima Airport to Fancher Airport, at Wenatchee (pl. I). After taking off from Yakima and gaining the desired altitude, the edge of the city is circled until the Yakima River and the railroad track and highway running northward along it are picked up. These are followed to a point north of Roza; from this point the railroad and river are kept on the left, and a heading slightly to the east of north is followed, over the 3,000-foot ridge, along the irrigation canals, and across the railroad slightly east of Kittitas. The same general heading is followed along the stream in a northerly direction from Kittitas until the second-class highway leading to the Columbia River is seen; the highway is then followed until the full sweep of the Columbia River is in view when the airplane is headed directly for Wenatchee, and Fancher Airport is found northeast of the city, between the first- and second-class highways.

As a further exercise in chart reading, determine the highest surface elevation to be crossed on this flight, and note any additional landmarks.

This flight also illustrates another very desirable situation in landmark flying. If at any time the pilot had become confused as to his position, and the expected landmarks had failed to appear, he needed only to head toward the east, and after a short interval he could have been certain of sighting the Columbia River. Often a flight can be planned so that some continuous landmark (a highway, a railroad, a pipe line, or river) lies well to one side of the route. If the need arises, a pilot can always be sure of finding this landmark, and from it set a new course for his destination.

At other times the flight can be planned so that the route lies between two converging highways, two railroads, or combination of other landmarks, thus making certain that some definite landmark can always be found.

FLYING A RANGE

In order to keep on the desired route, it is a good practice whenever possible to select two landmarks ahead, which are known to be on the course, and fly the airplane so as to keep the two objects in line. This is known as flying a range. Before the first of the two landmarks is reached, another more distant object in line with them should be selected and a second range flown.

To illustrate the use of ranges, under conditions of good visibility and ceiling, suppose that a flight is planned from Yakima Airport to Boeing Field, at Seattle (pl. I). The route to be followed may be visualized by drawing on plate I a straight line from the town of Weikel (about 8 miles northwest of Yakima Airport) along the road following the Naches River valley to the end of the railroad spur from Lester; a second straight line from Lester along the Northern Pacific Railroad to the junction at Palmer; and thence to Boeing Field.

After taking off, the airport is circled until the desired altitude is reached; the airplane is then headed toward the northwest until the town of Weikel (a very small town) is sighted, just beyond the turn of the railroad. The section of railroad from Weikel to Tieton, and the Naches River and highway, lie directly along the plotted route, and they are therefore followed throughout. The same general heading is continued upstream and over the top of the ridge to the railroad.

From Lester to Palmer, the railroad itself again furnishes the best series of ranges. From Palmer the following points are lined up in turn to furnish a series of ranges: Palmer and Ravensdale; Ravensdale and Maple Valley; Maple Valley and the ponds northeast of Swan Lake; the ponds and the silver water tank; the water tank and Renton; and Renton and Boeing Field.

If desired, a table (see following page) listing landmarks and other data which may be obtained from a sectional chart, can be prepared for any given route.

Sometimes the selection of a range is very easy, as in the preceding example, when a road, railroad, or river parallels the route; at other times, the selection of a continuous series of ranges may prove difficult; for this reason, and also as an added factor of safety, it is desirable to refer to the magnetic compass as well. For this purpose we need not be concerned with magnetic variation, compass deviation, or wind drift; it is only necessary, while flying a range that is definitely known to lie along the route, to note the compass heading. This heading is the correct course to fly, and it should be maintained until another range is available. Then if the compass heading is compared again, any change in magnetic variation or wind conditions will be taken care of in the new compass heading noted.

Yakima Airport to Boeing Field (Seattle)

Landmarks	Location with respect to route	Distance from Yakima	Estimated flying time [1]	
		Miles	*Hour*	*Minutes*
Weikel	On route	8		6
Tieton	On route; end of railroad	13		10
Tieton River	Crossing; junction with Naches River 1 mile east.	16		13
Naches River and highway	On route	22–39		18–31
Top of ridge		54		43
End of railroad spur to Lester	On route	58		46
Lester	On route	64		51
Railroad, Lester to Palmer	On route	85	1	08
Maple Valley	On route	95	1	16
3 Ponds	On route	98	1	18
Renton	On route	104	1	23
Boeing Field	On route; east of river	110	1	28

[1] Flying time estimated by computer (pp. 139 to 145), or from fig. 100, using known cruising speed of 90 m. p. h. minus reported head wind of 15 m. p. h. or 75 m. p. h.

For example, on the flight from Yakima to Seattle described above, while flying the railroad from Weikel to Tieton a compass heading of 285° was noted. Shortly after crossing the Tieton River, an area of thick smoke was encountered, but the same compass heading was maintained. About 10 minutes later, on running out of the smoke, it was found that the airplane was still over the intended track, and the turn in the highway shortly afterward furnished a definite check of position.

MARKING DISTANCE ALONG THE PLOTTED ROUTE

It will be of considerable assistance in flight if, before taking off, the plotted route on the chart is divided into 10- or 20-mile intervals. The cross marks for 50- or 100-mile intervals should be made heavier, or emphasized, if in no other way, by noting opposite them the total mileage from the starting point. This scale of miles makes it easy to estimate the mileage of any point along the route, and also furnishes an excellent check on the ground speed being made good.

MARKING TIME INTERVALS

An alternative method preferred by some of the leading pilots is to divide the plotted route on the chart into time intervals, instead of miles. For example, if the plane has a cruising speed of 90 miles per hour, it will make 1.5 miles per minute, or 15 miles in 10 minutes. The first cross mark would be made 15 miles from the starting point but marked 10 minutes; the second, at 30 miles, would be marked 20 minutes, and so on. If these time intervals are added to the clock time for the beginning of the flight, we have the clock time when we may expect to reach the various points.

Of course, time intervals obtained in this way would hold good only under still-air conditions. A stiff head wind would retard the plane considerably, while a tail wind would place it progressively ahead of time. Some pilots, therefore, make such allowance as they can for wind effect. from weather reports, before beginning flight; others prefer to note the time intervals on the chart while in flight with the aid of an instrument called "spacing dividers."

The spacing dividers (fig. 44) can usually be obtained from companies selling drafting instruments. This instrument affords the quickest and easiest means of dividing the route into equal time intervals while in flight and of determining the exact time when any point will be reached in flight. The instrument consists of 11 teeth, numbered from 0 to 10 and so adjusted that they always divide the extreme setting of the dividers into 10 equal parts.

Now suppose that a plotted route crosses a railroad about 15 miles from an airport, and this railroad is identified and passed just 9 minutes after taking off. The tooth of the spacing dividers marked 0 is placed on the airport, and the dividers set so that the tooth marked 9 is at the point where the route crosses the railroad. The first 9 teeth of the dividers now indicate the position of the plane at the end of each of the first 9 minutes of flight, and the tooth marked 10 indicates the point the plane will have reached at the end of 10 minutes. In other words, the distance between teeth numbered 0 and 10 is the distance that will be made good during each 10 minutes of flight, provided there is little change in speed or wind conditions. With the dividers, 10-minute intervals can now be stepped off along the straight line on the chart, and by means of the intermediate teeth the exact minute when any prominent object will be reached can be noted. The spacing dividers may also be had with a special ground-speed arc. When adjusted as already described, the ground speed may be read directly from the arc.

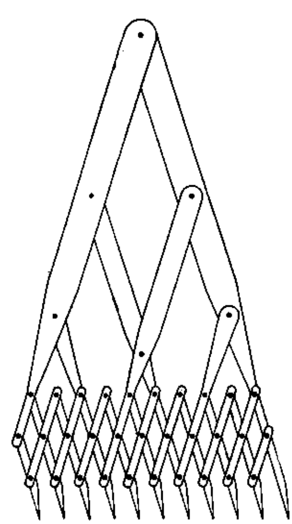


Figure 44.—Spacing dividers.

Many pilots prefer to combine the two methods, dividing the plotted route on the chart into 10- or 20-mile intervals before taking off, and noting on the chart while in flight, by means of the spacing dividers, the time for reaching the various landmarks along the way.

For the sectional charts, at about 8 miles to the inch, the spacing dividers can be set so that each tooth represents 1 minute of flying time, as suggested above. For the regional series, at about 16 miles to the inch, the dividers cannot be set that closely, and each tooth will be made to represent 2 or more minutes of flying time.

The computer (pp. 139 to 145), is very useful in determining the ground speed and dividing the route into time intervals. The use of the computer may be illustrated by the example given above, in which a railroad 15 miles distant was crossed in 9 minutes of flying time. Set 9 minutes on the inner disk (disk *B*) opposite 15 miles on the outer disk; the ground speed may then be read opposite the **MPH** index, and the miles made good for each 10-minute interval may be read on the outer disk (disk *A*), opposite the corresponding time intervals on disk *B*, without changing the setting of the computer. If the distance to a given landmark is known, the time required to reach it may be read on disk *B*, opposite the number of miles on disk *A*.

In the absence of both the spacing dividers and the computer, the same information may be obtained from figure 99, page 151. Referring to the graph, follow the horizontal line corresponding to 9 minutes across to its intersection with the (interpolated) vertical line representing 15 miles; the diagonal line drawn through this point, 100 m. p. h., represents the ground speed being made good. Following this same ground speed line to its intersection with the horizontal line representing 10 minutes, directly above it may be read at the top of the graph the number of miles made good in 10 minutes. In the same way, the number of miles made good for each successive 10-minute interval may be read at the top of the graph and plotted on the chart. As with the computer, if a given landmark or airport is known to be at a certain distance, following the vertical line representing that distance down to its intersection with the correct ground-speed line, and thence to the left border, will give the exact number of minutes required to reach the point in question.

LONG FLIGHTS

In the foregoing discussion we have considered cases within the limits of one chart. When the route lies between cities on different charts it is only necessary to join carefully the edges of adjacent charts, draw a straight line between the two points across all the charts involved, and proceed as before. This is possible because, in each of these series, any individual chart is constructed as though it were a section cut out of one big chart of the United States drawn at the scale of the series; obviously, then, any number of charts, in any direction, may be joined perfectly.

When the route lies between cities a long distance apart and on widely separated charts, it may prove more convenient first to draw on a smaller scale chart of the United States a straight line between the two points. The points at which the straight line crosses the meridians and parallels on the smaller scale chart should then be measured and the points transferred to the larger scale charts. The various sections of the straight line are drawn between these points on the large scale charts and the same procedure followed as before.

The Planning Chart of the United States (chart No. 3060 b) has been specially designed for this purpose. It should not be confused with chart No. 3060a, which formerly bore this title. Chart No. 3060 b shows a fairly complete drainage pattern, contours, and gradient tints, similar in treatment to the standard aeronautical charts. A great many cities have been added, as well as the civil airways, more than 400 of the principal airports, and lines of equal magnetic variation at intervals of 5°. With this more complete information it is possible to plan a long flight more intelligently and with much less effort.

The scale is 1:5,000,000, which is exactly one-tenth the scale of the sectional charts. The meridians and parallels which mark the limits of the sectional charts are subdivided into 10′ intervals, to facilitate transferring the route to larger scale charts by plotting the latitude and longitude of the points where the route crosses from one chart to another.

The name of each sectional chart is shown in the lower right corner of the area which it covers; having plotted the route on the planning chart, then, a pilot may see at once the sectional charts required. An index of the regional and radio direction finding charts is included in an inset.

The chart affords a high degree of accuracy in the measurement of long distances, and a scale of miles extending from 0 to 2,500 is printed in the margin.

FOLDING THE CHARTS

For laying out routes before taking off, for all detailed studies of a region, and for all general use, a flat chart, free from folds and wrinkles, is very desirable.

During actual flight, even in the larger transports, lack of space usually prevents the use of an unfolded chart. In light airplanes with open cockpits,

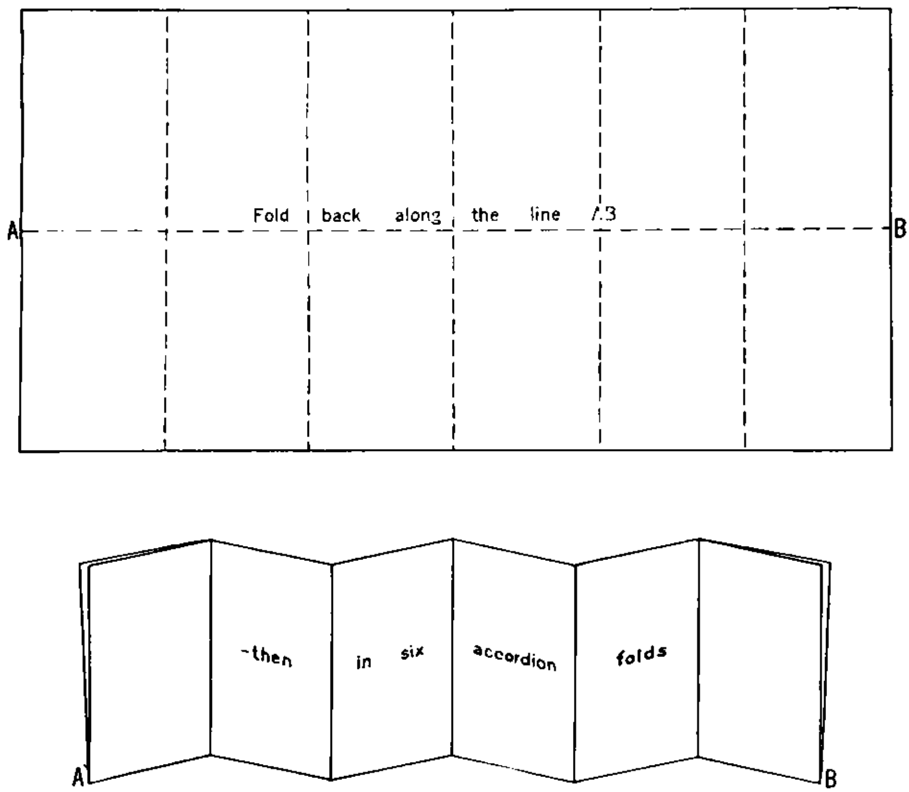


Figure 45.—Folding the chart for use in flight.

an unfolded chart has often blown away, with more or less serious results for the pilot. As a result, many methods of folding the charts have been devised, while those flying regular routes have made up strip charts or books cut from the published charts.

In order to avoid the handling of numerous charts even for short trips, and the resulting annoyance in all navigational problems, both sectional and regional charts have been designed to cover fairly large areas; nevertheless, charts of both series will be found very convenient for use in the air when properly folded. It is recommended that the charts be folded once, back to back, along the line *AB* (fig. 45), then in 4 or 6 "accordion folds" in the other direction, along the vertical broken lines indicated in the figure. In this way the entire chart may be consulted merely by turning over the accordion folds. Some even prefer to trim away parts of the margins and to make 8 folds; this provides smaller chart openings and easier handling in the air.

Strip charts are very convenient for those flying frequently over the same route, but they cannot fully satisfy the need, even for this type of flying. A pilot may be compelled to leave the charted airway, because of adverse weather conditions or other reasons, and find himself over unfamiliar territory with no chart of the ground below. In recognition of this danger, the Civil Air Regulations require that a pilot engaged in regular transport operations "have in his possession in the cockpit proper flight and navigational facility maps." This is interpreted as meaning charts covering the area at least 75 miles on each side of the airway and beyond each of the terminals involved.

Private pilots are not definitely affected by this requirement, yet compliance with it is obviously to their advantage. If a strip chart or book is

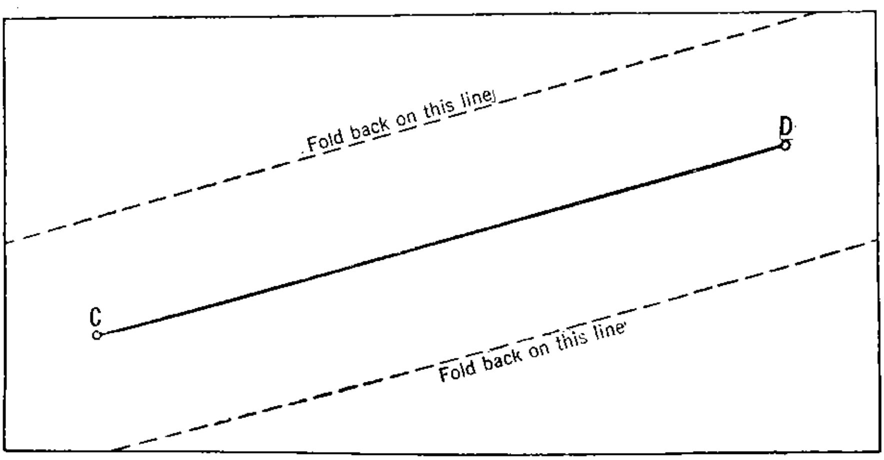


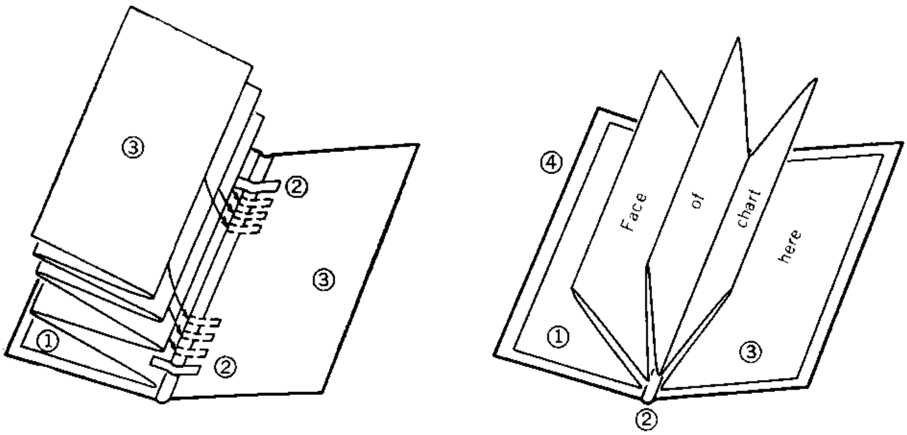
Figure 46.—Folding the chart as a strip.

prepared showing only the region immediately adjacent to the route, complete sectional charts showing a wider area, folded for most convenient reference in case of need, should also be carried.

Some very ingenious folds and route books have been devised, by means of which the entire route, or even whole charts, can be followed from point to point by the flip of a page. If such folds are made by pasting portions of the chart together so that they cannot be spread flat again for the plotting of new courses, they cannot be considered altogether satisfactory. Folds of this sort should by all means be supplemented by a flat chart or one so folded that it may again be opened out flat.

If a strip chart is desired and an additional chart is not available for reference in an emergency, the chart can be folded as a strip without destroying or cutting away any part of it. For example, if it is desired to make a strip chart covering the route *CD* (fig. 46), fold the chart so as to leave the route in the center of a strip 10 or 12 inches wide; then fold the strip in the accordion fold illustrated in figure 45. By this method the folded-back portions of the chart are still available if they should be needed.

A route book can also be prepared with little difficulty. (See fig. 47.) To do this, cut out the strip showing the plotted route and fold it accordion style; then paste one of the end folds to the inside cover of a book or cardboard cover of convenient size; next fasten to the back-strip of the book the folds touching that part, using adhesive tape or similar means; and, finally, paste the other end fold to the remaining book cover. Mounted in this way, the



1. Paste end fold of strip chart to book cover with rubber cement.
2. Attach center folds of strip to back of book by strips of adhesive tape.
3. Paste other end fold to remaining book cover.
4. Entire route can then be consulted by turning folds as pages of a book.

Figure 47.—Making a route book.

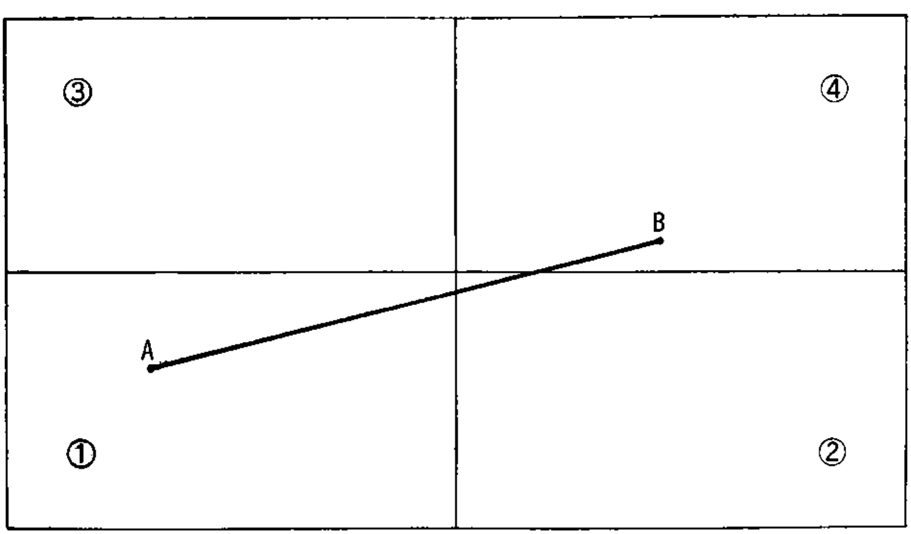


Figure 48.—Folding four charts for a route near their common corner.

more rigid covers to which the strip is attached facilitate handling in the air, and any part of the route may be consulted merely by turning the folds as pages of the book.

In describing the folding of charts, all the illustrations have shown the route as complete on a single chart. Unfortunately, it seems seldom to work out that way in practice. If it is desired to fly from *A* to *B* (fig. 48), even though the distance is not great, the route sometimes requires parts of four charts. For this situation, a strip chart made by pasting together parts of the four charts, will be found very convenient. If it is desired not to cut away or destroy the areas not wanted for this particular route, each of the charts may be folded in one of the ways already illustrated. For example (fig. 48), chart 1 should be folded as shown in figure 46; charts 2, 3, and 4 as shown in figure 45, with the corner nearest the junction exposed in each case.

A little thought given to the most suitable manner of folding the charts for each new combination that may arise will be found well worth while, in flight.

Whenever charts or portions of charts are to be joined together, as is often the case when making up strip charts, rubber cement should be used, since it does not cause the wrinkles and distortions so common when using other adhesives. If a thin coat of rubber cement is applied to both the surfaces to be joined, and allowed to dry before pressing the surfaces together, a fairly permanent junction can be made.

GENERAL RULES

In addition to the details already discussed, certain general principles should be observed.

In the event that position has become uncertain, it is important that a constant heading be maintained until position can again be identified. Keeping in mind the approximate position, from the best information available, the constant heading flown is a guide to the angle at which streams, railroads, highways, or other features, may be expected to appear, and thus aids in identifying them. Constantly changing the direction of flight, in search of landmarks, soon results in the loss of all sense of direction; it also leads to further uncertainty concerning even the approximate position, increasing the difficulties of identifying any landmarks.

There are exceptions to this rule, of course. If the heading being flown might lead out to sea, into the desert, or dangerously close to a range of mountains, some safer heading should be assumed, but the chosen heading should be maintained.

Under some conditions it is good practice to fly a course at some distance to one side of the destination. Suppose that a pilot is flying through an area where there are very few landmarks, to reach a town located on a railroad at right angles to his route. If he heads directly for the town, but reaches the railroad at some point other than the town, he may be uncertain as to whether the town is on his right or on his left. If, on the other hand, he deliberately heads for a point at some little distance to the right of his destination, when he reaches the railroad he knows that he should turn left, and reaches his objective with no time lost, other than the small amount of time required to fly the added distance.

When uncertain of position, the mistake is sometimes made of flying low, in an effort to identify landmarks by a closer view. In so doing the range of vision is greatly reduced, and the normal perspective is lost. By flying higher, the range of vision is increased and often some definite landmark can be seen.

In contact flying, the Civil Air Regulations impose but few restrictions on private pilots. Airways may be crossed at will, at any altitude (not less than 500 feet above the ground, nor within 300 feet of an overcast) without filing any flight plan. Nevertheless, added care should be exercised in crossing an airway. An air transport or other airplane on instruments, descending through an overcast in order to change to contact flying, might easily come into collision with aircraft, the presence of which beneath the overcast was entirely unreported and unknown. Such a collision, of course, would prove disastrous to both craft, and would be a real hazard to life and property on the ground.

Here, as nowhere else, "it pays to be careful."

QUESTIONS

1. Define piloting.

2. Outline the four necessary steps for piloting.

3. Name several topographic features that would be most helpful in piloting; several cultural landmarks.

4. How are rotating beacon sites marked for daylight identification from the air? How are intermediate fields marked?

5. What is meant by "flying a range?"

6. Is the use of a compass necessary in piloting?

7. What is the value of dividing the plotted route into 10-mile intervals?

8. How may a route be divided into time intervals?

9. For long flights, what advantage is there in using the planning chart, instead of merely joining the charts in question and plotting the routes on them?

10. Discuss the advantages and disadvantages of a strip chart.

11. In the table on page 58, suppose that the wind of 15 m. p. h. were a tail wind instead of a head wind, and fill in the last column for the new ground speed of 105 m. p. h.

12. For the flight from Yakima to Wenatchee (p. 56), prepare a table of landmarks similar to that on page 58.

13. Suggest a method of applying the data from the table on page 58 to the chart itself.

Chapter VI.—AIR NAVIGATION BY DEAD RECKONING

THE ADVANTAGES OF DEAD RECKONING

Cross-country flying by elementary methods of piloting is so simple under conditions of good visibility that many pilots practice no other form of navigation. Piloting an airplane by reference to visible landmarks is fundamental and must be combined with any other form of navigation that may be used; however, when a pilot is limited to flying by landmarks alone, he loses the saving in distance of the direct air route. He also loses the satisfaction of bringing his airplane directly to the intended destination by his own knowledge of navigation. Furthermore, if the weather should close in unexpectedly during flight and the familiar landmarks could not be found, the results might be extremely serious, not only to the pilot, but to the life and property of others as well.

As already defined, dead reckoning consists of determining position by means of direction and distance from a known position. By means of dead reckoning a pilot can fly fairly close to the landmarks for which he is looking, even when his information is not very reliable. Because he knows just about when and where to look for them, he will often succeed in finding them when a pilot without such training would miss them altogether. If he has fairly accurate knowledge of his own course and speed, and of wind direction and velocity, he may proceed even under adverse weather conditions with more certainty than an untrained pilot might have in clear weather. In any event, the ability to navigate by more advanced methods is certain to result in increased safety and greater operating efficiency, and will give considerable confidence and mental satisfaction to the pilot as well.

BASIC PROBLEMS IN DEAD RECKONING

There are two basic problems in navigation by dead reckoning, one being essentially the reverse of the other. They are:

Case I. When planning a flight, before taking off, to determine from the chart the distance and the compass heading to be followed between two points.

Case II. While in flight, from the observed compass heading and air speed of the airplane, to determine and plot on the chart the track being made good and the position of the airplane along the track at any time.

CASE I

Having drawn on the chart the intended track, either as a straight line or as a series of straight lines, in order to determine the compass headings to be followed four steps are necessary:

1. **Measure the true course,** or courses, on the chart;
2. **Find the magnetic course** by applying magnetic variation;
3. **Find the compass course** by applying compass deviation; and

4. **Find the compass heading** from the compass course by making allowance for the effect of wind.

Figure 61 provides a graphic definition of these terms.

As an alternate procedure, some recommend that these four steps be taken up in the following order:

1. Measure the true course.
2. Correct for wind.
3. Correct for variation.
4. Correct for deviation.

The reason given for this procedure is that, for utmost precision, the correction for compass deviation should be applied last, after the correction for wind has been applied, as the deviation on the final heading may differ somewhat from the deviation for the no-wind heading.

On the other hand, the three factors of true course, variation, and deviation all are known when working with the chart, while the wind information is usually the last to be known and must even be revised frequently while in flight. The advantage of being able to apply at one time, while working with the chart, all corrections except that for wind, in most cases outweighs the theoretical gain in precision that might result from applying deviation last. If the compass is not properly installed and compensated, and the deviations on adjacent headings are large or appreciably different, it is obvious that deviation should be applied last; but if the compass is properly compensated the difference in deviation between adjacent headings ordinarily should be so small as to be negligible in practice, and the order of procedure given on the preceding page is considered preferable.

The text that follows is based on the first method given above. It is believed that any confusion caused by introducing the alternate procedure at this point will be cleared up in discussing the four steps in the recommended procedure.

1. TO MEASURE THE TRUE COURSE

The true course may be defined as the course measured with the true geographic meridian printed on the chart.

As explained on page 20, and illustrated in figure 17, the true course should be measured with the meridian nearest halfway between the two points. This rule holds true, and the entire distance may be flown as one course, when the two points are separated by not more than 3° or 4° of longitude.

When the difference of longitude between the two points is more than 3° or 4° the straight line on the chart should be divided into sections crossing not more than 3° or 4° of longitude each, and the true course to be flown for each section should be measured with the middle meridian of that section.

For example, figure 49 illustrates the method of determining the series of true courses to be flown between St. Louis and Minot.

The distance is 863 miles, and the difference of longitude is nearly 12°, which is too great to be flown satisfactorily in one course. The route is therefore divided into three sections crossing approximately 4° of longitude each. The true course to be flown throughout the total length of each section should be measured with the middle meridian of that section and the course should be changed in flight as the end of each succeeding section is reached. This method makes it possible to fly the great circle route by a series of short courses (rhumb lines).

For the flight from St. Louis to Minot only two regional charts are required, and it would be a simple matter to join these two charts and draw the straight line between the two places. When using the sectional series six charts are

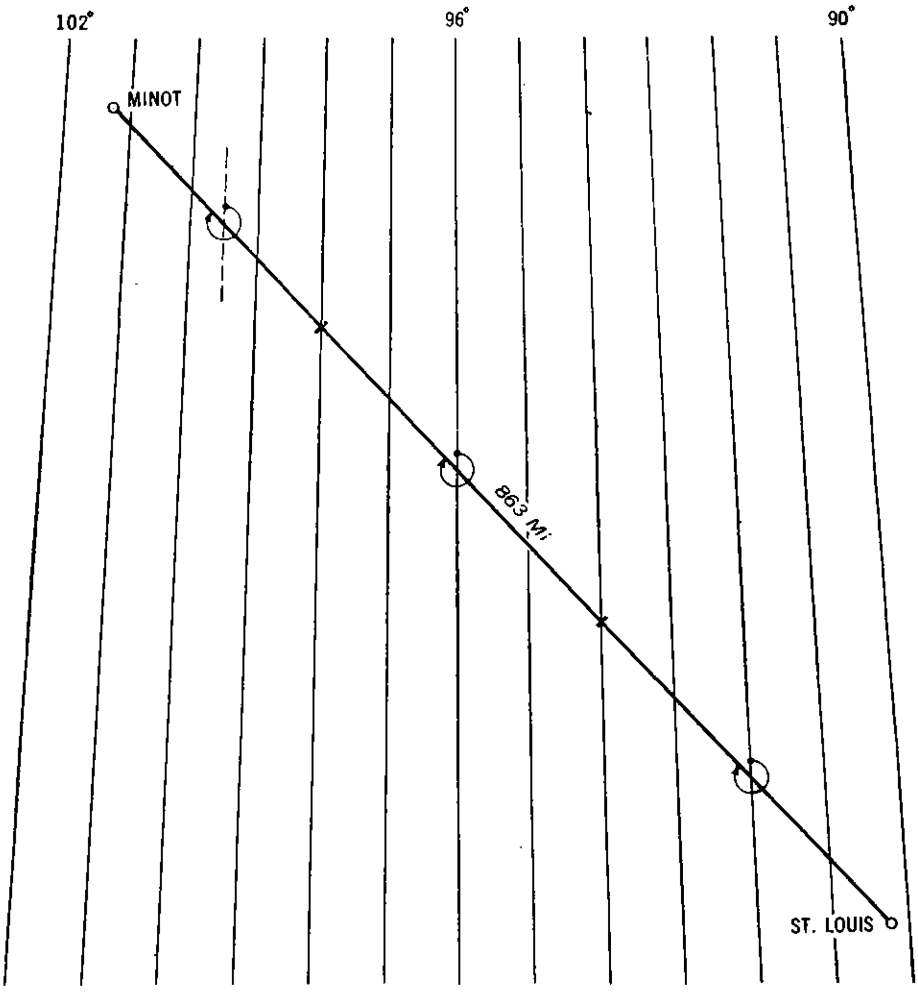


Figure 49.—Subdividing a long route.

necessary, and it is inconvenient to join so many charts; in this case, therefore, the route should first be plotted on the planning chart of the United States, and transferred to the sectional charts, as described on page 60.

Some pilots object to making frequent measurements with a protractor. Whenever possible, the protractor measurement supplies the most satisfactory and the safest information; but if the true course for the first section of a route is known, the true course for each succeeding section may be determined as follows:

For flight in an easterly direction add 6/10 of a degree [1] for each degree of longitude between the middle meridian of the first section and the middle meridian of the section under consideration;

For flight in a westerly direction, subtract 6/10 of a degree for each degree of longitude.

If this method is used and there is any difficulty in remembering when to add and when to subtract the correction, an exaggerated sketch similar to figure 50 will remove any doubt. It is clear that the course angle at *A* is greater than the angle at *B* therefore, **add** the correction when going toward *A* (east), **subtract** when going toward B (west).

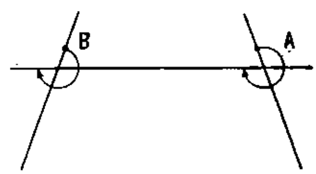


Figure 50.—The correction for convergence of meridians.

Instead of applying a correction of six-tenths of a degree for each degree of longitude crossed, some prefer to think of the correction as 2° for every 3° of longitude crossed, which is just as accurate. These pilots then make it a practice to change course at the central meridian and edge of each sectional chart, remembering only to add 2° at each course change when flying east, and to subtract 2° at each change when flying west. This is only the change in true course, and does not take into account the change in magnetic variation.

Except in large airplanes with provision for a separate navigator, it is usually impossible to do much, if any, plotting or drawing while in flight. Instead, any routes or alternate routes that might possibly be required should be plotted before leaving the ground, and the data noted on the chart.

If some entirely new and unforeseen route must be adopted after beginning a flight, there is little opportunity to do more than estimate the course angle. To be prepared for such need, it is good to practice drawing on a piece of paper a series of angles, estimating the number of degrees in each, and checking the estimates with a protractor. In flight, a nearby compass rose on the chart is of considerable assistance in making an accurate estimate.

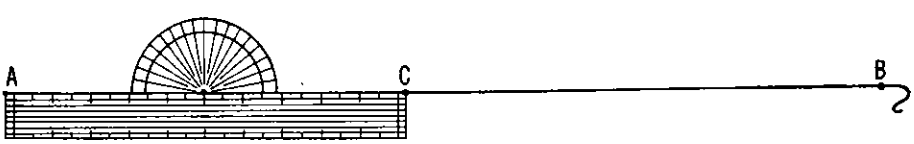


Figure 51.—Protractor used as a long straightedge.

A long straightedge is not always available, even for plotting on the ground. A very satisfactory substitute is a protractor used as illustrated in figure 51. This protractor was especially designed for use with the aeronautical charts of the Coast and Geodetic Survey, on the Lambert projection. It may also be used as a parallel ruler, and contains scales of statute miles for both the sectional charts (1 : 500,000), and the regional charts (1 : 1,000,000); the scale of miles for the sectional series is equally suitable for chart No. 3060 b, since it is exactly one-tenth their scale (1 : 5,000,000). If a long straight line is desired as between *A* and *B* in the figure, a thread may be inserted in the

[1] This is the angle of convergence between meridians 1° apart on all Lambert aeronautical charts of the United States. It is not precise, the exact figure being 0.6305; but for any ordinary distances it is entirely satisfactory. The maximum course error introduced by using the approximate figure amounts to only 3/10 of a degree for an east-west flight of 500 miles; for the final section of the longest straight-line flight possible in the United States, the error amounts to less than 1.°7.

hole at the center of the protractor; then with one end of the straightedge of the protractor at *A*, the thread is stretched to pass through the point *B*; the other end of the straightedge is caused to line up with the thread and the line *AC* is drawn. The operation is then reversed with the straightedge at *B* and the thread passing through *A*, and another section of the line is drawn; any center sections may be drawn in the same way, and the long straight line completed. This can be done more quickly and easily than it can be described.

In the absence of other equipment, the edge of a chart may be made to serve as a straightedge. Often even the edge of the same chart on which the route is to be drawn can be folded back and used in this way.

2. TO FIND THE MAGNETIC COURSE

As explained above, the true course is measured with reference to a true meridian printed on the chart, or true north. However, magnetic compasses

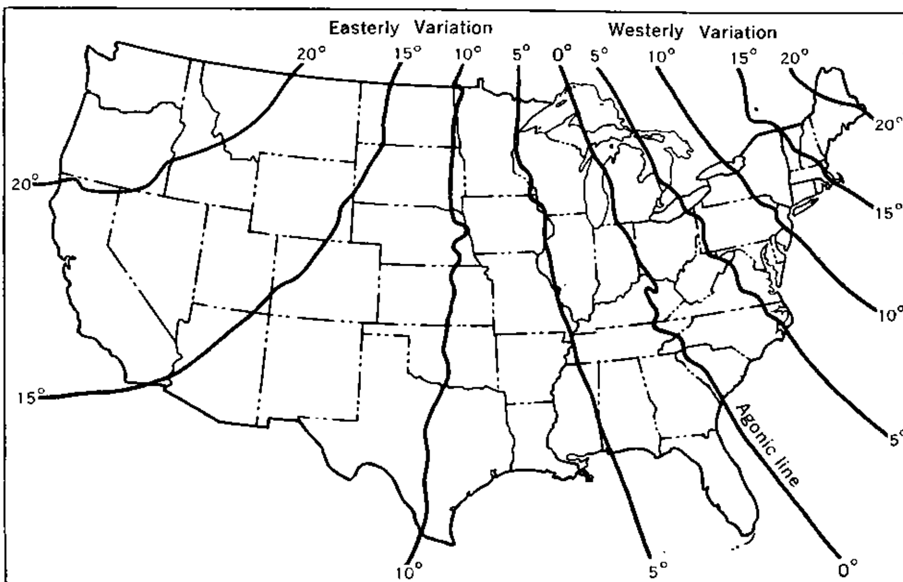


Figure 52.—Magnetic variation in the United States, 1935.

are used in air navigation, and these instruments, of course, refer all directions to magnetic north. In most localities magnetic north does not coincide with true north, chiefly because the earth's magnetic poles are at considerable distances from the true north and south poles. The angular difference between true north and magnetic north at any place is known in navigation as the **magnetic variation** of the place.[2] It is called westerly variation or easterly variation, depending upon whether magnetic north lies to the west or to the east of true north.

Figure 52 shows the lines of equal magnetic variation in the United States for 1935, at intervals of 5°. These lines, which are also known as isogonic

[2] It is also known as variation of the compass, or simply variation. In engineering and scientific work, variation is known as magnetic declination, but the term "variation" has been used at sea for many years, in order to avoid confusion with the term "declination" as employed in celestial navigation, and this usage has very properly been continued in air navigation.

lines, are shown on the aeronautical charts for each degree of variation, and in a few cases for each half degree. A chart of the United States (No. 3077), size 22 by 28 inches, showing lines of equal magnetic variation at 1° intervals, may be obtained from the Director, Coast and Geodetic Survey.

On the regional, direction finding, and planning charts, isogonic lines are shown in considerable detail, since it is felt that irregularities in magnetic variation probably extend to appreciable altitudes. Arrangements are being made for conducting research into the magnetic variation existing at flight levels, as compared with the surface pattern.

On the sectional charts, isogonic lines are shown in less detail. Because of the larger scale and relatively smaller area of a sectional chart, the more general treatment affords the essential information in clearer form than a detailed representation when seen apart from its relationship to the whole.

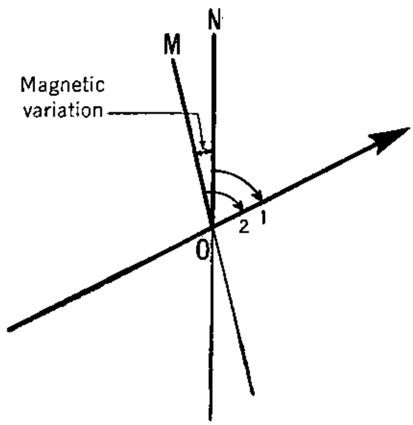


Figure 53.—Magnetic variation.

At all points along any given isogonic line, the magnetic variation is the same in direction and amount. Referring to figure 52, it may be seen that in the northeastern part of the United States the magnetic compass points **west** of true north (that is, the variation is westerly); in the southern and western part of the country the magnetic compass points **east** of true north (easterly variation). The dividing line between these two areas of opposite variation, that is, the line of 0° variation, is known as the agonic line. At all points along the line the direction of magnetic north and true north are the same. Minor bends and turns in the isogonic lines are chiefly the result of local attraction.

When a course is referred to magnetic north rather than true north, it is known as a magnetic course.

A magnetic course has no importance of its own to a pilot; it is simply a necessary step in converting a true course to a compass heading, and as such must have some name for reference. It may be defined further as the true course plus or minus magnetic variation.

There is no other single item in the whole field of navigation as important as the proper application of magnetic variation. Ships have been piled on the rocks, and planes have crashed into the sides of mountains or have been completely lost because of misapplication of this item.

For our present problem just one rule is necessary, but it should be learned so thoroughly that a wrong application is impossible. To convert a true course into a magnetic course, **ADD WESTERLY VARIATION.**

Numerous rhymes and jingles have been contrived to help navigators remember this rule, but often the rhymes have proved more confusing and harder to remember than the rule itself. It is believed that if the pilot can fix in his mind the relation pictured in figure 53, there will never be any question as to the correct application of magnetic variation.

262048°—40——6

In figure 53, *N* represents the true geographic meridian, and angle *1* is the true course for the route shown.

M represents the direction of magnetic north in the vicinity of *O* and is west of true north as indicated.

Angle *NOM* is the magnetic variation, which is westerly.

Obviously, when magnetic north lies to the west of true north, the angle *NOM* must be added to the true course (angle *1*) to obtain the magnetic course (angle *2*), or the magnetic direction of the route.

If westerly variation is to be added, easterly variation must be subtracted; but if we can always remember the rule, **ADD WESTERLY VARIATION,** there will never be any danger of an erroneous treatment.

The application of magnetic variation may be further clarified by two specific illustrations:

Near Portland, Maine, the variation is about 17° west, resulting in the condition shown in figure 54. Note that in this case the magnetic compass reading is everywhere 17° greater than the corresponding true direction.

Near Portland, Oreg., the variation is about 22° east, as in figure 55, the magnetic compass reading being 22° less than the true for any chosen course.

After dividing the route into sections of practical length and determining the series of true courses, as already outlined, the average magnetic variation for each section is applied in order to find the series of magnetic courses.

If this procedure is disregarded and a long route is flown in one mean magnetic course, considerable departure from the intended track may result. For example, figure 56 shows the conditions actually existing in 1935 along the Canadian border between longitudes 90° and 96°, a distance of 273 miles. The true course for the route from *O* to *C* is 270°; the magnetic direction at the point *O* is 268°, while the mean magnetic course for the route as a whole is 264°. If this mean magnetic course is flown for the entire distance, beginning at *O* the course is in error by about 4°, and the plane will track the broken line south of the parallel. At the center of the route the track will be 4.1 miles south of the parallel, gradually returning to meet it at *C*. These conditions are typical for the northeast quarter of the United States, the departure from this cause being greatest, of course, where the greatest differences in magnetic variation occur.

The following examples will help to fix in mind the application of magnetic variation.

True course (measured from chart)	Mean magnetic variation (from chart)	Magnetic course
135°	17° W	152°.
263°	5° E	258°.
340°	10° E	330°.
355°	10° W	5° (=365°−360°).[1]
5°	10° E	355° (=5°+360°−10°).[1]

[1] When the true course to be converted is near 0°, 360° may be added or subtracted as necessary in order to perform the required operations.

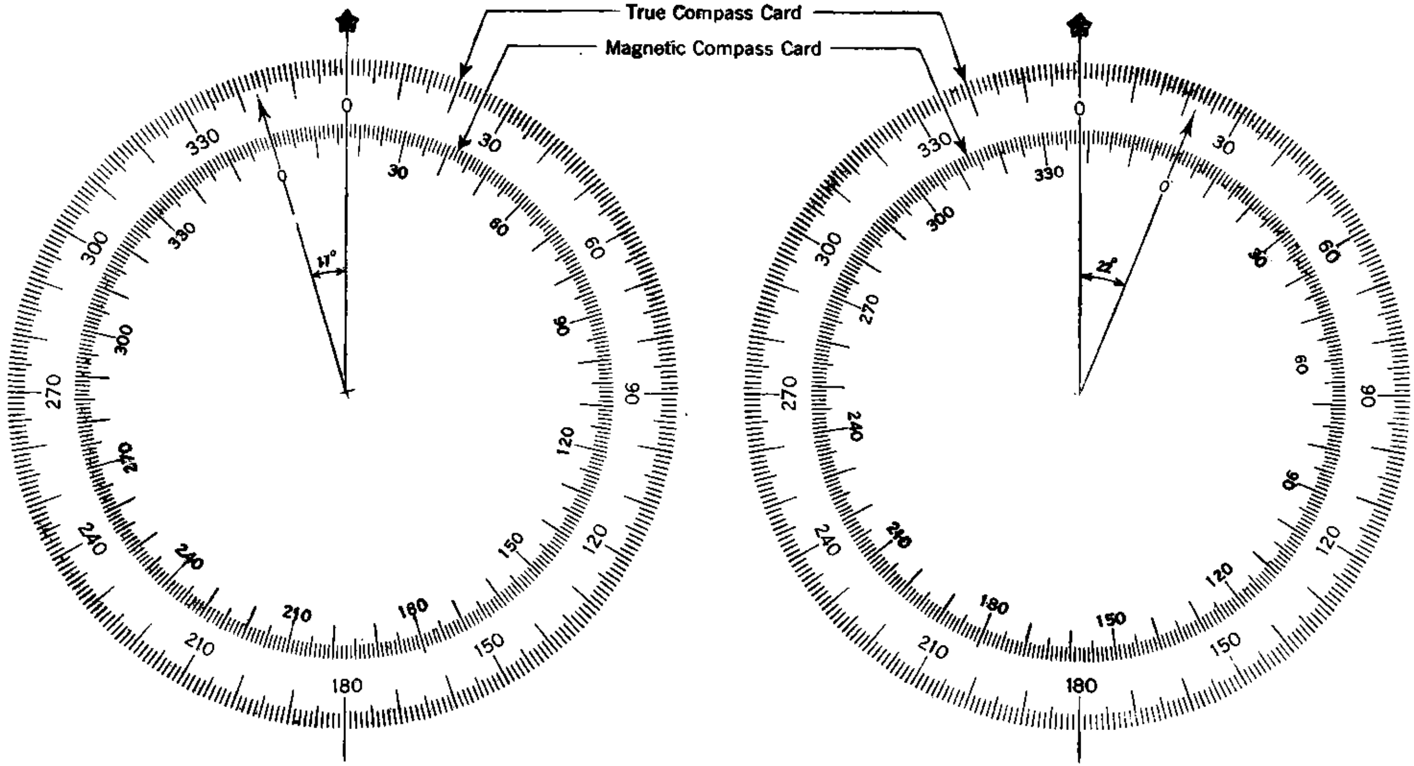


Figure 54.—At Portland, Maine, magnetic variation is about 17° west, and the magnetic compass reading is 17° greater than the true for any chosen course.

Figure 55.—At Portland, Oreg., magnetic variation is about 22° east, and the magnetic compass reading is 22° less than the true for any chosen course.

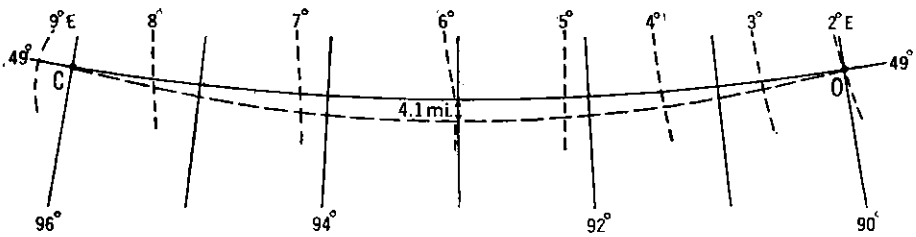


Figure 56.—Departure from intended track due to flying a mean magnetic course.

3. TO FIND THE COMPASS COURSE

As already stated, magnetic attractions in the plane itself—metal parts, ignition system, electric lights, placing of tools or cargo, etc.—affect the compass so that it fails to indicate magnetic north correctly on most headings.

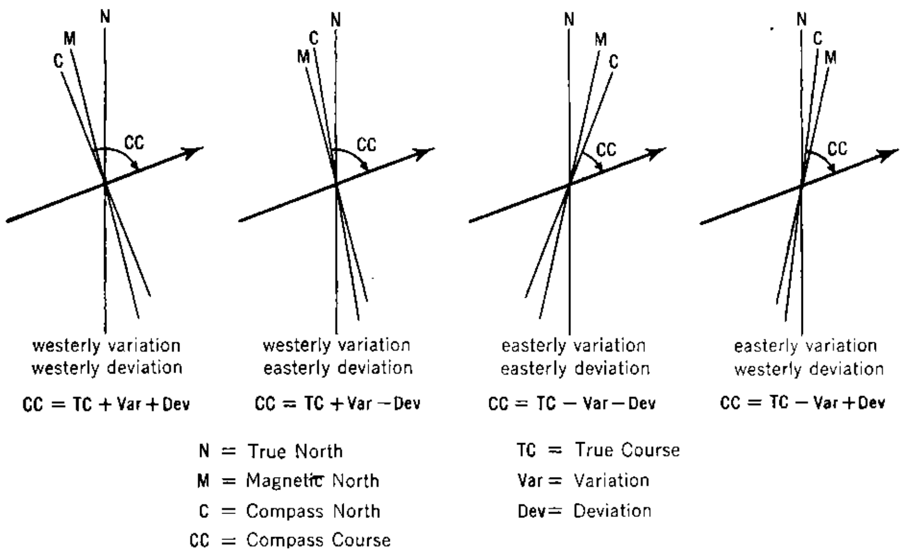


Figure 57.—Applying variation and deviation to find the compass course.

The angular difference between magnetic north and the north indication of the compass on any particular heading of the aircraft is known as the **compass deviation** for that heading.

Deviation differs in magnitude and direction as the airplane is pointed on different headings; it also differs, of course, for each compass, and even for each new location of a compass in the same airplane. Like magnetic variation, deviation is known as westerly, or easterly, according as compass north is west of, or east of magnetic north.

When a course is referred to compass north rather than true north or magnetic north, it is known as a compass course.

Like a magnetic course, a compass course has no importance of its own, since it would be useful in air navigation only in still air or when the wind is parallel to the route. (See To Find the Compass Heading, following.) It is simply another step in the process of finding the compass heading, and may be defined further as the **true course plus or minus magnetic variation and compass deviation.**

By proper adjustments, deviation on the various headings may be greatly reduced, but a reduction of the deviation is less important than knowing exactly the amount of deviation on the respective headings. Some pilots, when they have reduced deviation errors to a maximum of 2° or 3°, ignore this correction altogether, feeling that the uncertainties and variations of wind alone are likely to produce greater errors. While this may be satisfactory under some conditions, it is not good navigation and is not recommended. The fact that some errors **must** be present in a problem is no justification for introducing another; in fact, the more uncertainties involved, the greater is the need for accuracy in the other factors, lest the errors become additive and of excessive magnitude.

The correction for compass deviation is exactly similar to the correction for magnetic variation, and we need change only one word in our rule: **ADD WESTERLY DEVIATION.**

As with magnetic variation, it is obvious that if westerly deviation is to be added, easterly deviation must be subtracted.

Figure 57 illustrates the conversion of the true course for different conditions of variation and deviation.

4. TO FIND THE COMPASS HEADING

As defined above, the compass course is the direction by compass in which an airplane should be headed in order to reach its destination in still air, or with the wind parallel to the course; it also was defined as the true course plus or minus variation and deviation, but with no allowance for wind. In practice, however, the same term is often applied to the heading of the airplane after due allowance has been made for wind.

To avoid any confusion at this point, the use of two separate and distinctive terms is very desirable, and the following formal definitions are given:

Compass course: The true course plus or minus variation and deviation, but **without** allowance for wind effect.

Compass heading: The true course plus or minus variation and deviation, and **including** allowance for wind; the direction by compass in which the airplane is pointed.

Figure 61 provides a graphic definition of these terms. Already they have found limited acceptance in air navigation, and their general adoption is recommended.

In order to make the necessary allowance for the effect of wind, and to find the compass heading from the compass course, the action of the wind upon an aircraft must be fully understood. One of the best illustrations is found in the old catch question about the toy balloon.

While in flight, a pilot sighted a toy balloon directly over a church steeple. He continued on his way for 15 minutes, then reversed his course and turned back to see if he could again find the drifting balloon. It was sighted over a point which he knew from his chart was 7 miles south of the steeple. The problem was to determine the wind direction and velocity from this information.

At first, the data seem insufficient. On further consideration, of course, it is realized that the airplane drifts with the wind in exactly the same direction and amount as the balloon. Disregarding the surface of the earth, and considering only relationships in the air, it is as though the balloon were motionless in a sea of air, since it moves with it and as a part of it. The distance in the air between the airplane and the balloon is unchanged by anything except the air speed of the airplane itself. If the pilot flew away from the balloon for 15 minutes, regardless of the direction, it will also take him 15 minutes to return. Thirty minutes will have passed, therefore, between the sighting of the balloon over the steeple and sighting it again 7 miles south, and the wind can be determined as 14 m. p. h., from the north. In exactly the same way, an airplane in flight is subject to the full effect of the wind, even though the airplane may be moving under its own power in an entirely different direction.

For example, an airplane headed due east from *O* (fig. 58) flying at an air speed of 100 m. p. h., should reach *D* (100 miles distant) in 1 hour; but, during the hour of flight the plane has also been subject to the full effect of a wind of

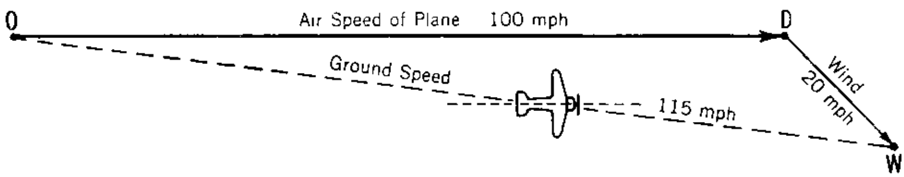


Figure 58.—Wind drift.

20 miles per hour, from 315°. As indicated in the figure, it actually reaches *W*, the line *OW* representing the track followed by the airplane over the ground. If the length of *OW* is measured by the same scale with which *OD* and *DW* were laid off, we may determine also the speed the airplane has made over the ground in passing from *O* to *W*, or 115 m. p. h.

Air speed is the speed of the airplane with respect to the air, and is the speed registered by the air speed indicator (when corrected for altitude, temperature, and installation error; see pp. 148 and 149). It is represented by the line *OD* in the figure.

Ground speed is the speed of the airplane with respect to the ground, and is the resultant of the heading and air speed of the airplane and the direction and velocity of the wind. It is represented by the line *OW* in the figure. *OD* is the compass heading, while *OW* is the track, or line of flight.

Figure 58 illustrates what would happen if a pilot followed a compass course without regard for wind effect. Under the conditions shown, the airplane would pass well south of and beyond its objective, the angle *DOW* being known as the **drift angle.** In order to avoid such an error, the airplane must be headed into the wind at such an angle that the effect of the wind is counteracted; if this is done correctly the plane will be over the intended track throughout the flight. This angle at which the airplane must be headed into the wind in order to make good the intended course is known as the **wind correction angle.**

The drift angle may be determined with a simple drift sight. (See p. 31.) It may also be determined by heading the airplane on the compass course and noting its track with respect to landmarks below; knowing the distance of these landmarks from the starting point and also to the right or left of his course, the drift angle may found from the graph on page 159.

In the absence of other means of determining drift, the pilot should select certain points on the tail surfaces or other suitable parts of the airplane, and determine the angle between them when viewed from his normal position in the cockpit. By noting the passage of objects on the ground with respect to these reference points, some reasonable estimate of drift may be made.

Many pilots think they have satisfactorily corrected for wind effect if they turn toward the wind the same number of degrees as the observed drift angle. Under average conditions this may not be greatly in error, and it is the most natural approach in trying to find the wind correction angle by trial and error. However, the wind angle may be appreciably greater, equal to, or appreciably less than the observed drift angle, depending on the direction and velocity of the wind with respect to the direction and velocity of the airplane.

The general rule may be stated as follows:

For winds coming from any direction within about 75° from the airplane's head, the wind correction angle is less than the observed drift angle.

For winds at an angle of about 80° from the airplane's head, the wind correction angle and the observed drift angle are equal; also, the air speed and ground speed are equal.

For winds at angles greater than about 80° from the airplane's head, the wind correction angle is greater than the observed drift angle.

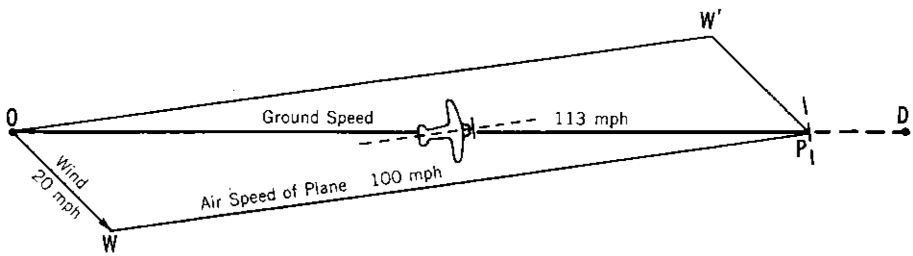


Figure 59. Correction to course for wind, and determination of ground speed.

When the wind direction and velocity are known a pilot can determine graphically the wind correction angle required to make good the intended course. The procedure is as follows:

The true course from *O* to a distant point, *D* (fig. 59) is found to be 90°, or due east. From the point of departure, *O*, on any convenient scale lay off *OW* to represent the direction and velocity of the wind. From *W*, with radius equal to the air speed of the airplane describe an arc meeting the intended track at *P*. Draw *OW'* parallel to *WP*, and *W'P* parallel to *OW*. In the figure it is now evident that *OW'* = *WP* = air speed of plane; *W'P* = *OW* = wind direction and velocity; and the angle *W'OP* is the wind correction angle or the number of degrees the plane must be headed into the wind in order to track the line *OD* exactly. The angle may be measured with a protractor and applied to the compass course (obtained by correcting the true course of 90° for variation and deviation).

OP is measured and found to represent 113 m. p. h., the ground speed along the route; from the ground speed the exact flying time between *O* and *D* can be obtained.

OW′ represents the compass heading, or the direction in which the airplane must be pointed in order to make good the intended track *OD*.

It must be remembered that wind directions given in weather reports are **true** directions: in constructing the "triangle of velocities" to obtain the wind correction and ground speed, the course and the wind direction both must be in true directions, or both must be converted to compass directions. The results obtained would be the same whether true directions or compass directions are used, but it is important that **both directions should be in the same terms.**

Referring again to figure 59, it has been stated that the angle *W′OP* is the wind correction angle. It is also the drift angle that will be observed in flight as long as the airplane is headed in the direction *OW′* and there is no material change in wind. This constitutes a valuable check, enabling the pilot while in flight to determine easily if the wind conditions being met are in accordance with those predicted. Winds vary with time, place, and altitude, and the conditions experienced in flight may differ considerably from

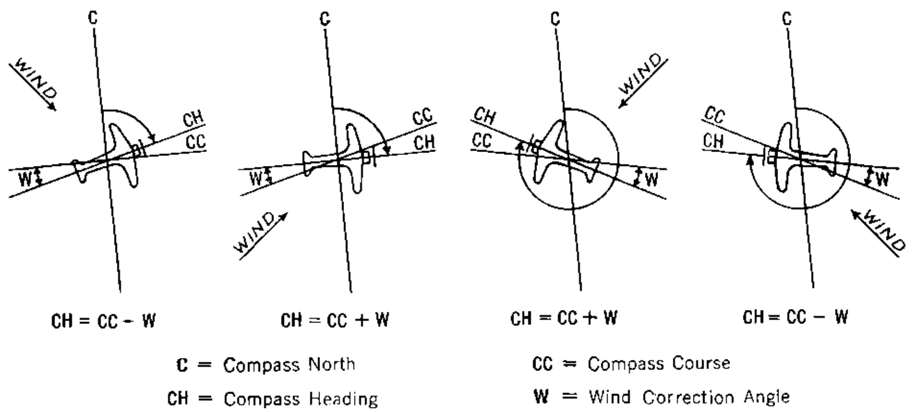


Figure 60.—Combining compass course and wind correction to find the compass heading.

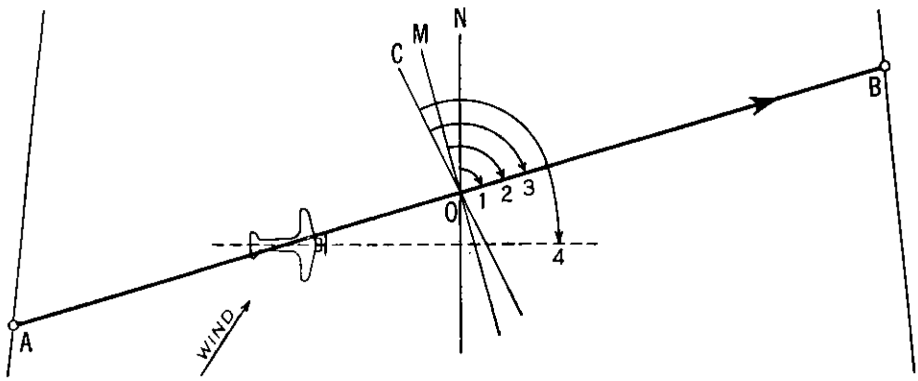
those indicated in weather reports and forecasts. One probable cause of changing conditions may often be eliminated by maintaining a constant altitude. Whenever an appreciably different drift angle is observed, it is a warning that wind conditions have changed and revised corrections must be determined and applied. For the best methods of doing this while in the air, see chapter VIII.

Practically all methods of determining ground speed are based on the assumption of constant air speed, which in turn is based on the assumption of level flight. Quite obviously, the forward speed over the ground is materially reduced when climbing, and allowance for any such periods should be made when determining the position along the intended track.

Figure 60 illustrates the application of the allowance, or correction, for wind effect under varying conditions. For any particular case it is believed that a rough sketch similar to one of those in the figure will remove any doubt the pilot may have as to whether the allowance for wind should be added or subtracted.

By comparing the various parts of figure 60 we can formulate this general rule: For wind from the right, add the correction; for wind from the left, subtract. This may be remembered more readily if we follow the form of our rule for applying variation and deviation, making this rule read, **ADD WIND RIGHT**—and, of course, we would not wish to add wrong!

From the rule just stated, and also from a study of figure 60, it should be apparent that if a pilot wishes to reverse his direction of flight, and retrace his course, he must reverse the correction for wind. If 5° were added to the compass course for drift on the original heading, 5° must be subtracted from the compass course (10° from the compass *heading*) after turning back.



N = True North (geographic meridian)
M = Magnetic North
angle NOM = Magnetic variation (westerly)
C = Compass North
angle MOC = Compass deviation on this heading (westerly)
angle 1 = True Course
angle 2 = Magnetic Course
angle 3 = Compass Course
angle 4 = Compass Heading
AB = Track (or intended track)

Figure 61.—Graphic definition of terms used in dead reckoning.

There are many methods of obtaining the wind correction and ground speed when the wind direction and velocity are known, but the method just outlined is the foundation on which all others are based, and is certain to find frequent use. Among the other types of solution commonly used, the following may be mentioned:

1. **Tabular solutions.**—These are of two kinds, (*a*) a special table, or series of tables, based upon particular air speeds; (*b*) a general table giving wind velocities in percent of air speed. These percentages, of course, must be converted into miles-per-hour velocities based on the air speed being made good at the moment. The method is therefore not so convenient in practice.

2. **Mechanical solutions,** in which the triangle of velocities and other navigational problems are solved by means of mechanical devices, such as the Computer, page 139.

3. **Graphic solutions,** in which lengthy tabulated corrections have been reduced to the form of simple graphs. (See ch. VIII.)

By way of summary, figure 61 affords a graphic definition of the terms commonly used in navigation by dead reckoning, and of their interrelation. For the effect of wind in making a turn, see page 111.

CASE II

In the preceding discussion only the first of the two cases of dead reckoning has been considered, namely, determining from the chart, when planning a flight and before taking off, the distance and compass heading to be followed.

The second case is concerned with plotting on the chart while in flight, from the observed compass heading and ground speed, the track being made good and the position of the airplane along the track at any time. As already pointed out, plotting and drawing in the air are scarcely practicable except in larger airplanes, with facilities for a separate navigator. The pilot-navigator of a light airplane will normally have to content himself with plotting, before he begins his flight, the route lines, courses, and distances he may need in order to spot his position by estimate. With a little practice it will be found that most of the estimates required are simple enough to be taken care of by mental arithmetic, without drawing or computing.

It may seem that the plotting of the airplane's track and position in the air should never be necessary if the course is properly determined before beginning the flight; however, wide departures from the charted route are altogether possible, intentionally or otherwise. In this event it may happen that after leaving a certain position the only data which can be obtained are (1) the compass heading, (2) the approximate ground speed, and (3) the elapsed time.

Essentially, this problem is the reverse of the first. In Case I, we start with the true course measured on the chart and apply variation, deviation, and an allowance for wind effect in order to obtain the compass heading. In Case II, starting with the compass heading observed in flight, all these factors are included and must be taken away in order to obtain the true course to be plotted on the chart. Obviously, then, all the rules of Case I must be reversed: Whatever would have been added then must be subtracted now, and vice versa. This process of "taking away" may be called **rectifying.** As in Case I, four steps are necessary:

1. **Find the magnetic heading** (magnetic direction in which the airplane is pointed) by rectifying the compass heading for deviation.
2. **Find the true heading** (true direction in which the airplane is pointed) by rectifying the magnetic heading for variation.
3. **Find the true course** (track) being made good over the ground, by rectifying the true heading for wind.
4. **Plot the true course** on the chart, using the same procedure outlined for measuring a course.

1. TO FIND THE MAGNETIC HEADING

If we remember the rule laid down that to convert a magnetic course to a compass course **under Case I** we **ADD WESTERLY DEVIATION,** it is evident that to rectify the compass heading for deviation we must reverse the process and subtract westerly deviation; easterly deviation, of course, should be added.

2. TO FIND THE TRUE HEADING

As with deviation, we must reverse the rule of Case I, subtracting westerly variation and adding easterly variation in order to find the true heading.

If there should remain any confusion as between adding in Case I, and subtracting in Case II, it should be necessary only to remember that problem one, finding the compass heading from the chart, is normally the first and basic operation, and **for Case I** we must **ADD WESTERLY** variation or deviation. For the second operation, performed in the air, we simply reverse the procedure.

3. TO FIND THE TRUE COURSE MADE GOOD

When the drift angle can be obtained, the true heading of the airplane may be rectified for wind, and the true course found, simply by adding or subtracting the drift angle.

Figure 62 illustrates the rectifying of the true heading for wind under varying conditions. By comparing the various parts of the figure, we see that

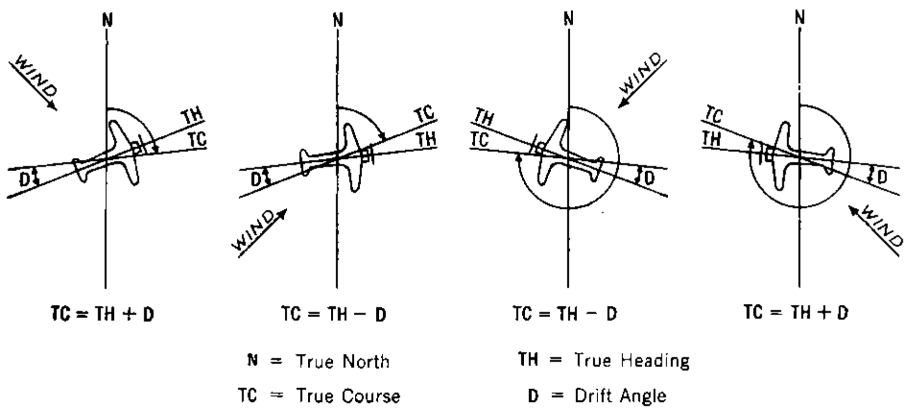


Figure 62.—Combining the true heading and drift to find the track (true course made good).

here, again, we **reverse the rule of Case I,** and subtract the drift angle for wind from the right.

When drift observations are not possible because of adverse weather conditions, the true heading is rectified for wind by means of a triangle of velocities, or other similar means, using the wind direction and velocity as given in weather reports or as last known.

4. TO PLOT THE TRUE COURSE ON THE CHART

Having obtained the true course (track) from the three preceding steps, there remains only the problem of plotting it on the chart. For distances no greater than about 100 miles in an east-west direction, the course may be plotted at the meridian of the last known position with a course error of about 1°; for 175 miles east-west the error will be approximately 2°, always toward the south from the true position (in the United States). Under some conditions this may be sufficiently exact; for more precise results, we must remember that we are dealing with a course, not a bearing. The course should be plotted with the meridian nearest halfway between the last known position and the new position.

On the ground, or in large airplanes, this may be done satisfactorily by estimating roughly the course and distance on the chart, selecting the meridian nearest halfway, laying off the course therewith, and paralleling the line so obtained with a line through the last known position.

To illustrate, in figure 63, *A* marks the last known position of an airplane and the known data are as follows:

Compass heading in flight	55°
Ground speed (approximate)	110 m. p. h.
Elapsed time	1 hr. 20 min.
Drift angle (wind from left)	10°
Compass deviation on compass heading of 55°	3° W.
Magnetic variation, average, from chart	7° E.

The true course is found in accordance with the rules already given, as follows:

1. Magnetic heading = Compass heading − deviation (westerly).
   $=55°-3°=52°$.
2. True heading = Magnetic heading + variation (easterly).
   $=52°+7°=59°$.
3. True course = True heading + drift angle (wind from left).
   $=59°+10°=69°$.

4. The approximate distance covered in $1^{hr}20^{mins}$ at 110 m.p.h. is 147 miles. By inspection it is seen that 147 miles on a true course of 69° crosses approximately 3° of longitude. The course angle of 69° is measured with the meridian nearest halfway, 1°30′ east of *A*, at any convenient intersection, *O*, and the line *TC* obtained. The line *AB*, drawn from *A* parallel to *TC*, is the dead reckoning track made good; a point, *B*, on the track line, 147 miles distant from *A*, marks the position of the airplane by dead reckoning.

In the air, the pilot of a small airplane will have little opportunity for this kind of plotting. Instead, it is assumed that he has plotted his route carefully

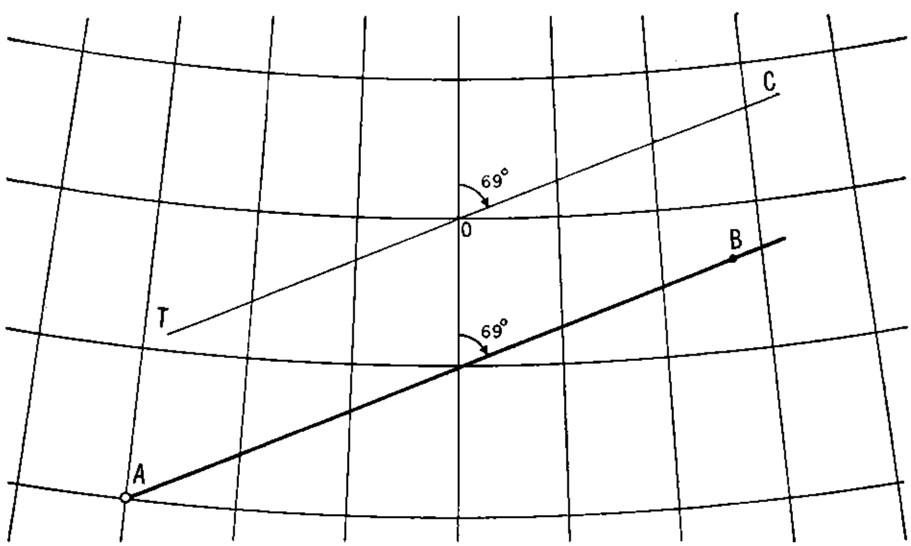


Figure 63.—Plotting on the chart the track, or true course made good.

before taking off, and that he has subdivided it into 10-mile intervals. If his intended true course was determined as 72°, the true course made good actually lies about 3° to the northward. Estimating the distance of 147 miles along the plotted route (seven-tenths of the distance between the 140-mile and the 150-mile ticks), a point is marked on the chart along an imaginary line at an angle of 3° to the plotted route, and the time noted.

In estimating small angles, it may be of some aid to remember the old formula that an angle of 1° is represented by an offset of 1 in 60. That is, if a line is drawn 60 inches in length, and at one end a perpendicular 1 inch long is erected, a line from the top of the perpendicular to the other end of the line will meet it at an angle of 1°. Similarly, 1 centimeter in 60, 1 mile in 60, or 10 miles in 600 all represent angles of 1°; 2 miles in 60 represents an angle of 2°, etc.

Applying this principle to the above problem (an angle of 3° at 147 miles), an angle of 1° has an offset of 1 mile in 60, 2 miles in 120, 2½ miles in 150, and 3 miles in 180 miles. An angle of 3° will have an offset 3 times as great, or 7½ miles in 150. A point about 7½ miles north of the plotted route line, at 147 miles from the starting point, represents the dead reckoning position desired.

In practice, it must be realized that there are a number of sources of possible error in a position so determined. For example, due to irregularities in handling an airplane, pilots are seldom able to fly a given heading closer than 1°; the determination of drift can only be considered as within a degree or two, at best, due to variable winds and difficulties of observation; and even the ground speed can only be considered approximate at times.

In many cases, these various errors tend to cancel out; in others, they may become additive. Pilots should learn to estimate the total error possible in any given case. The dead reckoning position, plotted as described above, should then be considered, not as an actual position, but as the center of an "error circle," at any point within which the true position might lie.

To illustrate, after an hour of flight at an estimated ground speed of 120 m. p. h., it is believed that the total course error may reach as much as 5°. An error of 1° is represented by 1 mile in 60, 2 miles in 120. An error of 5°, then, amounts to 10 miles in 120, and a circle with radius of 10 miles is drawn around the dead reckoning position. If landmarks seen at the end of the hour are not in agreement with those near the plotted position on the chart, they may probably be found somewhere within the circle of error. The pilot is often able to identify his position more quickly by placing this limit on the chart area within which to look for the landmarks seen beneath him.

SUMMARY

The following comparison may serve to fix in mind the procedure in the two general cases of dead reckoning:

Case I: Chart to compass heading:

1. Measure the true course.
2. ADD WESTERLY VARIATION.
3. ADD WESTERLY DEVIATION.
4. ADD WIND RIGHT, i. e., add the correction for wind from right.

Case II: Compass heading to chart:

1. SUBTRACT WESTERLY DEVIATION.
2. SUBTRACT WESTERLY VARIATION.
3. SUBTRACT WIND RIGHT, i. e., for wind from the right.
4. Plot true course on chart.

SPECIAL PROBLEMS OF DEAD RECKONING

RETURNING TO THE INTENDED TRACK

As already stated, intentional departures from the plotted route are sometimes made in order to avoid unfavorable weather conditions, or for other reasons; often, however, the departure is unintentional and is not realized until the position is definitely determined in flight, by reference to known landmarks or other methods. Ordinarily, when a departure from the intended

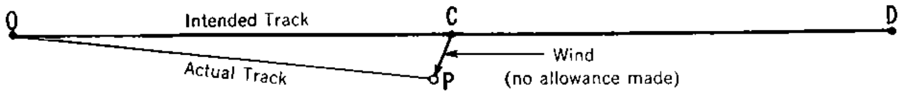


Figure 64.—Departure from intended track due to failure to apply correction for wind.

track is noted, a new compass heading, to make good the course from the newly determined position to the destination, is determined by applying variation, deviation, and a revised allowance for wind. Under other conditions it may be desired to return to the intended track and complete the flight as originally planned.

To return the plane to the intended track many approximate methods are practiced. Some of these are unsound in principle, and are therefore not very satisfactory. To be satisfactory, any method must take into account the reasons causing the departure. For example, in figure 64, a pilot is flying from *O* to *D*, 100 miles due east, at 100 m. p. h. After 30 minutes of flight when

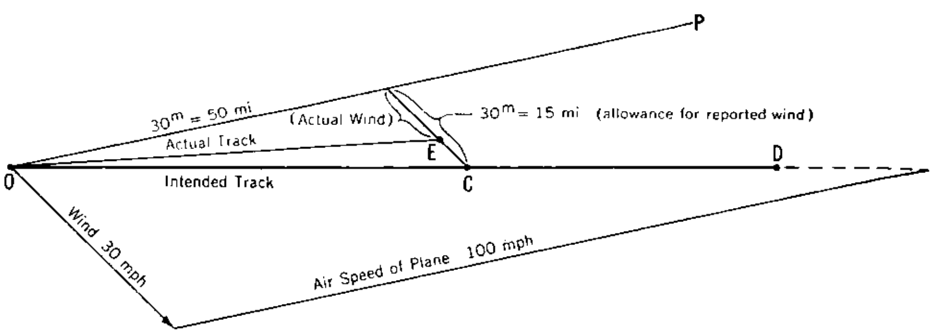


Figure 65.—Departure from intended track due to over-correction for wind.

he should be at *C*, he finds himself directly over a town at *P*. Since he was making no correction or allowance for wind, the line *CP* represents the direction and velocity of the wind; *OP* is the track, and the angle *COP* is the drift angle.

In figure 65, on another occasion a pilot is flying between the same two points, making allowance for a northwest wind of 30 m. p. h. After proceeding on the proper heading *OP* for 30 minutes he should be at *C*, but finds himself over a town at *E*, due to the fact that the wind was only 20 m. p. h., instead of 30 m. p. h. as reported. It should be evident that to return to the intended track under these conditions will require a procedure different from that required in the preceding figure.

A good general rule to follow is to head the airplane toward the intended track at an angle of about 45° thereto. Allowance for wind can be made, taking into account the wind data just learned from the determination of position, and the time of arrival over the plotted route can be found with a fair degree of accuracy.

The simplest method (if the wind is at such an angle to the plotted route that it is practical) is to line the airplane up with the wind, approaching the intended track directly into the wind (fig. 64), or with the wind (fig. 65). In either case the ground speed may be known from the air speed of the airplane and the wind velocity, and the time of arrival over the intended track is most easily determined.

RADIUS OF ACTION

By radius of action is meant the distance an aircraft may fly, with a given amount of fuel and given wind conditions, and still return to the starting point. The solution of this problem also includes the headings to be flown on

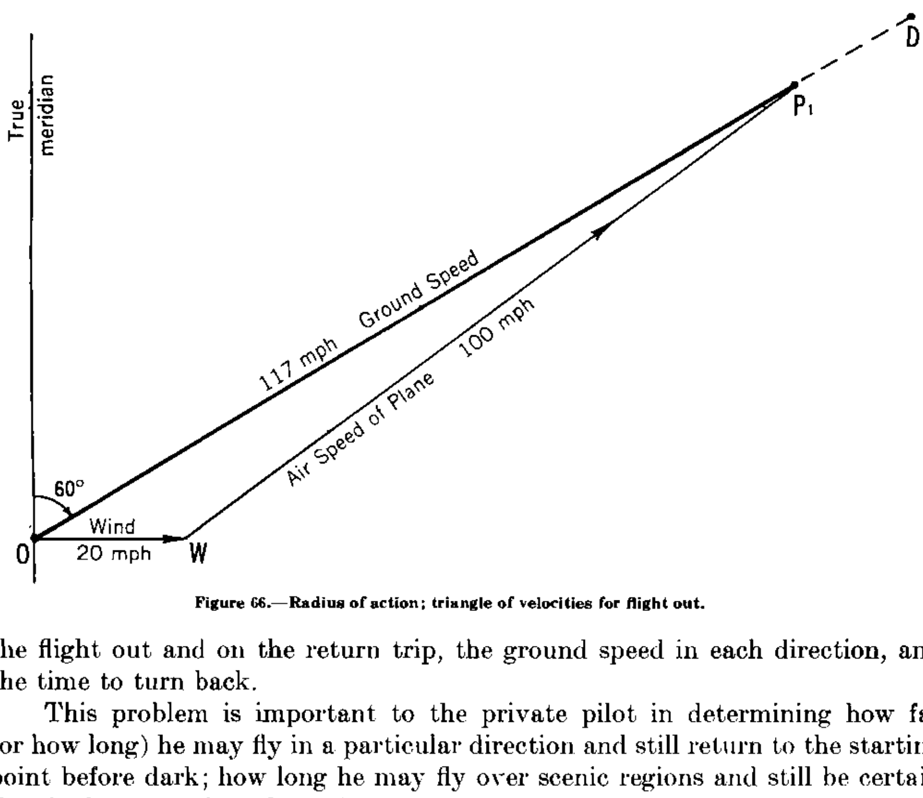


Figure 66.—Radius of action; triangle of velocities for flight out.

the flight out and on the return trip, the ground speed in each direction, and the time to turn back.

This problem is important to the private pilot in determining how far (or how long) he may fly in a particular direction and still return to the starting point before dark; how long he may fly over scenic regions and still be certain that he has enough fuel for the return trip, and so on. It is important to the commercial pilot when the weather at his destination is doubtful and he wishes to know how long he may continue toward his destination and still be able to return to his starting point, if need be.

Favorable winds reduce flying time for a one-way trip, but if the same wind continues for the return flight the round trip always requires more flying time than it would if there were no wind. In other words, for a two-way trip wind is always a hindrance, never a help.[3]

Radius of action problems consist of two parts, each of which may be solved by a triangle of velocities similar to that shown in figure 59. To illus-

[3] This is always true unless the wind changes during flight so as to afford a tail wind in both directions.

trate, let it be required that an airplane fly from *O* (fig. 66) as far as possible toward a distant point *D*, and return to *O*. Cruising speed of airplane 100 m. p. h., wind 20 m. p. h. from the west (270°), true course 60° for trip out, 240° for return flight. The total time available is 3 hours. Figure 66 is the triangle of velocities for the flight out, figure 67 the triangle for the return flight. In each case the correct heading to fly is ascertained, and the ground speed that will be made good along the intended track.

In practice, these two triangles are usually combined into one figure, as shown in figure 68, in order to save time in laying off angles and distances.

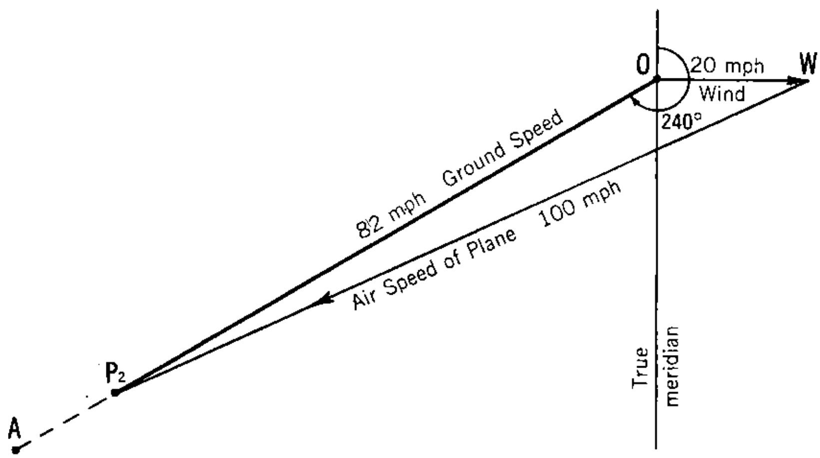


Figure 67.—Radius of action; triangle of velocities for return flight.

Having found the ground speed out and the ground speed back, the radius of action for each hour of flying time available is found from the formula

$$\text{radius of action}=\frac{\text{ground speed out}\times\text{ground speed back.}}{\text{ground speed out}+\text{ground speed back}}$$

In the example just given, then,

$$\text{radius of action}=\frac{117\times 82}{117+82}=48.2 \text{ miles for each hour.}$$

Since 3 hours of flying time are available, the total radius of action is 3×48.2, or 144.6 miles. The time required to reach the point of turning back is the time required to fly 144.6 miles at the ground speed (out) of 117 m. p. h., or $\frac{144.6}{117}=1.24$ hours, or 1 hour 14 minutes.

From the above example it should be obvious that the radius of action is the same whether the flight out is **with** the wind or **against** the wind. If the example were reversed, figure 67 would represent the flight out, figure 66 the return flight, and the same values would be used to compute the radius of action. In this case, however, the time to turn back would be the time required to fly 144.6 miles at the ground speed (out) of 82 m. p. h., or 1.76 hours=1 hour 46 minutes.

It is also of interest that minimum radius of action exists with wind parallel to the route (head or tail winds); maximum radius occurs with the wind at right angles to the route.

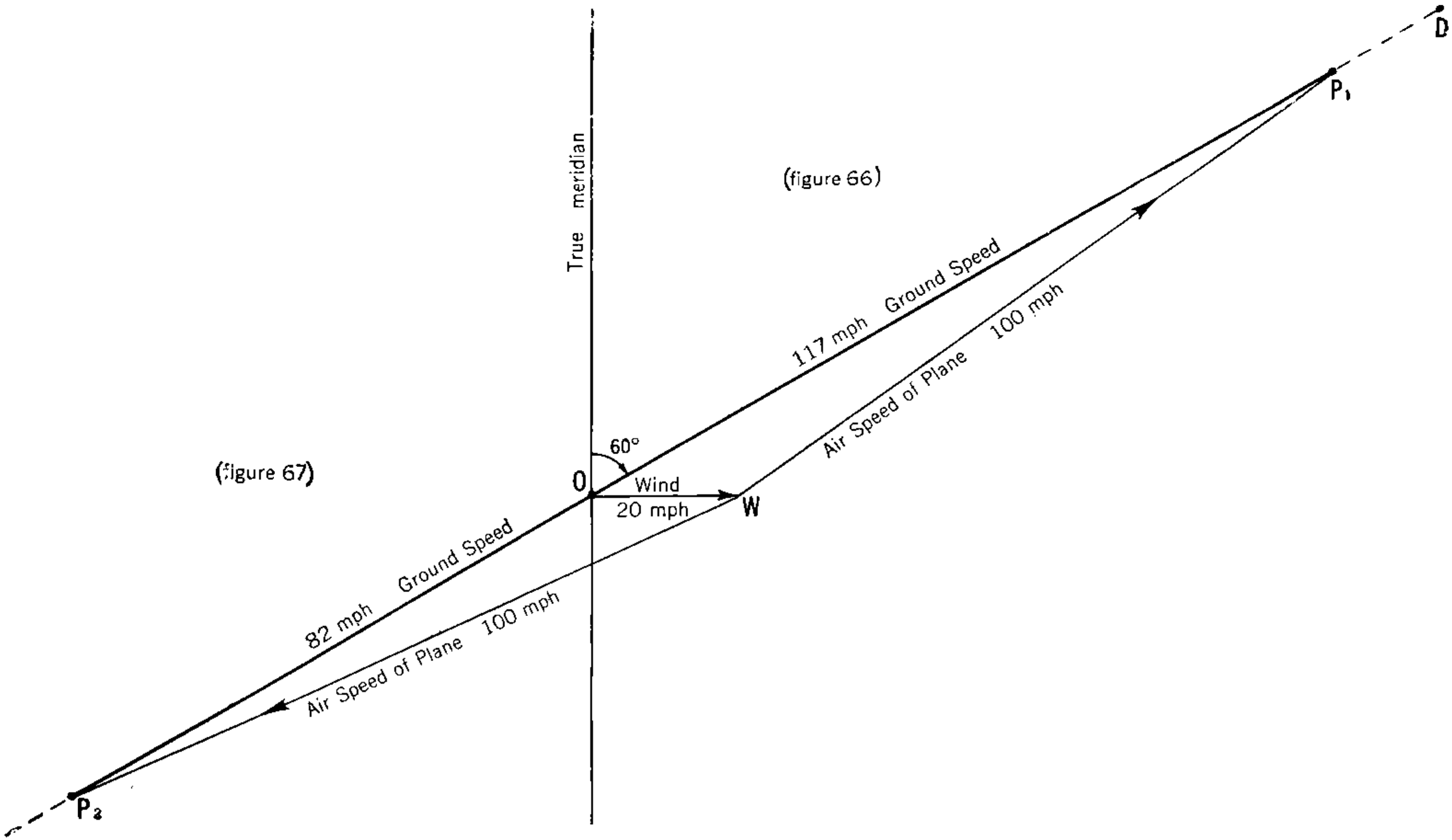


Figure 68.—Radius of action; triangle for flight out combined with triangle for return flight.

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Results obtained as above are precise; for many purposes, less exact values are satisfactory, and a convenient table showing the approximate radius of action for various wind conditions is given in chapter VIII.

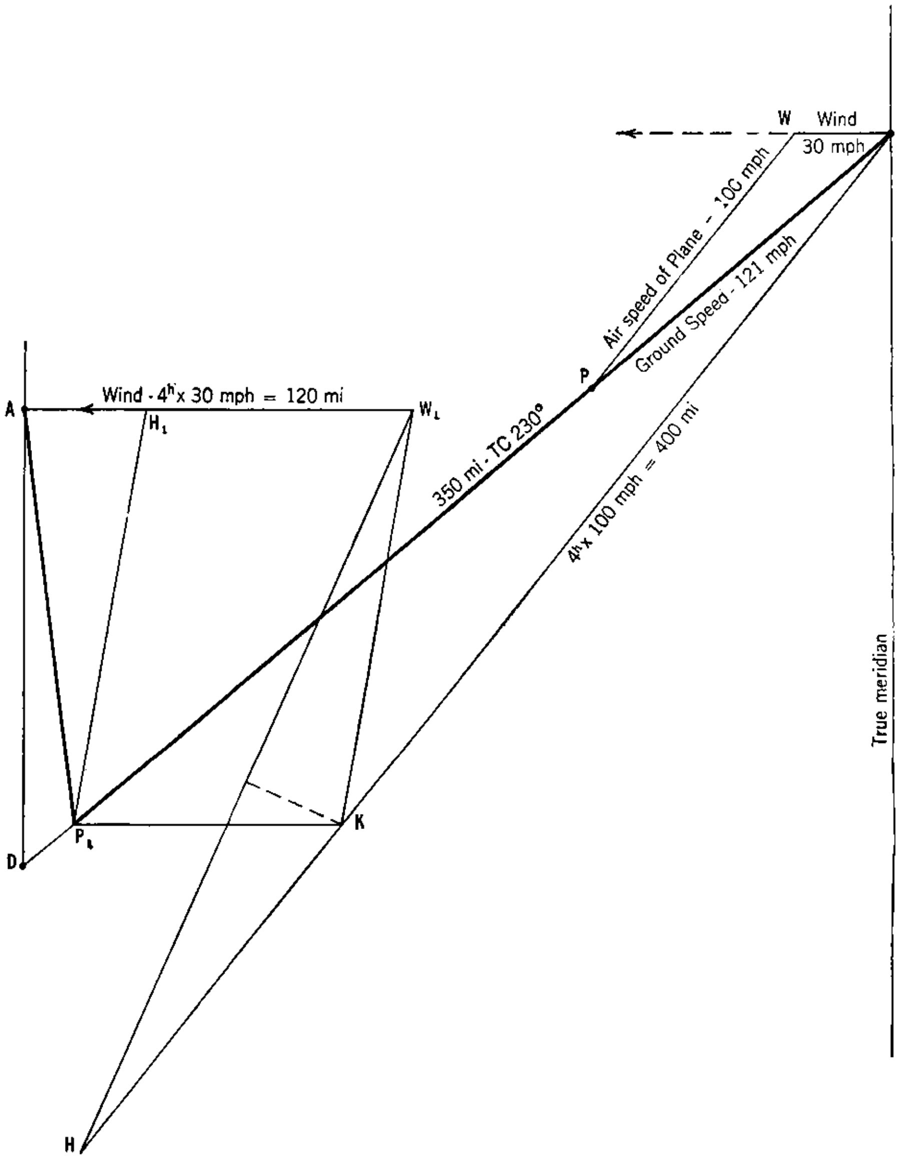

Figure 69.—Radius of action when turning back to an alternate airport (for whole flight).

A more difficult problem, but one which may prove valuable in an emergency, is that of determining the radius of action before turning back to an alternate airport. For example (fig. 69), a pilot leaves an airport at *O*, for a distant point *D*, with just 4 hours' fuel supply, aside from the required reserve. Weather conditions at *D* are very uncertain, but conditions at *A* are satisfactory and are expected to remain so. How far may he proceed toward *D* and still have fuel enough to reach A if advised by radio that the weather at D has closed in altogether?

The known data are as follows:

$OD = 350$ miles, true course 230°.
$DA = 140$ miles due north.
Air speed of airplane, 100 m. p. h.
Wind, 30 m. p. h. from 90°.

The first step is to plot the three points, O, D, and A, in their proper relative positions. The line OD, drawn at an angle of 230° to the true meridian, represents the intended track, or the true course it is desired to make good.

The next step is to construct a triangle of velocities OWP, in order to determine the correction to the course for wind. The true heading to be flown, OH, is laid off, equal to the total time available multiplied by the air speed of the airplane—in this case $4 \times 100 = 400$ miles.

From A lay off AW_1 into the wind and equal to the wind velocity multiplied by the total time in the air, which is 4×30, or 120 miles; draw HW_1.

Next it is desired to draw a line from W_1 to some point K on the line OH. so that $KW_1 = KH$. The easiest way to do this is to erect a perpendicular to the line HW_1 at its middle point; the intersection of this perpendicular with OH provides the point K, and by simple geometry $KW_1 = KH$. KP_1 is drawn parallel to the wind.

A simple explanation of this seemingly complicated plotting now becomes possible. An airplane leaving O on the heading OH with 4 hours' fuel supply can make good the air distance represented by OH. Since $KW_1 = KH$, it may also fly an air distance represented by $OK + KW_1$ in 4 hours' time; but since an airplane in flight is also subject to the full effect of the wind, the airplane in this case will have been drifted due west a distance equal to the wind velocity multiplied by the total time in the air, or $30 \times 4 = 120$ miles = the line AW_1, by construction.

We may now see that if the airplane flies the headings OK and KW_1 for a total time of 4 hours, and during the 4 hours is subject to a total drift represented by AW_1, the final position of the airplane will be the point A. Also, the heading OH was determined in order to make good the track OD; in flying that heading an air distance equal to OK, the airplane will have drifted westward by an amount equal to the line KP_1, and will have made good the track OP_1.

The point P_1 is the farthest point to which the pilot may fly toward D and still be able to arrive at A within 4 hours of flying time.

P_1H_1, parallel to KW_1, is the heading required to make good the desired track P_1A.

The time required to reach the point of turning back may be found either by scaling the distance OP_1 and dividing by the ground speed, or by scaling OK and dividing by the air speed. OK measures 272 miles, which divided by $100 = 2$ hours 43 minutes; P_1H_1 measures 129 miles, which divided by $100 = 1$ hour 17 minutes; total, 4 hours.

The above solution was presented first, to aid in visualizing the problem as a whole. It is entirely sound in principle, but is subject to the disadvantage that, since all three points must be plotted in one drawing, the scale of the triangle of velocities is necessarily quite small. This reduces the accuracy of the solution to some extent, and an alternate solution, based on only 1 hour of flying, is preferred.

To illustrate this method, it is required that a pilot fly from *O* (fig. 70) as far as possible toward a distant point *D*, and still be able to return to an alter-

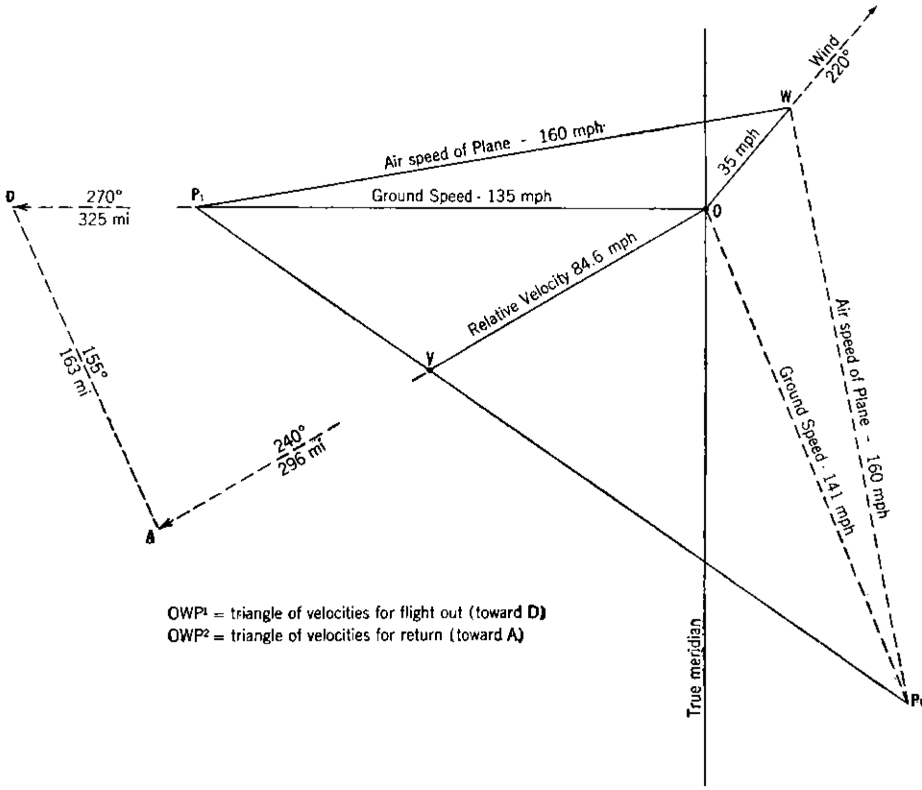

Figure 70.—Radius of action when turning back to an alternate airport (1-hour plot).

nate airport at *A;* he has fuel for 3.5 hours of flight, aside from the required reserve. The other data in this case are as follows:

> *OD*=325 miles, true course 270°.
> *DA*=163 miles, 155°.
> *OA*=296 miles, 240°.
> Air speed of airplane, 160 m. p. h.
> Wind, 35 m. p. h., from 220°.

Having drawn the true meridian, construct the triangle of velocities OWP_1. This is the triangle for the flight toward *D*, and determines the wind correction angle and ground speed.

Next, it is assumed that, if it is necessary to turn back, the pilot returns to the starting point *O;* but it is further assumed that the point *O* is steadily in motion toward *A* during the 3.5 hours of flight, and at the end of 3.5 hours will be at *A*. In this case, the point *O* must travel 296 miles in 3.5 hours, or at the "relative velocity" of 84.6 miles per hour.

The relative velocity *OV* is then laid off from *O* toward *A*, equal to 84.6 m. p. h., and the line P_1V is drawn, extending well beyond *V*, as shown. From

W a line equal to the air speed of 160 m. p. h. is drawn to meet the line P_1V extended, at P_2 and the line OP_2 is drawn. The triangle OWP_2 is the triangle of velocities for the flight from the point of turning back to the alternate airport at A.

From the two triangles, the ground speed and the true heading for the two parts of the flight may be found. The point of turning back, and the time of turning, may be found from mathematical formulas. They may be found more easily, however, by drawing a line from A on the chart, at the angle determined by the line OP_2; the intersection of this line with the line OD is the point of turning, T. The distance OT, divided by the ground speed of 135 m. p. h., gives the time of turning. Note that it is the ground speed line OP_2 that is to be plotted from A, not the air speed line; it is always the ground speed line that represents the course.

EXAMPLES

Example 1.—Starting at 10 a. m., a flight is to be made from Scott Field (near Wheeling, W. Va.) to Huntington Airport (Huntington sectional chart). Weather is reported as satisfactory for contact flight. Cruising speed of airplane, 90 m. p. h.: wind 15 m. p. h. from 45°.

Required.—The distance, compass heading, and time of arrival.

A straight line is drawn on the chart between the two airports, and is found to be a practical route, with two intermediate airports and an abundance of landmarks for checking the route of the airplane in flight.

By means of the border scale of miles the distance is found to be 151 miles.

When the route crosses not more than 3° or 4° of longitude, the course may be measured for the route as a whole, but must be measured with the meridian nearest halfway between the two points, as illustrated in figure 17. By inspection it is seen that the meridian of 81°30′ is nearest halfway.

219° true course, measured with meridian of 81°30′.
+3° westerly magnetic variation (average).
222° magnetic course.
+2° westerly deviation on this heading (from deviation card).
224° compass course.

The wind from 45°, in this case, is almost directly behind the airplanes hence there will be no correction to the course for wind, and the compass course (the true course plus or minus variation and deviation) is also the compass heading (the compass course plus or minus the correction for wind effect).

With a tail wind of 15 m. p. h., the ground speed becomes 105 m. p. h. The total distance of 151 miles will be covered in $\frac{151}{105} \times 60$ minutes, or a little more than 1 hour 26 minutes, making the time of arrival 11:26 a. m.

This is checked in flight by noting that the town of Woodsfield, 34 miles southwest of Scott Field, is passed in about 19.5 minutes of flying. The spacing dividers are set with the tooth marked 0 on Scott Field, and the tooth marked 10 just a little south of the town of Woodsfield; each tooth now represents 2 minutes of flying time, and the space between teeth numbered 0 and 10 represents 20 minutes. Four 20-minute sections are stepped off along the route, and the short section remaining is found to represent 7 minutes, which checks rather closely the data obtained before taking off.

By means of the spacing dividers the exact time when the plane should pass Marietta, Parkersburg, Gallipolis, the bends of the Ohio River, or other characteristic landmarks may be noted.

The section below Marietta, where the route follows the general trend of the Ohio River, affords a splendid opportunity for checking the compass heading in flight.

Attention should be given to the number of landmarks along this route. Starting from Scott Field, in about 9 minutes the airplane should pass the town of Jacobsburg, which is near the top of a ridge and at the end of a rail-

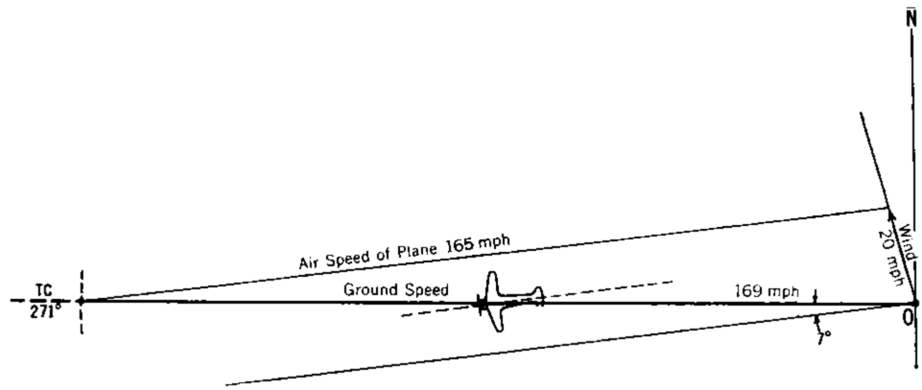

Figure 71.—Graphic determination of wind correction and ground speed.

road. Note also the race tracks at Woodsfield, Marietta, Parkersburg, and Gallipolis; the two bridges at Marietta, with dam and lock between; the dams and locks along the Ohio River; and the location of the Huntington Airport with respect to the dam and bridge.

Example 2.—A flight is to be made from Pittsburgh-Allegheny County Airport to Chanute Field, Rantoul, Ill.

For this flight either the Cleveland and Chicago sectional charts or regional chart 9M may be used. In this case the ship is fairly fast, dead reckoning (rather than piloting) will be employed, and the drainage pattern and larger cities will furnish sufficient check of position; therefore chart 9M is chosen. The flight will be made only when the weather permits contact flying. Cruising speed of airplane 165 m. p. h.; wind 20 m. p. h., from 165°.

Required.—The distance, compass headings, and the total flying time.

A straight line between the two airports is drawn on the chart and, by means of the border scale of miles, the distance is found to be 434 miles.

When the route crosses more than 3° or 4° of longitude the straight line should be divided into sections crossing approximately 2° of longitude each, and the true course for each section should be measured with the middle meridian of that section.

After a careful study the route is divided into three sections:

(*a*) Pittsburgh-Mount Vernon, Ohio.

(*b*) Mount Vernon-Portland, Ind.

(*c*) Portland-Chanute Field.

The data for each section are tabulated as follows:

	Pittsburgh to Mount Vernon	Mount Vernon to Portland	Portland to Chanute Field
Meridian nearest halfway	81°15′	83°45′	86°30′.
True course	271°	270°	268°.
Variation	+4°	+2°	−1°.
Magnetic course	275°	272°	267°.
Deviation	+1°	+1°	+1°.
Compass course	276°	273°	268°.
Wind [1]	−7°	−7°	−7°.
Compass heading	269°	266°	261°.
Length	136 miles	132 miles	166 miles.
Time	48 minutes	47 minutes	59 minutes.

[1] With the known data of true course and air speed of plane and direction and velocity of wind, a triangle of velocities is constructed for each section of the route. Fig. 71 shows the solution for the first section. In each case the correction to the course is determined as 7°, and since the wind is from the left the correction must be subtracted; the ground speed is 169 m. p. h.

Example 3.—A flight is proposed from Pittsburgh-Allegheny County Airport to North Platte Airport, Nebr.

Required.—The distance and compass headings.

The cruising speed of the airplane in this case is relatively low, and the flight will be chiefly for pleasure. Navigation will consist in large measure of piloting (contact flying), and the sectional charts will therefore be used.

In view of the distance, and the number of sectional charts required (Cleveland, Chicago, Des Moines, and Lincoln), this route should first be plotted on the Planning Chart, then transferred to the large-scale charts.

It is found that the straight-line route on the Planning Chart passes very close to the airports at Fort Wayne, Moline, and Omaha, and that these three places are fairly evenly spaced between the two terminals, at distances of about 275 miles which is just under the normal cruising radius of the airplane. The three places mentioned are therefore chosen as stops.

The first section is now drawn on the Planning Chart, from Pittsburgh-Allegheny County Airport to Fort Wayne Airport. This section of the route crosses the 84th meridian (the west boundary of the Cleveland chart) at latitude 41°. On the Cleveland chart, then, a line is drawn from the airport at Pittsburgh to latitude 41° on the 84th meridian. This represents the first portion of the route, on the Cleveland chart. The other sections of the route to North Platte are plotted on the remaining charts in the same way.

The route on the Cleveland chart is subdivided into 10-mile intervals, the total distance on this chart being 218 miles. The distances from the various charts are totaled, of course, to obtain the distance for the entire route.

The route from Pittsburgh to Fort Wayne crosses about 5° of longitude. This section is therefore broken down into two sections, crossing about 2½° of longitude each. The course should be changed at about longitude 82°30′, which in this case is marked for the pilot by the city of Mansfield. The magnetic course for the first section is found as 287°; for the second section, 283°.

QUESTIONS

1. Name several advantages of dead reckoning.

2. What are the two basic problems of dead reckoning?

3. State the four steps of case I, with an alternate procedure, and state why one or the other is preferred.

4. Define true course and true heading, and distinguish between them. Can they ever be the same?

5. In general, what should be the greatest length of route to be flown as one course?

6. What is the angle of convergence between meridians a degree apart on the Lambert projection, and what practical use may be made of it?

7. What substitute might be used for a straightedge, in plotting a long straight route?

8. Define magnetic variation, and state the rule for its application (*a*) in Case I; (*b*) in Case II.

9. Name some of the causes of compass deviation.

10. The magnetic course is often printed on a chart; why is the compass course never given?

11. Distinguish between magnetic course and compass course.

12. Define the drift angle.

13. Will the wind correction angle be greater or less than the observed drift angle when the wind is (*a*) 30° from the airplane's head? (*b*) 60° from the airplane's head? (*c*) 120°? (*d*) 80°?

14. Construct a triangle of velocities for the following data, to determine the wind correction angle and the ground speed: True course, 320°; air speed of airplane, 130 m. p. h.; wind, 30 m. p. h., from 225°.

15. If a true course of 245° were being flown should the correction be added or subtracted (*a*) for wind from 90°? (*b*) for wind from 270°? (*c*) from 180°?

16. Explain the difference between plotting a course and plotting a bearing.

17. What is the approximate rule for estimating an angle of 1°?

18. Give the formula for determining radius of action per hour when returning to the same base.

19. Determine the compass heading in each case from the following data; the letters *L*, or *R* after the wind correction angle indicate that the wind is from the left, or right, respectively:

	(1)	(2)	(3)	(4)	(5)
True course	70°	330°	165°	240°	40°.
Variation	7° W	17° E	4° E	6° W	12° E.
Deviation	3° E	3° E	5° W	10° E	2° E.
Wind correction angle	8° R	8° R	5° L	9° R	15° L.

20. Determine the true course in each case from the following data; the letters *L* or *R* after the drift angle indicate that the airplane is being drifted toward the left, or right, respectively:

	(1)	(2)	(3)	(4)	(5)
Compass heading	140°	240°	35°	330°	90°.
Deviation	10° E	3° W	2° W	5° E	1° W.
Variation	10° E	13° E	9° W	0°	6° E.
Drift angle	10° R	8° L	12° L	15° R	20° L.

21. Deviation cards for two compasses are shown below. With which compass should the recommended procedure outlined on p. 66 be followed? With which should the alternate procedure, given on p. 67 be followed?

For	N	330	300	W	240	210
Steer	1	333	301	268	240	209
For	S	150	120	E	60	30
Steer	179	147	118	92	62	33

For	N	330	300	W	240	210
Steer	3	335	309	282	247	213
For	S	150	120	E	60	30
Steer	178	146	110	79	51	26

Chapter VII.—RADIO NAVIGATION

THE IMPORTANCE OF AERONAUTICAL RADIO

In many respects, radio navigation offers the simplest and easiest methods of position-finding in flight. Radio aids to navigation are available which keep a pilot on course and warn him of any departure from the radio path; which point out his destination and keep him informed of the weather ahead; provide him with maps and printed communications while in flight; tell him how high he is above the ground; bring him landing instructions from the traffic control towers of busy airports; and are even beginning to guide him down to safe landings when he cannot see the ground.

The importance of aeronautical radio is steadily increasing, not only because of improved equipment and an increasing number of aids, but also because it continues to function in blind flying, when other methods fail or become very uncertain. Even the lightplane owner, with no more equipment than an inexpensive portable receiver, may enjoy radio range navigation; with the same equipment he may add to his safety by receiving the latest weather reports while in flight, and landing instructions from the control tower when he reaches his journey's end. Already there are a number of airports where aircraft not equipped with radio are forbidden.

Within the limits of one brief chapter it is impossible to treat in detail all the varied equipment that is available or to discuss the special methods possible with the various forms, and the merits and disadvantages of each. Rather, it is the aim here to present the general principles involved and to outline the methods of converting the information received into bearings and positions which may be plotted on a suitable chart. An important consideration in this connection is that the underlying principles do not change, although it sometimes seems impossible to keep a text up to date with the present rapid development of radio apparatus.

For the United States, a chart on the Lambert projection is ideal for all methods of radio navigation, since its meridians converge so nearly in conformity with the meridians of the earth that no corrections nor computations of any sort are required. A radio bearing may be plotted directly and correctly on the chart.

THE RADIO RANGE SYSTEM

Of the various methods of radio navigation, perhaps the simplest and best known is provided by the radio range system of the Civil Aeronautics Administration, illustrated in figure 72.

Each radio range station marks four courses, or equisignal zones, which are normally 90° apart, although this spacing is often varied in order that the courses may coincide with the established airways. For example (see fig. 73), the northeasterly course of the Jacksonville radio range station is directed

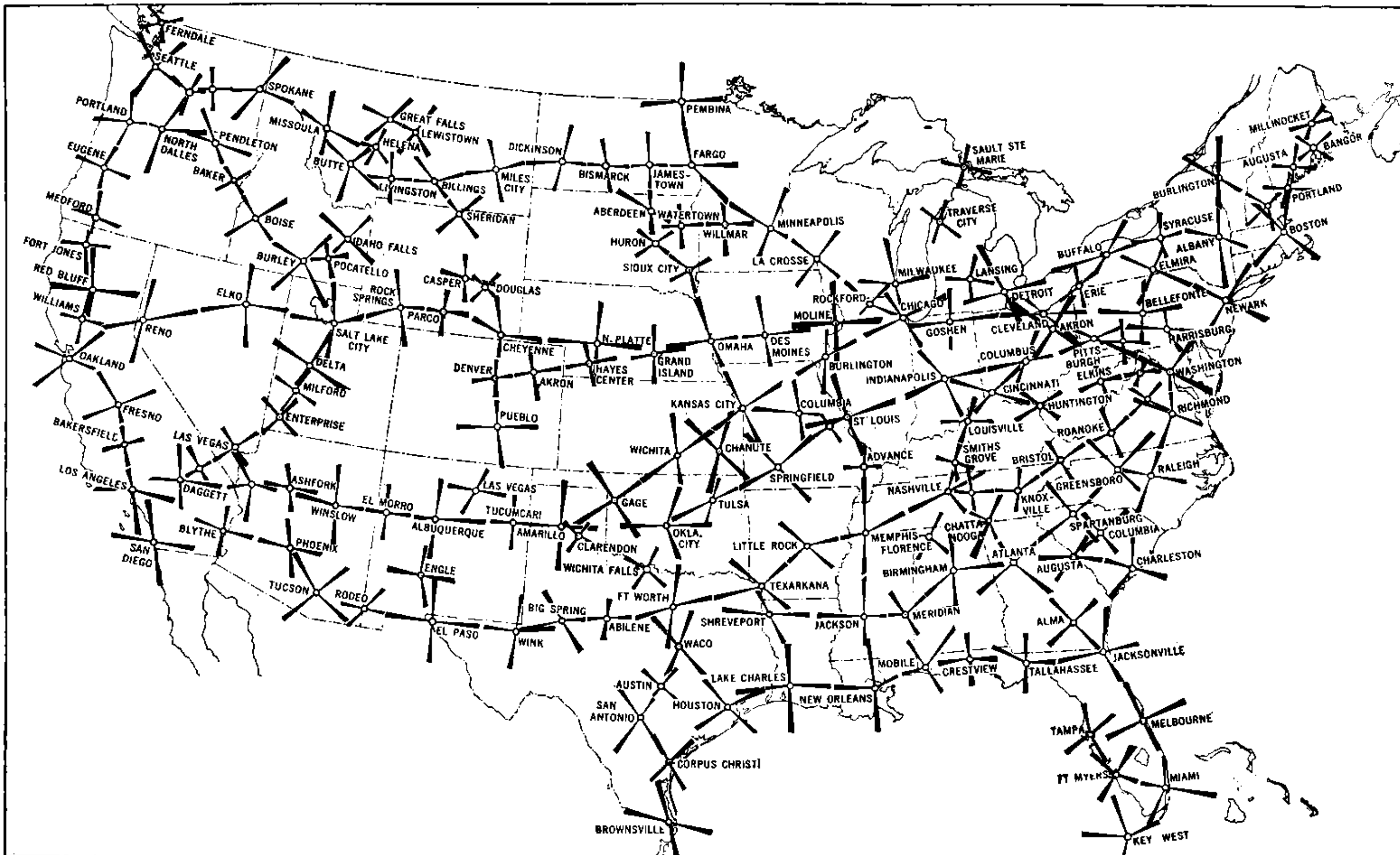

Figure 72.—The radio range system of the Civil Aeronautics Administration.

along the airway to Savannah; the southeasterly course along the airway to Miami. The westerly course serves no particular airway, although it is directed toward Tallahassee, and meets the easterly course of the Tallahassee radio range station, while the easterly course is directed out to sea. The four courses from each station are obtained as follows:

Into two diagonally opposite quadrants (fig. 73) the letter *N* (—.) is transmitted in Morse code, and into the remaining pair of quadrants the letter *A* (.—) is transmitted. Each quadrant slightly overlaps the neighboring quadrants, and in the narrow wedge formed by the overlap the two signals are

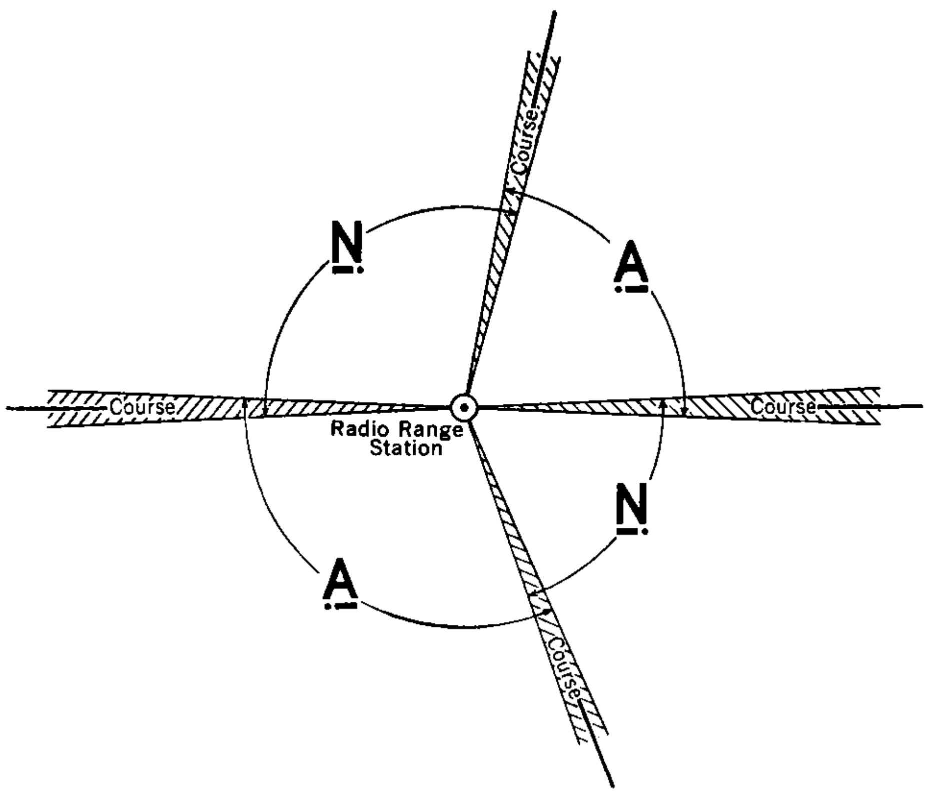

Figure 73.—Jacksonville radio range station.

heard with equal intensity, the dots and dashes of the two signals interlocking to produce a continuous signal, or monotone. Thus, a pilot will hear the continuous dash while he is on course; if he deviates to one side of the course he will hear the dot-dash (*A*) signal, and if he deviates to the other side he will hear the dash-dot (*N*) signal.

On the aeronautical charts of the Coast and Geodetic Survey the radio range system is shown in a pink tint, and the *A* and *N* quadrants of each station are indicated by conspicuous letters. By reference to the chart pilots may know from the signals received whether they are on course, or to the right or left of the course.

The on-course (equisignal) zone is about 3° in width, depending largely upon the orientation of the courses, the receiving equipment used, and the technique of the observer. Maximum sharpness of course is obtained with the receiving set tuned to the minimum practical volume.

As an aid to orientation, a uniform procedure is followed in the designation of quadrants. The letter *N* is always assigned to the quadrant through which the true north line from the station passes; or if the center of an equisignal zone coincides with true north, the letter *N* is assigned to the adjacent quadrant on the west.[1]

The range signals are interrupted about twice each minute for the transmission of the identifying signal of the station, which consists of two letters in continental code. (See p. 231.) This signal is always transmitted first in the *N* pair of quadrants, then in the *A* quadrants. If a pilot is near the bisector of an *N* quadrant, he will hear the dash-dot (*N*) signal, followed by the identifying signal, but will not hear the dot-dash (*A*) signal, nor the identifying signal which is transmitted into the *A* quadrants.

If he is on course, he will hear a dash, or monotone 25 seconds long, (the *A* and *N* signals interlocked) followed by the identifying signals, which are transmitted first into the *N* quadrants and then into the *A* quadrants. As long as a pilot remains in the equisignal zone, the identifying signals from both the *A* and the *N* quadrants will be heard with equal intensity; when following a radio range course, therefore, some pilots fly so as to keep these two signals of equal strength instead of trying to maintain the on-course monotone. If a departure from the course occurs, one identifying signal becomes noticeably weaker than the other; if the first of the two signals received is the weaker, the pilot knows he is in an *A* quadrant; if the second signal is weaker, he is in an *N* quadrant. In either case, of course, he knows his position with reference to the equisignal zone. When off course, experienced pilots are able to estimate approximately the angular departure from the course by means of the relative strength of the two identifying signals received.

Under good receiving conditions the first method (flying so as to maintain the on-course monotone) is more precise; under unfavorable atmospheric condition the latter method is generally preferred.

At most of the range stations now in operation provision is made for simultaneous broadcast of voice and range signals. By means of filters, pilots may listen to the range signals, the broadcast, or both. At a number of stations,[2] equipment has been installed for the transmission of a series of dots, as a warning, to pilots who may be listening to the range only, that a voice broadcast is about to be made.

At the older stations, a number of which are still in service, the range signals are interrupted at scheduled intervals for brief weather reports of interest to those flying the airway on which the station is located. In order to provide continuous range operation in emergencies, weather broadcasts may be omitted on request.

The radio range stations are usually located near a terminal airport or an intermediate landing field, and, whenever possible, they are so situated that one

[1] In Canada a different system of orienting range courses is practiced. Pilots flying into Canada should obtain local information.

[2] A total of 14 stations, July 1940.

of the four courses lies aong the principal runway or landing area of the airport, thus facilitating radio approach landings under conditions of low visibility.

In addition to the airway radio range stations operated by the Civil Aeronautics Administration, a number of important terminal airports are also equipped with privately operated airport radio range stations. These are exactly similar to the radio range stations already described, except that they are of quite limited power and range. They are always so located as to localize the landing area very definitely, and provide a positive control of landings in bad weather. The range courses from the airport radio range stations are shown by a pink tint on the aeronautical charts, but the bearings are omitted in order to avoid confusion in the congested areas surrounding major airports. Pilots desiring complete data should always obtain them from the TABULATION OF AIR NAVIGATION RADIO AIDS, which is issued at frequent intervals by the Civil Aeronautics Administration and may be had free upon request.

From the foregoing it is evident that the use of the radio range system is basically quite simple, and should present little difficulty even for pilots with no previous training in this type of navigation. There are several factors, however, which may prove confusing until the principles involved are understood.

First, it is obvious that as an airplane passes over a radio range station there is an apparent reversal of the directions of the *A* and *N* quadrants. For example, an airplane approaching the radio station of figure 73 from the north will have the *A* quadrant on its left, the *N* quadrant on its right; but as soon as it has passed the station the *N* quadrant will be to the left and the *A* quadrant to the right.

THE CONE OF SILENCE

Directly above the antennas or towers of the radio range station there is a cone of silence, a limited area shaped like an inverted cone, in which all signals fade out. Just before entering the cone of silence the volume of the signals increases rapidly; as the airplane enters the cone, the signals fade out abruptly for a few seconds, the length of time depending on the speed of the airplane and the diameter of the cone at the level of flight. When the airplane first leaves the cone, the signals surge back with great volume before they begin to fade as the distance from the station increases. If the airplane passes over the station a bit to one side of the cone, and the receiver is not kept to minimum volume, the signals do not entirely fade out.

Sometimes there is a momentary fading of signals, or a false cone of silence, at other points along the airway, but this can be distinguished from the true cone of silence by the absence of the surge of volume at the edges of the cone, and by the nonreversal of signals, which should have taken place in passing over the station. In order to avoid any uncertainty from this cause, most ranges are now equipped with a new type of marker beacon ("Z type"), which emits a distinctive, high frequency radio signal in the cone of silence.

MULTIPLE COURSES

When flying away from a radio range station it is important to check the magnetic course being made good (the compass heading plus or minus deviation and wind effect) at frequent intervals, as multiple courses exist at some locations—particularly in mountainous country. That is, the equisignal zone, which is normally about 3° in width, may be broken up into a number of narrow on-course bands with a total spread of 10° or 15°, or even more. Between these narrow on-course bands the proper quadrant signal is usually heard, although an *A* signal is sometimes found in an *N* quadrant, and vice versa. Figure 74 shows the conditions on the Salt Lake City radio range courses at distances of about 12 and 28 miles from the station.

By checking the magnetic course being made good against the magnetic direction of the range course printed on the chart, pilots can lessen the danger of following one of these false courses away from the established airway; also, a multiple course can often be recognized by its narrow width in comparison with the true range course. This item is of less importance when flying toward the station, since even a false range course would serve perfectly as a homing

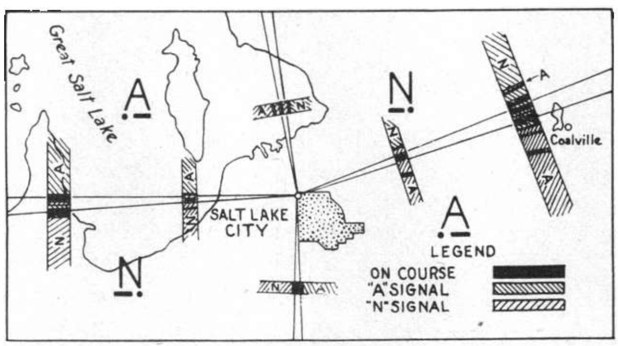

Figure 74.—Salt Lake City radio range station, showing multiple courses.

device; however, in this case it should be remembered that such a course may lead over terrain that is dangerous because of high mountain peaks.

BENT COURSES

A related difficulty is found in bent courses. As a rule, the bend is relatively small, and is of little importance since it bends away from and around the obstruction that causes it; however, in mountainous country bends of as much as 45° have been noted. Several such bends may occur in a short distance, and to attempt to follow them without a thorough knowledge of their relation to the terrain, previously gained under conditions of good visibility, might prove impossible. If the airplane continues in straight flight under these conditions, the range courses seem to be swinging from side to side.

NIGHT EFFECT

Courses from range stations using the old loop antenna do swing at night—often to such an extent that they are not usable at distances more than 25 miles from the station. This phenomenon is known as night effect, and has been practically eliminated in more recent installations by using four vertical radiators instead of two crossed loop antennas. In view of the difficulties mentioned, when flying blind (on instruments) it is important to maintain an altitude well above any nearby peaks or obstructions—and in interpreting the word "nearby" a generous allowance should be made for any possible uncertainty as to the position of the airplane.

Mention of these weaknesses should not destroy confidence in the radio range system, which as a whole is very dependable, and the most effective aid yet developed. They are presented here in order that pilots may be ever on the alert, taking nothing for granted when the safety of life and property is at stake.

Some of these difficulties may be greatly reduced as the result of development work now being conducted by the Civil Aeronautics Administration. For example, in addition to the regular low-frequency radio range, a complete radio range system is being installed between Chicago and New York, using ultra-high frequencies; this is expected to afford definitely improved performance.

An experimental installation has been made of a 2-course radio range, also on ultra-high frequency, which is expected to afford simpler means of orientation, as well as certain other advantages. Considerable work has been done on an omnidirectional radio beacon, which is intended to give the equivalent of a range course from any direction toward the transmitter.

THE RADIO RANGE AND DEAD RECKONING

For most effective use, the radio range system should be regarded as an aid to dead reckoning. With any form of radio navigation there is always the possibility of excessive static and of mechanical failure, either in transmission or reception; in such cases, the pilot who has neglected other methods of navigation may find himself hopelessly lost and without the information necessary for safely completing the flight.

One of the greatest advantages of the radio range system is that pilots need not be directly concerned with corrections for drift. As long as the airplane is kept along the right side of the equisignal zone (with reasonable precaution against multiple courses), they can be certain of the track made good over the ground. This does not mean, however, that drift may be safely neglected; in order to keep the airplane along the edge of the range course it may be necessary to head the airplane into the wind at an appreciable angle in order to stay on course. It is important that this angle be observed, and that every possible check should be made of current wind conditions and the proper allowance for wind.

Figure 75 illustrates what actually happened in one case, through failure to make proper allowance for wind. A pilot was flying south, along the right side of the equisignal zone, at position 1. Due to a pronounced change in wind direction which had not yet been detected, no allowance was made for the northwest wind. Under the action of this wind the aircraft drifted into the northeasterly *A* quadrant, as shown at 2. The pilot supposed he had crossed the westerly course of the range, and was in the southwesterly *A* quadrant, at 3. He therefore turned toward the east, with the idea of getting on the southerly course of the range, but struck the side of a mountain, near 2, as indicated.

ORIENTATION

Ordinarily, the most difficult problem that may arise is that of quadrant identification and of finding the range course as quickly as possible from an unknown position. For the solution of this problem an accurate aeronautical chart is indispensable; only from this source can the pilot learn the identifying signals of the stations in his vicinity, the relative positions of the four radio range courses from each station, and the magnetic directions of the courses. Here, again, the fact should be emphasized that a chart, once sold, can be corrected only by the user. Before beginning any flight in which the use of radio may become necessary, the charted data should be checked against the latest TABULATION OF AIR NAVIGATION RADIO AIDS and the subsequent WEEKLY NOTICE TO AIRMEN, and any changes should be noted on the chart.

There are several favored methods of quadrant identification and of finding the range course as quickly as possible, and the pilot should become thoroughly familiar with each of them in order to solve any given problem with the least delay. In the following discussion of the various methods it will be assumed in each case that the pilot knows, from the signals received that he is in one of the two *A* quadrants of the Harrisburg radio range station, but does not know which one.

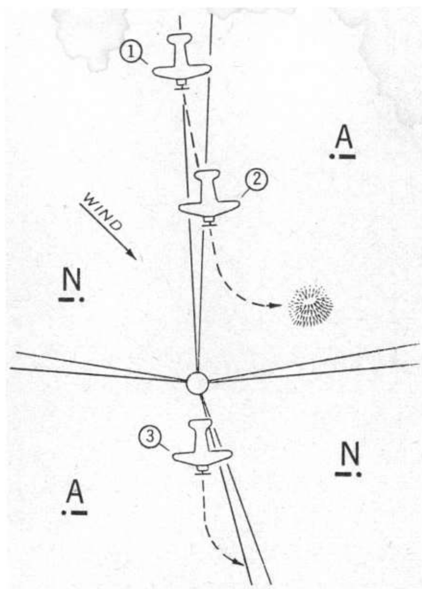

Figure 75.—The danger of neglecting drift in radio range navigation.

The 90° turn method.—This was the first method of orientation to be developed. It is still popular because of its simplicity and uniformity, and is probably as good as any when within reasonable distance of a range which has 90° quadrants.

Under this system a course is flown at right angles to the average bisector of the two possible quadrants (fig. 76). When the course-pattern of a station is not symmetrical it is important to use the *average* bisector of the two quadrants, since it is equally suitable for either of the quadrants in which the airplane may be located. The bisector of the northeast quadrant is (14°+113°)÷2, or 63°; the bisector of the southwest quadrant is (172°+284°)÷2, or 228°. The reciprocal bearing of 228° is 228°−180°, or 48°. The average bisector of the two quadrants then is (63°+48°)÷2, or 56°. For greater ease in reading the compass or directional gyro during orientation procedure, the headings are usually determined to the nearest 5°. The average bisector in this case is therefore considered as 55°, and the course at right angles may be either 145° or 325°.

If the course of 325° is chosen, then it is certain that courses 2 and 3 are somewhere behind the airplane.

The pilot continues on the course of 325° until the on-course signal is received; through the equisignal zone until the first *N* signal on the other side is heard; then makes a 90° turn to the right.

He knows he has intercepted either course 1 or course 4. If it is course 4, the *N* signal continues after the turn; if it is course 1, the on-course signals will be heard first, then the *A* signal again. Thus the signals received definitely identify the course intercepted.

In either case, the pilot makes a general turn to the left, away from the station, and gradually eases into the equisignal zone, as shown; he then follows the range course in to the station, and from that point on to the local airport or a more distant destination. When approaching the radio range station and

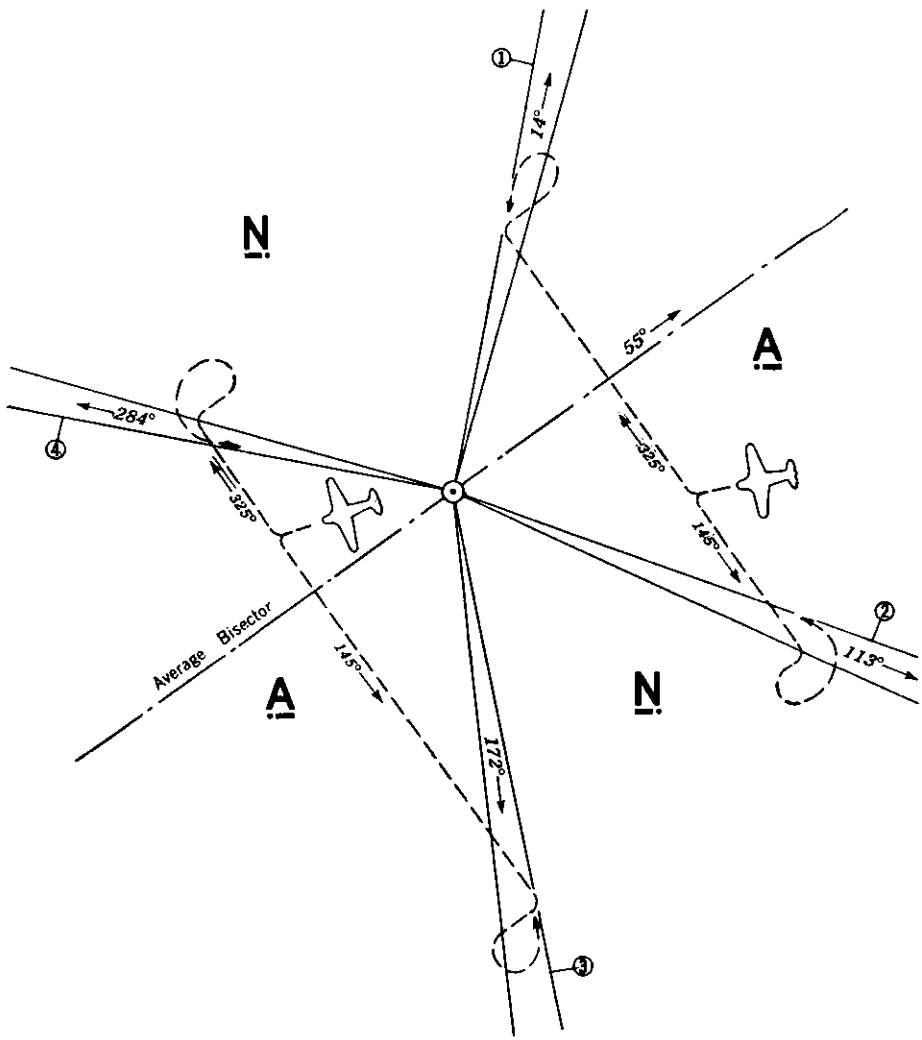

Figure 76.—Identification of the quadrant and range course; 90° turn method.

close to it, pilots may fly in the on-course zone; pilots flying **from** a station **are** definitely required to fly to the right of the equisignal zone.[3]

If the course of 145° is chosen, rather than 325°, the procedure will still be the same as before, as shown in figure 76.

Where multiple courses are known to exist, instead of making the 90° turn as soon as the first *N* signal is heard, it is advisable to fly for some little

[3] Provided for in the Civil Air Regulations, which may be obtained from the Civil Aeronautics Administration.

distance before making the turn, selecting the true range course from among the several false ones encountered, if possible.

After identifying the course intercepted, by means of the 90° turn to the right described above, instead of making the general turn to the left it was formerly the practice in some cases to make another turn to the right until the range course was again intercepted, and then follow it in to the station. This has the disadvantage that the airplane crosses the course at a very sharp angle, nearer to the station; if the distance from the station is not great, the course is so narrow that it may be crossed without the pilot being aware of it, and further time is lost feeling the way back to the equisignal zone again. Also, if the airplane is close to the range station, making the second turn to the right may cause it to cross not only the course first intercepted, but another course as well. In this case confusion would certainly result, and valuable time would be lost while the entire problem is worked out once more.

In the example just given it was assumed that the pilot was near the center of an *A* quadrant; now suppose he is near enough to one of the range courses that he can faintly hear the identification signal transmitted into the *N* quadrants as well as the identification signal transmitted into the *A* quadrants. This means that he is either just north of course 2 or course 3, or just south of course 4 or course 1.

If he flies the 325° course, at right angles to the average bisector of the quadrants, and the faint signal begins to fade, he knows he is flying away from the nearest on-course zone, and that he is therefore just north of course 2 or course 3; he makes a 180° turn, approaching the equisignal zone on the 145° course, and the procedure from this point is identical with that illustrated in figure 76.

If he flies the 325° course and the faint signal becomes stronger, the pilot knows he is approaching the equisignal zone, and that his position is therefore just south of course 4 or course 1. He therefore continues on the same heading, his further procedure being exactly as shown in the figure.

If flying entirely blind, the pilot should make sure that he is maintaining a safe altitude above the highest elevation in either *A* quadrant. The highest contour shown on the chart within reasonable distance of the Harrisburg station is 2,000 feet, but the color gradient of elevations, as shown in the margin, is from 2,000 to 3,000 feet; therefore an altitude well above 3,000 feet should be maintained until the position of the airplane can be definitely known.

Under favorable conditions, this is a very dependable method. Its chief disadvantage may be seen from figure 73. If the airplane is in a quadrant where the courses meet at a wide angle (as the northwest quadrant of figure 73), on a course at right angles to the average bisector of the quadrants it may be necessary to fly a considerable distance before picking up the on-course signals, particularly if there is any appreciable amount of drift.

The fade-out method.—Under this system the pilot flies a course paralleling the average bisector of the two quadrants (instead of at right angles thereto), with the volume of his receiver as low as possible. If the signal fades out, he knows that he is flying away from the station; if the volume increases, he knows that he is approaching it. This procedure identifies the particular quadrant in which he is flying, unless some of the difficulties mentioned later prevent.

Referring to figure 77, if the pilot is flying a course of 55° and the signal fades out, he knows he is in the easterly *A* quadrant with the station behind him; he makes a 180° turn and flies to and through an equisignal zone. As soon as the first *N* signal is received, he turns left, not more than 180°, until the on-course signal is again received.

Then, with volume as low as practical, he straightens out along the right side of the range course and flies until the volume fades out or builds up appreciably. If it is increasing, he follows it in to the station; if it fades out, he

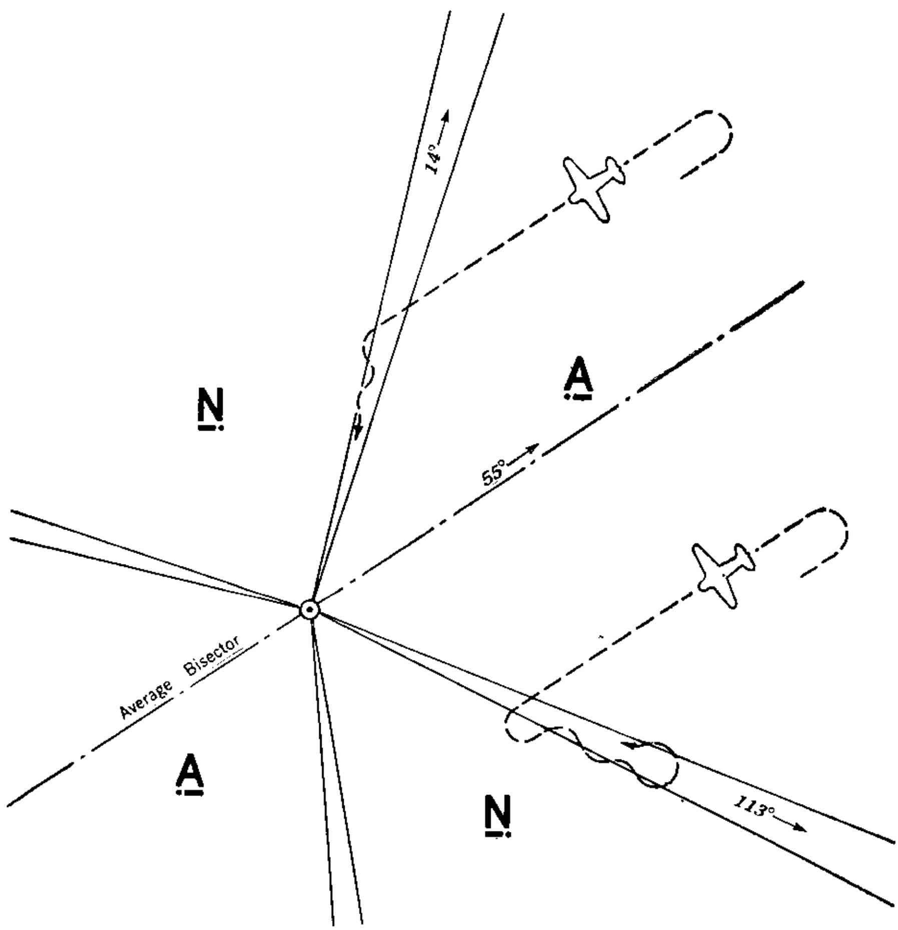

Figure 77.—Identification of the quadrant and range course; fade-out method.

makes a 180° turn and then follows it in to the station as a new point of departure.

One weakness of this system is that for some stations the signal strength is variable due to irregularities of the terrain, or night effect; the signals from these stations alternately increase and fade so that it is difficult to decide definitely, without undue loss of time, whether the volume is increasing or fading out. Also, in the case of "squeezed courses" (that is, when the courses are not 90° apart; see fig. 73) it is possible to fly away from a station and have the signals become stronger, instead of weaker.

It should be understood that under any conditions the greatest signal strength is found along the bisectors of the quadrants, the lowest signal strength along the edges, where the on-course zones are located. Therefore, flying parallel to the bisector, but at a considerable distance from it, the signal strength may decrease as the on-course is approached, even though the station is nearer. If the decreased signal strength is due to approaching an on-course zone, the double signals of the twilight zone should be heard upon turning up the volume. If the twilight signals are not heard with the increased volume, it is definitely known that the airplane is proceeding away from the station. In either case the quadrant is identified, the direction with respect to the station is known, and the pilot may proceed as outlined above and as illustrated in figure 77.

Several combinations of these two methods will suggest themselves. For example, after intercepting an equisignal zone, the range course may be identified and followed in to the station by essentially the same procedure as that illustrated in figure 76. Also, as in the first method, if the two identification signals are heard, one loud and one weak, and the weak one begins to fade out, it is evident that the pilot is flying away from the nearest range course as well as from the station; the 180° turn is made at once, and the procedure is then as shown in the figure.

A standard method. For a particular situation, one procedure may have certain advantages; at another time a different method is preferable. To prevent confusion and loss of time in trying to choose the most suitable method when the position of the aircraft is uncertain, some standard procedure is desirable—one that will fit ANY conditions that may arise.

It has already been pointed out that the 90° turn method first described is not practical under some conditions. Others object to the fade-out method because of the excessive turning required after intercepting a course (see fig. 77). The following method—in principle, at least—has been adopted as standard by some of the major airlines, since it may be used satisfactorily on any and all ranges.

First, the quadrant is identified by the fade-out method described above, and the airplane is headed parallel to the bisector, toward the station (fig. 78). It will intercept either course 1 or course 2.

At Harrisburg the final approach should be made from the west, over course 4. It would be desirable, therefore, to intercept course 2 rather than course 1, continuing on course 2 past the cone of silence and out on course 4, then making a 180° turn for the final approach. Under this "standard method," the pilot assumes that he actually will intercept the desired course (course 2). As he enters the twilight zone he changes heading so as to approach course 2 (if his assumption is correct) at an angle of 30°; an easy turn on reaching the equisignal zone then brings him on course. If his assumption is wrong (a 50–50 chance), he will intercept course 1 and pass quickly through it. The fact that the course was crossed so quickly is notice that he has intercepted course 1, rather than course 2. He may either turn back to course 1 and by a series of turns settle down on that course, ultimately following it in to the station; or he may fly on into the northwest *N* quadrant for a time, then turn toward course 4 at an angle of about 90° thereto, and follow it in to the station upon reaching the on-course zone.

In a narrow quadrant this latter method (approaching a known course at right angles) materially reduces the time required for identifying an equisignal zone and beginning the approach.

The parallel method.—Under this system, desiring to reach the station over course 2 as before (fig. 78), the pilot flies parallel to course 1 until the on-course signals are heard, then makes a turn away from the station and settles down on course. A 180° turn then heads him toward the station.

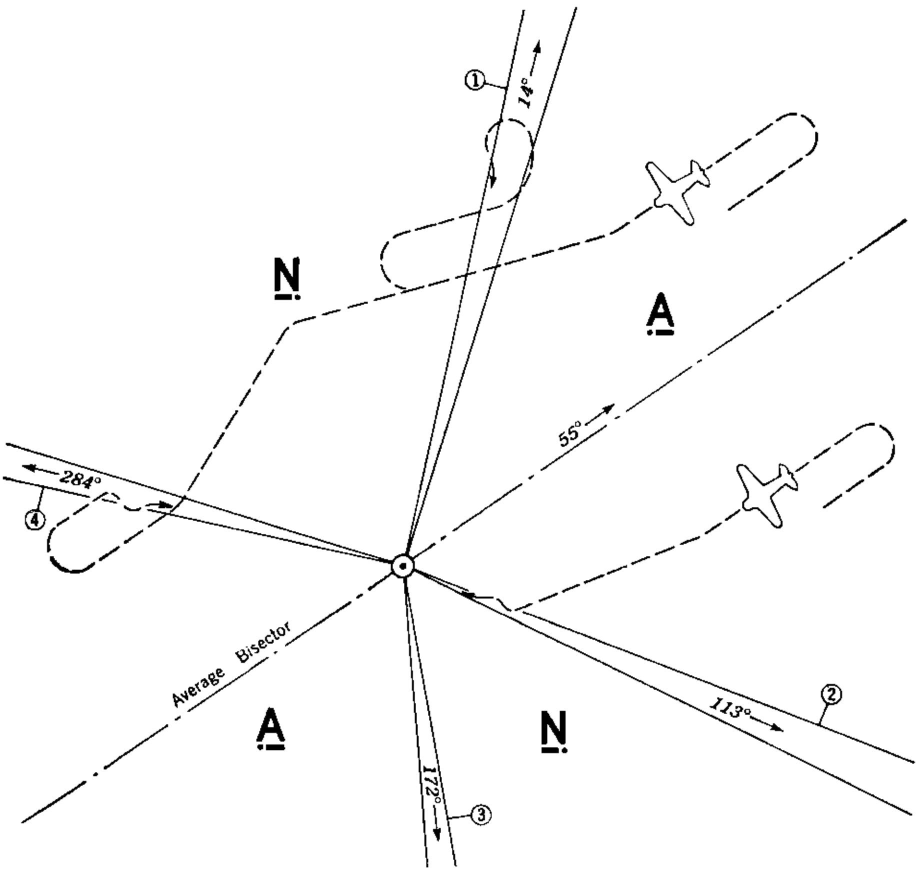

Figure 78.—Identification of the quadrant and range course; a standard method.

Various other methods of quadrant identification and orientation have been used, but it is believed that those just described are among the simplest yet developed and represent the best present practice. At least one of them will be found suitable for any problem that may arise.

The airport orientator is a valuable aid in all problems of quadrant and range course identification. In this instrument a circular chart showing the airport in relation to the courses of the radio range, with other pertinent data, is directly attached to a disc member on the top of the directional gyro. Once the chart of the orientator has been properly aligned with the corresponding features on the ground, it remains so, as the result of gyroscopic action. Thereafter, regardless of the number of turns, a faithfully oriented picture of the attitude of the airplane with respect to the range courses is given by the orientator chart—without mental effort on the part of the pilot.

With a radio compass using a visual indicator, quadrant identification is generally unnecessary, since the pilot may determine the direction of the station and fly directly to it, setting a new course from that point toward his destination.

In addition to the general problem of quadrant identification, certain other rules must be observed. For example, in order to prevent meeting aircraft flying in the opposite direction, it is important that pilots fly to the right of the radio range courses. As an added safeguard, the Civil Air Regulations require that flights along an airway be made at definite altitudes[4]—in one direction at the odd thousand-foot levels (as 3,000, 5,000, or 7,000 feet above sea level), and in the opposite direction at the even thousand-foot levels (as 4,000, 6,000, or 8,000 feet). This insures that there will always be at least 1,000 feet vertical separation between planes flying in opposite directions. Definite altitudes are fixed for crossing another airway, and other restrictions have been placed upon instrument flying within 10 miles of the center of an established civil airway, or within 25 miles of the center of a control zone of intersection, by pilots not engaged in scheduled air transportation. All these requirements are set forth in detail in the Civil Air Regulations. Pilots are urged to obtain the latest copy of these regulations, and to become thoroughly familiar with them.

Due to the effect of wind, as well as irregularities in maintaining the required heading, it is seldom possible to hold steadily to the course marked out by the range. Instead, if the pilot is slightly to the right of the course he heads a few degrees to the left until the on-course signals are heard, then a few degrees to the right until the off-course signals again predominate, etc. In this way he "weaves" along the right-hand edge of the equisignal zone, making frequent checks of the course by means of his compass.

RADIO MARKER BEACONS

At critical points along the radio range courses there are also radio marker beacons. These are low power transmitters which emit a distinctive signal on the same frequency as that of the range on which they are located, and serve to inform the pilot of his progress along the route. When located at the intersection, or junction, of courses from two radio range stations, marker beacons operate on the frequencies of both stations. When the pilot receives the signal of a marker beacon so located, it serves as a reminder to tune his set to the frequency of the radio range next ahead of him.

All radio marker beacons of this type are equipped for two-way voice communication, and are prepared to furnish weather reports and other emergency information, or to report the passage of an airplane, on request. In case the airplane is not equipped with a transmitter, if the pilot circles the marker beacon the operator will come on the air with the weather for that particular airway. The pilot indicates that he has received the information by a series of short blasts of his engine, and proceeds on his way.

More recent installations of marker beacons are of the ultra-high-frequency "fan type." These beacons operate on a frequency of 75 megacycles (75,000

[4] This applies only to *instrument* flight, and not *contact* flight.

kilocycles), and have no facilities for voice communication. From one to four fan markers may be located around any given range station, usually at distances of about 20 miles. Beacons of this type are in operation on three of the four courses of the Newark range (fig. 79). The remaining course has no fan marker, since it serves no airway but is directed out to sea. Each such marker beacon transmits a fan-shaped radio pattern across the equisignal zone. The markers around a given radio range station are identified by a

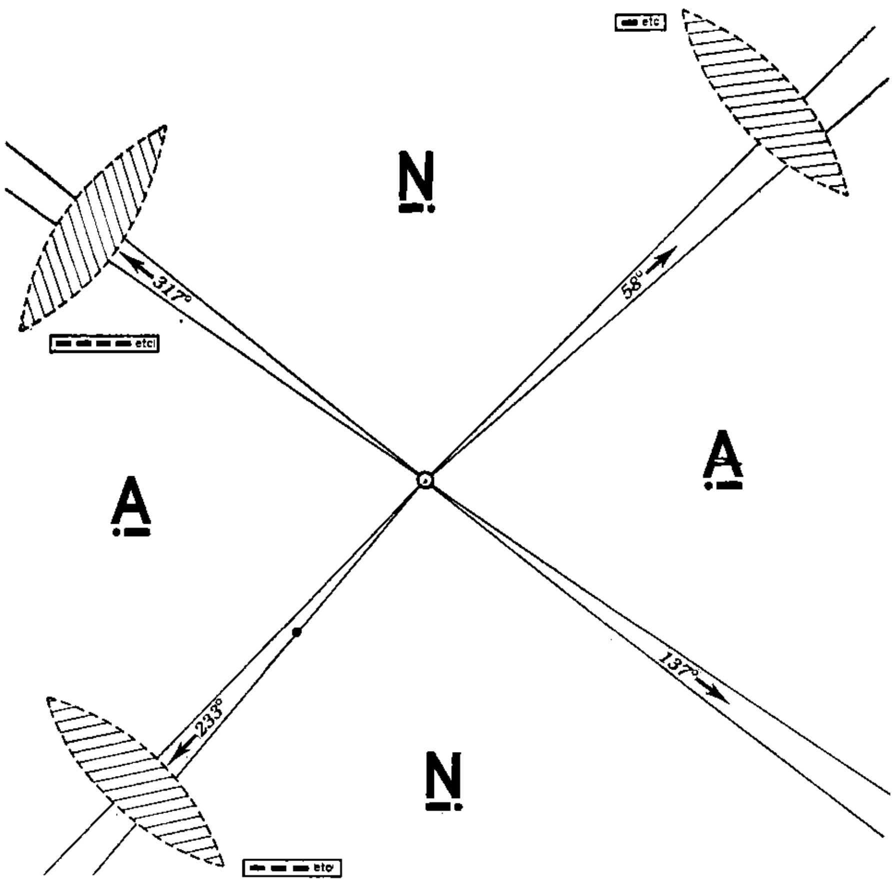

Figure 79.—Fan marker beacons around the Newark radio range station.

succession of single dashes, or by groups of two, three, or four dashes. The single-dash identification is always assigned to a course directed true north from a station, or to the first course in a clockwise direction therefrom; the groups of two, three, or four dashes are assigned respectively to the second, third, and fourth courses of the station, proceeding clockwise from true north. The identifying signals assigned to the fan markers around the Newark range (fig. 79) illustrate this practice. The signal of a fan marker beacon, then, identifies a particular course of a range, and also a position along that course; it therefore definitely fixes the location of the airplane. The fan marker beacons also constitute an important link in the system of airway traffic control.

In thick weather, when visual observations cannot be made, ground speed can be determined by noting the time required to reach a given marker beacon, or from the elapsed time between passing successive marker beacons, range stations, or cross beams from other radio range stations. Such points are known as "radio fixes," and are important in the system of airway traffic control.

EFFECT OF WIND ON TURNS

The effect of high winds on some of the orientation problems should be understood. Figure 80 is the same as figure 76 (the 90° turn method of orienta-

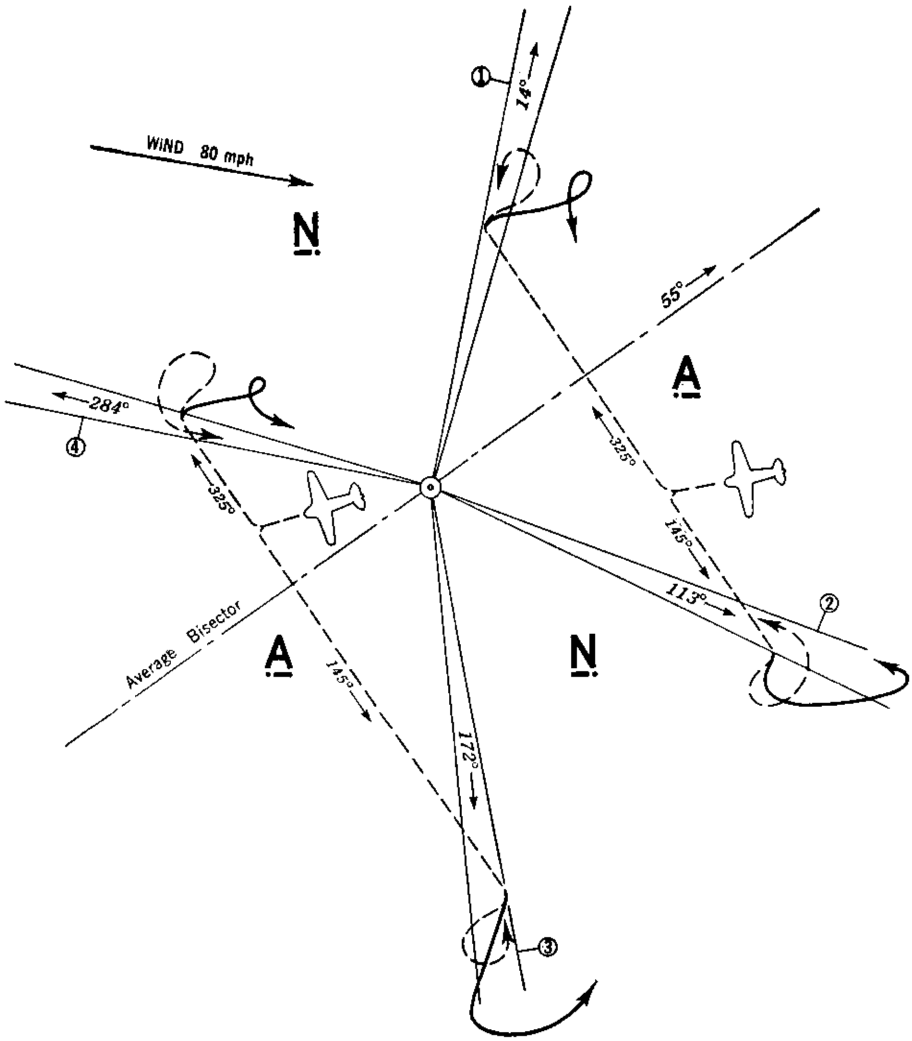

Figure 80.—Effect of wind on turns in orientation procedure.

tion), except that heavy solid lines have been added, showing the paths of the airplane at different points under the action of a high westerly wind. In order to illustrate the situation more clearly, a wind of 80 miles an hour is assumed, with an air speed of only 110 miles an hour.

At position 1 in the figure, with wind of this proportion, the airplane will not follow the light broken line and return to the range course as intended, but will follow the heavy line.

At position 2, the case is not so bad, resulting only in increased distance from the station.

At position 3, upon turning back into the range, drift would keep the pilot in the on-course zone so long he would probably doubt the whole procedure. If he continued with the problem, his track would be as shown. With the wind more nearly at right angles to the course, the airplane might even be kept in the *N* quadrant by drift, leading the pilot to suppose he was at position 2.

At position 4, as at position 1, it is unlikely that the airplane would ever return to the range course.

While these are extreme conditions, not likely to be experienced in practice, they serve to emphasize the effect of wind in turns. Pilots should make every effort to know the wind at all times during flight, and to visualize the effect of wind upon the headings being flown, or the maneuvers being performed.

RADIO DIRECTION FINDING

There are several types of equipment under this general head. In each case, however, use is made of the directional characteristics of a loop antenna. The loop may be either fixed or rotatable, and signals may be received aurally or visually, or both.

An installation using a fixed loop and visual indicator is properly known as a radio compass. With this arrangement, as long as the airplane is headed directly toward a radio station the needle of the indicator remains centered; headings to the right or left of the station result in a corresponding deflection of the needle. The radio compass is used chiefly as a "homing" device, and bearings of radio stations off the line of flight may be obtained only by turning the airplane toward the station and noting the magnetic compass heading when the indicator needle is centered.

An installation using a rotatable loop is generally known as a radio direction finder. With the rotatable loop, bearings may be obtained without turning the airplane itself. The loop is rotated until the position of minimum signal strength, or "null," is obtained; the bearing of the station with reference to the heading of the airplane (the "relative bearing") may then be read from a graduated dial. By means of separate dials, on some instruments allowance may be made for variation and deviation, so that true bearings, magnetic bearings, or bearings relative to the head of the airplane may be read directly from the instrument. This equipment is properly referred to as a "radio direction finder." On some recent installations it is only necessary to tune in the station desired; the loop is then rotated automatically, and the indicator points continuously toward the station. This type is known as the "automatic direction finder."

Both the radio compass and the direction finder are valuable aids when flying the radio range system. For example, if a pilot is flying a range course and is able at the same time to obtain the bearing of some off-course radio station, the intersection of this bearing with the range course, when plotted on the chart, definitely fixes the position of the airplane along the course at the moment the observation was made. Or if the pilot is appreciably off course he may identify the quadrant in which he is flying by means of the observed bearing to the radio station. This also informs him of the location of the equisignal zones, and he may proceed to the station without the extra flying required by other methods.

ORIENTATION WITH THE RADIO COMPASS

Under certain atmospheric conditions it is sometimes necessary to disconnect the "sense antenna," without which it is impossible to determine directly whether a radio station is before or behind the airplane. That is, it is impossible to know whether the station is in the direction of the indicated bearing or of its reciprocal. It then becomes necessary to work an orientation problem in much the same manner as that used with the radio ranges.

In figure 81, suppose that an airplane is being flown on a heading of 310° true when, at 1, the radio-compass bearing of the station RS is determined as either 75° (station behind) or 255° (station ahead). In either case, with the loop in homing position a 90° turn is made to the left of the homing course, as

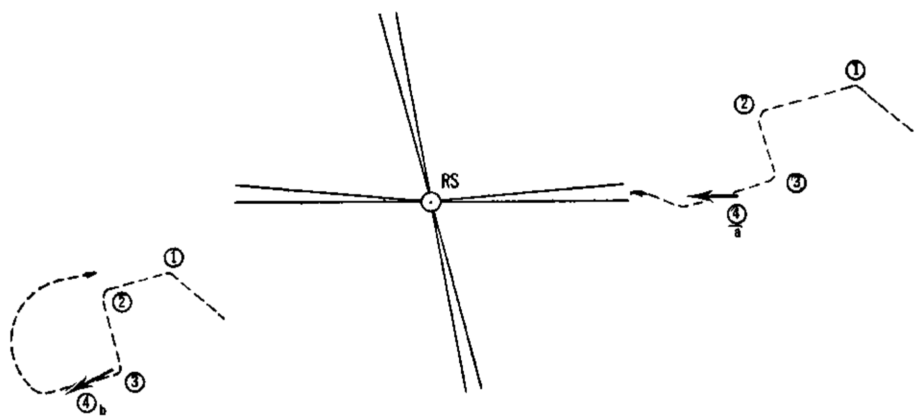

Figure 81.—Orientation with the radio compass.

at 2. This heading is maintained for a period of from 3 to 10 minutes, depending on the ground speed and the distance from the station. A 90° turn to the right is then made, returning the ship to the original homing course, as at 3. If the new bearing indicates that the station is now to the right of the original bearing (4a) the station is still ahead; if to the left of the original bearing (4b) the station is behind.

Use of the radio compass merely as an auxiliary for radio-range flying is a very limited application of this equipment, however; when used with charts on the Lambert projection it is as useful for direction finding and position determination off the airways as on the radio-range system itself. By its use pilots are enabled to tune in any broadcasting station of which the position is known—commercial or Government—and fly directly to the station selected, merely by heading the airplane so as to keep the pointer of the indicator centered. A straight line drawn on the (Lambert) chart from any given position to the radio station in question, represents the no-wind track the airplane would make good over the ground in flying to the station.

PLOTTING RADIO BEARINGS

When the radio station is a little to one side or the other of the direct route to the airport of destination, it is good practice, as a rule, to approach the radio station on a heading in line with the bearing between the radio station and the airport; this makes it relatively easy to locate the airport, even in thick weather.

If the pilot wishes only to determine his position, rather than to fly to the station, he may obtain the true bearing of the station and plot it on the chart; the intersection of this bearing with a bearing from a second station determines the position of the airplane. Unlike most other projections, the projection used for these charts is so accurate that no computations nor corrections for distortion are required.

The simplicity of plotting the observed bearings is illustrated in figure 82. A pilot flying in the vicinity of *F* determines the bearing *X* of the radio station *RS*. He is uncertain of his position, but assumes that he is near the point *P*

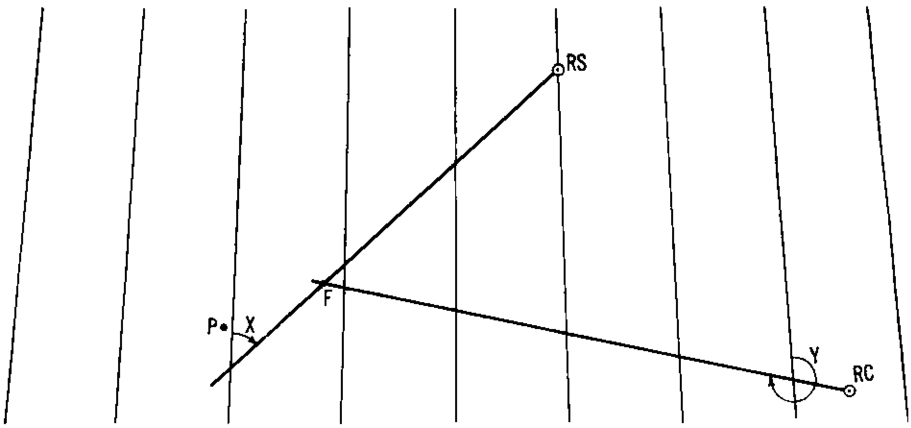

Figure 82.—Position determination by means of radio bearings.

and plots the observed bearing on the chart at the meridian nearest the assumed position, moving the protractor along the meridian until the bearing passes through the radio station. For all practical purposes the line so drawn may be considered as a radio line of position (see p. 122), at some point on which the airplane is located.

In the same figure, *RC* is a naval radio direction finder station. By means of equipment similar to that on the aircraft itself, and at the same time the above bearing was obtained, the bearing *Y* of the aircraft from this station was determined and reported to the pilot by radio. In this case, the bearing is plotted with the meridian nearest *RC*, and the intersection of the two bearings fixes the location of the airplane at *F*.

For the plotting of radio bearings a protractor of the type illustrated in figure 51 will be found most convenient. If the arm of the protractor is not long enough to reach from the assumed position to the radio station, the observed bearing may be plotted from any convenient point on the meridian nearest the assumed position; a line drawn parallel thereto from the radio station represents the bearing.

In the example just given, the radio direction finder station was introduced in order to illustrate the plotting of bearings so determined. Also, for the sake of simplicity it was assumed that the bearing of the airplane was determined there at the same time that the pilot observed the bearing of the other radio station; in practice, this could scarcely be the case.

A RUNNING FIX

Under favorable conditions, and with modern equipment, bearings on two or three radio stations may be determined in less than a minute. In this case it may be considered for all practical purposes that the bearings were taken at the same instant.

Under other conditions an appreciable time interval may pass. When any considerable time elapses between the determination of the two bearings, the position of the airplane is determined by what is known as a "running fix." For example, figure 83 illustrates the same problem as that of figure 82, except that the direction finder station *RC* is replaced by a second radio station *R*,

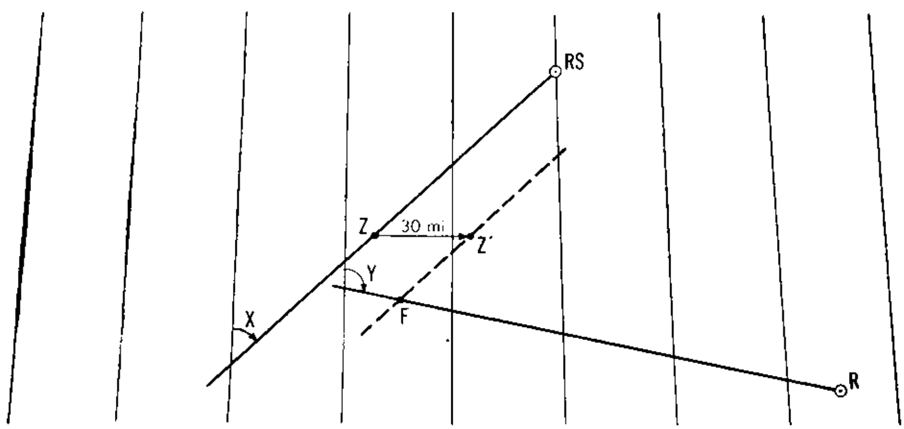

Figure 83. -A "running fix" from radio bearings.

and that after obtaining the bearing *X*, the airplane flew due east (true) for a period of 10 minutes at a ground speed of 180 m. p. h. before obtaining the bearing *Y* of the second radio station.

In 10 minutes at a ground speed of 180 m. p. h. the airplane will have traveled 30 miles. From any convenient point [5] *Z* on the line representing the bearing to the first station, draw a line *ZZ′* running due east a distance of 30 miles. Then through the point *Z′* draw a line parallel to the original bearing line; the intersection of this line with the plotted bearing of the second radio station fixes the position of the airplane at the time the second bearing was obtained. Note that the bearing *Y* is plotted with the next meridian east of the one used for plotting the bearing *X*, since the assumed position has also moved 30 miles eastward, and is now nearer to the more easterly meridian.

If, after carrying forward the bearing *X*, it is found that the assumed position is greatly in error—say, by one degree of longitude [6] or more—a more accurate determination of position may be had by replotting the observed bearings at the meridian nearest the fix. In the second plotting of the bearing

[5] From a theoretical standpoint, the nearer the point selected is to the correct position of the airplane at the time of the first observation, the more accurate will be the results. In practice, however, "any convenient point" will be well within any desired limits of accuracy.

[6] An error in the latitude of the assumed position, however great, will not affect the accuracy of the result.

the line representing the bearing of the first radio station must still be carried forward to obtain the fix, exactly as in the first plotting.[7]

BEARING FROM STATION ON ADJOINING CHART

When the radio station observed falls within the limits of the chart being used, the method illustrated in figure 82—plotting the observed bearing from the meridian nearest the assumed position *P* through the radio station—is the simplest and most accurate. When using the sectional charts for this purpose it is quite likely that the station observed may be off the chart. In this case, since it is not practical to join the two charts while in flight, it will be necessary to plot the bearing directly from the radio station on the adjoining chart to the border, and to measure the angle at which the plotted bearing crosses the last meridian before reaching the border; the point of crossing that meridian must then be transferred to the other chart, and the bearing line continued at the same angle.

To plot the bearing directly from the station some pilots add (or subtract) 180° and plot the reciprocal bearing, but this is inaccurate. Due to convergence of the meridians (see p. 69) the bearing at the radio station is never the reciprocal of the bearing observed at the airplane. The bearing to be plotted from the radio station is obtained as follows:

1. To the bearing observed at the airplane, add (or subtract) 180°.
2. If the AIRPLANE is WEST of the radio station ADD $\frac{6}{10}$ of a degree for each degree of longitude between them; if the airplane is east of the station subtract $\frac{6}{10}$ of a degree for each degree of longitude.

It will be noted that the foregoing rules follow the same form as our rule for applying magnetic variation and deviation, and that the rule begins with the airplane, where the bearings are actually determined.

A FIX FROM TWO BEARINGS ON ONE STATION

A fix may be obtained graphically, when the ground speed is known, by plotting two bearings on one radio station. Each of the two plotted bearings will constitute a side of a triangle; the third side of the triangle is a line representing the course and distance made good in the time between taking the two bearings. By marking along the edge of a piece of paper the distance made good, and moving the paper toward or away from the station while keeping the edge of the paper parallel with the direction of flight, a position is quickly found where the distance made good is exactly included between the lines representing the two bearings. The intersection of the second bearing with the edge of the piece of paper is the fix desired.

In order to be of practical accuracy, the distance run between the two bearings must be great enough that the difference between the two bearings will be at least 10°.

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[7] For utmost precision only the last bearing should be plotted at the meridian nearest the fix; the first bearing should be plotted at the meridian nearest the point where it was observed, and then carried forward. This meridian could be found by carrying the fix *backward* the dead reckoning distance and direction made good between the two bearings; however, if both bearings are plotted at the same meridian and the first bearing is then carried forward, the maximum error in the fix, with a run of 50 miles or more between the two observations, would only be about 1 mile for every 100 miles distance from the radio station, which is too small to justify the longer procedure. Regardless of the meridian selected for plotting the first bearing the line must still be carried forward as described above.

This type of fix may also be computed very easily. If we let b_1 represent the first bearing, b_2 the second, and D_1 the distance run between them, then D_2 (the distance from the station when the second bearing was taken) may be obtained from the following formula:

$$D_2 = D_1 \times \frac{\sin b_1}{\sin (b_2 - b_1)}$$

Tables of logarithms, and log sines or tables of natural sines, would be required, of course, for this solution. When D_2 is found, it is only necessary to lay off this distance along the plotted second bearing, from the station, to determine the fix. It is not necessary to plot the first bearing at all.

RELATIVE BEARINGS

As already defined, in radio navigation the relative bearing of a radio station is its bearing with reference to the heading of the aircraft at the moment. In other words, it is the angle between the longitudinal axis of the aircraft and the line toward the station, measured from 0° to 180°, toward the right or left from the heading of the airplane.

Many pilots become confused in trying to convert a relative bearing into a true bearing that may be plotted on a chart. The first step, of course, is to convert the compass heading at the moment into a true heading, by rectifying it for deviation and variation. After this, only one simple rule is required to obtain the true bearing:

ADD relative **BEARINGS** for stations to the **RIGHT;**

Subtract bearings for stations to the left.

Some radio direction finder dials show green in the semicircle to the right of 0°, red in the semicircle to the left of 0°. With 0° in line with the heading of the aircraft, the above rule then becomes:

ADD GREEN Bearings; subtract red.

Note that the above rule (**ADD BEARINGS RIGHT**) corresponds with our rule for applying the wind correction (Case I): **ADD WIND RIGHT.** It is believed that this rule will eliminate any confusion, with the possible exception of true bearings near 360°. In this case, 360° may be added to or subtracted from the bearings, as necessary in order to perform the required operations.

For example, suppose that the true heading of the airplane is 30°, and the relative bearing of a radio station is 60° to the left. According to the rule, 60° should be subtracted from 30°; since this is impossible, 360° is first added to the 30°, thus: 360°+30°=390°; 390°−60°=330°, the true bearing of the station. Or if the true heading of the airplane is 330° and the relative bearing is 60° to the right, the answer is obtained as follows: 330°+60°=390°; 390°−360°=30°, the true bearing of the station.

As in other forms of navigation, some of the plotting described above is impractical in flight, except for large aircraft with facilities for a separate navigator. To avoid plotting while in flight, it is good practice before taking off to draw on the chart, from each radio station which might be used along the route, radial lines extending well across the flight area, at intervals of 10°. These radial lines should be drawn with different colored pencils, in order to avoid confusion. With the chart prepared in this way, any bearings observed may be applied to the chart by inspection.

SPECIAL CHARTS FOR RADIO DIRECTION FINDING

The preceding discussion and methods apply to all standard aeronautical charts on the Lambert projection, and are essential to a clear understanding of the subject. However, the scale of both the sectional and regional charts often is too large for convenient use in this work, while the scale of chart No. 3060 b is too small. To bridge this gap and to provide the quickest and easiest means of position-finding from radio bearings, the series of aeronautical charts for radio direction finding was designed.

These special charts are at a scale of 1:2,000,000, six charts being required to cover the United States (see frontispiece), with generous overlaps. As a result, it is seldom, if ever, necessary to plot a bearing from a station on an adjoining chart.

Around each radio range station there is a special compass rose (see fig. 43) oriented to the magnetic meridian instead of the true meridian. These compass roses are intended primarily for plotting reciprocal bearings, and therefore the larger (outer) figures read from 0 at magnetic south. When plotting bearings from these stations it is not necessary to add or subtract 180° to obtain a reciprocal bearing. It is only necessary to draw a line from the radio station through the graduation corresponding to the observed magnetic bearing (using the outer figures). The line so drawn is the desired line of position. (See example 4, p. 136.)

Some inaccuracy is introduced by this method, since the magnetic variation at the station is used, rather than the variation at the point of observation (that is, at the position of the airplane); also, no correction is made for convergence of the meridians. If utmost accuracy is required, corrections may be applied for these two items. The correction for convergence has already been described. The difference between the magnetic variation at the airplane and at the radio station should be added when westerly variation increases toward the station, or when easterly variation decreases toward the station; subtracted if the reverse. In the majority of cases, this correction will be of the same sign as the correction for convergence.

It may be easier for some to understand the application of the correction for the difference in variation by thinking of variation as being a maximum in the eastern United States and gradually decreasing through zero (at the agonic line) to a minimum on the west coast. The rule may then be stated as follows: ADD the difference if the variation at the airplane is LESS than at the radio station; subtract if the variation at the airplane is greater.

In planning these charts it was decided that the rapid and frequent determination of approximate positions was more desirable than more tedious though more exact methods—particularly in view of the limited accuracy of radio bearings now attainable. If greater accuracy is desired, instead of applying the above corrections it may be easier to disregard the compass roses altogether, and plot the bearings with a protractor, by the methods already described. Other charts, designed for general radio navigation, are in process of development.

A number of commercial radio broadcasting stations, selected with regard to their suitability for radio direction finding, also appear on these charts. Because of congestion it is impractical to print compass roses around all these stations, and bearings from them must be plotted in the conventional manner described in the preceding section.

ERRORS IN RADIO DIRECTION FINDING

Like the magnetic compass, and for much the same reasons, the radio compass is usually subject to deviation on some headings. This may be determined and applied in exactly the same way that deviation of the magnetic compass is determined and applied. In the more recent installations a correction for deviation is incorporated in the instruments themselves, and bearings may be used directly as read. Obviously, this is to be preferred.

It should be remembered that radio compass bearings are subject to the same distortions that produce multiple radio range courses in mountainous country. They are also affected by interference between stations broadcasting on the same frequency, and by "night effect."

THE RADIO COMPASS AND WIND

In radio compass navigation, as in all other methods, wind is the principal complicating factor; once understood, however, the proper allowance for wind can be made and the pilot may proceed with certainty even though the ground is not visible.

As already stated, the radio compass with nonrotatable loop is used chiefly as a homing device, and cross bearings can be obtained only by turning the ship itself to head toward the station in question. It is not without its advantages for the pilot-navigator, but with it the allowance for wind is more complicated and precise navigation a little more difficult.

When using the radio compass solely as a homing device, even though the pilot heads his airplane directly for the radio station *RS* of figure 84, under the effect of cross winds the airplane will follow the round-about broken line of the figure instead of the direct route.

From the standpoint of the added distance alone this is often unimportant, since it would seldom require appreciably more time to fly the round-about course than to head into the wind and crab along the intended track at reduced ground speed; on the other hand, it is always desirable to know with reasonable precision the track being made good. At times this is absolutely essential in order to keep the airplane over favorable terrain or to avoid dangerous flying conditions. Furthermore, as is usually the case, more precise methods of navigation do result in some saving of flying time.

In view of the wind factor, precise navigation with the radio compass is possible only in conjunction with a stable magnetic compass, or with a gyrocompass. To illustrate, suppose that a pilot leaves a point *O* and proceeds toward a distant radio station *R*. From the chart he knows that the true course from *O* to *R* is 90°. With a true heading of 90°, he soon finds from his radio compass that he has drifted to the left. Heading slightly into the wind, after another period of flying he finds (by turning for a moment to the original heading of 90°) that he has now returned to the direct route; this means that he has made more allowance for wind than is necessary in order only to maintain the intended track, so he assumes a heading between the first and second. After a period of flight on this intermediate heading, he turns momentarily to the original heading of 90°, just long enough to determine from the radio compass that he is still on the direct line to the station at *R*; this indicates that he is making the proper allowance for wind, and he returns to the intermediate heading. Subsequent checks made by turning the plane momentarily to the original heading of 90° will keep him advised of any deviation from the direct route and enable him to make any further changes in heading that may prove necessary. An additional check is found in the fact that while the correct heading is maintained the pointer of the radio compass will read off center. As long as it remains off center by the same amount it may be considered that the plane is making good the direct track to the station. The procedure is the same whether flying toward a radio station, or flying away from a station.

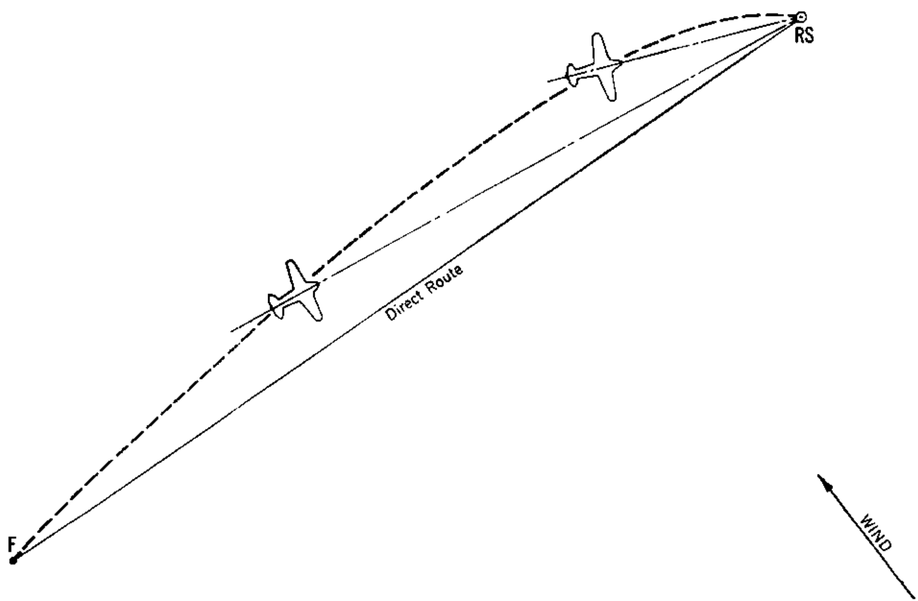

Figure 84.—The radio compass and wind effect.

The process of finding the correct heading to fly in order to make good the direct route to the station may be somewhat simplified if the pilot is able to determine the drift angle. By heading into the wind at an angle equal to the observed drift angle, the approximate heading is found at once. Subsequent checks, as outlined in the preceding paragraph, will provide the data for any further modification that may be necessary.

THE RADIO DIRECTION FINDER AND WIND

The foregoing applies to the nonrotatable loop antenna; when using the rotatable loop the procedure is simpler. If a deviation to the left is noted, the airplane is turned slightly into the wind as before, and the loop rotated the same number of degrees in the opposite direction. The indicator will then show the same amount of deviation from the route as before, but if enough allowance has been made this will gradually decrease to zero. This indicates that the airplane is again over the intended track, and a slightly smaller allowance for wind should keep it there. By trial and error, each time the heading is changed rotating the loop an equal number of degrees in the opposite direction, a heading is found on which the indicator will remain centered as long as the heading is maintained. While this condition exists, the plane is making good the direct route toward the station. If the route being followed is a long one, as the route from St. Louis to Minot (fig. 49), the heading must be changed to conform to the change in true course as the end of each succeeding section is reached.[8] If the wind were constant, the steering perfect, and the airplane started on the proper heading, this would not be necessary; as long as the indicator remained centered the airplane would track the great circle toward the station, and the ever-changing direction of the bearing (fig. 17) would be automatically registered by the compass or gyro. Since such ideal conditions do not exist in practice, it is necessary to make the changes periodically, as suggested.

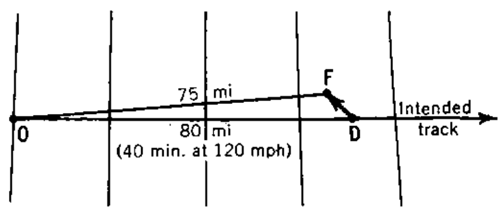

Figure 85.—Determination of wind by radio direction finder.

With the rotatable loop of the automatic type referred to, the procedure is still simpler. If a departure to the left is noted, as in the previous instances, the pilot turns toward the right until the original bearing is again indicated. It is then only necessary, by trial and error, to find a heading such that the original bearing is indicated continuously, without changing. As long as the compass heading and the indicated bearing both remain constant, the direct track toward the station is being made good. The difference between the compass heading and the bearing in this case is the drift angle.

Under unusual conditions, if the airplane is already close to dangerous topography, instead of returning to the intended track as described above, it may even be desirable to circle back, reaching the plotted route at a position nearer the starting point. The arrival over the intended route must be determined by the radio compass in conjunction with the gyro or magnetic compass.

When a fix has been obtained by cross bearings, as described on page 114, the wind direction and velocity may be obtained graphically, if desired. In figure 85, after flying due east from *O* for a period of 40 minutes and at an air speed of 120 m. p. h., a fix was obtained at *F*. From the chart it is found that *F* scales 75 miles from *O*. *OD* represents the heading and air speed of the airplane, *OF* the track and ground speed, and the angle at *O* the drift angle. *DF* represents the wind direction and velocity, which is found to scale 7 miles, and is from the southeast (135°); since the 7-mile drift occurred in a period of 40 minutes, the wind velocity is 10 m. p. h.

If the airplane is proceeding from a radio station as a point of departure, using the radio compass as a homing device (flying away from home), and the visual indicator shows a deviation from the direct route the drift angle may be determined simply by heading the plane so as to center the indicator and noting

[8] In theory there is some difficulty in the combined use of a compass (or gyro) and the radio compass, since the latter determines a bearing at a point while the former determines a course; however, as explained on p. 21, when courses are properly determined the departure of the course from the straight line representing the bearing is negligible.

the difference in degrees from the original heading. While one drift angle cannot determine a position, if this angle is plotted on the chart and the estimated distance made good is scaled along it, an approximate position is obtained which may be of some assistance.

A RADIO LINE OF POSITION

In the preceding section reference has been made to a radio line of position. While a full understanding of this term is not strictly necessary, it should help to clarify the problem and may be useful under certain conditions.

If the bearing of an airplane is determined at a radio station, and plotted at the meridian of the station, then the straight line between the station and the airplane is a radio line of position. The radio station is definitely fixed

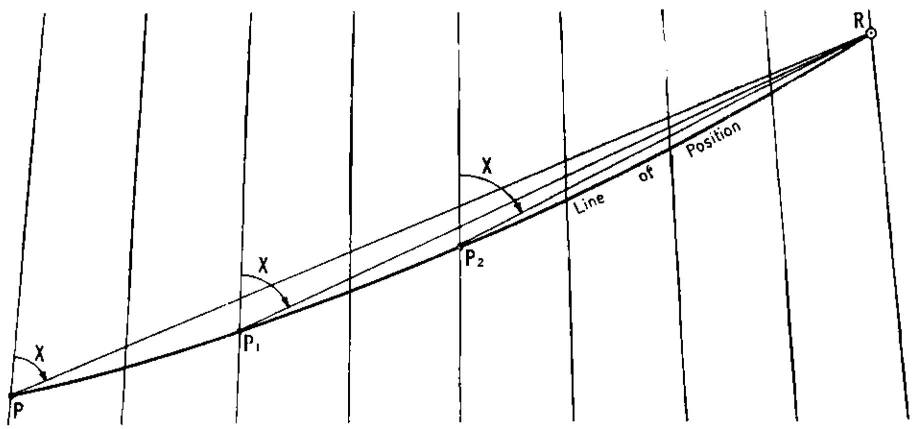

Figure 86.—A radio line of position from bearing determined at airplane.

on the chart, and the bearing of the airplane is accurately known; the plotted bearing, therefore, is positively determined as the line on which the airplane is located.

If the bearing X of the radio station R (fig. 86), is determined at the airplane and plotted at the meridian nearest the *assumed* position of the airplane, then the point P on the meridian is only a point on the radio line of position. There is also a point P_1 on another meridian where the same bearing might have been observed, a similar point P_2 on still another meridian, and so on; the airplane might have been located at any point on the curved line (greatly exaggerated) drawn through these points where the bearing of R is the same. Strictly speaking, then, this curved line is the radio line of position as determined at the uncertain location of the airplane.

If strictest accuracy in plotting is required, the radio line of position may be easily obtained by plotting the observed bearing at two or three meridians on each side of the assumed position and drawing a curved line through the points so obtained. For all practical purposes this is unnecessary; unless the assumed position is greatly in error (say 50 miles or more), the bearing plotted at the meridian nearest the assumed position so nearly coincides with the radio line of position that they may be considered identical. If the assumed position is proved to be greatly in error when a preliminary fix is obtained, entirely satisfactory results may be had by a second plotting of the bearing, as already described.

INSTRUMENT LANDINGS

Experimental work on instrument landing systems has been definitely under way since 1928. A number of systems have been developed, differing chiefly in minor details. One features a curved glide path which necessitates continual change in the attitude of the airplane but brings it to the ground in approximately the normal position for landing. Another features a straight glide path, which is considered superior by some. A third substitutes micro-waves and a frequency of 750 megacycles, which is not affected by ordinary static.

The various systems must all be regarded as still in progress; however, early in 1940 the Civil Aeronautics Authority had made available at Indianapolis, for service tests, an instrument landing system embodying the best features of all the systems.

The Indianapolis system is illustrated in figures 87 and 88. The figures and the following text describing them have been adapted from an article in the CIVIL AERONAUTICS JOURNAL, April 1, 1940.

The system consists of four fundamental elements: A runway localizer which provides a range course for lateral guidance; a glide path which provides a means for descent; and two vertical marker beacons to indicate the progress of approach to the landing field.

The effect of the localizer beam radio transmission is to provide an imaginary vertical plane extending along the centerline of the runway in the direction of approach. (See fig. 87.)

A needle on an instrument before the pilot remains in a vertical position as long as the airplane is in this imaginary plane. If the airplane deviates to the right, the needle swings to the left and the pilot must turn his craft to the left until the needle swings back to the vertical. Exactly the opposite occurs if the aircraft deviates to the left.

The effect of the glide path radio transmission is to provide a surface [9] inclining away from the approach end of the runway at an angle of 3° to 4° from the earth's surface. At about 5 miles from the end of the runway the glide path is approximately 1,500 feet above the ground. (See fig. 88.)

A horizontal pointer, crossing the vertical needle mentioned previously, tells the pilot whether the aircraft is flying above or below, or directly along the imaginary inclined surface. If the needle falls below the horizontal the pilot must descend to intercept the glide path and, conversely, if the needle swings above the horizontal the pilot must climb to regain the glide path. (See fig. 87, insets showing instrument readings.)

The intersection of these two imaginary surfaces provides an imaginary line (see black line followed by aircraft in fig. 87) which inclines at a gentle angle upward from the end of the runway for many miles. By means of the two instrument indications already described the pilot can fly his aircraft downward along this imaginary line with a high degree of precision.

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[9] Actually, the glide path is formed by a portion of a curved surface, but the portion utilized for the approach is relatively straight, and for the purpose of a simplified explanation may be thought of as a narrow inclined surface, curved slightly at the bottom to meet the runway at a gentle angle.

The radio marker beams are directed upward and the signals fill an inverted fan-shaped space intersecting the localizer beam and crossing the glide path. (See fig. 87). The outer marker is about 2 miles from the airport and inter-

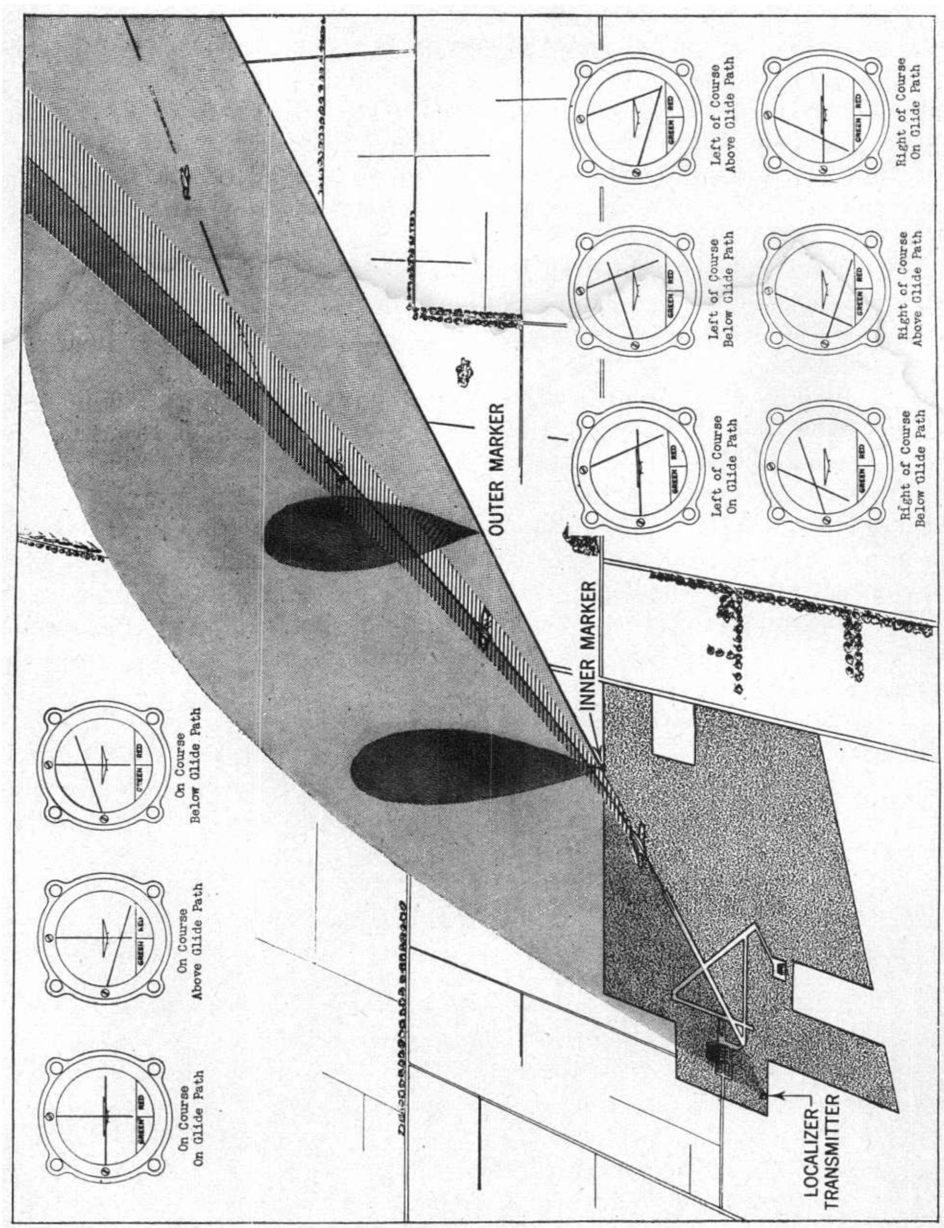

Figure 87.—Indianapolis instrument landing system.

cepts the glide path at a point where it is 510 feet from the ground. The inner marker is located at the boundary of the field in line with the runway and intercepts the glide path at an altitude of 45 feet. The exact distances are shown in figure 88.

Flying over the outer marker causes a purple light to flash on the aircraft's instrument panel at a rate of two dashes per second for a period of 8 seconds, while at the same time a characteristic audible signal is received by the pilot through his headphones. The inner marker flashes an amber light at a rate of six dots per second for approximately 1½ seconds, and provides an audible signal plainly distinguishable from that of the outer marker.

At the bottom of the instrument faces shown in figure 87 there is a sector split in the middle with green on the left and red on the right. The chart used by the pilot is tinted red in the area to the left of the localizer beam and green to the right, as indicated in figure 88. Thus, whenever the vertical

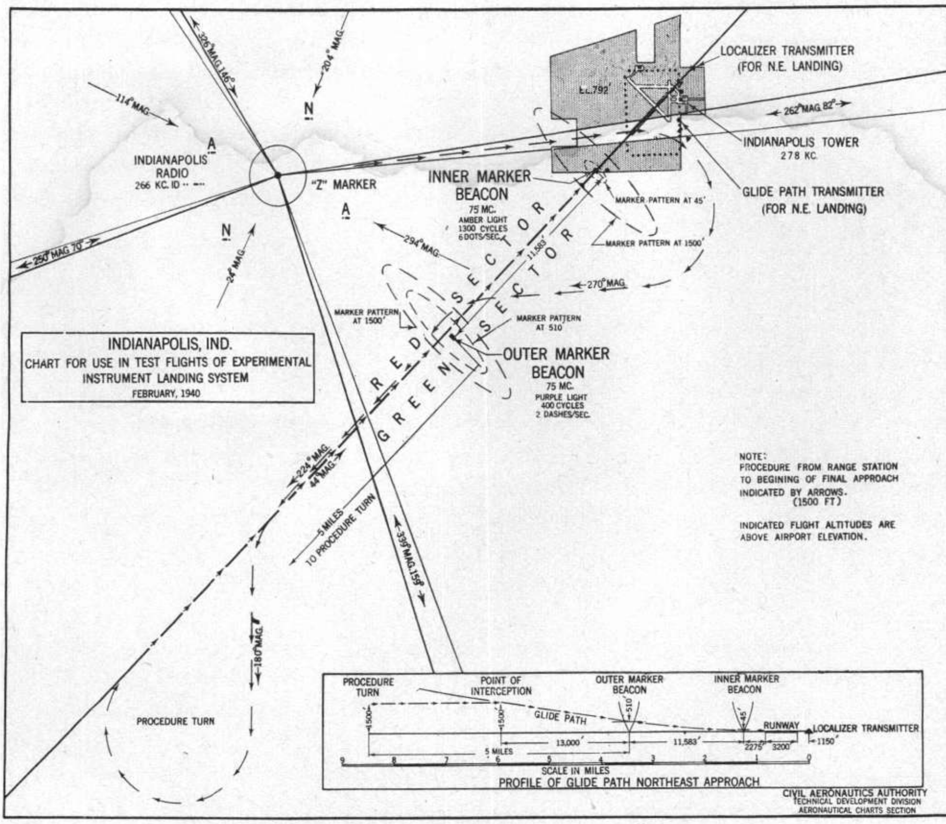

Figure 88.—Chart used in test flights of Indianapolis instrument landing system.

needle points to the green sector the pilot knows he is in the green area indicated on the chart, and if the needle points to the red sector he can be sure he is in the red area of the chart, regardless of the heading of the ship.

Four complete sets of equipment are installed at Indianapolis, providing instrument landing facilities for four wind directions. The whole system is monitored and controlled from the airport control tower, permitting a ready choice of the proper runway suitable for use under existing wind conditions at the time of landing.

The procedure employed by the pilot to approach and intercept the glide path is clearly shown by the broken arrows and explanatory comment in figure 88.

A set of controlled approach lights is operated in conjunction with the instrument landing system at Indianapolis. This system has three possible applications: It can be used independently of radio aids to assist in contact landings at night or under conditions of restricted visibility; it can be used in conjunction with the conventional directional radio range whereby the approach would be made on instruments and the landing by contact; and, thirdly, it can be used to supplement an instrument landing system.

In the latter case, an instrument landing approach is made in the manner previously described and the first steps of an instrument landing followed, but upon passing the inner marker the pilot picks up the approach lights as soon as they become visible. The pilot is thereby provided with visual aids for making actual contact with the runway.

The first 1,200 feet of approach lights are equally spaced at 200-foot intervals on each side of the approach. The remaining 1,300 feet of approach lights are spaced at 100-foot intervals. Flush type runway lights then continue along either side of the runway proper.

NEON TUBE APPROACH LIGHTS

As a further visual aid in making landings under conditions of restricted visibility, there has been installed along the southwest approach to the southwest-northeast runway at Indianapolis, a row of 15 neon tube approach lights spaced at 100-foot intervals, commencing 3,100 feet from the end of the paved runway, approximately 800 feet before reaching the inner marker, and extending 1,400 feet on toward the runway.

These lights consist of horizontal neon bars, each 6 feet 6 inches long, mounted approximately 4 feet above ground. They are brilliantly lighted with the characteristic neon red color and are focused toward the incoming aircraft.

At the present time (1940), about a dozen of these systems are being installed at principal airports throughout the country.

It need scarcely be pointed out that with the general installation of a satisfactory system for instrument landings, and with pilots proficient in its use, the last essential for a complete system of safe, all-weather air transportation is provided.

RADIO OPERATOR'S PERMIT

In order to operate 2-way radio, a pilot is required to hold at least a third class radiotelephone operator's permit, issued by the Federal Communications Commission. The examination for this permit consists of 10 questions, as follows:

Three on the Communications Act of 1934.
Two on the International General Radio Regulations (Cairo Revision).
Five on the Rules and Regulations of the Federal Communications Commission.

The 10 questions which make up any given examination are selected from those in the following pages. The answers to these questions have been included here as an aid in presenting the information for passing the examination. Those desiring more complete information with regard to the basic law, are referred to the Study Guide and Reference Material for Commercial Radio Operator Examinations, published by the Federal Communications Commission. The pamphlet may be obtained from the Superintendent of Documents, Washington, D. C., for 15 cents. Additional information may also be obtained from any local inspector of the Federal Communications Commission.

QUESTIONS AND ANSWERS FOR RESTRICTED RADIOTELEPHONE OPERATOR'S PERMIT

1. Q. State five grounds, on any one of which, the Federal Communications Commission has the authority to suspend a radio operator's license or permit.

A. The Federal Communications Commission may suspend a radio operator's license or permit for:

(*a*) Violation of any provision of any act, treaty, or convention binding on the United States which the Commission is authorized to administer, or any regulation made by the Commission under any such act, treaty, or convention.

(*b*) Failure to carry out a lawful order of the master or person lawfully in charge of a ship or aircraft on which the operator is employed.

(*c*) Willfully damaging or permitting radio apparatus or installations to be damaged.

(*d*) Transmitting superfluous radio communications or signals, or communications containing profane or obscene words, language, or meaning.

(*e*) Transmission of false or deceptive signals or communications.

(*f*) Using a call signal or letter which has not been assigned by proper authority to the station which he is operating.

(*g*) Willfully or maliciously interfering with any other radio communication or signal.

(*h*) Obtaining or attempting to obtain, or assisting another to obtain, or to attempt to obtain an operator's license by fraudulent means.

2. Q. Is an operator subject to the penal provisions of the Act if he violates the terms of the treaty of which the United States is a party?

A. Operators are subject to the penal provisions of the Act for violating the terms of the radio treaty of which the United States is a party.

3. Q. State at least two provisions made in the Communications Act to insure the priority of communications or signals relating to ships in distress.

A. The Communications Act provides that—

(*a*) All radio stations, including government stations and stations on board foreign vessels, when within the territorial waters of the United States, shall give absolute priority to radio communications or signals relating to ships in distress, and

(*b*) Shall cease sending on all frequencies which will interfere with radio communications or signals of distress, and except when engaged in answering or aiding a ship in distress, shall refrain from sending any radio communications or signals until there is assurance that no interference will be caused in radio communications or signals relating thereto, and shall assist the vessel in distress so far as possible by complying with its instructions.

4. Q. In what class of radio station, and under what conditions is an operator permitted to adjust the transmitter for a maximum of radiation without regard to the interference produced?

A. Radio stations on board ships may be adjusted to produce a maximum of radiation irrespective of the amount of interference which may thus be caused for the purpose of transmitting distress signals.

5. Q. In what cases may a transmitter on board ship be adjusted to produce a maximum of radiation irrespective of interference which may be caused?

A. While engaged in transmitting a distress message.

6. Q. What communications, if any, are not subject to the secrecy provisions of the Communications Act?

A. Radio transmissions which broadcast entertainment, weather, or programs of general interest, transmission by amateurs or others for the use of the general public, or transmissions relating to ships in distress are exempted from the secrecy provisions of the Communications Act.

7. Q. State in your own words the prohibitions, if any, against transmission of false calls and communications relating to distress.

A. It is unlawful to transmit false signals of distress or communications relating thereto. Signals of distress may be transmitted only upon orders of the master or other person lawfully in command of the ship on which the operator is employed.

8. Q. State in your own words the law regarding the transmission of false or fraudulent signals of distress or communications relating thereto.

A. No person within the jurisdiction of the United States (all radio stations and operators licensed by the Federal Communications Commission are under the jurisdiction of the United States) shall knowingly utter or transmit or cause to be uttered or transmitted any false or fradulent signals of distress or communications relating thereto.

9. Q. State in your own words the substance of the Communications Act that is provided to insure the secrecy of radiograms.

A. No person receiving or assisting in receiving, transmitting, or assisting in transmitting any interstate or foreign communications by wire or radio, shall divulge or publish the existence, contents, substance, purport, effect, or meaning thereof except through authorized channels of transmission and reception to any person other than the addressee, his agent or attorney, or to a person employed or authorized to relay such communications to its destination, or to distributing officers of the various communication centers over which the radiogram may be passed, or to the master of the ship under whom he is serving, or in response to a court order issued by a court of competent jurisdiction.

10. Q. Does the Communications Act of 1934, as amended, contain any provision that prohibits the interception, use, and publication of radio communication?

A. Yes. See answer to No. 9, above.

11. Q. What form of language, if transmitted by the operator, renders him subject to the penal provisions of the Communications Act?

A. No person within the jurisdiction of the United States shall utter any obscene, indecent, or profane language by means of radio communication.

12. Q. What provisions are made in the Communications Act to insure communication between stations in the mobile service?

A. The Communications Act provides that every land station open to general public service between the coast and vessels at sea and within the scope of its normal operation be bound to exchange radio communication or signals with any ship at sea, and each station on shipboard at sea shall within the scope of its normal operation be bound to exchange radio communications or signals with any other station on shipboard at sea or with any land station open to general public service between the coast and vessels at sea.

13. Q. Does the Federal Communications Commission have authority to issue a radio operator's license or permit to a citizen of a country other than the United States?

A. No. This is prohibited by the Communications Act of 1934.

14. Q. Has the master of a ship radiotelephone station the authority to forbid the transmission of messages by anyone on board?

A. The Communications Act, as amended, states in effect that in case of a ship of the United States, the radio installation, the operators, transmission and receipt of messages except as may be regulated by law or international agreement or by rules and regulations in pursuance thereof, shall be under the supreme control of the master. Therefore, it appears that the master would be well within his rights in regulating or prohibiting the transmission of any radiotelephone or other communication from the ship.

15. Q. Has the master of a ship station the authority to regulate the transmission or reception of messages on shipboard?

A. Yes. See answer to No. 14, above.

16. Q. Under what conditions is the utterance or transmission of a false or fraudulent signal of distress or communication relating thereto permissible?

A. Under no condition. See answer to No. 8, above.

17. Q. Under what condition is the utterance of obscene, indecent, or profane language by means of radio communication permissible?

A. Under no condition. See answer to No. 11, above.

18. Q. What is the Radiotelephony Safety Signal?

A. The Radiotelephony Safety Signal is the spoken word "SECURITY" repeated three times. Communications preceded by a safety signal are third in order of priority.

19. Q. Under what conditions may a mobile station, if necessary, disregard the General Radio Regulations (Cairo)?

A. A mobile station may use any means available to it for drawing attention, signaling its position, and obtaining help when in distress. When distress, emergency, or safety is involved, the telegraph transmission speed, in general, shall not exceed 16 words per minute.

20. Q. What is the radiotelephony urgent signal?

A. In radiotelephony the urgent signal shall consist of three transmissions of the expression "PAN" (corresponding to the French pronunciation of the word "Panne"). It shall be transmitted before the call to indicate that the calling station has a very urgent message to transmit concerning the safety of a ship, an aircraft, or another vehicle, or concerning the safety of some person on board or sighted from on board.

21. Q. What signals and messages are forbidden by international agreement?

A. The transmission of unnecessary or unidentified signals or correspondence shall be forbidden to all stations.

22. Q. What precautions must an operator observe before proceeding with a transmission?

A. Before transmitting, any station must keep watch over a sufficient interval to assure itself that it will cause no harmful interference with the transmissions being made within its range; if such interference is likely, the station shall await the first stop in the transmission which it may disturb.

23. Q. What does the receipt of the signal "PAN" transmitted by radiotelephony indicate?

A. See answer to No. 20, above.

24. Q. What should an operator do if he intercepts the word "SECURITY" repeated three times?

A. All stations hearing the safety signal must continue listening on the wave on which the safety signal has been sent until the message so announced has been completed: they must, moreover, keep silence on all waves likely to interfere with the message.

25. Q. An urgent signal sent by an aircraft and not followed by a message indicates what?

A. In aeronautical service the urgent signal "PAN" shall be used in radiotelephony to indicate that the aircraft transmitting is in trouble and is forced to land, but that it is not in need of immediate help. This signal, as far as possible, to be followed by a message giving additional information.

26. Q. What obligation rests on an operator intercepting the signal "PAN"?

A. "PAN" is the urgent signal used in radiotelephony and shall have priority over all other communications, except distress communications, and all mobile stations must take care not to interfere with the message which follows the urgent signal.

27. Q. What procedure must be followed by a radio station receiving a distress call from a mobile station which is unquestionably in its vicinity?

A. Stations of the mobile service which receive a distress message from a mobile station which is unquestionably in their vicinity must acknowledge receipt thereof at once.

28. Q. What essential information should be transmitted in a distress message?

A. The name and position of the mobile station in distress together with any other information necessary for prompt and efficient aid by the station receiving the message.

29. Q. By what authority may the operator of a ship or aircraft station transmit a distress call or message?

A. The distress call and message shall be sent only by order of the master or person responsible for the ship, aircraft, or other vehicle carrying mobile station.

30. Q. What is the international distress signal to be used in radiotelephony?

A. In radiotelephony, the distress signal shall consist of the spoken expression "MAY DAY" (corresponding to the French pronunciation of the expression "M'AIDER"), to announce that the ship, aircraft, or other vehicle which sends the signal is threatened by serious and imminent danger and requests immediate assistance.

31. Q. What does the interception of "MAY DAY" transmitted by telephony announce?

A. See answer to No. 30, above.

32. Q. What radio waves may be used under the provisions of the treaty in transmitting distress messages in case of an emergency by aircraft stations?

A. Any aircraft in distress must transmit the distress call in the watch wave of the land or mobile stations capable of helping it; when the call is addressed to stations of the maritime service, the waves (frequencies) to be used are the distress wave (frequency) or watch wave (frequency) of these stations.

33. Q. State the priority of radio communications in the mobile service.

A. The order of priority of radio communications in the mobile service shall be as follows:

1. Distress calls, distress messages, and distress traffic.
2. Communications preceded by an urgent signal.
3. Communications preceded by a safety signal.
4. Communications relative to radio direction finding bearings.
5. Government radio telegrams for which priority right has not been waived.
6. All other communications.

34. Q. What information must be contained in a distress message transmitted in an emergency from a radio station aboard aircraft flying over land?

A. As a general rule, an aircraft flying over land shall signal its position by the name of the nearest locality, his approximate distance from this point, accompanied according to the case, by one of the words, NORTH, SOUTH, EAST or WEST, or, in some cases, words indicating intermediate directions.

35. Q. What information must be contained in the distress message?

A. The message shall include the distress call followed by the name of the ship, aircraft, or the vehicle in distress, information regarding the position of the latter, the nature of the help requested, and any other further information which might facilitate this assistance.

36. Q. When, after having sent its distress message an aircraft station is unable to signal its position, what procedure shall be followed to assist others in determining its approximate location?

A. When, in its distress message, an aircraft is unable to signal its position, it shall endeavor after transmission of the incomplete message to send its call signal long enough so that radio direction-finding stations may determine its position.

37. Q. State at least two classes of stations which cannot be operated by the holder of a restricted radiotelephone operator's permit.

A. The holder of a restricted radiotelephone operator's permit may NOT operate any of the various classes of broadcast stations other than a relay broadcast station; he may NOT operate a coastal telephone station or a coastal harbor station other than in the Territory of Alaska; he may NOT operate a ship station licensed to use type A-3 emission for communication with coastal telephone stations.

38. Q. Under what conditions may the holder of a restricted radiotelephone operator's permit operate a station for which the permit is valid?

A. The holder of a restricted radiotelephone operator's license may operate any station for which the permit is valid: *Provided*, That—(1) he is prohibited from making adjustments that may result in improper transmitter operation; (2) the equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation; (3) any needed adjustments of the transmitter that may affect the proper operation of the station are regularly made by or in the presence of an operator holding a first-class or second-class license, either telephone or telegraph, who shall be responsible for the proper operation of the equipment.

39. Q. State at least two classes of ship stations which the holder of a restricted radiotelegraph operator's permit is prohibited from operating.

A. The holder of a restricted radiotelegraph operator's permit is prohibited from operating—(1) any of the various classes of broadcast stations other than relay broadcast; (2) any ship station licensed to use type A–3 emission for communication with coastal telephone stations; (3) any radiotelegraph station on board a vessel required by treaty or statute to be equipped with a radio installation; (4) any ship telegraph, coastal telegraph, or marine relay station open to public correspondence.

40. Q. Who is permitted to make adjustments or tests in the presence of the licensed operator responsible for the maintenance of the transmitter and under his responsibility for the proper operation of the equipment?

A. Any person.

41. Q. Within what period of time must any person receiving official notice of a violation of the terms of the Communications Act of 1934, as amended, Treaty or Rules and Regulations of the Commission be answered?

A. Within three days after receipt of notice of a violation, an answer must be sent to the Federal Communications Commission, Washington, D. C., and a copy thereof to the office of the Commission originating the notice of a violation: *Provided, however,* That if an answer cannot be sent within three days by reason of illness or other unavoidable circumstances, acknowledgment and answer shall be made at the earliest practicable date with a satisfactory explanation of the delay.

42. Q. What is the obligation of an operator whose license or permit has been lost, mutilated, or destroyed?

A. An operator whose license or permit has been lost, mutilated, or destroyed shall immediately notify the Commission. A sworn application for a duplicate should be submitted to the office of issue embodying a statement attesting to the facts thereof. If a license has been lost, the applicant must state that a reasonable search has been made for it, and further, that in the event it be found either the original or the duplicate will be returned for cancelation. The applicant must also give a statement of the service that has been obtained under the lost license.

43. Q. How may the holder of a radiotelegraph or radiotelephone first- or second-class license indicate to representatives of the Commission that he is legally qualified to adjust equipment operated by holders of restricted radiotelephone operator permits?

A. The holder of a radiotelegraph or radiotelephone first- or second-class license who is employed as a service and maintenance operator at stations operated by holders of restricted operator permits shall post at such station his operator's license or a verified statement from the Commission, Form 759 properly executed, in lieu thereof.

44. Q. How may an operator show proof of his legal qualifications to operate a radio transmitter?

A. By posting his original operator's license at the place where he is on duty, or by keeping it in his possession in the manner specified in the regulations governing the class of station concerned. If two or more stations, at which posting of license is required, are operated by the same operator, his license is required to be posted at the station which he principally operates and a verified statement from the Commission, Form 759, properly executed, at each other station so operated.

45. Q. What is an operator of a radio station, who has submitted his license for renewal or applied for a duplicate license, required to exhibit as his authority to continue operation of the station pending receipt of the license?

A. When a duplicate operator's license or permit has been requested, or a request for renewal upon service has been made, the operator shall exhibit in lieu thereof a signed copy of the application for duplicate, or renewal, which has been submitted by him.

46. Q. What is the holder of a radiotelegraph or radiotelephone first- or second-class license, who is employed as a service and maintenance operator at stations operated by holders of restricted operator permits, obligated to post at the stations?

A. See answer to No. 43, above.

47. Q. How may corrections be made in a log?

A. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

48. Q. Is it lawful to erase an entry made in a station log?

A. It is unlawful to erase an entry made in a station log.

49. Q. What are the Commission's requirements with regard to the retention of a radio-station log?

A. Logs of a radio station, when required by the F. C. C. rules and regulations, must be kept for 1 year except when specifically specified for the particular service or class of station concerned, except that, logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee has been notified, shall be retained by the licensee until specifically authorized in writing by the Commission to destroy them: *And provided further*, that logs incident to or involved in any claim or complaint of which the licensee has notice shall be retained by the licensee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the same for the filing of suits upon such claims.

50. Q. How long must the licensee retain a station log which involves communications incident to a disaster?

A. See answer to No. 49, above.

51. Q. What is the Commission's rule with regard to rough logs?

A. Rough logs may be transcribed into condensed form, but in such cases the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

52. Q. What procedure should one follow if he wishes to resist an order of suspension of his operator's license or permit?

A. The notice of suspension shall not be effective until actually received by the operator, and he shall have 15 days in which to make an application to the Commission for a hearing. Upon receipt by the Commission of application for a hearing, said order of suspension shall be held in abeyance until the conclusion of the hearing, at which time the Commission will affirm, modify, or revoke said order of suspension.

53. Q. What is the responsibility of a licensee of a radio station with respect to permitting it to be inspected by representatives of the Commission?

A. The licensee of any radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour and under the regulations governing the class of station concerned.

54. Q. Who is responsible for the control of distress traffic?

A. The control of distress traffic shall devolve upon the mobile station in distress, or upon any station which becomes aware that a mobile station is in distress when (*a*) the mobile station is not itself in a position to transmit the distress message, or (*b*) in the case of mobile stations when the master or person in charge of the mobile station believes that further help is necessary, or (*c*) in the case of other stations when directed by the station in control of the distress traffic to do so, when the control station has reason to believe that the distress call which it has intercepted has not been received by any station in a position to render aid.

55. Q. Are logs subject to inspection by representatives of the Commission?

A. The logs shall be made available upon request by an authorized representative of the Commission.

56. Q. By whom may the log of a radio station be kept?

A. Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty.

57. Q. Under what conditions may a distress message be retransmitted?

A. (*a*) When the station in distress is not itself in a position to do so; (*b*) in the case of mobile stations, when the master or the person in charge of the ship, aircraft, or other vehicle carrying the station which intervenes believes that further help is necessary; (*c*) in the case of other stations, when directed to do so by the station in control of distress traffic or when it has reason to believe that a distress call which it has intercepted has not been received by any station in a position to render aid.

58. Q. What tolerance in operating power is permissible under normal circumstances?

A. (1) When maximum power only is specified, the operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified; (2) When the exact power is specified, the operating power shall not be more than 5 percent above nor less than 10 percent below such power.

59. Q. Under what conditions may a station be operated in a manner other than that specified in the station license?

A. The licensee of any station, except amateur, may, during a period of emergency such as disruption of normal communication facilities as a result of hurricane, flood, earthquake, or similar disaster, utilize such station for emergency communication in a manner other than that specified in the station license: *Provided*, That as soon as possible after the beginning of such emergency operation, notice be sent to the Commission at Washington, D. C., and to the inspector in charge of the district in which the station is located stating the nature of the emergency and the use to which the station is put and that emergency use of the station be discontinued as soon as substantially normal communication facilities are again available, at which time the licensee shall notify the Commission in Washington, D. C., and the inspector in charge of the district in which the station is located that emergency operation has been terminated.

60. Q. What is the Commission's rule with respect to measurement of the radio frequency?

A. The licensee of each station shall provide means for the measurement of the station frequency independent of the frequency control for the transmitter and measurements shall be conducted in accord with the regulations governing the class of station concerned.

61. Q. When may operation be resumed after a station has been notified to cease transmission because of interference to distress traffic?

A. No station having been notified to cease operation shall resume operation on the frequency or frequencies which may cause interference to distress traffic, until notified by the station issuing the original notice that the station involved will not interfere with distress traffic as it is then being routed or until the receipt of a general notice that the need for handling distress traffic no longer exists.

EXAMPLES

Example 1.—While flying the radio range course between The Dalles, Oregon, and Ellensburg, Washington (pl. II), in thick weather, a pilot wished to verify his position along the course. By means of radio direction finder he determined the true bearing of the Pendleton radio range station as 118°.

Required.—The position of the airplane.

The pilot supposed himself to be somewhere near Yakima; consequently, the bearing was plotted with the meridian passing through Yakima, at latitude 46°30′. This line passed well to the north of Pendleton, so a second line was drawn, from the Pendleton range station and parallel to the first line. The intersection of the second line with the northeasterly course of the North Dalles radio range station marks the position of the airplane, about 3 miles southwest of Harrah.

Instead of drawing the two lines, as just described, some prefer to adjust the protractor to the desired angle, then slide it along the meridian until the protractor arm passes through the point in question. The bearing may then be drawn directly from the station.

If the Seattle sectional chart were being used on this flight, it would be easier to plot the bearing directly from the Pendleton radio range station on the La Grande chart, transferring the bearing to the Spokane chart, and in turn to the Seattle chart, where it crosses the boundaries between the charts. The bearing to be plotted from the Pendleton station is obtained as follows (see p. 116):

118° bearing observed at airplane.
+180°
———
298° reciprocal bearing.

The difference of longitude between the airplane and the radio range station is not quite 2°. Multiplying this number by the convergence of 0°.6 per degree of longitude (see p. 69), we obtain $2 \times 0°.6 = 1°.2$, or, to the nearest whole degree, 1°. The correction is to be added, since the airplane is west of the station.

298° reciprocal bearing.
+1° correction for convergence.
———
299° bearing to be plotted from Pendleton radio range station.

The added work of obtaining the bearing to be plotted from the station, and the inconvenience of transferring the bearing from one chart to another (or even to a third chart, as in this example), well illustrates the need for, and the convenience of, the smaller scale charts for plotting radio bearings.

Example 2.—In the preceding example, if the Pendleton radio range station had been equipped with the necessary apparatus (as are the naval radio direction finder stations along our coasts), the pilot might have called Pendleton and requested that his bearing from that station be determined.

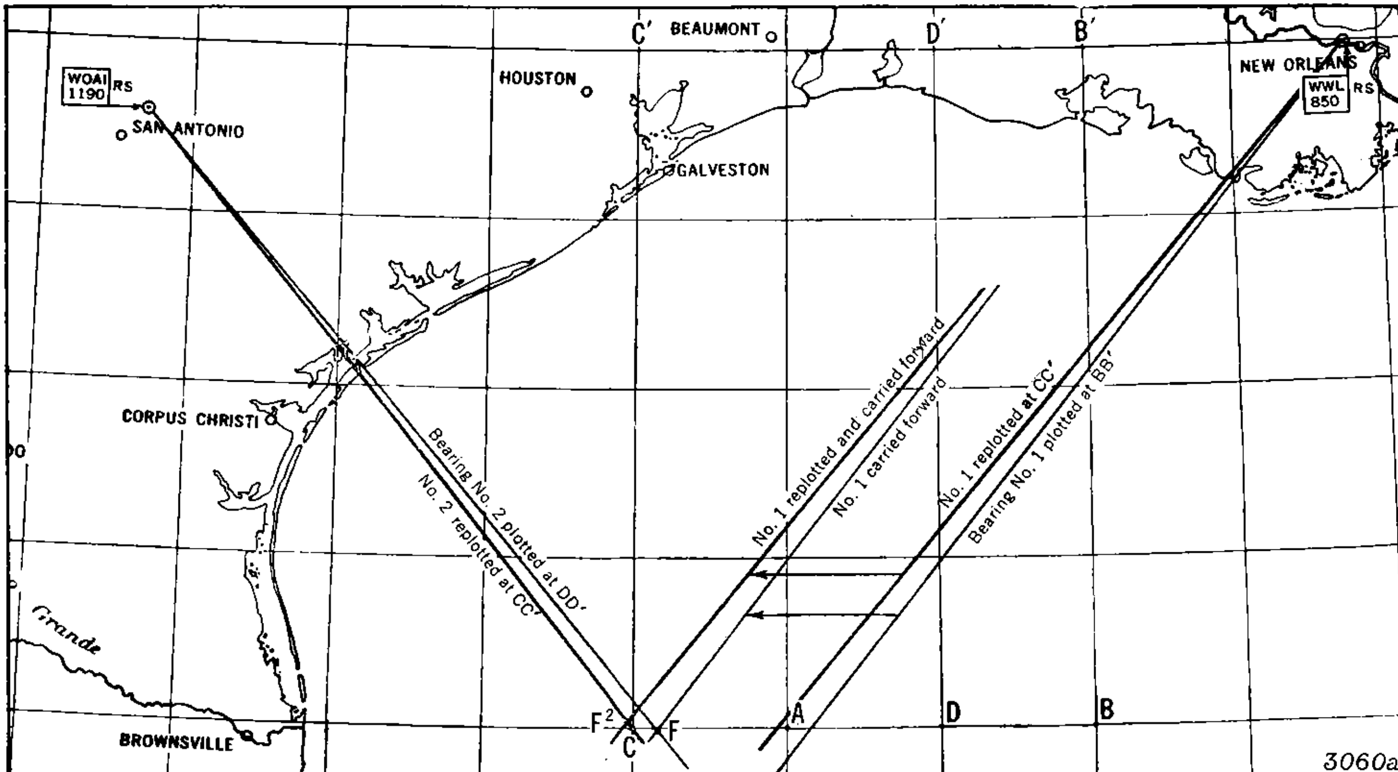

Figure 89.—A fix from radio bearings when the assumed position is considerably in error.

When the bearing was reported back by radio, he could have plotted the bearing at once with the meridian nearest the radio station (not with the meridian nearest the location of the airplane), and its intersection with the North Dalles radio range course would have determined his position as in example 1.

Example 3.—On a direct flight from Key West, Fla., to Brownsville, Tex., a pilot was approximately at position *A*, figure 89, but by dead reckoning believed himself to be in the vicinity of *B*. By radio direction finder he determined the bearing of WWL (New Orleans) as 39°, which was plotted on the

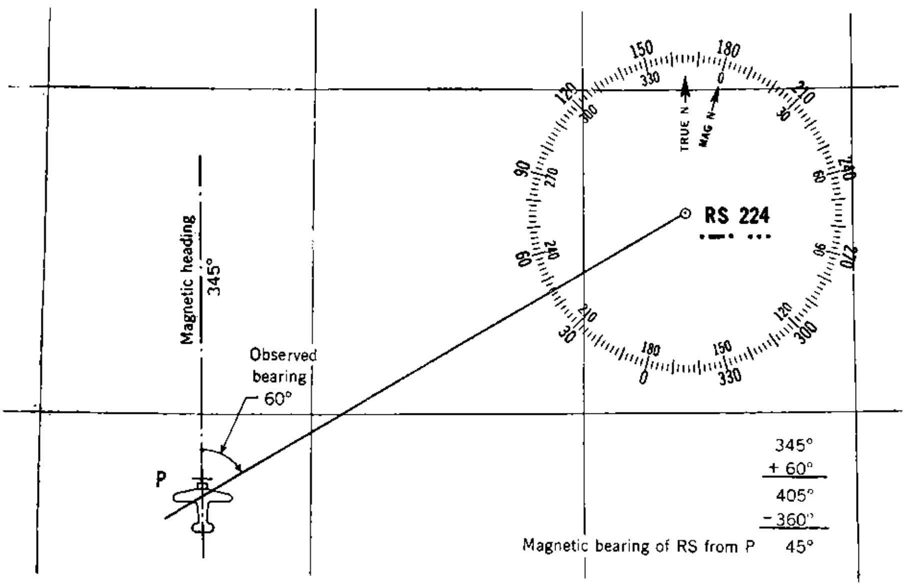

Figure 90.—Plotting a radio bearing on a radio direction finding chart.

chart with the meridian nearest *B*, affording "bearing No. 1." Not until 30 minutes later was he able to obtain the bearing of WOAI (San Antonio). Since he was flying due west at an estimated ground speed of 125 m. p. h., his true position was now at *C*, although he believed himself to be near *D*. The bearing of WOAI, 322° true, was therefore plotted at the meridian of *D*, resulting in "bearing No. 2." Carrying bearing No. 1 due west 62.5 miles (the dead-reckoning distance and direction made good between the taking of the two bearings), fixes the approximate position of the airplane at *F*.

Since this fix is nearly 2° of longitude away from the supposed position at *D*, it is decided to replot both bearings, plotting them at the meridian nearest the preliminary fix. Bearing No. 2 is replotted, and No. 1 is replotted and carried forward as shown, giving the fix at F_2. From F_2 an adjusted course to Brownsville can be determined, and the estimated time of arrival is revised, not only to allow for the shorter distance ahead, but also for the tail winds which had placed the airplane so much farther ahead than was supposed.

Example 4.—A pilot was flying in the vicinity of *P* (fig. 90) when, by means of radio direction finder, he obtained the bearing of the radio station *RS*.

Known data:

Compass heading, 347°.
Compass deviation, 2° W.
Bearing of *RS*, 60° to the right of the airplane's head.

Required.—The line of position on the radio direction finding chart of the region.

To rectify for deviation of the compass (Case II, p. 80), subtract westerly deviation: 347°−2°=345°, the magnetic heading of the plane when the bearing was obtained.

The observed bearing was 60° to the right of the airplane's head, or 45° magnetic. From the radio station draw a straight line through the 45° graduation of the compass rose as read from the outer figures; this is the desired line of position, at some point on which the airplane was located when the bearing was observed.

QUESTIONS

1. Name three of the most important functions of aeronautical radio.

2. In what three ways is radio of importance to the light-plane owner?

3. How are the four courses from a radio range station obtained?

4. The true bearings of the range courses at a station are 15°, 80°, 160°, and 260°; sketch the four courses and mark the *A* and *N* quadrants.

5. How may a pilot know to what radio range station he is listening?

6. Describe two methods of keeping in the on-course zone of a radio range.

7. How may a pilot be sure that the radio aids to navigation on his chart are up to date?

8. What is meant by a cone of silence?

9. What is a false cone of silence? How may it be distinguished from a true cone of silence?

10. What is the function of a Z marker beacon?

11. What is meant by multiple courses? bent courses? night effect?

12. Of what importance is drift in radio range flying? in orientation procedure?

13. Determine the average bisector of the *A* quadrants of question 4; of the *N* quadrants.

14. If a pilot located himself as being in one of the *N* quadrants of the Jacksonville radio range, what method of orientation procedure should he follow?

15. What precautions may be taken to insure against following a multiple course?

16. What information may be obtained from a fan marker beacon?

17. How may weather information be obtained from an ordinary radio marker beacon when the airplane is equipped with receiver only?

18. What is meant by a radio fix?

19. Distinguish between a radio compass and a radio direction finder.

20. What is an automatic radio direction finder?

21. What is meant by a relative bearing?

22. From the following data obtain the true bearing in each case; the letters *L* or *R* after the relative bearing indicate that the station is toward the left, or right, respectively:

	(1)	(2)	(3)	(4)	(5)
Compass heading	20°	350°	240°	160°	160°.
Deviation	2° E.	3° W.	5° E.	2° W.	2° E.
Variation	4° E.	8° W.	13° E.	6° E.	6° W.
Relative bearing	28° L.	40° L.	110° R.	35° R.	35° L.

23. What is meant by an aural null?

24. Under what condition may orientation with a radio compass become necessary?

25. What is meant by a radio line of position?

26. What is a running fix?

27. What is the difference between the reciprocal of an observed bearing, and the angle derived from a bearing observed aboard the aircraft, for plotting from the station itself?

28. State the rule for applying to radio bearings the correction for convergence.

29. From the following data, obtain in each case the bearing to be plotted from the magnetic compass rose of an aeronautical chart for radio direction finding; the letters *L* or *R* after the relative bearing indicate that the station is toward the left, or right, respectively:

	(1)	(2)	(3)	(4)	(5)
Compass heading	35°	270°	315°	330°	170°.
Deviation	4° W.	2° E.	3° W.	7° E.	5° W.
Relative bearing	35 ° L.	95° R.	175° R.	40° R.	38° L.

30. How may the drift angle be obtained by means of the radio compass or direction finder?

Chapter VIII.—AIR NAVIGATION COMPUTER, GRAPHS, AND TABLES

EXPLANATION

In the preceding chapters, problems pertaining to wind effect have been solved graphically by means of triangles of velocities. This principle is essential to a clear understanding of the factors involved, but the construction of such a triangle in flight is often impractical, and may be considered laborious even on the ground.

Many pages of tables and computations have been reduced to form the following graphs, by means of which pilots may read at a glance the answer to any problem involving the effect of wind or time-speed-distance relations. Each graph has its own special use and is easy to interpret with the aid of the simple examples given. It is believed that pilots will be well repaid for the little time required to become thoroughly familiar with their special uses.

In order to make the graphs useful for airplanes of all cruising speeds, it is necessary to arrange some of them for wind velocities and ground speeds in terms of percent of air speed. This means, of course, that the answer is found in terms of percentage velocities, which must be converted into the usual miles-per-hour velocities, but it was felt that the ease and rapidity of the graphic solution justified this extra step.

In an effort to eliminate the conversion of percentage velocities, the air navigation computer described in the following pages has been developed. The various parts of the computer are included as pages in this book, to be cut out and assembled by the student, with the purpose of demonstrating the usefulness of such devices.

The air navigation computer affords an almost instantaneous solution to most of the problems of flight, its accuracy being limited chiefly by the care with which it is assembled. It may be conveniently carried and kept always at hand. For some, the use of the computer will supersede the use of most of the graphs; others may still prefer the latter. In a few instances (as in fig. 105) the graphs afford solutions which cannot be obtained with the computer.

With the computer, as with all the graphs, it is immaterial whether statute miles or nautical miles are used; the answers will be obtained in the same units with which the graphs are entered, or the computer set up. Any required conversion as between nautical and statute miles may be performed from figure 95, by inspection.

THE AIR NAVIGATION COMPUTER

The computer consists of five parts, as shown facing page 138. These parts are assembled to make up the two sides of the computer, as shown in figures 91 and 93. Disks *A* and *B* form the slide rule side of the computer, for solving all problems of speed-time-distance relations, fuel consumption, air speed corrections, multiplication and division, and related problems. The compass rose, wind grid (in red), and drift grid (on celluloid) make up the wind triangle side, for solving by inspection any problems involving these factors. The graduations around the outer edge of the compass rose permit its use as a protractor also, when a more convenient protractor is not available.

The accuracy of the solution of the various flight problems will depend chiefly on the care with which the parts are assembled. The five parts may be mounted by any convenient method; for example, on a wire paper clip, bent to hold them in place; by means of a small rivet and washers; or preferably by a grommet.

Disk *A* and the compass rose may be pasted back to back, if desired, to give a little more rigid mounting, although this is not necessary. If they are to be pasted together, prick holes *exactly* through the centers of both disks, coat the backs of both with rubber cement, and allow the cement to dry. Lay one disk down on a sheet of writing paper, larger than the disk itself, with the rubber-cement side next to the paper (the dry rubber cement will not adhere to the uncoated paper). Insert a pin through the center of the disk, through the paper, then through the second disk so that the cement-coated backs are together, with the sheet of paper between. With the two disks accurately centered, hold them together at one edge, separate them at the opposite edge, and tear out a substantial piece of the separating paper. Press the disks together where the paper has been torn away, and they will adhere firmly; then tear out the remaining paper and press the whole disks together. Do not use other adhesives, or the disks will warp and stretch beyond use.

The little "window" in the upper part of disk *B* should be cut out, and the disk mounted over disk *A*, as shown in figure 91.

The wind grid (printed in red) should next be mounted over the compass rose, with the drift grid (on celluloid) on top, and the computer is complete. The tab on the side of the red wind grid should not be cut off, as this makes it much easier to adjust.

THE SLIDE RULE SIDE

The slide rule side may be used for any problems of multiplication and division. These are explained first, since they illustrate the principle on which other problems depend.

First, it should be explained that all numbers on disk *A* and on the **MIN** scale of disk *B* may be regarded as multiples of 10—that is, 25 may be considered as 2.5, 25, 250, 2,500, etc., according to the problem. The figures of the **HR** scale are for convenience in converting minutes into hours; they have no other purpose on the computer.

Above the "100" on disk *B* is an "index," in the form of an open triangle. This is often called the unit index, since it is at the 100 mark (or the 1.00 mark). The **X** below this index is the multiplication sign, and is intended as a reminder that this is the index for multiplying (and the reverse problem of dividing).

To multiply one number by another, rotate disk *B* until the **X** index is opposite one of the numbers (the multiplicand) on disk *A;* the product is then

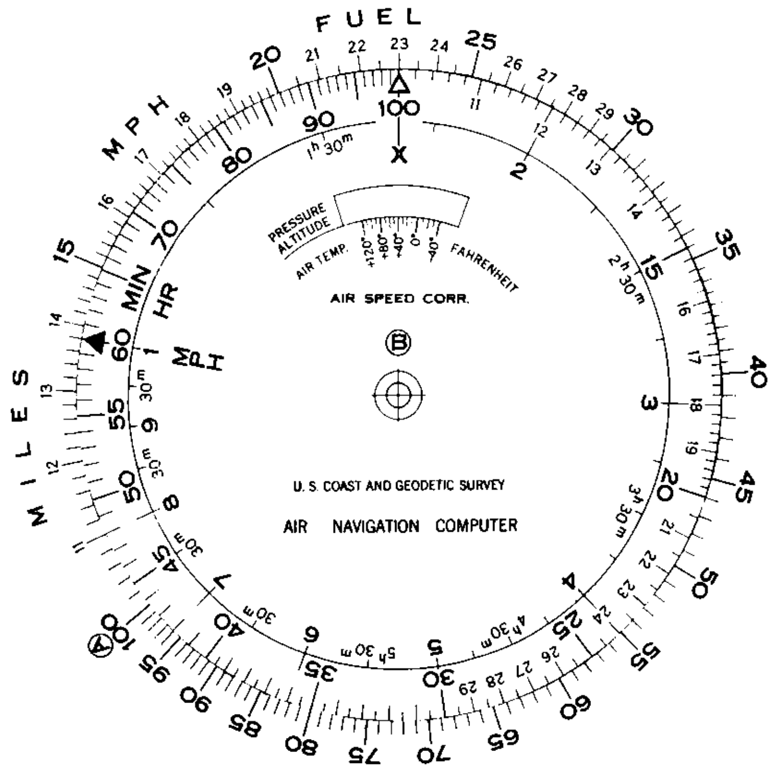

Figure 91.—Air navigation computer—slide rule side.

read from disk *A*, opposite the other of the two numbers (the multiplier) on disk *B*. For example, in figure 91 the number 23 (on disk *A*, opposite the **X** index) is to be multiplied by 19; opposite 19 on disk *B*, the product is read from disk *A* as 437. Note that with the **X** index at 23, at this one setting the product of 23 with *any* number may be read on disk *A* opposite the number on disk *B:* 23×15=345; 23×20=460; 23×60=1380 (138); 23×80=1840; and so on.

To divide, bring the dividend on disk *A* opposite the divisor on disk *B*, and the **X** index will then point to the quotient. For example (fig. 91), 1840÷80=23; 1380÷60=23; 460÷20=23; and 345÷15=23.

Problems in percentage are in reality only problems in multiplication. For example (fig. 91), 23 percent of 15=3.45; 23 percent of 20=4.6; 23 percent of 60=13.8; and 23 percent of 80=18.4.

Above the "60" on disk *B* is the **MPH** index, which is used for most of the problems involving time-speed-distance relations.

For example (fig. 91), a prominent landmark 11.5 miles from the starting point was passed after 5 minutes of flight. With 5 miles (50) on disk *B* opposite 11.5 on disk *A*, the ground speed of 138 m. p. h. is read from disk *A*, opposite the **MPH** index. Without changing the setting, the miles that will be made

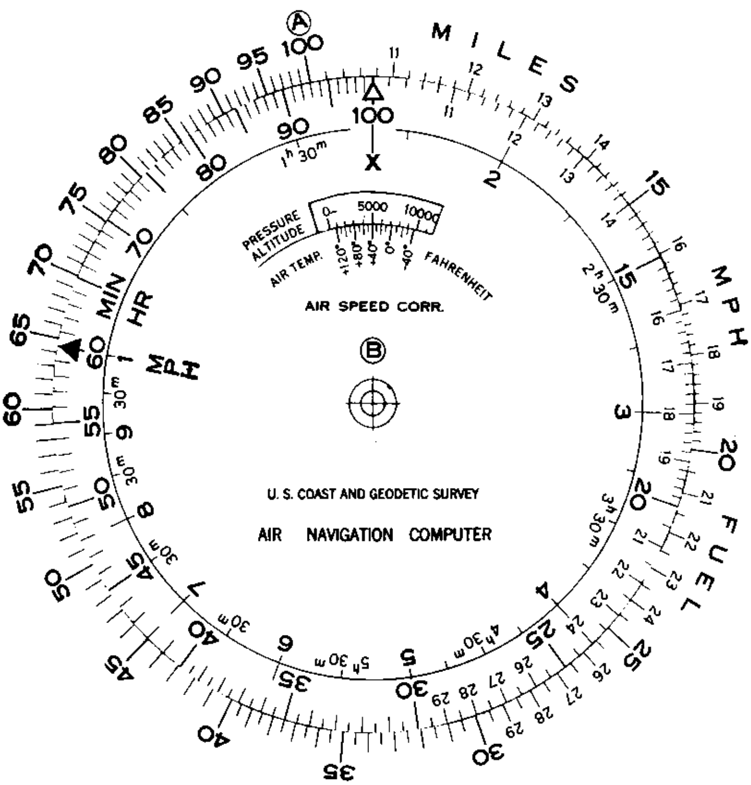

Figure 92.—Finding the true air speed with the air navigation computer.

good in any time interval at 138 m. p. h. may now be read from disk *A*: 34.5 miles opposite 15 minutes, 46 miles opposite 20 minutes, and so on. Having determined the ground speed, a glance at the computer informs the pilot at once just how far along his route he should be at any given time, which is often of considerable value in identifying position. It is also of value in dividing a route into time intervals.

By setting the **MPH** index to the ground speed in m. p. h., the ground speed in miles per minute may be read opposite the **X** index. In figure 91, with the ground speed of 138 m. p. h. opposite the **MPH** index, a ground speed of 2.3 miles per minute is read opposite the **X** index. Knowing the general relationship of the various quantities, the placing of the decimal point is most easily arrived at by mental arithmetic.

To convert nautical and statute miles, bring the **X** index opposite 115 on disk *A*. Then, in all cases, the number of statute miles may be found on disk *A* opposite the corresponding number of nautical miles on disk *B*. The factor 1.15 (115) is the number of statute miles in 1 nautical mile. If it is desired to convert nautical and statute miles frequently, it is suggested that a red dot or arrow, and the letters **ST**, be placed at 115 on disk *A*, as an aid in setting the computer and in remembering which disk represents the number of statute miles.

It may also be desired to add a red (or blue) index at "36" on disk *B* (one second is the 3600th part of 60 minutes), for solving problems involving short distances and time in seconds. For example, an airplane is flown over a 2-mile speed course in 40 seconds. By bringing 40 on disk *B* adjacent to 2 (20) on disk *A*, the ground speed is found opposite the "36" index, on disk *A*, as 180 m. p. h.

Air speed indicator corrections are found by bringing the observed temperature at the level of flight opposite the pressure altitude in the cut-out near the top of disk *B*. The true air speed may then be read from disk *A* opposite any indicated air speed on disk *B*. For example (fig. 92), the pressure altitude is 5,000 feet, and the temperature read from a wing-strut thermometer is 40° F. Opposite an indicated air speed of 140 m. p. h. on disk *B* may be read the true air speed of 150 m. p. h. on disk *A*. If the indicated air speed is 170 m. p. h., then the true air speed is 182 m. p. h.; indicated airspeed 85 m. p. h., true 91, and so on.

Problems in fuel consumption may generally be solved as simple problems in multiplication and division. For example (fig. 91), with a fuel consumption of 23 gallons per hour (**X** index opposite 23) 80.5 gallons will be required for a flight of 3 hours and 30 minutes (80.5 on disk *A* is opposite 3.5 on disk *B*). To find how long 104 gallons of fuel will last with a fuel consumption of 23 gallons per hour, set 23 on disk *B* opposite 104 on disk *A*, and read 4.5 hours on disk *A* opposite the **X** index.

An alternate procedure which some may prefer for problems in fuel consumption, is to set the **MPH** index against the fuel consumption on disk *A*, and read the fuel required for any given time interval opposite the time on the HR scale on disk *B*. Using this procedure in the example given in the preceding paragraph, set the **MPH** index against the fuel consumption of 23 gallons per hour on disk *A*, and opposite 3^h 30^m on disk *B* read 80.5 gallons required for that time interval. At the same rate of consumption, 104 gallons on disk *A* is found opposite 4^h 30^m on disk *B*; that is, 104 gallons will last 4 hours and 30 minutes.

Problems in proportion, in combined multiplication and division, in rate of ascent or descent, and other problems of flight may also be solved with this side of the computer, but the examples given illustrate those most frequently required.

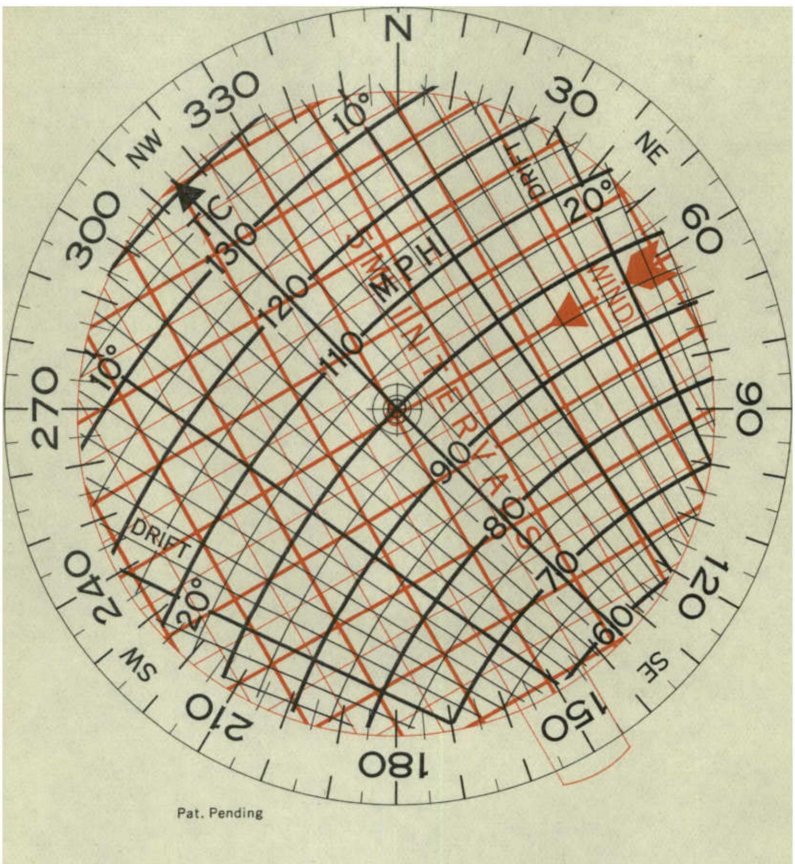

FIGURE 93. - Air Navigation computer-wind triangle side.

THE NAVIGATIONAL SIDE

The navigational side of the computer may be used for all problems involving drift, wind correction angle, heading, ground speed, and track. It is simply a convenient means of obtaining a triangle of velocities for any reasonable wind conditions.

The **TC** index on the celluloid drift grid may represent either the true course or the true heading, according to the problem, but in this instance it should not be confusing. The following examples illustrate the varied problems which may be solved. A little practice will show that problems can be solved more quickly than they can be explained.

Example 1.—The true course for a given flight is 315°; cruising speed 120 m. p. h.; wind 30 m. p. h., from 60°. Find the wind correction angle, the compass heading, and the ground speed that will be made good. (See fig. 93.)

(*a*) Set the **TC** (true course) index of the drift grid to the true course of 315° on the compass rose.

(*b*) Rotate the red wind grid until the wind arrow is adjacent to 60° on the compass rose. All red lines parallel to the wind arrow represent the direction of the wind; those at right angles to the wind arrow represent the velocity of the wind, both sets of lines being spaced at intervals representing 5 m. p. h.

(*c*) On the cruising speed arc for 120 m. p. h. find a point 30 miles distant from the true course line, measured parallel with and toward the wind arrow.

Perhaps the easiest way to find this point is to mark off the wind velocity from the center of the compass rose toward the wind arrow, and from the point so marked to draw on the celluloid a line parallel to the true course line and intersecting the cruising speed arc.

(*d*) This intersection lies very nearly on the drift grid line for 14°, which is the wind correction angle desired. Since the wind is from the right, this angle must be added to the true course to obtain the true heading: 315° + 14° = 329°. The compass heading is found by applying variation and deviation to the true heading.

(*e*) A line from the same intersection, parallel to the wind direction, intersects the true course line of the drift grid at the arc for 125 m.p.h, which is the ground speed that will be made good.

Any steps of the foregoing solution may be further clarified by figure 94, from which it is seen that the computer merely represents the significant part of the triangle of velocities. In the background, shown by dotted lines and figures, may be seen the various parts of the computer. In light solid lines there is shown the conventional triangle of velocities. The portions of the triangle actually vizualized by the computer in the solution of the problem are shown in heavy solid lines.

Example 2.—A pilot flying over the top at 100 m. p. h., on a true heading of 270°, is advised by radio that the wind is 20 m. p. h. from 45°. Find the track, or true course being made good, and the ground speed.

(*a*) Set the **TC** index to the true heading of 270° on the compass rose, and the wind arrow to 45°.

(*b*) The cruising speed arc in this case passes through the center, so the "true heading side" of the triangle of velocities is represented by the true course line, from the center back toward the "90" of the compass rose.

(*c*) The wind is from the right, and the airplane will therefore be drifted to the left from the true heading. The "wind side" of the triangle is represented by the red line from the center, to its intersection with the red line for a velocity of 20 m. p. h. This intersection marks the drift angle of 7°, as measured by the lines of the drift grid. The track, or true course made good, is equal to the true heading minus the drift angle: 270°−7°=263°.

(*d*) The same intersection lies on the arc for 115 m. p. h., which is the ground speed. The "ground speed side" of the triangle is represented by the (interpolated) grid line for 7°, from the intersection referred to, back to the common point of intersection of all the drift grid lines.

Example 3.—A pilot, flying over broken clouds at an air speed of 120 m. p. h., and on a true heading of 90°, was able to determine a drift angle of 10° to the right; at the same time he noted that smoke from a chimney was practically at right angles to his heading. Find the wind direction and velocity, the track, and the ground speed.

(*a*) Set the **TC** index to the true heading of 90°, and set the wind grid with the arrow perpendicular to the true course line, on the left.

(*b*) From the intersection of the true course line and the cruising speed arc for 120 m. p. h., draw (or estimate) a line parallel to the wind arrow to intersect with the drift grid line for 10° to the right. This intersection, measured by the red wind grid, is 21 miles from the true course line, and the wind is 21 m. p. h.

(*c*) The same intersection lies about one-fifth of the way between the arcs for 120 and 125 m. p. h., and is read as 121 m. p. h., which is the desired ground speed.

(*d*) Since the wind is from the left, the drift angle must be added to the true heading to obtain the track: 90°+10°=100°.

(*e*) The wind being at right angles to the true heading of 90°, and from the left, is seen to be from true north.

Example 4.—An airplane cruising at an air speed of 90 m. p. h. is headed true north. By means of a drift indicator, a drift angle of 10° to the left is observed; the ground speed has been determined as 103 m. p. h. Find the wind direction and velocity.

(*a*) Set the **TC** index to the true heading of north.

(*b*) Draw a line on the celluloid drift grid, from the intersection of the grid line for 10° left and the (interpolated) arc for 103 m. p. h., to the intersection of the 90 m. p. h. arc and the true course line.

(*c*) Rotate the red wind grid until the wind arrow is parallel to the line so drawn, and on the right (since the drift is to the left). The position of the wind arrow then indicates the true direction of the wind, near 120°.

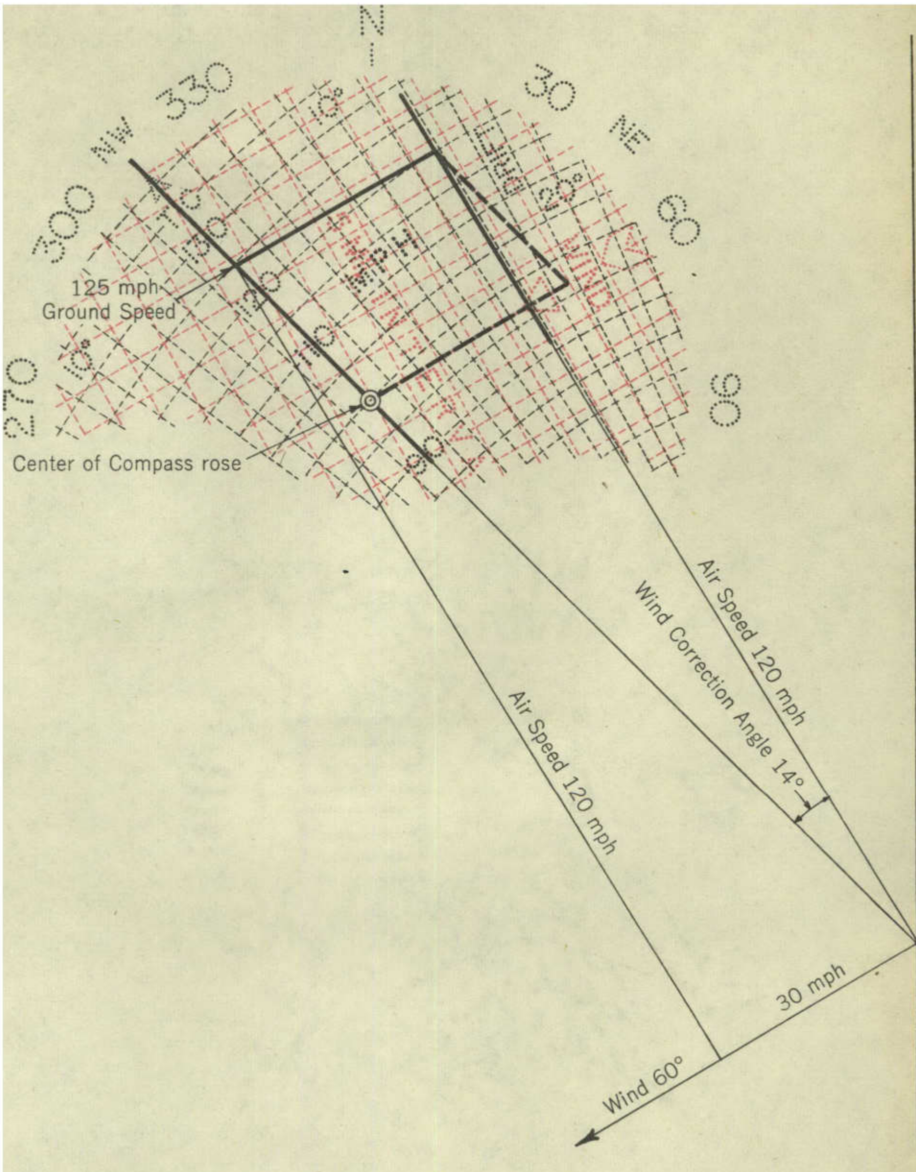

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FIGURE 94. - Triangle of velocities superimposed on computer.

(*d*) The line drawn represents the wind velocity, which is measured, by reference to the grid lines, as 21 m. p. h.

Example 5.—The true course is 30°, wind from 100° at 25 m. p. h. It is desired to maintain a ground speed of 110 m. p. h. Find the air speed and the true heading required.

(*a*) Set the "TC" index to the true course of 30°, and the wind arrow to 100°.

(*b*) The true course line, from its intersection with the cruising speed arc of 110 m. p. h. back toward 210° represents the "ground speed side" of the triangle of velocities.

(*c*) From this intersection draw a line parallel to and toward the wind arrow, 25 miles in length. This line represents the "wind side" of the triangle.

(*d*) The extremity of the wind line lies between 120 and 125 m. p. h., at 121 m. p. h., which is the air speed required The "air speed side" of the triangle is the (interpolated) drift line (about 11°) from the extremity of the wind line back to the common intersection of all the drift grid lines.

(*e*) The 11° determined by the extremity of the wind line is the wind correction angle, which must be added to the true course to find the true heading, since the wind is from the right: 30°+11°=41°.

Example 6.—The true course is 240°; cruising speed 165 m. p. h.; wind 40 m. p. h., from 315°. Find the wind correction angle, the compass heading and the ground speed.

When the cruising speed or wind velocity is outside the range of velocities included in the computer, resort must be had to percentage velocities. From the slide rule side, it is found that the wind of 40 m. p. h. is about 24 percent of the cruising speed of 165 m. p. h. The procedure from this point is as follows:

(*a*) Set the "TC" index at 240° on the compass rose, and the wind arrow at 315°.

(*b*) From the center of the computer, which is on the arc for 100 m. p. h. (100 percent in this case) follow the red wind line toward the arrow, out to the velocity representing 24 m. p. h. (24 percent), and from this point draw a line parallel to the true course line and intersecting the 100 m. p. h. arc.

(*c*) This intersection marks the wind correction angle of nearly 14°, which must be added to the true course to obtain the true heading: 240°+14°=254°. The compass heading is obtained by applying variation and deviation.

(*d*) A line from the same intersection, parallel to the wind arrow, intersects the true course line at 91. That is, the ground speed is 91 percent of the air speed. From the slide rule side it is found that 91 percent of 165=150 m. p. h.

CONVERSION OF PERCENTAGE VELOCITIES AND MILES-PER-HOUR VELOCITIES

[See fig. 96]

This graph is intended to facilitate the conversion from miles per hour to percentage velocities, as well as the reverse process. It needs no explanation other than the following examples:

Example 1.—A wind velocity of 20 m. p. h. is reported. What percent is this of an air speed of 120 m. p. h.?

Follow the curve for 20 m. p. h. across to its intersection with the vertical line for 120 m. p. h.; opposite this point at the left read the percentage velocity of 17. That is, 20 m. p. h. is 17 percent of the air speed of 120 m. p. h.

Example 2.—From figure 100 it is found that a ground speed equal to 116 percent of the air speed of 140 m. p. h. will be made good along the intended track. What is the ground speed in m. p. h.?

Follow the horizontal line corresponding to 116 percent across to the vertical line for an air speed of 140 m. p. h., and read 162 m. p. h. (interpolating between the curves for 160 and 165 m. p. h.).

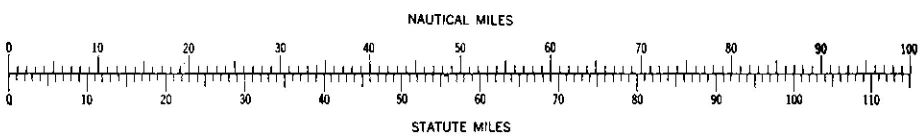

Figure 95.—Nautical-statute miles conversion scale.

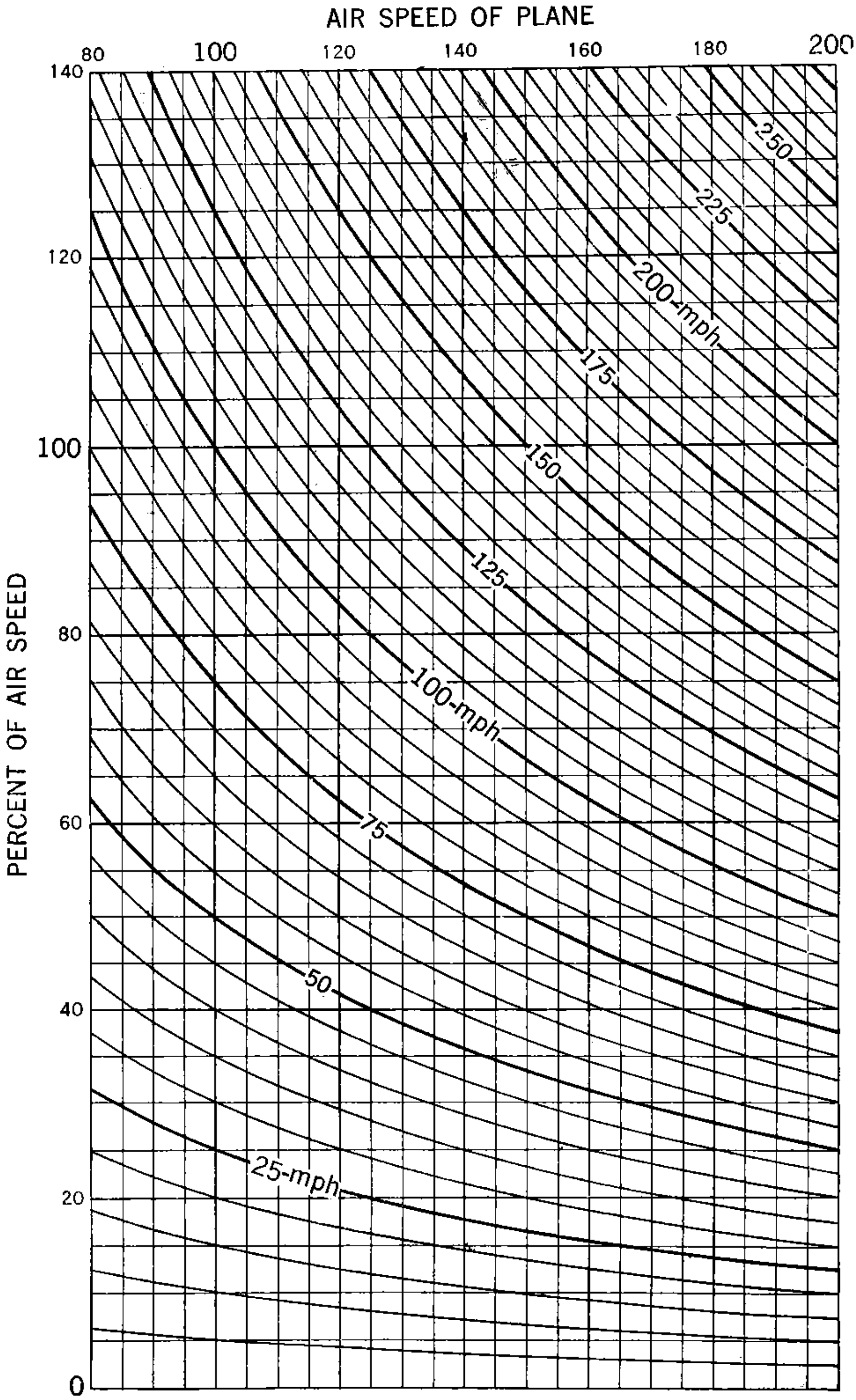

Figure 96.—Graph for converting miles-per-hour and percentage velocities.

FINDING THE TRUE AIR SPEED

[See fig. 98]

For many problems of piloting and dead reckoning a knowledge of the true air speed is essential. The airspeed meter records the pressure of the air against the pressure chamber of the instrument in terms of speed. Pressure varies with altitude and with the temperature of the air, and the indicated air speed must therefore be corrected for these factors in order to obtain the true air speed. This correction may be found from figure 98.

In using the graph it is assumed that the airspeed meter has previously been corrected or calibrated for any instrumental or installation errors. Perhaps the most satisfactory method of calibration is to fly a measured course under no-wind (or known wind) conditions, noting the time with a stop watch. The "pressure altitude" with which the graph is entered is the reading of the altimeter when set for the standard barometric pressure of 29.92 inches of mercury (and corrected for instrumental and installation errors). Temperature recorded in degrees Centigrade may be converted into degrees Fahrenheit, or vice versa, by means of figure 97. The following examples illustrate the use of figure 98.

Example 1.—A pilot flying at an altitude of 5,000 feet, at an indicated air speed of 135 m. p. h., wishes to determine his true air speed. The temperature, read from a wing strut thermometer at the time, is 50° F.

Follow the horizontal line corresponding to an altitude of 5,000 feet across to its intersection with the vertical line for a temperature of 50°, and read the true air speed from the nearest curve—a little more than 108 percent of the indicated air speed.

Referring to figure 96, it is seen that 108 percent of the indicated air speed of 135 m. p. h. is 146 m. p. h., which is the true air speed required.

Example 2.—At 10,000 feet the indicated air speed is 150 m. p. h.; temperature 5° C. Find the true air speed.

From figure 97 it is seen that 5° C. is equal to 41° F. In figure 98 follow the horizontal line for 10,000 feet across to its intersection with the vertical line for 41° F., and read the true air speed as 118.5 percent of 150, or 178 m. p. h.

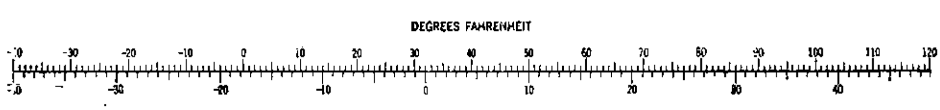

Figure 97.—Fahrenheit-centigrade temperature conversion scale.

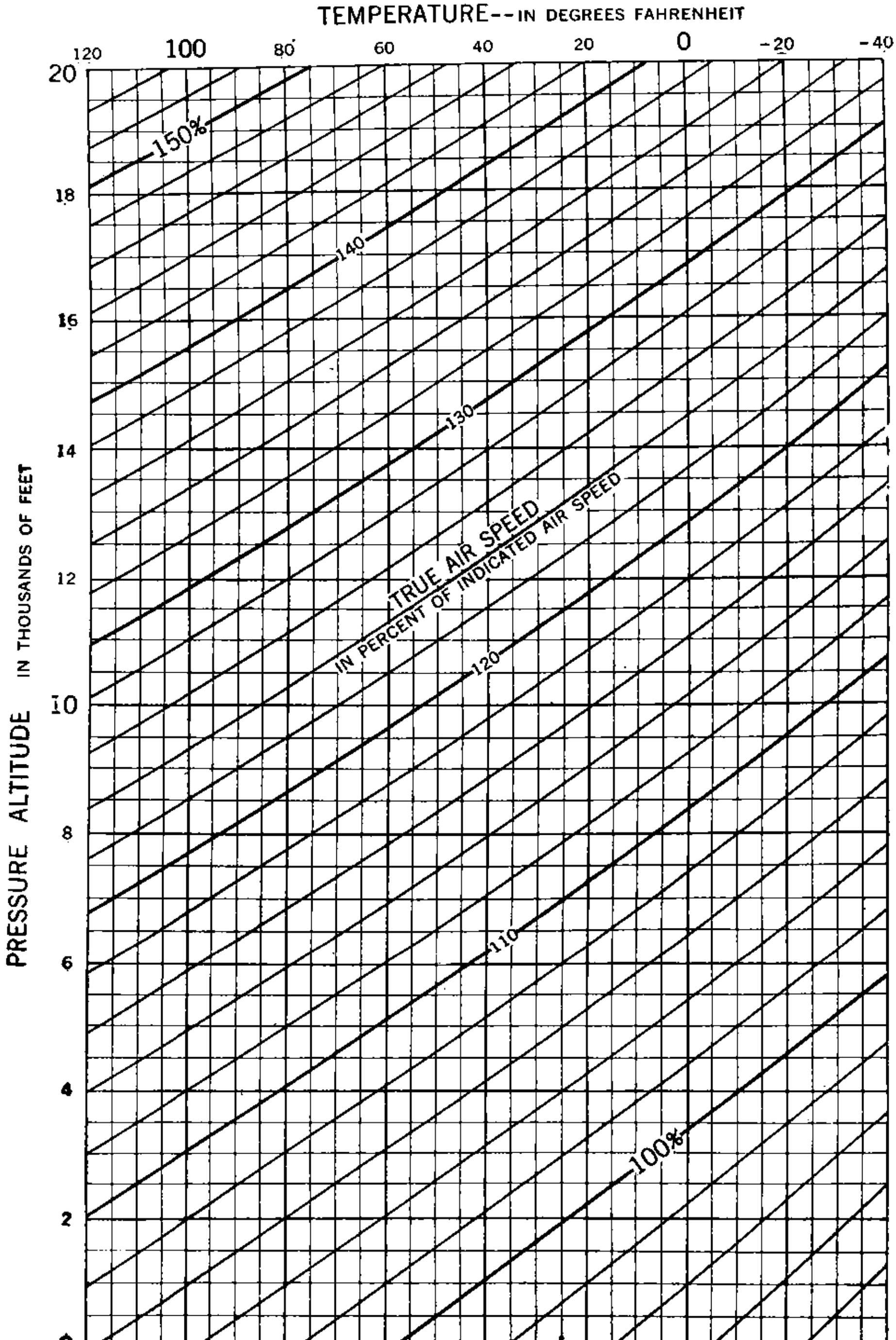

Figure 98.—Graph for finding the true air speed.

TIME—SPEED—DISTANCE PROBLEMS

[See fig. 99]

Example 1.—A prominent charted landmark, along the desired route and 6 miles from the starting point, is passed in 3 minutes of flight. What is the ground speed being made good?

Using the inner scales (see note below graph), follow the vertical line corresponding to 6 miles down to its intersection with the horizontal line for 3 minutes. The diagonal line passing through the intersection, 120 m. p. h., is the ground speed required.

Example 2.—With a ground speed of 120 m. p. h., how many minutes will be required to reach a town 95 miles distant?

Using the outer scales (see note below graph), follow the vertical line corresponding to 95 miles down to its intersection with the ground speed line for 120 m. p. h., then follow the horizontal line across to read the required time of 47.5 minutes.

Example 3.—An airplane is making good a ground speed of 150 m. p. h. and it is desired to divide the route into time intervals of 10 minutes each. Find the number of miles that will be made good for each 10 minutes.

Follow the horizontal line for 10 minutes across to the ground speed line for 150 m. p. h., and above this point read 25 miles, the distance to be made good for each 10 minutes of flight.

Example 4.—A flight of 850 miles is to be made, and a ground speed of about 140 m. p. h. is expected. Find the total flying time required.

For the infrequent cases involving distances in excess of 100 miles, multiply the two outer scales by 10. Follow the vertical line corresponding to 850 miles (85 miles) down to its intersection with the ground speed line for 140 m. p. h., then across to read the time interval of 365 minutes (36.5), or 6 hours 5 minutes, which is the time required.

Example 5.—Find the ground speed corresponding to a distance of 10.5 miles made good in 4.5 minutes.

For distances over 10 miles and time less than 6 minutes, the graph is not directly useful, since the ground speed lines are too close together to be read easily and many of them must be omitted. This portion of the graph should seldom be used, as results obtained from high speeds and short distances (or time) are not likely to be very dependable.

When such a problem arises, multiply both time and distance by any convenient number, as 2. In this case the distance becomes 21 miles and the time 9 minutes, and the ground speed of 140 m. p. h. is easily read from the corresponding point on the graph.

CORRECTION TO COURSE FOR WIND AND DETERMINATION OF GROUND SPEED

[See fig. 100]

This graph is intended for use when the wind direction and velocity are definitely known. It would ordinarily be used to determine the correct compass heading from weather reports before taking off, as well as the ground speed that will be made good along the intended track while flying the correct compass heading.

The correction to the course that is read from the graph is also the drift angle that will be observed in flight, as long as the correct compass heading is maintained and there is little change in wind. This provides a very definite

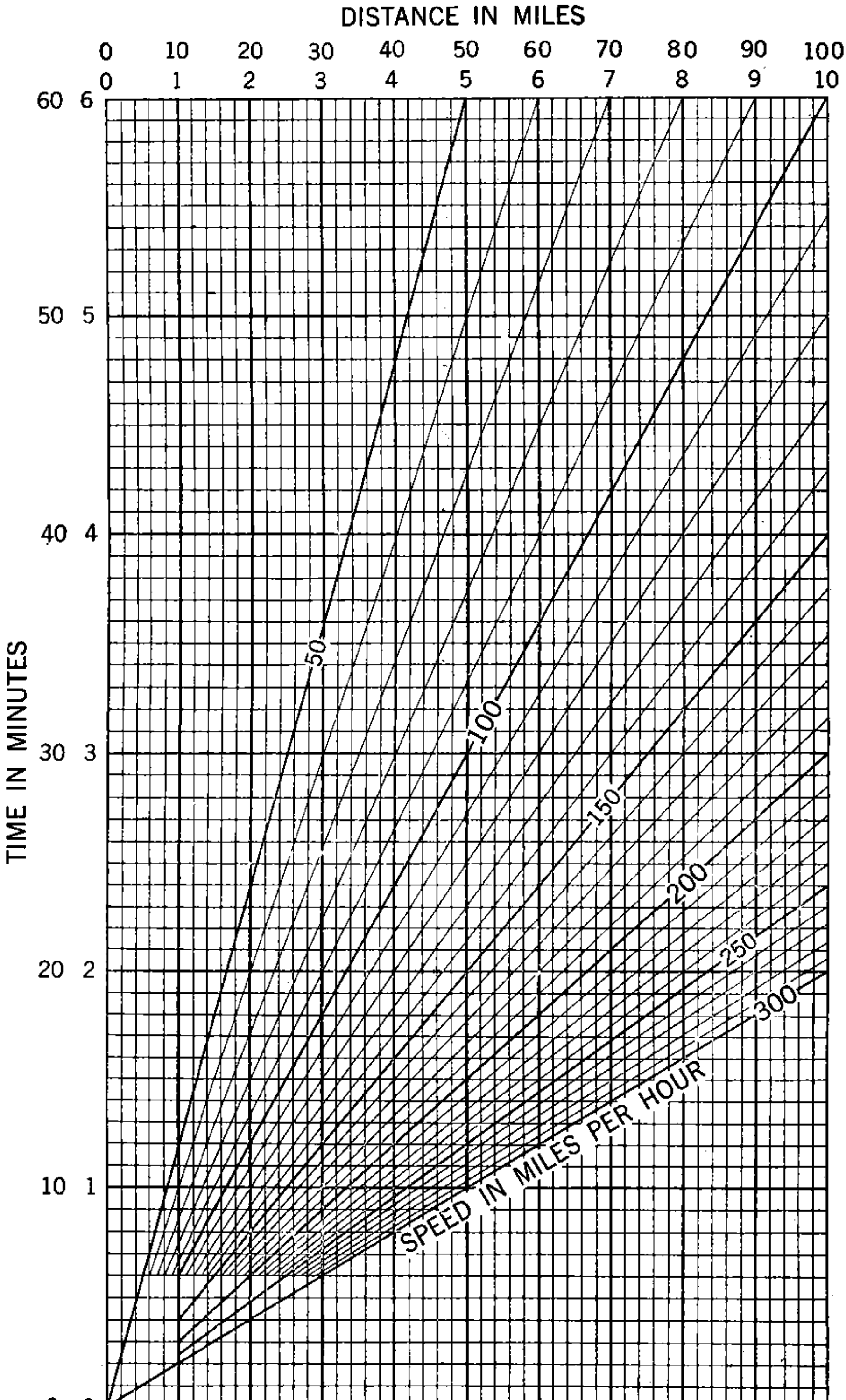

Figure 99.—Time-speed-distance graph.

For distance under 10 miles or time under 6 minutes use the inner scales.
For distance over 10 miles or time over 6 minutes use the outer scales.

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check, then, as to whether the conditions encountered in the air are as predicted. If at any time an appreciably different drift angle is observed, corrections based on the new wind conditions should be determined as outlined in connection with figure 103 or figure 105.

To use this graph, the wind velocity in miles per hour must first be converted into percent of air speed; the ground speed is read from the graph in percent of air speed and must be converted into miles per hour. This is done most readily by reference to figure 96.

The "angle between wind and true course" is reckoned from dead ahead, i. e., looking toward the destination, from 0° to 180° on either side.

Example 1.—The cruising speed of airplane is 160 m. p. h.; true course, 85°; wind, 25 m. p. h., from 45°. Find the correction to the course for wind,

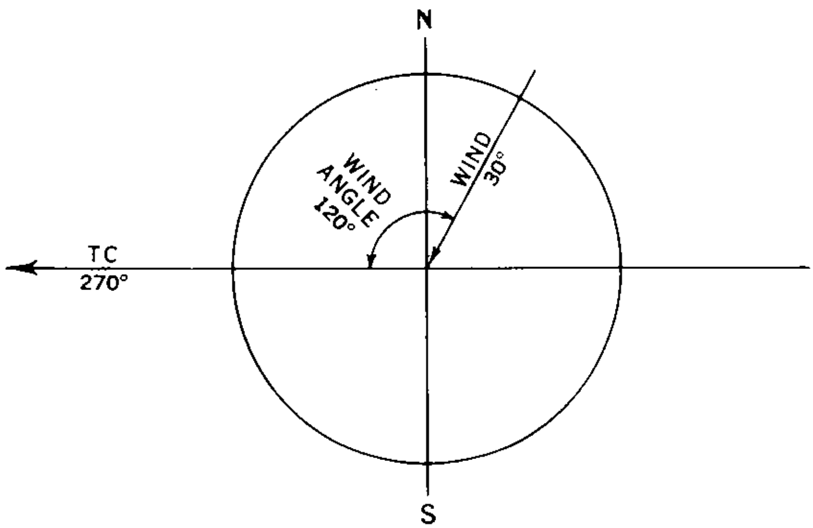

Figure 101.—Determining the wind angle.

and the ground speed that will be made good along the intended track while flying the correct compass heading.

The angle between the wind and the true course is 85°—45°, or 40°. By reference to figure 96 it is seen that the wind velocity of 25 m. p. h. is 16 percent of the cruising speed of 160 m. p. h. Now, in figure 100, follow the vertical line corresponding to a wind velocity of 16 percent down to its intersection with the horizontal line for 40° wind angle and read from the red curve the correction to the course, which is 6°; by interpolation between the black curves, the ground speed that will be made good along the intended track is found to be 87 percent of the air speed of 160 m. p. h., or 140 m. p. h. This is the ground speed that will be made good along the intended track. Since the wind is from the left, the correction of 6° must be subtracted from the true course.

Example 2.—The cruising speed of airplane is 135 m. p. h.; true course, 270°; wind, 32 m. p. h., from 30°. Find the correction to the course for wind and the ground speed that will be made good along the intended track.

The angle between the wind and the true course is 120°. If this factor is not entirely clear at any time, a crude sketch similar to figure 101 will guard against errors.

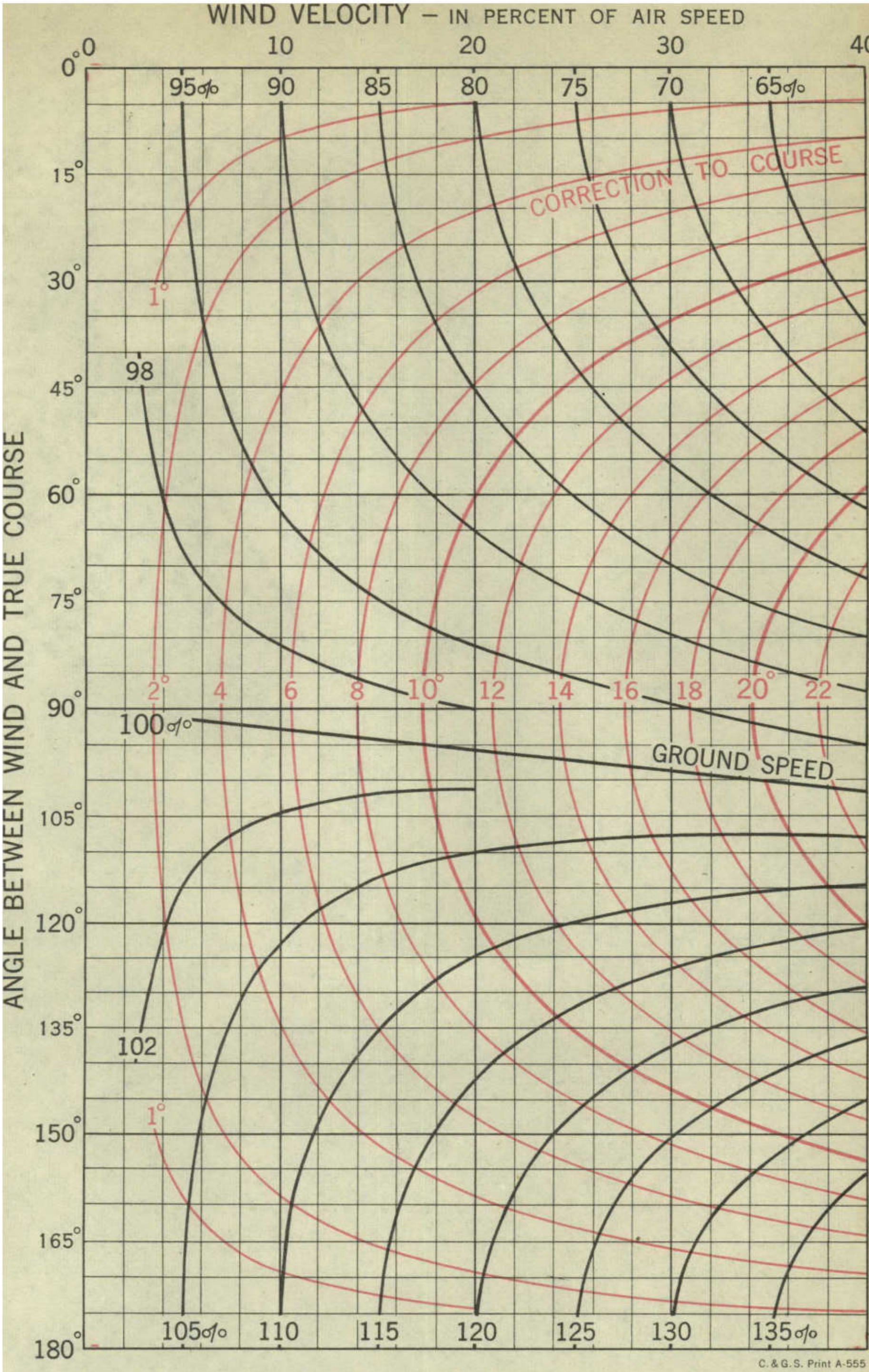

FIGURE 100. - Graph for finding the wind correction angle and ground speed when the wind direction and velocity are known.

From figure 96 it is seen that the wind velocity of 32 m. p. h. is 24 percent of the cruising speed of 135 m. p. h. Now, in figure 100 follow the vertical line for 24 percent down to its intersection with the horizontal line for 120° and read the correction to the course, which is 12°. Since the wind is from the right, this correction must be added to the true course. At the same point in the graph, a ground speed equal to 110 percent of the air speed is indicated; referring again to figure 96 it is seen that 110 percent of 135 m. p. h. = 148 m. p. h., which is the ground speed that will be made good along the intended track.

Example 3.—A pilot flying the radio-range course has been able to determine his ground speed as 90 percent of the air speed, and finds that he has to head 10° to the right of the magnetic course on the chart in order to keep along the right side of the equisignal zone, because of cross winds. Find the direction and velocity of the wind.

Table 1.—Correction to course for wind, and determination of ground speed

["Corr." is the correction to the course for wind; to be ADDED for wind from the RIGHT, subtracted for wind from the left].

["G. S." is the ground speed that will be made good along the intended track; it is expressed in percent of air speed].

Wind angle	Wind velocity—in percent of air speed															
	5		10		15		20		25		30		35		40	
	Corr.	G. S.	Corr.	G. S.	Corr.	G. S.	Corr.	G. S.	Corr.	G. S.	Corr.	G. S.	Corr.	G. S.	Corr.	G. S.
	°	%	°	%	°	%	°	%	°	%	°	%	°	%	°	%
0°	0	95	0	90	0	85	0	80	0	75	0	70	0	65	0	60
10°	0	95	1	90	1	85	2	80	2	75	3	70	3	65	4	60
20°	1	95	2	90	3	86	4	81	5	76	6	71	7	66	8	61
30°	1	96	3	91	4	87	6	82	7	78	9	73	10	68	12	63
40°	2	96	4	92	6	88	7	84	9	80	11	75	13	71	15	66
50°	2	97	4	93	7	90	9	86	11	82	13	78	16	74	18	69
60°	2	97	5	95	7	92	10	88	13	85	15	82	18	78	20	74
70°	3	98	5	96	8	94	11	91	14	89	16	86	19	82	22	79
80°	3	99	6	98	8	96	11	95	14	93	17	90	20	88	23	85
90°	3	100	6	99	9	99	12	98	14	97	17	95	20	94	24	92
100°	3	101	6	101	8	102	11	102	14	101	17	101	20	100	23	99
110°	3	102	5	103	8	104	11	105	14	106	16	106	19	106	22	106
120°	2	102	5	105	7	107	10	108	13	110	15	112	18	113	20	114
130°	2	103	4	106	7	109	9	112	11	114	13	117	16	119	18	121
140°	2	104	4	107	6	111	7	114	9	118	11	121	13	124	15	127
150°	1	104	3	109	4	113	6	117	7	121	9	125	10	129	12	133
160°	1	105	2	109	3	114	4	119	5	123	6	128	7	132	8	137
170°	0	105	1	110	1	115	2	120	2	124	3	129	3	134	4	139
180°	0	105	0	110	0	115	0	120	0	125	0	130	0	135	0	140

The 10° which the pilot must head into the wind is the wind correction angle. In figure 100, locate the point where the black curve corresponding to a ground speed of 90 percent intersects the red curve for a wind correction angle of 10°; directly above this point find the wind velocity, which is 19 percent of the air speed, and at the left find the wind angle, which is about 63° to the right of the true course.

If preferred, table 1 can be used for these problems, instead of figure 100. The table affords the same information as the graph, but in some respects is less exact and requires mental interpolations. For example, for a wind velocity equal to 28 percent of the air speed the corrections must be interpolated between the values given in the column for 25 percent and the column for 30 percent. If the wind of 28 percent is at an angle of 80° from the head of the airplane, the correction to the course for wind is 16°, and the ground speed that will be made good along the intended track is 91 percent of the air speed.

CORRECTION TO COURSE AND DETERMINATION OF COMPASS HEADING AND GROUND SPEED BY THE DOUBLE-DRIFT METHOD

[See fig. 103]

Figure 100 and table 1 are intended chiefly for determining the ground speed and the correction to course before beginning a flight, from predicted wind velocities and directions. Their use is subject to the disadvantage that winds vary with time, place, and altitude, and the conditions actually experienced in flight may differ appreciably from those predicted.

By the use of figure 103, the pilot needs only to make two drift observations, and may read directly the correction to the course and the resultant ground speed. The results are precise and are based on conditions existing at the moment, rather than on predicted conditions.

Without the graph, this could be accomplished by plotting the two drift angles in a combined figure ("wind star") from which the wind direction and velocity could be scaled, and then applying a correction for the wind so determined. By the use of this graph the plotting is eliminated altogether and the desired corrections are read opposite the observed drift angles. The procedure is as follows:

1. Fly a compass course at an angle of 45° to the right of the intended track and observe the drift angle—say, 10° to the right.
2. While returning to the intended track and at an angle of 45° to the left thereof, observe a second drift angle—say, 5° to the right.
3. With these two values enter the graph and read the correction to the course as 11° (turn 11° toward the left), and the ground speed that will be made good along the intended track as 90 percent of the air speed.

Figure 102 further illustrates the procedure. The compass course from *O* to a distant point *D* (not allowing for wind) is 60°. Upon reaching the point *B*, it is decided to determine definitely the correction to course and ground speed by this method. A compass course of 105° (45° to the right) is therefore flown until the drift angle is determined; the ship is then turned through 90°, returning to the plotted route on a compass course of 15° (45° to the left), and the second drift angle is determined. Under average conditions, the airplane should be approximately over the intended track when the second drift angle is obtained, and the data read from the graph supply the pilot with the exact compass heading and ground speed toward his destination.

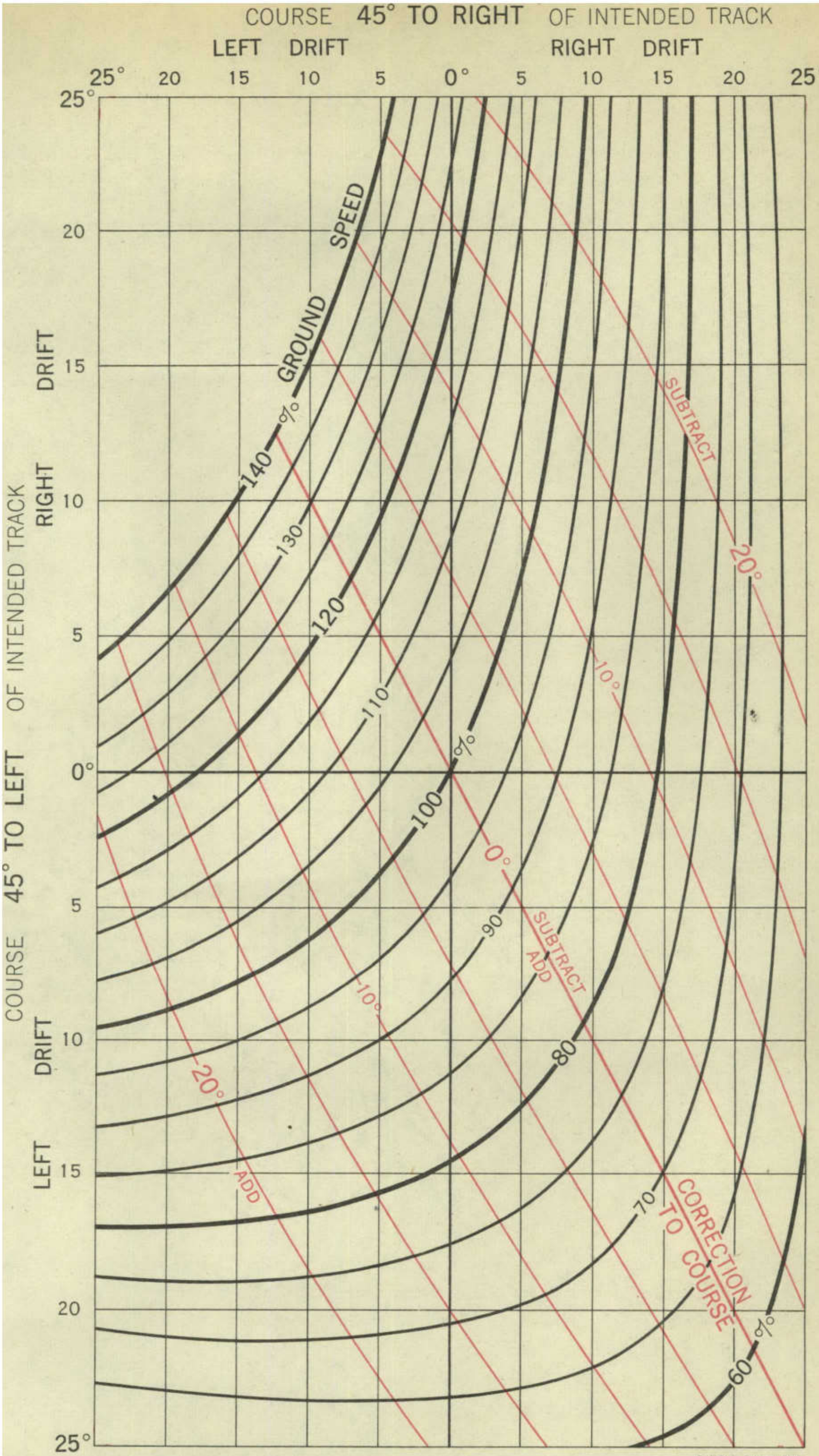

FIGURE 103. - Graph for finding the wind correction angle and ground speed by the double drift method.

As previously stated, the "correction to the course" is also the drift angle that will be observed as long as the plane is kept on the corrected compass heading and the wind remains unchanged. If at any time an appreciably different drift angle is observed, it is notice of changed wind conditions, and the new ground speed and correction to course should be determined as before.

In flying the two courses at 45° to the plotted route, it is not necessary to consider differences of compass deviation unless they are excessively large. Minor differences such as would ordinarily be present, would not affect the results.

In the above process the pilot does not learn—in fact, does not need to know—the direction and velocity of the wind. Instead, these values have been

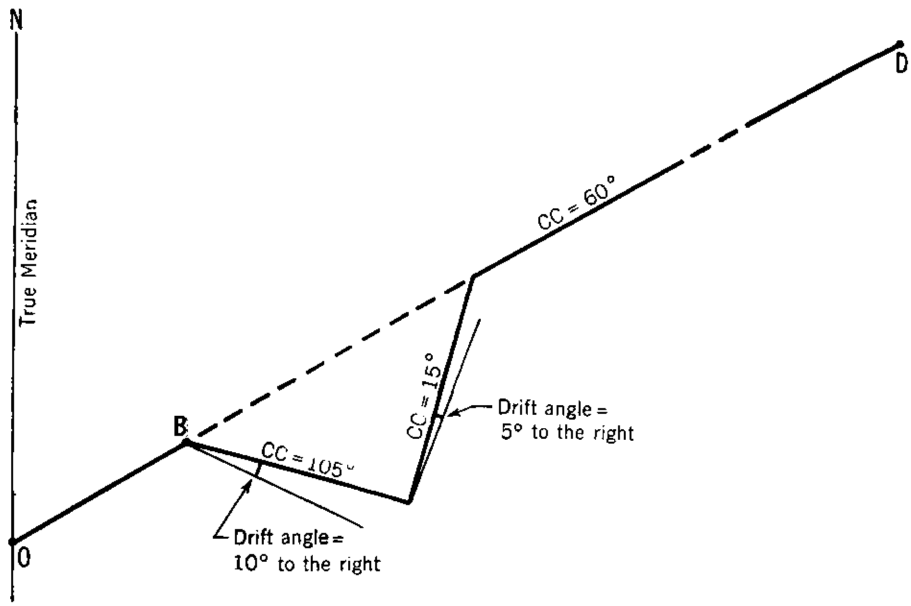

Figure 102.—Measuring the two drift angles.

previously computed and incorporated in the graph, and the pilot reads from it only the corrections required. If, for any special purpose, the pilot should wish to know the wind direction and velocity, he can obtain them from the corrections read from the graph, as explained in example 3, p. 156, or from the computer.

This detailed explanation of the graph and of the method involved may sound complicated. As a matter of fact, it is very simple and one of the most accurate methods devised to date. The simplicity is shown by the following examples.

Example 1.—A pilot desiring to make good a compass course of 78°, flies first on a compass course of 125° (about 45° to the right), then on a course of 35° (about 45° to the left), observing the drift angle on each course. On the first course a drift angle of 15° to the right was obtained; on the second, a drift angle of 5° to the left. Find the correction to the course, and the ground speed that will be made good.

At the top of the graph are shown the drift angles for the course 45° to the right of the intended track; follow the vertical line corresponding to a drift angle of 15° to the right down to its intersection with the horizontal line for a drift of 5° to the left, and read 7° correction to be subtracted from the course, and a ground speed of 77 percent. The compass heading to be flown, then, is 78°−7°=71°, and the ground speed will be 77 percent of the air speed of the plane.

Example 2.—The compass course from *A* to *B* is 225°; observed drift angle on compass course of 270° (45° to the right), 20° to the left; drift angle on compass course of 180° (45° to the left), 5° to the right. Find the correction to the course and the ground speed that will be made good.

From the top of the graph, follow the vertical line for a drift of 20° to the left down to its intersection with the horizontal line for a drift of 5° to the right, and read 12° correction to be added to the course, and a ground speed of 136

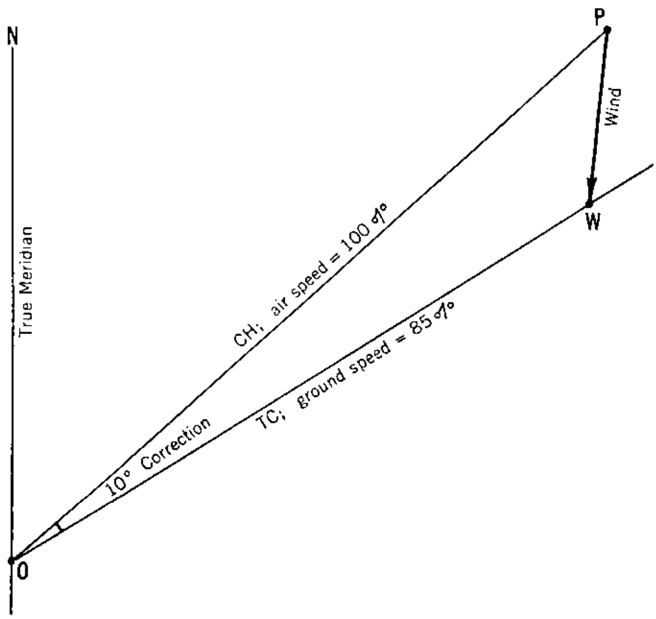

Figure 104.—Finding the wind direction and velocity from figure 100.

percent. The compass heading to be flown is 225°+12°=237°, and the ground speed will be 136 percent of the air speed.

As long as the compass heading of 237° is maintained and there is no appreciable change in wind, a drift angle of 12° to the left will be observed. If any great change from this value is noted, the correction to course and the ground speed should be redetermined.

Example 3.—A pilot, having obtained from figure 103 a correction to the course of 10° to the left and a ground speed of 85 percent, wishes to determine the direction and velocity of the wind.

At the meridian *ON* (fig. 104) lay off the true course *OW* and plot the correction to the course. The air speed is in the direction of the compass heading *OP*, which is therefore plotted=100 percent; the ground speed is in the direction of *OW*, which is plotted=85 percent. *PW* then represents the wind velocity in percent of air speed, and its direction, with respect to true north or to the true course, may be measured from the drawing with a protractor. Wind direction and velocity may also be obtained readily by the use of figure 106, or with the computer.

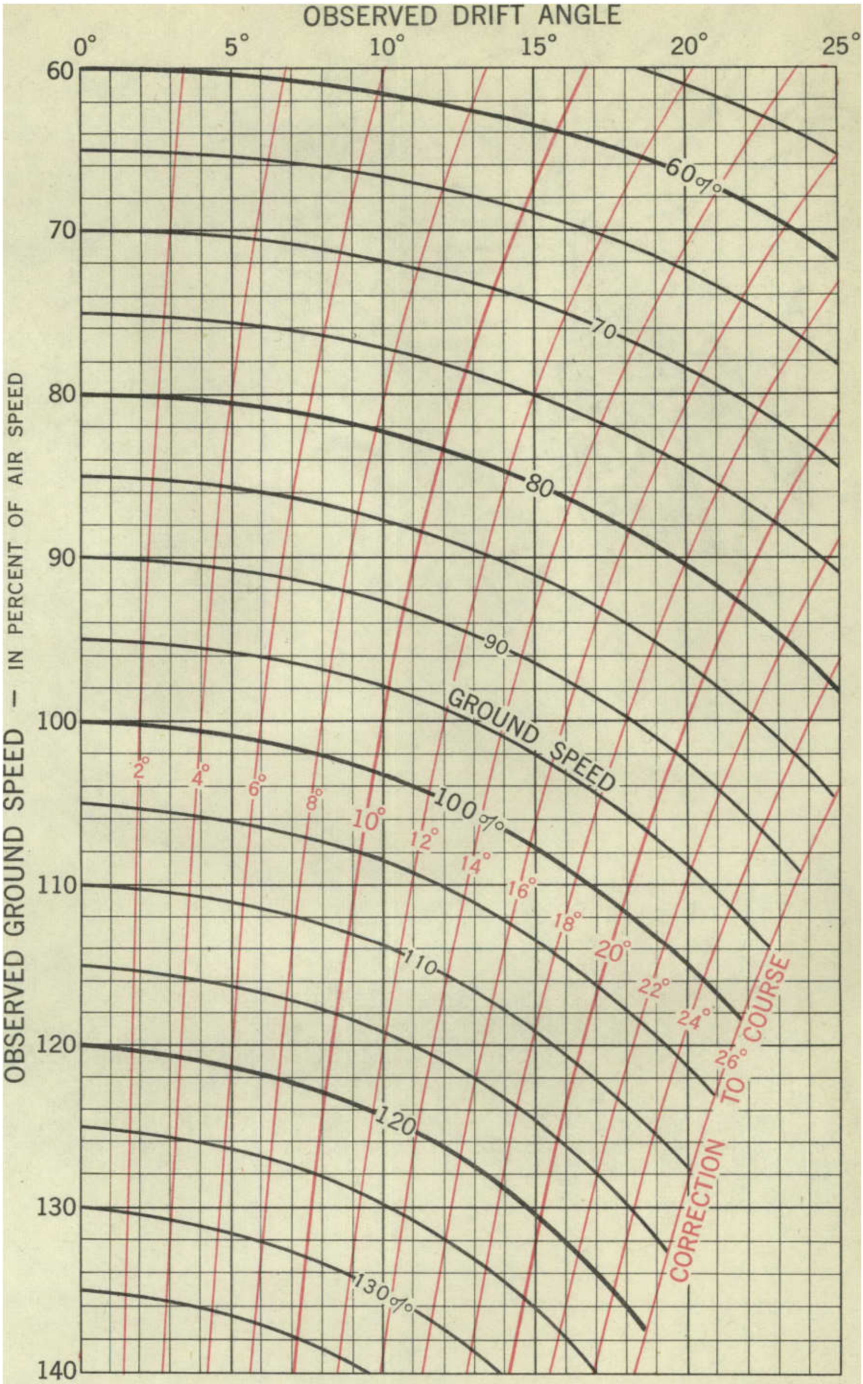

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FIGURE 105. - Graph for finding the wind correction angle and ground speed from one observation with a drift indicator.

FINDING WIND CORRECTION AND GROUND SPEED IN FLIGHT FROM ONE OBSERVATION WITH A DRIFT INDICATOR

[See fig. 105]

As with the preceding figure, the corrections obtained from this graph are based upon conditions actually being experienced in flight rather than upon predicted conditions which may or may not hold good. The procedure is as follows:

1. Head the airplane along the no-wind compass course to the destination.
2. Note the drift angle and the ground speed being made good.
3. With these data read directly from the graph the correction to the course and the ground speed that will be made good, in percent of air speed.

This method is the simplest possible, and its precision is limited only by the accuracy with which the ground speed can be determined. With some drift indicators fairly good determinations of ground speed are possible; at other times this factor can be definitely known by reference to landmarks, radio marker beacons, etc. Whenever the ground speed can be satisfactorily determined, this method is the quickest and most satisfactory. It should be noted that with this method no departure from the course is necessary in order to make the drift-and-ground speed observations.

Example 1.—An airplane flying at an air speed of 140 m. p. h. is headed on the no-wind compass course when a drift angle of 11° to the right is observed with a drift indicator, and the ground speed is determined as 153 m. p. h. Find the correction to the course and the ground speed that will be made good along the intended track.

By reference to figure 96 it is seen that 153 m. p. h. is 109 percent of the air speed of 140 m. p. h. Follow the vertical line corresponding to an 11° drift angle down to the (interpolated) horizontal line for 109 percent and read, from the nearest red curve, 12°, the correction to the course for wind; the nearest black curve, 105 percent, indicates that a ground speed equal to 105 percent of the air speed will be made good along the intended track. Referring again to figure 96, it is seen that 105 percent of 140 m. p. h. = 147 m. p. h. Since the drift is to the right, the wind is from the left, and the 12° must be subtracted from the compass course.

RECTIFYING THE HEADING AND GROUND SPEED FOR THE EFFECT OF WIND

[See fig. 106]

This graph is intended chiefly for rectifying the heading and ground speed for the effect of known wind, in order to plot on the chart the true course and distance made good (Case II of dead reckoning). It may also be used to determine wind direction and velocity. As in the preceding figures, wind velocities and ground speeds are indicated in percent of air speed.

In effect, figure 106 contains all possible combinations of the triangle of velocities. It consists of a red wind compass superimposed on a series of black drift angles and ground speed arcs.

The red wind compass is graduated to show wind direction at 10° intervals, and concentric red circles for reading wind velocities are drawn from the center at intervals corresponding to 5 percent of the air speed of the airplane.

The black drift angles are at intervals of 2°, and the central line marked 0° may be considered either as true north or as the heading of the airplane, according to the problem. The black arcs are spaced at intervals of 5 per cent of the air speed, and provide a convenient scale for reading ground speeds.

Example 1.—A pilot flying over the top at 100 m. p. h. on a true heading of 270° is advised by radio that the wind at his altitude is 20 m. p. h. from 45°. Find the track (or true course) being made good and the ground speed.

It is seen that the wind is from the right of the airplane and 135° from its head, and the wind velocity of 20 m. p. h. is 20 percent of the air speed of the airplane. Following the (interpolated) red line for 135° toward the left from the center, to its intersection with the circle for 20 percent, it is seen that the ground speed is 115 percent of the air speed, or 115 m. p. h., and the drift angle is 7° to the left. 270°−7°=263°, which is the track, or true course desired.

Example 2.—A pilot flying over broken clouds at an air speed of 120 m. p. h. and on a true heading of 90° was able to determine a drift angle of 10° to the right; at the same time he noted that smoke from a chimney was practically at right angles to his heading. Find the wind direction and velocity, the track, and the ground speed.

Following the red line at right angles to the center line out to its intersection with the black line representing a 10° drift to the right, we find a wind velocity equal to 17.5 percent of the air speed, or 21 m. p. h. The wind is from the left and 90° from the airplane's head, or from true north.

Since the wind is from the left, the drift angle of 10° must be added: 90°+10°=100°, the track made good. The ground speed is also read from the graph as 101 percent of the air speed, or 121 m. p. h.

Example 3.—An airplane cruising at a speed of 90 m. p. h. is headed true north, and, by means of a drift indicator, a drift angle of 10° to the right and a ground speed of 103 m. p. h. are observed. Find the wind direction and velocity.

The ground speed of 103 m. p. h. is 114 percent of the airspeed. Follow the black drift line marked 10° (to the right of 0°) out to its intersection with the (interpolated) black ground speed arc representing 114 percent. The position of this intersection between the red circles for 20 and 25 percent indicates the velocity of the wind, which is 23 percent of the airspeed, or 21 m. p. h., and the nearest radial red line from the center, 120°, indicates the direction of the wind with reference to the airplane's head. Since the heading of the airplane in this case is true north, or 360°, the wind is from 360°−120°, or from 240° true.

DRIFT DETERMINATION WITHOUT A DRIFT INDICATOR

[See fig. 107]

Most texts on air navigation include a "table of course errors," showing the angular errors corresponding to the miles off-course for any distance flown. It is usually stated that, in any given case, if the tabulated error is applied to the compass heading the airplane will then parallel the original intended track; or that if double the error is applied the airplane will return to the original track in the same distance. Such statements are mathematically incorrect when the departure from the course is due to wind, as is most often the case.

Figure 107 shows the course errors for any departure from the track and any distance flown. As already pointed out, this error applied to the compass

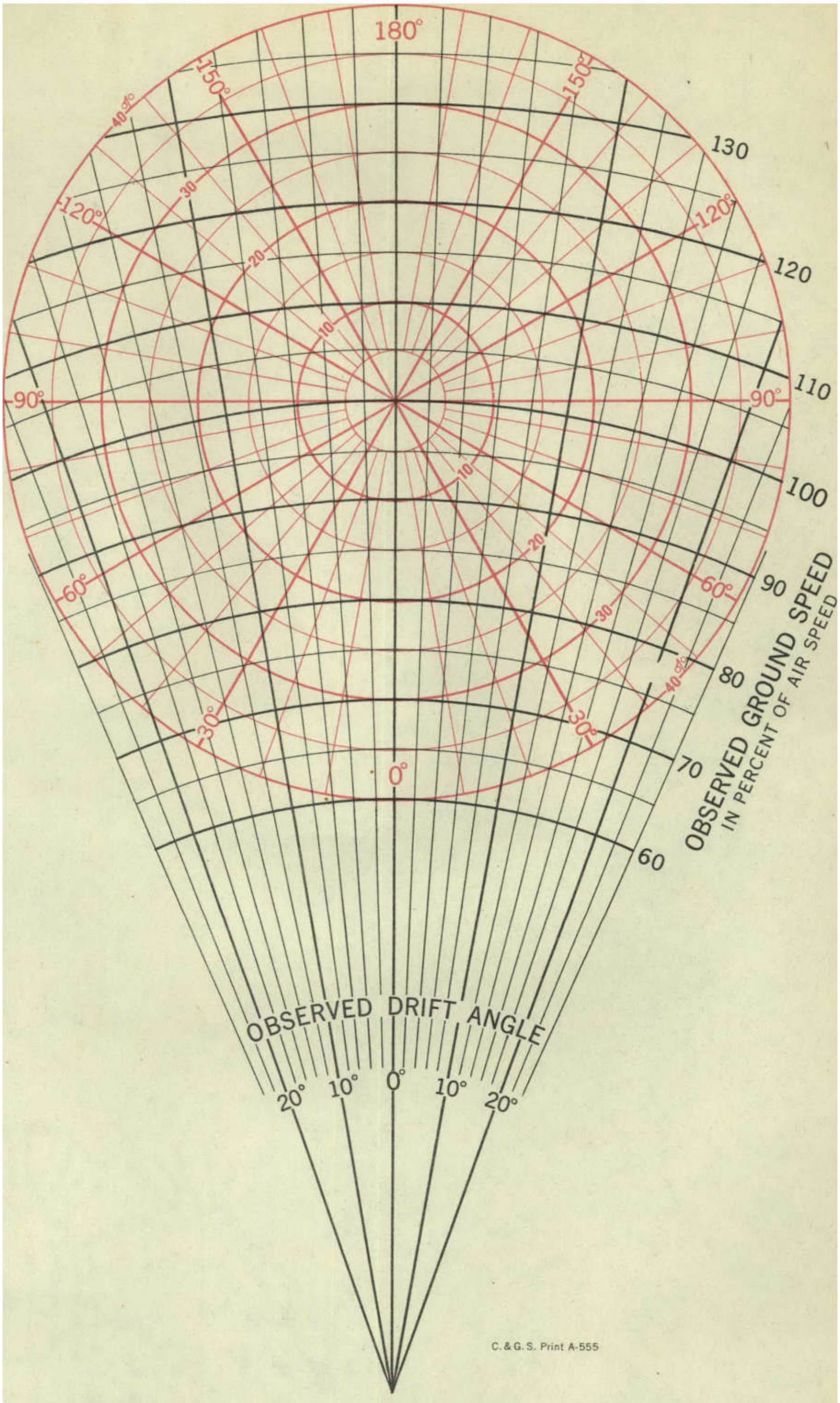


FIGURE 106. - Graph for rectifying heading and ground speed for wind.

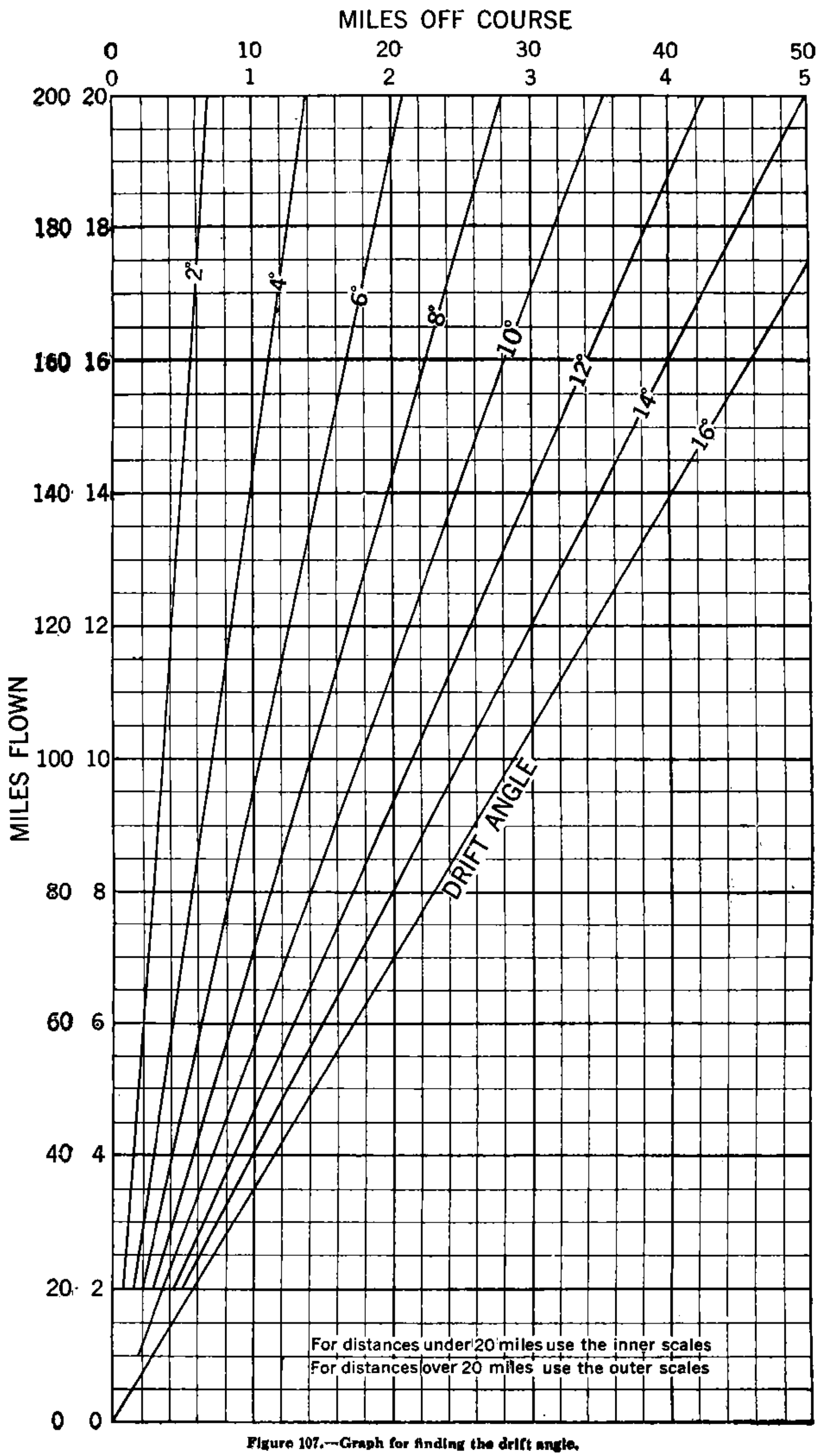


Figure 107.—Graph for finding the drift angle.

heading will not give the correct heading to fly. The graph serves just one useful purpose: When the error is due to wind drift (and not to erroneous measurement of the course on the chart, or compass errors) the course error indicated on the graph is the drift angle.

In the absence of a drift indicator, then, the drift angle can be obtained by means of this graph. The ground speed can be obtained from figure 99 from the elapsed time and distance flown. With the drift angle and ground speed known, the correction to the course and the ground speed that will be made good along the intended track can be obtained at a glance from figure 105. Or if wind direction and velocity are required, these may be obtained from figure 106 with the same data.

Example 1.—In flying between two airports, on a true heading of 189° and at an air speed of 120 m. p. h., a pilot passes directly over a town just 4.5 minutes after taking off. Knowing that this town is west of his intended track, he wishes to find the correction to be made to his course, and the ground speed that will be made good.

From the chart he finds that the town is 10.5 miles from his starting point and 2 miles west of the intended track. He notes, from figure 107, that this corresponds to a drift angle of 11°, and from figure 99 that the ground speed is 140 m. p. h., which is 117 percent of the airplane's air speed. (See example 5, p. 150.) Referring to figure 105 with these data he reads the correction to his course as 13°, and the ground speed that will be made good along the intended track as 112 percent of the air speed, or 134 m. p. h. Since the wind is from the left, the correction of 13° must be subtracted from the heading: 189°−13°=176°, the true heading to be flown.

If he should wish to know the direction and velocity of the wind, he may enter figure 106 with a drift angle of 11° to the right and a ground speed of 117 percent, and read the wind velocity as 27 percent of the air speed, or 32 m. p. h., and the wind direction as 125° from the heading of the airplane, or 189°−125°=64° true.

RADIUS OF ACTION

Radius of action problems are treated on pages 85 to 91. The solutions offered there are precise, and should be followed whenever exact data are essential. Often the approximate radius of action is all that is required, and for quick convenience the following approximate table is given. It tabulates the distance an airplane may fly under given wind conditions and still return to the point of departure.

Minimum radius of action exists with the wind parallel to the route (head or tail winds); maximum radius occurs with the wind at right angles to the route. The difference between maximum and minimum is surprisingly small, amounting to only:

10 percent for a 40 percent wind (wind 40 percent of airplane's airspeed);
5 percent for a 30 percent wind;
3 percent for a 25 percent wind; and
2 percent for a 20 percent wind.

The values given in table 2 are for wind parallel to the route, and therefore represent **minimum** radius of action. For other conditions slightly greater radius is possible.

The radius of action indicated in the table is the radius for one hour's flight, and should be multiplied by the number of hours of flying time available.

That is, for an airplane with an air speed of 120 m. p. h. and a wind of 25 m. p. h., the radius of action indicated in the table is 57 miles for each hour's flight. Fuel for 3 hours and 30 minutes is available; therefore the radius of action is 3.5×57, or 199 miles.

Table 2.—Approximate radius of action for each hour of flying time available

Airspeed of plane	Wind velocity—in m. p. h.									
	5	10	15	20	25	30	35	40	45	50
75	37	36	36	34	33	------	------	------	------	------
80	39	39	38	37	36	34	------	------	------	------
85	42	41	41	40	38	37	------	------	------	------
90	44	44	43	42	41	40	38	------	------	------
95	47	47	46	45	44	42	41	------	------	------
100	49	49	48	48	46	45	43	42	------	------
105	52	52	51	50	49	48	46	44	------	------
110	54	54	54	53	52	50	49	47	------	------
115	57	57	56	55	54	53	52	50	48	------
120	59	59	59	58	57	56	54	53	51	------
125	62	62	61	60	60	58	57	56	54	52
130	64	64	64	63	62	61	60	58	56	55
135	67	67	66	66	65	64	62	61	60	58
140	69	69	69	68	67	66	65	64	62	61
145	72	72	71	71	70	69	68	66	65	63
150	74	74	74	73	72	72	70	69	68	66
155	77	77	76	76	75	74	73	72	70	69
160	79	79	79	78	78	77	76	75	73	72
165	82	82	81	81	80	79	78	77	76	74
170	84	84	84	83	83	82	81	80	79	77
175	87	87	86	86	85	84	84	82	81	80
180	89	89	89	88	88	87	86	85	84	83
185	92	92	91	91	90	90	89	88	87	85
190	94	94	94	93	93	92	91	90	89	88
195	97	97	96	96	95	95	94	93	92	91
200	99	99	99	99	98	97	96	96	94	93
205	102	102	101	101	100	100	99	98	97	96
210	104	104	104	104	103	102	102	101	100	98
215	107	107	106	106	106	105	104	103	102	101
220	109	109	109	109	108	107	106	106	105	104
225	112	112	112	111	111	110	109	108	108	106
230	114	114	114	114	113	113	112	111	110	109
235	117	117	117	116	116	115	114	114	113	112
240	119	119	119	119	118	118	117	116	115	114
245	122	122	122	121	121	120	120	119	118	117
250	124	124	124	124	123	123	122	121	120	120

THE BEAUFORT SCALE

In the preceding pages various methods have been given for correcting the course of an airplane for the effect of wind. For dependable navigation it is desirable to obtain wind data as accurately as possible; however, in the absence of better facilities the following table may be of some assistance in estimating wind velocities. It is commonly known as the Beaufort scale.

Table 3.—Beaufort scale for estimating wind velocities

Beaufort number	Specifications for use on land	Miles per hour (statute)	Terms used in U. S. Weather Bureau forecasts [1]
0	Calm; smoke rises vertically	Less than 1	Light.
1	Direction of wind shown by smoke drift, but not by wind vanes.	1–3	Light.
2	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4–7	Light.
3	Leaves and small twigs in constant motion; wind extends light flag.	8–12	Gentle.
4	Raises dust and loose paper; small branches are moved.	13–18	Moderate.
5	Small trees in leaf begin to sway; crested wavelets form on inland waters.	19–24	Fresh.
6	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	25–31	Strong.
7	Whole trees in motion; inconvenience felt in walking against wind.	32–38	Strong.
8	Breaks twigs off trees; generally impedes progress.	39–46	Gale.
9	Slight structural damage occurs (chimney pots and slate removed).	47–54	Gale.
10	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	55–63	Whole gale.
11	Very rarely experienced; accompanied by widespread damage.	64–75	Whole gale.
12		Above 75	Hurricane.

[1] Except for the word "calm," these terms are not ordinarily used in aeronautical weather reports and forecasts.

The Beaufort numbers are represented on weather maps by the number and length of the barbs on the wind arrows, and indicate the approximate wind velocities at the various reporting stations. They are seldom used for any other purpose, and should not be confused with wind velocities in Weather Bureau reports and forecasts, which are always given in miles per hour.

Chapter IX.—THE PRACTICE OF NAVIGATION

CONTACT FLYING

In presenting all the individual steps in the process of air navigation, there is danger of becoming lost in the details. In order to correlate the various items and to develop the practical side of flying, the following example has been prepared in fairly complete form. While the importance of the correct measurement of courses and related details should not be minimized, the emphasis in this case is upon the actual conduct of the flight.

The trip was planned from the Omaha municipal airport to the municipal airport at Joliet (28 miles southwest of Chicago) with one stop at Moline Airport (Illinois) for refueling. The route was plotted on the Des Moines and Chicago sectional charts and subdivided into 10-mile intervals.

The straight-line route from Omaha to Moline lies well to the right of the civil airway, and therefore satisfies the requirement of keeping to the right. Since this portion of the route covers about 5½ degrees of longitude, the straight line was broken into two sections, at Indianola (south of Des Moines). The portion of the route between Moline and Joliet was also broken into two sections, the change of course in this case being made at Sheridan Junction, for reasons to be explained later. The data for the four sections of the route were as follows:

Section of route	Magnetic course	Miles	Total
	Degrees		
Omaha-Indianola	79	122	
Indianola-Moline	83	158	280
Moline-Sheridan Junction	83	94	
Sheridan Junction-Joliet	88	28	122

The trip was to be made in accordance with contact flight rules, and the airplane was not equipped with radio. It was planned to leave Omaha early on April 18, 1940, but at the airport Weather Bureau office it was learned from the 7:30 a. m. map that a low pressure area was centered to the north of Lake Erie, and that precipitation and low ceilings and visibility existed west of Chicago. At Omaha, visibility was only three-fourths mile, and contact flying was not permitted.

When the 1:30 p. m. weather map was [1] posted in the afternoon it was seen that ceilings had lifted, and there was no precipitation west of Pennsylvania. It was planned to fly at altitudes not more than 1,000 feet above the ground, and therefore only the surface winds were of interest.

[1] The example cited in this section of the text has been taken from Weather Map D-1, of Civil Aeronautics Bulletin No. 25, Meteorology for Pilots, which may be consulted, if desired, to verify the data and values used in the example.

At Omaha, the surface wind was northwest, Beaufort force 2 (about 7 m. p. h.).

At Des Moines, surface wind was not shown, but a layer of stratus clouds was shown, moving southward at 2,000 feet.

At Moline, surface wind was ENE., Beaufort force 2 (7 m. p. h.); cumulus clouds moving southward at 3,000 feet.

At Chicago, surface wind was NNW., Beaufort force 4 (about 18 m. p. h.).

Wind of force 2 on the Beaufort scale represents velocities of 4 to 7 m. p. h.; force 4 represents velocities of 13 to 18 m. p. h. The maximum velocity is used in each case, since at 1,000 feet the wind velocity usually is nearly double that at the surface.

The cruising speed of the airplane was 120 m. p. h., and by means of the air navigation computer the correction for wind was found as 3° for the first section; ground speed 124 m. p. h. The slide rule side of the computer was then set for the estimated ground speed of 124 m. p. h., and fastened with a paper clip to prevent accidental rotation, for easy reference in flight.

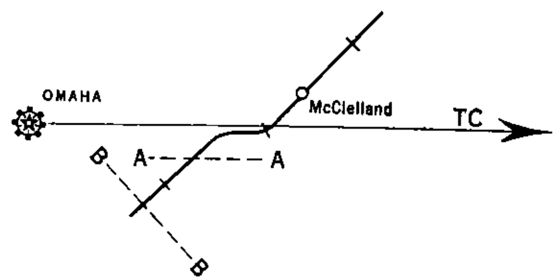


Figure 108.—Checking the track by the angle and position of crossing railroads.

As mentioned in describing the slide rule side of the computer (ch. VIII), with the MHP index set at the ground speed, the number of minutes required to make good any given number of miles may be read on disk *B* opposite the number of miles on disk *A*. The time required to make good 10 miles, 20 miles, 30 miles, etc., was obtained in this way and written adjacent to the appropriate mileage ticks on the chart.

In addition to the pilot's wrist watch, the only chronometer carried was a dollar watch. With the watch set to 12 o'clock at the time of taking off, the time registered by it thereafter is the elapsed time of flight. With the elapsed time intervals noted on the chart, a glance at the dollar watch informed the pilot just where he was along the route, with no necessity for thinking in terms of miles at all. Later, as positions were identified from time to time in flight, the elapsed time was written on the chart adjacent to the feature, in a different color. This provided the means for rechecking ground speed if it should become necessary.

No flight plan was filed, and the flight was cleared by the Omaha control tower at 3:30 p. m. After circling for altitude, the airplane was turned to the compass heading for the first section, which was 74° (79° MC−2° E. dev. −3° WC=74°).[2]

The pilot now began to check the accuracy of his compass heading by landmarks. An excellent check was obtained just 4 minutes from Omaha, in crossing the CGW railroad, about 8 miles distant. The true course plotted on the chart passed just to the north of the short east-west section of the railroad, as shown in figure 108; the pilot found that he crossed the railroad in just about this position, confirming the accuracy of his compass heading.

[2] See p. 230 for abbreviations.

If the wind had been stronger, or more northerly, and the same heading were flown, the crossing would have been as indicated at *AA* in the figure, and additional correction should have been made for wind.

If the compass heading were considerably in error for any reason, the crossing might have been as at *BB*. The angle and the position of crossing not only check position, but indicate the nature and even the amount of any additional corrections that may be required.

Similar checks were obtained at Oakland (13 minutes from Omaha) and Lewis (about 21 minutes from Omaha), as shown in figure 109. At Oakland,

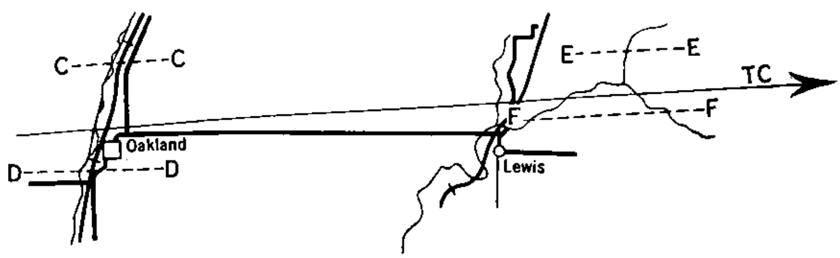


Figure 109. -Checking the track by cultural and topographic landmarks.

a crossing of the stream, railroad, and highway pattern at any other point (as *CC*, or *DD*) could easily have been detected. At Lewis the same is true; in addition, the east-west section of the stream provides a further definite check. A crossing at *EE* would be at an entirely different angle from a crossing at *FF*. The straight section of highway between Oakland and Lewis, so nearly parallel to the route, also furnishes an excellent check on the compass heading.

Shortly after passing Lewis it became apparent that the airplane was being drifted somewhat south of the intended track. This was in keeping

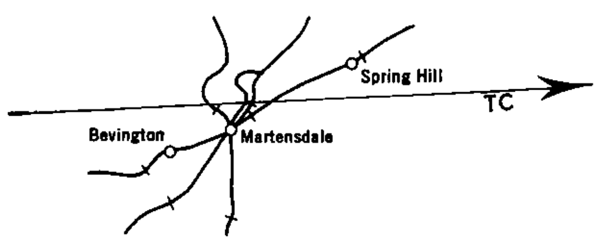


Figure 110. -Railroad pattern at Martensdale, Iowa.

with the southward moving clouds noted at Des Moines on the weather map. No change was made in the heading however, until Martensdale was identified, about 15 miles southwest of Des Moines. The unusual railroad pattern here could not be mistaken; see figure 110. The railroads were picked up to the south of Martensdale, and were followed back to the position of the plotted route.

It was seen from the mileage ticks along the route on the chart that Martensdale was about 60 miles from Lewis. The airplane had been about 3 miles south of the intended track at Martensdale, and an error of 3 miles in 60 meant an error of 3° in the compass heading.

The compass heading was to have been changed at about this point from 74° (the heading for the first section) to 78° (83° MC—2° E. dev.—3° WC=78°), for the second section. An additional 3° correction for wind was applied, which made the compass heading 75°.

With only minor variations, the same procedure was followed until the Mississippi River was sighted near Muscatine, and followed in to Rock Island and the Moline Airport.

Landing was made at Moline at 2:20 by the dollar watch, 5:50 by the pilot's wrist watch, indicating an average ground speed of exactly 120 m. p. h. for the 280 miles. The first section had been at about 124 m. p. h., the second at about 118 m. p. h.

At 6:15, the take-off was made for Joliet, with the dollar watch again set to 12 o'clock. The course had been plotted from Moline to Sheridan Junction.

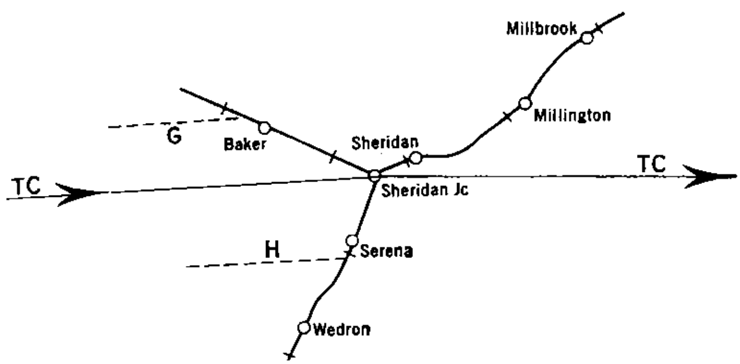


Figure 111.—Railroad pattern at Sheridan Junction.

The latter is only a railroad junction, not a town, but it was selected as the turning point for two good reasons. First, it is well to the right of the airway itself, and thus meets the requirements of right side traffic. Second, the railroad pattern provides an ideal check point; see figure 111.

If the airplane is directly on course with this pattern, the converging railroads can scarcely be mistaken, the point of intersection is definitely fixed, and the new heading can be assumed with certainty.

If the airplane is too far to either side, as at *G* or *H*, the angle at which the railroad is met is positive notice of the direction off course, the railroad is followed to the point of intersection, and the new heading assumed with an added correction based on the estimated distance the airplane was off course.

The angle of crossing the highway pattern, which adheres closely to the section lines running north-south and east-west, through much of the West and Middle West, furnishes an additional check in estimating true directions.

In this case the junction was reached at 12:48 by the dollar watch, 7:03 by wrist watch, with just sufficient daylight to identify it. The airplane was turned to the final heading for the Joliet Airport, and landing was made at 7:18 p. m., 1 hour and 3 minutes from Moline.

INSTRUMENT FLYING

Instrument flying has been defined as "flight of aircraft in which visual reference is not continuously available and the attitude of the aircraft and its flight path can be controlled in part or in whole by reference to instruments only."

For instrument flying, aircraft must carry at least the following navigating instruments:

- Airspeed indicator.
- Altimeter.
- Magnetic compass.
- Bank-and-turn indicator (gyroscopic).
- Sensitive altimeter.
- Rate of climb indicator.
- Clock with sweep-second hand.
- Two-way radio.

Before taking off for an instrument flight, a number of formalities must be complied with, and some very important things must be done. First, a flight plan must be filed with the airway traffic control center of the Civil Aeronautics Administration (if in an airway traffic control area), or with the nearest airway communication station (if outside such areas).

The flight plan itself should be carefully worked out, remembering that its one purpose is to assure safety for everyone on the airway. Not only should the latest weather map be studied, and discussed with the meteorologist if possible, but also the last two or three weather sequences. Only in this way can the trend of the weather be learned: that is, the movement of precipitation areas and fronts, and whether conditions are becoming better or worse. The upper air reports should also be studied, remembering that they are usually quite different from surface winds in direction and velocity. The radio fixes must be noted, and the chart must be checked to make certain that its radio data are up to date. Courses, distances, ground speed, and fuel consumption must be carefully computed, since in this case no help can be had from landmarks. An alternate airport must be selected where safe landing is certain if weather at the intended destination should close in altogether.

A flight plan includes the identification number of the aircraft and the nature of the service in which it is employed; the name of the pilot; point of departure; proposed altitude of flight, cruising speed and time of departure; radio equipment carried; estimated time of arrival; the alternate airport; and other pertinent information. The information required, and the form in which it is to be prepared, may be found in the Civil Air Regulations.

As already suggested, the flight plan for an instrument flight must be approved by the airway traffic control center, before taking off. On airways outside traffic control areas, the flight plan is submitted to the airway communication station, and teletyped to the destination and all communication stations along the route.

To correlate the various phases of this type of flying, an instrument flight from Spokane, Wash., to Portland, Oreg., via Pendleton (see pl. II), will be described. In this case also, the emphasis is placed upon the procedure of the flight, rather than upon the measurement of courses and bearings, or the indications and behavior of the navigating instruments in flight.

A consultation with the airport meteorologist at Spokane shows that there is general precipitation throughout the area; ceilings range from 3,000 feet at Portland to 2,000 feet at Spokane, the ceilings lifting slightly as the center of precipitation moves eastward; visibility is nowhere less than 2 miles. A sea fog is moving slowly up the Columbia River valley from the coast, and Portland Airport may become closed; the airport at North Dalles is certain to remain open, and is selected as the alternate airport. The wind data are included in the following tabulation prepared for the flight. Cruising speed of airplane, 135 m. p. h.

Route	Miles	MC	Wind	Wind correction angle	Ground speed	Elapsed time	
		Degrees				*H.*	*M.*
Blue Airway No. 1: Spokane to Pendleton.	154	180	12 m. p. h., 210°	0	123 m. p. h.	1	15
Red Airway No. 1: Pendleton to Arlington range.	64	249	16 m. p. h., 270°	0	119 m. p. h.		36
Arlington to NE leg, North Dalles range.	50	247	12 m. p. h., 270 °	0	123 m. p. h.		24
NE leg, North Dalles, to Portland range.	72	243	5 m. p. h., 270°	0	130 m. p. h.		34
Portland range to Portland Airport.	15						10
Total	355					2	59

The Civil Air Regulations call for flight altitudes at even thousands when southbound on blue civil airways, and when westbound on red civil airways. The highest ground within the limits of the airway is between 3,000 and 4,000 feet, but not far from the airway elevations range from 5,000 to 6,000 feet. As an added factor of safety, then, the flight plan specified flight at 8,000 feet.

Just before 9:30, the pilot called the Spokane control tower as follows: "NC 1234, calling Spokane tower. Ready to taxi. Departing for Portland. Flight plan given to Airways. Go ahead."

The control tower operator acknowledged with the following reply: "Spokane tower answering NC 1234. Time is 928. Field elevation 1960. Altimeter setting 2975. Wind south-southwest 12, S-S-W-12. Okay to taxi out. Go ahead."

When the pilot had taxied into position, he received this additional message: "Spokane tower calling NC 1234. Airways at Pendleton advises no traffic reported. Clear for take-off."

After the airplane was in the air, the control tower operator called again: "Spokane tower calling NC 1234. Airways at Pendleton advises no traffic reported. Spokane tower off."

The pilot answered, "Okay NC 1234," and, by means of his range receiver and compass, headed his airplane on the magnetic course of 180°, along the south course of the Spokane range. Since the wind was a head wind, no correction was required, other than to find the ground speed.

The estimated elapsed time had been noted along the mileage ticks, as in the previous example, and an occasional check against the elapsed time showed the progress along the route. Slight changes in heading were necessary from time to time, now to one side, now to the other, in order to keep along the right edge of the on-course zone.

At 10:28, the pilot called the Pendleton control tower, as follows: "NC 1234 calling Pendleton tower. Go ahead."

The reply from the tower was: "Pendleton tower answering NC 1234. Go ahead."

The following message was then sent: "NC 1234 answering Pendleton tower. Southbound. Over Walla Walla at 8,000. Estimate over Pendleton at 10:45. Proceeding to Portland on west leg. Cleared to tower. Go ahead."

The Pendleton operator replied: "Pendleton tower calling NC 1234. Field elevation 1495. Ceiling 2,000 feet. Visibility 3 miles. Altimeter setting 2982. Wind west 16--W-16. Airways at North Dalles advises no traffic. Go ahead."

This message was acknowledged by the pilot with, "Okay NC 1234."

Again at 10:45 the pilot called: "NC 1234 calling Pendleton tower. Over the station at 8,000. Proceeding to Portland on west leg. Go ahead."

The required reply was made by the Pendleton operator, and the flight proceeded in the same way to North Dalles, past the marker beacon at Stevenson, and to the cone of silence (or the "Z" marker) over the Portland range station. The west leg of the Portland range was followed, with the airplane losing altitude at the predetermined rate, and the pilot "broke through" the overcast, at about 3,500 feet, over the Columbia River. A contact landing was made, in accordance with traffic instructions from the Portland control tower.

The flight just described represents about the simplest possible case. The winds met in flight were in accord with those predicted, radio reception was good, and the range courses were followed without difficulty. It was not even necessary to work out a problem in orientation.

Things rarely work out so ideally in practice, and every precaution should be taken that might be helpful in an emergency. Most important of all (as already pointed out), radio should be regarded as an AID to dead reckoning—not as a substitute for it. In the event of failure of radio, either in transmission or reception, the pilot who has failed to keep accurate record of heading, drift, and ground speed is left without any dependable information on which to base his plans.

In the event of becoming temporarily lost, it is very important to maintain a constant heading until the position can be identified by some means. In contact flying, this affords some idea of the angle at which one may expect to cross streams, railroads, and other charted features. In instrument flying, even though no landmarks can be seen, it is just as essential. If the heading being flown is one that might prove dangerous if continued too far—for example, if it may lead out to sea, or into an area of high mountain peaks—turn to some safer heading, but then maintain it.

There is no surer way of getting hopelessly lost, even with good visibility, than circling aimlessly about in search of some feature that can be identified. In a short while the sense of direction becomes so confused that even familiar features are not recognized.

Two final rules might be stated, which apply to all phases of navigation and flying:

1. Take nothing for granted.
2. Plan ahead; consider all the things that may happen, and know what to do in each case.

Chapter X—CELESTIAL NAVIGATION

PRACTICAL VALUE

Celestial navigation is the art of determining position on the earth from observations of celestial bodies (the sun, moon, stars, and planets).

For flights of 500 to 1,000 miles, celestial navigation with present methods and equipment will seldom prove of practical importance. For such distances, its chief value is that of a fascinating hobby which may some day prove of value, since the combined use of piloting, dead reckoning, and radio should ordinarily afford satisfactory results.

With the development of large transports capable of flying great distances nonstop, longer and longer flights have been included in air-transportation schedules. Regular flights across both the Atlantic and the Pacific are already an accepted fact. For flights such as these celestial navigation is not only practical, but necessary.

The transoceanic routes, like the airways within the United States, are equipped with the latest and best radio facilities. There are those who believe that radio will always provide the leading navigational method in air transportation, and probably they are right. For communications it is a necessity, and for easy position finding it is unexcelled; however, it is always possible that failure may occur, either in transmission or reception, and celestial navigation should be practiced in order to assure proficiency in such emergencies, if for no other reason.

Efficient operation demands that long flights be made at high altitudes, and a large percentage of such flights would be above any overcast. This would prevent the direct determination of drift and ground speed, and would make dead reckoning of doubtful value; it would not affect radio, except in the event of complete failure or excessive static, and it would not affect celestial navigation. For longer flights, then, especially over ocean routes, celestial navigation becomes a primary method, and of at least equal importance with radio.

ACCURACY

The accuracy of the results depends on the skill of the observer, the instrumental equipment, and the conditions under which the sextant observations are taken. By means of astronomical obervations a surveyor on the stable earth can determine the geographic location of his position within a few yards; on a ship at sea, position can usually be determined within a mile or two. Under average conditions in the air, an accuracy of 5 to 10 miles should ordinarily be obtained, although considerably greater errors may occur with a light airplane and bumpy air.

Since a single observation may be greatly in error, it is common practice to take from 5 to 10 observations in quick succession, and to determine the line of position from the average of the observations. Obviously, the better the flying conditions the smaller the number of observations needed for a satisfactory determination.

SIMPLICITY

There is a widespread belief that celestial navigation is very difficult, and can be used only by experts. On the contrary the method is very simple. In the practice of celestial navigation the most difficult part of the whole process is the taking of the sextant observation; obviously, this is largely a matter of mechanical practice.

Aside from the observation with a sextant, three other steps are necessary. The first is to note the exact time of the observation; the second is to compute the line of position from the sextant observation and the time it was made; and the third is to plot the line of position on the chart. An error of 4 seconds in noting the time of observation will produce a maximum error of only 1 mile in the line of position; the computations have been reduced to simple arithmetic, and the plotting of the position line on the chart is as simple as measuring the course angle.

In addition to the instruments ordinarily used in other methods of navigation, the following equipment is required: sextant, chronometer (accurate watch), the current Air Almanac, and tables for performing the necessary computations, such as the line-of-position table appearing at the end of this chapter. A suitable form for computing the line of position is convenient, but is not absolutely necessary.

BASIC PRINCIPLES

Almost directly above the North Pole of the earth there is a fairly bright star known to most people as the North Star. It is also called the Pole Star, or, more properly, Polaris. Let us suppose that this star were *exactly* over the North Pole: To an observer at that point its altitude, or angle of elevation above the horizon, would be 90°, or exactly overhead (in the zenith). Now if the observer moves southward for a distance of 10°, to latitude 80°, the altitude of the star is found to be 80°; from any point on this parallel, whether toward Asia from the Pole or toward North America, the altitude is the same. The 80th parallel may therefore be called a circle of position, and all points at which the altitude of Polaris is 80° must be located somewhere on that circle, and nowhere else.

Similarly, from any point in latitude 30°, when the observer is 60° from the Pole, the altitude is 30° and the 30th parallel is another circle of position; and so on until at the Equator, when the observer is 90° from the Pole, the altitude of the star is 0°, and the Equator becomes the farthest circle from which the star is visible.

From the foregoing we see that:

1. The point directly beneath the star is the center of a system of concentric circles of position.
2. From every point on any given circle the altitude of the star is the same.
3. As we move away from the point directly beneath the star there is a decrease in the altitude of the star proportional to the distance moved; if we

move away a distance equal to 1′ of latitude the altitude decreases 1′; if we move away 10° farther, the altitude decreases another 10°, and so on.

4. In each instance the radius of the circle of position (that is, the distance of the observer from the point beneath the star), is equal to 90° minus the observed altitude.

These principles hold true not only for a star directly over the Pole, but for all stars, and the relation between the observed altitude and the corresponding circle of position is illustrated in figure 112. Evidently, the smaller the altitude

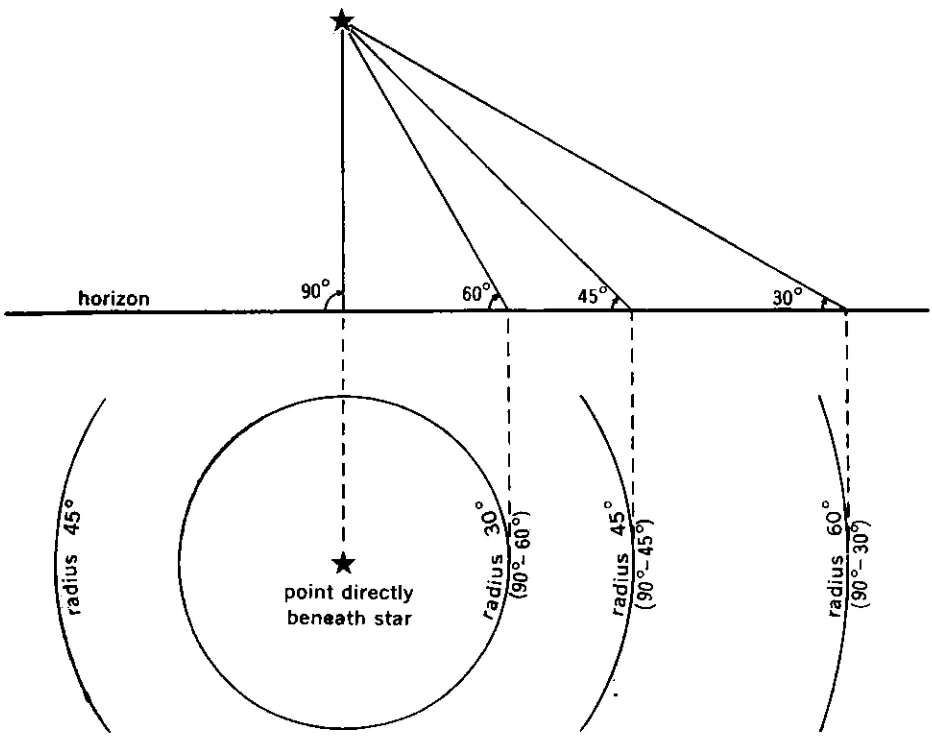


Figure 112. Relation between observed altitudes of a star and circles of position.

observed, the greater the distance from the point on the earth directly beneath the star.

Through long familiarity with latitude we are accustomed to measuring distances along a meridian, north and south, in terms of degrees and minutes. We do not usually think of distances in other directions in these terms, yet great-circle distances in any direction are always computed in degrees and minutes, and then converted into nautical miles, statute miles, meters, or other desired units.

A chart may have a scale of distances in terms of degrees and minutes of a great circle, just as it has a scale of distances in terms of statute or nautical miles. If a small scale chart (the scale of No. 3060 b, or smaller) were provided with such a scale, it would be possible to plot on the chart, from the Air Almanac, the position beneath any star at the instant of observation; and with that point as a center, to draw the circle of position graphically, with a radius equal to 90° minus the observed altitude, with no computations whatever.

This principle may prove of very practical value on special charts of the trans-oceanic routes, or even some of the transcontinental routes.

We have seen that the observed altitude of a star definitely determines a circle of position at a known distance from the point beneath the star. If at the same time and place the altitude of a second star is observed, a second circle of position is determined; since the observer is on both circles, he must be at a point where the two intersect. This is illustrated in figure 113, which is a greatly reduced representation of chart No. 3060 b. The positions of the stars observed (Vega and Alphecca) at the moment of observation were plotted on the chart from data in the Almanac; then with radius equal to 90° minus the

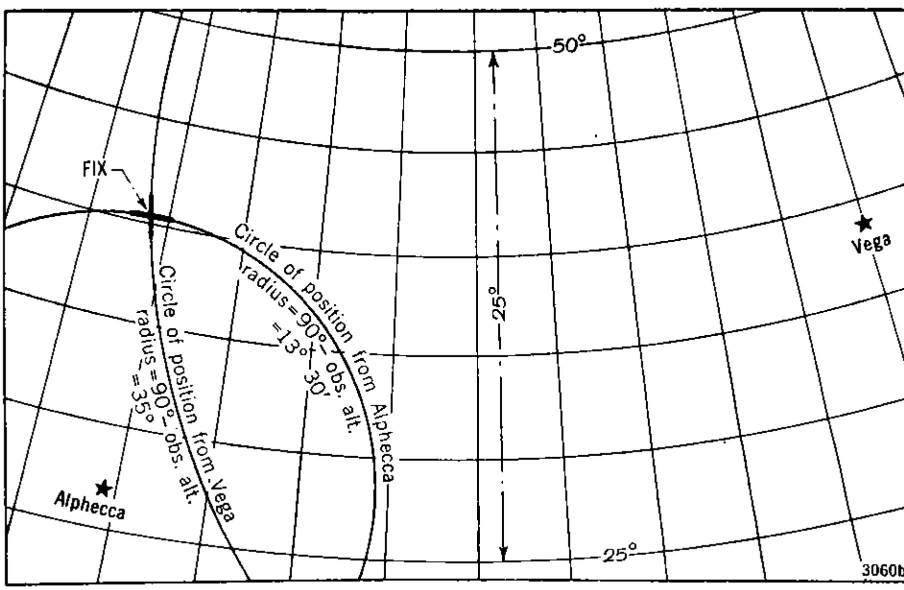


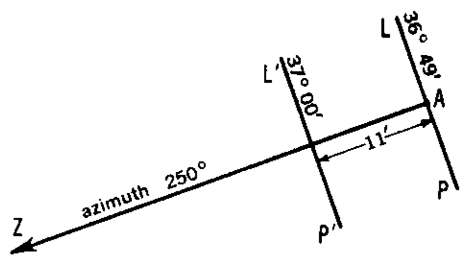
Figure 113.—Two circles of position establish location.

observed altitude in each case, the two circles of position were drawn, determining the fix as shown. Note that the distance between the top and bottom parallels of the chart is 25°, the lengths of the radii being laid off proportionately at the same scale.

From the figure it may be seen that the two circles of position would also intersect just outside the southern border of the chart. For every pair of intersecting circles there must be two points of intersection, but this is not confusing, in practice, since the two points are usually far enough apart that one of them may be dismissed as impossible. In the problem illustrated, the poorest navigator, somewhere in Nevada, should be able to know at once that he was not in Mexico, 1,500 miles away. When using larger scale charts for this purpose, the radius of the circle of position is often too long for the limits of the chart and the circle of position cannot be drawn as just described; the procedure must therefore be slightly modified.

THE LINE OF POSITION

To determine a circle of position on the larger scale charts, the navigator starts with an assumed position, *A*, figure 114, which may be either his dead reckoning position or a nearby projection intersection. From the line of position table (pp. 210 to 224) he computes the azimuth and the altitude of the star as it would have been observed from the assumed position at the instant of observation. Let us suppose that the computed azimuth of the star is 250° and the computed altitude 36°49′: the line *AZ* is plotted from *A*, and represents the azimuth of the observed body; in reality it is the end section of a radius of the circle of position on which the point *A* was located at the instant of observation, and the line *LP*, at right angles thereto, is a short section of that circle. Now suppose that the altitude actually observed was 37°00′: this is 11′ greater than the altitude computed for the assumed position and we know, therefore, from page 173, that the observation must have been taken at some point on a circle of position 11′ closer to the star than the circle of which *LP* is a part. Therefore, a distance equal to 11′ of latitude is laid off along *AZ*, toward the star, and the line *L′P′* (at right angles to *AZ* and parallel to *LP*) is a short section of the circle of position on which the navigator was located when the observation was made. In such cases the radius of the circle of position is so long that the short sections of circumference may be drawn as straight lines without appreciable error. Such a short section is commonly called a **line of position.**



A = Assumed position
LP = Line of position through assumed position
36° 49′ = Altitude computed for assumed position
37° 00′ = Altitude observed
11′ = Difference between observed and computed altitudes
L′P′ = Line of position through true position

Figure 114.—The line of position on large scale charts.

In practice, of course, it is not necessary to draw the line *LP;* the altitude difference (see p. 179) is simply laid off from the assumed or dead reckoning position along the plotted azimuth, and a line at right angles thereto through the point so obtained is the desired line of position.

As in the case of a radio line of position (p. 122), a line of position from a single star does not definitely determine position; it determines only a line at some point on which the observer was located at the instant of observation. In order to obtain a fix, lines of position from two or more stars must be obtained; since the observer is somewhere on each line of position, he must be located at their common point of intersection. When three lines of position are plotted they seldom meet in a point, because of inaccuracies of observation; instead, a triangle is formed, and the position may be regarded as anywhere within the triangle.[1]

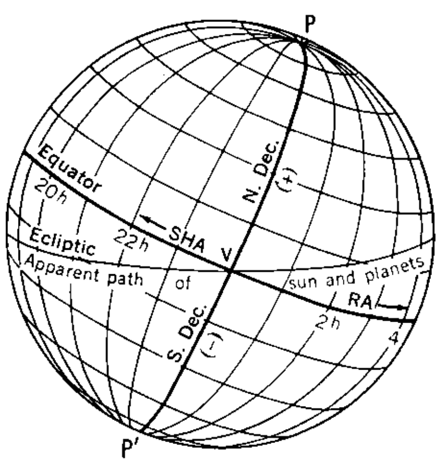
[1] The most probable position of the observer is often outside the triangle formed by the three lines of position. In air navigation, however, the exact solution of this "triangle of error" is an unnecessary refinement, and for practical purposes the position may be regarded as anywhere within the triangle.

Although one line of position does not provide a fix, it may still prove of real value. For example, if the line is approximately parallel to the path of the plane, it informs the pilot as to whether or not he is on course; if the line of position is approximately at right angles to the track it furnishes a definite check on the distance made good, and also on the ground speed. A single line of position from celestial observations may also be combined with a radio line of position in order to obtain a fix. Or, if a pilot has been able to determine his position as somewhere along a fairly straight section of river, shore line, or other landmark, a single position line crossing the feature would provide a fix.

In celestial navigation, as in other methods, the projection of the chart is of no little importance. When the difference between the observed and computed altitudes is comparatively large, as is frequently the case in the air, additional error is introduced by the use of unsuitable projections. Due to the accuracy of the Lambert projection in representing azimuths, and the fact that a straight line thereon very closely approximates the track of a great circle, error from this source is almost entirely absent. The properties of the Lambert projection also make it particularly suitable for the graphic method of position finding from celestial observations, as suggested above for small scale charts.

CELESTIAL COORDINATES

As we look at the night sky, it is as though a great bowl were inverted over the earth, and the stars and other heavenly bodies were fixed to its inner surface. This inverted bowl is referred to as the celestial sphere; it has a system of coordinates which correspond closely with those of the terrestrial sphere, although the names are different. The easiest way to become thoroughly familiar with the celestial coordinates is to compare them with the familiar terrestrial terms.



P, P′ = the celestial poles.

V = the vernal equinox, or "celestial Greenwich."

Declination is measured:
North of the equator (+), or
South of the equator (−).

Right Ascension is measured from V toward the east, from 0h up to 24h.

Sidereal Hour Angle is measured from V toward the west, from 0° up to 360°

Figure 115.—The celestial sphere.

The earth rotates on its axis, the extremities of the axis being known as the North and South Poles, respectively. Halfway between the poles, an imaginary plane perpendicular to the axis cuts the surface of the earth in a line known as the equator. The terrestrial axis and equator are considered as extended to meet the celestial sphere, their intersections therewith being known as the north and south celestial poles and the celestial equator. As the earth rotates daily from west to east on its axis, there results an *apparent* rotation of the celestial sphere from east to west, on the axis passing through the celestial poles.

On the earth, latitude is reckoned from 0° at the Equator to 90° north latitude at the North Pole and 90° south latitude at the South Pole; on the celestial sphere latitude is known as **declination.** The distance north or south of the celestial equator is known as north or south declination; as with terrestrial latitude, declination is expressed in degrees, minutes, and seconds. North declination is often designated as plus (+), while south declination is known as minus (−).

Table 4.—Coordinates of the celestial sphere and corresponding terms on the terrestrial sphere

Terrestrial sphere	Celestial sphere
North Pole	North Pole.
South Pole	South Pole.
Equator	Equator.
Latitude:	Declination:
North latitude	North declination (+):
0° to 90° north of Equator.	0° to 90° north of celestial equator.
South latitude	South declination (−):
0° to 90° south of Equator.	0° to 90° south of celestial equator.
Longitude:	Right ascension:
Reckoned from Greenwich	Reckoned eastward from vernal equinox, or first point of Aries:
0° to 180° east or west of G.	0^h to 24^h east of ♈ (cf. "east longitude").
0^h to 12^h east or west of G.	Sidereal hour angle:
	Reckoned westward from vernal equinox, or first point of Aries:
	0° to 360° west of ♈ (cf. "west longitude").
	Greenwich hour angle:
	Difference of longitude between the point directly beneath the celestial body and the meridian of Greenwich.
	Local hour angle:
	Difference of longitude between the point directly beneath the body and the observer's meridian.

The longitude of a point on the earth is usually referred to the meridian of Greenwich as a zero point; on the celestial sphere the zero point is known as the vernal equinox, or the first point of Aries. For convenience, this point is usually designated by the symbol ♈, which is suggested by the horns of Aries, the Ram. It is the intersection of the ecliptic [2] and the celestial equator, and is the point at which the sun appears to cross the equator in the spring, as the earth makes its annual journey around the sun.

On the earth, longitude is usually reckoned up to 180° east or west of the meridian of Greenwich, although it is sometimes reckoned up to 360°. It is occasionally reckoned in terms of time, 15° being equal to 1 hour of time. Thus a point on the earth may be described either as 75° 30′ west of Greenwich, or as 5^h 02^m (5 hours and 2 minutes) west of Greenwich. On the celestial

[2] The ecliptic is the intersection of the plane of the earth's orbit with the celestial sphere. (See p. 9.)

sphere longitude is known as **right ascension,** and is always reckoned in terms of time. Right ascension is always measured in the same direction, from west to east, the complete circumference of 360° being equal to 24^h.

The difference of longitude between the point directly beneath a heavenly body and the meridian of Greenwich is known as the **Greenwich hour angle (GHA)** of the body; the difference of longitude between the point directly beneath the body and the meridian passing through the position of the observer is known as the **local hour angle (LHA).**

For greater ease in obtaining the GHA of a body, a quantity known as the sidereal hour angle has been introduced in the Air Almanac. This is always measured from east to west, from 0° at the vernal equinox up to 360°. It is equal to 360° minus the right ascension of a body.

For convenient reference and comparison, table 4 lists the various terms of the celestial sphere opposite the corresponding terms for the terrestrial sphere. Figure 115 shows these terms graphically.

THE ASTRONOMICAL TRIANGLE

It is not essential that pilots understand, or even read, this section on the astronomical triangle. It is presented here for the benefit of those who wish to know the mathematical principles involved in computing the line of position, but the explanation presented elsewhere in this text is sufficient for practical purposes.

In spherical trigonometry, if any three parts of a triangle are known (whether sides or angles), the remaining three parts may be computed. The position of the star on the celestial sphere, the latitude and longitude of the assumed or dead reckoning position, and the observed time and altitude provide the information needed to compute the astronomical triangle and to obtain the data for the line of position. This is illustrated in figure 116, which shows the celestial poles, P and P', the Equator, and the horizon. The earth is a tiny dot at the center of the celestial sphere, and Z is the zenith, or the point directly above the *assumed or dead reckoning position* of the observer.

The circumference PZP' represents the meridian passing through the assumed position of the observer, and the arc PS is a portion of the meridian passing through the observed star S. The angle between these two meridians ZPS is the local hour angle, and the angle PZS is the azimuth of the star from the assumed position. Some students can visualize the triangle more readily if they think of it as projected down upon the earth; in this case P becomes the terrestrial pole, Z the assumed or dead reckoning position of the observer, and S the point directly beneath the star.

The arc from the Equator to the star is the declination of the star, and is known from the Almanac. It is also known that the arc from the Equator to the pole is 90°. Therefore, the side $SP=90°-$declination.[3]

Since Z is the point directly above the assumed or dead reckoning position of the observer, the declination of the point Z is the same as the assumed latitude, and the side $ZP=90°-$latitude.

The local hour angle of the star may be known by combining the Greenwich hour angle of the star at the instant of observation (obtained from informa-

[3] If the star were south of the Equator (in south declination), the side $SP=90°+$ declination.

tion in the Almanac), and the assumed or dead reckoning longitude of the observer.

From these three known parts, two of the remaining parts of the triangle are computed: the azimuth of the star, *PZS*, from the assumed position of the observer; and the side *SZ*, which is the distance from the star to the assumed position, or the radius of the circle of position through the assumed position. In figure 116, it is seen that the arc from the horizon to the zenith *Z* is 90°, and the computed altitude (*Hc*) of the star is therefore equal to 90°—*SZ*.

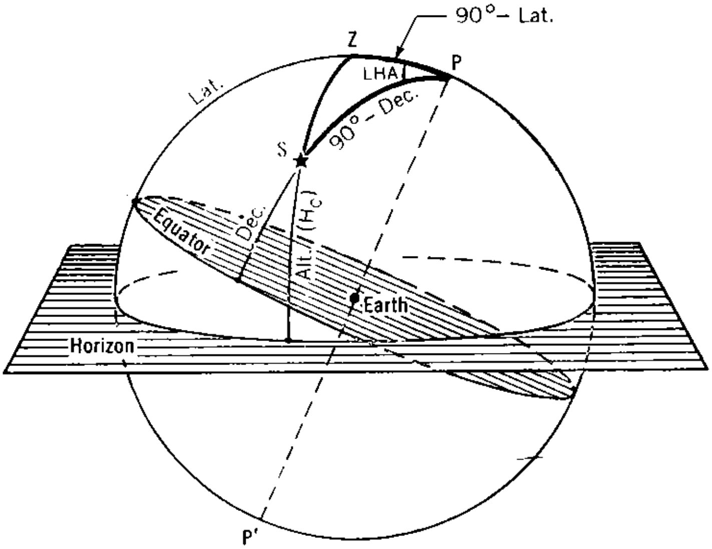


Figure 116. The astronomical triangle.

In order to save as much time as possible, the line of position table (pp. 210 to 224) is so arranged that it may be entered directly with the declination of the star and the latitude of the assumed position (instead of 90° minus these quantities, as might be supposed from the above explanation); also, the computed altitude is obtained directly instead of the side *SZ*.

Unless the navigator happened to be exactly on the circle of position passing through the assumed or dead reckoning position when the sextant observation was made, the computed altitude will differ from the altitude observed. The altitude difference and the computed azimuth provide all the data needed for plotting the line of position, as illustrated in figure 114. If the observed altitude is **greater** than the computed altitude, the airplane was **toward** the star from the assumed position, and the altitude difference is therefore laid off **toward** the star; if the observed altitude was less, the airplane was farther away than the assumed position. (See fig. 112.)

THE SEXTANT OBSERVATION

Before actually making the sextant observation the navigator should be able to identify the star observed. It is as impossible to compute and plot on the chart a line of position from an unknown star as to plot a radio bearing from an unknown radio station. The identification of the stars and planets is not difficult, and is treated at the end of this chapter.

It is also important to select for observation stars that are favorably situated for the problem under consideration. The value of a line of position from a star directly along the line of flight, or from a star directly to the right or left of the aircraft, has already been pointed out. The more nearly two position lines are at right angles to each other, the more accurate is the fix obtained. An intersection at an angle of less than 30° is not desirable, although even this may prove of value in an emergency. Whenever possible, then, stars (or other bodies) should be observed which differ in azimuth by approximately 90°; if at all possible, they should differ in azimuth by not less than 30°. Because of the varying effect of refraction (p. 181) on the observation of a star near the horizon, the bodies selected should also be at least 15° above the horizon, if possible.

For celestial navigation by day there is, of course, little choice among the heavenly bodies. The sun is available, and at times, the moon. At night, however, we have our choice of the stars, usually of one or more of the planets, and, about half the time, of the moon.

The moon, and the planets Venus and Jupiter, are so much brighter than the stars and are so easily identified that they tempt the beginner. With the Air Almanac, the computation of a line of position from one of these bodies is no more difficult than for the stars; all should be used from time to time as a matter of practice, in order to be able to use them quickly and with confidence if the need should arise.

The sextant observation is probably the most difficult step in the practice of celestial navigation. Certainly, it is the most important. No matter how accurate the computations, a line of position based on an inaccurate observation is still inaccurate.

Sextants are of various types, some making use of the natural (sea) horizon, others making use of an artificial horizon formed by a bubble level. Most bubble sextants can also be used with the natural horizon, if desired. In some sextants the eyepiece is to be pointed directly at the celestial body, while in others the eyepiece is always horizontal, and the body observed is reflected through an arrangement of mirrors. In any case, good sextant observations are largely a matter of practice and of thorough familiarity with the instrument.

The bubble sextant is generally used in air navigation, since the natural sea horizon is often not available because the airplane is over land, or above clouds or haze, or because the horizon is obscured by darkness.

After the observations are made and recorded, several corrections must be applied. One of these is for the **index error** of the instrument itself. Obviously, if an altitude of 0° 5′ is indicated when the reading should be 0°, this same error will affect all altitudes measured with the instrument, and a correction for this error must be applied to all observations. It is often possible to adjust the sextant so that it does read correctly, and this correction becomes unnecessary. The method of adjustment will not be discussed here, since it is assumed that anyone who purchases an instrument will receive with it complete instructions on its care and adjustment. In the absence of detailed instructions for the adjustment of a particular sextant, general instructions of a very practical nature are contained in The American Practical Navigator (Bowditch), published by the United States Hydrographic Office. The correction for index error, if any, is usually abbreviated as I. C. (Index Correction).

If the natural horizon is used in taking the sextant observation (instead of the artificial bubble horizon), a correction must be applied for **dip,** or the height of eye of the observer. This is made necessary because the eye of the aviator is higher than the true horizon. In addition to the angle between a truly horizontal plane and the observed body, he also measures the small angle between the horizontal plane and the lower "horizon" which he sees below him. This small angle, therefore, must always be subtracted from the observed altitude.

When the natural horizon is used for an observation on the sun or moon, the altitude is taken when the reflection of the upper or lower edge (the "upper limb" or the "lower limb") of the body, is brought into contact with the horizon.

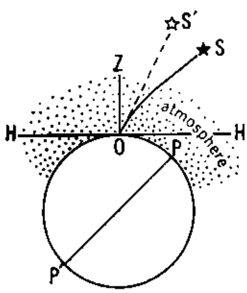


Figure 117.—Refraction.

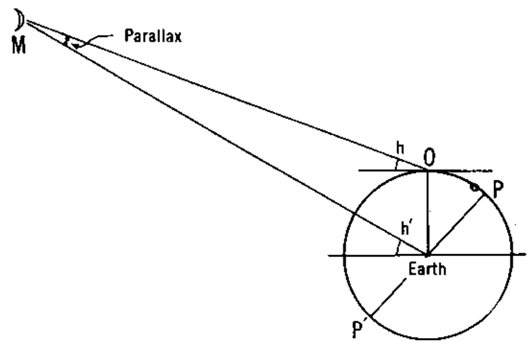


Figure 118.—Parallax.

Since the altitude of the center of the body is required, it is clear that a correction for the **semidiameter** (half the diameter) of the body must be applied. Consequently, the semidiameter of the sun and of the moon is given for each day, on the corresponding page of the Air Almanac. If the lower limb is observed, the semidiameter must be added in order to find the altitude of the center; if the upper limb is observed, the semidiameter must be subtracted.

Additional corrections must be made for **refraction** and, in the case of the moon, for **parallax.** In one sense, it is immaterial whether the student understands the theory of these corrections or not; by means of tables given in the Air Almanac the application of the corrections is very simple. For the benefit of those who wish to understand the principles involved, the following brief explanation of these two corrections may be passed over without reading, if desired.

In figure 117, the earth is represented P and P' being the poles; HH is the horizon of an observer at O, S the star observed. A ray of light from the star to the observer is bent by the effect of the earth's atmosphere, much the same as a stick partly submerged in water appears to bend where it enters the water. As a result of refraction, a star always appears to the observer to be slightly higher than it really is, at S' rather than at S, and the angle of elevation measured is always too large. As the star approaches the horizon its light must pass through a thicker section of the earth's atmosphere (OH), at a more oblique angle than when it is near the zenith (OZ); consequently, the correction for refraction is greatest for bodies near the horizon and decreases with the altitude of the observed body above the horizon.

The correction for parallax is illustrated in figure 118, in which the circle represents the earth, P, P' the poles of the earth, and M the moon. For an observer at O the altitude of the moon is represented by the angle h; but to be used for position determination all altitudes must be reduced to the horizontal plane through the center of the earth, where the altitude is h'. The difference between the two angles, $h'-h$, is the parallax (as used in celestial navigation). By geometry it can be shown that the angle at $M=h'-h$, and therefore represents the parallax; it is the angle formed at the observed body by lines to the observer's position and to the center of the earth. From the figure it may be seen that the angle at M is greatest when the body is near the horizon and decreases to zero when the body is overhead. It is also evident that as the distance of the celestial body from the earth increases, the angle at M (parallax) becomes smaller. Parallax is of navigational importance only in the case of the moon, which is comparatively near the earth; the sun and planets are far enough from the earth that parallax is negligible, while the stars are at such infinite distances that it cannot be measured.

While considerable time has been used in explaining these corrections, with a little practice they can be taken from the tables and applied in a very few moments with little possibility of error.[4]

FORMS FOR COMPUTATION

A standard form for computing the line of position is not absolutely necessary, but for convenience, speed, and accuracy, a blank form is very desirable. One of the chief advantages of using a form is that it reduces the entire operation to a routine procedure which may be followed through correctly, even though the navigator has forgotten all the reasons why. The successive steps are presented in order, and the processes of addition or subtraction are clearly indicated.

Figure 119 shows one such form, especially designed for use with the line of position table appearing in pages 210 to 224. For other tables, of course. other forms are more suitable.

In the upper left corner of the form two rules are included, as a convenient reminder; their application will be discussed later. The only other rules required are the two which appear at the tops of the pages of the table itself. Below the rules on the form, spaces are provided for recording the date, the time, and the star or other body observed.

The abbreviation GCT stands for Greenwich civil time, which is simply the standard time at Greenwich; the only difference is that Greenwich civil time is reckoned from 0 (at midnight) to 24 hours each day, instead of 0 to 12 and then repeating. That is, 2:40 p. m. would be written as 14^h40^m. For some purposes, this would be written as 1440; 8:20 a. m. would be written as 0820. The navigator's watch should be set to keep Greenwich civil time, and should be reset or checked at least once every day by radio time signals. (See appendix.)

In the upper right corner space is provided for recording a series of as many as 10 sextant observations. The abbreviation H_s is the altitude (height actually measured with the sextant). Under Par (Parallax), Dip, Ref (refraction), S. D. (semidiameter), and I. C. (index correction), any corrections for these items are entered. The total of these corrections (Corr.) is then applied to H_s to obtain H_o, which is considered as the observed altitude.

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[4] For an additional correction, made necessary by the rotation of the earth, see p. 238.

At the upper left of the part of the form used for the actual computations, there are two columns for obtaining the GHA of the observed body: one to be used for the sun, the moon, or a planet, the other to be used for a star. The

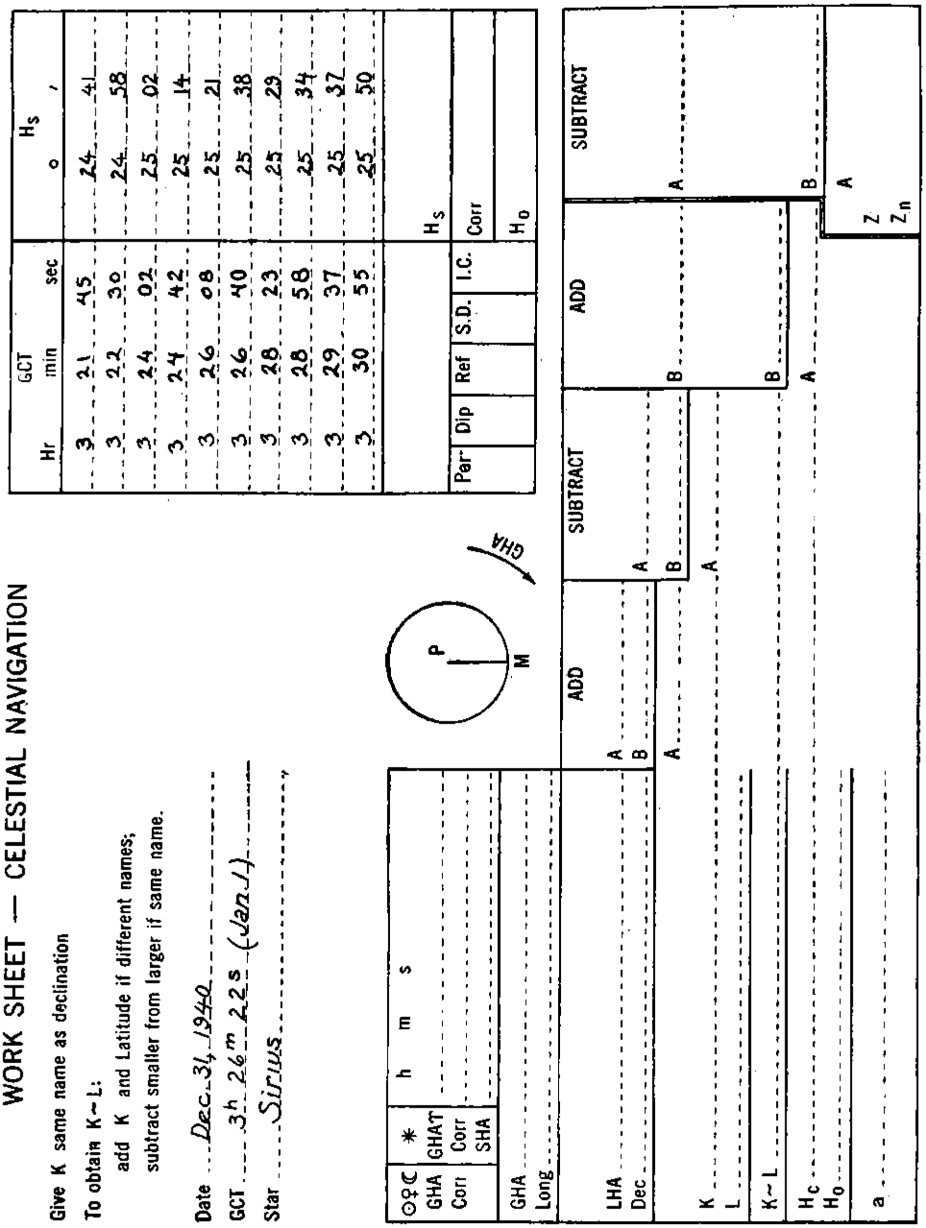

Figure 119.—Form for computing the line of position, showing all data obtained by observation.

first column is headed by the symbols for the sun (☉), the moon (☾), and Venus (♀), the brightest of the planets; the second is headed by the symbol for a star (*). If the data for a star are being computed, it is recommended that the other column be crossed out to avoid confusion, and vice versa.

The other quantities and abbreviations appearing on the form are briefly defined in the tabulation below. They are explained more fully in the section, "Computing the line of position."

GHA = The Greenwich hour angle of the observed body to the nearest (smaller) 10 minutes of GCT; taken from the Air Almanac.

Corr. = Correction from the Air Almanac for any additional minutes and seconds; to be added to the GHA as obtained for the nearest 10 minutes of GCT, in order to find the GHA for the exact time of observation.

Long, = The longitude of the assumed or dead reckoning position.

LHA = The local hour angle; obtained by combining the GHA and the longitude assumed.

Dec. = The declination of the observed body; taken from the Air Almanac.

K = An auxiliary part introduced to facilitate solution of the astronomical triangle, but of no importance in itself.

L = The latitude of the assumed or dead reckoning position.

$K \sim L$ = Obtained by combining K and latitude in accordance with the rules at the top of the form.

H_c = The computed altitude of the observed body; this is the exact altitude of the body for the **assumed** position at the instant of observation.

H_o = The altitude observed at the **actual** position of the observer; the sextant altitude corrected for index error, refraction, etc.

a = The difference between the observed and computed altitudes; often called the intercept, or altitude difference.

Z = The azimuth of the observed body, reckoned from true north up to 180° toward the east or west (in the Northern Hemisphere).[5]

Z_n = The azimuth of the observed body reckoned in the conventional way, clockwise from true north, from 0° up to 360°.

THE AIR ALMANAC

Beginning with January 1941, The American Air Almanac has been issued by the Nautical Almanac Office of the United States Naval Observatory. Previously, the American Nautical Almanac has been used both for surface navigation and for air navigation. Some may prefer to continue using the Nautical Almanac, with which they are familiar, but the Air Almanac is intended to replace it in air navigation. It incorporates a number of new features, all designed to afford simpler and quicker results in flight, while keeping well within the limits of accuracy required in the air. In order to keep it of convenient size and weight, the Air Almanac for each year is issued in three sections covering 4 months each. In computing a line of position from a sextant observation, an understanding of the features of the Air Almanac is essential, and the following description is therefore offered.

The Air Almanac has been arranged so as to afford the desired information from a single page opening in most cases. The information for the sun, moon, and three planets has therefore been listed on a separate page for each day. The values for a. m. are given on the front of the page, and for p. m. on the back. (See pp. 205 and 207.)

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[5] If the navigator were south of the Equator, Z as taken from the table would be reckoned from the south, from 0° to 180° toward the east or west.

The data on the page for each day are tabulated at 10-minute intervals throughout the 24 hours. Two identical tables are provided for interpolating between the 10-minute tabulations, for the exact time of observation. (See p. 206.) One of these is on a flap which may be inserted facing the p. m. side of the page; the other is on the inside of the front cover. It is expected that the daily pages will be removed from day to day, leaving the interpolation table on the inside of the front cover always facing the a. m. side of the page for the current day. In either case, all the data that are needed for a solution for the sun, moon, or a planet, may be obtained at one opening of the almanac. Tables for refraction and dip (see p. 209) are on the back cover, and a convenient table is provided for converting an observed altitude of Polaris into latitude (see p. 209).

On the a. m. side of each daily sheet (p. 207), at the tops of the respective columns appear the names and the symbols representing the sun, three planets, and the moon. The stellar magnitudes of the planets (p. 198) are also indicated. Beneath each heading the GHA and the declination of the body is given.

Column 3 tabulates the GHA ♈; that is, the GHA of the vernal equinox. As explained later, this quantity is used in obtaining the GHA of a star.

The last column lists the correction for parallax, for observations of the moon. The plus sign is a reminder that this correction is always to be added to the sextant altitude. Near the bottom of this column are the corrections for semidiameter (S. D.) for the sun and for the moon. When interpolating for the GHA of the moon, under some conditions a slight error is introduced. A correction to eliminate this error, when needed, is given at the bottom of the same column, under "Corr. HA ☾."

The diagram at the right-hand edge of the sheet shows the positions of the moon, planets, vernal equinox, and four stars, with respect to the sun. The sun and moon are represented by their conventional symbols. The planets are also identified by conventional symbols beneath the dots showing their locations. Their respective symbols are also shown adjacent to their names at the top of the page, as an aid to memory. The stars are represented by asterisks, with the letters *a*, *b*, *c*, and *d* indicating Aldebaran, Regulus, Spica, and Antares, respectively.

The diagram represents the narrow band along the ecliptic within which the sun, moon, and planets appear to move. The ends of the diagram are each 180° from the sun; that is, each half of the diagram represents a complete arc across the sky, from horizon to horizon. If the diagram is held toward the southern sky, with the symbol for the sun toward the eastern horizon (sunrise) and the west end toward the western horizon, the relative positions of the stars and planets near the time of sunrise may be visualized from the west half of the diagram. If the symbol for the sun is held toward the western horizon (sunset), with the east end toward the east, the other half of the diagram pictures the visible planets and selected stars near the time of sunset.

On the p. m. side (p. 205), the tables at the right show the time of rising and setting of the sun and moon, and the duration of civil twilight. The last column, under the heading of "Diff.," gives the number of minutes later at which the moon will rise or set on the following day.

The inside back cover (p. 208) lists the sidereal hour angle (SHA), right ascension (RA), and declination (Dec.) of 55 navigational stars. The Greenwich hour angle (GHA) of a star is obtained by adding the GHA of the vernal equinox (GHA ♈), as given in the daily pages, and the SHA of the star. As a convenient reminder, it might be well to write this equation at the bottom of the page of star data:

$$GHA^* = GHA ♈ + SHA^*.$$

COMPUTING THE LINE OF POSITION

Figure 119 records all the data actually obtained by observation, for a series of 10 bubble sextant altitudes of the star Sirius; figure 120 shows the complete solution for a line of position from the recorded data. At first glance it may look somewhat complicated, but with a little practice the complete solution should require no more than 3 to 5 minutes.

Opposite each observed altitude of the series, the Greenwich civil time of the observation is recorded; since the average altitude and the average time of the series is used in computing the line of position, these quantities are averaged by adding each column and then dividing the totals by the number of observations.

Errors of arithmetic in averaging the times of observation and the sextant altitudes are more likely than in performing the remainder of the computation. Improved sextants are in process of development by means of which these quantities are averaged mechanically or visually. Various short cuts in arithmetic are also used.

For example, in averaging the times recorded in figure 120, if 3^h20^m are subtracted from each recording and only the remainder is averaged, one works with much smaller quantities; some time is saved, and mistakes are much less probable. The average obtained in that case would be 6^m22^s; the 3^h20^m subtracted is then restored, making the average $3^h26^m22^s$.

Next, any necessary corrections are applied to the average sextant altitude in order to obtain the observed altitude H_o, which is used to determine the altitude difference a, at the bottom of the form.

It should be noted that the form is dated December 31, but the Greenwich civil time recorded is for January 1. The civil time where the observations were made (about longitude 83°45′) was about 9:52 p. m. ($=21^h52^m$), eastern standard time, but the time at Greenwich was approximately 5½ hours later, nearly 3½ hours past midnight and hence January 1. When this situation exists it should be noted on the form, to avoid any possibility of taking the values from the Air Almanac for the wrong day.

After recording and correcting the sextant observations; the next step is to determine the Greenwich hour angle (GHA) of the body at the instant of observation. This is to be taken from the Air Almanac, and the method of

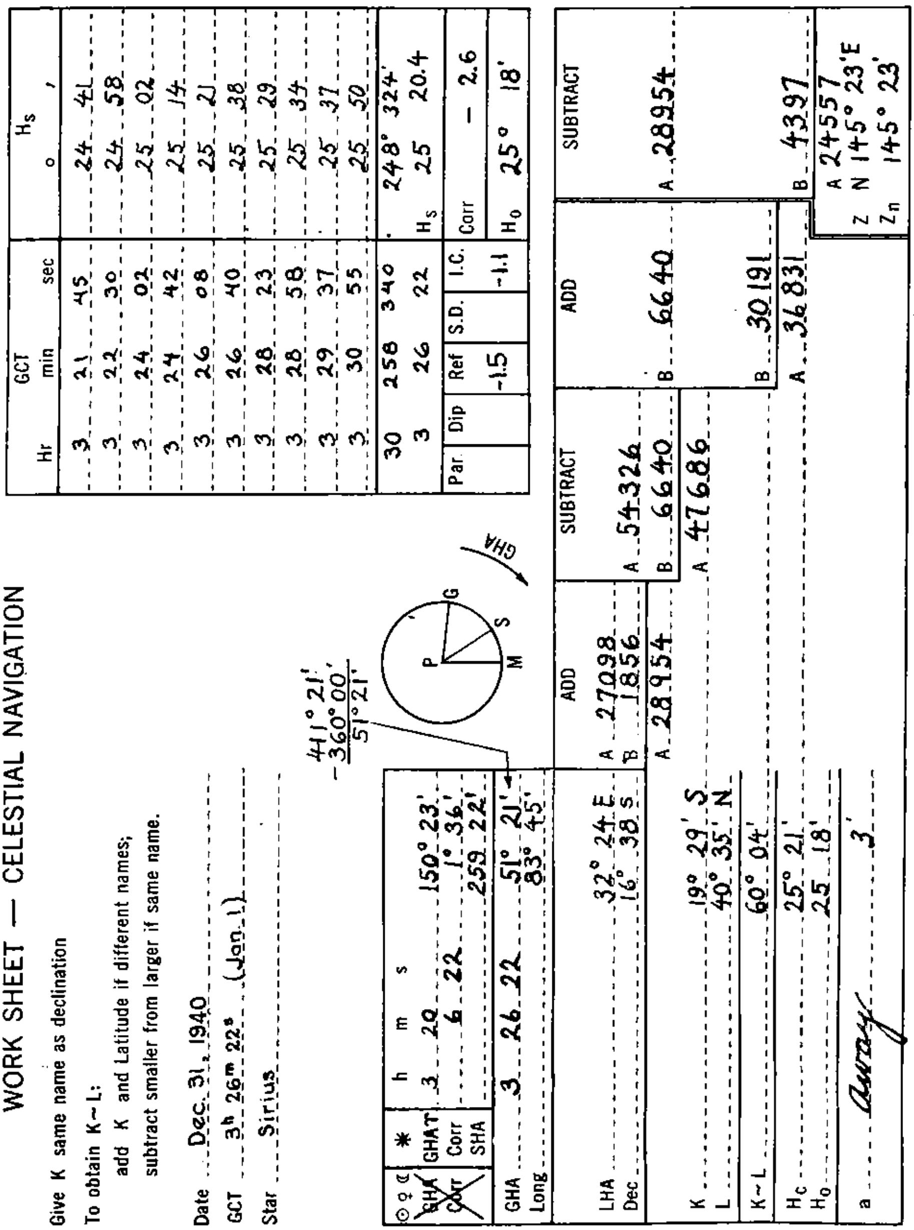

Figure 120.—Form for computing the line of position, showing the complete solution.

obtaining it under all circumstance may best be illustrated by working out the GHA for the sun, a planet, the moon, and a star, from the sample pages of the Air Almanac, pages 205 to 209. In each case a Greenwich civil time (GCT) of $21^h26^m22^s$ on January 1, 1941, is assumed.

Example 1.—GHA of the sun. From the table on page 205, we find the GHA for $21^h\ 20^m$ GCT, on Wednesday, January 1. From the table on page 206, we find the correction for $6^m\ 22^s$. Adding these, the required GHA is obtained.

GHA $21^h\ 20^m$		139° 03′
Corr.	$6^m\ 22^s$	1° 36′
GHA $21^h\ 26^m\ 22^s$		140° 39′

Example 2.—GHA of Venus. From the table on page 205, we find the GHA for $21^h\ 20^m$ GCT, and from the table on page 206, the same correction as in example 1, for $6^m\ 22^s$. Adding these, the GHA is obtained.

GHA $21^h\ 20^m$		167° 16′
Corr.	$6^m\ 22^s$	1° 36′
GHA $21^h\ 26^m\ 22^s$		168° 52′

Example 3.—GHA of the moon. From the table on page 205, we find the GHA for $21^h\ 20^m$ GCT. From the table on page 206, under "Moon," the correction for $6^m\ 22^s$. Adding these, the required GHA is obtained.

GHA $21^h\ 20^m$		89° 42′
Corr.	$6^m\ 22^s$	1° 32′
GHA $21^h\ 26^m\ 22^s$		91° 14′

Example 4.—GHA of Sirius. From the table on page 205, we find the GHA ♈ for $21^h\ 20^m$ GCT, and from the table on page 206, the same correction as in examples 1 and 2, for $6^m\ 22^s$. From the table on page 208 we obtain the SHA of Sirius. Adding these three quantities, the required GHA is obtained.

GHA ♈ $21^h\ 20^m$		61° 08′
Corr.	$6^m\ 22^s$	1° 36′
SHA		259° 22′
GHA	$21^h\ 26^m\ 22^s$	322° 06′

Having found the GHA from the Air Almanac, the local hour angle (LHA) is found by combining the GHA and the longitude of the dead reckoning or assumed position. Since both are referred to Greenwich as the zero meridian this should present no difficulty; however, as an aid to clear understanding of the problem, the circle (time diagram) on the work sheet is usually filled in. The blank form shows only the circle, and the radius *PM* (see fig. 119). The circle represents the earth as it would appear looking straight down upon it from a point over the pole. *P* is the pole and the circumference represents the equator; *PM* is the meridian passing through the position of the observer. For the problem illustrated in figure 120, the longitude of the assumed position is 83°45′ west; the meridian of Greenwich *PG* can, therefore, be drawn in, about 84° east of *M*. The GHA of the star was about 51°, and the meridian passing through the star *PS* can therefore be drawn, the angle GPS being approximately 51°. The GHA is always measured from the meridian of Greenwich in the direction indicated by the arrow. The angle MPS is the LHA.

The LHA is measured from 0° to 180° east or west from the observer's meridian. It is desirable to note on the work sheet whether the LHA is east or west of the observer, to avoid error in laying off the altitude difference *a* toward or away from the star. For the same reason, it is desirable to estimate the azimuth of the body upon completing the sextant observations.

For an observer in the United States (that is, in west longitude) three conditions for obtaining the LHA are possible; these are illustrated in figure 121, with the operation required for obtaining the LHA in each case. The problem illustrated in figure 120 is similar to case *b* in the figure.

The declination of the star, or other body, is taken from the Air Almanac. Along with the degrees and minutes of declination, it should be noted whether the body is north (*N*) or south (*S*) of the equator, and when "*K*" is found it should be named *N* or *S*, according as the declination is *N* or *S*. See rule at top of form: "Give *K* same name as declination." *K* is an auxiliary part of the triangle needed for the solution, but of no importance in itself.

a. Star west of the observer and west of the meridian of Greenwich:
GM = longitude
GMS = GHA
MS = LHA
LHA = GHA − longitude

b. Star east of the observer and west of the meridian of Greenwich:
GM = longitude
GS = GHA
MS = LHA
LHA = longitude − GHA

c. Star east of the observer and east of the meridian of Greenwich
GM = longitude
GMS = GHA
MGS = LHA
GS = 360° − GHA
LHA = 360° − GHA + longitude

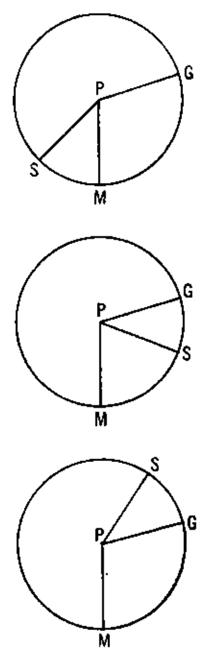

Figure 121.—Determining the local hour angle (LHA).

The corrections to the sextant altitude, and the data obtained from the Air Almanac (LHA, declination, etc.), are preliminary steps. They supply the data needed for the actual computation, which is the simplest part of the whole problem; it may be performed by means of the Line of Position Table (pp. 210 to 224).

The Line of Position Table is an abridged form of the "Dead Reckoning Altitude and Azimuth Table," prepared by Lieut. Arthur A. Ageton, United States Navy, and published by the United States Hydrographic Office as H. O. No. 211. It is reproduced here by the courtesy of that Bureau. Those desiring further information as to the derivation and other uses of the table are referred to the original publication.

One should not be misled by the phrase "dead reckoning" which appears in the name of the table, since it has no application to navigation by that method; rather, it signifies that the computation may be made from the dead reckoning position as readily as from any other position. This feature is more important than is at first apparent. Although there are other tables which yield a solution with a slight saving in time and figures, with those tables a position must be arbitrarily assumed such that the table may be entered with a whole degree. The data for the line of position may be obtained in a trifle less time, but before it can be drawn on the chart the additional position assumed for convenient use of the tables must be plotted, consuming whatever time may have been saved in computing. With the table beginning on page 210, the dead reckoning position or any convenient projection intersection may be used for the computation; since both of these appear on the chart the line of position can be plotted more quickly.

The table itself is very short, and no interpolation is necessary; the few rules required are ever before the pilot—either on the pages of the table itself or on the work form—and the procedure is practically uniform under all conditions. Although many of the other "short methods" are very good and have certain advantages, for the reasons given it is believed that this method is entirely satisfactory for the most experienced navigator and among the best yet available for the student.

It has already been remarked that the use of the table for computing the altitude (H_c) and azimuth (Z) is the simplest part of the whole problem. For each degree and minute up to 180° there are listed in separate columns an A value and a B value. The values given are sufficiently accurate without interpolation. The work consists only in copying down these values and adding or subtracting as indicated on the standard form. To illustrate, we shall follow through the problem of figure 120.

The LHA is determined as 32°24′, and the A value for that angle is copied from the table in the space indicated on the form.

Next the B value for 16°38′ (declination to the nearest whole minute) is copied in the space indicated, and the corresponding A value is written in the next column.

As indicated on the form, the first column is added, and totals 28954; this is shown on the form as an A value. We run through the tables until 28964 (the number nearest 28954) is found in the A column and take out the corresponding B value, which is written in columns 2 and 3, the A value being repeated in column 4.

Now the subtraction required in column 2 is performed, obtaining 47686; the value nearest this number is found in the A columns of the table, and the degrees and minutes under which it is found are entered at the left of the form as the value of K. The value of K is found at the top of the column or at the bottom of the column in accordance with the rule at the top of the pages of the table.

K is then combined with L, and the B value corresponding to $K \sim L$ is entered in column 3 and the required addition performed. The number nearest this result is found in the A columns of the table, and the corresponding B value entered in column 4; at the top of the same column in the table there is read the number of degrees, and at the left the minutes, of the computed altitude, which is now entered in the form as H_c.

The difference between H_c and H_o is recorded at a, and the word **toward or away** is entered on the form, according as the actual position is toward the star from the assumed position, or away from it. (See p. 175.)

Finally, the subtraction indicated in the fourth column is performed, and the A value corresponding to the azimuth Z is found. The value of Z is taken from the tables in accordance with the rule at the top of the pages of the table—and the data for the line of position have been computed.

The azimuth obtained in the problem of figure 120 is 145°23′. In north latitudes azimuth is reckoned from the north up to 180° toward the east or west. From the time diagram and data of figure 120, it is seen that the star is to the east of the observer, and the azimuth is therefore named N. 145°23′ E. This means that the body is 145°23′ toward the east from true north. An azimuth of N. 145°23′ *W* means that the body is 145°23′ toward the *west* from true north.

Below Z there is a space for Z_n, the azimuth from the north reckoned in the conventional way, from 0° to 360°. An azimuth of N. 145°23′ W. could be entered in this space as 214°37′. This conversion is optional with the navigator, and need not be made unless the first form is confusing.

The process of computing a line of position is not nearly as difficult nor as time consuming as it sounds when put into words. Students may prove this to their own satisfaction by working out a few practical examples.

OTHER METHODS

There are several short-cut methods for obtaining the data for a line of position. For example, there are mechanical computers, on which the observed data and the information from the Air Almanac can be set up, and the answer can then be read directly from the instrument. By their use, some slight saving in time is effected, and any possibility of error in arithmetic is removed; but it is as possible to set up the data erroneously, on the computer, as to make a mistake in arithmetic, and in either case the results are worthless.

Another short cut is found in the use of precomputed altitudes. By this method, using the best data available, the estimated positions of the airplane along a projected route are determined by dead reckoning, for a series of regular time intervals. The altitudes and azimuths of the bodies selected for observation on the flight are then computed for the dead reckoning positions and the corresponding times. These altitudes are then plotted in the form of a graph, against the proper time intervals, and a smooth curve is drawn through the points so obtained. The computed azimuths are each plotted on the chart of the route, from the dead reckoning positions to which they apply.

This method affords no saving in labor; its one advantage is that the labor is performed on the ground, before taking off, leaving a minimum of work to be performed in the air. The procedure while in flight may be outlined as follows:

Having obtained the corrected sextant altitude and noted the time of observation, as already described, read from the graph the precomputed altitude for the same time. The difference between the precomputed altitude and the observed altitude is the altitude difference (intercept) required for plotting the line of position.

If the time of observation coincides with one of the dead reckoning positions chosen for computing the curve, the azimuth is already plotted on the chart, and it is only necessary to lay off the altitude difference, from the dead reckoning position toward or away from the body according as the observed altitude is greater or less than the precomputed altitude. If the time of observation happens to fall between two of the dead reckoning positions used for the computations, a new dead reckoning position corresponding to the time of observation is plotted on the chart, and the azimuth is laid off by eye, in a direction roughly parallel to or intermediate between the azimuths plotted from the nearby positions; the altitude difference is then laid off as before, to obtain the line of position. If curves are precomputed and plotted for two or more celestial bodies, lines of position from each can be most quickly plotted, as already described, and their intersection fixes the position of the plane.

Any difference between the actual position of the plane and the dead reckoning position does not affect the accuracy of the line of position, provided only that the azimuth and altitude difference are laid off from the dead reckoning position on the plotted route as determined from the original data used in precomputing the altitude curve, rather than from any data obtained during the flight.

If desired, the corrections for index, error, refraction, etc., can be applied to the precomputed altitudes, with reversed signs, when plotting the curve. In this way, sextant altitudes can be used directly as read from the instrument, still further reducing the work required while in the air.

Perhaps the simplest method of all is provided by the "star altitude curves." In this method, intersecting circles of position from three stars are printed on the same graph in different colors; the altitudes of the stars for which the curves have been drawn are observed in quick succession, and the Greenwich sidereal time [6] of the observations recorded. It is then necessary only to note the point of intersection of the curves corresponding to the altitudes observed, and read from the margins of the graph the latitude of the observer's position and the local sidereal time at that place. Combined with the Greenwich sidereal time by ordinary arithmetic, the local sidereal time affords the longitude in terms of time; this may be converted to arc by means of a special table in the Air Almanac, and the position has been fixed with a minimum of time and almost no arithmetic.

This method is subject to the disadvantage that it cannot be used by day and is available for relatively few stars at night. For satisfactory results, not more than a minute should elapse between the two altitude observations; if more time does elapse, a method is provided for carrying forward the curve corresponding to the first observation.

A LINE OF POSITION FROM POLARIS

In the case of Polaris, a line of position may be obtained with very little computation, the line of position being the parallel of latitude on which the observer is located.

As suggested on page 172, the altitude of the celestial pole is equal to the latitude of the place from which it is observed; however, Polaris is not exactly

[6] For a discussion of sidereal time, see p. 196.

at the pole, but moves about it in a small circle with a radius of about 1° 2′.5. (See fig. 122.) Now if the altitude of the pole is equal to the latitude, it is apparent that when Polaris is directly above the pole the radius of 1° 2′.5 must be subtracted from the altitude of the star in order to find the altitude of the pole—and hence the latitude of the place. If the star is directly below the pole, the radius of 1° 2′.5 must be added to the altitude of the star in order to obtain the altitude of the pole; if the star is directly to the right or to the left of the pole, the altitude of the star is the same as the altitude of the pole.

In the Air Almanac there is a special table (see p. 209), giving the correction to be applied to an observed altitude of Polaris for various values of the LHA ♈ (local hour angle of the vernal equinox). The GHA ♈ is taken from the daily

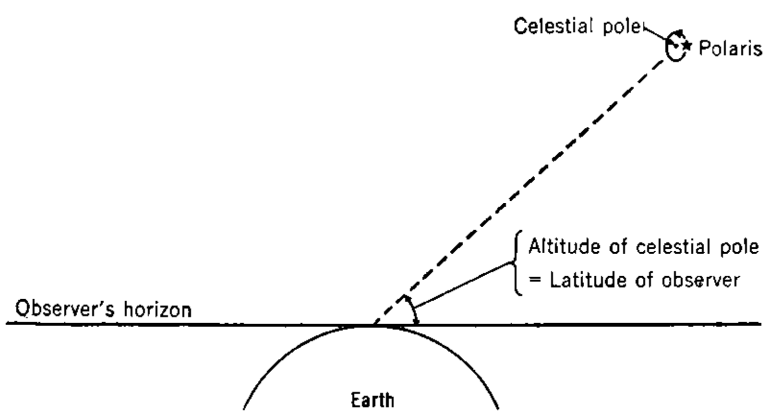

Figure 122. Latitude from Polaris.

sheet of the Air Almanac, and combined with the longitude of the assumed position in the usual way in order to obtain the LHA ♈. With this LHA the special table is entered and a correction obtained which is to be added to or subtracted from the corrected sextant altitude H_o, as indicated. The result is the latitude of the observer, which is most easily plotted on the chart as a line of position.

A line of position from Polaris (latitude) requires a minimum of time; therefore, whenever this star is visible it might well be one of the stars selected. When Polaris is chosen, the other star should be as nearly due east or due west as possible. Another good practice is to select a star directly before or behind the airplane, and another to one side; the first line of position in this case checks the progress along the route, while the line from the second determines whether or not the airplane is tracking the intended route.

The process of taking and recording 5 to 10 sextant observations, computing the data, and plotting the line of position on the chart will probably require not less than 10 minutes. That is, after obtaining one line of position about 10 minutes may elapse before a second can be plotted on the chart. During this period a fast airplane can cover 30 to 35 miles, and the first line of position must be carried forward the course and distance made good by dead reckoning between the two observations, just as described in connection with radio bearings, on page 115. Similarly, the resulting fix must be carried forward the distance and direction made good after the second observation, in order to obtain the current position of the airplane. If Polaris is selected as the second star, the distance that the first line of position or the fix must be carried forward is reduced to a minimum because of the shorter time required for computing and plotting a line of position (latitude) from Polaris.

A LINE OF POSITION FROM AN UNIDENTIFIED STAR

A few stars, such as Sirius and Vega, possess such distinctive characteristics that they could probably be identified, even if no other stars were visible; for the most part, however, a star is identified by its position with reference to known star groups (such as the Great Dipper) more than from its individual appearance.

Assume that a transatlantic flight is in progress, and that the airplane has been enveloped in clouds for several hours; the radio has failed, and a position from celestial observations is urgently required. Finally a break appears in the clouds and a single star of about the first magnitude is seen for only a few minutes. In this brief interval, four sextant altitudes of the star are obtained, but since the identity of the star is unknown, the necessary data for computing the line of position cannot be taken from the Air Almanac. By some method, the star must be identified before the line of position can be computed.

There are available several star finders from which, after the approximately known data are set up, the star may be identified. Perhaps the most accurate of these is The Rude Star Finder and Identifier, published by the United States Hydrographic Office as H. O. No. 2102a. There are also special Star Identification Tables, H. O. No. 127, by means of which the star may be identified with but little difficulty.

The line of position table (pp. 210 to 224) may be used for star identification, if desired. The method is basically simple, but, like most other methods, it requires enough time that it would not be used in air navigation except under extreme conditions.

The method consists essentially in working the ordinary problem backward in order to find the declination and LHA of the star observed; with these values approximately found, we can identify the star in the Air Almanac, and the problem is then worked in the usual way (as in fig. 120) to obtain the line of position. A convenient form for the first part of the problem (the identification of the star) is shown in figure 123, on which the problem just presented is worked out.

As shown on the form, the mean time for the series of observations was 23^h42^m GCT, January 1, 1941; the corrected sextant altitude H_o was 12°44′; and the azimuth of the star was estimated as approximately 85° east of true north. The A value of the azimuth is added to the B value of the corrected altitude, and the result A 1247 is obtained (column 1). This total is repeated in column 4, and the B value corresponding to this number is written in columns 2 and 3 as indicated. The subtraction required in column 2 is now performed to obtain the A value of K; K and L are combined (as in fig. 120) and the B value of $K \sim L$ added as indicated in column 3, the result being the A value of the declination of the star observed; the corresponding B value is then subtracted as required in column 4, to obtain the *A* value of the LHA which is marked east, from the known direction of the star. The declination is marked north or south in accordance with the rule appearing on the form.

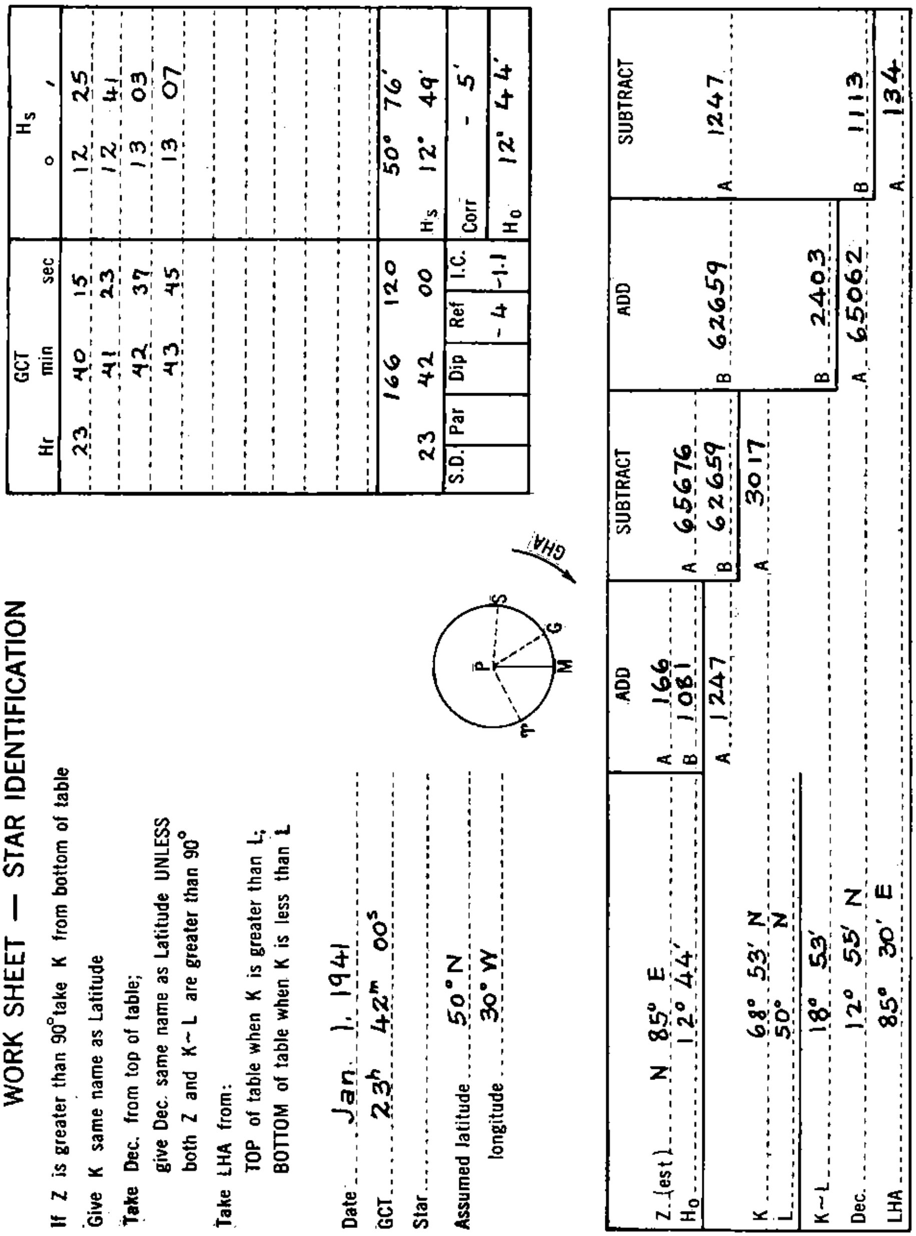

Figure 123.—Form for star identification.

On the circle (time diagram) which appears on the form, the meridian of Greenwich is now drawn in, 30° east of *M* (the observer's meridian). and also the meridian of the star, approximately 85° east of *M*. Next, the GHA ♈ for 23^h42^m GCT is obtained from the Air Almanac as 96°44′, and added to the time diagram, about 96° to the west of *G*.

From the relationship pictured, the SHA of the star is equal to 360° minus the angle ♈PS, and the angle ♈PS is equal to the LHA+GHA♈−long. That is,

$$\begin{aligned} SHA &= 360° - ♈PS \\ &= 360° - (LHA + GHA♈ - long.) \\ &= 360° - (85°30' + 96°44' - 30°) \\ &= 360° - 152°14' \\ &= 207°46' \end{aligned}$$

At the right side of the page of star data in the Air Almanac (see p. 208), stars are listed in order of increasing SHA. Running down the list, we find 208°41′ SHA, and declination 12°15′ N., for the first magnitude star Regulus. No other star even approaches these values, and it is therefore safe to assume that Regulus was the star observed. The data for Regulus are therefore entered on the form shown in figure 119, and the line of position computed as before.

SIDEREAL TIME

With the introduction of the Air Almanac, a knowledge of sidereal time is no longer necessary for any of the standard methods of celestial navigation. There are certain special methods, however, such as the use of the star altitude

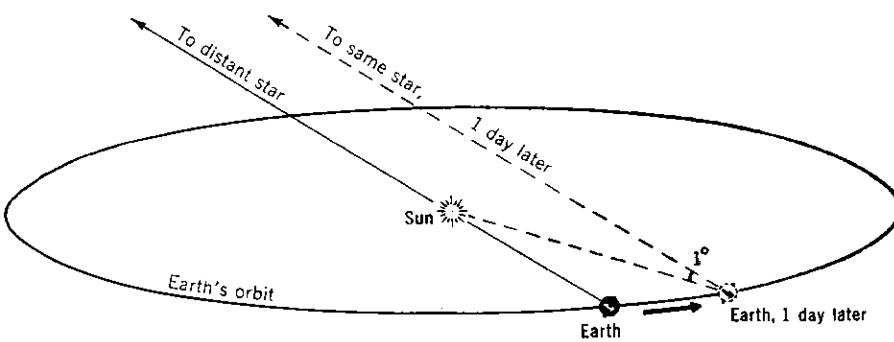

Figure 124.—The civil day and sidereal time.

curves, which offer very real advantages, and which require the use of sidereal time. In order to make use of these methods some knowledge of sidereal time is essential.

Ordinary civil time is based on the rotation of the earth with respect to the sun,[7] the civil day being the period of time required for one complete rotation. Sidereal time is also based on the rotation of the earth, but a sidereal day is the period required for one complete rotation with respect to the stars.

As illustrated in figure 124, at the same time that the earth rotates on its axis it is also traveling along its orbit around the sun, at the rate of almost a degree a day (360° in approximately 365 days).

Since the nearest star is so much farther away than the sun, there is no appreciable difference in the direction of a star throughout the year, while the direction of the sun changes from day to day. Thus, the solid earth and the sun (fig. 124) are in direct line with a distant star, which we will suppose is

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[7] Strictly speaking, with respect to the *mean* sun.

located exactly at the vernal equinox, or first point of Aries. As the point on the earth which is directly toward the sun and star begins to rotate, the civil day and the sidereal day for that point begin simultaneously. The dotted earth marks its position near the end of the civil day, about 1° farther along in its orbit. It has already completed one rotation with respect to the distant star, but must turn almost another degree to complete one rotation with respect to the sun. It is evident, then, that the civil day is longer than the sidereal day, the difference amounting to about $3^m\ 56^s$.

An important distinction to remember is that a sidereal time interval is always less than a civil time interval, but when used for angular measure (GHA or LHA) the two are equal. In both cases a complete circumference of 360° is equal to 24^h.

On the daily pages of the Air Almanac, the quantity GHA ♈ is in reality the GST (Greenwich sidereal time), in terms of arc, for the corresponding interval of GCT. That is (see p. 205), the GST of 12 noon on January 1, 1941, is 280°45′; converted into time, this is equal to $18^h\ 43^m\ 00^s$. A navigator, desiring the correct Greenwich sidereal time, when he receives the radio time signal corresponding to GCT noon on that date, should set his sidereal watch to $18^h\ 43^m\ 00^s$, or 6:43 p. m.

IDENTIFICATION OF STARS

It has already been pointed out that it is useless to observe the altitude of a star unless the identity of the star is known. The beginner is apt to be confused by the number of stars, and to suppose that it is difficult to distinguish one star from another. On the contrary, stars differ from one another considerably, in relative brightness, in color, and in their peculiar groupings. The Air Almanac lists 55 principal navigational stars, all of which are shown on the navigational star chart in the back of the Almanac.

Any flat map has its difficulties. This is painfully apparent in the star chart of the Almanac, in which the poles are stretched out into lines extending all the way across the chart. Globes are not so convenient to carry about, but the serious student will be well repaid for the purchase of a good celestial globe, some of which may now be had quite reasonably. With a globe, the astronomical triangle and celestial coordinates can be clearly seen; the relation between civil and sidereal time can be demonstrated, and the approximate solutions of navigational problems can be obtained graphically. With any good star chart, however, and a little patience, it is not difficult to identify any or all of the principal stars, if we start from some familiar group.

For example, everyone is familiar with the "Big Dipper" which is part of the constellation (star group) known as Ursa Major. Most people are also aware that the two "pointer stars" in the bowl of the dipper point to Polaris, the North Star. The star nearer the pole is named Dubhe, the other Merak. Now, if we follow the curving handle of the dipper, extending the curve beyond the dipper about the length of the dipper itself, we come to the bright yellow star Arcturus, in the constellation Boötes. Continuing the same curve about an equal distance again we find the star Spica, in Virgo, a little fainter than Arcturus and blue-white in color.

On the opposite side of Polaris from the Big Dipper, and about the same distance from it, is an easily recognized *W* (or *M*, depending on the position), which is the distinguishing feature of Cassiopeia. Three of the stars in the *W* have special names: Caph, Ruchbah, and Schedir. Toward the south from the *W* and about as far from it as the *W* is from the pole, is "the great square in Pegasus," the four stars of the square being known as Alpheratz, Algenib, Markab, and Scheat. In the same way, a few at a time, all the navigational stars may be learned.

STAR NAMES

For centuries, the brighter stars have been known by special names, as Sirius and Vega. They also have another name, consisting of a letter of the Greek alphabet and the possessive form of the constellation name. Thus, Alpheratz is also known as α Andromedae. In celestial geography this is about the same as a city and state name, α being the city and Andromeda the state. We may have α Andromedae and α Cassiopeiae, just as we have Portsmouth, N. H., and Portsmouth, Va. The Greek alphabet is given in table 5.

Table 5.—The Greek alphabet

Letter	Name	Letter	Name	Letter	Name
α	Alpha.	ι	Iota.	ρ	Rho.
β	Beta.	κ	Kappa.	σ	Sigma.
γ	Gamma.	λ	Lambda.	τ	Tau.
δ	Delta.	μ	Mu.	υ	Upsilon.
ϵ	Epsilon.	ν	Nu.	ϕ	Phi.
ζ	Zeta.	ξ	Xi.	χ	Chi.
η	Eta.	o	Omicron.	ψ	Psi.
θ	Theta.	π	Pi.	ω	Omega.

BRIGHTNESS OF STARS

Stars are classified as first magnitude, second magnitude, etc., according to their apparent brightness. A first magnitude star is 2½ times as bright as a second magnitude star, and so on; conversely, a second magnitude star is ⅖ as bright as a first. Antares and Spica are first magnitude stars; Polaris is second magnitude.

A few stars are brighter than first magnitude, and are classified in order of increasing brightness as 0, −1, or −2 magnitude. Sirius, the brightest star, is −2 magnitude; Arcturus is 0 magnitude, which is one magnitude brighter than first.

In the preceding paragraphs the nearest whole magnitudes are given, as is usually done in speaking of them. Astronomers determine magnitudes to the nearest hundredth, and each whole magnitude includes approximately half a magnitude on either side of it. Thus, first magnitude extends from 0.51 to 1.50, second from 1.51 to 2.50, and so on. In the Air Almanac magnitudes are tabulated to the nearest tenth, Sirius being listed as −1.6 (nearest whole magnitude −2).

THE PLANETS

The stars are self-luminous like the sun, which is our nearest star; the planets (of which the Earth is one) shine only by light reflected from the sun, just as the moon does. Of our sun's family of planets, only four are of interest to the navigator: Venus, Jupiter, Saturn, and Mars. They can usually be distinguished by their steady light, which does not twinkle like the light from a star.

Venus is easy to recognize, since it is brighter than any star; it is golden yellow in color and is often called the evening star, or the morning star, since it is rarely seen more than 3 hours after sunset or 3 hours before sunrise.

Jupiter is a little fainter than Venus, but brighter than Sirius, the brightest star. It is, therefore, also very easy to identify.

Saturn is about as bright as a first magnitude star and is pale yellow in color.

Mars is decidedly red in color, and varies in brightness from second magnitude (as bright as Polaris) to minus 3 magnitude, which is between Jupiter and Venus in brightness.

The sun and its planets all appear to move along approximately the same path or plane in the sky, known as the ecliptic; frequently there are one or more planets to be seen at night, and it is not difficult to visualize the approximate position of the ecliptic, along the line connecting them. If at any time a bright star is seen near the ecliptic where none is shown on the star maps, it is fairly certain to be one of the four planets mentioned above.

MOTION OF THE STARS AND PLANETS

All are familiar with the way in which the sun rises in the east, climbs up the sky on an inclined path till noon, when it is toward the south (for an observer in the United States), and circles downward to set in the west. In exactly the same way the stars and planets pass across the night sky from east to west. Stars close to Polaris, the North Star, do not set. They describe small circles around it and never pass below the horizon, passing from view in the daytime only because of the greater brightness of the sun. As the distance from the North Pole increases, the radii of the circles increase until, near the southern horizon, stars describe only flattened arcs not very high above the horizon.

For an observer in south latitudes, of course, this is reversed in some details. Stars (or other celestial bodies) that are farther north than the observer, rise in the east and follow an inclined path up the sky to a point north of the observer, then descend to set in the west. Stars close to the south celestial pole do not set, but describe small circles around the pole. As the distance of the star from the south celestial pole increases, the radius of the circle increases until, near the northern horizon, stars describe only flattened arcs.

Aside from this nightly passage of the stars across the sky, their apparent motions in space with respect to each other are so slight that they are spoken of as "fixed," and the star patterns or constellations remain unchanged for millenniums. By way of contrast, there is an appreciable motion of the sun and planets against the background of the stars, even from day to day. In spite of

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this, the new arrangement of the Air Almanac makes it as easy to determine positions from these bodies as from the stars. This is all the more important since they are the brighter and therefore the more easily observed bodies.

Some of the subjects mentioned briefly in this final section, such as the motion of the stars and planets, may be considered as general astronomy. They are not essential to the practice of celestial navigation. If these elements are known, however, the various problems are more clearly understood, and may be solved more intelligently and quickly. Those who desire to study the subject further are referred to some of the standard texts listed in the bibliography (p. 238), and also to any of the better encyclopedias.

EXAMPLES

Example 1.—A pilot flying "over the top" by dead reckoning, believed his position to be about latitude 37° 30′, longitude 99° 30′, when he was able to obtain a series of altitudes of the sun.

Having made the necessary computations with the aid of the line of position table, the pilot has these data:

Azimuth (bearing) of the sun	235°
Observed altitude, H_o	42° 34′
Computed altitude, H_c	42° 20′
Altitude difference, *a*	14′

The azimuth, or bearing, of the sun is laid off from the dead reckoning position of the airplane. The altitude difference of 14 minutes is equal to 14 minutes of latitude; therefore, a distance equal to 14 minutes of latitude is measured on any convenient meridian, and laid off along the bearing, toward the body (since the observed altitude is greater than the computed altitude). A line drawn at right angles to the bearing through the point so obtained is the required line of position.

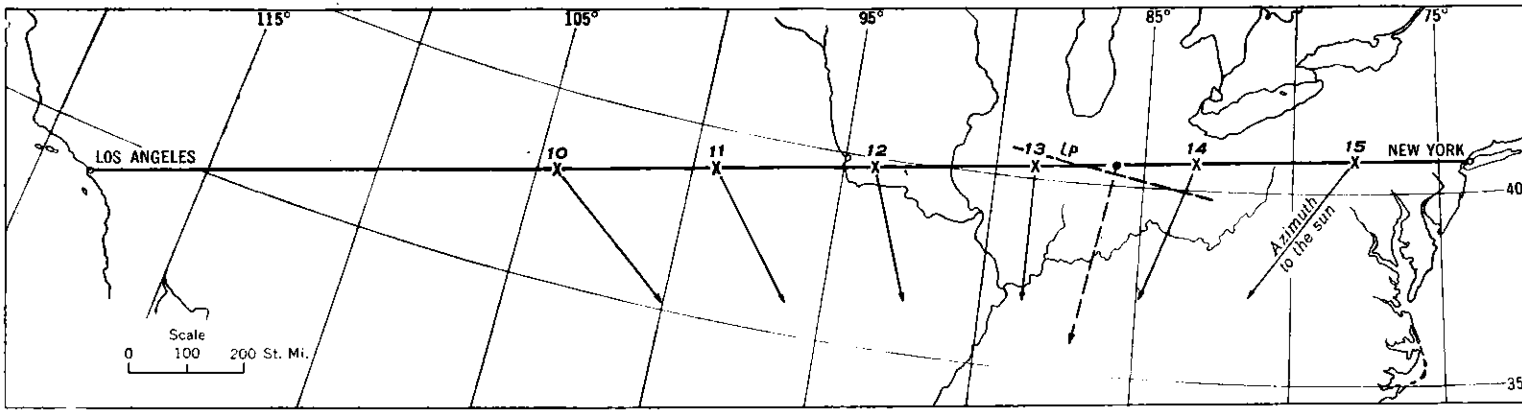
The intersection of this line of position with a second line obtained by observing the moon (if visible by daylight), or the intersection of lines of position from two stars at night, fixes the location of the airplane.

Example 2.—A nonstop flight is planned from Los Angeles municipal airport to LaGuardia Field, New York City. The flight is to be made in the substratosphere, at 20,000 feet, January 1, 1941. From the best data available, a ground speed of 287 m. p. h. is expected (265 m. p. h. cruising speed plus 22 m. p. h. assistance along the course from a WNW. wind of 30 m. p. h.).

The distance as scaled from the planning chart is about 2,475 miles, and approximately 8 hours and 40 minutes are required for the flight. From the daily page of the Air Almanac (see p. 205) it is found that the sun sets in the latitude of New York on this date at about $16^h\ 45^m$, or 4:45 p. m., E. S. T. It is desired to land at New York about 1 hour before sunset, at $15^h\ 45^m$; the departure from Los Angeles is therefore set for $8^h\ 40^m$ earlier, or 7:05 a. m., E. S. T.—4:05 Pacific time.

From the foregoing, it is evident that the airplane will be in flight about 3 hours before the sun is high enough for observation. The dead reckoning positions of the airplane for each hour, beginning at 10 o'clock E. S. T., are determined, and each position is assigned a number corresponding to the eastern standard time when the airplane should be at that place. The dead reckoning positions at these time intervals are as shown in figure 125.

Using the latitude, longitude, and GCT corresponding to each dead reckoning position, as shown in the table of figure 125, the altitude and azimuth of the sun for each position are computed by means of the line of position table, pages 210 to 224. From the refraction table on the back of the Air Almanac, the



D R POSITION	LATITUDE	LONGITUDE	G C T	AZIMUTH	ALTITUDE	ALTITUDE (corr. for ref.)
10	38°08′	104° 22′	$15^h\,00^m$	126° 23′	6°45′	6° 49′
11	39°08′	99° 14′	16 00	141° 32′	17° 24′	17° 28′
12	39°56′	93°58′	17 00	159° 54′	24°23′	24° 24′
13	40°30′	88°35′	18 00	180°30′	26°31′	26°32′
14	40°49′	83°09′	19 00	200°58′	23°18′	23° 19′
15	40°52′	77° 42′	20 00	219° 09′	15° 30′	15° 32′

Figure 125.—Data for route from Los Angeles to New York.

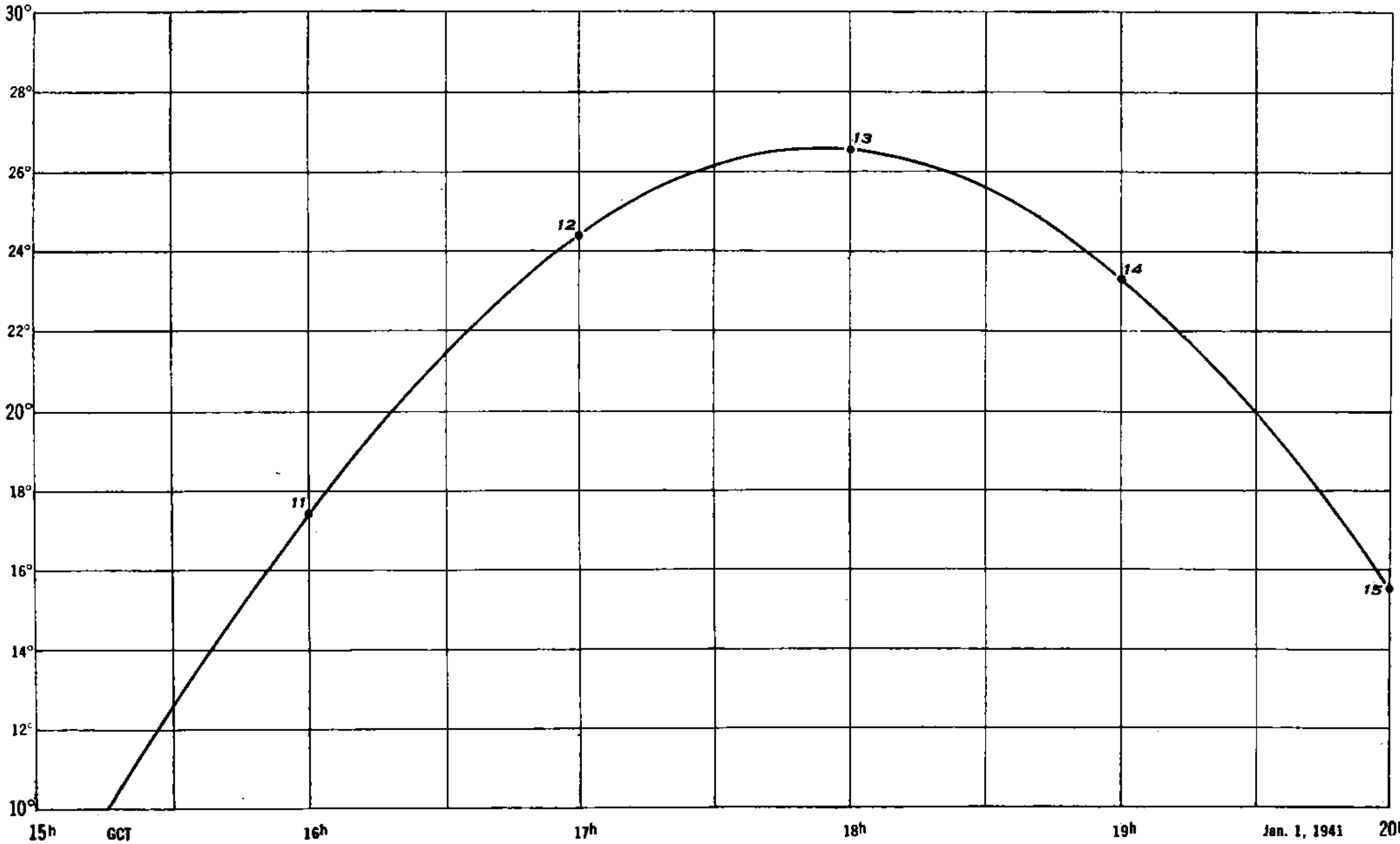


Figure 126.—Precomputed altitude curve for the sun.

corrections for refraction are applied with reversed sign. During flight, then, the only correction to be applied to sextant observations of the sun is that for index error (if any). The azimuths from the various dead reckoning positions are laid off, and the precomputed altitude curve of figure 126 is plotted and drawn.

To illustrate the use of the method in flight, suppose that at $18^h 30^m$ GCT a sextant altitude of 25° 49′ is obtained. Applying a known index correction of −1′, the corrected sextant altitude is 25° 48′. From the curve of figure 126 the altitude of the sun for $18^h 30^m$ is read as 25° 36′. Since the observed altitude is 12′ greater, the position at the time of observation is 12′ closer to the sun. At $18^h 30^m$ the dead reckoning position of the airplane is halfway between positions 13 and 14; the approximate azimuth of the sun is laid off through that point, as indicated by the light broken line, and the line of position *LP* is drawn 12′ toward the sun from the dead reckoning position.

At night, precomputed altitude curves for two or more bodies (stars, planets, or moon) can be constructed. Lines of position can be obtained in each case as simply as in the problem just described, and a fix can be obtained practically without computation.

Example 3.—On a night flight, high above an overcast, a position is required, using the star altitude curves. With this method the correction for refraction is incorporated in the curves themselves, and the only correction necessary (when using the bubble sextant) is the correction for index error, if any. The following sextant altitudes were obtained, after the index correction had been applied: Vega, 39°35′; and Polaris, 37°58′.

The appropriate page is selected, as shown in figure 127, and the intersection of the (interpolated) curves is found near the upper left corner of the page. Opposite the intersection, at either side of the page, the latitude of the observer is read as 38° 58′. Directly above, or below, the intersection, the LST (local sidereal time) of the observer's position is read as 1409.5 ($14^h 09^m.5$). For this method, the simplest procedure is to carry a chronometer set for GST (Greenwich sidereal time). The GST of the observations for this problem was noted as $20^h 16^m.5$. Subtracting $14^h 09^m.5$ from $20^h 16^m.5$ gives the longitude of the observer in terms of time, as $6^h 07^m$, which is equivalent to a longitude of 91° 45′. No computation other than this one subtraction is required.

Vega was observed first, and Polaris immediately afterward. The average time of the observations of Vega was used for both stars, as the altitude of Polaris changes so slowly. It is to be noted that the line from the intersection of the two altitude curves to the side of the page is always drawn parallel to the upper and lower borders, not parallel to the altitude curves. In this case, the curves for Polaris are very nearly parallel to this line; on other pages, the curves for Polaris may be at an appreciable angle to the upper and lower borders.

SPECIMEN PAGES FROM THE AIR ALMANAC

Pages 205 to 209 are from the Air Almanac for 1941. They are included here to illustrate the use of the Almanac in the solution of the typical examples presented herein.

THE LINE OF POSITION TABLE

The line of position table is an abridged form of the dead reckoning altitude and azimuth table, prepared by Lieutenant Arthur A. Ageton, United States Navy, and published by the United States Hydrographic Office as H. O. No. 211. It is reproduced here by the courtesy of that Bureau. Those desiring further information as to the derivation and other uses of the table are referred to the original publication.

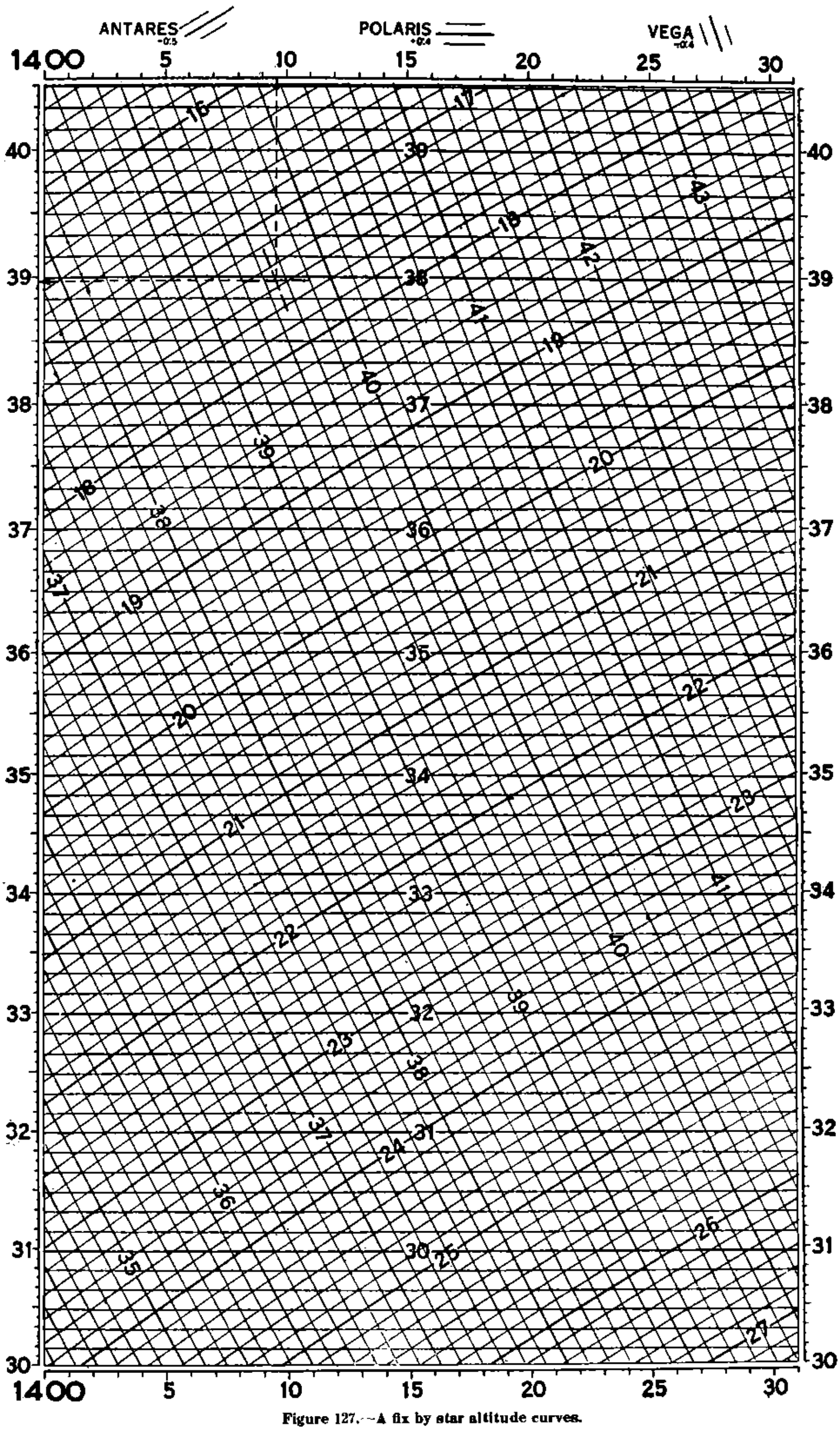


Figure 127.—A fix by star altitude curves.

VI GREENWICH P. M. 1941 JANUARY 1 (WEDNESDAY)

GCT h m	☉ SUN GHA ° ′	SUN Dec. ° ′	♈ GHA ° ′	♀ VENUS −3.4 GHA ° ′	VENUS Dec. ° ′	♃ JUPITER −2.2 GHA ° ′	JUPITER Dec. ° ′	♄ SATURN 0.4 GHA ° ′	SATURN Dec. ° ′	☽ MOON GHA ° ′	MOON Dec. ° ′
12 00	359 06	S23 01	280 45	27 24	S21 30	246 58	N12 19	244 21	N11 50	314 06	S9 58
10	1 36		283 15	29 54		249 29		246 51		316 31	56
20	4 06		285 46	32 23		251 59		249 21		318 57	55
30	6 36	· ·	288 16	34 53	· ·	254 30	· ·	251 52	· ·	321 22	· 53
40	9 06		290 46	37 23		257 00		254 22		323 47	52
50	11 36		293 17	39 53		259 30		256 53		326 12	51
13 00	14 06	S23 00	295 47	42 23	S21 31	262 01	N12 19	259 23	N11 50	328 38	S9 49
10	16 36		298 18	44 53		264 31		261 54		331 03	48
20	19 06		300 48	47 23		267 02		264 24		333 28	46
30	21 36	· ·	303 18	49 52	· ·	269 32	· ·	266 54	· ·	335 53	· 45
40	24 06		305 49	52 22		272 02		269 25		338 19	43
50	26 36		308 19	54 52		274 33		271 55		340 44	42
14 00	29 06	S23 00	310 50	57 22	S21 31	277 03	N12 19	274 26	N11 50	343 09	S9 41
10	31 35		313 20	59 52		279 34		276 56		345 34	39
20	34 05		315 51	62 22		282 04		279 26		348 00	38
30	36 35	· ·	318 21	64 52	· ·	284 35	· ·	281 57	· ·	350 25	· 36
40	39 05		320 51	67 21		287 05		284 27		352 50	35
50	41 35		323 22	69 51		289 35		286 58		355 15	33
15 00	44 05	S23 00	325 52	72 21	S21 32	292 06	N12 19	289 28	N11 50	357 41	S9 32
10	46 35		328 23	74 51		294 36		291 59		0 06	31
20	49 05		330 53	77 21		297 07		294 29		2 31	29
30	51 35	· ·	333 23	79 51	· ·	299 37	· ·	296 59	· ·	4 57	· 28
40	54 05		335 54	82 21		302 07		299 30		7 22	26
50	56 35		338 24	84 50		304 38		302 00		9 47	25
16 00	59 05	S23 00	340 55	87 20	S21 32	307 08	N12 19	304 31	N11 50	12 12	S9 23
10	61 35		343 25	89 50		309 39		307 01		14 38	22
20	64 05		345 55	92 20		312 09		309 32		17 03	20
30	66 35	· ·	348 26	94 50	· ·	314 39	· ·	312 02	· ·	19 28	· 19
40	69 05		350 56	97 20		317 10		314 32		21 53	18
50	71 35		353 27	99 50		319 40		317 03		24 19	16
17 00	74 05	S23 00	355 57	102 19	S21 33	322 11	N12 19	319 33	N11 50	26 44	S9 15
10	76 35		358 28	104 49		324 41		322 04		29 09	13
20	79 05		0 58	107 19		327 12		324 34		31 35	12
30	81 34	· ·	3 28	109 49	· ·	329 42	· ·	327 04	· ·	34 00	· 10
40	84 04		5 59	112 19		332 12		329 35		36 25	09
50	86 34		8 29	114 49		334 43		332 05		38 51	07
18 00	89 04	S22 59	11 00	117 19	S21 33	337 13	N12 19	334 36	N11 50	41 16	S9 06
10	91 34		13 30	119 48		339 44		337 06		43 41	04
20	94 04		16 00	122 18		342 14		339 37		46 06	03
30	96 34	· ·	18 31	124 48	· ·	344 44	· ·	342 07	· ·	48 32	· 02
40	99 04		21 01	127 18		347 15		344 37		50 57	9 00
50	101 34		23 32	129 48		349 45		347 08		53 22	8 59
19 00	104 04	S22 59	26 02	132 18	S21 34	352 16	N12 19	349 38	N11 50	55 48	S8 57
10	106 34		28 32	134 48		354 46		352 09		58 13	56
20	109 04		31 03	137 17		357 16		354 39		60 38	54
30	111 34	· ·	33 33	139 47	· ·	359 47	· ·	357 09	· ·	63 04	· 53
40	114 04		36 04	142 17		2 17		359 40		65 29	51
50	116 34		38 34	144 47		4 48		2 10		67 54	50
20 00	119 04	S22 59	41 05	147 17	S21 34	7 18	N12 19	4 41	N11 50	70 20	S8 48
10	121 34		43 35	149 47		9 49		7 11		72 45	47
20	124 04		46 05	152 17		12 19		9 42		75 10	45
30	126 34	· ·	48 36	154 46	· ·	14 49	· ·	12 12	· ·	77 35	· 44
40	129 04		51 06	157 16		17 20		14 42		80 01	42
50	131 33		53 37	159 46		19 50		17 13		82 26	41
21 00	134 03	S22 59	56 07	162 16	S21 35	22 21	N12 19	19 43	N11 50	84 51	S8 40
10	136 33		58 37	164 46		24 51		22 14		87 17	38
20	139 03		61 08	167 16		27 21		24 44		89 42	37
30	141 33	· ·	63 38	169 46	· ·	29 52	· ·	27 14	· ·	92 07	· 35
40	144 03		66 09	172 15		32 22		29 45		94 33	34
50	146 33		68 39	174 45		34 53		32 15		96 58	32
22 00	149 03	S22 59	71 09	177 15	S21 35	37 23	N12 19	34 46	N11 50	99 23	S8 31
10	151 33		73 40	179 45		39 53		37 16		101 49	29
20	154 03		76 10	182 15		42 24		39 47		104 14	28
30	156 33	· ·	78 41	184 45	· ·	44 54	· ·	42 17	· ·	106 39	· 26
40	159 03		81 11	187 15		47 25		44 47		109 05	25
50	161 33		83 41	189 44		49 55		47 18		111 30	23
23 00	164 03	S22 58	86 12	192 14	S21 35	52 26	N12 19	49 48	N11 50	113 55	S8 22
10	166 33		88 42	194 44		54 56		52 19		116 21	20
20	169 03		91 13	197 14		57 26		54 49		118 46	19
30	171 33	· ·	93 43	199 44	· ·	59 57	· ·	57 19	· ·	121 11	· 17
40	174 03		96 14	202 14		62 27		59 50		123 37	16
50	176 33		98 44	204 44		64 58		62 20		126 02	14
24 00	179 03	S22 58	101 14	207 13	S21 36	67 28	N12 19	64 51	N11 50	128 28	S8 13

Lat. °	Sunrise h m	Twil. m	Moonrise h m	Diff. m
N 60	9 03	57	10 14	19
58	8 46	51	08	21
56	32	47	10 03	23
54	19	43	9 58	25
52	8 08	40	54	26
50	7 59	38	50	28
45	38	33	42	30
40	22	31	35	33
35	7 08	28	29	35
30	6 56	27	23	38
20	35	24	14	41
10	17	23	9 06	43
0	6 00	22	8 58	46
10	5 43	23	50	50
20	24	24	42	52
30	5 03	27	33	55
35	4 50	29	28	57
40	35	33	21	60
45	4 18	36	14	62
50	3 56	43	06	65
52	45	47	8 02	66
54	33	52	7 57	68
56	19	60	52	70
58	3 03	71	47	72
60 S	2 43	93	7 41	74

Lat. °	Sunset h m	Twil. m	Moonset h m	Diff. m
N 60	15 05	57	20 16	74
58	21	51	22	71
56	36	47	26	70
54	48	43	30	68
52	15 59	40	34	66
50	16 08	37	37	65
45	29	33	44	62
40	45	31	50	59
35	16 59	28	20 56	56
30	17 11	27	21 00	54
20	32	24	08	51
10	17 50	22	14	48
0	18 07	22	21	45
10	18 25	23	27	43
20	18 43	25	34	39
30	19 05	27	41	36
35	18	29	46	34
40	32	33	51	31
45	19 50	37	21 56	30
50	20 12	44	22 03	26
52	22	49	06	25
54	34	54	09	24
56	20 48	62	13	22
58	21 04	73	17	20
60 S	21 24	96	22 22	18

INTERPOLATION OF GHA

SUN, PLANETS, ♈

Int. m s	Corr. ° '
00 00	0 00
01	0 01
05	0 02
09	0 03
13	0 04
17	0 05
21	0 06
25	0 07
29	0 08
33	0 09
37	0 10
41	0 11
45	0 12
49	0 13
53	0 14
57	0 15
01 01	0 16
05	0 17
09	0 18
13	0 19
17	0 20
21	0 21
25	0 22
29	0 23
33	0 24
37	0 25
41	0 26
45	0 27
49	0 28
53	0 29
57	0 30
02 01	0 31
05	0 32
09	0 33
13	0 34
17	0 35
21	0 36
25	0 37
29	0 38
33	0 39
37	0 40
41	0 41
45	0 42
49	0 43
53	0 44
57	0 45
03 01	0 46
05	0 47
09	0 48
13	0 49
17	0 50
21	

Int. m s	Corr. ° '
03 17	0 50
21	0 51
25	0 52
29	0 53
33	0 54
37	0 55
41	0 56
45	0 57
49	0 58
53	0 59
57	1 00
04 01	1 01
05	1 02
09	1 03
13	1 04
17	1 05
21	1 06
25	1 07
29	1 08
33	1 09
37	1 10
41	1 11
45	1 12
49	1 13
53	1 14
57	1 15
05 01	1 16
05	1 17
09	1 18
13	1 19
17	1 20
21	1 21
25	1 22
29	1 23
33	1 24
37	1 25
41	1 26
45	1 27
49	1 28
53	1 29
57	1 30
06 01	1 31
05	1 32
09	1 33
13	1 34
17	1 35
21	1 36
25	1 37
29	1 38
33	1 39
37	1 40
41	

Int. m s	Corr. ° '
06 37	1 40
41	1 41
45	1 42
49	1 43
53	1 44
57	1 45
07 01	1 46
05	1 47
09	1 48
13	1 49
17	1 50
21	1 51
25	1 52
29	1 53
33	1 54
37	1 55
41	1 56
45	1 57
49	1 58
53	1 59
57	2 00
08 01	2 01
05	2 02
09	2 03
13	2 04
17	2 05
21	2 06
25	2 07
29	2 08
33	2 09
37	2 10
41	2 11
45	2 12
49	2 13
53	2 14
57	2 15
09 01	2 16
05	2 17
09	2 18
13	2 19
17	2 20
21	2 21
25	2 22
29	2 23
33	2 24
37	2 25
41	2 26
45	2 27
49	2 28
53	2 29
57	2 30
10 00	

MOON

Int. m s	Corr. ° '
00 00	0 00
02	0 01
06	0 02
10	0 03
14	0 04
18	0 05
22	0 06
26	0 07
31	0 08
35	0 09
39	0 10
43	0 11
47	0 12
51	0 13
55	0 14
01 00	0 15
04	0 16
08	0 17
12	0 18
16	0 19
20	0 20
24	0 21
29	0 22
33	0 23
37	0 24
41	0 25
45	0 26
49	0 27
53	0 28
58	0 29
02 02	0 30
06	0 31
10	0 32
14	0 33
18	0 34
22	0 35
26	0 36
31	0 37
35	0 38
39	0 39
43	0 40
47	0 41
51	0 42
55	0 43
03 00	0 44
04	0 45
08	0 46
12	0 47
16	0 48
20	0 49
24	

Int. m s	Corr. ° '
03 20	0 49
24	0 50
29	0 51
33	0 52
37	0 53
41	0 54
45	0 55
49	0 56
53	0 57
58	0 58
04 02	0 59
06	1 00
10	1 01
14	1 02
18	1 03
22	1 04
27	1 05
31	1 06
35	1 07
39	1 08
43	1 09
47	1 10
51	1 11
56	1 12
05 00	1 13
04	1 14
08	1 15
12	1 16
16	1 17
20	1 18
25	1 19
29	1 20
33	1 21
37	1 22
41	1 23
45	1 24
49	1 25
54	1 26
58	1 27
06 02	1 28
06	1 29
10	1 30
14	1 31
18	1 32
23	1 33
27	1 34
31	1 35
35	1 36
39	1 37
43	

Int. m s	Corr. ° '
06 39	1 37
43	1 38
47	1 39
52	1 40
56	1 41
07 00	1 42
04	1 43
08	1 44
12	1 45
16	1 46
20	1 47
25	1 48
29	1 49
33	1 50
37	1 51
41	1 52
45	1 53
49	1 54
54	1 55
58	1 56
08 02	1 57
06	1 58
10	1 59
14	2 00
18	2 01
23	2 02
27	2 03
31	2 04
35	2 05
39	2 06
43	2 07
47	2 08
52	2 09
56	2 10
09 00	2 11
04	2 12
08	2 13
12	2 14
16	2 15
21	2 16
25	2 17
29	2 18
33	2 19
37	2 20
41	2 21
45	2 22
50	2 23
54	2 24
58	2 25
10 00	

Correction to be added to GHA for interval of GCT

GREENWICH A. M. 1941 JANUARY 1 (WEDNESDAY)

GCT	☉ SUN GHA	Dec.	♈ GHA	♀ VENUS −3.4 GHA	Dec.	♃ JUPITER −2.2 GHA	Dec.	♄ SATURN 0.4 GHA	Dec.	☽ MOON GHA	Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0 00	179 10	S23 03	100 15	207 34	S21 25	66 29	N12 19	63 51	N11 50	139 54	S11 37
10	181 40		102 46	210 04		68 59		66 21		142 19	36
20	184 10		105 16	212 34		71 30		68 51		144 44	35
30	186 40	· ·	107 46	215 03	· ·	74 00	· ·	71 22	· ·	147 09	· 33
40	189 09		110 17	217 33		76 30		73 52		149 34	32
50	191 39		112 47	220 03		79 01		76 23		151 59	31
1 00	194 09	S23 03	115 18	222 33	S21 25	81 31	N12 19	78 53	N11 50	154 24	S11 29
10	196 39		117 48	225 03		84 02		81 23		156 49	28
20	199 09		120 18	227 33		86 32		83 54		159 14	27
30	201 39	· ·	122 49	230 03	· ·	89 03	· ·	86 24	· ·	161 40	· 25
40	204 09		125 19	232 32		91 33		88 55		164 05	24
50	206 39		127 50	235 02		94 03		91 25		166 30	22
2 00	209 09	S23 03	130 20	237 32	S21 26	96 34	N12 19	93 56	N11 50	168 55	S11 21
10	211 39		132 51	240 02		99 04		96 26		171 20	20
20	214 09		135 21	242 32		101 35		98 56		173 45	18
30	216 39	· ·	137 51	245 02	· ·	104 05	· ·	101 27	· ·	176 10	· 17
40	219 09		140 22	247 32		106 35		103 57		178 36	16
50	221 39		142 52	250 01		109 06		106 28		181 01	14
3 00	224 09	S23 02	145 23	252 31	S21 26	111 36	N12 19	108 58	N11 50	183 26	S11 13
10	226 39		147 53	255 01		114 07		111 28		185 51	12
20	229 09		150 23	257 31		116 37		113 59		188 16	10
30	231 39	· ·	152 54	260 01	· ·	119 07	· ·	116 29	· ·	190 41	· 09
40	234 09		155 24	262 31		121 38		119 00		193 06	08
50	236 39		157 55	265 01		124 08		121 30		195 32	06
4 00	239 08	S23 02	160 25	267 30	S21 27	126 39	N12 19	124 01	N11 50	197 57	S11 05
10	241 38		162 55	270 00		129 09		126 31		200 22	03
20	244 08		165 26	272 30		131 39		129 01		202 47	02
30	246 38	· ·	167 56	275 00	· ·	134 10	· ·	131 32	· ·	205 12	11 01
40	249 08		170 27	277 30		136 40		134 02		207 37	10 59
50	251 38		172 57	280 00		139 11		136 33		210 03	58
5 00	254 08	S23 02	175 28	282 30	S21 27	141 41	N12 19	139 03	N11 50	212 28	S10 57
10	256 38		177 58	284 59		144 12		141 33		214 53	55
20	259 08		180 28	287 29		146 42		144 04		217 18	54
30	261 38	· ·	182 59	289 59	· ·	149 12	· ·	146 34	· ·	219 43	· 52
40	264 08		185 29	292 29		151 43		149 05		222 08	51
50	266 38		188 00	294 59		154 13		151 35		224 34	50
6 00	269 08	S23 02	190 30	297 29	S21 28	156 44	N12 19	154 06	N11 50	226 59	S10 48
10	271 38		193 00	299 59		159 14		156 36		229 24	47
20	274 08		195 31	302 28		161 44		159 06		231 49	46
30	276 38	· ·	198 01	304 58	· ·	164 15	· ·	161 37	· ·	234 14	· 44
40	279 08		200 32	307 28		166 45		164 07		236 39	43
50	281 38		203 02	309 58		169 16		166 38		239 05	41
7 00	284 08	S23 02	205 32	312 28	S21 28	171 46	N12 19	169 08	N11 50	241 30	S10 40
10	286 38		208 03	314 58		174 16		171 39		243 55	39
20	289 07		210 33	317 28		176 47		174 09		246 20	37
30	291 37	· ·	213 04	319 57	· ·	179 17	· ·	176 39	· ·	248 45	· 36
40	294 07		215 34	322 27		181 48		179 10		251 11	34
50	296 37		218 04	324 57		184 18		181 40		253 36	33
8 00	299 07	S23 01	220 35	327 27	S21 29	186 49	N12 19	184 11	N11 50	256 01	S10 32
10	301 37		223 05	329 57		189 19		186 41		258 26	30
20	304 07		225 36	332 27		191 49		189 11		260 51	29
30	306 37	· ·	228 06	334 57	· ·	194 20	· ·	191 42	· ·	263 17	· 27
40	309 07		230 37	337 26		196 50		194 12		265 42	26
50	311 37		233 07	339 56		199 21		196 43		268 07	25
9 00	314 07	S23 01	235 37	342 26	S21 29	201 51	N12 19	199 13	N11 50	270 32	S10 23
10	316 37		238 08	344 56		204 21		201 44		272 57	22
20	319 07		240 38	347 26		206 52		204 14		275 23	20
30	321 37	· ·	243 09	349 56	· ·	209 22	· ·	206 44	· ·	277 48	· 19
40	324 07		245 39	352 26		211 53		209 15		280 13	18
50	326 37		248 09	354 55		214 23		211 45		282 38	16
10 00	329 07	S23 01	250 40	357 25	S21 30	216 53	N12 19	214 16	N11 50	285 03	S10 15
10	331 37		253 10	359 55		219 24		216 46		287 29	13
20	334 07		255 41	2 25		221 54		219 16		289 54	12
30	336 37	· ·	258 11	4 55	· ·	224 25	· ·	221 47	· ·	292 19	· 11
40	339 06		260 41	7 25		226 55		224 17		294 44	09
50	341 36		263 12	9 55		229 26		226 48		297 09	08
11 00	344 06	S23 01	265 42	12 24	S21 30	231 56	N12 19	229 18	N11 50	299 35	S10 06
10	346 36		268 13	14 54		234 26		231 49		302 00	05
20	349 06		270 43	17 24		236 57		234 19		304 25	03
30	351 36	· ·	273 14	19 54	· ·	239 27	· ·	236 49	· ·	306 50	· 02
40	354 06		275 44	22 24		241 58		239 20		309 16	10 01
50	356 36		278 14	24 54		244 28		241 50		311 41	9 59
12 00	359 06	S23 01	280 45	27 24	S21 30	246 58	N12 19	244 21	N11 50	314 06	S9 58

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SD ☉ 16′

SD ☾ 15′

Corr. HA ☾

Int. m	Corr. ′
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STARS

Alphabetical order								Order of SHA				
Name	Mag.	SHA		Dec.		RA		SHA		Dec.		Name
		°	'	°	'	h	m	°	'	°	'	
Acamar	3.4	316	00	S40	33	2	56	14	33	N14	53	Markab
Achernar	0.6	336	08	S57	32	1	35	16	24	S29	56	**Fomalhaut**
Acrux	1.6	174	10	S62	46	12	23	28	52	S47	15	Al Na'ir
Adhara	1.6	255	55	S28	54	6	56	34	41	N 9	36	Enif
Aldebaran (a)	1.1	291	52	N16	23	4	33	50	09	N45	04	**Deneb**
Alioth	1.7	167	08	N56	17	12	51	54	45	S56	55	Peacock
Al Na'ir	2.2	28	52	S47	15	22	5	63	01	N 8	43	**Altair**
Alnilam	1.8	276	42	S 1	15	5	33	77	06	S26	22	Nunki
Alphard	2.2	218	49	S 8	24	9	25	81	16	N38	44	**Vega**
Alphecca	2.3	126	57	N26	55	15	32	84	56	S34	25	Kaus Aust.
Alpheratz	2.2	358	40	N28	46	0	5	91	12	N51	30	Etamin
Altair	0.9	63	01	N 8	43	19	48	96	57	N12	36	Rasalague
Al Suhail	2.2	223	32	S43	12	9	6	97	36	S37	04	Shaula
Antares (d)	1.2	113	33	S26	18	16	26	103	15	S15	39	Sabik
Arcturus	0.2	146	45	N19	29	14	13	(109	24)	S68	55	α Tri. Aust.
ε Argus	1.7	234	40	S59	19	8	21	113	33	S26	18	**Antares**
Bellatrix	1.7	279	30	N 6	18	5	22	120	47	S22	27	Dschubba
Betelgeux	0.1–1.2	272	00	N 7	24	5	52	126	57	N26	55	Alphecca
Canopus	−0.9	264	20	S52	40	6	23	(137	17)	N74	24	Kochab
Capella	0.2	281	55	N45	56	5	12	141	06	S60	35	**Rigil Kent.**
Caph	2.4	358	30	N58	50	0	6	146	45	N19	29	**Arcturus**
θ Centauri	2.3	149	12	S36	05	14	3	149	12	S36	05	θ Centauri
β Crucis	1.5	168	55	S59	22	12	44	159	28	S10	51	**Spica**
γ Crucis	1.6	173	01	S56	47	12	28	159	36	N55	14	Mizar
Deneb	1.3	50	09	N45	04	20	39	167	08	N56	17	Alioth
Denebola	2.2	183	29	N14	54	11	46	168	55	S59	22	β Crucis
Deneb Kait.	2.2	349	51	S18	19	0	41	173	01	S56	47	γ Crucis
Dubhe	2.0	194	58	N62	04	11	0	174	10	S62	46	**Acrux**
Dschubba	2.5	120	47	S22	27	15	57	183	29	N14	54	Denebola
Enif	2.5	34	41	N 9	36	21	41	194	58	N62	04	Dubhe
Etamin	2.4	91	12	N51	30	17	55	208	41	N12	15	**Regulus**
Fomalhaut	1.3	16	24	S29	56	22	54	218	49	S 8	24	Alphard
Hamal	2.2	329	02	N23	11	2	4	221	51	S69	29	Miaplacidus
Kaus Aust.	2.0	84	56	S34	25	18	20	223	32	S43	12	Al Suhail
Kochab	2.2	(137	17)	N74	24	14	51	234	40	S59	19	ε Argus
Marfak	1.9	309	58	N49	39	3	20	244	34	N28	10	**Pollux**
Markab	2.6	14	33	N14	53	23	2	245	56	N 5	22	**Procyon**
Miaplacidus	1.8	221	51	S69	29	9	13	255	55	S28	54	Adhara
Mizar	2.4	159	36	N55	14	13	22	259	22	S16	38	**Sirius**
Nunki	2.1	77	06	S26	22	18	52	264	20	S52	40	**Canopus**
Peacock	2.1	54	45	S56	55	20	21	272	00	N 7	24	**Betelgeux**
Polaris	2.1	(334	12)	N88	59	1	43	276	42	S 1	15	Alnilam
Pollux	1.2	244	34	N28	10	7	42	279	30	N 6	18	Bellatrix
Procyon	0.5	245	56	N 5	22	7	36	281	55	N45	56	**Capella**
Rasalague	2.1	96	57	N12	36	17	32	282	04	S 8	16	**Rigel**
Regulus (b)	1.3	208	41	N12	15	10	5	291	52	N16	23	**Aldebaran**
Rigel	0.3	282	04	S 8	16	5	12	309	58	N49	39	Marfak
Rigil Kent.	0.3	141	06	S60	35	14	36	316	00	S40	33	Acamar
Ruchbah	2.8	339	31	N59	56	1	22	329	02	N23	11	Hamal
Sabik	2.6	103	15	S15	39	17	7	(334	12)	N88	59	**Polaris**
Shaula	1.7	97	36	S37	04	17	30	336	08	S57	32	**Achernar**
Sirius	−1.6	259	22	S16	38	6	43	339	31	N59	56	Ruchbah
Spica (c)	1.2	159	28	S10	51	13	22	349	51	S18	19	Deneb Kait.
α Tri. Aust.	1.9	(109	24)	S68	55	16	42	358	30	N58	50	Caph
Vega	0.1	81	16	N38	44	18	35	358	40	N28	46	Alpheratz

SHA = 360°—RA

POLARIS

LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.
° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′
357 55	−54	88 38	−27	128 21	+14	179 34	+55	270 37	+26	310 17	−15
0 00	−55	89 41	−26	129 19	+15	181 49	+56	271 40	+25	311 15	−16
2 16	−56	90 43	−25	130 18	+16	184 15	+57	272 42	+24	312 12	−17
4 45	−57	91 46	−24	131 18	+17	186 56	+58	273 42	+23	313 12	−18
7 15	−58	92 48	−23	132 18	+18	190 21	+59	274 42	+22	314 12	−19
10 25	−59	93 48	−22	133 16	+19	194 30	+60	275 43	+21	315 12	−20
14 34	−60	94 48	−21	134 13	+20	201 15	+61	276 46	+20	316 12	−21
21 15	−61	95 48	−20	135 12	+21	211 15	+60	277 47	+19	317 12	−22
31 15	−60	96 48	−19	136 15	+22	217 30	+59	278 45	+18	318 12	−23
37 30	−59	97 47	−18	137 17	+23	221 47	+58	279 42	+17	319 12	−24
41 25	−58	98 45	−17	138 18	+24	225 00	+57	280 42	+16	320 12	−25
44 41	−57	99 42	−16	139 18	+25	227 45	+56	281 41	+15	321 15	−26
47 15	−56	100 42	−15	140 19	+26	230 13	+55	282 41	+14	322 17	−27
49 45	−55	101 42	−14	141 24	+27	232 30	+54	283 39	+13	323 22	−28
52 02	−54	102 41	−13	142 30	+28	234 34	+53	284 37	+12	324 27	−29
54 03	−53	103 39	−12	143 32	+29	236 25	+52	285 34	+11	325 31	−30
55 57	−52	104 36	−11	144 34	+30	238 12	+51	286 32	+10	326 33	−31
57 49	−51	105 34	−10	145 40	+31	240 00	+50	287 30	+ 9	327 36	−32
59 30	−50	106 32	− 9	146 49	+32	241 40	+49	288 27	+ 8	328 45	−33
61 05	−49	107 30	− 8	147 57	+33	243 16	+48	289 25	+ 7	329 53	−34
62 39	−48	108 25	− 7	149 05	+34	244 50	+47	290 22	+ 6	331 01	−35
64 13	−47	109 21	− 6	150 13	+35	246 19	+46	291 17	+ 5	332 09	−36
65 44	−46	110 17	− 5	151 21	+36	247 47	+45	292 13	+ 4	333 20	−37
67 12	−45	111 15	− 4	152 30	+37	249 15	+44	293 10	+ 3	334 31	−38
68 33	−44	112 12	− 3	153 41	+38	250 39	+43	294 08	+ 2	335 42	−39
69 52	−43	113 08	− 2	154 52	+39	251 58	+42	295 03	+ 1	336 54	−40
71 11	−42	114 04	− 1	156 07	+40	253 17	+41	296 03	0	338 09	−41
72 30	−41	115 00	0	157 22	+41	254 36	+40	297 01	− 1	339 28	−42
73 48	−40	115 57	+ 1	158 41	+42	255 52	+39	297 57	− 2	340 47	−43
75 07	−39	116 55	+ 2	160 00	+43	257 07	+38	298 53	− 3	342 06	−44
76 18	−38	117 52	+ 3	161 23	+44	258 19	+37	299 48	− 4	343 28	−45
77 30	−37	118 47	+ 4	162 46	+45	259 31	+36	300 46	− 5	344 51	−46
78 41	−36	119 43	+ 5	164 10	+46	260 40	+35	301 44	− 6	346 19	−47
79 52	−35	120 38	+ 6	165 35	+47	261 49	+34	302 41	− 7	347 47	−48
81 01	−34	121 38	+ 7	167 03	+48	262 57	+33	303 36	− 8	349 15	−49
82 09	−33	122 35	+ 8	168 40	+49	264 05	+32	304 32	− 9	350 50	−50
83 15	−32	123 33	+ 9	170 19	+50	265 13	+31	305 28	−10	352 30	−51
84 20	−31	124 31	+10	172 00	+51	266 18	+30	306 26	−11	354 17	−52
85 26	−30	125 28	+11	173 45	+52	267 23	+29	307 24	−12	356 04	−53
86 31	−29	126 26	+12	175 34	+53	268 28	+28	308 21	−13	357 55	−54
87 36	−28	127 24	+13	177 30	+54	269 33	+27	309 19	−14	0 00	−55
88 38		128 21		179 34		270 37		310 17		2 16	

1941

REFRACTION

All observed altitudes must be corrected for refraction. *Subtract* the correction given below from the observed altitude.

Height in feet	Observed altitude						
	5°	10°	15°	20°	30°	45°	60°
	′	′	′	′	′	′	′
0	10	5	4	3	2	1	1
5,000	8	5	3	2	1	1	0
10,000	7	4	3	2	1	1	0
15,000	6	3	2	2	1	1	0
20,000	5	3	2	1	1	1	0
25,000	4	2	2	1	1	0	0
30,000	3	2	1	1	1	0	0
35,000	3	2	1	1	1	0	0
40,000	2	1	1	1	0	0	0

DIP

Altitudes measured from the *sea horizon* must be corrected for dip. *Subtract* the correction below from the observed altitude.

Height	Corr.	Height	Corr.	Height	Corr.	Height	Corr.
Ft.	′	*Ft.*	′	*Ft.*	′	*Ft.*	′
0	1	160	13	620	25	1380	37
2	2	180	14	670	26	1460	38
6	3	210	15	730	27	1540	39
12	4	250	16	780	28	1620	40
21	5	280	17	840	29	1700	41
31	6	310	18	900	30	1790	42
43	7	350	19	960	31	1870	43
58	8	390	20	1030	32	1960	44
75	9	430	21	1090	33	2060	45
93	10	480	22	1160	34	2150	46
114	11	520	23	1230	35	2250	47
137	12	570	24	1310	36	2340	48
162		620		1380		2440	

Table 6. Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	0°00′		1°00′		2°00′		3°00′		4°00′		5°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	------	0.0	175814	6.6	145718	26.5	128120	59.6	115641	105.9	105970	165.6	60
1	353627	0.0	175097	6.8	145358	26.9	127880	60.2	115461	106.8	105826	166.7	59
2	323524	0.0	174391	7.1	145000	27.3	127640	60.9	115282	107.7	105683	167.8	58
3	305915	0.0	173696	7.3	144646	27.8	127403	61.6	115103	108.6	105539	168.9	57
4	293421	0.0	173012	7.5	144295	28.3	127166	62.2	114925	109.5	105397	170.0	56
5	283730	0.0	172339	7.8	143946	28.7	126931	62.9	114747	110.4	105254	171.1	55
6	275812	0.1	171676	8.0	143600	29.2	126697	63.6	114571	111.3	105113	172.3	54
7	269118	0.1	171023	8.2	143257	29.6	126465	64.3	114395	112.2	104971	173.4	53
8	263318	0.1	170379	8.5	142916	30.1	126233	65.0	114220	113.1	104830	174.5	52
9	258203	0.1	169745	8.7	142579	30.6	126003	65.7	114045	114.0	104690	175.7	51
10	253627	0.2	169121	9.0	142243	31.1	125774	66.4	113872	114.9	104550	176.8	50
11	249488	0.2	168505	9.3	141911	31.5	125546	67.1	113699	115.9	104411	178.0	49
12	245709	0.3	167897	9.5	141581	32.0	125320	67.8	113526	116.8	104272	179.1	48
13	242233	0.3	167298	9.8	141253	32.5	125094	68.5	113354	117.7	104133	180.3	47
14	239015	0.4	166708	10.1	140928	33.0	124870	69.2	113183	118.7	103995	181.4	46
15	236018	0.4	166125	10.3	140605	33.5	124647	69.9	113013	119.6	103857	182.6	45
16	233215	0.5	165550	10.6	140285	34.0	124425	70.6	112843	120.5	103720	183.7	44
17	230583	0.5	164982	10.9	139967	34.5	124204	71.3	112674	121.5	103583	184.9	43
18	228100	0.6	164422	11.2	139651	35.0	123985	72.1	112506	122.4	103447	186.1	42
19	225752	0.7	163868	11.5	139338	35.5	123766	72.8	112338	123.4	103311	187.2	41
20	223525	0.7	163322	11.8	139027	36.0	123549	73.5	112171	124.3	103175	188.4	40
21	221406	0.8	162783	12.1	138718	36.5	123332	74.3	112005	125.3	103040	189.6	39
22	219385	0.9	162250	12.4	138411	37.1	123117	75.0	111839	126.2	102905	190.8	38
23	217455	1.0	161724	12.7	138106	37.6	122903	75.8	111674	127.2	102771	192.0	37
24	215607	1.1	161204	13.0	137804	38.1	122690	76.5	111510	128.2	102637	193.2	36
25	213834	1.1	160690	13.3	137504	38.6	122478	77.3	111346	129.2	102504	194.4	35
26	212130	1.2	160182	13.6	137205	39.2	122267	78.0	111183	130.1	102371	195.6	34
27	210491	1.3	159680	13.9	136909	39.7	122057	78.8	111020	131.1	102238	196.8	33
28	208912	1.4	159184	14.2	136615	40.3	121848	79.5	110858	132.1	102106	198.0	32
29	207388	1.5	158693	14.6	136322	40.8	121639	80.3	110696	133.1	101974	199.2	31
30	205916	1.7	158208	14.9	136032	41.4	121432	81.1	110536	134.1	101843	200.4	30
31	204492	1.8	157728	15.2	135744	41.9	121226	81.9	110375	135.1	101712	201.6	29
32	203113	1.9	157254	15.6	135457	42.5	121021	82.6	110216	136.1	101581	202.8	28
33	201777	2.0	156784	15.9	135173	43.0	120817	83.4	110057	137.1	101451	204.1	27
34	200480	2.1	156320	16.2	134890	43.6	120614	84.2	109898	138.1	101321	205.3	26
35	199221	2.3	155861	16.6	134609	44.2	120412	85.0	109740	139.1	101192	206.5	25
36	197998	2.4	155406	16.9	134330	44.7	120211	85.8	109583	140.1	101063	207.8	24
37	196808	2.5	154956	17.3	134052	45.3	120010	86.6	109426	141.1	100934	209.0	23
38	195650	2.7	154511	17.6	133777	45.9	119811	87.4	109270	142.2	100806	210.3	22
39	194522	2.8	154070	18.0	133503	46.5	119612	88.2	109115	143.2	100678	211.5	21
40	193422	2.9	153633	18.4	133231	47.1	119415	89.0	108960	144.2	100550	212.8	20
41	192350	3.1	153201	18.7	132961	47.6	119218	89.8	108805	145.2	100423	214.0	19
42	191303	3.2	152774	19.1	132692	48.2	119022	90.6	108651	146.3	100296	215.3	18
43	190282	3.4	152350	19.5	132425	48.8	118827	91.4	108498	147.3	100170	216.5	17
44	189283	3.6	151931	19.9	132159	49.4	118633	92.3	108345	148.4	100044	217.8	16
45	188307	3.7	151515	20.3	131896	50.0	118440	93.1	108193	149.4	99918	219.1	15
46	187353	3.9	151104	20.6	131633	50.7	118248	93.9	108041	150.5	99793	220.3	14
47	186419	4.1	150696	21.0	131373	51.3	118056	94.7	107890	151.5	99668	221.6	13
48	185505	4.2	150292	21.4	131114	51.9	117866	95.6	107739	152.6	99544	222.9	12
49	184609	4.4	149892	21.8	130856	52.5	117676	96.4	107589	153.6	99420	224.2	11
50	183732	4.6	149495	22.2	130600	53.1	117487	97.3	107439	154.7	99296	225.5	10
51	182872	4.8	149103	22.6	130346	53.7	117299	98.1	107290	155.8	99172	226.8	9
52	182029	5.0	148713	23.1	130093	54.4	117112	99.0	107141	156.9	99049	228.1	8
53	181201	5.2	148327	23.5	129841	55.0	116925	99.8	106993	157.9	98926	229.4	7
54	180390	5.4	147945	23.9	129591	55.7	116739	100.7	106846	159.0	98804	230.7	6
55	179593	5.6	147566	24.3	129342	56.3	116554	101.6	106698	160.1	98682	232.0	5
56	178810	5.8	147190	24.7	129095	56.9	116370	102.4	106552	161.2	98560	233.3	4
57	178042	6.0	146817	25.2	128849	57.6	116187	103.3	106406	162.3	98439	234.6	3
58	177287	6.2	146448	25.6	128605	58.2	116004	104.2	106260	163.4	98318	235.9	2
59	176544	6.4	146081	26.0	128362	58.9	115823	105.0	106115	164.5	98197	237.2	1
60	175814	6.6	145718	26.5	128120	59.6	115641	105.9	105970	165.6	98076	238.6	0
	A	B	A	B	A	B	A	B	A	B	A	B	
	179°00′		178°00′		177°00′		176°00′		175°00′		174°00′		′

Table 6.—Line of position table.

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	6°00′ A	6°00′ B	7°00′ A	7°00′ B	8°00′ A	8°00′ B	9°00′ A	9°00′ B	10°00′ A	10°00′ B	11°00′ A	11°00′ B	′
0	98076	**239**	91411	**325**	85644	**425**	80567	**538**	76033	**665**	71940	**805**	60
1	97957	**240**	91308	**326**	85555	**426**	80487	**540**	75961	**667**	71875	**808**	59
2	97837	**241**	91205	**328**	85465	**428**	80407	**542**	75890	**669**	71810	**810**	58
3	97717	**243**	91103	**330**	85376	**430**	80328	**544**	75819	**672**	71746	**813**	57
4	97598	**244**	91001	**331**	85286	**432**	80249	**546**	75747	**674**	71681	**815**	56
5	97480	**245**	90899	**333**	85197	**434**	80170	**548**	75676	**676**	71616	**818**	55
6	97361	**247**	90798	**334**	85108	**435**	80091	**550**	75605	**678**	71552	**820**	54
7	97243	**248**	90696	**336**	85020	**437**	80012	**552**	75534	**680**	71488	**823**	53
8	97126	**249**	90595	**337**	84931	**439**	79933	**554**	75464	**683**	71423	**825**	52
9	97008	**251**	90494	**339**	84843	**441**	79855	**556**	75393	**685**	71359	**828**	51
10	96891	**252**	90394	**341**	84755	**443**	79777	**558**	75322	**687**	71295	**830**	50
11	96774	**253**	90293	**342**	84667	**444**	79698	**560**	75252	**690**	71231	**833**	49
12	96658	**255**	90193	**344**	84579	**446**	79620	**562**	75182	**692**	71167	**835**	48
13	96542	**256**	90093	**345**	84492	**448**	79542	**564**	75112	**694**	71104	**838**	47
14	96426	**257**	89994	**347**	84404	**450**	79465	**566**	75042	**696**	71040	**840**	46
15	96310	**259**	89894	**349**	84317	**452**	79387	**568**	74972	**699**	70976	**843**	45
16	96195	**260**	89795	**350**	84230	**454**	79309	**570**	74902	**701**	70913	**845**	44
17	96080	**262**	89696	**352**	84143	**455**	79232	**573**	74832	**703**	70850	**848**	43
18	95966	**263**	89597	**353**	84056	**457**	79155	**575**	74763	**706**	70786	**850**	42
19	95851	**264**	89499	**355**	83970	**459**	79078	**577**	74693	**708**	70723	**853**	41
20	95737	**266**	89401	**357**	83884	**461**	79001	**579**	74624	**710**	70660	**855**	40
21	95624	**267**	89303	**358**	83797	**463**	78924	**581**	74555	**712**	70597	**858**	39
22	95510	**269**	89205	**360**	83711	**465**	78847	**583**	74486	**715**	70534	**860**	38
23	95397	**270**	89107	**362**	83626	**467**	78771	**585**	74417	**717**	70471	**863**	37
24	95285	**271**	89010	**363**	83540	**468**	78694	**587**	74348	**719**	70409	**865**	36
25	95172	**273**	88913	**365**	83455	**470**	78618	**589**	74279	**722**	70346	**868**	35
26	95060	**274**	88816	**366**	83369	**472**	78542	**591**	74210	**724**	70284	**870**	34
27	94948	**276**	88719	**368**	83284	**474**	78466	**593**	74142	**726**	70221	**873**	33
28	94836	**277**	88623	**370**	83199	**476**	78390	**595**	74073	**729**	70159	**876**	32
29	94725	**279**	88526	**371**	83114	**478**	78315	**598**	74005	**731**	70097	**878**	31
30	94614	**280**	88430	**373**	83030	**480**	78239	**600**	73937	**733**	70034	**881**	30
31	94503	**281**	88334	**375**	82945	**482**	78164	**602**	73869	**736**	69972	**883**	29
32	94393	**283**	88239	**376**	82861	**483**	78088	**604**	73801	**738**	69910	**886**	28
33	94283	**284**	88143	**378**	82777	**485**	78013	**606**	73733	**740**	69849	**888**	27
34	94173	**286**	88048	**380**	82693	**487**	77938	**608**	73665	**743**	69787	**891**	26
35	94063	**287**	87953	**381**	82609	**489**	77863	**610**	73597	**745**	69725	**894**	25
36	93954	**289**	87858	**383**	82526	**491**	77788	**612**	73530	**747**	69664	**896**	24
37	93845	**290**	87764	**385**	82442	**493**	77714	**615**	73462	**750**	69602	**899**	23
38	93736	**292**	87669	**387**	82359	**495**	77639	**617**	73395	**752**	69541	**901**	22
39	93628	**293**	87575	**388**	82276	**497**	77565	**619**	73328	**755**	69479	**904**	21
40	93519	**295**	87481	**390**	82193	**499**	77491	**621**	73260	**757**	69418	**907**	20
41	93411	**296**	87387	**392**	82110	**501**	77417	**623**	73193	**759**	69357	**909**	19
42	93304	**298**	87294	**393**	82027	**503**	77343	**625**	73127	**762**	69296	**912**	18
43	93196	**299**	87201	**395**	81945	**504**	77269	**627**	73060	**764**	69235	**914**	17
44	93089	**301**	87107	**397**	81863	**506**	77195	**630**	72993	**766**	69174	**917**	16
45	92982	**302**	87015	**399**	81780	**508**	77122	**632**	72926	**769**	69113	**920**	15
46	92876	**304**	86922	**400**	81698	**510**	77048	**634**	72860	**771**	69053	**922**	14
47	92769	**305**	86829	**402**	81617	**512**	76975	**636**	72794	**774**	68992	**925**	13
48	92663	**307**	86737	**404**	81535	**514**	76902	**638**	72727	**776**	68931	**928**	12
49	92558	**308**	86645	**405**	81453	**516**	76828	**641**	72661	**779**	68871	**930**	11
50	92452	**310**	86553	**407**	81372	**518**	76756	**643**	72595	**781**	68811	**933**	10
51	92347	**311**	86461	**409**	81291	**520**	76683	**645**	72529	**783**	68750	**935**	9
52	92242	**313**	86370	**411**	81210	**522**	76610	**647**	72463	**786**	68690	**938**	8
53	92137	**314**	86278	**412**	81129	**524**	76537	**649**	72397	**788**	68630	**941**	7
54	92032	**316**	86187	**414**	81048	**526**	76465	**652**	72332	**791**	68570	**943**	6
55	91928	**317**	86096	**416**	80967	**528**	76393	**654**	72266	**793**	68510	**946**	5
56	91824	**319**	86006	**418**	80887	**530**	76320	**656**	72201	**796**	68450	**949**	4
57	91720	**320**	85915	**419**	80807	**532**	76248	**658**	72135	**798**	68391	**951**	3
58	91617	**322**	85825	**421**	80727	**534**	76176	**660**	72070	**800**	68331	**954**	2
59	91514	**323**	85734	**423**	80647	**536**	76105	**663**	72005	**803**	68272	**957**	1
60	91411	**325**	85644	**425**	80567	**538**	76033	**665**	71940	**805**	68212	**960**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	173°00′		172°00′		171°00′		170°00′		169°00′		168°00′		

Table 6.—Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	12°00′ A	12°00′ B	13°00′ A	13°00′ B	14°00′ A	14°00′ B	15°00′ A	15°00′ B	16°00′ A	16°00′ B	17°00′ A	17°00′ B	′
0	68212	**960**	64791	**1128**	61632	**1310**	58700	**1506**	55966	**1716**	53406	**1940**	60
1	68153	**962**	64736	**1130**	61582	**1313**	58653	**1509**	55922	**1719**	53365	**1944**	59
2	68093	**965**	64682	**1133**	61531	**1316**	58606	**1512**	55878	**1723**	53324	**1948**	58
3	68034	**968**	64627	**1136**	61481	**1319**	58559	**1516**	55834	**1727**	53283	**1952**	57
4	67975	**970**	64573	**1139**	61430	**1322**	58512	**1519**	55790	**1730**	53241	**1956**	56
5	67916	**973**	64518	**1142**	61380	**1325**	58465	**1523**	55746	**1734**	53200	**1960**	55
6	67857	**976**	64464	**1145**	61330	**1329**	58418	**1526**	55703	**1738**	53159	**1964**	54
7	67798	**978**	64410	**1148**	61279	**1332**	58372	**1529**	55659	**1741**	53118	**1967**	53
8	67739	**981**	64356	**1151**	61229	**1335**	58325	**1533**	55615	**1745**	53077	**1971**	52
9	67681	**984**	64302	**1154**	61179	**1338**	58278	**1536**	55572	**1749**	53036	**1975**	51
10	67622	**987**	64248	**1157**	61129	**1341**	58232	**1540**	55528	**1752**	52995	**1979**	50
11	67563	**989**	64194	**1160**	61079	**1344**	58185	**1543**	55484	**1756**	52954	**1983**	49
12	67505	**992**	64140	**1163**	61029	**1348**	58138	**1546**	55441	**1760**	52914	**1987**	48
13	67447	**995**	64086	**1166**	60970	**1351**	58092	**1550**	55397	**1763**	52873	**1991**	47
14	67388	**997**	64032	**1169**	60929	**1354**	58046	**1553**	55354	**1767**	52832	**1995**	46
15	67330	**1000**	63978	**1172**	60879	**1357**	57999	**1557**	55311	**1771**	52791	**1999**	45
16	67272	**1003**	63925	**1175**	60830	**1360**	57953	**1560**	55267	**1774**	52751	**2003**	44
17	67214	**1006**	63871	**1178**	60780	**1364**	57907	**1564**	55224	**1778**	52710	**2007**	43
18	67156	**1008**	63818	**1181**	60730	**1367**	57860	**1567**	55181	**1782**	52670	**2010**	42
19	67098	**1011**	63764	**1184**	60681	**1370**	57814	**1571**	55138	**1785**	52629	**2014**	41
20	67040	**1014**	63711	**1187**	60631	**1373**	57768	**1574**	55095	**1789**	52588	**2018**	40
21	66982	**1017**	63658	**1190**	60582	**1377**	57722	**1578**	55051	**1793**	52548	**2022**	39
22	66925	**1020**	63605	**1193**	60533	**1380**	57676	**1581**	55008	**1796**	52508	**2026**	38
23	66867	**1022**	63551	**1196**	60483	**1383**	57630	**1584**	54965	**1800**	52467	**2030**	37
24	66810	**1025**	63498	**1199**	60434	**1386**	57584	**1588**	54922	**1804**	52427	**2034**	36
25	66752	**1028**	63445	**1202**	60385	**1390**	57538	**1591**	54880	**1808**	52387	**2038**	35
26	66695	**1031**	63392	**1205**	60336	**1393**	57493	**1595**	54837	**1811**	52346	**2042**	34
27	66638	**1033**	63340	**1208**	60287	**1396**	57447	**1598**	54794	**1815**	52306	**2046**	33
28	66580	**1036**	63287	**1211**	60238	**1399**	57401	**1602**	54751	**1819**	52266	**2050**	32
29	66523	**1039**	63234	**1214**	60189	**1403**	57356	**1605**	54708	**1823**	52226	**2054**	31
30	66466	**1042**	63181	**1217**	60140	**1406**	57310	**1609**	54666	**1826**	52186	**2058**	30
31	66409	**1045**	63129	**1220**	60091	**1409**	57265	**1612**	54623	**1830**	52146	**2062**	29
32	66352	**1047**	63076	**1223**	60042	**1412**	57219	**1616**	54581	**1834**	52106	**2066**	28
33	66296	**1050**	63024	**1226**	59994	**1416**	57174	**1619**	54538	**1837**	52066	**2070**	27
34	66239	**1053**	62971	**1229**	59945	**1419**	57128	**1623**	54496	**1841**	52026	**2074**	26
35	66182	**1056**	62919	**1232**	59896	**1422**	57083	**1627**	54453	**1845**	51986	**2078**	25
36	66126	**1059**	62867	**1235**	59848	**1425**	57038	**1630**	54411	**1849**	51946	**2082**	24
37	66069	**1061**	62815	**1238**	59800	**1429**	56992	**1634**	54368	**1853**	51906	**2086**	23
38	66013	**1064**	62763	**1241**	59751	**1432**	56947	**1637**	54326	**1856**	51867	**2090**	22
39	65957	**1067**	62711	**1244**	59703	**1435**	56902	**1641**	54284	**1860**	51827	**2094**	21
40	65900	**1070**	62659	**1247**	59654	**1439**	56857	**1644**	54242	**1864**	51787	**2098**	20
41	65844	**1073**	62607	**1250**	59606	**1442**	56812	**1648**	54199	**1868**	51747	**2102**	19
42	65788	**1076**	62555	**1253**	59558	**1445**	56767	**1651**	54157	**1871**	51708	**2106**	18
43	65732	**1079**	62503	**1257**	59510	**1449**	56722	**1655**	54115	**1875**	51668	**2110**	17
44	65676	**1081**	62451	**1260**	59462	**1452**	56677	**1658**	54073	**1879**	51629	**2114**	16
45	65620	**1084**	62400	**1263**	59414	**1455**	56632	**1662**	54031	**1883**	51589	**2118**	15
46	65564	**1087**	62348	**1266**	59366	**1459**	56588	**1665**	53989	**1887**	51550	**2122**	14
47	65509	**1090**	62296	**1269**	59318	**1462**	56543	**1669**	53947	**1890**	51510	**2126**	13
48	65453	**1093**	62245	**1272**	59270	**1465**	56498	**1673**	53905	**1894**	51471	**2130**	12
49	65398	**1096**	62194	**1275**	59222	**1469**	56454	**1676**	53864	**1898**	51432	**2134**	11
50	65342	**1099**	62142	**1278**	59175	**1472**	56409	**1680**	53822	**1902**	51392	**2138**	10
51	65287	**1101**	62091	**1281**	59127	**1475**	56365	**1683**	53780	**1906**	51353	**2143**	9
52	65231	**1104**	62040	**1284**	59079	**1479**	56320	**1687**	53738	**1910**	51314	**2147**	8
53	65176	**1107**	61989	**1288**	59032	**1482**	56276	**1691**	53697	**1913**	51275	**2151**	7
54	65121	**1110**	61938	**1291**	58984	**1485**	56231	**1694**	53655	**1917**	51236	**2155**	6
55	65066	**1113**	61887	**1294**	58937	**1489**	56187	**1698**	53614	**1921**	51197	**2159**	5
56	65011	**1116**	61836	**1297**	58889	**1492**	56143	**1701**	53572	**1925**	51158	**2163**	4
57	64956	**1119**	61785	**1300**	58842	**1495**	56099	**1705**	53531	**1929**	51119	**2167**	3
58	64901	**1122**	61734	**1303**	58795	**1499**	56054	**1709**	53489	**1933**	51080	**2171**	2
59	64846	**1125**	61683	**1306**	58748	**1502**	56010	**1712**	53448	**1936**	51041	**2175**	1
60	64791	**1128**	61632	**1310**	58700	**1506**	55966	**1716**	53406	**1940**	51002	**2179**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	167°00′		166°00′		165°00′		164°00′		163°00′		162°00′		

Table 6.—Line of position table

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	18°00′		19°00′		20°00′		21°00′		22°00′		23°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	51002	**2179**	48736	**2433**	46595	**2701**	44567	**2985**	42642	**3283**	40812	**3597**	60
1	50963	**2183**	48699	**2437**	46560	**2706**	44534	**2990**	42611	**3288**	40782	**3603**	59
2	50924	**2188**	48662	**2442**	46525	**2711**	44501	**2994**	42580	**3294**	40753	**3608**	58
3	50885	**2192**	48626	**2446**	46491	**2715**	44468	**2999**	42549	**3299**	40723	**3613**	57
4	50846	**2196**	48589	**2450**	46456	**2720**	44436	**3004**	42518	**3304**	40693	**3619**	56
5	50808	**2200**	48553	**2455**	46422	**2724**	44403	**3009**	42486	**3309**	40664	**3624**	55
6	50769	**2204**	48516	**2459**	46387	**2729**	44370	**3014**	42455	**3314**	40634	**3630**	54
7	50730	**2208**	48480	**2463**	46353	**2734**	44337	**3019**	42424	**3319**	40604	**3635**	53
8	50692	**2212**	48443	**2468**	46318	**2738**	44305	**3024**	42393	**3324**	40575	**3640**	52
9	50653	**2216**	48407	**2472**	46284	**2743**	44272	**3029**	42362	**3329**	40545	**3646**	51
10	50615	**2221**	48371	**2477**	46249	**2748**	44239	**3033**	42331	**3335**	40516	**3651**	50
11	50576	**2225**	48334	**2481**	46215	**2752**	44207	**3038**	42300	**3340**	40486	**3657**	49
12	50538	**2229**	48298	**2485**	46181	**2757**	44174	**3043**	42269	**3345**	40457	**3662**	48
13	50499	**2233**	48262	**2490**	46146	**2761**	44142	**3048**	42238	**3350**	40427	**3667**	47
14	50461	**2237**	48225	**2494**	46112	**2766**	44109	**3053**	42207	**3355**	40398	**3673**	46
15	50423	**2241**	48189	**2499**	46078	**2771**	44077	**3058**	42176	**3360**	40368	**3678**	45
16	50385	**2246**	48153	**2503**	46043	**2775**	44044	**3063**	42145	**3366**	40339	**3684**	44
17	50346	**2250**	48117	**2507**	46009	**2780**	44012	**3068**	42115	**3371**	40310	**3689**	43
18	50308	**2254**	48081	**2512**	45975	**2785**	43979	**3073**	42084	**3376**	40280	**3695**	42
19	50270	**2258**	48045	**2516**	45941	**2789**	43947	**3078**	42053	**3381**	40251	**3700**	41
20	50232	**2262**	48009	**2521**	45907	**2794**	43914	**3083**	42022	**3386**	40222	**3705**	40
21	50194	**2266**	47973	**2525**	45873	**2799**	43882	**3088**	41991	**3391**	40192	**3711**	39
22	50156	**2271**	47937	**2530**	45839	**2804**	43850	**3092**	41961	**3397**	40163	**3716**	38
23	50117	**2275**	47901	**2534**	45805	**2808**	43818	**3097**	41930	**3402**	40134	**3722**	37
24	50080	**2279**	47865	**2539**	45771	**2813**	43785	**3102**	41899	**3407**	40105	**3727**	36
25	50042	**2283**	47829	**2543**	45737	**2818**	43753	**3107**	41869	**3412**	40076	**3733**	35
26	50004	**2287**	47793	**2547**	45703	**2822**	43721	**3112**	41838	**3418**	40046	**3738**	34
27	49966	**2292**	47758	**2552**	45669	**2827**	43689	**3117**	41808	**3423**	40017	**3744**	33
28	49928	**2296**	47722	**2556**	45635	**2832**	43657	**3122**	41777	**3428**	39988	**3749**	32
29	49890	**2300**	47686	**2561**	45601	**2836**	43624	**3127**	41746	**3433**	39959	**3755**	31
30	49852	**2304**	47650	**2565**	45567	**2841**	43592	**3132**	41716	**3438**	39930	**3760**	30
31	49815	**2309**	47615	**2570**	45534	**2846**	43560	**3137**	41685	**3444**	39901	**3766**	29
32	49777	**2313**	47579	**2574**	45500	**2851**	43528	**3142**	41655	**3449**	39872	**3771**	28
33	49739	**2317**	47544	**2579**	45466	**2855**	43496	**3147**	41625	**3454**	39843	**3777**	27
34	49702	**2321**	47508	**2583**	45433	**2860**	43464	**3152**	41594	**3459**	39814	**3782**	26
35	49664	**2325**	47472	**2588**	45399	**2865**	43432	**3157**	41564	**3465**	39785	**3788**	25
36	49626	**2330**	47437	**2592**	45365	**2870**	43400	**3162**	41533	**3470**	39756	**3793**	24
37	49589	**2334**	47402	**2597**	45332	**2874**	43369	**3167**	41503	**3475**	39727	**3799**	23
38	49551	**2338**	47366	**2601**	45298	**2879**	43337	**3172**	41473	**3480**	39698	**3804**	22
39	49514	**2343**	47331	**2606**	45265	**2884**	43305	**3177**	41443	**3486**	39669	**3810**	21
40	49477	**2347**	47295	**2610**	45231	**2889**	43273	**3182**	41412	**3491**	39641	**3815**	20
41	49439	**2351**	47260	**2615**	45198	**2893**	43241	**3187**	41382	**3496**	39612	**3821**	19
42	49402	**2355**	47225	**2619**	45164	**2898**	43210	**3192**	41352	**3502**	39583	**3826**	18
43	49365	**2360**	47189	**2624**	45131	**2903**	43178	**3197**	41322	**3507**	39554	**3832**	17
44	49327	**2364**	47154	**2628**	45097	**2908**	43146	**3202**	41291	**3512**	39525	**3838**	16
45	49290	**2368**	47119	**2633**	45064	**2913**	43114	**3207**	41261	**3517**	39497	**3843**	15
46	49253	**2372**	47084	**2637**	45031	**2917**	43083	**3212**	41231	**3523**	39468	**3849**	14
47	49216	**2377**	47049	**2642**	44997	**2922**	43051	**3217**	41201	**3528**	39439	**3854**	13
48	49179	**2381**	47014	**2646**	44964	**2927**	43020	**3222**	41171	**3533**	39411	**3860**	12
49	49141	**2385**	46978	**2651**	44931	**2932**	42988	**3227**	41141	**3539**	39382	**3865**	11
50	49104	**2390**	46943	**2656**	44898	**2936**	42956	**3233**	41111	**3544**	39353	**3871**	10
51	49067	**2394**	46908	**2660**	44864	**2941**	42925	**3238**	41081	**3549**	39325	**3876**	9
52	49030	**2398**	46873	**2665**	44831	**2946**	42893	**3243**	41051	**3555**	39296	**3882**	8
53	48993	**2403**	46839	**2669**	44798	**2951**	42862	**3248**	41021	**3560**	39268	**3888**	7
54	48957	**2407**	46804	**2674**	44765	**2956**	42830	**3253**	40991	**3565**	39239	**3893**	6
55	48920	**2411**	46769	**2678**	44732	**2961**	42799	**3258**	40961	**3571**	39211	**3899**	5
56	48883	**2416**	46734	**2683**	44699	**2965**	42768	**3263**	40931	**3576**	39182	**3904**	4
57	48846	**2420**	46699	**2688**	44666	**2970**	42736	**3268**	40902	**3581**	39154	**3910**	3
58	48809	**2424**	46664	**2692**	44633	**2975**	42705	**3273**	40872	**3587**	39125	**3916**	2
59	48772	**2429**	46630	**2697**	44600	**2980**	42674	**3278**	40842	**3592**	39097	**3921**	1
60	48736	**2433**	46595	**2701**	44567	**2985**	42642	**3283**	40812	**3597**	39069	**3927**	0
	A	B	A	B	A	B	A	B	A	B	A	B	
′	161°00′		160°00′		159°00′		158°00′		157°00′		156°00′		′

Table 6.—Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	24°00′		25°00′		26°00′		27°00′		28°00′		29°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	39069	**3927**	37405	**4272**	35816	**4634**	34295	**5012**	32839	**5406**	31443	**5818**	60
1	39040	**3932**	37378	**4278**	35790	**4640**	34270	**5018**	32815	**5413**	31420	**5825**	59
2	39012	**3938**	37351	**4284**	35764	**4646**	34246	**5025**	32792	**5420**	31397	**5832**	58
3	38984	**3944**	37324	**4290**	35738	**4651**	34221	**5031**	32768	**5426**	31375	**5839**	57
4	38955	**3949**	37297	**4296**	35712	**4659**	34196	**5038**	32744	**5433**	31352	**5846**	56
5	38927	**3955**	37270	**4302**	35686	**4665**	34172	**5044**	32720	**5440**	31329	**5853**	55
6	38899	**3961**	37243	**4308**	35661	**4671**	34147	**5051**	32697	**5447**	31306	**5860**	54
7	38871	**3966**	37216	**4314**	35635	**4677**	34122	**5057**	32673	**5454**	31284	**5867**	53
8	38842	**3972**	37189	**4320**	35609	**4683**	34097	**5064**	32649	**5460**	31261	**5874**	52
9	38814	**3978**	37162	**4326**	35583	**4690**	34073	**5070**	32625	**5467**	31238	**5881**	51
10	38786	**3983**	37135	**4332**	35558	**4696**	34048	**5076**	32692	**5474**	31216	**5888**	50
11	38758	**3989**	37108	**4337**	35532	**4702**	34024	**5083**	32579	**5481**	31193	**5895**	49
12	38730	**3995**	37081	**4343**	35506	**4708**	33999	**5089**	32555	**5487**	31170	**5902**	48
13	38702	**4000**	37055	**4349**	35481	**4714**	33974	**5096**	32532	**5494**	31148	**5909**	47
14	38674	**4006**	37028	**4355**	35455	**4721**	33950	**5102**	32508	**5501**	31125	**5917**	46
15	38645	**4012**	37001	**4361**	35429	**4727**	33925	**5109**	32484	**5508**	31103	**5924**	45
16	38617	**4017**	36974	**4367**	35404	**4733**	33901	**5115**	32461	**5515**	31080	**5931**	44
17	38589	**4023**	36948	**4373**	35378	**4739**	33876	**5122**	32438	**5521**	31058	**5938**	43
18	38561	**4029**	36921	**4379**	35353	**4746**	33852	**5128**	32414	**5528**	31035	**5945**	42
19	38533	**4035**	36894	**4385**	35327	**4752**	33827	**5135**	32391	**5535**	31013	**5952**	41
20	38506	**4040**	36867	**4391**	35302	**4758**	33803	**5142**	32367	**5542**	30990	**5959**	40
21	38478	**4046**	36841	**4397**	35276	**4764**	33779	**5148**	32344	**5549**	30968	**5966**	39
22	38450	**4052**	36814	**4403**	35251	**4771**	33754	**5155**	32320	**5555**	30945	**5973**	38
23	38422	**4057**	36787	**4409**	35225	**4777**	33730	**5161**	32297	**5562**	30923	**5980**	37
24	38394	**4063**	36761	**4415**	35200	**4783**	33705	**5168**	32274	**5569**	30900	**5988**	36
25	38366	**4069**	36734	**4421**	35174	**4789**	33681	**5174**	32250	**5576**	30878	**5995**	35
26	38338	**4075**	36708	**4427**	35149	**4796**	33657	**5181**	32227	**5583**	30856	**6002**	34
27	38311	**4080**	36681	**4433**	35123	**4802**	33632	**5187**	32204	**5590**	30833	**6009**	33
28	38283	**4086**	36655	**4439**	35098	**4808**	33608	**5194**	32180	**5596**	30811	**6016**	32
29	38255	**4092**	36628	**4445**	35073	**4815**	33584	**5200**	32157	**5603**	30788	**6023**	31
30	38227	**4098**	36602	**4451**	35047	**4821**	33559	**5207**	32134	**5610**	30766	**6030**	30
31	38200	**4103**	36575	**4457**	35022	**4827**	33535	**5214**	32110	**5617**	30744	**6038**	29
32	38172	**4109**	36549	**4463**	34997	**4833**	33511	**5220**	32087	**5624**	30721	**6045**	28
33	38144	**4115**	36522	**4469**	34971	**4840**	33487	**5227**	32064	**5631**	30699	**6052**	27
34	38117	**4121**	36496	**4475**	34946	**4846**	33462	**5233**	32041	**5638**	30677	**6059**	26
35	38089	**4127**	36469	**4481**	34921	**4852**	33438	**5240**	32018	**5645**	30655	**6066**	25
36	38061	**4132**	36443	**4487**	34896	**4859**	33414	**5247**	31994	**5651**	30632	**6073**	24
37	38034	**4138**	36417	**4493**	34870	**4865**	33390	**5253**	31971	**5658**	30610	**6080**	23
38	38006	**4144**	36390	**4499**	34845	**4871**	33366	**5260**	31948	**5665**	30588	**6088**	22
39	37979	**4150**	36364	**4506**	34820	**4878**	33342	**5266**	31925	**5672**	30566	**6095**	21
40	37951	**4155**	36338	**4512**	34795	**4884**	33318	**5273**	31902	**5679**	30544	**6102**	20
41	37924	**4161**	36311	**4518**	34770	**4890**	33293	**5280**	31879	**5686**	30521	**6109**	19
42	37896	**4167**	36285	**4524**	34744	**4897**	33269	**5287**	31856	**5693**	30499	**6116**	18
43	37869	**4173**	36259	**4530**	34719	**4903**	33245	**5293**	31833	**5700**	30477	**6124**	17
44	37841	**4179**	36233	**4536**	34694	**4910**	33221	**5300**	31809	**5707**	30455	**6131**	16
45	37814	**4185**	36206	**4542**	34669	**4916**	33197	**5306**	31786	**5714**	30433	**6138**	15
46	37786	**4190**	36180	**4548**	34644	**4922**	33173	**5313**	31763	**5720**	30411	**6145**	14
47	37759	**4196**	36154	**4554**	34619	**4929**	33149	**5320**	31740	**5727**	30389	**6153**	13
48	37732	**4202**	36128	**4560**	34594	**4935**	33125	**5326**	31717	**5734**	30367	**6160**	12
49	37704	**4208**	36102	**4566**	34569	**4941**	33101	**5333**	31694	**5741**	30345	**6167**	11
50	37677	**4214**	36076	**4573**	34544	**4948**	33077	**5340**	31672	**5748**	30322	**6174**	10
51	37650	**4220**	36050	**4579**	34519	**4954**	33054	**5346**	31648	**5755**	30300	**6181**	9
52	37623	**4225**	36024	**4585**	34494	**4961**	33030	**5353**	31626	**5762**	30278	**6189**	8
53	37595	**4231**	35998	**4591**	34469	**4967**	33006	**5360**	31603	**5769**	30256	**6196**	7
54	37568	**4237**	35972	**4597**	34445	**4973**	32982	**5366**	31580	**5776**	30235	**6203**	6
55	37541	**4243**	35946	**4603**	34420	**4980**	32958	**5373**	31557	**5783**	30213	**6210**	5
56	37514	**4249**	35920	**4609**	34395	**4986**	32934	**5380**	31534	**5790**	30191	**6218**	4
57	37486	**4255**	35894	**4615**	34370	**4993**	32910	**5386**	31511	**5797**	30169	**6225**	3
58	37459	**4261**	35868	**4622**	34345	**4999**	32887	**5393**	31488	**5804**	30147	**6232**	2
59	37432	**4266**	35842	**4628**	34320	**5005**	32863	**5400**	31466	**5811**	30125	**6240**	1
60	37405	**4272**	35816	**4634**	34295	**5012**	32839	**5406**	31443	**5818**	30103	**6247**	0
	A	B	A	B	A	B	A	B	A	B	A	B	
′	155°00′		154°00′		153°00′		152°00′		151°00′		150°00′		′

Table 6.—Line of position table

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	30°00′		31°00′		32°00′		33°00′		34°00′		35°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	30103	**6247**	28816	**6693**	27579	**7158**	26389	**7641**	25244	**8143**	24141	**8663**	60
1	30081	**6254**	28795	**6701**	27559	**7166**	26370	**7649**	25225	**8151**	24123	**8672**	59
2	30059	**6262**	28774	**6709**	27539	**7174**	26350	**7657**	25206	**8160**	24105	**8681**	58
3	30037	**6269**	28753	**6716**	27518	**7182**	26331	**7665**	25188	**8168**	24087	**8690**	57
4	30016	**6276**	28732	**6724**	27498	**7190**	26311	**7674**	25169	**8177**	24069	**8699**	56
5	29994	**6284**	28711	**6731**	27478	**7197**	26292	**7682**	25150	**8185**	24051	**8708**	55
6	29972	**6291**	28690	**6739**	27458	**7205**	26273	**7690**	25132	**8194**	24033	**8717**	54
7	29950	**6298**	28669	**6747**	27438	**7213**	26253	**7698**	25113	**8202**	24015	**8726**	53
8	29928	**6305**	28648	**6754**	27418	**7221**	26234	**7707**	25094	**8211**	23997	**8734**	52
9	29907	**6313**	28627	**6762**	27398	**7229**	26214	**7715**	25076	**8219**	23979	**8743**	51
10	29885	**6320**	28606	**6770**	27377	**7237**	26195	**7723**	25057	**8228**	23961	**8752**	50
11	29863	**6328**	28586	**6777**	27357	**7245**	26176	**7731**	25038	**8237**	23943	**8761**	49
12	29841	**6335**	28565	**6785**	27337	**7253**	26157	**7740**	25020	**8245**	23925	**8770**	48
13	29820	**6342**	28544	**6791**	27317	**7261**	26137	**7748**	25001	**8254**	23907	**8779**	47
14	29798	**6350**	28523	**6800**	27297	**7269**	26118	**7756**	24983	**8262**	23889	**8788**	46
15	29776	**6357**	28502	**6808**	27277	**7277**	26099	**7764**	24964	**8271**	23871	**8797**	45
16	29755	**6364**	28481	**6815**	27257	**7285**	26079	**7773**	24946	**8280**	23854	**8806**	44
17	29733	**6372**	28461	**6823**	27237	**7293**	26060	**7781**	24927	**8288**	23836	**8815**	43
18	29711	**6379**	28440	**6831**	27217	**7301**	26041	**7789**	24909	**8297**	23818	**8824**	42
19	29690	**6386**	28419	**6839**	27197	**7309**	26022	**7798**	24890	**8305**	23800	**8833**	41
20	29668	**6394**	28398	**6846**	27177	**7317**	26002	**7806**	24872	**8314**	23782	**8842**	40
21	29647	**6401**	28378	**6854**	27157	**7325**	25983	**7814**	24853	**8323**	23764	**8850**	39
22	29625	**6409**	28357	**6862**	27137	**7333**	25964	**7823**	24835	**8331**	23747	**8859**	38
23	29604	**6416**	28336	**6869**	27117	**7341**	25945	**7831**	24816	**8340**	23729	**8868**	37
24	29582	**6423**	28315	**6877**	27098	**7349**	25926	**7839**	24798	**8349**	23711	**8877**	36
25	29560	**6431**	28295	**6885**	27078	**7357**	25907	**7848**	24779	**8357**	23693	**8886**	35
26	29539	**6438**	28274	**6893**	27058	**7365**	25887	**7856**	24761	**8366**	23675	**8895**	34
27	29517	**6446**	28253	**6900**	27038	**7373**	25868	**7864**	24742	**8375**	23658	**8904**	33
28	29496	**6453**	28233	**6908**	27018	**7381**	25849	**7873**	24724	**8383**	23640	**8913**	32
29	29475	**6461**	28212	**6916**	26998	**7389**	25830	**7881**	24706	**8392**	23622	**8922**	31
30	29453	**6468**	28191	**6923**	26978	**7397**	25811	**7889**	24687	**8401**	23605	**8931**	30
31	29432	**6475**	28171	**6931**	26958	**7405**	25792	**7898**	24669	**8409**	23587	**8940**	29
32	29410	**6483**	28150	**6939**	26939	**7413**	25773	**7906**	24650	**8418**	23569	**8949**	28
33	29389	**6490**	28130	**6947**	26919	**7421**	25754	**7914**	24632	**8427**	23551	**8958**	27
34	29367	**6498**	28109	**6954**	26899	**7429**	25735	**7923**	24614	**8435**	23534	**8967**	26
35	29346	**6505**	28089	**6962**	26879	**7437**	25716	**7931**	24595	**8444**	23516	**8976**	25
36	29325	**6513**	28068	**6970**	26860	**7445**	25697	**7940**	24577	**8453**	23498	**8986**	24
37	29303	**6520**	28047	**6978**	26840	**7453**	25678	**7948**	24559	**8461**	23481	**8995**	23
38	29282	**6528**	28027	**6985**	26820	**7462**	25659	**7956**	24540	**8470**	23463	**9004**	22
39	29261	**6535**	28006	**6993**	26800	**7470**	25640	**7965**	24522	**8479**	23446	**9013**	21
40	29239	**6543**	27986	**7001**	26781	**7478**	25621	**7973**	24504	**8488**	23428	**9022**	20
41	29218	**6550**	27965	**7009**	26761	**7486**	25602	**7982**	24486	**8496**	23410	**9031**	19
42	29197	**6558**	27945	**7017**	26741	**7494**	25583	**7990**	24467	**8505**	23393	**9040**	18
43	29175	**6565**	27925	**7024**	26722	**7502**	25564	**7998**	24449	**8514**	23375	**9049**	17
44	29154	**6573**	27904	**7032**	26702	**7510**	25545	**8007**	24431	**8523**	23358	**9058**	16
45	29133	**6580**	27884	**7040**	26682	**7518**	25526	**8015**	24413	**8531**	23340	**9067**	15
46	29112	**6588**	27863	**7048**	26663	**7526**	25507	**8024**	24395	**8540**	23323	**9076**	14
47	29091	**6595**	27843	**7056**	26643	**7535**	25488	**8032**	24376	**8549**	23305	**9085**	13
48	29069	**6603**	27823	**7064**	26623	**7543**	25469	**8041**	24358	**8558**	23288	**9094**	12
49	29048	**6610**	27802	**7071**	26604	**7551**	25451	**8049**	24340	**8567**	23270	**9104**	11
50	29027	**6618**	27782	**7079**	26584	**7559**	25432	**8058**	24322	**8575**	23252	**9113**	10
51	29006	**6625**	27761	**7087**	26565	**7567**	25413	**8066**	24304	**8584**	23235	**9122**	9
52	28985	**6633**	27741	**7095**	26545	**7575**	25394	**8075**	24286	**8593**	23218	**9131**	8
53	28964	**6640**	27721	**7103**	26526	**7484**	25375	**8083**	24267	**8602**	23200	**9140**	7
54	28942	**6648**	27701	**7111**	26506	**7592**	25356	**8091**	24249	**8611**	23183	**9149**	6
55	28921	**6655**	27680	**7118**	26486	**7600**	25338	**8100**	24231	**8619**	23165	**9158**	5
56	28900	**6663**	27660	**7126**	26467	**7608**	25319	**8108**	24213	**8628**	23148	**9168**	4
57	28879	**6671**	27640	**7134**	26447	**7616**	25300	**8117**	24195	**8637**	23130	**9177**	3
58	28858	**6678**	27619	**7142**	26428	**7625**	25281	**8125**	24177	**8646**	23113	**9186**	2
59	28837	**6686**	27599	**7150**	26409	**7633**	25263	**8134**	24159	**8655**	23095	**9195**	1
60	28816	**6693**	27579	**7158**	26389	**7641**	25244	**8143**	24141	**8663**	23078	**9204**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	149°00′		148°00′		147°00′		146°00′		145°00′		144°00′		

Table 6.—Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	36°00′ A	36°00′ B	37°00′ A	37°00′ B	38°00′ A	38°00′ B	39°00′ A	39°00′ B	40°00′ A	40°00′ B	41°00′ A	41°00′ B	′
0	23078	**9204**	22054	**9765**	21066	**10347**	20113	**10950**	19193	**11575**	18306	**12222**	60
1	23061	**9213**	22037	**9775**	21050	**10357**	20097	**10960**	19178	**11585**	18291	**12233**	59
2	23043	**9223**	22020	**9784**	21033	**10367**	20082	**10971**	19163	**11596**	18277	**12244**	58
3	23026	**9232**	22003	**9794**	21017	**10376**	20066	**10981**	19148	**11606**	18262	**12255**	57
4	23009	**9241**	21987	**9803**	21001	**10386**	20050	**10991**	19133	**11617**	18248	**12266**	56
5	22991	**9250**	21970	**9813**	20985	**10396**	20035	**11001**	19118	**11628**	18233	**12277**	55
6	22974	**9259**	21953	**9822**	20969	**10406**	20019	**11011**	19103	**11638**	18219	**12288**	54
7	22957	**9269**	21937	**9832**	20953	**10416**	20004	**11021**	19088	**11649**	18204	**12299**	53
8	22939	**9278**	21920	**9843**	20937	**10426**	19988	**11032**	19073	**11660**	18190	**12310**	52
9	22922	**9287**	21903	**9851**	20921	**10436**	19973	**11042**	19058	**11670**	18175	**12321**	51
10	22905	**9296**	21887	**9861**	20905	**10446**	19957	**11052**	19043	**11681**	18161	**12332**	50
11	22887	**9305**	21870	**9870**	20888	**10456**	19942	**11063**	19028	**11692**	18146	**12343**	49
12	22870	**9315**	21853	**9880**	20872	**10466**	19926	**11073**	19013	**11702**	18132	**12354**	48
13	22853	**9324**	21837	**9889**	20856	**10476**	19911	**11083**	18998	**11713**	18117	**12365**	47
14	22836	**9333**	21820	**9899**	20840	**10486**	19895	**11094**	18983	**11724**	18103	**12376**	46
15	22818	**9342**	21803	**9909**	20824	**10496**	19880	**11104**	18968	**11734**	18089	**12387**	45
16	22801	**9352**	21787	**9918**	20808	**10505**	19864	**11114**	18953	**11745**	18074	**12398**	44
17	22784	**9361**	21770	**9928**	20792	**10515**	19849	**11124**	18939	**11756**	18060	**12410**	43
18	22767	**9370**	21754	**9937**	20776	**10525**	19834	**11135**	18924	**11766**	18045	**12421**	42
19	22750	**9380**	21737	**9947**	20760	**10535**	19818	**11145**	18909	**11777**	18031	**12432**	41
20	22732	**9389**	21720	**9957**	20744	**10545**	19803	**11156**	18894	**11788**	18017	**12443**	40
21	22715	**9398**	21704	**9966**	20728	**10555**	19787	**11166**	18879	**11799**	18002	**12454**	39
22	22698	**9407**	21687	**9976**	20712	**10565**	19772	**11176**	18864	**11809**	17988	**12465**	38
23	22681	**9417**	21671	**9986**	20696	**10575**	19756	**11187**	18849	**11820**	17974	**12476**	37
24	22664	**9426**	21654	**9995**	20680	**10585**	19741	**11197**	18834	**11831**	17959	**12487**	36
25	22647	**9435**	21638	**10005**	20665	**10595**	19726	**11207**	18820	**11842**	17945	**12499**	35
26	22630	**9445**	21621	**10015**	20649	**10605**	19710	**11218**	18805	**11852**	17931	**12510**	34
27	22612	**9454**	21605	**10024**	20633	**10615**	19695	**11228**	18790	**11863**	17916	**12521**	33
28	22595	**9463**	21588	**10034**	20617	**10625**	19680	**11239**	18775	**11874**	17902	**12532**	32
29	22578	**9473**	21572	**10044**	20601	**10635**	19664	**11249**	18760	**11885**	17888	**12543**	31
30	22561	**9482**	21555	**10053**	20585	**10646**	19649	**11259**	18746	**11895**	17873	**12554**	30
31	22544	**9492**	21539	**10063**	20569	**10656**	19634	**11270**	18731	**11906**	17859	**12566**	29
32	22527	**9501**	21522	**10073**	20553	**10666**	19618	**11280**	18716	**11917**	17845	**12577**	28
33	22510	**9510**	21506	**10082**	20537	**10676**	19603	**11291**	18701	**11928**	17831	**12588**	27
34	22493	**9520**	21489	**10092**	20522	**10686**	19588	**11301**	18686	**11939**	17816	**12599**	26
35	22476	**9529**	21473	**10102**	20506	**10696**	19572	**11311**	18672	**11949**	17802	**12610**	25
36	22459	**9538**	21457	**10112**	20490	**10706**	19557	**11322**	18657	**11960**	17788	**12622**	24
37	22442	**9548**	21440	**10121**	20474	**10716**	19541	**11332**	18642	**11971**	17774	**12633**	23
38	22425	**9557**	21424	**10131**	20458	**10726**	19527	**11343**	18627	**11982**	17760	**12644**	22
39	22408	**9566**	21407	**10141**	20442	**10736**	19511	**11353**	18613	**11993**	17745	**12655**	21
40	22391	**9576**	21391	**10151**	20427	**10746**	19496	**11364**	18598	**12004**	17731	**12667**	20
41	22374	**9585**	21375	**10160**	20411	**10756**	19481	**11374**	18583	**12014**	17717	**12678**	19
42	22357	**9595**	21358	**10170**	20395	**10767**	19466	**11385**	18569	**12025**	17703	**12689**	18
43	22340	**9604**	21342	**10180**	20379	**10777**	19450	**11395**	18554	**12036**	17689	**12700**	17
44	22323	**9614**	21326	**10190**	20364	**10787**	19435	**11406**	18539	**12047**	17674	**12711**	16
45	22306	**9623**	21309	**10199**	20348	**10797**	19420	**11416**	18525	**12058**	17660	**12723**	15
46	22289	**9632**	21293	**10209**	20332	**10807**	19405	**11427**	18510	**12069**	17646	**12734**	14
47	22272	**9642**	21277	**10219**	20316	**10817**	19390	**11437**	18495	**12080**	17632	**12745**	13
48	22256	**9651**	21260	**10229**	20301	**10827**	19375	**11448**	18481	**12091**	17618	**12757**	12
49	22239	**9661**	21244	**10239**	20285	**10838**	19359	**11458**	18466	**12102**	17604	**12768**	11
50	22222	**9670**	21228	**10248**	20269	**10848**	19344	**11469**	18451	**12112**	17590	**12779**	10
51	22205	**9680**	21212	**10258**	20254	**10858**	19329	**11479**	18437	**12123**	17575	**12790**	9
52	22188	**9689**	21195	**10268**	20238	**10868**	19314	**11490**	18422	**12134**	17561	**12802**	8
53	22171	**9699**	21179	**10278**	20222	**10878**	19299	**11501**	18408	**12145**	17547	**12813**	7
54	22154	**9708**	21163	**10288**	20207	**10888**	19284	**11511**	18393	**12156**	17533	**12824**	6
55	22138	**9718**	21147	**10298**	20191	**10899**	19269	**11522**	18378	**12167**	17519	**12836**	5
56	22121	**9727**	21131	**10307**	20175	**10909**	19253	**11532**	18364	**12178**	17505	**12847**	4
57	22104	**9737**	21114	**10317**	20160	**10919**	19238	**11543**	18349	**12189**	17491	**12859**	3
58	22087	**9746**	21098	**10327**	20144	**10929**	19223	**11553**	18335	**12200**	17477	**12870**	2
59	22070	**9756**	21082	**10337**	20128	**10939**	19208	**11564**	18320	**12211**	17463	**12881**	1
60	22054	**9765**	21066	**10347**	20113	**10950**	19193	**11575**	18306	**12222**	17449	**12893**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	143°00′		142°00′		141°00′		140°00′		139°00′		138°00′		

Table 6.—Line of position table

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	42°00′		43°00′		44°00′		45°00′		46°00′		47°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	17449	12893	16622	13587	15823	14307	15051	15051	14307	15823	13587	16622	60
1	17435	12904	16608	13599	15810	14319	15039	15064	14294	15836	13575	16635	59
2	17421	12915	16595	13611	15797	14331	15026	15077	14282	15849	13564	16649	58
3	17407	12927	16581	13623	15784	14343	15014	15089	14270	15862	13552	16662	57
4	17393	12938	16567	13634	15771	14355	15001	15102	14258	15875	13540	16676	56
5	17379	12950	16554	13646	15758	14368	14988	15115	14246	15888	13528	16689	55
6	17365	12961	16540	13658	15744	14380	14976	15127	14233	15901	13517	16703	54
7	17351	12972	16527	13670	15731	14392	14963	15140	14221	15915	13505	16717	53
8	17337	12984	16513	13682	15718	14404	14951	15153	14209	15928	13493	16730	52
9	17323	12995	16500	13694	15705	14417	14938	15165	14197	15941	13481	16744	51
10	17309	13007	16487	13705	15692	14429	14925	15178	14185	15954	13470	16757	50
11	17295	13018	16473	13717	15679	14441	14913	15191	14173	15967	13458	16771	49
12	17281	13030	16460	13729	15666	14453	14900	15204	14161	15980	13446	16785	48
13	17267	13041	16446	13741	15653	14466	14888	15216	14149	15994	13435	16798	47
14	17253	13053	16433	13753	15640	14478	14875	15229	14136	16007	13423	16812	46
15	17239	13064	16419	13765	15627	14490	14863	15242	14124	16020	13411	16826	45
16	17225	13075	16406	13777	15614	14503	14850	15255	14112	16033	13400	16839	44
17	17212	13087	16392	13789	15602	14515	14838	15267	14100	16046	13388	16853	43
18	17198	13098	16379	13800	15589	14527	14825	15280	14088	16060	13376	16867	42
19	17184	13110	16366	13812	15576	14540	14813	15293	14076	16073	13365	16880	41
20	17170	13121	16352	13824	15563	14552	14800	15306	14064	16086	13353	16894	40
21	17156	13133	16339	13836	15550	14564	14788	15318	14052	16099	13341	16908	39
22	17142	13144	16325	13848	15537	14577	14775	15331	14040	16112	13330	16922	38
23	17128	13156	16312	13860	15524	14589	14763	15344	14028	16126	13318	16935	37
24	17114	13168	16299	13872	15511	14601	14750	15357	14016	16139	13306	16949	36
25	17101	13179	16285	13884	15498	14614	14738	15370	14004	16152	13295	16963	35
26	17087	13191	16272	13896	15485	14626	14725	15382	13992	16166	13283	16977	34
27	17073	13202	16259	13908	15472	14639	14713	15395	13980	16179	13272	16990	33
28	17059	13214	16245	13920	15459	14651	14701	15408	13968	16192	13260	17004	32
29	17046	13225	16232	13932	15447	14663	14688	15421	13956	16205	13248	17018	31
30	17032	13237	16219	13944	15434	14676	14676	15434	13944	16219	13237	17032	30
31	17018	13248	16205	13956	15421	14688	14663	15447	13932	16232	13225	17045	29
32	17004	13260	16192	13968	15408	14701	14651	15459	13920	16245	13214	17059	28
33	16990	13272	16179	13980	15395	14713	14639	15472	13908	16259	13202	17073	27
34	16977	13283	16166	13992	15382	14726	14626	15485	13896	16272	13191	17087	26
35	16963	13295	16152	14004	15370	14738	14614	15498	13884	16285	13179	17101	25
36	16949	13306	16139	14016	15357	14750	14601	15511	13872	16299	13168	17114	24
37	16935	13318	16126	14028	15344	14763	14589	15524	13860	16312	13156	17128	23
38	16922	13330	16112	14040	15331	14775	14577	15537	13848	16325	13144	17142	22
39	16908	13341	16099	14052	15318	14788	14564	15550	13836	16339	13133	17156	21
40	16894	13353	16086	14064	15306	14800	14552	15563	13824	16352	13121	17170	20
41	16880	13365	16073	14076	15293	14813	14540	15576	13812	16366	13110	17184	19
42	16867	13376	16060	14088	15280	14825	14527	15589	13800	16379	13098	17198	18
43	16853	13388	16046	14100	15267	14838	14515	15602	13788	16392	13087	17212	17
44	16839	13400	16033	14112	15255	14850	14503	15614	13777	16406	13075	17225	16
45	16826	13411	16020	14124	15242	14863	14490	15627	13765	16419	13064	17239	15
46	16812	13423	16007	14136	15229	14875	14478	15640	13753	16433	13053	17253	14
47	16798	13435	15994	14149	15216	14888	14466	15653	13741	16446	13041	17267	13
48	16785	13446	15980	14161	15204	14900	14453	15666	13729	16460	13030	17281	12
49	16771	13458	15967	14173	15191	14913	14441	15679	13717	16473	13018	17295	11
50	16757	13470	15954	14185	15178	14925	14429	15692	13705	16487	13007	17309	10
51	16744	13481	15941	14197	15165	14938	14417	15705	13694	16500	12995	17323	9
52	16730	13493	15928	14209	15153	14951	14404	15718	13682	16513	12984	17337	8
53	16717	13505	15915	14221	15140	14963	14392	15731	13670	16527	12972	17351	7
54	16703	13517	15901	14233	15127	14976	14380	15744	13658	16540	12961	17365	6
55	16689	13528	15888	14246	15115	14988	14368	15758	13646	16554	12950	17379	5
56	16676	13540	15875	14258	15102	15001	14355	15771	13634	16567	12938	17393	4
57	16662	13552	15862	14270	15089	15014	14343	15784	13623	16581	12927	17407	3
58	16649	13564	15849	14282	15077	15026	14331	15797	13611	16595	12915	17421	2
59	16635	13575	15836	14294	15064	15039	14319	15810	13599	16608	12904	17435	1
60	16622	13587	15823	14307	15051	15051	14307	15823	13587	16622	12893	17449	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	137°00′		136°00′		135°00′		134°00′		133°00′		132°00′		

Table 6.—Line of position table

WHEN LHA (E OR W) IS <u>GREATER</u> THAN 90°, TAKE "K" FROM <u>BOTTOM</u> OF TABLE

′	48°00′		49°00′		50°00′		51°00′		52°00′		53°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	12893	17449	12222	18306	11575	19193	10950	20113	10347	21066	9765	22054	60
1	12881	17463	12211	18320	11564	19208	10939	20128	10337	21082	9756	22070	59
2	12870	17477	12200	18335	11553	19223	10929	20144	10327	21098	9746	22087	58
3	12859	17491	12189	18349	11543	19238	10919	20160	10317	21114	9737	22104	57
4	12847	17505	12178	18364	11532	19253	10909	20175	10307	21131	9727	22121	56
5	12836	17519	12167	18378	11522	19269	10899	20191	10298	21147	9718	22138	55
6	12824	17533	12156	18393	11511	19284	10888	20207	10288	21163	9708	22154	54
7	12813	17547	12145	18408	11501	19299	10878	20222	10278	21179	9699	22171	53
8	12802	17561	12134	18422	11490	19314	10868	20238	10268	21195	9689	22188	52
9	12790	17576	12123	18437	11479	19329	10858	20254	10258	21212	9680	22205	51
10	12779	17590	12112	18451	11469	19344	10848	20269	10248	21228	9670	22222	50
11	12768	17604	12102	18466	11458	19359	10838	20285	10239	21244	9661	22239	49
12	12757	17618	12091	18481	11448	19375	10827	20301	10229	21260	9651	22256	48
13	12745	17632	12080	18495	11437	19390	10817	20316	10219	21277	9642	22272	47
14	12734	17646	12069	18510	11427	19405	10807	20332	10209	21293	9632	22289	46
15	12723	17660	12058	18525	11416	19420	10797	20348	10199	21309	9623	22306	45
16	12711	17674	12047	18539	11406	19435	10787	20364	10190	21326	9614	22323	44
17	12700	17689	12036	18554	11395	19450	10777	20379	10180	21342	9604	22340	43
18	12689	17703	12025	18569	11385	19466	10767	20395	10170	21358	9595	22357	42
19	12678	17717	12014	18583	11374	19481	10756	20411	10160	21375	9585	22374	41
20	12666	17731	12004	18598	11364	19496	10746	20427	10151	21391	9576	22391	40
21	12655	17745	11993	18613	11353	19511	10736	20442	10141	21407	9566	22408	39
22	12644	17760	11982	18627	11343	19527	10726	20458	10131	21424	9557	22425	38
23	12633	17774	11971	18642	11332	19542	10716	20474	10121	21440	9548	22442	37
24	12622	17788	11960	18657	11322	19557	10706	20490	10112	21457	9538	22459	36
25	12610	17802	11949	18672	11311	19572	10696	20506	10102	21473	9529	22476	35
26	12599	17816	11939	18686	11301	19588	10686	20522	10092	21489	9520	22493	34
27	12588	17831	11928	18701	11291	19603	10676	20537	10082	21506	9510	22510	33
28	12577	17845	11917	18716	11280	19618	10666	20553	10073	21522	9501	22527	32
29	12566	17859	11906	18731	11270	19634	10656	20569	10063	21539	9491	22544	31
30	12554	17873	11895	18746	11259	19649	10646	20585	10053	21555	9482	22561	30
31	12543	17888	11885	18760	11249	19664	10635	20601	10044	21572	9473	22578	29
32	12532	17902	11874	18775	11239	19680	10625	20617	10034	21588	9463	22595	28
33	12521	17916	11863	18790	11228	19695	10615	20633	10024	21605	9454	22612	27
34	12510	17931	11852	18805	11218	19710	10605	20649	10015	21621	9445	22630	26
35	12499	17945	11842	18820	11207	19726	10595	20665	10005	21638	9435	22647	25
36	12487	17959	11831	18834	11197	19741	10585	20680	9995	21654	9426	22664	24
37	12476	17974	11820	18849	11187	19756	10575	20696	9986	21671	9417	22681	23
38	12465	17988	11809	18864	11176	19772	10565	20712	9976	21687	9407	22698	22
39	12454	18002	11799	18879	11166	19787	10555	20728	9966	21704	9398	22715	21
40	12443	18017	11788	18894	11156	19803	10545	20744	9957	21720	9389	22732	20
41	12432	18031	11777	18909	11145	19818	10535	20760	9947	21737	9380	22750	19
42	12421	18045	11766	18924	11135	19834	10525	20776	9937	21754	9370	22767	18
43	12410	18060	11756	18939	11124	19849	10515	20792	9928	21770	9361	22784	17
44	12398	18074	11745	18953	11114	19864	10505	20808	9918	21787	9352	22801	16
45	12387	18089	11734	18968	11104	19880	10496	20824	9909	21803	9342	22818	15
46	12376	18103	11724	18983	11094	19895	10486	20840	9899	21820	9333	22836	14
47	12365	18117	11713	18998	11083	19911	10476	20856	9889	21837	9324	22853	13
48	12354	18132	11702	19013	11073	19926	10466	20872	9880	21853	9315	22870	12
49	12343	18146	11692	19028	11063	19942	10456	20888	9870	21870	9305	22887	11
50	12332	18161	11681	19043	11052	19957	10446	20905	9861	21887	9296	22905	10
51	12321	18175	11670	19058	11042	19973	10436	20921	9851	21903	9287	22922	9
52	12310	18190	11660	19073	11032	19988	10426	20937	9841	21920	9278	22939	8
53	12299	18204	11649	19088	11021	20004	10416	20953	9832	21937	9269	22957	7
54	12288	18219	11638	19103	11011	20019	10406	20969	9822	21953	9259	22974	6
55	12277	18233	11628	19118	11001	20035	10396	20985	9813	21970	9250	22991	5
56	12266	18248	11617	19133	10991	20050	10386	21001	9803	21987	9241	23009	4
57	12255	18262	11606	19148	10980	20066	10376	21017	9794	22003	9232	23026	3
58	12244	18277	11596	19163	10970	20082	10367	21033	9784	22020	9223	23043	2
59	12233	18291	11585	19178	10960	20097	10357	21050	9775	22037	9213	23061	1
60	12222	18306	11575	19193	10950	20113	10347	21066	9765	22054	9204	23078	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	131°00′		130°00′		129°00′		128°00′		127°00′		126°00′		

Table 6.—Line of position table

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	54°00′		55°00′		56°00′		57°00′		58°00′		59°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	9204	**23078**	8663	**24141**	8143	**25244**	7641	**26389**	7158	**27579**	6693	**28816**	60
1	9195	**23095**	8655	**24159**	8134	**25263**	7633	**26409**	7150	**27599**	6686	**22837**	59
2	9186	**23113**	8646	**24177**	8125	**25281**	7624	**26428**	7142	**27619**	6678	**28858**	58
3	9177	**23130**	8637	**24195**	8117	**25300**	7616	**26447**	7134	**27640**	6671	**28879**	57
4	9168	**23148**	8628	**24213**	8108	**25319**	7608	**26467**	7126	**27660**	6663	**28900**	56
5	9158	**23165**	8619	**24231**	8100	**25338**	7600	**26486**	7118	**27680**	6655	**28921**	55
6	9149	**23183**	8611	**24249**	8092	**25356**	7592	**26506**	7111	**27701**	6648	**28942**	54
7	9140	**23200**	8602	**24267**	8083	**25375**	7584	**26526**	7103	**27721**	6640	**28964**	53
8	9131	**23218**	8593	**24286**	8075	**25394**	7575	**26545**	7095	**27741**	6633	**28985**	52
9	9122	**23235**	8584	**24304**	8066	**25413**	7567	**26565**	7087	**27761**	6625	**29006**	51
10	9113	**23252**	8575	**24322**	8058	**25432**	7559	**26584**	7079	**27782**	6618	**29027**	50
11	9104	**23270**	8567	**24340**	8049	**25451**	7551	**26604**	7071	**27802**	6610	**29048**	49
12	9094	**23288**	8558	**24358**	8041	**25469**	7543	**26623**	7064	**27823**	6603	**29069**	48
13	9085	**23305**	8549	**24376**	8032	**25488**	7535	**26643**	7056	**27843**	6595	**29091**	47
14	9076	**23323**	8540	**24395**	8024	**25507**	7526	**26663**	7048	**27863**	6588	**29112**	46
15	9067	**23340**	8531	**24413**	8015	**25526**	7518	**26682**	7040	**27884**	6580	**29133**	45
16	9058	**23358**	8523	**24431**	8007	**25545**	7510	**26702**	7032	**27904**	6573	**29154**	44
17	9049	**23375**	8514	**24449**	7998	**25564**	7502	**26722**	7024	**27925**	6565	**29175**	43
18	9040	**23393**	8505	**24467**	7990	**25583**	7494	**26741**	7017	**27945**	6558	**29197**	42
19	9031	**23410**	8496	**24486**	7982	**25602**	7486	**26761**	7009	**27965**	6550	**29218**	41
20	9022	**23428**	8488	**24504**	7973	**25621**	7478	**26781**	7001	**27986**	6543	**29239**	40
21	9013	**23446**	8479	**24522**	7965	**25640**	7470	**26800**	6993	**28006**	6535	**29261**	39
22	9004	**23463**	8470	**24540**	7956	**25659**	7462	**26820**	6985	**28027**	6528	**29282**	38
23	8995	**23481**	8461	**24559**	7948	**25678**	7453	**26840**	6978	**28047**	6520	**29303**	37
24	8985	**23498**	8453	**24577**	7940	**25697**	7445	**26860**	6970	**28068**	6513	**29325**	36
25	8976	**23516**	8444	**24595**	7931	**25716**	7437	**26879**	6962	**28089**	6505	**29346**	35
26	8967	**23534**	8435	**24614**	7923	**25735**	7429	**26899**	6954	**28109**	6498	**29367**	34
27	8958	**23551**	8427	**24632**	7914	**25754**	7421	**26919**	6947	**28130**	6490	**29389**	33
28	8949	**23569**	8418	**24650**	7906	**25773**	7413	**26939**	6939	**28150**	6483	**29410**	32
29	8940	**23587**	8409	**24669**	7898	**25792**	7405	**26958**	6931	**28171**	6475	**29432**	31
30	8931	**23605**	8401	**24687**	7889	**25811**	7397	**26978**	6923	**28191**	6468	**29453**	30
31	8922	**23622**	8392	**24706**	7881	**25830**	7389	**26998**	6916	**28212**	6460	**29475**	29
32	8913	**23640**	8383	**24724**	7873	**25849**	7381	**27018**	6908	**28233**	6453	**29496**	28
33	8904	**23658**	8375	**24742**	7864	**25868**	7373	**27038**	6900	**28253**	6446	**29517**	27
34	8895	**23675**	8366	**24761**	7856	**25887**	7365	**27058**	6892	**28274**	6438	**29539**	26
35	8886	**23693**	8357	**24779**	7848	**25907**	7357	**27078**	6885	**28295**	6431	**29560**	25
36	8877	**23711**	8349	**24798**	7839	**25926**	7349	**27098**	6877	**28315**	6423	**29582**	24
37	8868	**23729**	8340	**24816**	7831	**25945**	7341	**27117**	6869	**28336**	6416	**29604**	23
38	8859	**23747**	8331	**24835**	7823	**25964**	7333	**27137**	6862	**28357**	6409	**29625**	22
39	8850	**23764**	8323	**24853**	7814	**25983**	7325	**27157**	6854	**28378**	6401	**29647**	21
40	8842	**23782**	8314	**24872**	7806	**26002**	7317	**27177**	6846	**28398**	6394	**29668**	20
41	8833	**23800**	8305	**24890**	7798	**26022**	7309	**27197**	6839	**28419**	6386	**29690**	19
42	8824	**23818**	8297	**24909**	7789	**26041**	7301	**27217**	6831	**28440**	6379	**29711**	18
43	8815	**23836**	8288	**24927**	7781	**26060**	7293	**27237**	6823	**28461**	6372	**29733**	17
44	8806	**23854**	8280	**24946**	7773	**26079**	7285	**27257**	6815	**28481**	6364	**29755**	16
45	8797	**23871**	8271	**24964**	7764	**26099**	7277	**27277**	6808	**28502**	6357	**29776**	15
46	8788	**23889**	8262	**24983**	7756	**26118**	7269	**27297**	6800	**28523**	6349	**29798**	14
47	8779	**23907**	8254	**25001**	7748	**26137**	7261	**27317**	6792	**28544**	6342	**29820**	13
48	8770	**23925**	8245	**25020**	7740	**26157**	7253	**27337**	6785	**28565**	6335	**29841**	12
49	8761	**23943**	8237	**25038**	7731	**26176**	7245	**27357**	6777	**28586**	6327	**29863**	11
50	8752	**23961**	8228	**25057**	7723	**26195**	7237	**27377**	6770	**28607**	6320	**29885**	10
51	8743	**23979**	8219	**25076**	7715	**26214**	7229	**27398**	6762	**28627**	6313	**29907**	9
52	8734	**23997**	8211	**25094**	7707	**26234**	7221	**27418**	6754	**28648**	6305	**29929**	8
53	8726	**24015**	8202	**25113**	7698	**26253**	7213	**27438**	6747	**28669**	6298	**29950**	7
54	8717	**24033**	8194	**25132**	7690	**26273**	7205	**27458**	6739	**28690**	6291	**29972**	6
55	8708	**24051**	8185	**25150**	7682	**26292**	7197	**27478**	6731	**28711**	6283	**29994**	5
56	8699	**24069**	8177	**25169**	7674	**26311**	7190	**27498**	6724	**28732**	6276	**30015**	4
57	8690	**24087**	8168	**25188**	7665	**26331**	7182	**27518**	6716	**28753**	6269	**30037**	3
58	8681	**24105**	8160	**25206**	7657	**26350**	7174	**27539**	6709	**28774**	6261	**30059**	2
59	8672	**24123**	8151	**25225**	7649	**26370**	7166	**27559**	6701	**28795**	6254	**30081**	1
60	8663	**24141**	8143	**25244**	7641	**26389**	7158	**27579**	6693	**28816**	6247	**30103**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	125°00′		124°00′		123°00′		122°00′		121°00′		120°00′		

Table 6.—Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	60°00′		61°00′		62°00′		63°00′		64°00′		65°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	6247	**30103**	5818	**31443**	5406	**32839**	5012	**34295**	4634	**35816**	4272	**37405**	60
1	6240	**30125**	5811	**31466**	5400	**32863**	5005	**34320**	4628	**35842**	4266	**37432**	59
2	6232	**30147**	5804	**31488**	5393	**32887**	4999	**34345**	4622	**35868**	4261	**37459**	58
3	6225	**30169**	5797	**31511**	5386	**32910**	4993	**34370**	4615	**35894**	4255	**37487**	57
4	6218	**30191**	5790	**31534**	5380	**32934**	4986	**34395**	4609	**35920**	4249	**37514**	56
5	6210	**30213**	5783	**31557**	5373	**32958**	4980	**34420**	4603	**35946**	4243	**37541**	55
6	6203	**30235**	5776	**31580**	5366	**32982**	4973	**34444**	4597	**35972**	4237	**37568**	54
7	6196	**30256**	5769	**31603**	5360	**33006**	4967	**34469**	4591	**35998**	4231	**37595**	53
8	6189	**30278**	5762	**31626**	5353	**33030**	4961	**34494**	4585	**36024**	4225	**37623**	52
9	6181	**30300**	5755	**31649**	5346	**33054**	4954	**34519**	4579	**36050**	4220	**37650**	51
10	6174	**30322**	5748	**31672**	5340	**33077**	4948	**34544**	4573	**36076**	4214	**37677**	50
11	6167	**30345**	5741	**31694**	5333	**33101**	4941	**34569**	4566	**36102**	4208	**37704**	49
12	6160	**30367**	5734	**31717**	5326	**33125**	4935	**34594**	4560	**36128**	4202	**37732**	48
13	6152	**30389**	5727	**31740**	5320	**33149**	4929	**34619**	4554	**36154**	4196	**37759**	47
14	6145	**30411**	5720	**31763**	5313	**33173**	4922	**34644**	4548	**36180**	4190	**37786**	46
15	6138	**30433**	5714	**31786**	5306	**33197**	4916	**34669**	4542	**36206**	4185	**37814**	45
16	6131	**30455**	5707	**31809**	5300	**33221**	4910	**34694**	4536	**36233**	4179	**37841**	44
17	6124	**30477**	5700	**31833**	5293	**33245**	4903	**34719**	4530	**36259**	4173	**37869**	43
18	6116	**30499**	5693	**31856**	5286	**33269**	4897	**34744**	4524	**36285**	4167	**37896**	42
19	6109	**30521**	5686	**31879**	5280	**33293**	4890	**34770**	4518	**36311**	4161	**37924**	41
20	6102	**30544**	5679	**31902**	5273	**33318**	4884	**34795**	4512	**36338**	4155	**37951**	40
21	6095	**30566**	5672	**31925**	5266	**33342**	4878	**34820**	4506	**36364**	4150	**37979**	39
22	6088	**30588**	5665	**31948**	5260	**33366**	4871	**34845**	4500	**36390**	4144	**38006**	38
23	6080	**30610**	5658	**31971**	5253	**33390**	4865	**34870**	4493	**36417**	4138	**38034**	37
24	6073	**30632**	5651	**31994**	5247	**33414**	4859	**34896**	4487	**36443**	4132	**38061**	36
25	6066	**30655**	5644	**32018**	5240	**33438**	4852	**34921**	4481	**36469**	4127	**38089**	35
26	6059	**30677**	5638	**32041**	5233	**33462**	4846	**34946**	4475	**36496**	4121	**38117**	34
27	6052	**30699**	5631	**32064**	5227	**33487**	4840	**34971**	4469	**36522**	4115	**38144**	33
28	6045	**30721**	5624	**32087**	5220	**33511**	4833	**34997**	4463	**36549**	4109	**38172**	32
29	6037	**30744**	5617	**32110**	5214	**33535**	4827	**35022**	4457	**36575**	4103	**38200**	31
30	6030	**30766**	5610	**32134**	5207	**33559**	4821	**35047**	4451	**36602**	4098	**38227**	30
31	6023	**30788**	5603	**32157**	5200	**33584**	4815	**35073**	4445	**36628**	4092	**38255**	29
32	6016	**30811**	5596	**32180**	5194	**33608**	4808	**35098**	4439	**36655**	4086	**38283**	28
33	6009	**30833**	5590	**32204**	5187	**33632**	4802	**35123**	4433	**36681**	4080	**38311**	27
34	6002	**30856**	5583	**32227**	5181	**33657**	4796	**35149**	4427	**36708**	4075	**38338**	26
35	5995	**30878**	5575	**32250**	5174	**33681**	4789	**35174**	4421	**36734**	4069	**38366**	25
36	5987	**30900**	5569	**32274**	5168	**33705**	4783	**35200**	4415	**36761**	4063	**38394**	24
37	5980	**30923**	5562	**32297**	5161	**33730**	4777	**35225**	4409	**36787**	4057	**38422**	23
38	5973	**30945**	5555	**32320**	5155	**33754**	4771	**35251**	4403	**36814**	4052	**38450**	22
39	5966	**30968**	5549	**32344**	5148	**33779**	4764	**35276**	4397	**36841**	4046	**38478**	21
40	5959	**30990**	5542	**32367**	5142	**33803**	4758	**35302**	4391	**36867**	4040	**38506**	20
41	5952	**31013**	5535	**32391**	5135	**33827**	4752	**35327**	4385	**36894**	4035	**38533**	19
42	5945	**31035**	5528	**32414**	5128	**33852**	4746	**35353**	4379	**36921**	4029	**38561**	18
43	5938	**31058**	5521	**32438**	5122	**33876**	4739	**35378**	4373	**36948**	4023	**38589**	17
44	5931	**31080**	5515	**32461**	5115	**33901**	4733	**35404**	4367	**36974**	4017	**38617**	16
45	5924	**31103**	5508	**32484**	5109	**33925**	4727	**35429**	4361	**37001**	4012	**38645**	15
46	5917	**31125**	5501	**32508**	5102	**33950**	4721	**35455**	4355	**37028**	4006	**38674**	14
47	5909	**31148**	5494	**32532**	5096	**33974**	4714	**35481**	4349	**37055**	4000	**38702**	13
48	5902	**31170**	5487	**32555**	5089	**33999**	4708	**35506**	4343	**37081**	3995	**38730**	12
49	5895	**31193**	5481	**32579**	5083	**34024**	4702	**35532**	4337	**37108**	3989	**38758**	11
50	5888	**31216**	5474	**32602**	5076	**34048**	4696	**35558**	4332	**37135**	3983	**38786**	10
51	5881	**31238**	5467	**32625**	5070	**34073**	4690	**35583**	4326	**37162**	3978	**38814**	9
52	5874	**31261**	5460	**32649**	5064	**34097**	4683	**35609**	4320	**37189**	3972	**38842**	8
53	5867	**31284**	5454	**32673**	5057	**34122**	4677	**35635**	4314	**37216**	3966	**38871**	7
54	5860	**31306**	5447	**32697**	5051	**34147**	4671	**35661**	4308	**37243**	3961	**38899**	6
55	5853	**31329**	5440	**32720**	5044	**34172**	4665	**35686**	4302	**37270**	3955	**38927**	5
56	5846	**31352**	5433	**32744**	5038	**34196**	4659	**35712**	4296	**37297**	3949	**38955**	4
57	5839	**31375**	5427	**32768**	5031	**34221**	4652	**35738**	4290	**37324**	3944	**38984**	3
58	5832	**31397**	5420	**32792**	5025	**34246**	4646	**35764**	4284	**37351**	3938	**39012**	2
59	5825	**31420**	5413	**32815**	5018	**34270**	4640	**35790**	4278	**37378**	3933	**39040**	1
60	5818	**31443**	5406	**32839**	5012	**34295**	4634	**35816**	4272	**37405**	3927	**39069**	0
	A	B	A	B	A	B	A	B	A	B	A	B	
′	119°00′		118°00′		117°00′		116°00′		115°00′		114°00′		′

Table 6.—Line of position table

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	66°00′		67°00′		68°00′		69°00′		70°00′		71°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	3927	**39069**	3597	**40812**	3283	**42642**	2985	**44567**	2701	**46595**	2433	**48736**	60
1	3921	**39097**	3592	**40842**	3278	**42674**	2980	**44600**	2697	**46630**	2429	**48772**	59
2	3916	**39125**	3587	**40872**	3273	**42705**	2975	**44633**	2692	**46664**	2424	**48809**	58
3	3910	**39154**	3581	**40902**	3268	**42736**	2970	**44666**	2688	**46699**	2420	**48846**	57
4	3904	**39182**	3576	**40931**	3263	**42768**	2965	**44699**	2683	**46734**	2416	**48883**	56
5	3899	**39211**	3571	**40961**	3258	**42799**	2961	**44732**	2678	**46769**	2411	**48920**	55
6	3893	**39239**	3565	**40991**	3253	**42830**	2956	**44765**	2674	**46804**	2407	**48957**	54
7	3888	**39268**	3560	**41021**	3248	**42862**	2951	**44798**	2669	**46839**	2403	**48993**	53
8	3882	**39296**	3555	**41051**	3243	**42893**	2946	**44831**	2665	**46873**	2398	**49030**	52
9	3876	**39325**	3549	**41081**	3237	**42925**	2941	**44864**	2660	**46908**	2394	**49067**	51
10	3871	**39353**	3544	**41111**	3233	**42956**	2936	**44898**	2656	**46943**	2390	**49104**	50
11	3865	**39382**	3539	**41141**	3227	**42988**	2932	**44931**	2651	**46978**	2385	**49141**	49
12	3860	**39411**	3533	**41171**	3222	**43020**	2927	**44964**	2646	**47014**	2381	**49179**	48
13	3854	**39439**	3528	**41201**	3217	**43051**	2922	**44997**	2642	**47049**	2377	**49216**	47
14	3849	**39468**	3523	**41231**	3212	**43083**	2917	**45031**	2637	**47084**	2372	**49253**	46
15	3843	**39497**	3517	**41261**	3207	**43114**	2913	**45064**	2633	**47119**	2368	**49290**	45
16	3838	**39525**	3512	**41291**	3202	**43146**	2908	**45097**	2628	**47154**	2364	**49327**	44
17	3832	**39554**	3507	**41322**	3197	**43178**	2903	**45131**	2624	**47189**	2360	**49365**	43
18	3826	**39583**	3502	**41352**	3192	**43210**	2898	**45164**	2619	**47225**	2355	**49402**	42
19	3821	**39612**	3496	**41382**	3187	**43241**	2893	**45198**	2615	**47260**	2351	**49439**	41
20	3815	**39641**	3491	**41412**	3182	**43273**	2889	**45231**	2610	**47295**	2347	**49477**	40
21	3810	**39669**	3486	**41443**	3177	**43305**	2884	**45265**	2606	**47331**	2343	**49514**	39
22	3804	**39698**	3480	**41473**	3172	**43337**	2879	**45298**	2601	**47366**	2338	**49551**	38
23	3799	**39727**	3475	**41503**	3167	**43369**	2874	**45332**	2597	**47402**	2334	**49589**	37
24	3793	**39756**	3470	**41533**	3162	**43400**	2870	**45365**	2592	**47437**	2330	**49626**	36
25	3788	**39785**	3465	**40564**	3157	**43432**	2865	**45399**	2588	**47472**	2325	**49664**	35
26	3782	**39814**	3459	**40594**	3152	**43464**	2860	**45433**	2583	**47508**	2321	**49702**	34
27	3777	**39843**	3454	**40625**	3147	**43496**	2855	**45466**	2579	**47544**	2317	**49739**	33
28	3771	**39872**	3449	**41655**	3142	**43528**	2851	**45500**	2574	**47579**	2313	**49777**	32
29	3766	**39901**	3444	**41685**	3137	**43560**	2846	**45534**	2570	**47615**	2309	**49815**	31
30	3760	**39930**	3438	**41716**	3132	**43592**	2841	**45567**	2565	**47650**	2304	**49852**	30
31	3755	**39959**	3433	**41746**	3127	**43624**	2836	**45601**	2561	**47686**	2300	**49890**	29
32	3749	**39988**	3428	**41777**	3122	**43657**	2832	**45635**	2556	**47722**	2296	**49928**	28
33	3744	**40017**	3423	**41808**	3117	**43689**	2827	**45669**	2552	**47758**	2292	**49966**	27
34	3738	**40046**	3418	**41838**	3112	**43721**	2822	**45703**	2547	**47793**	2287	**50004**	26
35	3733	**40076**	3412	**41869**	3107	**43753**	2818	**45737**	2543	**47829**	2283	**50042**	25
36	3727	**40105**	3407	**41899**	3102	**43785**	2813	**45771**	2539	**47865**	2279	**50080**	24
37	3722	**40134**	3402	**41930**	3097	**43818**	2808	**45805**	2534	**47901**	2275	**50117**	23
38	3716	**40163**	3397	**41961**	3092	**43850**	2804	**45839**	2530	**47937**	2271	**50156**	22
39	3711	**40192**	3391	**41991**	3088	**43882**	2799	**45873**	2525	**47973**	2266	**50194**	21
40	3705	**40222**	3386	**42022**	3083	**43914**	2794	**45907**	2521	**48009**	2262	**50232**	20
41	3700	**40251**	3381	**42053**	3078	**43947**	2789	**45941**	2516	**48045**	2258	**50270**	19
42	3695	**40280**	3376	**42084**	3073	**43979**	2785	**45975**	2512	**48081**	2254	**50308**	18
43	3689	**40310**	3371	**42115**	3068	**44012**	2780	**46009**	2507	**48117**	2250	**50346**	17
44	3684	**40339**	3366	**42145**	3063	**44044**	2775	**46043**	2503	**48153**	2246	**50385**	16
45	3678	**40368**	3360	**42176**	3058	**44077**	2771	**46078**	2499	**48189**	2241	**50423**	15
46	3673	**40398**	3355	**42207**	3053	**44109**	2766	**46112**	2494	**48226**	2237	**50461**	14
47	3667	**40427**	3350	**42238**	3048	**44142**	2761	**46146**	2490	**48262**	2233	**50499**	13
48	3662	**40457**	3345	**42269**	3043	**44174**	2757	**46181**	2485	**48298**	2229	**50538**	12
49	3657	**40486**	3340	**42300**	3038	**44207**	2752	**46215**	2481	**48334**	2225	**50576**	11
50	3651	**40516**	8335	**42331**	3033	**44239**	2748	**46249**	2477	**48371**	2221	**50615**	10
51	3646	**40545**	3329	**42362**	3029	**44272**	2743	**46284**	2472	**48407**	2216	**50653**	9
52	3640	**40575**	3324	**42393**	3024	**44305**	2738	**46318**	2468	**48443**	2212	**50692**	8
53	3635	**40604**	3319	**42424**	3019	**44337**	2734	**46353**	2463	**48480**	2208	**50730**	7
54	3630	**40634**	3314	**42455**	3014	**44370**	2729	**46387**	2459	**48516**	2204	**50769**	6
55	3624	**40664**	3309	**42486**	3009	**44403**	2724	**46422**	2455	**48553**	2200	**50808**	5
56	3619	**40693**	3304	**42518**	3004	**44436**	2720	**46456**	2450	**48589**	2196	**50846**	4
57	3613	**40723**	3299	**42549**	2999	**44468**	2715	**46491**	2446	**48626**	2192	**50885**	3
58	3608	**40753**	3294	**42580**	2994	**44501**	2711	**46525**	2442	**48662**	2188	**50924**	2
59	3603	**40782**	3289	**42611**	2990	**44534**	2706	**46560**	2437	**48699**	2183	**50963**	1
60	3597	**40812**	3283	**42642**	2985	**44567**	2701	**46595**	2433	**48736**	2179	**51002**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	113°00′		112°00′		111°00′		110°00′		109°00′		108°00′		

Table 6.—Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	72°00′		73°00′		74°00′		75°00′		76°00′		77°00′		′
	A	B	A	B	A	B	A	B	A	B	A	B	
0	2179	**51002**	1940	**53406**	1716	**55966**	1506	**58700**	1310	**61632**	1128	**64791**	60
1	2175	**51041**	1936	**53448**	1712	**56010**	1502	**58748**	1306	**61683**	1125	**64846**	59
2	2171	**51080**	1933	**53489**	1709	**56054**	1499	**58795**	1303	**61734**	1122	**64901**	58
3	2167	**51119**	1929	**53531**	1705	**56099**	1495	**58842**	1300	**61785**	1119	**64956**	57
4	2163	**51158**	1925	**53572**	1701	**56143**	1492	**58889**	1297	**61836**	1116	**65011**	56
5	2159	**51197**	1921	**53614**	1698	**56187**	1489	**58937**	1294	**61887**	1113	**65066**	55
6	2155	**51236**	1917	**53655**	1694	**56231**	1485	**58984**	1291	**61938**	1110	**65121**	54
7	2151	**51275**	1913	**53697**	1691	**56276**	1482	**59032**	1288	**61989**	1107	**65176**	53
8	2147	**51314**	1910	**53738**	1687	**56320**	1479	**59079**	1284	**62040**	1104	**65231**	52
9	2143	**51353**	1906	**53780**	1683	**56365**	1475	**59127**	1281	**62091**	1101	**65287**	51
10	2138	**51392**	1902	**53822**	1680	**56409**	1472	**59175**	1278	**62142**	1099	**65342**	50
11	2134	**51432**	1898	**53864**	1676	**56454**	1469	**59222**	1275	**62194**	1096	**65398**	49
12	2130	**51471**	1894	**53905**	1673	**56498**	1465	**59270**	1272	**62245**	1093	**65453**	48
13	2126	**51510**	1890	**53947**	1669	**56543**	1462	**59318**	1269	**62296**	1090	**65509**	47
14	2122	**51550**	1887	**53989**	1665	**56588**	1459	**59366**	1266	**62348**	1087	**65564**	46
15	2118	**51589**	1883	**54031**	1662	**56632**	1455	**59414**	1263	**62400**	1084	**65620**	45
16	2114	**51629**	1879	**54073**	1658	**56677**	1452	**59462**	1260	**62451**	1081	**65676**	44
17	2110	**51668**	1875	**54115**	1655	**56722**	1449	**59510**	1257	**62503**	1079	**65732**	43
18	2106	**51708**	1871	**54157**	1651	**56767**	1445	**59558**	1253	**62555**	1076	**65788**	42
19	2102	**51747**	1868	**54199**	1648	**56812**	1442	**59606**	1250	**62607**	1073	**65844**	41
20	2098	**51787**	1864	**54242**	1644	**56857**	1439	**59654**	1247	**62659**	1070	**65900**	40
21	2094	**51827**	1860	**54284**	1641	**56902**	1435	**59703**	1244	**62711**	1067	**65957**	39
22	2090	**51867**	1856	**54326**	1637	**56947**	1432	**59751**	1241	**62763**	1064	**66013**	38
23	2086	**51906**	1853	**54368**	1634	**56992**	1429	**59800**	1238	**62815**	1061	**66069**	37
24	2082	**51946**	1849	**54411**	1630	**57038**	1425	**59848**	1235	**62867**	1059	**66126**	36
25	2078	**51986**	1845	**54453**	1627	**57083**	1422	**59896**	1232	**62919**	1056	**66182**	35
26	2074	**52026**	1841	**54496**	1623	**57128**	1419	**59945**	1229	**62971**	1053	**66239**	34
27	2070	**52066**	1837	**54538**	1619	**57174**	1416	**59994**	1226	**63024**	1050	**66296**	33
28	2066	**52106**	1834	**54581**	1616	**57219**	1412	**60042**	1223	**63076**	1047	**66352**	32
29	2062	**52146**	1830	**54623**	1612	**57265**	1409	**60091**	1220	**63129**	1045	**66409**	31
30	2058	**52186**	1826	**54666**	1609	**57310**	1406	**60140**	1217	**63181**	1042	**66466**	30
31	2054	**52226**	1823	**54708**	1605	**57356**	1403	**60189**	1214	**63234**	1039	**66523**	29
32	2050	**52266**	1819	**54751**	1602	**57401**	1399	**60238**	1211	**63287**	1036	**66580**	28
33	2046	**52306**	1815	**54794**	1598	**57447**	1396	**60287**	1208	**63340**	1033	**66638**	27
34	2042	**52346**	1811	**54837**	1595	**57493**	1393	**60336**	1205	**63392**	1031	**66695**	26
35	2038	**52387**	1808	**54880**	1591	**57538**	1390	**60385**	1202	**63445**	1028	**66752**	25
36	2034	**52427**	1804	**54922**	1588	**57584**	1386	**60434**	1199	**63498**	1025	**66810**	24
37	2030	**52467**	1800	**54965**	1584	**57630**	1383	**60483**	1196	**63551**	1022	**66867**	23
38	2026	**52508**	1796	**55008**	1581	**57676**	1380	**60533**	1193	**63605**	1020	**66925**	22
39	2022	**52548**	1793	**55051**	1578	**57722**	1377	**60582**	1190	**63658**	1017	**66982**	21
40	2018	**52588**	1789	**55095**	1574	**57768**	1373	**60631**	1187	**63711**	1014	**67040**	20
41	2014	**52629**	1785	**55138**	1571	**57814**	1370	**60681**	1184	**63764**	1011	**67098**	19
42	2010	**52670**	1782	**55181**	1567	**57860**	1367	**60730**	1181	**63818**	1008	**67156**	18
43	2007	**52710**	1778	**55224**	1564	**57907**	1364	**60780**	1178	**63871**	1006	**67214**	17
44	2003	**52751**	1774	**55267**	1560	**57953**	1360	**60830**	1175	**63925**	1003	**67272**	16
45	1999	**52791**	1771	**55311**	1557	**57999**	1357	**60879**	1172	**63978**	1000	**67330**	15
46	1995	**52832**	1767	**55354**	1553	**58046**	1354	**60929**	1169	**64032**	997	**67388**	14
47	1991	**52873**	1763	**55397**	1550	**58092**	1351	**60979**	1166	**64086**	995	**67447**	13
48	1987	**52914**	1760	**55441**	1546	**58138**	1348	**61029**	1163	**64140**	992	**67505**	12
49	1983	**52954**	1756	**55484**	1543	**58185**	1344	**61079**	1160	**64194**	989	**67563**	11
50	1979	**52995**	1752	**55528**	1540	**58232**	1341	**61129**	1157	**64248**	987	**67622**	10
51	1975	**53036**	1749	**55572**	1536	**58278**	1338	**61179**	1154	**64302**	984	**67681**	9
52	1971	**53077**	1745	**55615**	1533	**58325**	1335	**61229**	1151	**64356**	981	**67739**	8
53	1967	**53118**	1741	**55659**	1529	**58372**	1332	**61279**	1148	**64410**	978	**67798**	7
54	1964	**53159**	1738	**55703**	1526	**58418**	1329	**61330**	1145	**64464**	976	**67857**	6
55	1960	**53200**	1734	**55746**	1523	**58465**	1325	**61380**	1142	**64518**	973	**67916**	5
56	1956	**53241**	1730	**55790**	1519	**58512**	1322	**61430**	1139	**64573**	970	**67975**	4
57	1952	**53283**	1727	**55834**	1516	**58559**	1319	**61481**	1136	**64627**	968	**68034**	3
58	1948	**53324**	1723	**55878**	1512	**58606**	1316	**61531**	1133	**64682**	965	**68093**	2
59	1944	**53365**	1719	**55922**	1509	**58653**	1313	**61582**	1130	**64736**	962	**68153**	1
60	1940	**53406**	1716	**55966**	1506	**58700**	1310	**61632**	1128	**64791**	960	**68212**	0
	A	B	A	B	A	B	A	B	A	B	A	B	
′	107°00′		106°00′		105°00′		104°00′		103°00′		102°00′		′

Table 6.—Line of position table

ALWAYS TAKE "Z" FROM BOTTOM OF TABLE, EXCEPT WHEN "K" IS SAME NAME AND GREATER THAN LATITUDE, IN WHICH CASE TAKE "Z" FROM TOP OF TABLE

′	78°00′ A	78°00′ B	79°00′ A	79°00′ B	80°00′ A	80°00′ B	81°00′ A	81°00′ B	82°00′ A	82°00′ B	83°00′ A	83°00′ B	′
0	960	**68212**	805	**71940**	665	**76033**	538	**80567**	425	**85644**	325	**91411**	60
1	957	**68272**	803	**72005**	663	**76105**	536	**80647**	423	**85734**	323	**91514**	59
2	954	**68331**	800	**72070**	660	**76176**	534	**80727**	421	**85825**	322	**91617**	58
3	951	**68391**	798	**72136**	658	**76248**	532	**80807**	419	**85915**	320	**91720**	57
4	949	**68450**	796	**72201**	656	**76320**	530	**80887**	418	**86006**	319	**91824**	56
5	946	**68510**	793	**72266**	654	**76393**	528	**80967**	416	**86096**	317	**91928**	55
6	943	**68570**	791	**72332**	652	**76465**	526	**81048**	414	**86187**	316	**92032**	54
7	941	**68630**	788	**72397**	649	**76537**	524	**81129**	412	**86278**	314	**92137**	53
8	938	**68690**	786	**72463**	647	**76610**	522	**81210**	411	**86370**	313	**92242**	52
9	935	**68750**	783	**72529**	645	**76683**	520	**81291**	409	**86461**	311	**92347**	51
10	933	**68811**	781	**72595**	643	**76756**	518	**81372**	407	**86553**	310	**92452**	50
11	930	**68871**	779	**72661**	641	**76828**	516	**81453**	405	**86645**	308	**92558**	49
12	928	**68931**	776	**72727**	638	**76902**	514	**81535**	404	**86737**	307	**92663**	48
13	925	**68992**	774	**72794**	636	**76975**	512	**81617**	402	**86829**	305	**92769**	47
14	922	**69053**	771	**72860**	634	**77048**	510	**81698**	400	**86922**	304	**92876**	46
15	920	**69113**	769	**72926**	632	**77122**	508	**81780**	399	**87015**	302	**92982**	45
16	917	**69174**	767	**72993**	630	**77195**	506	**81863**	397	**87107**	301	**93089**	44
17	914	**69235**	764	**73060**	627	**77269**	504	**81945**	395	**87201**	299	**93196**	43
18	912	**69296**	762	**73127**	625	**77343**	503	**82027**	393	**87294**	298	**93304**	42
19	909	**69357**	759	**73193**	623	**77417**	501	**82110**	392	**87387**	296	**93411**	41
20	907	**69418**	757	**73260**	621	**77491**	499	**82193**	390	**87481**	295	**93519**	40
21	904	**69479**	755	**73328**	619	**77565**	497	**82276**	388	**87575**	293	**93628**	39
22	901	**69541**	752	**73395**	617	**77639**	495	**82359**	387	**87669**	292	**93736**	38
23	899	**69602**	750	**73462**	615	**77714**	493	**82442**	385	**87764**	290	**93845**	37
24	896	**69664**	747	**73530**	612	**77788**	491	**82526**	383	**87858**	289	**93954**	36
25	894	**69725**	745	**73597**	610	**77863**	489	**82609**	381	**87953**	287	**94063**	35
26	891	**69787**	743	**73665**	608	**77938**	487	**82693**	380	**88048**	286	**94173**	34
27	888	**69849**	740	**73733**	606	**78013**	485	**82777**	378	**88143**	284	**94283**	33
28	886	**69910**	738	**73801**	604	**78088**	483	**82861**	376	**88239**	283	**94393**	32
29	883	**69972**	736	**73869**	602	**78164**	482	**82945**	375	**88334**	281	**94503**	31
30	881	**70034**	733	**73937**	600	**78239**	480	**83030**	373	**88430**	280	**94614**	30
31	878	**70097**	731	**74005**	598	**78315**	478	**83114**	371	**88526**	279	**94725**	29
32	876	**70159**	729	**74073**	595	**78390**	476	**83199**	370	**88623**	277	**94836**	28
33	873	**70221**	726	**74142**	593	**78466**	474	**83284**	368	**88719**	276	**94948**	27
34	870	**70284**	724	**74210**	591	**78542**	472	**83369**	366	**88816**	274	**95060**	26
35	868	**70346**	722	**74279**	589	**78618**	470	**83455**	365	**88913**	273	**95172**	25
36	865	**70409**	719	**74348**	587	**78694**	468	**83540**	363	**89010**	271	**95285**	24
37	863	**70471**	717	**74417**	585	**78771**	467	**83626**	362	**89107**	270	**95397**	23
38	860	**70534**	715	**74486**	583	**78847**	465	**83711**	360	**89205**	269	**95510**	22
39	858	**70597**	712	**74555**	581	**78924**	463	**83797**	358	**89303**	267	**95624**	21
40	855	**70660**	710	**74624**	579	**79001**	461	**83884**	357	**89401**	266	**95737**	20
41	853	**70723**	708	**74693**	577	**79078**	459	**83970**	355	**89499**	264	**95851**	19
42	850	**70786**	706	**74763**	575	**79155**	457	**84056**	353	**89597**	263	**95966**	18
43	848	**70850**	703	**74832**	573	**79232**	455	**84143**	352	**89696**	262	**96080**	17
44	845	**70913**	701	**74902**	570	**79309**	454	**84230**	350	**89795**	260	**96195**	16
45	843	**70976**	699	**74972**	568	**79387**	452	**84317**	349	**89894**	259	**96310**	15
46	840	**71040**	696	**75042**	566	**79465**	450	**84404**	347	**89994**	257	**96426**	14
47	838	**71104**	694	**75112**	564	**79542**	448	**84492**	345	**90093**	256	**96542**	13
48	835	**71167**	692	**75182**	562	**79620**	446	**84579**	344	**90193**	255	**96658**	12
49	833	**71231**	690	**75252**	560	**79698**	444	**84667**	342	**90293**	253	**96774**	11
50	830	**71295**	687	**75322**	558	**79777**	443	**84755**	341	**90394**	252	**96891**	10
51	828	**71359**	685	**75393**	556	**79855**	441	**84843**	339	**90494**	251	**97008**	9
52	825	**71423**	683	**75464**	554	**79933**	439	**84931**	337	**90595**	249	**97126**	8
53	823	**71488**	680	**75534**	552	**80012**	437	**85020**	336	**90696**	248	**97243**	7
54	820	**71552**	678	**75605**	550	**80091**	435	**85100**	334	**90798**	247	**97361**	6
55	818	**71616**	676	**75676**	548	**80170**	434	**85197**	333	**90899**	245	**97480**	5
56	815	**71681**	674	**75747**	546	**80249**	432	**85286**	321	**91001**	244	**97598**	4
57	813	**71746**	672	**75819**	544	**80328**	430	**85376**	330	**91103**	243	**97717**	3
58	810	**71810**	669	**75890**	542	**80407**	428	**85465**	328	**91205**	241	**97837**	2
59	808	**71875**	667	**75961**	540	**80487**	426	**85555**	326	**91308**	240	**97957**	1
60	805	**71940**	665	**76033**	538	**80567**	425	**85644**	325	**91411**	239	**98076**	0
′	A	B	A	B	A	B	A	B	A	B	A	B	′
	101°00′		**100°00′**		**99°00′**		**98°00′**		**97°00′**		**96°00′**		

Table 6.—Line of position table

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	84°00′ A	84°00′ B	85°00′ A	85°00′ B	86°00′ A	86°00′ B	87°00′ A	87°00′ B	88°00′ A	88°00′ B	89°00′ A	89°00′ B	′
0	238.6	98076	165.6	105970	105.9	115641	59.6	128120	26.5	145718	6.6	175814	60
1	237.2	98197	164.5	106115	105.0	115823	58.9	128362	26.0	146081	6.4	176544	59
2	235.9	98318	163.4	106260	104.2	116004	58.2	128605	25.6	146448	6.2	177287	58
3	234.6	98439	162.3	106406	103.3	116187	57.6	128849	25.2	146817	6.0	178042	57
4	233.3	98560	161.2	106552	102.4	116370	56.9	129095	24.7	147190	5.8	178810	56
5	232.0	98682	160.1	106698	101.6	116554	56.3	129342	24.3	147566	5.6	179593	55
6	230.7	98804	159.0	106846	100.7	116739	55.7	129591	23.9	147945	5.4	180390	54
7	229.4	98926	157.9	106993	99.8	116925	55.0	129841	23.5	148327	5.2	181201	53
8	228.1	99049	156.9	107141	99.0	117112	54.4	130093	23.1	148713	5.0	182029	52
9	226.8	99172	155.8	107290	98.1	117299	53.7	130346	22.6	149103	4.8	182872	51
10	225.5	99296	154.7	107439	97.3	117487	53.1	130600	22.2	149495	4.6	183732	50
11	224.2	99419	153.6	107589	96.4	117676	52.5	130856	21.8	149892	4.4	184609	49
12	222.9	99544	152.6	107739	95.6	117866	51.9	131114	21.4	150292	4.2	185505	48
13	221.6	99668	151.5	107890	94.7	118056	51.3	131373	21.0	150696	4.1	186419	47
14	220.3	99793	150.5	108041	93.9	118248	50.7	131633	20.6	151104	3.9	187353	46
15	219.1	99918	149.4	108193	93.1	118440	50.0	131896	20.3	151515	3.7	188307	45
16	217.8	100044	148.4	108345	92.3	118633	49.4	132159	19.9	151931	3.6	189283	44
17	216.5	100170	147.3	108498	91.4	118827	48.8	132425	19.5	152350	3.4	190282	43
18	215.3	100296	146.3	108651	90.6	119022	48.2	132692	19.1	152774	3.2	191303	42
19	214.0	100423	145.2	108805	89.8	119218	47.6	132961	18.7	153201	3.1	192350	41
20	212.8	100550	144.2	108960	89.0	119415	47.1	133231	18.4	153633	2.9	193422	40
21	211.5	100678	143.2	109115	88.2	119612	46.5	133503	18.0	154070	2.8	194522	39
22	210.3	100806	142.2	109270	87.4	119811	45.9	133777	17.6	154511	2.7	195650	38
23	209.0	100934	141.1	109426	86.6	120010	45.3	134052	17.3	154956	2.5	196808	37
24	207.8	101063	140.1	109583	85.8	120211	44.7	134330	16.9	155406	2.4	197998	36
25	206.5	101192	139.1	109740	85.0	120412	44.2	134609	16.6	155861	2.3	199221	35
26	205.3	101321	138.1	109898	84.2	120614	43.6	134890	16.2	156320	2.1	200480	34
27	204.1	101451	137.1	110057	83.4	120817	43.0	135173	15.9	156784	2.0	201777	33
28	202.8	101581	136.1	110216	82.6	121021	42.5	135457	15.6	157254	1.9	203113	32
29	201.6	101712	135.1	110375	81.9	121226	41.9	135744	15.2	157728	1.8	204492	31
30	200.4	101843	134.1	110536	81.1	121432	41.4	136032	14.9	158208	1.7	205916	30
31	199.2	101974	133.1	110696	80.3	121639	40.8	136322	14.6	158693	1.5	207388	29
32	198.0	102106	132.1	110858	79.5	121848	40.3	136615	14.2	159184	1.4	208912	28
33	196.8	102238	131.1	111020	78.8	122057	39.7	136909	13.9	159680	1.3	210491	27
34	195.6	102371	130.1	111183	78.0	122267	39.2	137205	13.6	160182	1.2	212130	26
35	194.4	102504	129.2	111346	77.3	122478	38.6	137503	13.3	160690	1.1	213834	25
36	193.2	102637	128.2	111510	76.5	122690	38.1	137804	13.0	161204	1.1	215607	24
37	192.0	102771	127.2	111674	75.8	122903	37.6	138106	12.7	161724	1.0	217455	23
38	190.8	102905	126.2	111839	75.0	123117	37.1	138411	12.4	162250	0.9	219385	22
39	189.6	103040	125.3	112005	74.3	123332	36.5	138718	12.1	162783	0.8	221406	21
40	188.4	103175	124.3	112171	73.5	123549	36.0	139027	11.8	163322	0.7	223525	20
41	187.2	103311	123.4	112338	72.8	123766	35.5	139338	11.5	163868	0.7	225752	19
42	186.1	103447	122.4	112506	72.1	123985	35.0	139651	11.2	164422	0.6	228100	18
43	184.9	103583	121.5	112674	71.3	124204	34.5	139967	10.9	164982	0.5	230583	17
44	183.7	103720	120.5	112843	70.6	124425	34.0	140285	10.6	165550	0.5	233215	16
45	182.6	103857	119.6	113013	69.9	124647	33.5	140605	10.3	166125	0.4	236018	15
46	181.4	103995	118.7	113183	69.2	124870	33.0	140928	10.1	166708	0.4	239015	14
47	180.3	104133	117.7	113354	68.5	125094	32.5	141253	9.8	167298	0.3	242233	13
48	179.1	104272	116.8	113526	67.8	125320	32.0	141581	9.5	167897	0.3	245709	12
49	178.0	104411	115.9	113699	67.1	125546	31.5	141911	9.3	168505	0.2	249488	11
50	176.8	104550	114.9	113872	66.4	125774	31.1	142243	9.0	169121	0.2	253627	10
51	175.7	104690	114.0	114045	65.7	126003	30.6	142579	8.7	169745	0.1	258203	9
52	174.5	104830	113.1	114220	65.0	126233	30.1	412916	8.5	170379	0.1	263318	8
53	173.4	104971	112.2	114395	64.3	126465	29.6	143257	8.2	171023	0.1	269118	7
54	172.3	105113	111.3	114571	63.6	126697	29.2	143600	8.0	711676	0.1	275812	6
55	171.1	105254	110.4	114747	62.9	126931	28.7	143946	7.8	172339	0.0	283304	5
56	170.0	105397	109.5	114925	62.2	127166	28.3	144295	7.5	173012	0.0	293421	4
57	168.9	105539	108.6	115103	61.6	127403	27.8	144646	7.3	173696	0.0	305915	3
58	167.8	105683	107.7	115282	60.9	127640	27.4	145000	7.1	174391	0.0	323524	2
59	166.7	105826	106.8	115461	60.2	127880	26.9	145358	6.8	175097	0.0	353627	1
60	165.6	105970	105.9	115641	59.6	128120	26.5	145718	6.6	175814	0.0	------	0
′	95°00′ A	95°00′ B	94°00′ A	94°00′ B	93°00′ A	93°00′ B	92°00′ A	92°00′ B	91°00′ A	91°00′ B	90°00′ A	90°00′ B	′

Chapter XI.—APPENDIX

GLOSSARY OF PRINCIPAL NAVIGATIONAL TERMS

Airport of entry.—An airport through which air traffic may be cleared to or from a foreign country; aircraft making an international flight must take-off from and land at such an airport, to comply with customs regulations.

Airport traffic control.—The control of local traffic in the vicinity of an airport by the airport management.

Airspeed.—The velocity of an aircraft with respect to the air.

Airspeed indicator.—An instrument for indicating the air speed of an aircraft.

Airway traffic control.—The control of traffic on the airways, exercised by Federal personnel whenever visibility is restricted.

Altimeter.—An instrument for registering the altitude of an aircraft, usually in terms of feet above sea level. By adjustment of the barometric scale (on instruments so equipped), the altitude above a particular airport, or other point, may be indicated.

Altimeter setting.—The setting to be made to the barometric scale of an altimeter, such that, upon landing, the pointers of the instrument will indicate very closely the actual elevation of the airport above sea level.

Altitude.—The height of an airplane, usually expressed in feet above sea level.

In celestial navigation, the angle of elevation of a celestial body above the horizon.

Altitude difference.—The difference between the computed altitude and the observed sextant altitude after all necessary corrections have been applied.

Pressure altitude.—The altitude indicated by an altimeter when the barometric scale is adjusted to the standard sea level atmospheric pressure of 29.92 inches.

Aries, first point of.—The intersection of the celestial equator and the ecliptic; the vernal equinox. It is the origin of the celestial coordinates of right ascension and sidereal hour angle.

Azimuth.—See "direction."

Barometer, aneroid.—An instrument indicating atmospheric pressure mechanically, by means of a resilient pressure chamber from which most of the air has been exhausted.

Barometer, mercurial.—An instrument indicating atmospheric pressure in terms of the height in inches or in millimeters of the column of mercury supported by it in an evacuated glass tube.

Bearing.—See "direction."

Beaufort scale.—A scale for estimating wind velocities by noting the visible effects of the wind.

Bent courses.—Radio range courses deflected from their normal straight path because of topographic or other physical irregularities.

Bisector, average.—The average of the bearings of the individual bisectors of two opposite quadrants of a radio range station.

Chart, aeronautical.—A small scale representation of the earth, its culture, relief, and the various aeronautical aids; designed with special consideration for the needs of air navigation.

Chronometer.—An accurate clock or watch, often with special conveniences for use in navigation.

Circle, great.—The intersection with the earth's surface of any plane passing through the center of the earth.

Circle, small.—The intersection with the earth's surface of any plane which does not pass through the center of the earth.

Circle of position.—A circle drawn around the point on the earth directly beneath a star or other heavenly body, from all points of which the altitude of the body is the same.

Civil Air Regulations.—The regulations prescribed by the Civil Aeronautics Administration for the regulation and promotion of the many phases of aviation.

Compass compensation.—The systematic reduction of compass deviation by inserting or adjusting small magnets incorporated in a magnetic compass for that purpose.

Compass, magnetic.—An instrument indicating magnetic directions by means of a freely suspended magnetic element; the primary means of indicating the heading or direction of flight of an aircraft.

Compass rose.—A circle, graduated in degrees from 0 to 360, printed on aeronautical charts as a reference to directions, true or magnetic.

Compass testing platform.—A suitable platform at principal airports, designed for checking the directions indicated by the compass of an aircraft against known magnetic directions, and so determining the error, or deviation, of the compass.

Cone of silence.—A limited area, shaped like an inverted cone, directly above the towers of a radio range station, in which the range signals are not received.

Contact flying.—Flight of an aircraft in which the attitude of the aircraft and its flight path can at all times be controlled by visual reference to the ground or water.

Contour.—An imaginary line formed by the intersection of a horizontal plane with the surface of the earth, all points on any given contour being at the same elevation with respect to sea level (or other chosen reference plane).

Contour interval.—The vertical separation between the horizontal planes of two adjacent contours.

Convergence.—As used in this book, the angle between selected meridians of the Lambert conformal projection, the convergence amounting to 0°.6305 per degree of difference of longitude.

Course.—See "direction."

Culture.—Generally applied to the cities, railroads, highways, and other constructed features of the earth; often referred to as "the works of man."

Dead reckoning.—See "navigation."

Declination.—The angular distance of a celestial body north or south of the celestial equator; also, engineering term for magnetic variation.

Deviation.—The error of a magnetic compass due to magnetic influences in the structure and equipment of an aircraft.

Dip.—In celestial navigation, the error introduced when the natural sea horizon is viewed from altitudes above the surface of the sea.

Direction:

- **Azimuth.**—The initial direction of the arc of a great circle; the angle between the plane of the great circle and the meridian of the place. As used in air navigation it is measured from the north, in a clockwise direction, from 0° to 360°.
- **Bearing.**—In air navigation, the same as azimuth.
- **Course.**—The direction of the rhumb line, or the line of constant direction. As used in air navigation with the Lambert projection, it is measured at the meridian nearest halfway between the starting point and destination.
- **Heading.**—The direction in which the airplane is pointed, in contradistinction to its path over the ground.
- **Wind.**—The true direction *from* which the wind blows.

Directional gyro.—An instrument which maintains for a limited time, by gyroscopic means, any direction for which it may be set.

Double drift.—A method for determining the direction and velocity of the wind by means of the drift angles observed on two headings at right angles to each other.

Drift.—The angle between the heading of an aircraft and its track, or flight path over the ground.

Drift sight.—An instrument for determining the angle of drift; often accomplished by observing the apparent motion of points on the earth's surface along a grid incorporated in the instrument.

Ecliptic.—An imaginary line on the celestial sphere, traced by the intersection of the sphere with the plane of the earth's orbit.

Equator, celestial.—The intersection of the earth's equator, extended, and the celestial sphere.

Equator, magnetic.—An imaginary line on the earth's surface, approximately halfway between the magnetic poles of the earth.

Equator, terrestrial.—An imaginary line formed by the intersection of the earth's surface and a plane perpendicular to the earth's axis at its middle point.

Equinox, vernal.—See "Aries, first point of."

Equisignal zone.—The zone within which signals from two adjacent quadrants of a radio range station may be heard with equal strength.

Fading.—Diminishing of signal strength because of increasing distance from a radio station, or because of other radio phenomena.

Fix.—A definite position of an aircraft, determined by the intersection of two or more bearings or lines of position, or by other means.

Fix, running.—A fix obtained by moving forward the first of two lines of position the distance and direction made good between the taking of two observations, to intersect with the second line of position.

Flight plan.—A statement of the essential information for a proposed flight, which must be submitted to and approved by the airway traffic control center, for all flights other than contact flying.

Gnomonic.—A chart projection on which all great circles are exactly represented by straight lines.

Greenwich.—The location of the principal British observatory, near London. In most countries, longitude is reckoned east or west from the meridian passing through this observatory.

Ground speed.—The speed of an aircraft with reference to the surface of the earth.

Heading.—See "direction."

Horizon, artificial.—In celestial navigation, the horizon obtained by means of a spirit level incorporated in the optical system of a bubble sextant.

Horizon, natural.—The horizon line where sea and sky seem to meet.

Hour angle:

- **Greenwich.**—The difference of longitude between the meridian of Greenwich and the meridian of a celestial body. Measured from Greenwich toward the west, up to 360°.
- **Local.**—The difference of longitude between the meridian of the observer and the meridian of a celestial body. Measured from the meridian of the observer toward the east or west, from 0° to 180°.
- **Sidereal.**—The difference of longitude between the meridian passing through the vernal equinox and the meridian of a celestial body. Measured from the vernal equinox toward the west, up to 360°.

Instrument flying.—Flight of aircraft in which visual reference is not continuously available and the attitude of the aircraft and its flight path can be controlled in part or in whole by reference to instruments only.

Intercept.—In celestial navigation, the difference between the observed and computed sextant altitudes of a celestial body.

Isogonic line.—An imaginary line on the surface of the earth at all points on which the magnetic variation is the same.

Knot.—A velocity of one nautical mile per hour (1853.25 meters per hour).

Lambert conformal conic.—The chart projection used as a base for aeronautical charts of the Coast and Geodetic Survey. Straight lines on this projection closely approximate great circles, and distances may be measured with a high degree of accuracy.

Latitude.—Distance north or south of the equator, measured in degrees, minutes, and seconds of arc.

Line of position.—A short section of a circle of position; in reality, a tangent to a circle of position, constructed through the assumed position, which is at the end of a radius from the center of the circle.

Longitude.—The distance along the equator between the meridian passing through a place and (usually) the meridian of Greenwich; measured in degrees, minutes, and seconds of arc.

Meridian, true, or geographic.—Any of the great circles passing through the geographic poles of the earth.

Meridian, magnetic.—The great circle the plane of which makes an angle with the plane of the true meridian, equal in direction and magnitude to the magnetic variation of a place.

Mercator.—The chart projection commonly used for nautical charts. On this projection the rhumb line is represented by a straight line; great circles (radio bearings are great circles) are represented by curved lines. Due to the rapidly expanding scale, distances must be measured with the scale for the middle latitude between the two points in question.

Mile, nautical.—The ordinary unit of 6,080.20 feet (1,853.25 meters); for measuring distances at sea. For practical purposes a minute of latitude may be considered as equal to a nautical mile. It is approximately equal to 1.15 statute miles.

Mile, statute.—The ordinary unit of 5,280 feet for measuring distances on land. It is approximately equal to 0.87 nautical miles.

Millibar.—A unit of barometric pressure, 1,000 millibars being equal to 29.53 inches of mercury; conversely, 1 inch of mercury is equal to 33.86 millibars.

Multiple courses.—A number of narrow equisignal zones resulting from the breaking up of a radio range course by mountainous topography or other causes.

Navigation:

Celestial.—The determination of position by means of sextant observations of the celestial bodies, together with the exact time of observation.

Dead reckoning.—The determination of the distance and direction between two known points, or the determination of position from a knowledge of the distance and direction from a known point.

Piloting.—Directing an airplane with respect to visible landmarks; sometimes known as pilotage.

Radio.—The determination of position by means of observed radio bearings.

Night effect.—Variation in the positions of the radio range courses, or displacement of a radio bearing due to interference from reflected sky waves or other causes peculiar to night conditions.

North, magnetic.—The direction indicated at any place by the needle of a magnetic compass undisturbed by local magnetic attraction.

North, true.—The direction of the north geographic pole.

Orientation.—In radio navigation, a method of determining position relative to the quadrants and equisignal zones of a radio range station; or of determining position relative to a radio station by means of radio compass or direction finder.

Over-the-top flying.—Flight of aircraft made above an overcast, usually a cloud formation.

Parallax.—In air navigation, the angle at the moon between lines to the observer's position and to the center of the earth.

Parallel.—The intersection of the earth's surface with a plane parallel to the equator.

Pelorus.—A circular bearing plate, graduated in degrees, which may be used to determine the true or relative bearings of objects.

Pilotage.—See "Navigation, piloting."

Pole, celestial.—The point on the celestial sphere intersected by the extension of the earth's axis.

Pole, magnetic.—A point on the earth where a freely suspended magnet would point vertically. The north magnetic pole is located at about latitude 71° north, longitude 96° west; the south magnetic pole about latitude 73° south, longitude 156° east.

Pole, geographic.—The intersection of the earth's axis with the surface of the earth.

Projection.—The system of reference lines representing the earth's meridians and parallels on a chart. The projection is usually designed to retain some special property of the sphere, as true directions, true distances, true shape, or true area.

Radio altimeter.—A device for measuring the height of an aircraft above the surface of the earth (not above sea level), by means of reflected radio waves.

Radio compass.—A device employing a fixed loop antenna and visual indicator; used chiefly for "homing" flight (flight directly toward or away from a radio station).

Radio direction finder.—A device similar to the radio compass, but employing a rotatable loop antenna; signals are often received both aurally and visually.

Radio direction finder, automatic.—Similar to the ordinary radio direction finder, except that rotation of the loop is automatic, and the indicator needle continuously indicates the bearing of the station.

Radius of action.—The distance or time an aircraft may safely fly toward its destination before turning back to the starting point or to some alternate airport.

Range.—An alinement of landmarks along a route such that the desired track may be made good by flying so as to keep the objects continually in line.

Reciprocal.—Any given direction (whether course, bearing, or heading) plus or minus 180°.

Rectifying.—The process of removing from the compass heading observed in flight the errors due to deviation, variation, and wind.

Refraction.—The bending of the line of sight from a celestial body by the earth's atmosphere, as a result of which the observed altitude of the body always appears higher than the true altitude.

Relief.—The inequalities in elevation of the surface of the earth; represented on the aeronautical charts by contours and gradient tints.

Relative bearing.—The bearing of a radio station or object relative to the airplane's head.

Rhumb line.—A curved line ("loxodromic spiral") on the surface of the earth, crossing all meridians at a constant angle.

Right ascension.—In celestial navigation, the distance of a body on the celestial sphere from the vernal equinox; measured toward the east, from 0^h up to 24^h; corresponds to longitude on the terrestrial sphere.

Sextant.—An instrument used in celestial navigation for determining the altitude of a celestial body above the horizon.

Standard parallels.—The parallels of latitude at which the cone on which the Lambert conformal projection is developed intersects the sphere. Since they are identical on cone and sphere, the scale along the standard parallels is exact. The standard parallels for aeronautical charts of the United States are 33° and 45° of latitude; for Alaska the standard parallels are 55° and 65° of latitude.

Teletype.—A system of communications by automatic typewriters, operated by wire, or by radio. Extensively used by the Civil Aeronautics Administration in transmitting weather data and other flight information.

Terrain clearance indicator.—See "radio altimeter."

Time, civil.—Time measured by the rotation of the earth with respect to the mean sun.

Time, mean.—See "time, civil."

Time, sidereal.—Time measured by the rotation of the earth with respect to the vernal equinox.

Time, standard.—The civil time adopted as standard within a zone approximately 15° of longitude in width.

Tower, airport control.—The communication center through which pilots receive traffic instructions from the local airport management and from the Federal airway traffic control center, and to which they report the required flight information.

Track.—The actual flight path of an aircraft over the ground.

Variation, magnetic.—The angle between true north and magnetic north at any given place.

Wind angle.—The angle between the true course (or the heading, as the case may be) and the direction from which the wind is blowing; measured from the true course (or the heading) toward the right or left, from 0° up to 180°.

Wind correction angle.—The angle at which an aircraft must be headed into the wind in order to make good the desired track.

Wind direction.—See "direction, wind."

Wind star.—A graphic solution for the direction and velocity of the wind by plotting the drift angles observed on two headings approximately at right angles.

Zenith.—The point on the celestial sphere directly over the head of the observer.

CONVENIENT ABBREVIATIONS AND SYMBOLS

In the solution of navigational problems and the tabulation of data, the use of suitable abbreviations saves time and affords greater clarity. The following abbreviations are often used and will be found very convenient in practice:

a=Altitude difference (intercept).
AA=Air Almanac.
AP=Airport.
AS=Air speed.
Bn=Beacon.
C. A. R.=Civil Air Regulations.
CC=Compass course.
CH=Compass heading.
Corr=Correction.
D=Drift angle.
D/F=Direction finding.
DR=Dead reckoning.
Dec=Declination.
+=north dec.
−=south dec.
Dev=Deviation.
ETA=Estimated time of arrival.
G=Greenwich.
GCT=Greenwich civil time.
GHA=Greenwich hour angle.
GS=Ground speed.
GST=Greenwich sidereal time.
H_c=Computed altitude (from assumed or DR position).
H_o=Observed altitude (sextant altitude corrected for refraction, etc.).
H_s=Sextant altitude (uncorrected).
IC=Index correction.
Lat=Latitude
LHA=Local hour angle.
Long=Longitude.
LP=Line of position.
M=Meridian of observer.
mb=Millibar.
MC=Magnetic course.
MH=Magnetic heading.
m. p. h.=Miles per hour.
O=Origin, or starting point.
Par=Parallax.
RA=Right ascension.
R/A=Radius of action.
RBn=Marine radiobeacon.
RC=Radio compass (naval radio direction finder station).
Ref=Refraction.
RM=Radio marker beacon.
RRa=Radio range station.
RS=Radio station (commercial broadcast).
SD=Semidiameter.
SHA=Sidereal hour angle.
SP=Seaplane port.
TC=True course.
TH=True heading.
Var=Variation.
W=Wind (direction and velocity).
WC=Wind correction angle.
Z=Azimuth or bearing.
☽=Moon.
*=Star.
☉=Sun.
♈=Vernal equinox (first point of Aries).

Table 7.—Code adopted for airway use

A .—	M ——	Y —.——
B —...	N —.	Z ——..
C —.—.	O ———	0 ——
D —..	P .——.	1 .——
E .	Q ——.—	2 ..—
F ..—.	R .—.	3 ...—
G ——.	S ...	4 ....
H	T —	5 .—.
I ..	U ..—	6 —.—
J .———	V ...—	7 —..
K —.—	W .——	8 —...
L .—..	X —..—	9 ——.

Table 8.—Airports of entry

As of August 15, 1940

WITHOUT TIME LIMIT

Location	Name	Location	Name
Akron, Ohio	Municipal airport.	Nogales, Ariz	Nogales Municipal Airport.
Ajo, Ariz	Do.	Ogdensburg, N. Y.	Ogdensburg Seaplane Anchorage.
Albany, N. Y	Municipal field.	Pembina, N. Dak.	Fort Pembina Airport.
Brownsville, Tex	Brownsville-Pan American Airport.	Portal, N. Dak	Portal Airport.
Buffalo, N. Y	Buffalo Airport.	Port Angeles, Wash.	Port Angeles Airport.
Caribou, Maine	Caribou Municipal Airport.	Port Townsend, Wash.	Port Townsend Airfield.
Cleveland, Ohio	Cleveland Municipal Airport.	Put-in-Bay, Ohio	Put-in-Bay Airport.
Detroit, Mich	Detroit Municipal Airport.	Rochester, N. Y	Rochester Municipal Airport.
Do	Ford Airport.	Rouses Point, N.Y.	Rouses Point Seaplane Base.
Do	Wayne County Airport.	San Diego, Calif	San Diego Municipal Airport (Lindberg Field).
Douglas, Ariz	Douglas International Airport.	San Juan, P. R	Isla Grande Airport.
Duluth, Minn	Duluth Municipal Airport.	Seattle, Wash	Boeing Field.
Do	Duluth Boat Club Seaplane Base.	Do	Lake Union Seaplane Base.
Eagle Pass, Tex	Eagle Pass Airport.	Skagway, Alaska	Skagway Municipal Airport.
El Paso, Tex	El Paso Airport.	Swanton, Vt	Missisquoi Airport.
Fairbanks, Alaska	Weeks Municipal Airfield.	West Palm Beach, Fla.	Roosevelt Flying Service Base (Currie Common Park).
Juneau, Alaska	Juneau Airport.	Wrangell, Alaska	Wrangell Seaplane Base.
Key West, Fla	Meacham Field.		
Laredo, Tex	Laredo Airdrome.		
Miami, Fla	Pan American International Seaplane Base.		
Do	Pan American Airways Airport (or 36th St.).		

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Table 8.—Airports of Entry—**Continued**

As of August 15, 1940

TEMPORARY (1 YEAR)

Location	Name	Date designated
Alexandria Bay, N. Y.	Wellesley Farms Airport	May 1, 1940
Do.	Wellesley Farms Seaplane Base	Do.
Bangor, Maine	Bangor Municipal Airport	June 26, 1940
Bellingham, Wash.	Graham Airport	Apr. 18, 1940
Burlington, Vt.	Burlington Municipal Airport	June 29, 1940
Calexico, Calif.	Calexico Municipal Airport	Jan. 10, 1940
Cape Vincent, N. Y.	Cape Vincent Harbor	Apr. 25, 1940
Crosby, N. Dak.	Crosby Municipal Airport	June 28, 1940
Fort Yukon, Alaska	Fort Yukon Airfield	July 6, 1940
Great Falls, Mont.	Great Falls Municipal Airport	June 2, 1940
Havre, Mont.	Havre Municipal Airport	Do.
Malone, N. Y.	Malone Airport	Apr. 18, 1940
Miami, Fla.	Chalks Flying Service Airport	Sept. 17, 1940
Niagara Falls, N. Y.	Niagara Falls Municipal Airport	July 2, 1940
Plattsburg, N. Y.	Plattsburg Municipal Airport	June 2, 1940
Sandusky, Ohio	Sandusky Municipal Airport	June 1, 1940
Sault St. Marie, Mich.	Sault St. Marie Airport	Aug. 4, 1940
Spokane, Wash.	Spokane Municipal Airport (Felts Field)	June 2, 1940
Warroad, Minn.	Warroad Seaplane Base	Sept. 2, 1940
Watertown, N. Y.	Watertown Municipal Airport	June 2, 1940

RADIO TIME SIGNALS

The exact time is of great importance to accurate navigation, both at sea, and in the air. For this reason, radio time signals are broadcast from Arlington, Annapolis, and San Francisco, during the 5 minutes preceding each hour, with a few exceptions. The regular hours and frequencies are changed from time to time. The Naval Observatory, Washington, D. C., will furnish a copy of the schedule to those interested, on request.

Beginning at 5 minutes before the hour, a signal is transmitted each second except the twenty-ninth, to the fiftieth. From the fiftieth second to the end of the minute, signals are broadcast as shown in table 9. Vacant spaces in the table indicate the omission of a signal. Note that the number of signals in the group ending on the fifty-fifth second of each minute indicates the number of minutes yet to be broadcast. The sixtieth signal of each minute marks the exact beginning of the following minute.

With this arrangement of signals, the navigator is afforded many opportunities to check his watch during the 5 minutes, instead of merely waiting for the long dash at the end of the hour. For example, the watch may be checked on the thirtieth and sixtieth second of each minute.

Table 9.—Schedule of Radio Time Signals

Minutes	Seconds										
	50	51	52	53	54	55	56	57	58	59	60
55	—		—	—	—	—					—
56	—	—		—	—	—					—
57	—	—	—		—	—					—
58	—	—	—	—		—					—
59	—										——

PRICE LIST OF AERONAUTICAL CHARTS

All aeronautical charts published by the Coast and Geodetic Survey may be ordered from the Director, Coast and Geodetic Survey, Washington, D. C., or from the field stations of the Bureau at the following places:

10th Floor, Customhouse, Boston, Mass.
620 Federal Office Building, New York, N. Y.
314 Customhouse, 423 Canal Street, New Orleans, La.
307 Customhouse, San Francisco, Calif.
601 Federal Office Building, Seattle, Wash.

These charts are also stocked for sale by the recognized dealers listed below, and at principal airports. Corrections and additions to this list will appear from time to time in the Civil Aeronautics Journal, and the current list may be obtained, upon request, from the Director, Coast and Geodetic Survey.

Prices of charts per single copy are as follows:

Sectional aeronautical charts (1:500,000), 25 cents.
Regional aeronautical charts (1:1,000,000), 40 cents.
Aeronautical radio direction finding charts (1:2,000,000), 40 cents.
3060 b. Aeronautical planning chart, United States, Lambert projection (1:5,000,000); shows principal cities and airports, contours and gradient tints, index of aeronautical charts, and lines of equal magnetic variation at 5° intervals; 40 cents.
3074. Great-circle chart, United States, Gnomonic projection; shows principal airports; 40 cents.
3077. Magnetic chart of the United States, showing the lines of equal magnetic variation (declination) at 1° intervals, and of equal annual change, for the year 1935. This chart is revised at intervals of 5 years, the lines of annual change providing means of estimating variation for intervening years; 20 cents.
Kenai, Alaska (1:1,000,000), 40 cents.
St. Elias, Alaska (1:1,000,000), 40 cents.

A discount of 33⅓ percent from full published prices is allowed on orders for aeronautical and auxiliary charts amounting to $10 (gross value) made in one shipment to one address. They are not returnable.

RECOGNIZED DEALERS IN AERONAUTICAL CHARTS OF THE UNITED STATES COAST AND GEODETIC SURVEY

Alabama:

Birmingham: Municipal airport; Southern Airways, Inc.

Mobile: Bates Field; Oak Air Service, Inc.

Arizona: Phoenix: Sky Harbor Airport; Sky Harbor Air Service, Inc.

California:

Burbank: Union Air Terminal; Pacific Airmotive.

Glendale: Grand Central Air Terminal; Air Associates, Inc., 1100 Airway Drive.[1]

Los Angeles: Fowler Bros., 414 West 6th Street.

Oakland: Municipal airport; Boeing School of Aeronautics.

San Diego: Lindbergh Airport; San Diego Aeromarine Radio and Navigation, Administration Building.

San Francisco: Municipal airport; Pacific Airmotive, South San Francisco, Calif. United States Coast and Geodetic Survey, 307 Customhouse.[1]

Colorado: Denver: Municipal airport; airport manager.

Delaware: Wilmington: Du Pont Airport; airport manager.

District of Columbia: Washington: United States Coast and Geodetic Survey, Room 1128, Commerce Building.[1]

Florida:

Miami: Miami Airport; Embry-Riddle Co., Box 668.

Orlando: Cannon Mills Field; Florida Aeronautical and Supply Co., P. O. Box 2308.

St. Petersburg: Municipal airport; Aviation Sales and Service.

Georgia:

Atlanta: Municipal airport; Aviation Supply Corporation, P. O. Box 57, Hapeville, Ga.[1]

Augusta: Daniel Field; Southern Airways, Inc.

Illinois:

Chicago: Municipal airport; Air Associates, Inc., 5300 West 63rd Street.[1]

Springfield: Municipal airport; Springfield Aviation Co., Inc.

Indiana:

Indianapolis: Municipal airport; Roscoe Turner Aeronautical Corporation.

South Bend: Bendix Field; Indiana Air Service, Inc.

Iowa: Des Moines: Municipal airport; Iowa Airplane Co., P. O. Box 59.

Kentucky: Louisville: Bowman Field; Louisville Flying Service, Inc.

Louisiana:

New Orleans: United States Coast and Geodetic Survey, 314 Customhouse, 423 Canal Street.[1] New Orleans Airport; Henry B. Chapman.

Shreveport: Municipal airport; airport manager, P. O. Box 28.

Maine: Waterville: Municipal airport; Airways, Inc.

Maryland:

Annapolis: Weems System of Navigation.

Baltimore: Logan Field; airport manager, municipal airport.

Massachusetts: Boston: Municipal airport; Inter City Airlines, Inc., East Boston, Mass. United States Coast and Geodetic Survey, 10th Floor, Customhouse.[1]

Michigan: Detroit: Detroit City Airport; General Aircraft Supply Corporation.[1] Wayne County Airport; Board of Wayne County Road Commissioners, 3800 Barlum Tower.

Minnesota:

Duluth: Williamson-Johnson Airport; H. L. Peterson.

Minneapolis: Wold Chamberlain Field; director, municipal airport.

Missouri:

Kansas City: Municipal airport; Bredouw Aeromotive Corporation, Hangar Five.[1]

St. Louis: Lambert Airport; Supply Division, Inc., Robertson, Mo.[1]

New York:

Brooklyn: Floyd Bennett Field; Aeronautical Trading Co.

Buffalo: Municipal airport; Buffalo Aeronautical Corporation.[1]

Garden City: Roosevelt Field; Air Associates, Inc., Building No. 19.[1]

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[1] Dealers have advised that they carry a complete stock of aeronautical charts.

New York:—Continued.
- New York: C. S. Hammond & Co., Inc., 30 Church Street;[1] International Map Co., Inc., 90 West Street; United States Coast and Geodetic Survey, 620 Federal Office Building.[1]
- Rochester: Municipal airport; airport manager, 34 Court Street.[1]
- Schenectady: Schenectady County airport; airport manager.

North Carolina: Charlotte: Municipal airport; Charlotte Flying Service, Inc.

Ohio:
- Cincinnati: Cincinnati Airport; Cincinnati Aircraft Service, hangar No. 2.
- Cleveland: Municipal airport; Sundorph Aeronautical Corporation.
- Columbus: Port Columbus; John T. Corrodi, Inc., Box 185, Bexley Station.
- Dayton: Municipal airport; Moore Flying Service, P. O. Box 753.

Oregon: Portland: Portland Airport; S & M Flying Service.

Pennsylvania:
- Erie: Port Erie Airport; manager, Port Erie Corporation.
- Philadelphia: J. L. Smith Co., 1603 Sansom Street.
- Pittsburgh: Pittsburgh-Bettis; Pittsburgh Institute of Aeronautics, R. F. D., Homestead, Pa.
- Scranton: Scranton Airport; Scranton Airways, Inc., R. F. D. No. 1, Clarks Summit, Pa.

Pennsylvania:—Continued.
- York: Karl Ort, 608 West Poplar Street.[1]

South Carolina:
- Charleston: Municipal airport; Hawthorne Flying Service, Inc.
- Columbia: Municipal airport; Hawthorne Flying Service, Inc.

Tennessee: Memphis: Municipal airport; Southern Air Services, Inc.

Texas:
- Amarillo: English Field; Amarillo Airport Corporation.
- Dallas: Love Field; Air Associates, Inc.[1]
- Fort Worth: Meacham Field; Airport News Stand.
- Houston: Municipal airport; Air Activities, Inc.
- San Antonio: Stinson Field; Hangar Six, Inc.

Utah: Salt Lake City: Municipal airport; Thompson Flying Service, Inc.

Washington:
- Seattle: United States Coast and Geodetic Survey, 601 Federal Office Building.[1]
- Seattle: Boeing Field; Washington Aircraft Transport Corporation.

West Virginia: Huntington: Mayes Field; H. G. Mayes, manager.

Wisconsin: Milwaukee: Milwaukee County Airport; Midwest Airways, Inc., Box 147, Cudahy, Wis.

PUBLICATIONS OF THE CIVIL AERONAUTICS ADMINISTRATION

Listed below are the available publications of the Civil Aeronautics Administration and its predecessors, the Civil Aeronautics Authority and the Bureau of Air Commerce. There is a nominal charge for all printed publications issued subsequent to May 1939. The sales price, if any, of each publication is given in the following list.

The publications for which there is a charge must be obtained from the Superintendent of Documents, United States Government Printing Office, Washington, D. C. Others may be obtained from the Publications and Statistics Division, Civil Aeronautics Administration, Washington, D. C.

The rules of the Superintendent of Documents require that remittances be made in advance of shipment of publications, either by coupons, sold in sets of 20 for $1 and good until used, or by check or money order payable to the Superintendent of Documents. Currency may be sent at senders' risk. Postage stamps, foreign money, or smooth coins are not acceptable. A discount of 25 percent is allowable to book dealers and quantity purchasers of 100

[1] Dealers have advised that they carry a complete stock of aeronautical charts.

or more publications, on condition that the purchasers will adhere to the public sales price set by the Superintendent of Documents and that publications shall not be overprinted with any advertising matter.

Publications sold by the Government Printing Office are announced in regular lists issued by that office. These lists are sent to all depository libraries. Announcement of all publications is made in the CIVIL AERONAUTICS JOURNAL and in the WEEKLY NOTICE TO AIRMEN which is posted on the bulletin board at each airport.

CIVIL AERONAUTICS JOURNAL

This is the official periodical of the Civil Aeronautics Administration and the Civil Aeronautics Board. Published on the 1st and 15th of each month, it carries articles and news items dealing with civil aeronautics; information as to certificates and approvals issued; and notice of the issuance of new or revised publications. News of projects is emphasized but other information also is carried, particularly statistical material on scheduled air carriers and the miscellaneous operations and accidents, and aircraft manufacturing. A special section of the JOURNAL is devoted to official actions of the Civil Aeronautics Board. In this, all opinions, orders, and regulations are abstracted so as to give brief but complete descriptions. Volume 1, number 1 of the JOURNAL was issued on January 1, 1940, replacing the old monthly Air Commerce Bulletin. Subscription price of the CIVIL AERONAUTICS JOURNAL is $1 per year in the United States. Foreign subscriptions $1.50 per year. Single copies are sold at 5 cents each.

ANNUAL REPORT

First annual report of the Civil Aeronautics Authority, 1939, 25 cents per copy.

CIVIL AERONAUTICS BULLETINS

No. 3. Aircraft Accidents and Casualties.[1] September 1, 1938.
No. 4. State Aeronautical Legislation Digest and Uniform State Laws. October 1, 1939. 15 cents per copy.
No. 5. Flight Instructor's Manual. Revised. 30 cents.
No. 10. Airport Lighting.[1] September 1, 1938.
No. 11. Directory of Airports and Seaplane Bases. September 1, 1939. Issued in seven parts, each part covering the states in the corresponding C. A. A. field region. 10 cents per part.
No. 12. Air Marking.[1] October 1, 1938.
No. 22. Digest of the Civil Air Regulations for Student Pilots (3d edition). 20 cents.
No. 23. Civil Pilot Training Manual. 50 cents.
No. 24. Practical Air Navigation (Formerly U. S. Coast and Geodetic Survey Special Publication No. 197). $1.
No. 25. Meteorology for Pilots. 75 cents.
No. 26. Aerodynamics for Pilots. 30 cents.
No. 27. Pilots' Airplane Manual. 30 cents.
No. 28. Pilots' Powerplant Manual. 75 cents.
No. 29. Pilots' Radio Manual.[1]
No. 30. Ground Instructor's Manual. 15 cents.

MAP

Airway Map of the United States.[1] November 1, 1938.

LOG BOOK

Student Pilot Log Book. Designed for use in conjunction with the Civilian Pilot Training Program's controlled private flying course. 15¢ per copy.

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[1] Prices of these new publications and revisions not established at time of this printing.

PAMPHLETS

Statistical Study of Registered Civil Aircraft as of January 1, 1939. July 1939.

The Use of the Airway Radio Range and Other Radio Aids. October 1939.

Aeronautical Lights and Obstruction Marking Manual. December 1939.

MISCELLANEOUS

Tabulation of Air Navigation Radio Aids, issued monthly.

Aeronautical Trade Directories:

Lists of firms engaged in aeronautical activities. (Please request the list of companies engaged in the specific commodity in which you are interested.)

Lists of aeronautic publications:

Publications on various aeronautical subjects. (Please request list covering specific subject in which you are interested.)

Index to aeronautical navigation charts:

Aeronautical charts issued by the Coast and Geodetic Survey. Notices of new or revised editions are carried each month in the JOURNAL.

AERONAUTICS BULLETIN

No. 27. Aeronautic Radio. July 1, 1937.

TECHNICAL REPORTS

SAFETY AND PLANNING REPORTS

No. 1. Report on the Status of Instrument Landing Systems. October 1937.

No. 2. Report on 125-Megacycle Airport Traffic-Control Tests at Indianapolis. January 1938.

No. 3. Preliminary Report on a Four-Course Ultra-High-Frequency Radio Range. January 1938.

No. 4. Geographical Separation of Radio Range Stations Operating on the Same or Adjacent Frequencies in the 200–400 Kc. Band. January 1938.

No. 6. The Development of an Airways Ultra-High-Frequency Communications Circuit. February 1938.

No. 7. Development of a Safety and Planning Program. April 1938.

No. 8. Report on Cone of Silence Tests at Knoxville, Tenn. April 1938.

No. 9. Directory of Airport Managers or Administrative Officials. June 1939. (Replaces Report No. 9 dated February 1938.)

No. 10. Analysis of the Aviation Medicine Situation and Recommendations for a Bureau Program. April 1938.

DEVELOPMENT REPORTS

No. 2. An Ultra-High-Frequency Aircraft Receiver. September 1938.

No. 3. Aeronautical Light Nomenclature. October 1938.

No. 6. Survey of State Airport Zoning Legislation. June 1939.

No. 7. Tests With Ultra-High-Frequency Radio Transmitting and Receiving Equipment for Itinerant Aircraft Communication. July 1939.

No. 8. Report on Circuit Design for Low-Frequency Radio Ranges. November 1939.

No. 9. Preliminary Investigation of the Effects of Wave Polarization and Site Determination With the Portable Ultra-High-Frequency Visual Radio Range. February 1940.

OTHER PERTINENT PUBLICATIONS

THE CIVIL AERONAUTICS ACT OF 1938

The legislation (75th Cong., Public Law 706) which created the Civil Aeronautics Authority. 10¢ per copy.

AUTHORITY REPORTS TO CONGRESS (see also Annual Report)

Airport Survey—76th Congress, House Document 245. Recommendations as to the desirability of Federal participation in the construction, improvement, development, operation, and maintenance of a national system of airports. 75¢ per copy.

Foreign Rate Study—76th Congress, House Document 478. Investigation as to what extent, if any, the Federal Government should further regulate the rates, fares, and charges of air carriers engaged in foreign air transportation, and the classifications, rules, regulations, and practices affecting such rates, fares, or charges. 15¢ per copy.

ARMY-NAVY-COMMERCE REPORTS

ANC-1 (1) Spanwise Air Load Distribution. April 1938. 60¢ per copy.

ANC-5. Strength of Aircraft Elements. January 1938. 25¢ per copy. (Out of print—may be revised and reissued.)

BUBBLE SEXTANT CORRECTION FOR THE ROTATION OF THE EARTH

Nearly a century ago it was discovered that the rotation of the earth caused moving objects to be deflected to the right (clockwise) in the northern hemisphere, to the left in the southern hemisphere. Under the same force, the bubble of a bubble sextant is also deflected, the amount of the deflection depending upon the latitude of the observer and the velocity of flight.

The corrections for this displacement of the bubble are tabulated below. They are to be applied, not as corrections to the sextant altitude, but by moving each line of position obtained from a bubbles extant observation parallel to itself and in a direction 90° to the right of the track of the aircraft. From this it is obvious that no displacement results for a line of position at right angles to the track; maximum displacement occurs when the line of position is parallel to the track. The corrections may be applied as statute miles or as nautical miles, according to the unit of ground speed with which the table is entered.

Ground speed	Latitude								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
In m. p. h.									
100	0	0	1	1	2	2	2	2	3
150	0	1	1	2	3	3	3	4	4
200	0	1	2	3	3	4	5	5	5
250	0	1	2	3	4	5	6	6	6
300	0	1	3	4	5	6	7	7	8
350	0	2	3	5	6	7	8	9	9
400	0	2	4	5	7	8	9	10	10

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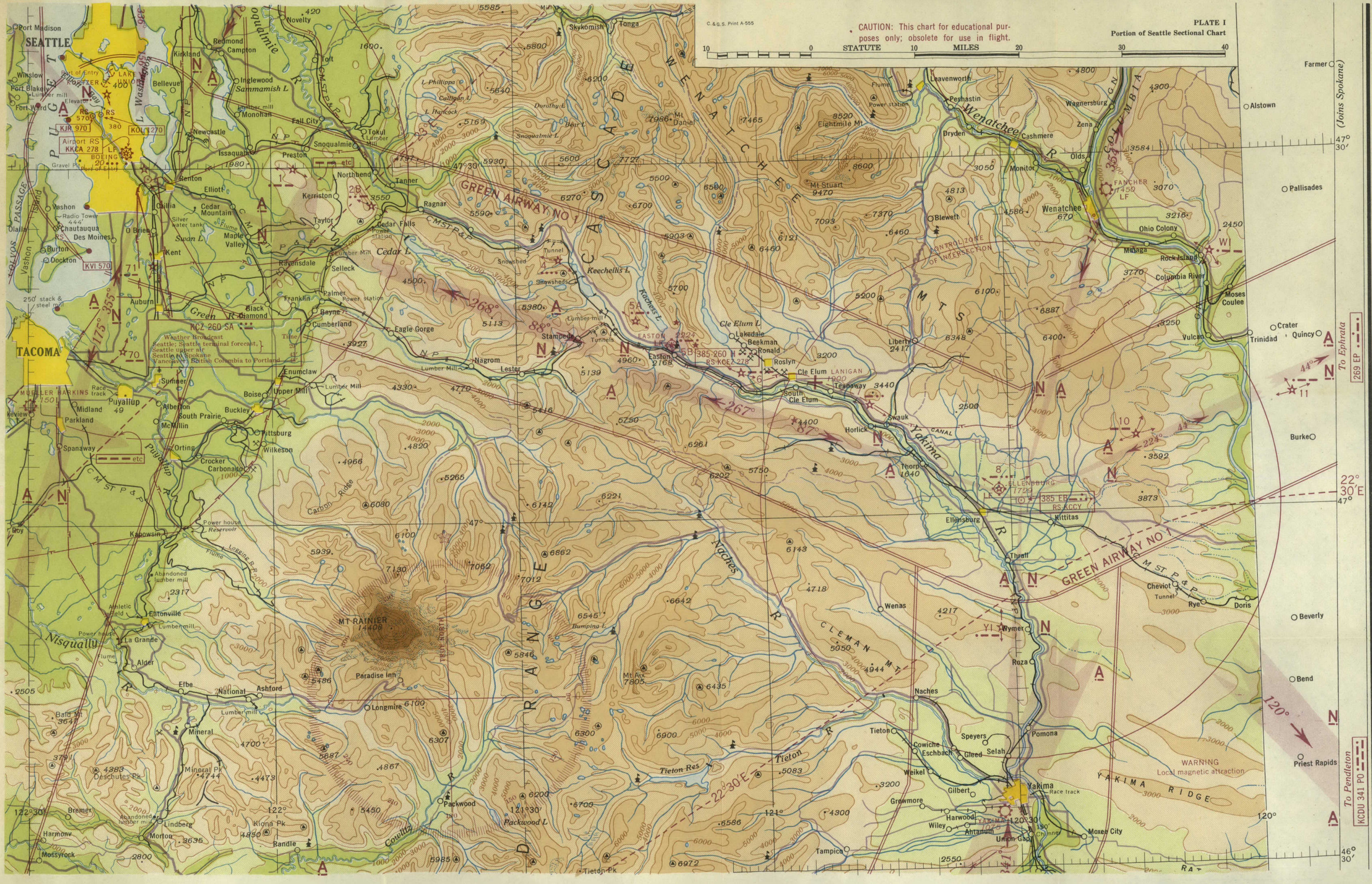
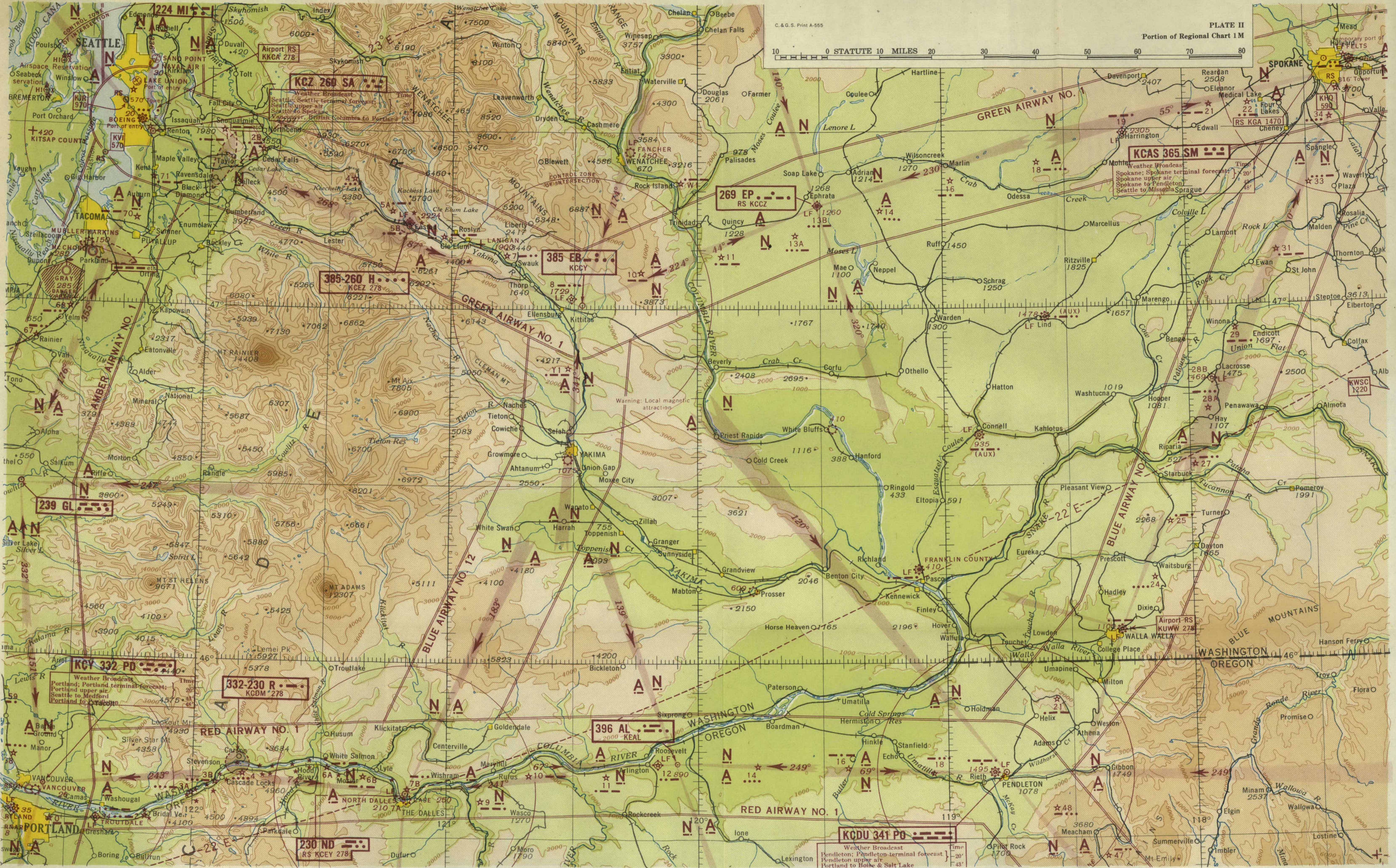
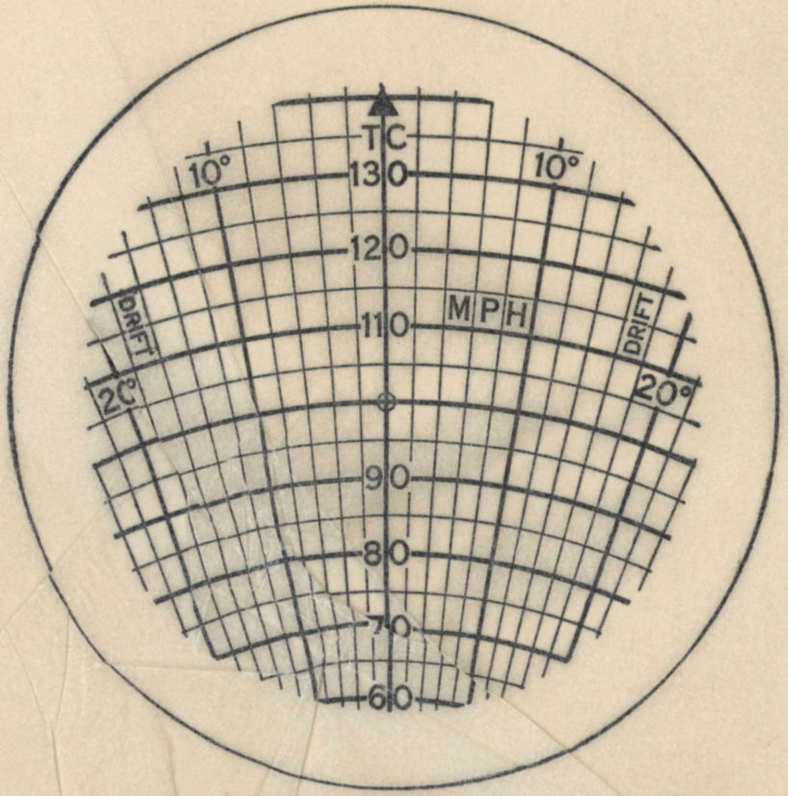


C. & G.S. Print A-555
CAUTION: This chart for educational purposes only; obsolete for use in flight.
PLATE I
Portion of Seattle Sectional Chart
STATUTE MILES
10 0 10 20 30 40
SEATTLE
TACOMA
MT RAINIER 14408
Paradise Inn
Longmire
CASCADE
RANGE
WENATCHEE MTS
Mt Stuart 9470
GREEN AIRWAY NO 1
Ellensburg
Cle Elum
Wenatchee
Yakima
Naches
CLEMAN MT
YAKIMA RIDGE
WARNING Local magnetic attraction
CONTROL ZONE OF INTERSECTION
Columbia River
(Joins Spokane)
To Ephrata
To Pendleton
Puget Sound
Nisqually
Puyallup
Kent
Auburn
Enumclaw
Snoqualmie
Renton
Keechelus L
Cle Elum L
Kachess L
Tieton Res
Packwood L
Mt Aix 7805

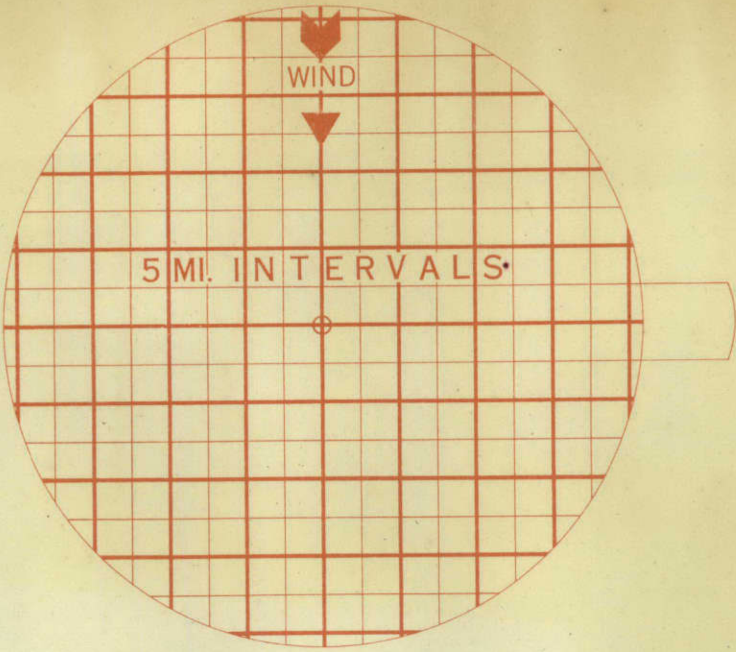

C.&G.S. Print A-555
PLATE II
Portion of Regional Chart 1 M
STATUTE MILES
SEATTLE
TACOMA
PORTLAND
SPOKANE
YAKIMA
WALLA WALLA
PENDLETON
WENATCHEE
ELLENSBURG
THE DALLES
VANCOUVER
GREEN AIRWAY NO. 1
AMBER AIRWAY NO. 1
BLUE AIRWAY NO. 12
BLUE AIRWAY NO. 1
RED AIRWAY NO. 1
KCZ 260 SA
KCAS 365 SM
269 EP
385 EB
385-260 H
239 GL
KCY 332 PD
332-230 R
396 AL
230 ND
KCDU 341 PD
MT RAINIER 14408
MT ADAMS 12307
MT ST HELENS 9671
COLUMBIA RIVER
WASHINGTON
OREGON
BLUE MOUNTAINS
WENATCHEE MOUNTAINS
Warning: Local magnetic attraction

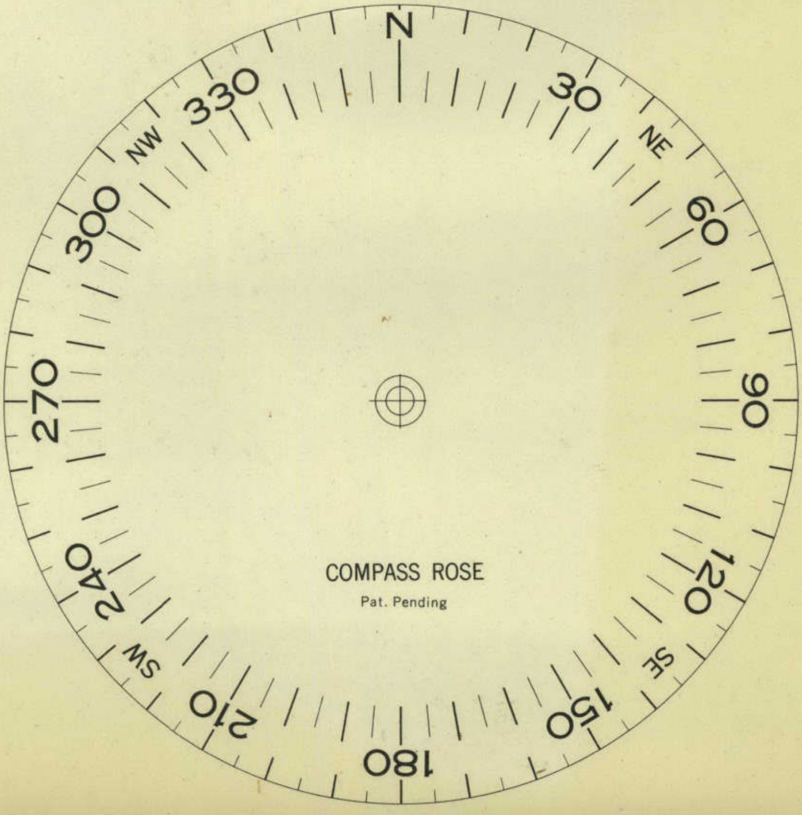
DRIFT GRID

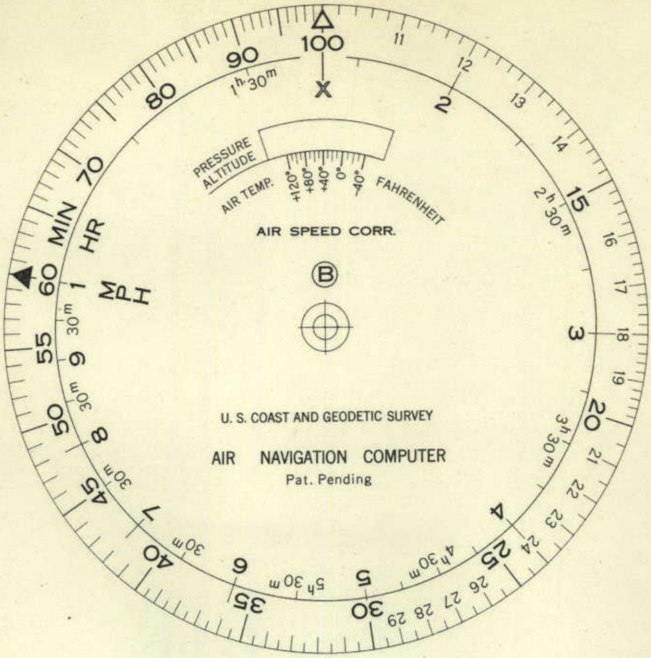


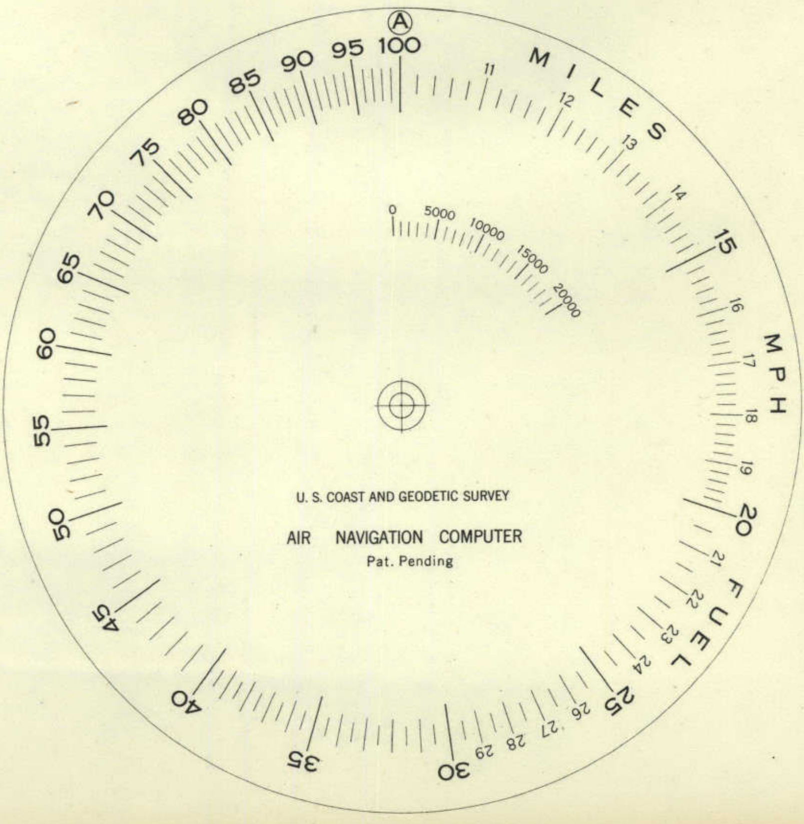
To preserve this Drift Grid plac: a transparent sheet of celluloid or pyratin over the Grid and cement with airplane dope. After the dope has thoroughly dried, trim out the circle and assemble according to instructions on page 139 of Civil Aeronautics Bulletin No. 24.

WIND GRID


WIND
5 MI. INTERVALS


N
30
NE
60
90
120
SE
150
180
210
SW
240
270
300
NW
330
COMPASS ROSE
Pat. Pending


B
PRESSURE ALTITUDE
AIR TEMP.
+120° +80° +40° 0° -40°
FAHRENHEIT
AIR SPEED CORR.
MIN
HR
MPH
U. S. COAST AND GEODETIC SURVEY
AIR NAVIGATION COMPUTER
Pat. Pending


A
MILES
MPH
FUEL
0 5000 10000 15000 20000
U. S. COAST AND GEODETIC SURVEY
AIR NAVIGATION COMPUTER
Pat. Pending