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Third (1939) Edition

PRACTICAL AIR NAVIGATION

and

THE USE OF THE AERONAUTICAL CHARTS OF THE U. S. COAST AND GEODETIC SURVEY

By

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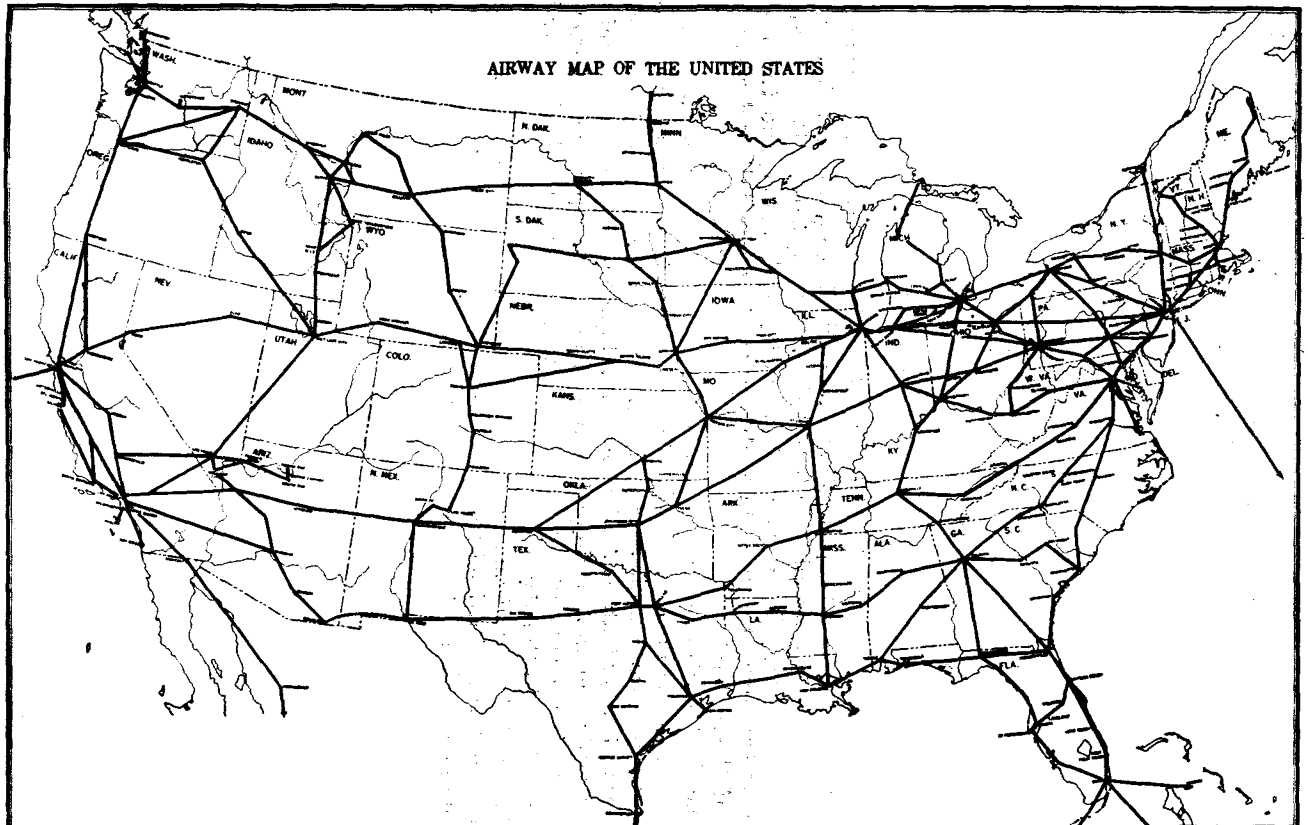
PREFACE TO THIRD EDITION

The aeronautical charts of the United States Coast and Geodetic Survey, because of the projection upon which they are constructed, provide for very simple methods of air navigation. The advantages which they afford were not generally understood, and the purpose of this book has been to enable pilots to make full and efficient use of these charts.

The first edition was quite brief. The second edition was considerably expanded, and chapters on celestial navigation and meteorology were added. In the present edition the entire work has been brought abreast of recent developments as far as possible. The chapter on meteorology has been somewhat expanded in order to meet the needs of the private flying program of the Civil Aeronautics Authority.

The first two editions were very favorably received, and it is hoped that this third edition may also contribute something to the development of practical air navigation.



Frontispiece.—Airway map of the United States.

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INTRODUCTION

The Air Commerce Act of 1926 provided for the charting of airways and the publication of aviation maps necessary for safety in flying and for the further development of air transportation. At that time there were no suitable maps of the country as a whole, nor even maps which could serve as an adequate base for the addition of aeronautical data. A new type of map, especially designed to meet the needs of a new industry, was urgently required, and the technical work of investigating this field, and of compiling and publishing the new maps of the airways was assigned to the United States Coast and Geodetic Survey of the Department of Commerce, with instructions "to provide as adequate charts for air navigation as it now provides for ocean navigation."

In order to satisfy the most immediate and pressing demands, the first maps published for this purpose by the Coast and Geodetic Survey were strip maps of the principal airways. However, it was realized that strip maps could not long meet the need, and in December 1930 an experimental edition of the first sectional airway map was published.

Although these early maps were very favorably received, they were little more than topographic maps showing the characteristic details of the terrain. Many experiments have since been made, resulting in a number of changes and improvements. With the development of more advanced methods of navigation, features that once were considered essential were replaced by others of greater relative importance. Certain items which should be included in a topographic map are now omitted in order not to obscure details of more importance to the navigator; other features are exaggerated beyond topographic justification, because of their landmark value. Thus, with the addition of the system of highly developed aids to navigation, the airway maps gradually assumed the character of the nautical charts so essential for safety at sea, and the designation of these highly specialized publications was changed to aeronautical charts.

The aeronautical chart cannot yet be considered as having reached its final form. Changing conditions of flight (such as higher speeds, longer flights, and higher altitudes) are fairly certain to result in changed methods of navigation, and further changes and improvements in the charts will be required. The chart should not merely keep pace with these advances, but should anticipate them.

Maps in general may be thought of as containing information which is subject to comparatively little change, even over a considerable period. By way of contrast, the aeronautical charts include 25,000 miles of airways equipped with beacon lights, radio ranges, teletype service, and other related features. (See frontispiece.) Over such an extensive system it is obvious that many changes must occur; new airways are being established and old routes rebuilt for more efficient operation; improved equipment is being installed, and aids are even being provided for the navigation of air routes across the oceans. The frequent correction of these charts to show the changes as they occur is a most important function of the Government, and is imperative for safety in all forms of air transportation.

The following aeronautical charts are now being published by the Coast and Geodetic Survey:

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

Regional charts,[1] to cover the whole country, in 17 sheets, at a scale of 1:1,000,000, or about 16 miles to the inch (fig. 2).

Radio direction finding charts, of the entire United States, in 6 sheets, at a scale of 1:2,000,000, or about 32 miles to the inch (fig. 3).

Aeronautical Planning Chart of the United States (chart No. 3060a), 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. 3060a.

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.

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, while the Great-Circle Chart shows the shortest route between any two places. The special uses of these two charts are described and compared more fully on pages 28 and 29.

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[1] Not all the regional charts have been published as yet. A list of those available may be obtained by addressing the Director, U. S. Coast and Geodetic Survey, Washington, D. C.

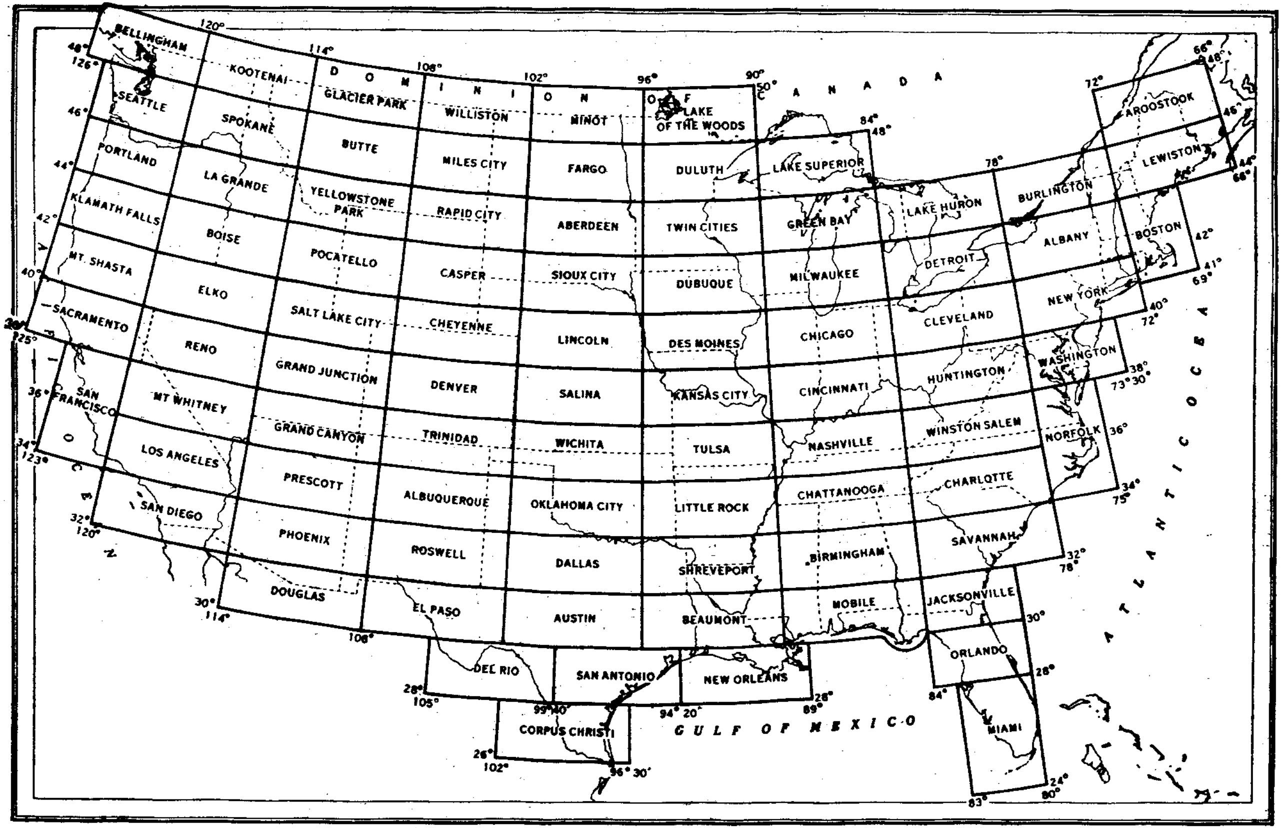

FIGURE 1.—Index of sectional aeronautical charts.

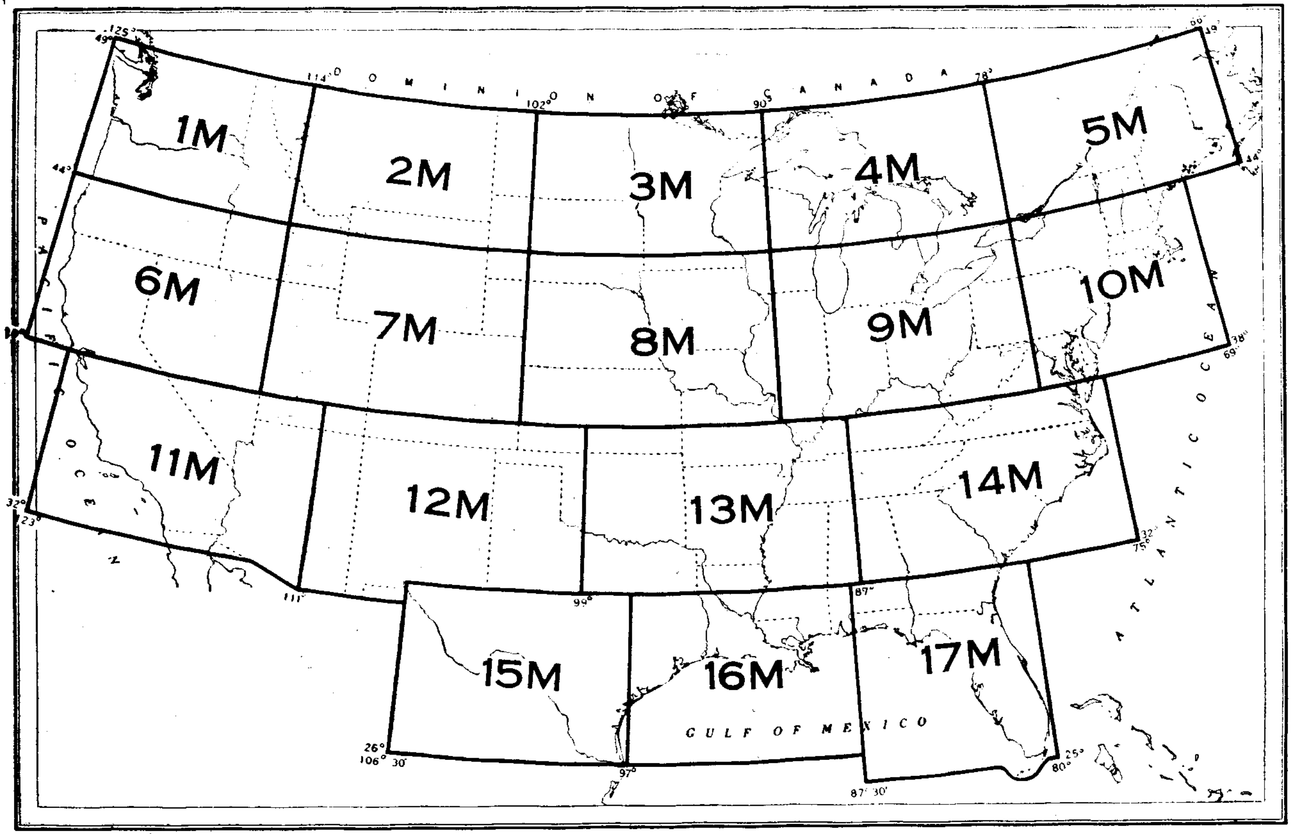

FIGURE 2.—Index of regional aeronautical charts.

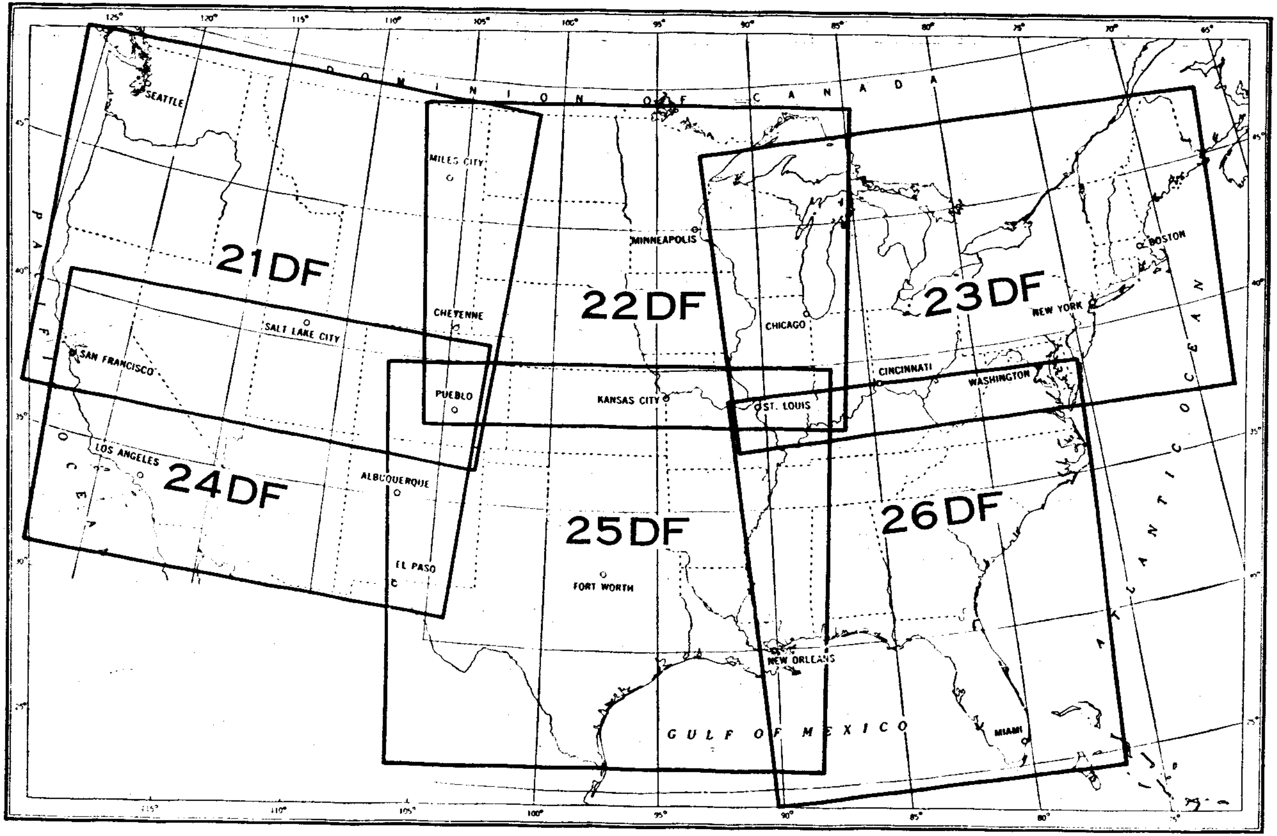

FIGURE 3.—Index of aeronautical charts for radio direction finding.

Chapter I.—CHART READING

THE IMPORTANCE OF CHART READING

An aeronautical chart is 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. Consequently, any time spent in learning to read and interpret its detailed information will be well repaid; that this is beginning to be appreciated is evidenced by the growing demand for these charts.

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 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. Those necessary to a clear and accurate topographic 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:

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

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

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

WATER FEATURES

[See fig. 4]

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.

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 lines of the glacial area, superimposed on the conventional brown.

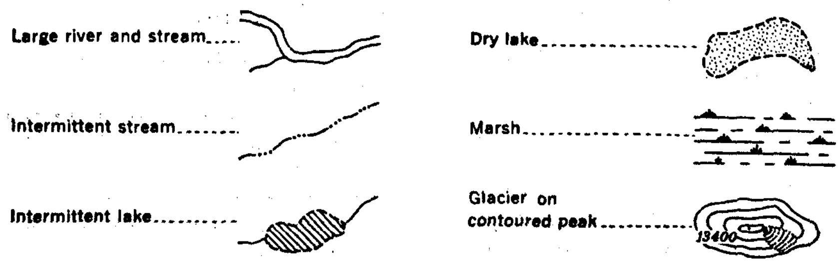

FIGURE 4.—Water features.

CULTURAL FEATURES

[See figs. 5 and 6]

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

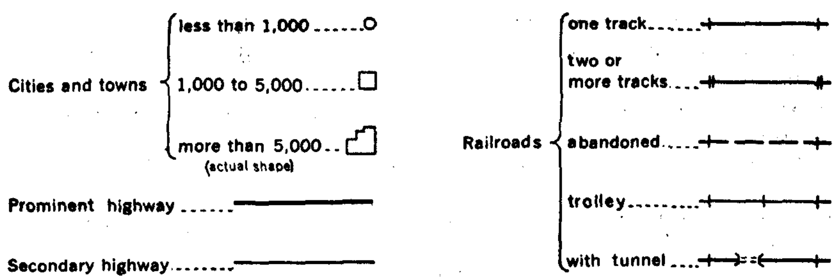

FIGURE 5.—Cultural features.

with crossties at $2\frac{1}{2}$-mile intervals. Thus, when the route parallels a railroad or electric railway, the spacing of crossties provides a convenient check on ground speed and distance covered.

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

Even if a railroad has been abandoned or torn up, the old roadbed is sometimes a prominent feature 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 confronted by a mountain side, 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. In a few instances very poor roads are charted because of 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 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 thickly settled eastern sections there are so many roads that it is impossible even to include all the highly improved roads. 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

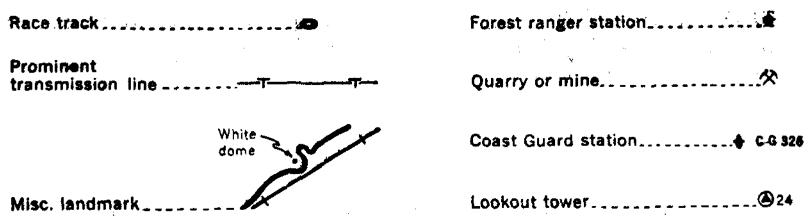

FIGURE 6.—Cultural features (landmarks).

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.

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 (fig. 13). 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.

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 airmarked 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 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 about 2,000 feet. Or, in the case of water features, a 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. 7]

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.

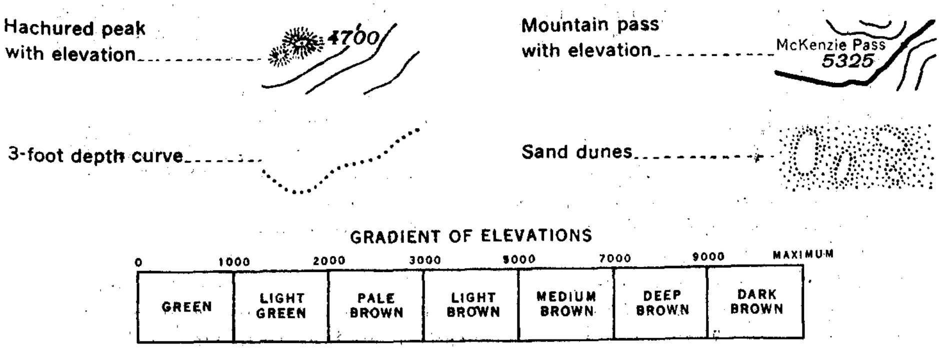

FIGURE 7.—Relief (elevation).

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.

162915°—39——2

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, 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 8 represents a pile of sand from the 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

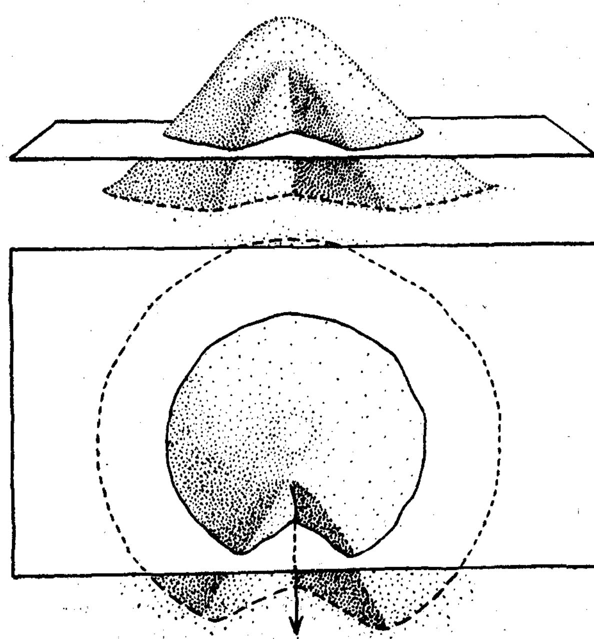

FIGURE 8.—Contours illustrated by a sand pile.

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 altitude.

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 9 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 altitude (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. 10). Now if the sea should rise 1,000 feet, the 1,000-foot contour would become the 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. 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.

The manner in which contours express altitude, form, and degree of slope is shown in figure 11. The sketch in the upper part of the figure represents a river valley that lies between two hills. In the foreground is the sea, with a bay that is partly enclosed by a hooked

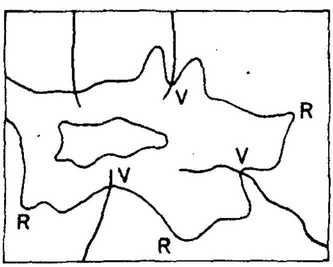

FIGURE 9.—Ridges and valleys shown by contours.

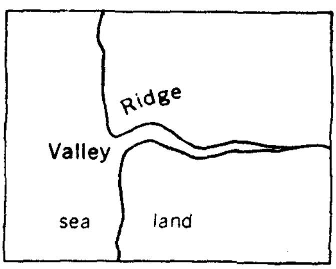

FIGURE 10.—The seashore as a contour.

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 11 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.

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 ris-

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

ing 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 addition of the 3,000-foot contour is not warranted. It should be noted that the gradient tint used in this case (pale brown, see fig. 7), 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. 7), may be thought of as an under-water contour, and every point along the curve is 3 feet

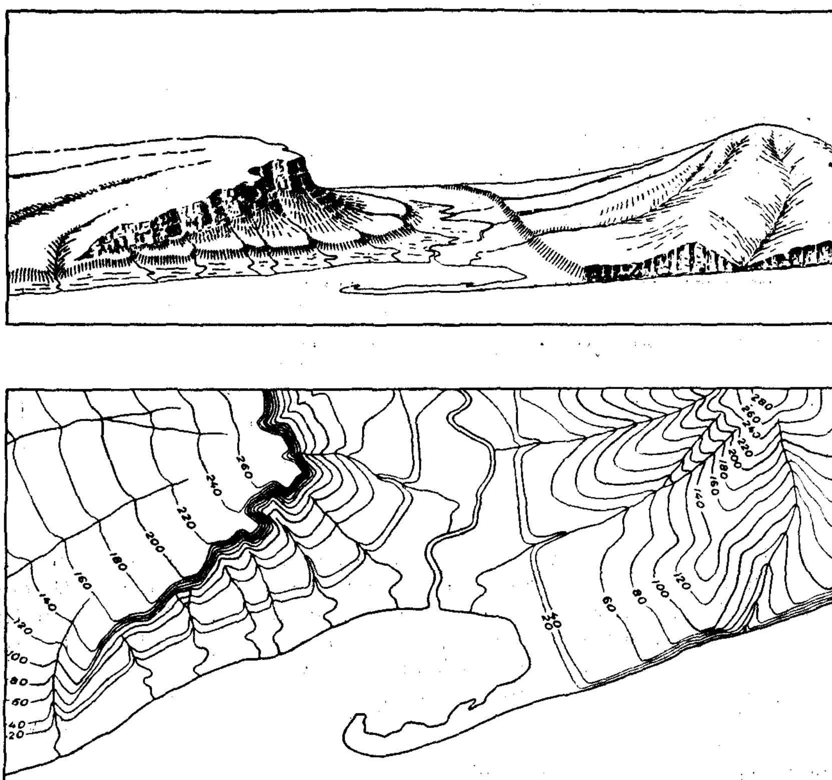

FIGURE 11.—Altitude, form, and slope expressed by contours.

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. 7).

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 INFORMATION

[See figs. 12 and 13]

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

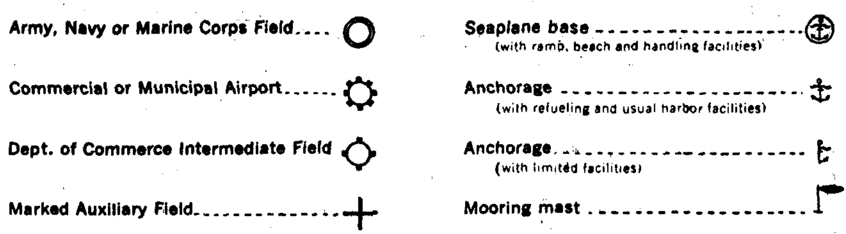

FIGURE 12.—Airport classification.

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.

Airport and airway changes subsequent to the date of printing are listed in the Air Commerce Bulletin (which is published monthly by the Civil Aeronautics Authority, at fifty cents a year), and in the weekly Notices to Airmen (which are posted at 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 the continued availability of facilities shown upon the chart.

Airports are classified as to their operation (whether commercial, municipal, Army, etc.), and are shown in accordance with the accompanying legend (fig. 12). 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.

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

[2] On the radio direction finding charts these features are shown in black.

entry, this fact is noted near the airport name. A complete list of airports of entry is included in the Appendix (p. 178).

Elevations of airports above sea level are indicated by slanting 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 Aeronautics Bulletin No. 11, or obtain local information.

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. Adjacent to the 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.

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 178.

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;

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

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, and should not be flown over at altitudes below 5,000 feet.

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 Wash-

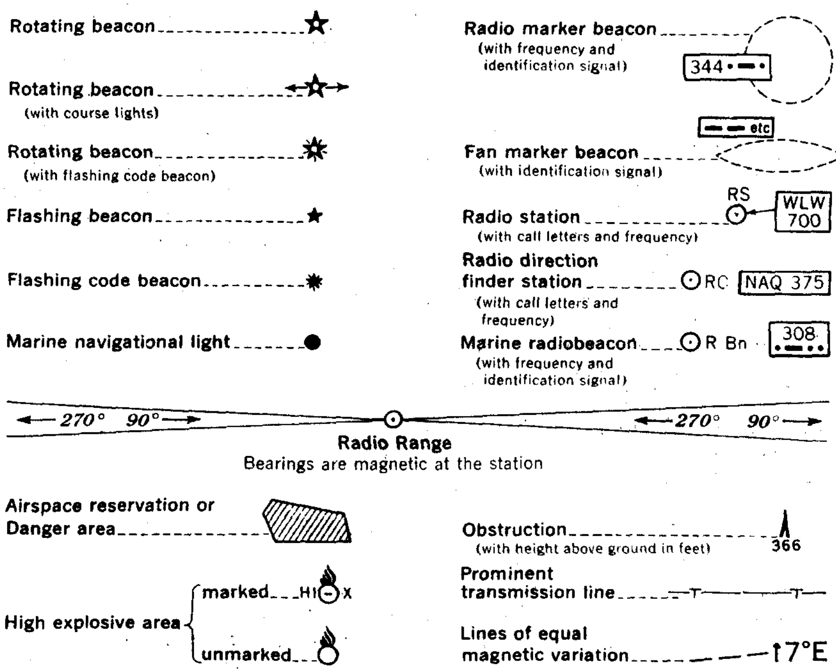

FIGURE 13.—Aeronautical data (miscellaneous).

ington. In such localities the charts are already too congested to indicate the restricted area, and pilots should keep informed of such matters through the Air Commerce Bulletin, 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.

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 toward or away from the station are indicated, and large letters mark the *A* and *N* quadrants of the system. Smaller letters are placed adjacent to and near the end of many of 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 (pp. 52–75).

A radio marker beacon is indicated by a broken circle around the location of the station. The fan-type marker beacons (see p. 64) are shown by a broken ellipse, suggesting the space pattern of these stations.

Weather broadcast schedules, as well as the call letters and identifying signals of the various radio stations, are shown adjacent to the airports to which they apply.

A number of commercial broadcasting stations are shown on the charts. Originally, they were included chiefly because of their danger

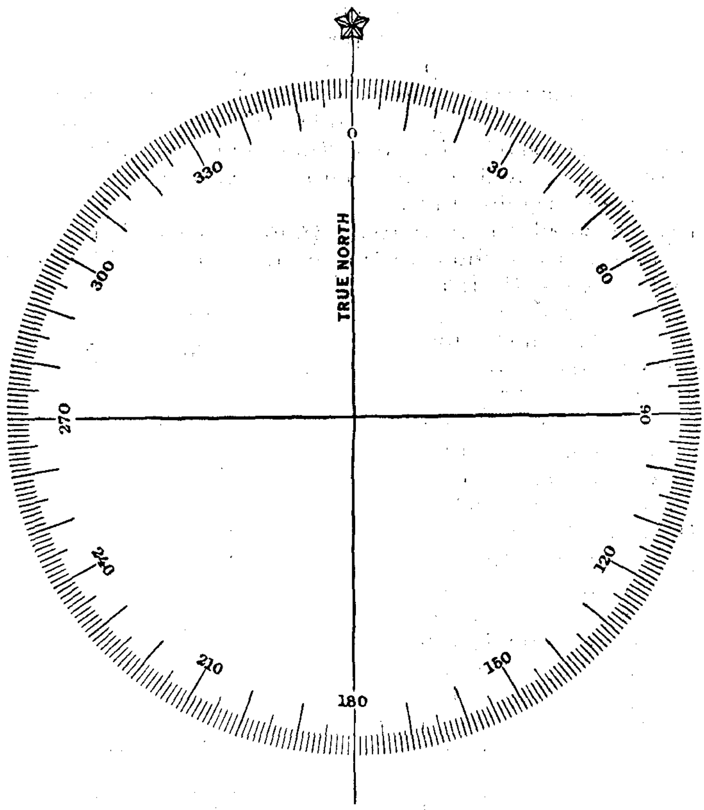

FIGURE 14.—True compass rose (sectional and regional charts).

as obstructions; with the development of the aircraft radio compass, 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*, and the frequency. 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 one 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.

Compass roses (fig. 14), 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 represented on the compass roses, in addition to their representation by isogonic lines.

Specially designed compass roses (fig. 15), 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 plane 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 on pages 69 and 70.

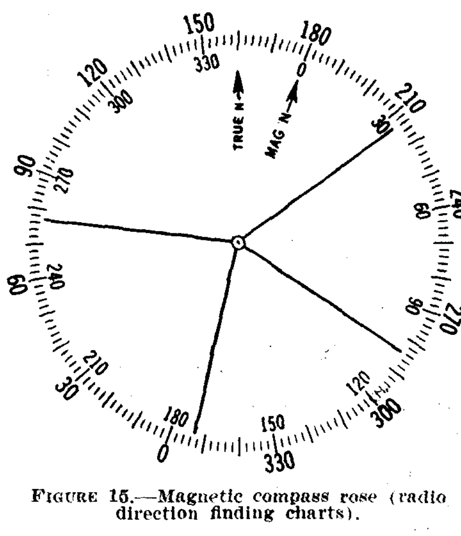

FIGURE 15.—Magnetic compass rose (radio direction finding charts).

PROJECTION AND SCALES

All aeronautical charts of the United States Coast and Geodetic Survey[4] are on the Lambert conformal projection, which affords many advantages for air navigation in the United States. In this projection, variations in scale are extremely small; therefore, in the

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

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. 3060a; 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 $\frac{1}{500,000}$, and is occasionally referred to as the fractional scale, or **representative fraction** of the chart to which it applies.

In the margins of 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. Their use is discussed in a later section (p. 154). On some charts the meridians and parallels have been subdivided into minutes of latitude and longitude; in this case, of course, the marginal scales are unnecessary and have been omitted.

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 15 minutes each way, and every fourth one, representing each whole degree, has been subdivided into minutes. Any point to be plotted will never be very far from one of the meridians and parallels and in most 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]

Should a scale of nautical miles 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.[6]

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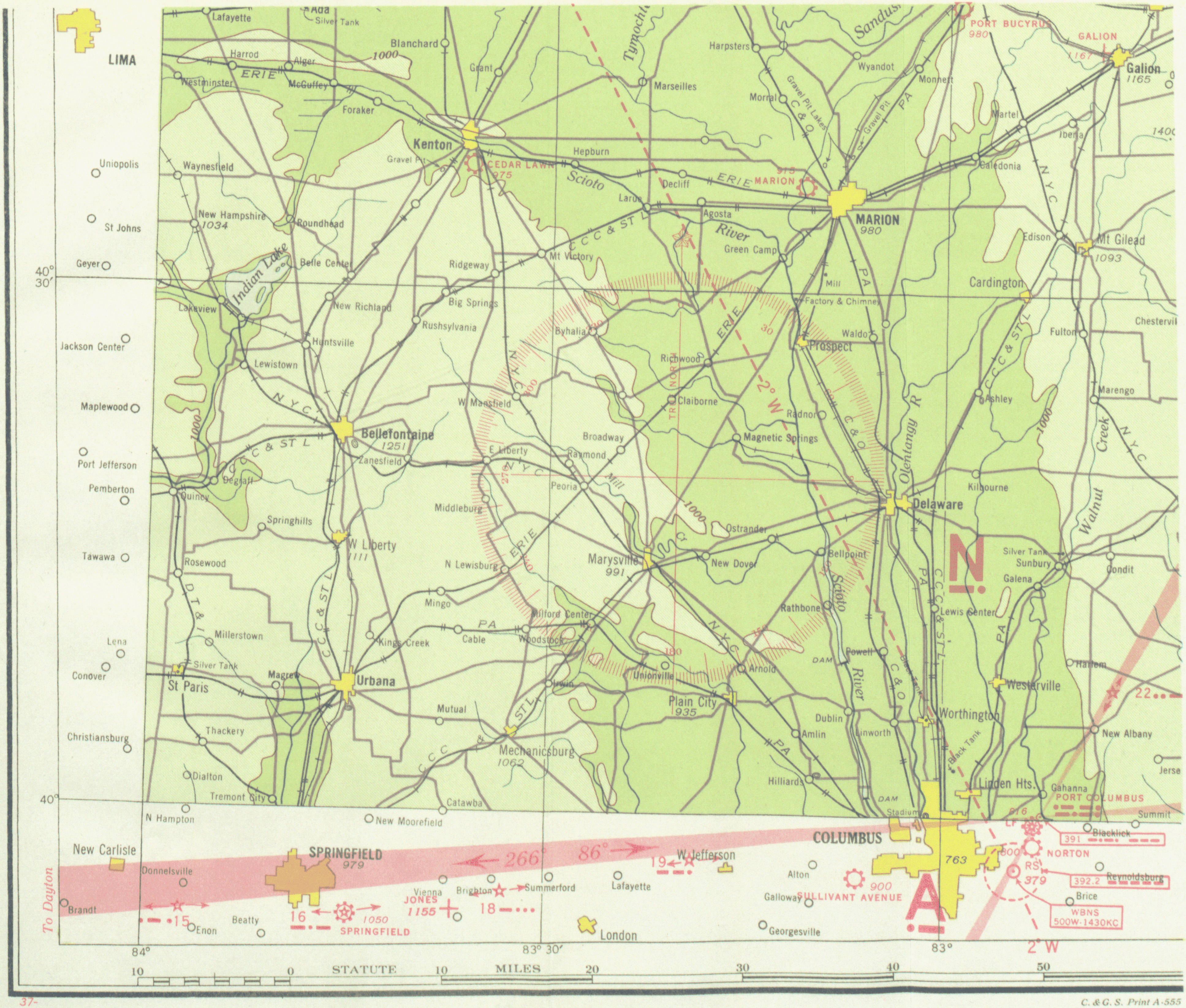
[5] On recent charts of this series the projection interval has been changed to 30 minutes each way.

[6] Since the earth is not a perfect sphere, the length of a minute of latitude varies, increasing with the latitude, from the equator to the poles. In the United States, however, the length of a nautical mile is definitely fixed at 6,080.20 feet.

(Portion of Cleveland Sectional Chart)



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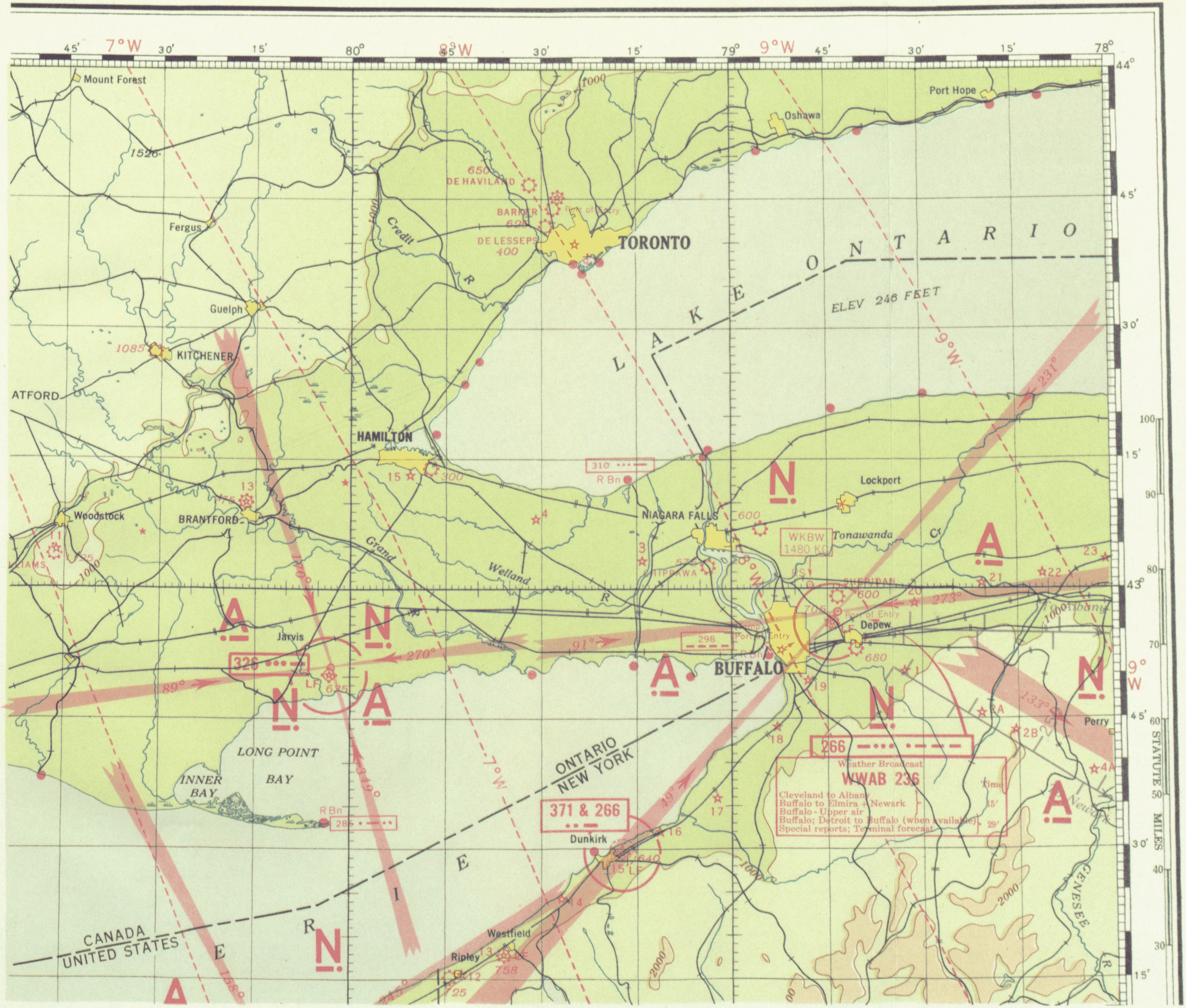
Portion of Regional Chart 9 MN



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Chapter II.—CROSS-COUNTRY FLYING—PILOTING

PROCEDURE

Air navigation is a subject to which much study can be given. Ordinary cross-country flying may be satisfactorily accomplished, however, 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. 21), 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; and the time required for the trip must be checked against the number of hours of daylight yet remaining. However, these factors have to do with the safe operation of the plane, 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 a plane from one place to another solely by reference to visible landmarks is known as **piloting.**

LANDMARKS

The cultural features of the terrain constitute a most important class of landmarks. For example (pl. I), compare the distinctive railroad pattern at Kenton with that at Urbana, or the different highway pattern southeast of Urbana with that southeast of Kenton. 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 stadium in Columbus and the black tank northeast of the city; the black tank in Worthington; the dams on the Scioto River; the mill and the factory and chimney south of

Marion; the gravel pit and "gravel pit lakes" north of Marion; the gravel pit southwest of Kenton; the race tracks at Bellefontaine, Urbana, and Hilliards; and the silver tank at St. Paris.

Intermediate fields and most of the beacons of the Civil Aeronautics Authority 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 steering a course. For example, in flying from Winchester, Va., to Washington, D. C., it is only necessary to head the plane 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 those 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 Springfield Airport to Port Bucyrus (pl. I). After taking off from Springfield and gaining the desired altitude, the edge of the city is circled until the tracks of the Cleveland, Cincinnati, Chicago & St. Louis Railroad are seen. This railroad is followed through Mechanicsburg and Milford Center (identified by railroad crossing; double track) to Marysville. From this point, the highway (identified by its sharp reverse curve) is followed to Marion, then the Pennsylvania Railroad (single track; note gravel pit and gravel pit lakes) in to Port Bucyrus.

STEERING 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 steer the plane so as to keep the two objects in line. This is known as steering 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 steered.

To illustrate the use of ranges, under conditions of good visibility and ceiling, suppose that a flight is planned from Norton Airport, at Columbus, to Cedar Lawn Airport, at Kenton, Ohio (pl. I). After taking off, the airport is circled until the desired altitude is reached; the plane is then headed toward the eastern edge of the built-up area at Linden Heights, which is in line with the center of Worthington (marked by a black tank). Before reaching Worthington, the town of Powell can be seen, on the Chesapeake & Ohio Railroad (double track), and a heading is maintained which will pass just to the left of Powell and just to the right of the bend in the Scioto River (at Rathbone). Continuing on the same heading, the town of Ostrander is reached, and the point where the stream crosses the Marysville-Marion Highway is lined up with the town of Claiborne. From

Claiborne, the plane is headed so that it gradually approaches the highway to Kenton, which can now be seen on the left; upon reaching the highway at Mount Victory, it is followed toward Kenton, and Cedar Lawn Airport is found on the left, just before reaching the city.

If desired, a table such as the following, listing landmarks and other data which may be obtained from a sectional chart, can be prepared for any given route.

Norton Airport (Columbus) to Cedar Lawn Airport (Kenton)

Landmarks	Location with respect to route	Distance from Columbus	Estimated flying time[1]	
		Miles	*Min.*	*Sec.*
Linden Heights	Just west	5	2	45
Black tank	1 mile west	7	3	45
Worthington (black tank)	On course	11	6	0
Powell	Just east; dam on Scioto River, with road to Powell, 2 miles west.	17	9	0
Scioto River (crossing at Rathbone)		21	11	0
Ostrander	Just west	27	15	0
Road and stream crossing	On course; town of Magnetic Springs about 2 miles east.	34	19	0
Claiborne	On course	39	21	0
Mount Victory	On course; crossing of highway and double-track railroad.	52	28	0
Highway to Kenton	*On course; follow to Cedar Lawn (on left)*			
Cedar Lawn Airport	West of highway and railroad; 2 miles south of city.	59	32	0

[1] Flying time estimated from fig. 94, using known cruising speed of plane (100 m. p. h.) plus reported tail wind (10 m. p. h.), or 110 m. p. h.

Sometimes the selection of a range is very easy, as when a road or railroad 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 steering a range that is definitely known to lie along the route, to note the compass heading. This heading is the correct course to steer, 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.

For example (pl. I), the route from Springfield Airport to Marion Airport lies between and roughly parallel to the Erie Railroad and the Springfield-Marion Highway. Flying this route, when a plane was about opposite Marysville a compass heading of 35° was noted. Shortly afterward an area of poor visibility was encountered unexpectedly, but the compass heading of 35° was maintained; on running into better conditions again, near Claiborne, it was found that the plane was still on the intended track, and position could easily be identified from the highway pattern east of Richwood.

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 furnishes an excellent check on the ground speed being made good along the route.

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."

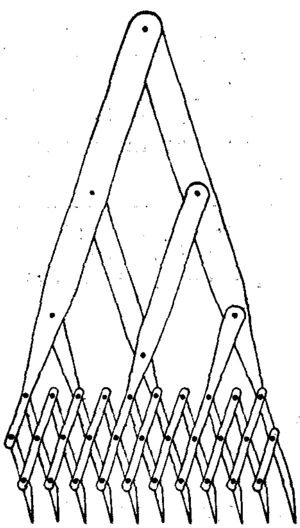


FIGURE 16.—Spacing dividers.

The spacing dividers (fig. 16) 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.

An added reason for dividing the route into time intervals is that the fuel supply is usually reckoned in terms of time, rather than distance. Many pilots prefer, however, 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 usually each tooth will be made to represent 2 minutes of flying time.

Included in the Appendix is a graph which will prove very useful in determining the ground speed and dividing the route into time intervals when spacing dividers are not available. The use of the graph may be illustrated by the example given above, in which a railroad 15 miles distant was crossed in 9 minutes of flying time. Referring to the graph (fig. 94, p. 165), 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. Also, 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 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 chart should then be measured and the points transferred to the larger 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. Chart No. 3060a of the Coast and Geodetic Survey (Aeronautical Planning Chart, United States), may well serve as the smaller-scale chart of the United States. It is especially suitable for this purpose, since it is constructed on the same framework, or projection, as the sectional and regional charts. Its scale is just one-tenth the scale of the sectional charts.

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 transport planes, lack of space usually prevents the use of an unfolded chart. 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

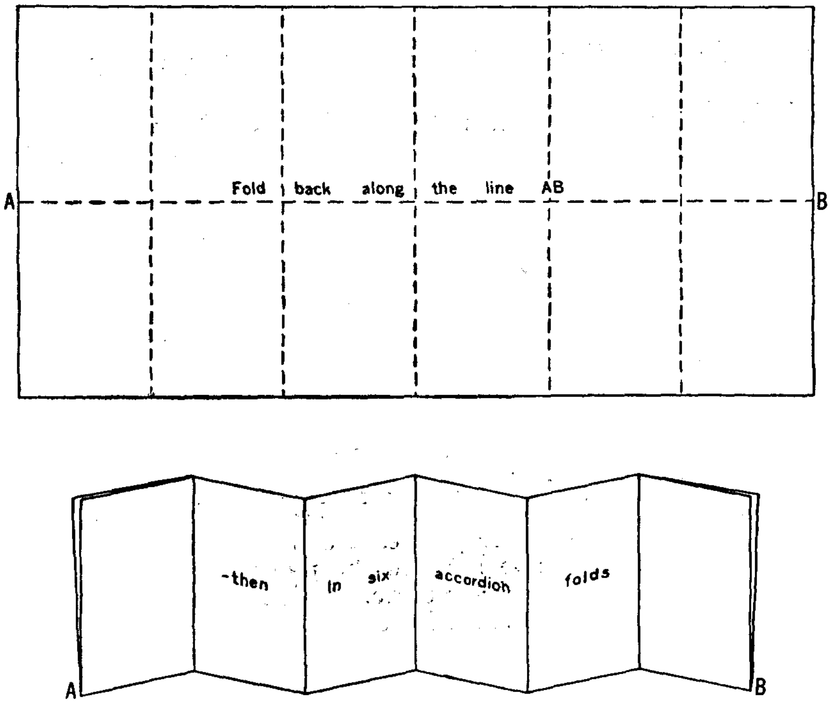


FIGURE 17.—Folding the chart for use in flight.

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. 17), 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.

Strip charts are very convenient for those flying frequently over the same route; however, as already suggested, 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 regulations of the Civil Aeronautics Authority require that pilots engaged in regular transport operations carry in the pilot's compartment charts covering the area at least 75 miles on each side of the airway and beyond each of the terminal involved.

Private pilots are not definitely affected by this requirement, yet compliance therewith is obviously to their advantage. If a strip chart or book is prepared showing only the region immediately

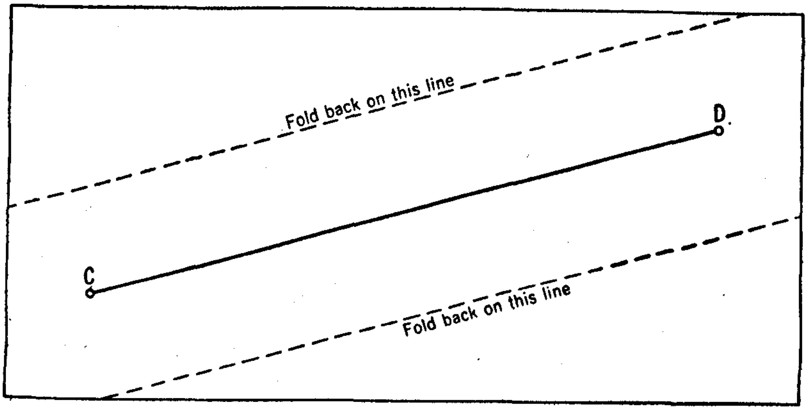
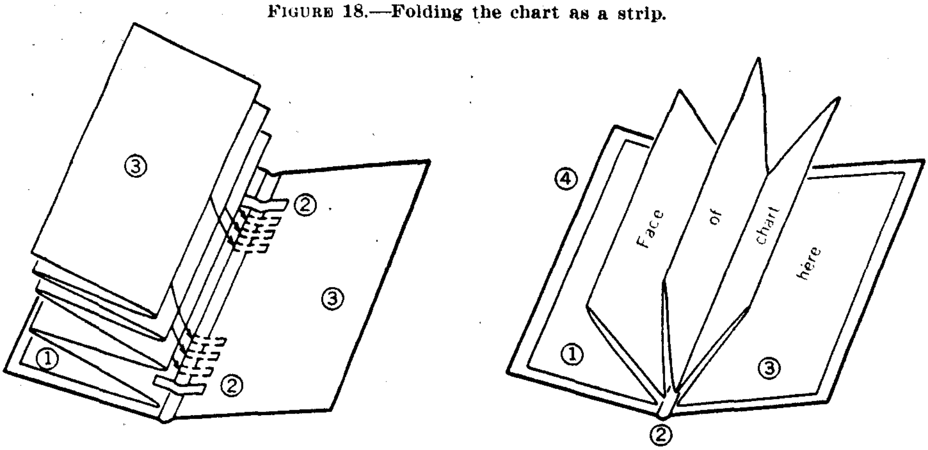


FIGURE 18.—Folding the chart as a strip.



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 19.—Making a route book.

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; however, if such folds are made by pasting portions of the chart together, they cannot be considered satisfactory for all purposes, since the chart cannot be spread flat again for the plotting of new courses, etc. 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 rout *CD* (fig. 18), 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 17. 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. 19.) 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 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 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.

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 the rubber cement is applied to both the surfaces to be joined, and allowed to dry before pressing the surfaces together, a very permanent junction can be made.

Chapter III.—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 a plane 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. 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.

In September 1935 a pilot, flying east, unexpectedly ran into fog just 20 miles east of Pittsburgh. Thinking it only a local condition, the flight was continued until it would have been as dangerous to turn back as to proceed. Relying solely upon dead reckoning, the ship was brought safely over the mountains, although the ground was not seen again until near Hagerstown, Md. If this pilot had been trained only in landmark flying, a crash would have been most probable.

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.

THE LAMBERT CONFORMAL PROJECTION

The solution of all problems of dead reckoning depends entirely upon the projection employed. The Lambert conformal conic projection, which was chosen for the aeronautical charts, was devised nearly 200 years ago, although it did not come into prominence until the World War; at that time it was adopted for the military maps of the Allied forces because it afforded a maximum accuracy in the measurement of distances and directions.

Distance and direction 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 remarkable combination of properties and advantages, among which are the following:

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, or azimuths, conform very closely to directions on the earth, i. e., great-circle directions.
4. It provides the best possible chart for piloting.
5. It affords a simple and satisfactory solution for all problems of dead reckoning, not excepting the rhumb line.
6. It affords the simplest possible means of practical great-circle navigation.
7. It is unsurpassed for all types of radio navigation.
8. It is unusually suitable for celestial navigation and all problems requiring the plotting of positions.

These conclusions were reached after many practical tests by the United States Coast and Geodetic Survey, and anyone particularly interested may obtain further data by addressing the Director of this Bureau.

In the Lambert projection, the meridians of the earth are represented by straight lines converging toward a common point outside the borders of the chart, and the parallels by curved lines which are sections of concentric circles whose center 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 scale error of any single chart is so small that distances may be measured directly by means of the graphic scales printed in the borders. If the entire United States is shown in a single chart (as No. 3060a), the maximum scale error for nearly 90 percent of the chart is about one-half of 1 percent—an error quite negligible in practice.

SMALL-SCALE CONTROL CHARTS

Reference has been made already to the use of chart No. 3060a for laying out routes between widely separated points. A second chart which may be used for this purpose is Coast and Geodetic Survey chart No. 3074, the Great-Circle Chart of the United States. As an aid to the most effective use of these two charts, there follows a brief description of the special properties of each.

Chart No. 3060a is on the Lambert projection and is at a scale of 1:5,000,000, or about 80 miles to the inch, which is exactly one-tenth the scale of the sectional charts. It affords a high degree of accuracy in the measurement of distances between widely separated points, and may also be used for the plotting of radio bearings, the necessary instructions for performing these operations being printed on the chart itself. About 40 of the principal broadcasting stations and 250 of the most important airports are shown in red, facilitating radio compass navigation and the plotting of routes. The plotting of routes is further simplified by an overprint showing the limits of each sectional chart; in this way the pilot may see at once which sectional charts will be required for a projected flight, and also the approximate location of the intended route on each chart. Lines of equal magnetic variation are shown. Courses may also be measured thereon, although in general they should be measured on one of the larger-scale charts, as recommended on pages 29 to 31. A straight line on this 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.

Chart No. 3074, being on the gnomonic projection, can have no constant scale, although it is at approximately the same scale as chart No. 3060a. It is not suitable for the measurement of courses, bearings, or distances, but any straight line on the gnomonic projection represents a precise great-circle track, and the chart is therefore very useful for an exact determination of the great-circle route over long distances. The airports shown on chart No. 3060a are included on this chart also; the radio stations are omitted, however, since the gnomonic projection is not adapted to radio navigation.

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 plane, to determine and plot on the chart the track being made good and the position of the plane 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 37 provides a graphic definition of these terms.

1. TO MEASURE THE TRUE COURSE

In order to understand clearly problems involving directions, it is important to distinguish carefully between a course and a bearing (or azimuth). Figure 20 illustrates the difference between these terms, as well as the methods of measuring courses and bearings on the Lambert projection, between any two points, *A* and *B*. Referring to the figure—

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*.

It should be noted that on the Lambert projection a course is always measured at the meridian nearest halfway between the two points in question; a bearing (or azimuth) is measured at the meridian passing through the place at which the bearing is determined (or to be determined).[1]

[1] For theoretical precision, long courses should be measured with the meridian of middle longitude between the 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.

Both courses and bearings are measured clockwise from the north, from 0° up to 360°.

A course 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); a bearing (or azimuth) is constantly changing as we progress along the route and is different at every point thereon (except for the special cases in which the two points are both on the same meridian, or are both on the equator).

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 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" are identical, but the former term is generally used in radio navigation, the latter in celestial navigation.

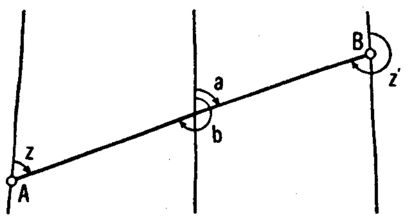


FIGURE 20.—Courses and bearings.

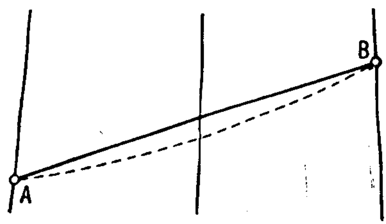


FIGURE 21.—Course and track.

If a course between two points is mistakenly measured as a bearing, with the initial meridian instead of with the meridian nearest halfway, considerable error may result.

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. 20), a plane following that course will not exactly follow the straight line *AB* on the chart, but will slightly depart therefrom near the middle of the route, as indicated by the light, broken line (greatly exaggerated) in figure 21. However, when courses are measured as recommended in the following paragraphs, the departure is so slight that it may be considered that the plane does exactly track the straight line throughout its entire length.

A course measured with the true geographic meridian printed on the chart is the true course.

When the two points are separated by not more than 3° or 4° of longitude the true course may be measured with the meridian nearest halfway, as described above and as illustrated in figure 20, and the entire distance flown as one course.

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 22 illustrates the method of determining the series of true courses to be flown between St. Louis and Minot.

The distance is 862.7 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.

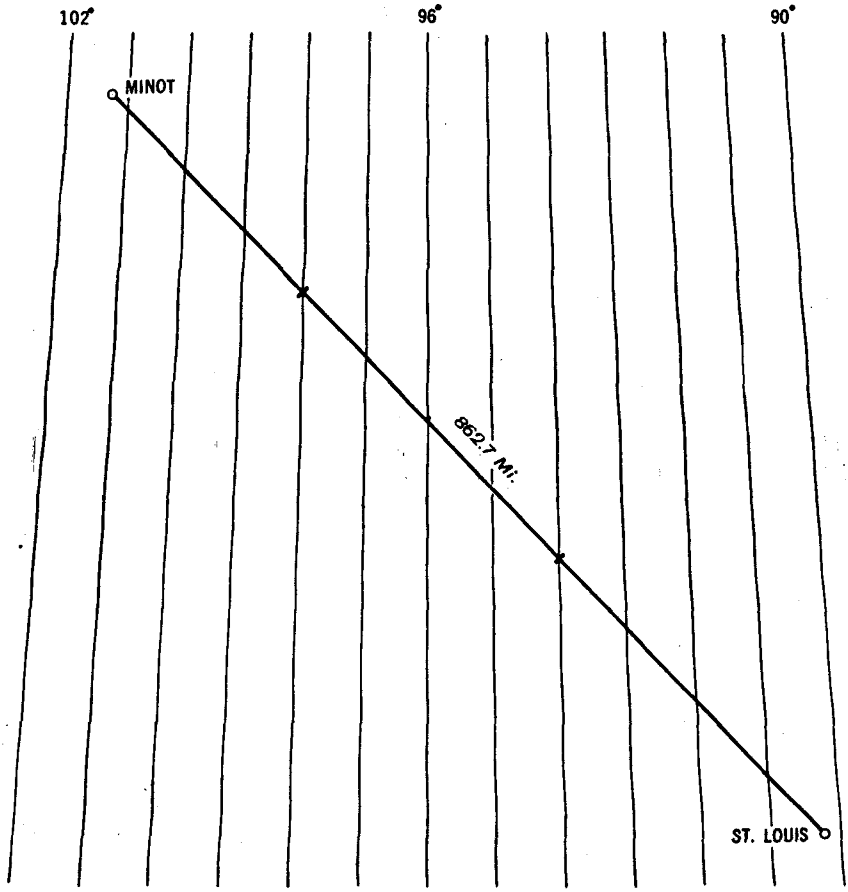


FIGURE 22.—Subdividing a long route.

On the Lambert projection, for all practical purposes, a straight line is the great-circle route (shortest possible distance) between its extremities. The method just outlined 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 necessary, and it is inconvenient to join so many charts; in this case, therefore, the route should first be plotted on one of the small-scale control charts and transferred to the sectional charts, as described on pages 23 and 28.

Some pilots object to making frequent measurements with a protractor. Whenever possible, that is the safest and best procedure, but under conditions of flight there are times when the frequent use of a protractor is impractical, if not impossible.

If the need should arise for laying out a new course while in flight, the straight line may be drawn to the destination on the planning chart itself, and subdivided thereon into convenient sections. With a protractor determine the true course to be followed for the first section; to find the true course for each succeeding section subtract $\frac{6}{10}$ of a degree [2] 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; add $\frac{6}{10}$ of a degree for each degree of longitude for flight in an easterly direction.

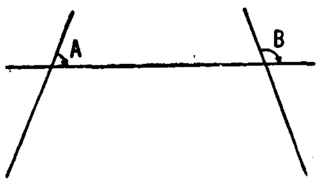


FIGURE 23.—The correction for convergence of meridians.

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 23 will remove any doubt. It is obvious that the course angle at *B* is greater than the angle at *A*; therefore, **add** the correction when going toward *B* (east), **subtract** when going toward *A* (west).

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.

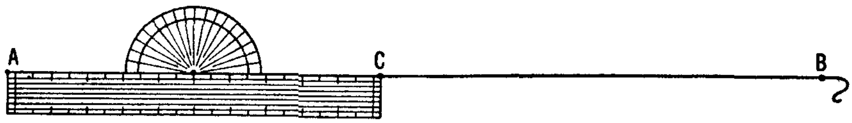


FIGURE 24.—Protractor used as a long straightedge.

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 24. 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. 3060a, 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 knotted

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[2] 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; however, for any ordinary distances it is entirely satisfactory. The maximum course error introduced by using the approximate figure amounts to only $\frac{3}{10}$ 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°.

thread may be inserted in the 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.

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

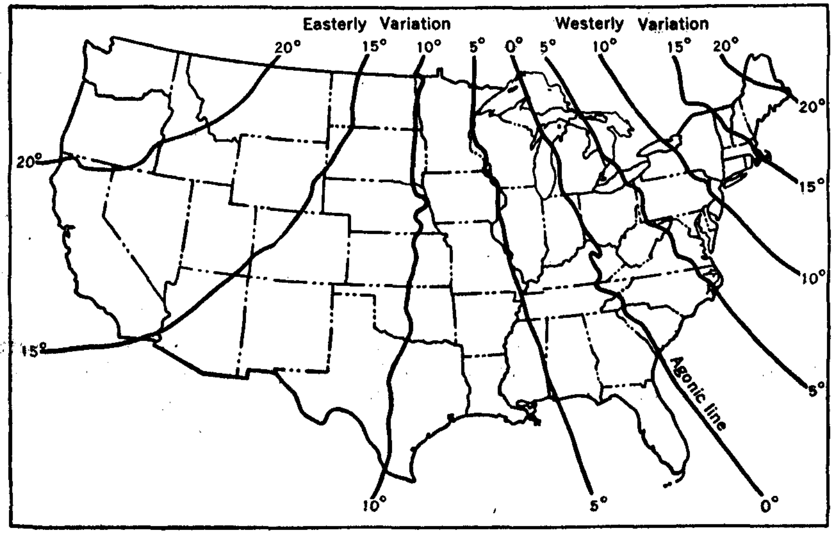


FIGURE 25.—Magnetic variation in the United States, 1935.

compasses 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.[3] 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 25 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 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

[3] 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.

magnetic variation at 1° intervals, may be obtained from the Director, Coast and Geodetic Survey.

At all points along any given isogonic line, the magnetic variation is the same in direction and magnitude. Referring to the figure, it may be seen that in the eastern part of the United States the magnetic compass points **west** of true north (that is, the variation is westerly); in the 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.

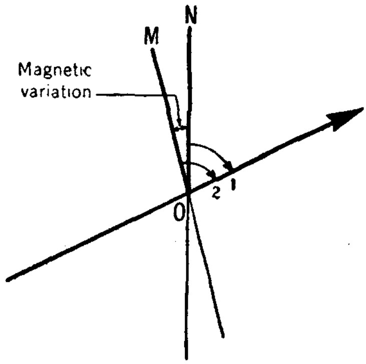


FIGURE 26.—Magnetic variation.

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 26, there will never be any question as to the correct application of magnetic variation.

In figure 26, *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 27. 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 28, 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 29 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.

3. TO FIND THE COMPASS COURSE

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.

This may be seen in a general way from figure 30, in which it is assumed that the aircraft engine *E* exerts a magnetic attraction upon the compass needle *C*. When the airplane is headed approximately along the magnetic meridian *M* (that is, toward magnetic north), the attraction of the engine is exerted in the same direction as the earth's magnetic force, and there would be little or no error in the indication of magnetic north from this cause. When the plane is headed to the left, the attraction of the engine is at right angles to the earth's magnetic force, resulting in a deflection of the needle to the left of

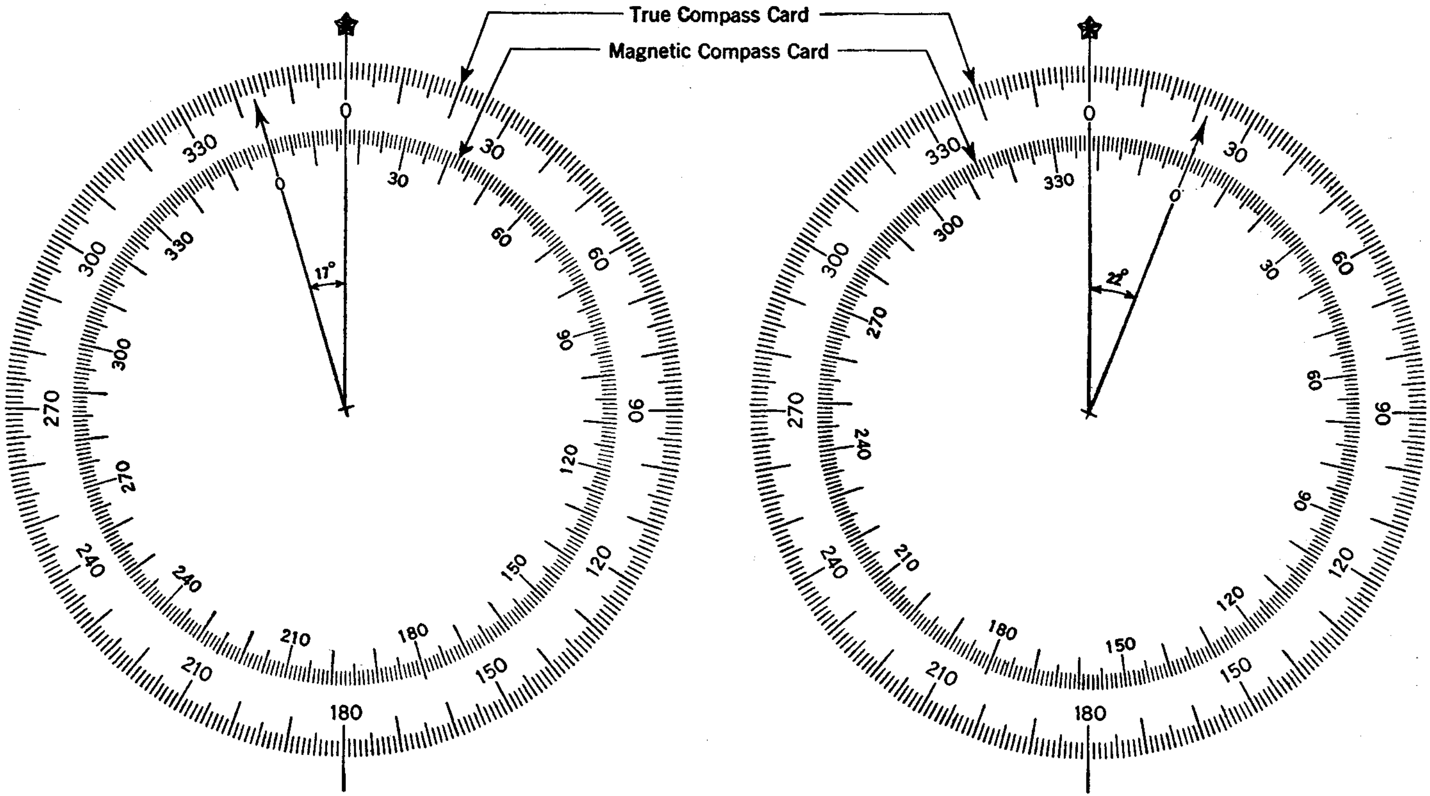


FIGURE 27.—At Portland, Maine, magnetic variation is about 17° west, and the magnetic compass reading is 17° greater than the true for any chosen course.

FIGURE 28.—At Portland, Oreg., magnetic variation is about 22° east, and the magnetic compass reading is 22° less than the true for any chosen course.

magnetic north; when the plane is headed in the opposite direction a deflection of the needle to the right results.

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.

In practice, deviation is not quite so simple, but from the foregoing it will be evident that it 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

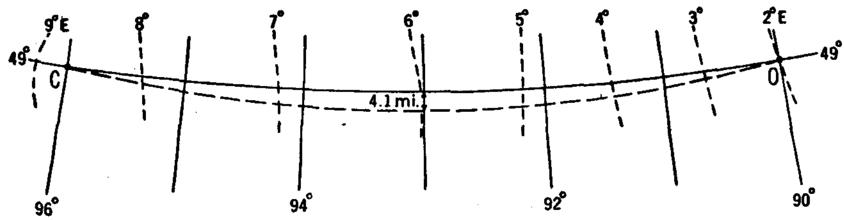


FIGURE 29.—Departure from intended track due to flying a mean magnetic course.

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, p. 38.) 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.**

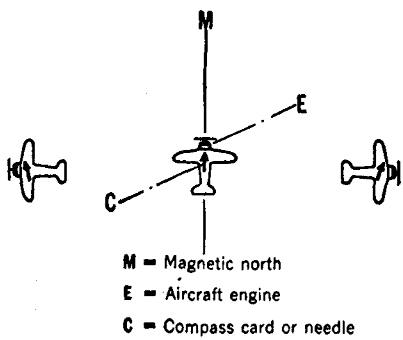


FIGURE 30.—Compass deviation.

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.

At some airports, magnetic stations and compass-testing platforms are available for the adjusting of compasses and the determination of deviation. It is desirable, by "swinging ship," to obtain and tabulate deviation for headings at intervals of 10° or 15°.

For accurate navigation it may prove desirable to have more than one deviation card for each compass; for example, one recording deviation with the plane in flying position and motor running, a second for the same conditions but with navigation lights on, etc. This should not be necessary, however, if the compass is properly installed and compensated.

Deviation is subject to change from time to time, for varying causes; it is also subject to change from place to place, especially where any considerable difference of latitude is involved, and should be checked often—certainly before beginning any important flight.

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.

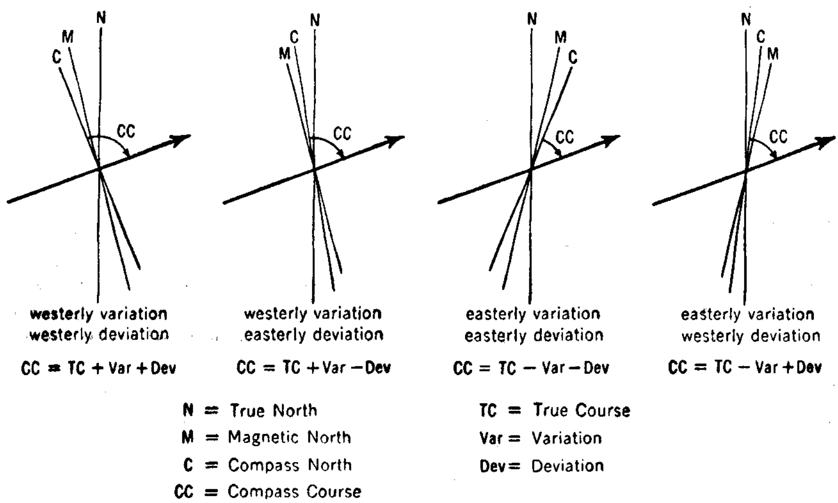


FIGURE 31.—Applying variation and deviation to find the compass course.

Figure 31 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 a plane 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 plane 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 plane is pointed.

Figure 37 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.

A free balloon is carried with the wind and at the same speed as the wind, just as a cork is carried on the surface of a stream. Now if

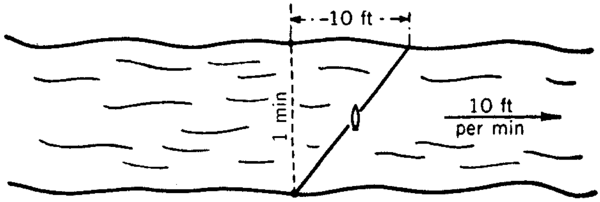


FIGURE 32.—Effect of current on a boat.

we substitute for the cork a toy motorboat which requires a minute to cross a small stream, and the stream is flowing at the rate of 10 feet per minute (fig. 32), even though the boat is headed directly across stream it will still feel the full effect of the current; during the minute of its crossing it will also be swept 10 feet downstream and will reach the opposite bank at a point 10 feet below the point of departure. The solid line of figure 32 represents the path of the boat in crossing the stream. In exactly the same way, an airplane in flight is subject to the full effect of the wind, even though the plane may be moving under its own power in an entirely different direction.

For example, a plane headed due east from *A* (fig. 33) flying at an air speed of 100 m. p. h., should reach *B* (100 miles distant) in

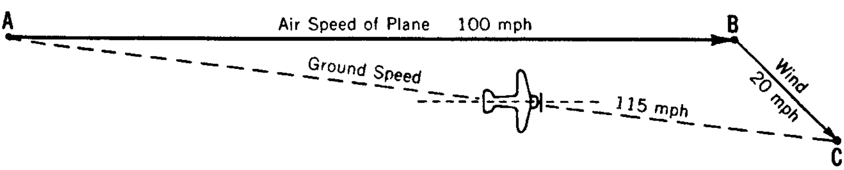


FIGURE 33.—Wind drift.

1 hour; but, during the hour of flight the plane has also been subject to the full effect of a wind of 20 m. p. h., from 315°. As indicated in the figure, it actually reaches *C*, the line *AC* representing the track followed by the plane over the ground. If the length of *AC* is measured by the same scale with which *AB* and *BC* were laid off, we may determine also the speed the plane has made over the ground in passing from *A* to *C*, or 115 m. p. h.

Air speed is the speed of the plane with respect to the air, and is the speed registered by the air speed indicator (when corrected for altitude, temperature, and installation error; see p. 162). It is represented by the line *AB* in the figure.

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

Figure 33 illustrates what would happen if a pilot followed a compass course without regard for wind effect. Under the conditions shown, the plane would pass well south of and beyond its objective, the angle *BAC* being known as the **drift angle.** In order to avoid such an error, the plane must be headed into the wind at such an

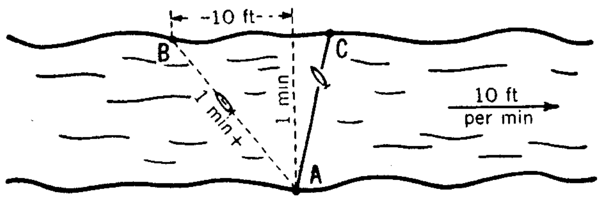


FIGURE 34.—Correcting for the effect of current on a boat.

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 plane must be headed into the wind in order to make good the intended course is known as the **wind correction angle.**

Many pilots think that they have satisfactorily corrected for wind effect if they turn into the wind the same number of degrees as the observed drift angle; however, if we return to the illustration of the toy motorboat, we may see that the wind correction angle is always greater than the drift angle. Referring to figure 34, if the

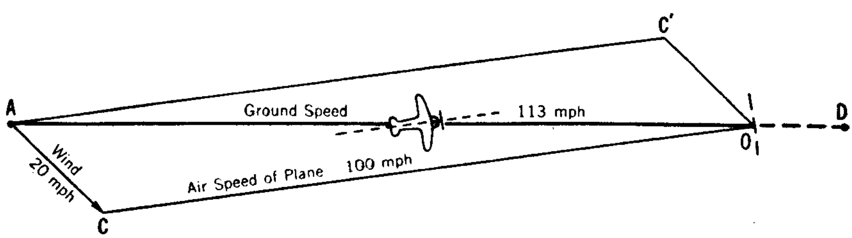


FIGURE 35.—Correction to course for wind, and determination of ground speed.

boat is headed toward a point 10 feet upstream from the starting point *A*, it will require as much time to cross the stream as though it actually traveled the line *AB*. Since the time required is more than 1 minute, the boat will be carried more than 10 feet downstream in crossing and will reach the opposite bank at a point downstream from the starting point, the line *AC* representing the actual track of the boat. To reach the other bank at a point opposite *A*, the boat must be headed toward a point more than 10 feet upstream.

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 A to a distant point, D (fig. 35) is found to be 90°, or due east. From the point of departure, A, on any convenient scale lay off AC to represent the direction and velocity of the wind. From C, with radius equal to the air speed of the plane, describe an arc meeting the intended track at O. Draw AC' parallel to CO, and $C'O$ parallel to AC. In the figure it is now evident that $AC'=CO=$air speed of plane; $C'O=AC=$wind direction and velocity; and the angle $C'AO$ is the wind correction angle, or the number of degrees the plane must be headed into the wind in order to track the line AD 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).

AO 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 A and D can be obtained.

AC' represents the compass heading, or the direction in which the plane must be pointed in order to make good the intended track AD.

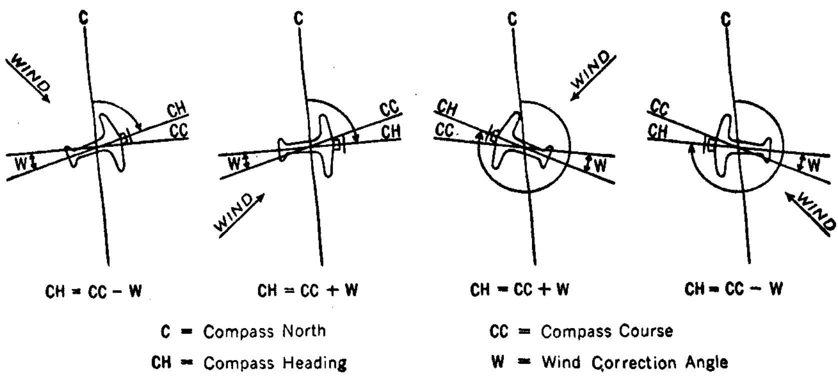


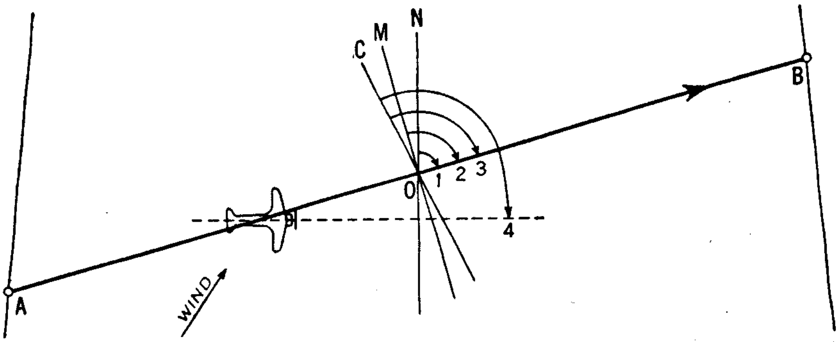
FIGURE 36.—Combining compass course and wind correction to find the compass heading.

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 35, it has been stated that the angle $C'AO$ is the wind correction angle. It is also the drift angle that will be observed in flight as long as the plane is headed in the direction AC' 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 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 Appendix, pages 159–178.

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 36 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.



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 37.—Graphic definition of terms used in dead reckoning.

By comparing the various parts of figure 36 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!

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 the air speed of each particular plane; (b) a general table

giving wind velocities in percent of air speed. For convenient use these percentages should be converted into wind velocities corresponding to the air speed of any given plane.

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

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

By way of summary, figure 37 affords a graphic definition of the terms commonly used in navigation by dead reckoning, and of their interrelation.[4]

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 plane along the track at any time. It may seem that this 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. **Rectify the compass heading for deviation** to obtain the magnetic heading (magnetic direction in which the plane is pointed).
2. **Rectify the magnetic heading for variation** to obtain the true heading (true direction in which the plane is pointed).
3. **Rectify the true heading for wind** to obtain the true course (track) being made good over the ground.
4. **Plot the true course on the chart,** using the same procedure outlined for measuring a course.

---

[4] 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. For this reason some recommend that the 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.

However, 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 in the preceding pages is considered preferable.

1. TO RECTIFY THE COMPASS HEADING FOR DEVIATION

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 we must reverse the process and subtract westerly deviation; easterly deviation, of course, should be added.

2. TO RECTIFY THE MAGNETIC HEADING FOR VARIATION

As with deviation, we must reverse the rule of Case I, subtracting westerly variation and adding easterly variation.

If there should remain any confusion as between adding in Class 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.

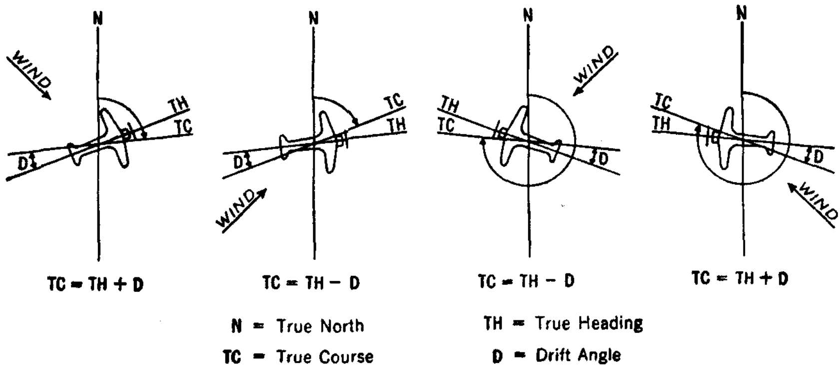


FIGURE 38.—Combining the true heading and drift to find the track (true course made good).

3. TO RECTIFY THE TRUE HEADING FOR WIND

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

Figure 38 illustrates the rectifying of the true heading for wind under varying conditions. By comparing the various parts of the figure, we see that 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 (see example 4, p. 136), 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. Here we must remember again that we are dealing with a course, not a bearing; if we are to avoid error it must be plotted, not with the meridian of the last known position, but with the meridian nearest halfway between that position and the new position.

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 39, *A* marks the last known position of a plane 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^h20^m 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 plane by dead reckoning.

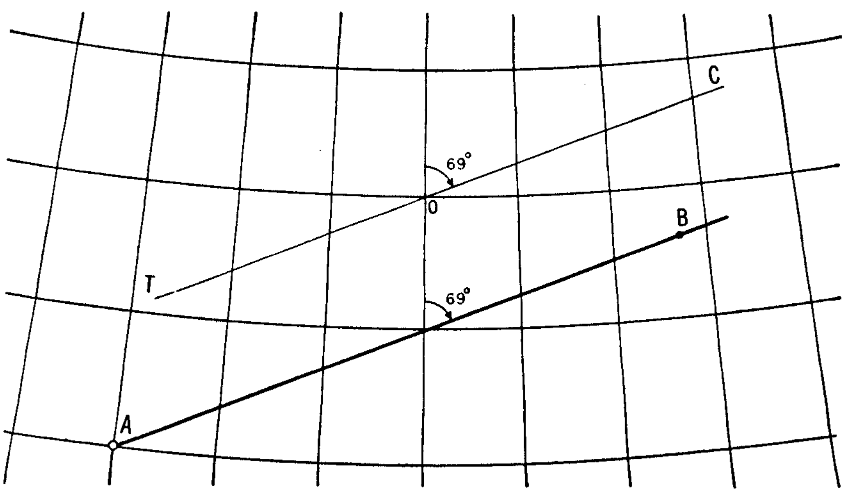


FIGURE 39.—Plotting on the chart the track, or true course made good.

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:	Case II: Compass heading to chart:
1. Measure the true course.	1. Subtract westerly deviation.
2. ADD WESTERLY VARIATION.	2. Subtract westerly variation.
3. ADD WESTERLY DEVIATION.	3. Subtract wind right, i. e., for wind from the right.
4. ADD WIND RIGHT, i. e., add the correction for wind from 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 track is noted, a new course is laid out on the chart from the newly determined position to the destination; by applying variation, deviation, and a revised allowance for wind,

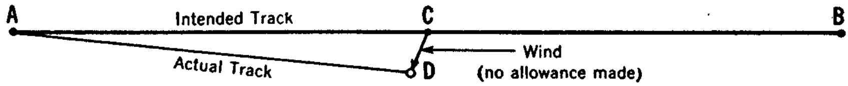


FIGURE 40.—Departure from intended track due to failure to apply correction for wind.

the proper compass heading to make good the course is obtained. 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 40, a pilot is flying from *A* to *B*, 100 miles due east, at 100 m. p. h. After 30 minutes of flight when he should be at *C*, he finds himself directly over a town at *D*. Since he was making no

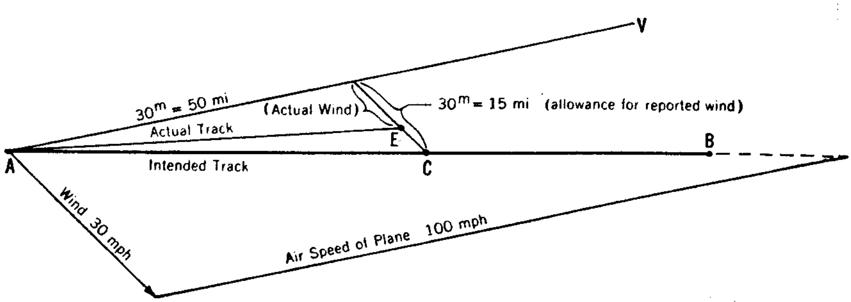


FIGURE 41.—Departure from intended track due to overcorrection for wind.

correction or allowance for wind, the line *CD* represents the direction and velocity of the wind; *AD* is the track, and the angle *CAD* is the drift angle.

In figure 41, 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 *AV* 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 plane 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 plane up with the wind, approaching the intended track directly into the wind (fig. 40), or with the wind (fig. 41). In either case the ground speed may be known from the air speed of the plane 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 courses to be steered on the flight out and on the return trip, the ground speed in each direction, and the time to turn back.

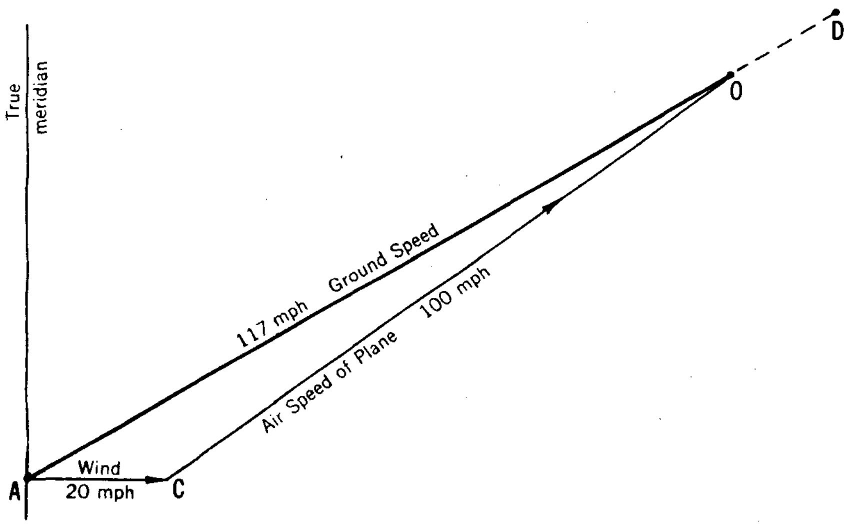


FIGURE 42.—Radius of action; triangle of velocities for flight out.

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 transport 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.[5]

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

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 35. To illustrate, let it be required that a plane fly from A (fig. 42) as far as possible toward a distant point D, and return to A. Cruising speed of plane 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 42 is the triangle of velocities for the flight out, figure 43 the triangle for the return flight. In each case the correct heading to steer is ascertained, and the ground speed that will be made good along the corrected heading.

In practice, these two triangles are usually combined into one figure, as shown in figure 44, in order to save time in laying off angles and distances. 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,

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

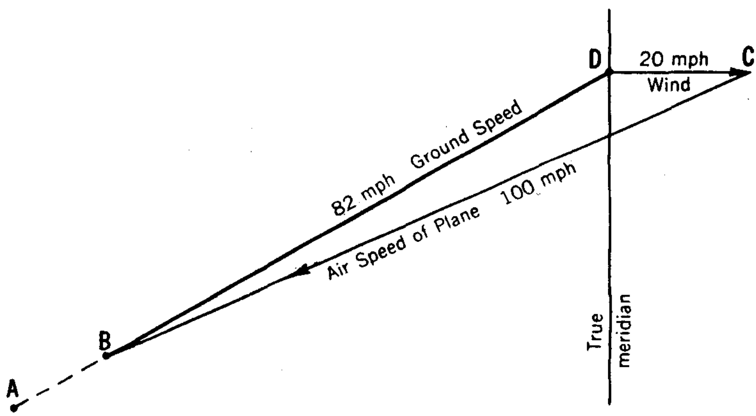


FIGURE 43.—Radius of action; triangle of velocities for return flight.

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 43 would represent the flight out, figure 42 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.

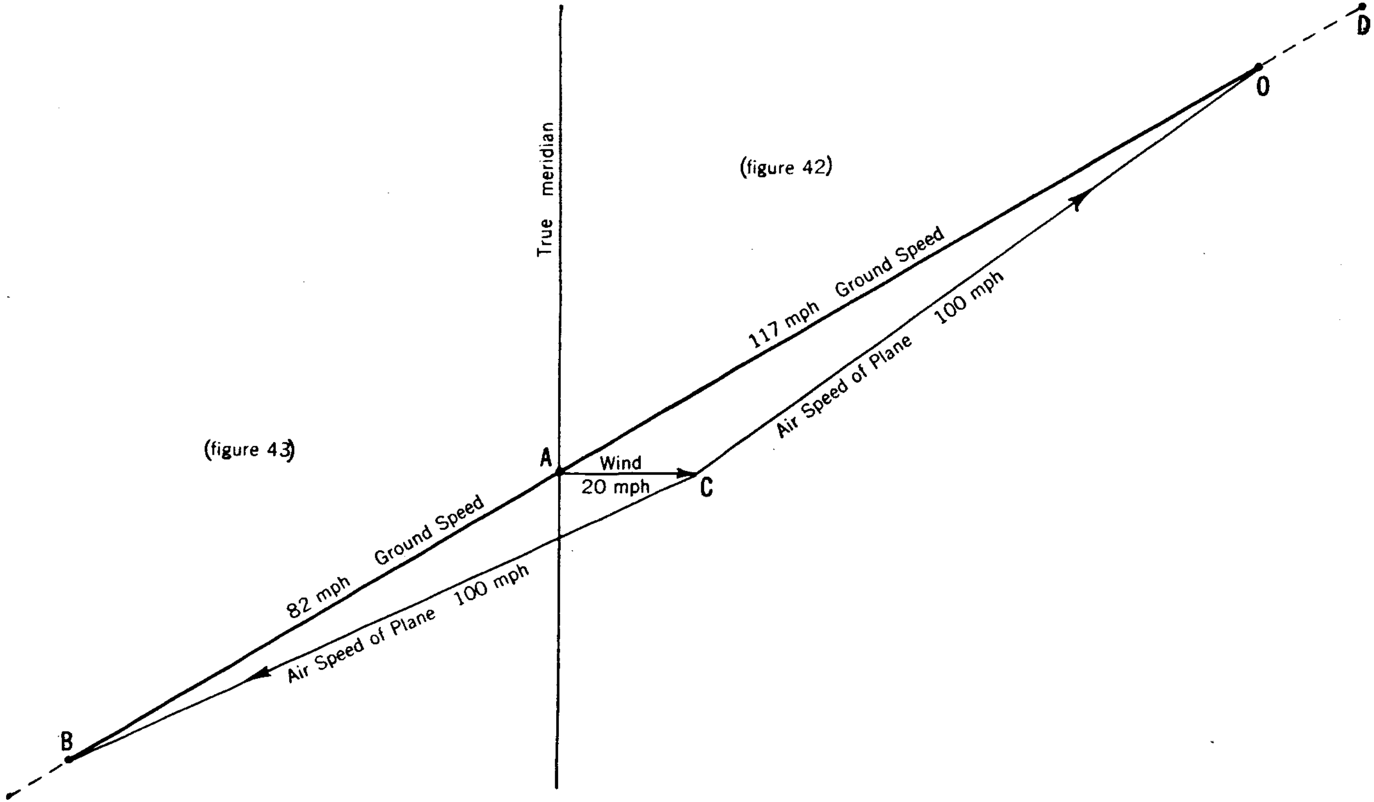


FIGURE 44.—Radius of action; triangle for flight out combined with triangle for return flight.

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.

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 the Appendix, page 176.

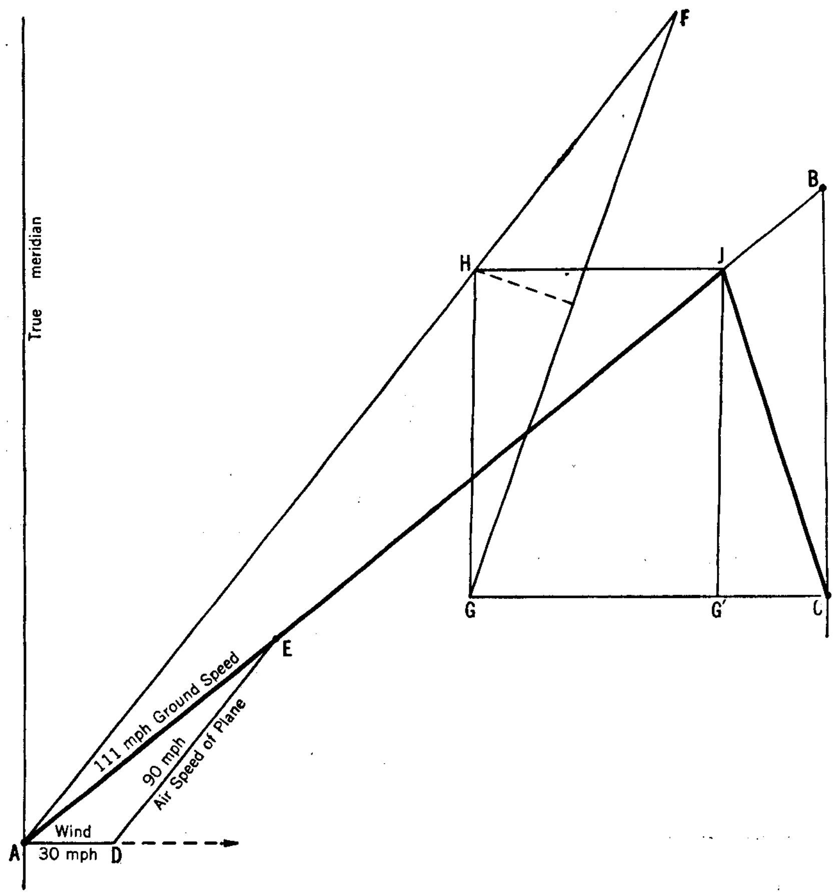


FIGURE 45.—Radius of action when returning to some place other than the starting point.

A more difficult problem, but one which may prove valuable in an emergency, is that of determining the radius of action before returning to some point other than the starting point. For example (fig. 45), a pilot leaves an airport at *A*, for a distant point *B*, with just 4 hours' fuel supply, aside from the required reserve. Weather conditions at *B* are very uncertain, but conditions at *C* are satisfactory and are expected to remain so. How far may he proceed toward *B* and still have fuel enough to reach *C* if advised by radio that the weather at *B* has closed in altogether?

The known data are as follows:

AB=350 miles, true course 50°.
BC=140 miles due south.
Air speed of plane, 90 m. p. h.
Wind, 30 m. p. h., from 270°.

The first step is to plot the three points, *A*, *B*, and *C*, in their proper relative positions. The line *AB*, drawn at an angle of 50° to the meridian halfway between *A* and *B*, represents the intended track, or the true course it is desired to make good.

The next step is to construct a triangle of velocities *ADE*, in order to determine the correction to the course for wind. The true heading to be steered, *AF*, is laid off, equal to the total time available multiplied by the air speed of the plane—in this case $4 \times 90 = 360$ miles.

From *C* lay off *CG* 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 *FG*.

Next it is desired to draw a line from *G* to some point *H* on the line *AF*, so that *HG*=*HF*. The easiest way to do this is to erect a perpendicular to the line *FG* at its middle point; the intersection of this perpendicular with *AF* provides the point *H*, and by simple geometry *HG*=*HF*. *HJ* is drawn parallel to the wind.

A simple explanation of this seemingly complicated plotting now becomes possible. A plane leaving *A* on the heading *AF* with 4 hours' fuel supply can make good the air distance represented by*AF*. Since *HG*=*HF*, it may also fly an air distance represented by *AH*+*HG* in 4 hours' time; but since a plane in flight is also subject to the full effect of the wind (see p. 39), the plane in this case will have been drifted due east a distance equal to the wind velocity multiplied by the total time in the air, or $30 \times 4 = 120$ miles=the line *CG*, by construction.

We may now see that if a plane flies the headings *AH* and *HG* for a total time of 4 hours, and during the 4 hours is subject to a total drift represented by *CG*, the final position of the plane will be the point *C*. Also, the heading *AF* was determined in order to make good the track *AB*; in flying that heading an air distance equal to *AH*, the plane will have drifted eastward by an amount equal to the line *HJ*, and will have made good the track *AJ*.

The point *J* is the farthest point to which the pilot may fly toward *B* and still be able to arrive at *C* within 4 hours of flying time.

JG', parallel to *HG*, is the heading required to make good the desired track *JC*.

The time required to reach the point of turning back may be found either by scaling the distance *AJ* and dividing by the ground speed, or by scaling *AH* and dividing by the air speed. *AH* measures 248 miles, which divided by 90=2 hours 45 minutes; *JG'* measures 112 miles, which divided by 90=1 hour 15 minutes; total, 4 hours.

Chapter IV.—RADIO NAVIGATION

THE IMPORTANCE OF AERONAUTICAL RADIO

In many respects, radio navigation offers the simplest and easiest method of position-finding in flight. Its importance 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.

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 Authority, illustrated in figure 46.

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. 47), the northerly course of the Nashville radio range station is directed along the Nashville-Louisville airway; the southeasterly course is directed along the airway to Chattanooga; and the southwesterly course serves the airway from Memphis. The easterly course serves no particular airway. The four courses from each station are obtained as follows:

Into two diagonally opposite quadrants (fig. 47) 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 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.

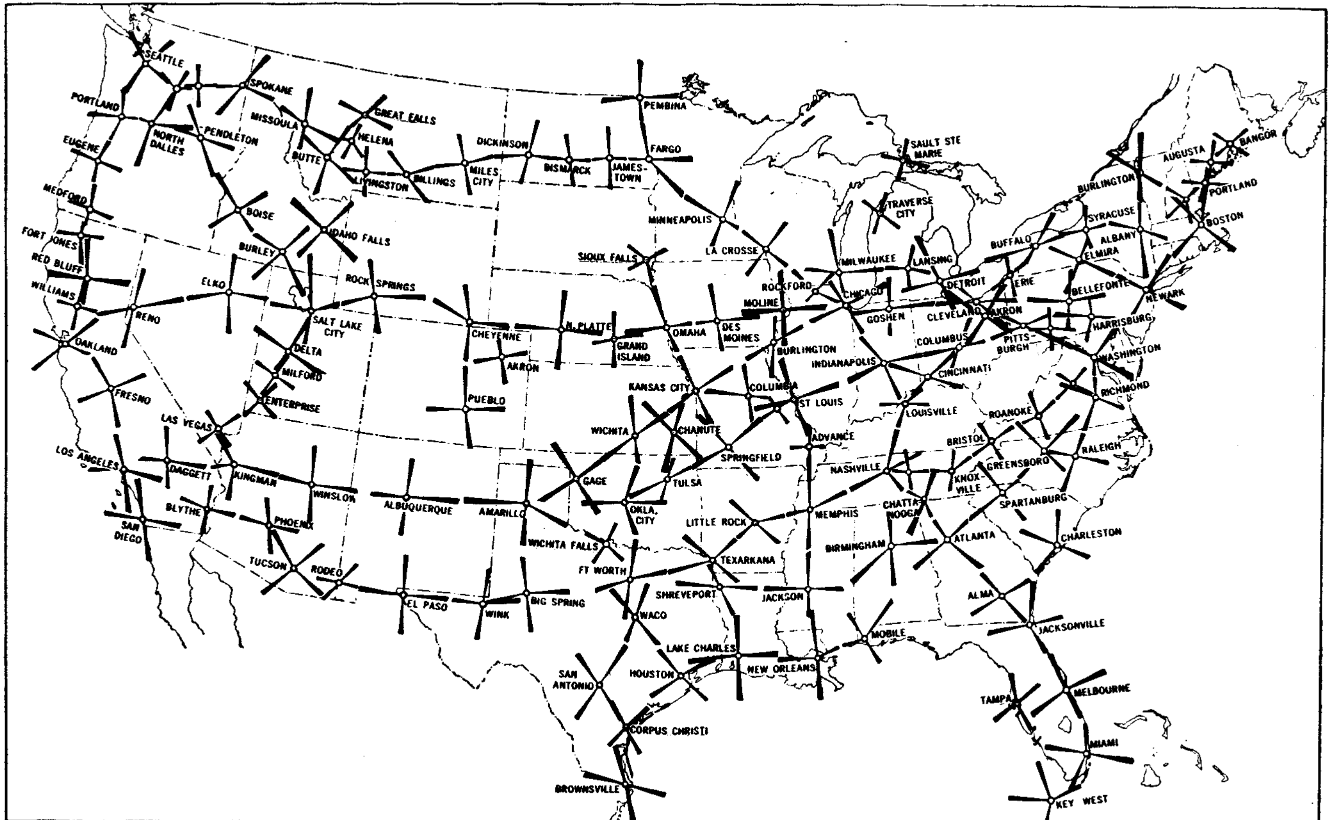


FIGURE 46.—The radio range system of the Civil Aeronautics Authority.

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. 178.) 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.

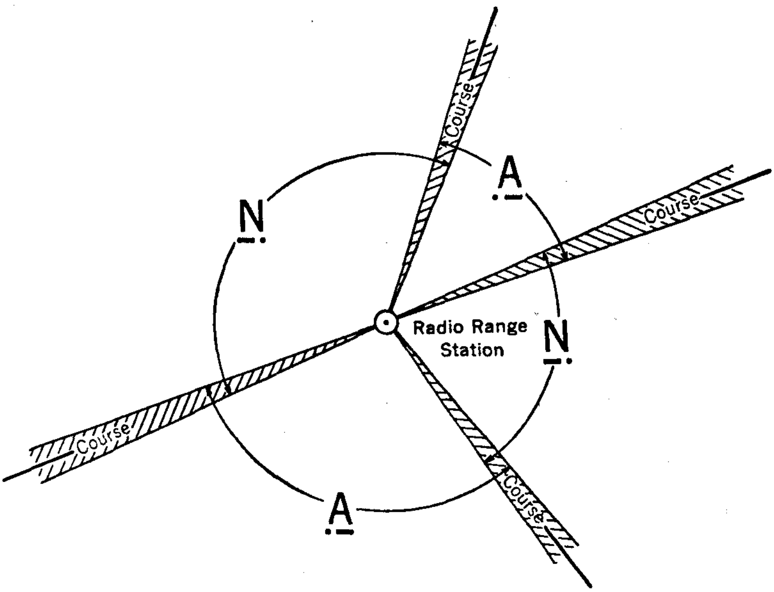


FIGURE 47.—Nashville radio range station.

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 flying a radio range course, therefore, some pilots steer 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

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

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 conditions the latter method is generally preferred.

The range signals are also 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. Recent installations of the Civil Aeronautics Authority provide for simultaneous reception of range signals and broadcasts on the same frequency, thus eliminating the necessity of omitting either the range or telephone service.

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

One of the greatest advantages of this system is that pilots need not be concerned with corrections for drift. As long as they keep the plane along the right side of the equisignal zone (with reasonable precaution against multiple courses; see p. 56), they can be certain of the track being made good over the ground.

In addition to the airway radio range stations operated by the Civil Aeronautics Authority, 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 courses from the airport radio range stations are also shown by a pink tint on the aeronautical charts; however, to avoid confusion in the congested areas surrounding major airports, full information is not indicated on the charts. Pilots desiring complete data should obtain them from the "Tabulation of Air Navigation Radio Aids," which is issued at frequent intervals by the Civil Aeronautics Authority 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; however, there are several factors which may prove confusing until the principles involved are understood.

First, it is obvious that as a plane passes over a radio range station there is an apparent reversal of the directions of the *A* and *N* quadrants. For example, a plane approaching the radio station of figure 47 from the west will have the *A* quadrant on its right, the *N* quadrant on its left, but as soon as it has passed the station the *N* quadrant will be to the right and the *A* quadrant to the left.

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 plane enters the cone, the signals fade out abruptly for a few seconds, the length of time depending on the speed of the plane and the diameter of the cone at the level of flight. When the plane 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 plane 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, ranges are now being equipped with a new type of marker beacon ("Z type"), which emits a distinctive, high frequency radio signal in the cone of silence.

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[2] exist at some locations—particularly in mountainous country. 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 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.

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 plane continues in straight flight under these conditions, the range courses seem to be swinging from side to side. Courses from range stations using the old loop antenna usually swing excessively at night beyond 25 miles from the station. This phenomenon is known as **night effect,** and has been practically eliminated in 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 plane.

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.

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[2] 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.

Some of these difficulties may be greatly reduced as the result of development work now being conducted by the Civil Aeronautics Authority. For example, a supplementary range service on ultra-high frequencies has already been made available at some stations, resulting in 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 omni-directional radio beacon, which is intended to give the equivalent of a range course from any direction toward the transmitter.

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.

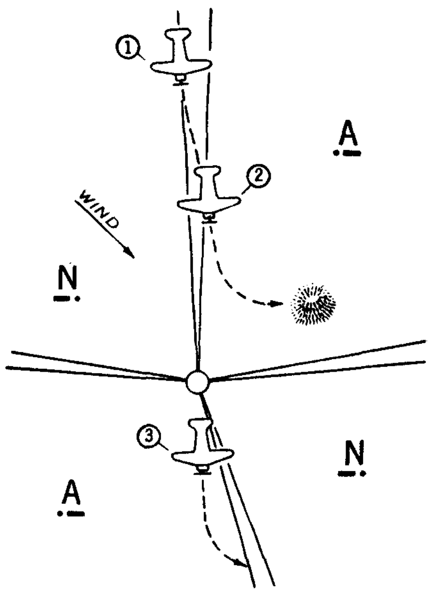


FIGURE 48.—The danger of neglecting drift in radio range navigation.

It has been remarked that pilots need not be concerned with corrections for drift when flying the radio ranges. In a general way this is true, but it should not be taken to mean that drift may be safely neglected. As long as the airplane is kept along the right side of the equisignal zone the track over the ground is known; but 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 therefor.

Figure 48 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.

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 position 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 Notices 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. No one method is suitable for all conditions, 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.

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. 49). When the course-pattern of a station is not symmetrical it is important to use the *average* bisector, since it is equally suitable for either of the two quadrants in which the plane may be located. In this case, a course at right angles to the average bisector may be either 337° or 157°.

If the course of 337° is chosen, then it is certain that courses 2 and 3 are somewhere behind the plane.

The pilot continues on the course of 337° 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 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 157° is chosen, rather than 337°, the procedure will still be the same as before, as shown in figure 49.

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

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

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 plane 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

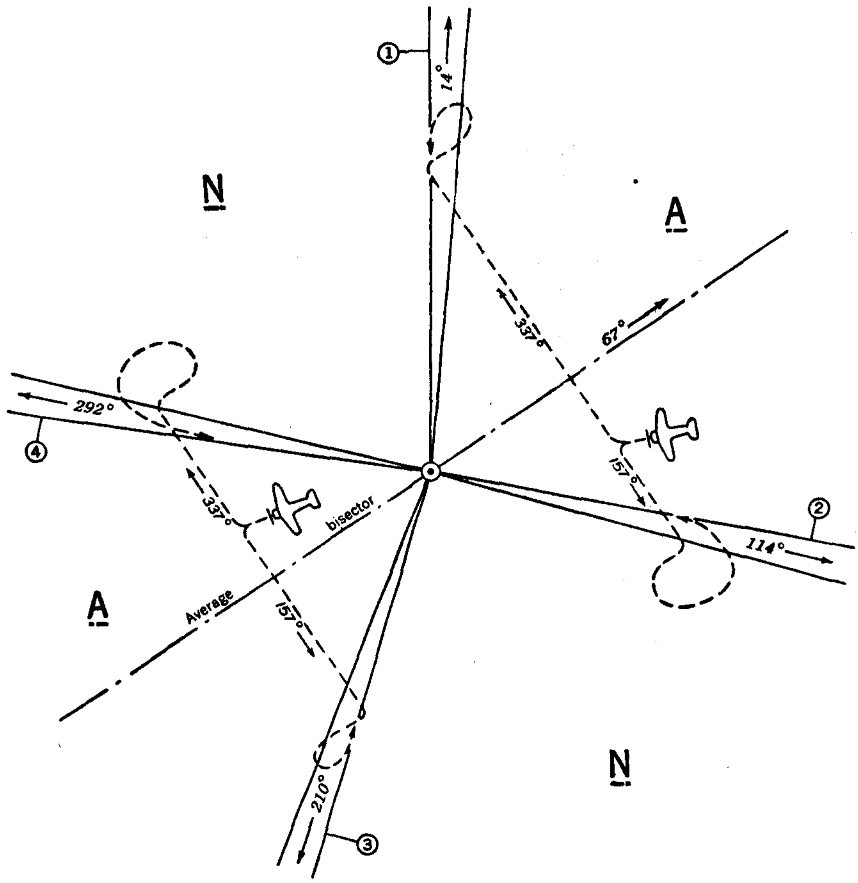


FIGURE 49.—Identification of the quadrant and range course: 90°-turn method.

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 plane 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 337° 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 157° course, and the procedure from this point is identical with that illustrated in figure 49.

If he flies the 337° 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 plane can be definitely known.

Under favorable conditions, this a very dependable method. Its chief disadvantage may be seen from figure 47. If the plane is in a quadrant where the courses meet at a wide angle (as the northwest quadrant of figure 47), 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 degree 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 50, if the pilot is flying a course of 67° 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 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. 47) 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,

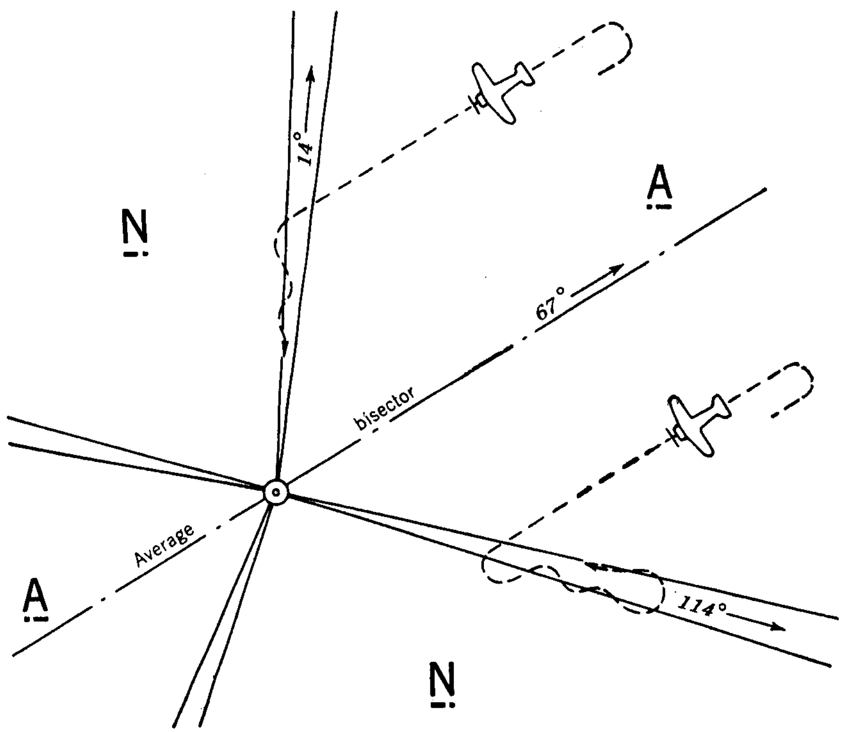


FIGURE 50.—Identification of the quadrant and range course; fade-out method.

and the pilot may proceed as outlined above and as illustrated in figure 50.

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 49. 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 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. 50). The following method—in principle, at least—has been adopted as standard by some of the major air lines, since it may be used satisfactorily on any and all ranges.

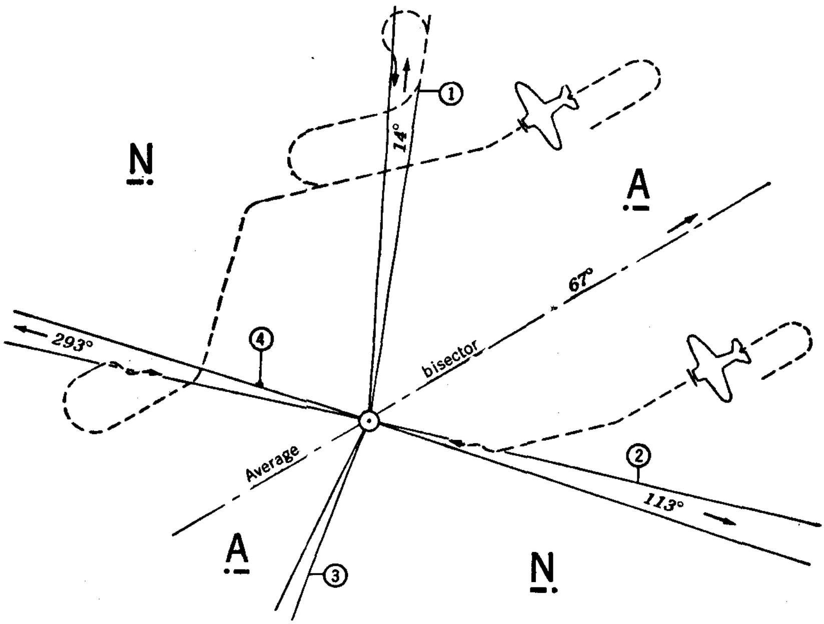


FIGURE 51.—Identification of the quadrant and range course; a standard method.

First, the quadrant is identified by the fade-out method described above, and the airplane is headed parallel to the bisector of the quadrant, toward the station (fig. 51). 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 fifty-fifty 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 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. 51), 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.

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—in one direction at the odd thousand-foot levels (as 1,000, 3,000, or 5,000 feet above sea level), and in the opposite direction at the even thousand-foot levels (as 2,000, 4,000, or 6,000 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 by pilots not engaged in scheduled air transportation. All these requirements are set forth in detail in the Civil Air Regulations published by the Civil Aeronautics Authority; 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 steering, 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.

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 a plane, on request. In case the plane 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 ultrahigh frequency "fan type." These beacons operate on a frequency of 75 megacycles (75,000 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. 52). 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 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. 52) 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 plane. The fan marker beacons also constitute an important link in the system of airways 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.

THE RADIO COMPASS

There are several types of equipment under the general head of "radio compass." Signals may be received aurally or visually, or both, by means of a loop antenna, which may be either fixed or rotatable. Strictly speaking, the radio compass refers to installations employing a fixed loop and a visual indicator. With this arrangement, as long as the plane is headed directly toward a radio station the indicator hand remains centered; headings to the right or left of the station result in a corresponding deflection of the hand.

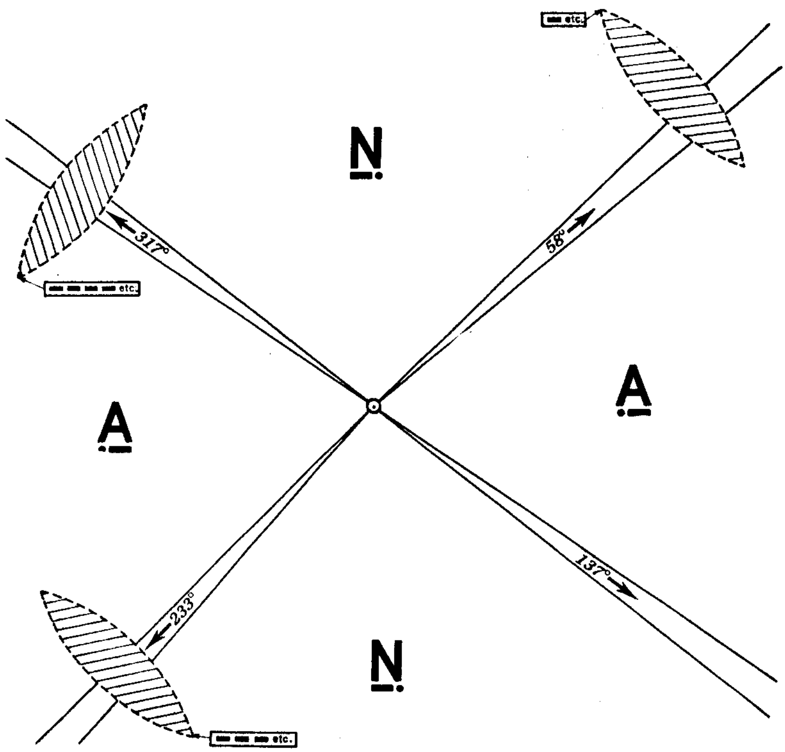


FIGURE 52.—Fan marker beacons around the Newark radio range station.

The radio compass is chiefly used as a "homing device," and bearings of radio stations off the line of flight may be obtained only by turning the plane toward the station and noting the compass heading when the indicator is centered.

With the rotatable loop, bearings may be obtained without turning the plane itself. The loop is rotated until the position of minimum signal strength, or "null," is obtained; the bearing of the station may then be read from a graduated dial. By means of separate dials, on recent installations 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."

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 plane 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.

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

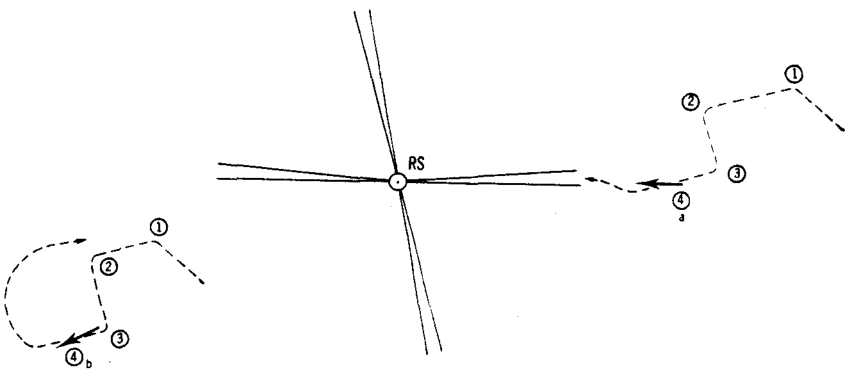


FIGURE 53.—Orientation with the radio compass.

becomes necessary to work an orientation problem in much the same manner as that used with the radio ranges.

In figure 53, 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 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 plane 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 plane would make good over the ground in flying to the station.

Or 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 plane. 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 54. 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* 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

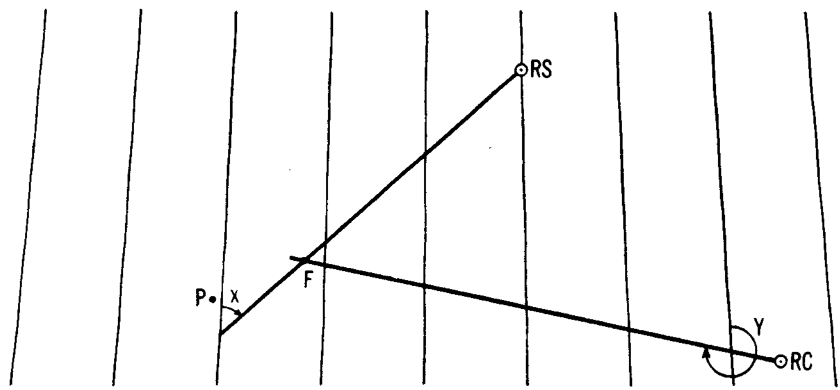


FIGURE 54.—Radio compass navigation (radio bearings).

station. For all practical purposes the line so drawn may be considered as a radio line of position (see p. 71), at some point on which the plane 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, this station determined the bearing *Y* of the aircraft from the station, and reported it 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 plane at *F*.

For the plotting of radio bearings a protractor of the type illustrated in figure 24 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 plane 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. The services of a direction finder station are not always available, and even if they were, some time interval would certainly elapse between the determination of the two bearings. If the pilot must determine both bearings himself from the plane, an appreciable time interval may intervene.

When any considerable time elapses between the determination of the two bearings, the position of the plane is determined by what is known as a "running fix." For example, figure 55 illustrates the same problem as that of figure 54, except that the direction finder station *RC* is replaced by a second radio station *R*, and that after obtaining the bearing *X*, the plane 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 plane will have traveled 30 miles. From any convenient point[4] *Z* on the line representing the bearing to the first station, draw a line *ZZ'* running

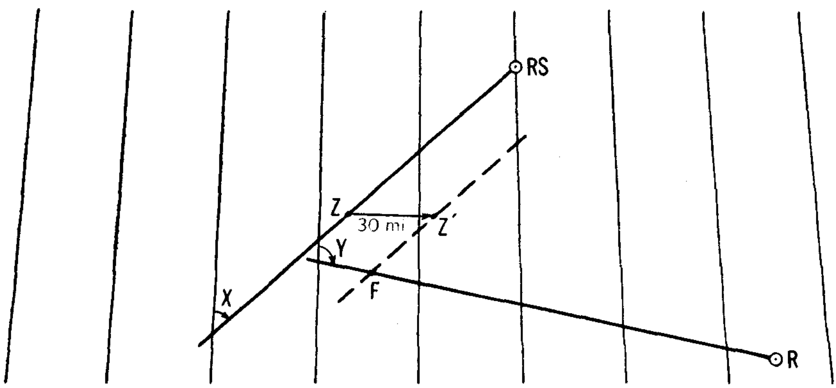


FIGURE 55.—Radio compass navigation; a "running fix."

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 plane 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[5] 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 the line representing the bearing

[4] From a theoretical standpoint, the nearer the point selected is to the correct position of the plane 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.

[5] An error in the latitude of the assumed position, however great, will not affect the accuracy of the result.

of the first radio station must still be carried forward to obtain the fix, exactly as in the first plotting.[6]

When the radio station observed falls within the limits of the chart being used, the method illustrated in figure 54—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. 30) the bearing at the radio station is never the reciprocal of the bearing observed at the plane. The bearing to be plotted from the radio station is obtained as follows:

1. To the bearing observed at the plane, add (or subtract) 180°.
2. If the PLANE is WEST of the radio station ADD 6/10 of a degree for each degree of longitude between them; if the plane is east of the station subtract 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 plane, where the bearings are actually determined. The rule may also be remembered from the familiar initials, PWA.

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 is too large for convenient use in this work, while the scale of chart No. 3060a 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 (fig. 3), 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. 15) oriented to the magnetic meridian instead of the true meridian. These compass roses are intended primarily for plotting

[6] 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.

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, nor to apply the correction for convergence described in the preceding section. 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 8, p. 154.)

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 plane); 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 (p. 69). 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.

Some may more readily 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 plane is LESS than at the radio station; subtract if the variation at the plane is greater.

For all ordinary purposes these two corrections need not be applied. In planning these charts it was felt 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.

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 impossible to print compass roses around these stations, and bearings from them must be plotted in the conventional manner described in the preceding section.

ERRORS OF THE RADIO COMPASS

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; however, in some installations, especially when the rotatable loop antenna is used, the deviation is incorporated in the dial scale so that 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."

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 a plane is determined at a radio station, and plotted at the meridian of the station, then the straight line between the station and the plane is a radio line of position. The radio station is definitely fixed on the chart, and the bearing of the plane is accurately known; the plotted bearing, therefore, is positively determined as the line on which the plane is located.

If the bearing X of the radio station R (fig. 56), is determined at the plane and plotted at the meridian nearest the *assumed* position of the plane, 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

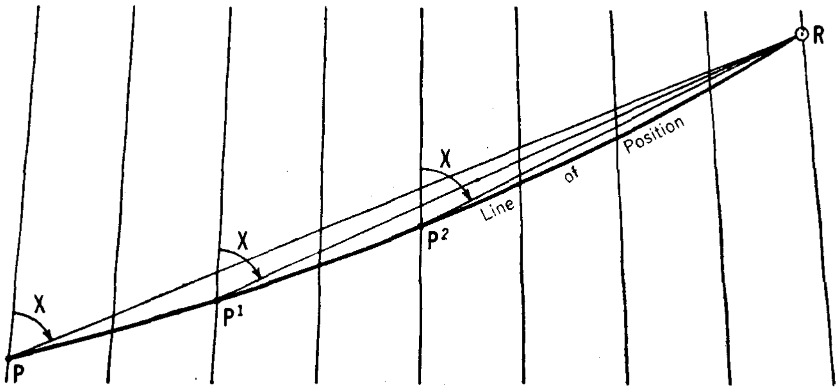


FIGURE 56.—A radio line of position from bearing determined at plane.

on still another meridian, and so on; the plane 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 plane.

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.

RADIO AND THE CORRECTION FOR 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.

Two general types of radio compass are in use on aircraft, the one employing a rotatable loop antenna, the other a nonrotatable loop. With the former, bearings may be taken of stations in any direction by rotating the loop, without turning the plane; with the more recent equipment of this type rotation of the loop is automatic, and continuous indication of direction is provided. 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

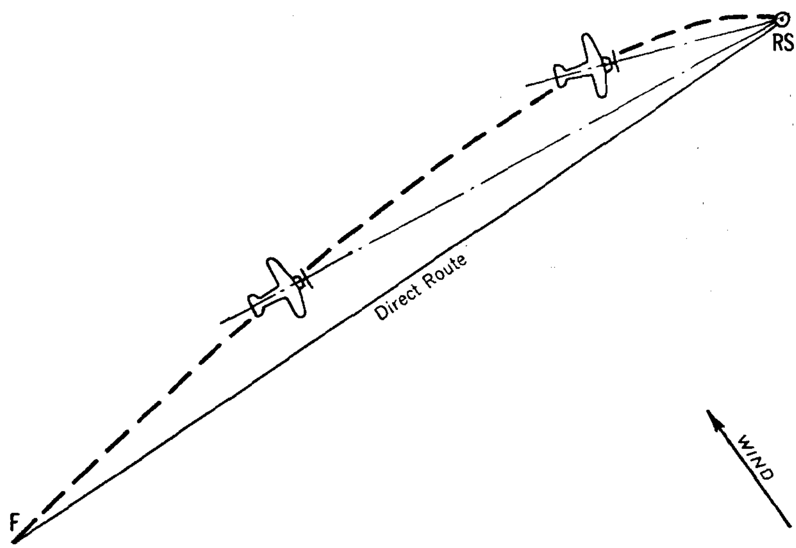


FIGURE 57.—The radio compass and wind effect.

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 plane directly for the radio station *RS* of figure 57, under the effect of cross winds the plane 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 plane 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 gyro compass. To illustrate, suppose that a pilot leaves a point A and proceeds toward a distant radio station B. From the chart he knows that the true course from A to B 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 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 B; 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 indicator hand 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.

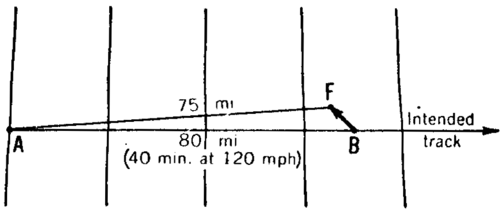


FIGURE 58.—Determination of wind by radio compass.

The process of finding the correct heading to steer 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 just a little greater than 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 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 plane 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 plane 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. 22), the heading must be changed to conform to the change in true course as the end of each succeeding section is reached.[7] If the wind were constant, the steering perfect, and the plane started on the proper heading, this would not be necessary; as long as the indicator remained centered the plane would track the great circle toward the station, and the ever-changing direction of the bearing (fig. 20) 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.

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; as pointed out below, this provides the necessary information for determining wind direction and velocity, if this should be desired.

Under unusual conditions, if the plane 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 67, the wind direction and velocity may be obtained graphically, if desired. In figure 58, after flying due east from *A* 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 *A*. *AB* represents the heading and air speed of the plane, *AF* the track and ground speed, and the angle at *A* the drift angle. *BF* 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 plane 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 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.

INSTRUMENT LANDINGS

A number of instrument landing systems are now undergoing service tests. Equipment and methods are not yet sufficiently standardized to justify detailed discussion here. Essentially, however,

[7] 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. 30, when courses are properly determined the departure of the course from the straight line representing the bearing is negligible.

they may be said to consist of (1) a low powered radio range, or runway localizer; (2) similar equipment turned on edge to provide an equisignal zone, or glide path, in the vertical plane; and (3) a pair of marker beacons in line with the landing beam and at prescribed distances from the airport.

The different systems vary 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 microwaves and a frequency of 750 megacycles, which is not affected by ordinary static.

Aside from such differences of detail, the methods of landing are essentially the same. The aircraft is flown over the runway and its approaches by reference to the localizer beam, as often as may be necessary to be sure of the proper heading, with the pilot checking his progress by means of the two marker beacons. The correct heading is then set on the directional gyro and the airplane is headed toward the airport, reaching a prescribed altitude over the outer marker beacon. Losing altitude at a predetermined rate, the glide path is followed to the proper altitude over the inner marker beacon, which is located at the edge of the field. Continuing on the same glide path brings the aircraft to the landing area with a high degree of precision.

It need scarcely be pointed out that with the installation of a satisfactory system for instrument landings, and with pilots proficient in its use, the last essential for a complete system of safe air transportation is provided.

Chapter V.—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 from the West coast to the Orient are already commonplace, and a route across the North Atlantic is now an accepted fact. For flights such as these celestial navigation is not only practical, but necessary.

The Pacific route to the Orient, like the airways within the United States, is 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 observations 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 plane 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), Nautical Almanac for the current year, and tables for performing the necessary computations, such as the line of position table appearing in pages 182 to 194 of this book. 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° further, 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 59. Evidently, the smaller the altitude 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

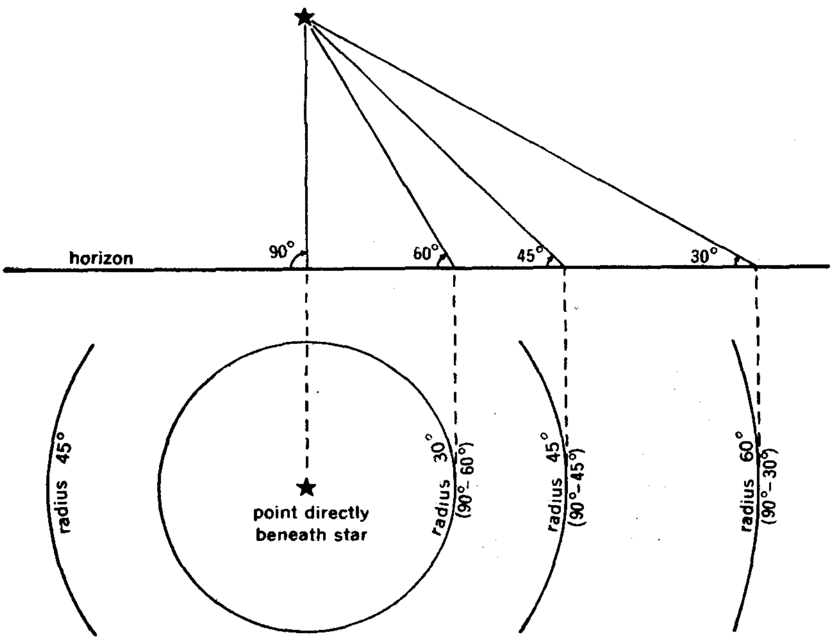


FIGURE 59.—Relation between observed altitudes of a star and circles of position.

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, etc.

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. 3060a, or smaller) were provided with such a scale, it would be possible to plot on the chart, from the Nautical 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 route to the Orient, the transatlantic 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 60, which is a greatly reduced representation of chart No. 3060a. The positions of the stars observed (Vega and Alphecca) at the moment of observation were plotted on the chart from data in the Nautical Almanac; then with radius equal to 90° minus the 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

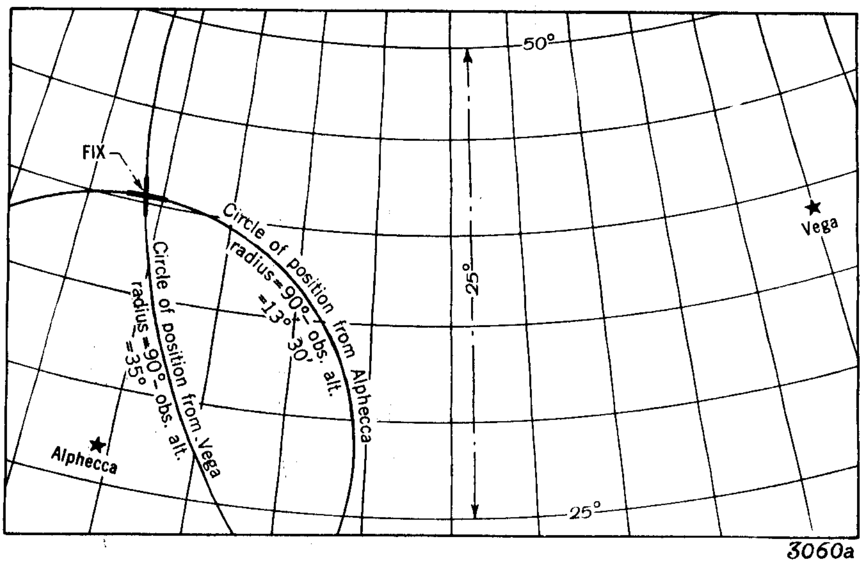
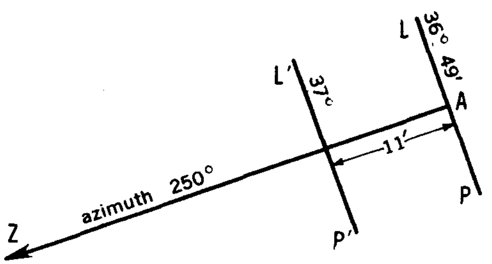


FIGURE 60.—Two circles of position establish location.

every pair of intersecting circles there must be two points of intersection; this is not confusing, however, 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.

To determine a circle of position on the larger scale charts, the navigator starts with an assumed position, *A*, figure 61, which may be either his dead reckoning position or a nearby projection intersection. From the line of position table (pp. 182 to 194) 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°: this is 11′ greater than the altitude computed for the assumed position and we know, therefore, from page 78, 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.**



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 61.—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. 88) 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. 71), 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]

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

[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.

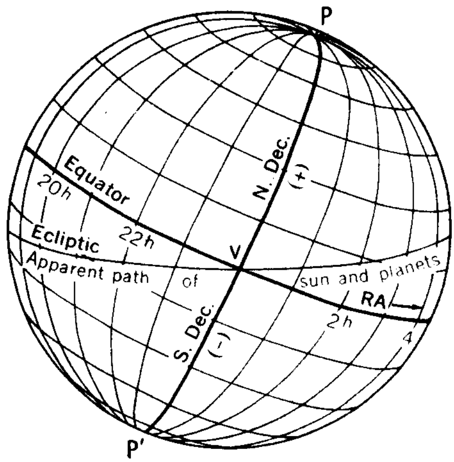
observations may also be combined with a radio line of position in order to obtain a fix.

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.

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.



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.

FIGURE 62.—The celestial sphere.

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 (−).

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 often 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^h02^m (5 hours and 2 minutes) west of Greenwich. On the celestial 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 convenient reference and comparison, table 1 lists the various terms of the celestial sphere opposite the corresponding terms for the terrestrial sphere. Figure 62 shows these terms graphically.

Table 1.—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 declination (+),
0° to 90° north of Equator	(*Dec.*) 0° to 90° north of celestial equator.
	south declination (−),
0° to 90° south of Equator	*0° to 90° south of celestial equator.*
Longitude; reckoned from Greenwich (*G*)	Right Ascension; reckoned from vernal equinox, or first (*RA*) point of Aries (♈).
0° to 180° east or west of *G*	0^h to 24^h east of ♈.
0^h to 12^h east or west of *G*.	
	GHA. Greenwich Hour Angle; difference of longitude between the point directly beneath the celestial body and the meridian of Greenwich.
	LHA. Local Hour Angle; difference of longitude between the point directly beneath the body and the observer's meridian.

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.

[2] The ecliptic is the intersection of the plane of the earth's orbit with the celestial sphere (see fig. 62).

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 provided us with the data needed to compute the astronomical triangle and to obtain the data for the line of position. This is illustrated in figure 63, 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

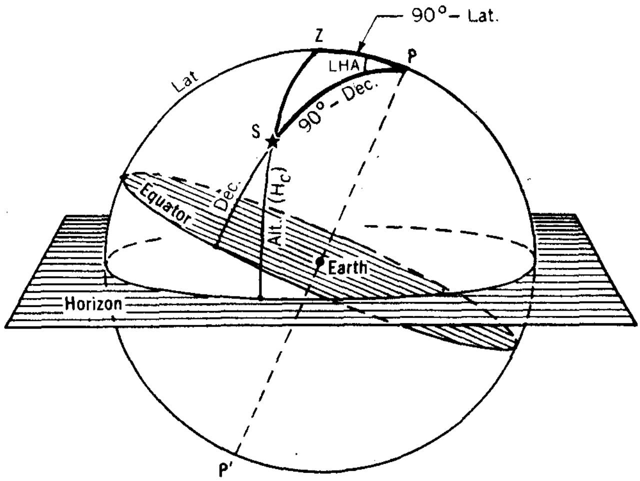


FIGURE 63.—The astronomical triangle.

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 Nautical 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 (found

[3] If the star were south of the Equator (in south declination), the side $SP=90°+$declination.

in the Nautical 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 63, it is seen that the arc from the horizon to the zenith *Z* is 90°, and the computed altitude (H_c) of the star is therefore equal to $90° - SZ$.

In order to save as much time as possible, the line of position table (pp. 182 to 194) 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 61. If the observed altitude is **greater** than the computed altitude, the plane 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 plane was farther away than the assumed position. (See fig. 59.)

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 (pp. 101 to 103).

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 (p. 80). 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. 85) 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 present arrangement of the Nautical Almanac, the computation of a line of position from one of these bodies is only slightly more difficult than for the stars, and requires very little more time; 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 plane is over land, or above clouds or haze, or because the horizon is obscured by darkness.

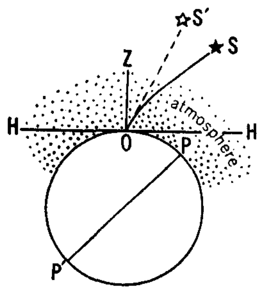


FIGURE 64. Refraction.

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 the instrument does not indicate zero properly, a correction for this error must be applied to all observations. It is often possible to adjust the sextant so that it does correctly indicate zero, and this correction becomes unnecessary. The method of adjustment will not be discussed here, since it is assumed that any one 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.

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. (See p. 105.) This is made necessary because the aviator sees a horizon further away, "over the rim" of the round earth, and hence lower than the horizon he would see if his eye were at the surface.

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. 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 for various dates appears on each page of the Nautical Almanac devoted to these bodies. 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. Ordinarily the sun's lower limb is observed, and the corrections for semidiameter, refraction, and parallax are combined into one table (table A, p. 105).

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; a table is always given in the Nautical Almanac and in many navigational tables (p. 106), in which these items are combined into one correction for any observed altitude. Its application is very simple. For the benefit of those who wish to understand the principles involved, the following brief explanation of these two corrections is given in small type; it may be passed over without reading, if desired.

In figure 64, 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 65, 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.[4] 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 is 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 disappears altogether.

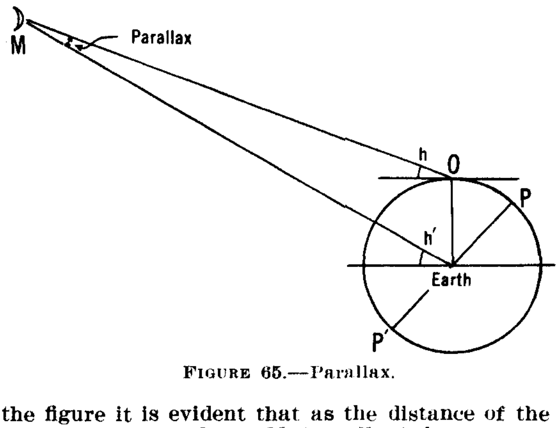


FIGURE 65.—Parallax.

From figure 65 it may also 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. The parallax when the body is at the horizon is referred to as the **horizontal parallax.** In the Nautical Almanac, at the bottom of each page devoted to the moon there is tabulated the moon's horizontal parallax for each day. When using the table of bubble sextant corrections for the moon (p. 107), the combined correction for refraction and parallax is found in the column under the horizontal parallax for that date, and opposite the observed altitude.

[4] As used in celestial navigation.

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.

FORMS FOR COMPUTATION

A standard form for computing the line of position is not absolutely necessary; however, for convenience, speed, and accuracy, a

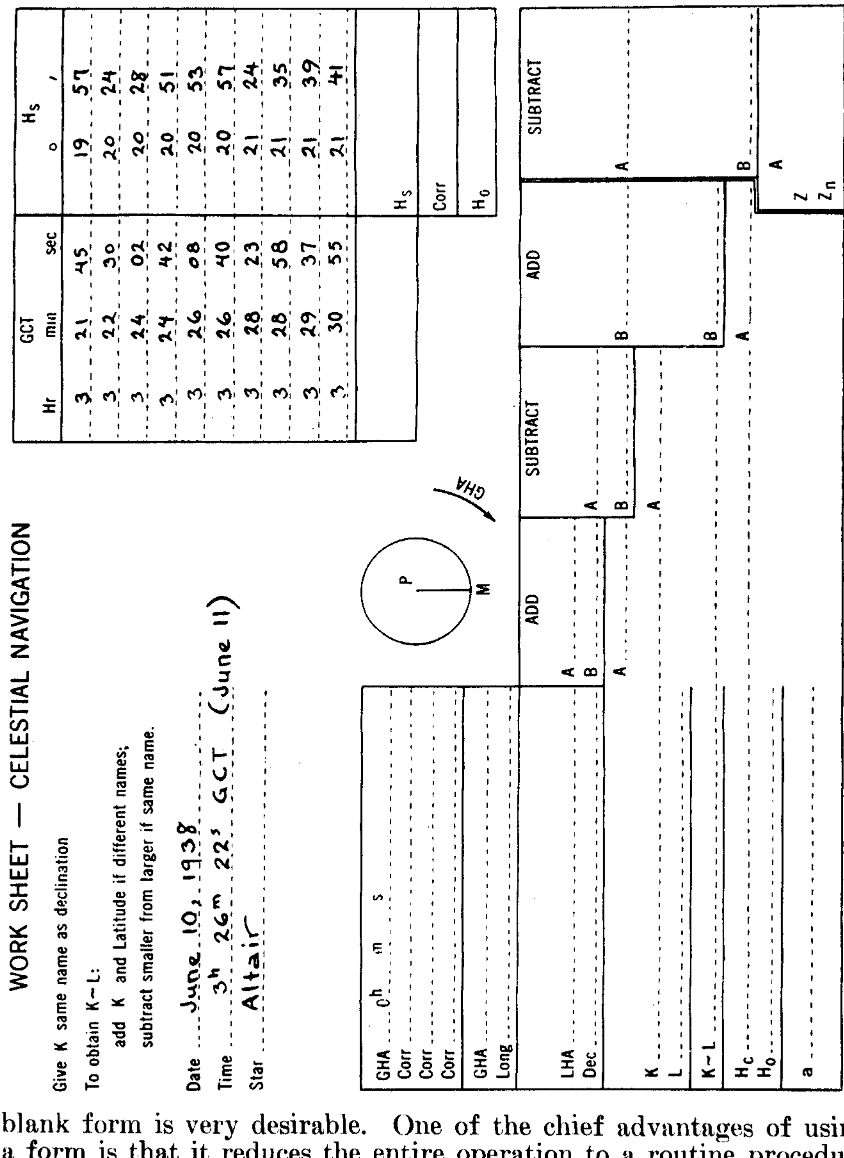


FIGURE 66.—Form for computing the line of position, showing all data obtained by observation.

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 66 shows one such form, especially designed for use with the line of position table appearing in pages 182 to 194. 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 top 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.

In the upper right corner, space is provided for recording a series of as many as 10 sextant observations. The abbreviation GCT stands for Greenwich civil time, while H_s is the altitude (*H*eight actually measured with the sextant). The other quantities and abbreviations appearing on the form are briefly defined in the tabulation below. They will be explained more fully in the succeeding section, "Computing the line of position."

GHA, 0^h=The Greenwich hour angle of the observed body at 0^h (midnight) GCT; taken from the Nautical Almanac.

Corr.=Corrections from the Nautical Almanac, to be added to the GHA for 0^h 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 Nautical 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∼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°.

COMPUTING THE LINE OF POSITION

Figure 66 records all the data actually obtained by observation, for a series of 10 bubble sextant altitudes of the star Altair; figure 67 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 (see p. 90) of the observation is recorded; since the average

[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.

altitude and the average time of the series are 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.

The average sextant altitude is next corrected for any index error, and a combined correction for refraction and parallax (if any) is

WORK SHEET — CELESTIAL NAVIGATION

Give K same name as declination

To obtain K~L:

add K and Latitude if different names;

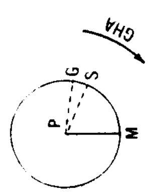
subtract smaller from larger if same name.

Date June 10, 1938

Time 3^h 26^m 22^s GCT (June 11)

Star Altair

GCT Hr	GCT min	GCT sec	H_s °	H_s ′
3	21	45	19	57
3	22	30	20	24
3	24	02	20	28
3	24	42	20	51
3	26	08	20	53
3	26	40	20	57
3	28	23	21	24
3	28	58	21	35
3	29	37	21	39
3	30	55	21	41
30	258	340	203°	409
3	26	22	H_s 20	58′.9
			Corr	− 3.0*
			H_o 20°	55′.9



	h	m	s	°	′
GHA	0			321°	43′.4
Corr	3	26		51	38.5
Corr			22		5.5
Corr					
GHA	3	26	22	13°	27′
Long				83	30 W
LHA				70°	3′ E
Dec				8	42 N
K				24°	9′ N
L				40	30 N
K~L				16°	21′
H_c				20°	47′
H_o				20	55.9
a	TOWARD				8′.9

ADD	SUBTRACT	ADD	SUBTRACT
A 2688	A 82027		
B 503	B 43210	B 43210	A 3191
A 3191	A 38817		
		B 1793	
		A 45003	B 2922
			A 269
			Z N. 96° 22′ E.
			Z_n 96° 22′

FIGURE 67.—Form for computing the line of position, showing the complete solution.

applied from the table on page 106 (p. 107, if the moon is observed), when using a bubble sextant. When using the natural horizon, the correction for height of eye must be applied, and a combined correction for refraction, parallax, and semidiameter is applied from the

*Correction for refraction is −2′.5, and an index error of −0′.5 is assumed; total −3′.0.

tables on pages 105 and 108. The corrected sextant altitude is considered as the observed altitude H_o, and is used to determine the altitude difference a, at the bottom of the form.

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. Greenwich civil time as used in navigation is simply the standard time at Greenwich, the only difference being that it is reckoned from 0 (at midnight) to 24 hours each day, instead of 0 to 12 and then repeating. Thus, 2:40 p. m. would be written as $14^h 40^m$. For some purposes, as in coded weather reports, this would be written as 1440; 8:20 a. m. would be written as 0820.

It should be noted that the form is dated June 10, but the GCT recorded is for June 11. The civil time where the observations were made (about longitude 83°30′) was about 10:26 p. m. ($=22^h26^m$), eastern standard time, but the time at Greenwich was approximately 5 hours later, nearly 3½ hours past midnight and hence June 11. When this situation exists it should be noted on the form, to avoid any possibility of taking the values from the Nautical 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 Nautical Almanac, and the method of obtaining it under all circumstances may best be illustrated by working out the GHA for a star, the sun, the moon, and a planet, from the sample pages of the Nautical Almanac, pages 105 to 118. In each case, the GCT of the problem of figure 67 will be used, namely $3^h26^m22^s$ GCT, June 11, 1938. Once the GHA is obtained, the computation is identical, whether the observed body be sun, moon, star, or planet.

Example 1.—GHA of Altair. From the table on page 109 we find the GHA for 0^h GCT on June 11. From the table on page 110 we find the corrections to be added to the GHA of a star for 3^h26^m, and for 22^s; adding these corrections we find the GHA for the day and hour required.

GHA,	0^h			321°	43′.4
Corr.	3^h	26^m		51	38′.5
Corr.			22^s		5′.5
				373°	27′.4
				−360	
GHA,	3^h	26^m	22^s	13°	27′.4

Example 2.—GHA of the sun. From the table on page 105 we find the GHA for 2^h GCT on Saturday, June 11. From the table on page 106 we find the corrections for 1^h26^m, and for 22^s. Adding these, the required GHA is obtained.

GHA,	2^h	00^m		210°	11′.0
Corr.	1^h	26^m		21	30′.0
Corr.			22^s		5′.5
GHA,	3^h	26^m	22^s	231°	46′.5

Example 3.—GHA of the moon. From the table on page 113 we find the GHA for 3^h GCT on June 11. From the table of Multiples of Variation per Minute, in small type just to the right on the same page, we obtain the corrections to be added for 20^m, and for 6^m; the correction for 22^s is a little more than one third

(22/60) of the correction for 1^m. Adding these corrections, the required GHA is obtained.

GHA,	3^h	00^m		66°	57′.2
Corr.		20^m			290′.2
Corr.		6^m			87′.1
Corr.			22^s		5′.3
				66°	439′.8, or
GHA,	3^h	26^m	22^s	73°	19′.8

The corrections just applied are considered only approximate, and special tables are also provided in the Nautical Almanac for finding the GHA of the moon with greater precision; however, the method just given is sufficiently accurate for air navigation, and in this way the GHA of the moon can be found complete on one page. For this problem the more precise method differs from the approximate results by only 0′.06.

Example 4.—GHA of Jupiter. From the table on page 114 we find the GHA for 0^h GCT on June 11, and note also that the "variation per minute" is 15′.0397. The corrections to be added to the GHA of a planet are tabulated under the variation per minute, the corrections for hours on page 115, and the corrections for minutes and seconds on page 116. The correction for a variation of 15′.0397 lies 0.7 of the way between the corrections tabulated for for 15′.039 and 15′.040. For 3^h this correction is determined as 45°7′.1. For 26^m, the desired correction lies 0.97 of the way between the values for 15′.03 and 15′.04, and is determined as 6°31′. The correction for 22^s is found in the column at the right of the same page. Adding these corrections we find the GHA for the day and hour required.

GHA,	0^h			284°	16′.2
Corr.	3^h			45	7′.1
Corr.		26^m		6	31′.0
Corr.			22^s		5′.5
GHA,	3^h	26^m	22^s	335°	59′.8

Having found the GHA from the Nautical Almanac, the local hour angle (LHA) is found by combining the GHA and the longitude of

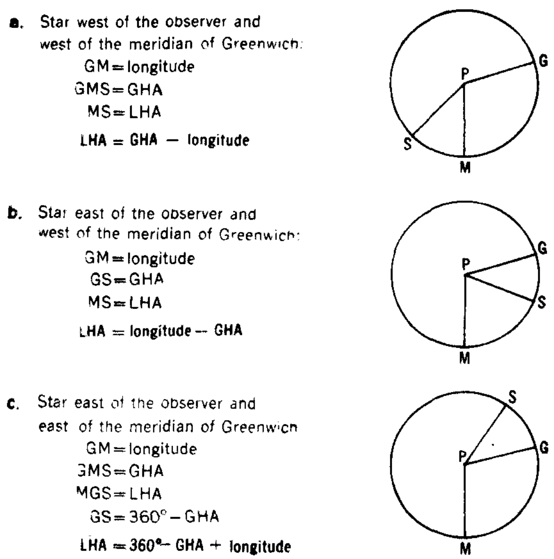


FIGURE 68.—Determining the local hour angle (LHA).

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. 66). 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 67, the longitude of the assumed position is 83°30′ west; the meridian of Greenwich *PG* can, therefore, be drawn in, about 83° east of *M*. The GHA of the star was about 14°, and the meridian passing through the star *PS* can therefore be drawn, the angle GPS being approximately 14°. 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 68, with the operation required for obtaining the LHA in each case. The problem illustrated in figure 67 is similar to case *b* in the figure.

The declination of the star, or other body, is taken from the Nautical Almanac. For a star, the change in declination is so slight that it is given only for each month (see p. 109). For a planet the declination is tabulated for 0^h of each day, with the difference between successive days indicated (see p. 114); if the change is great enough to warrant, a correction can be applied for the time elapsed since 0^h, just as with the GHA, and special tables are provided in the Nautical Almanac for this purpose. For the sun, declination is tabulated at intervals of 2^h for each day (see pp. 111, 112); the maximum change in declination for the 2-hour period is only about 2′, and it is easy to interpolate for any intervening period. The declination of the moon is given for every hour, and in smaller type to the right is given the variation per minute, so that correction for any period is quickly made (see p. 113).

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.

The corrections to the sextant altitude, and the data obtained from the Nautical 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. 182 to 194).

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 182, 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. Many of the other "short methods" are very good and have certain advantages; however, for the reasons given it is believed that this method is entirely satisfactory for the most experienced navigator and 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 will follow through the problem of figure 67.

The LHA is determined as 70°3′, and the A value for that angle is copied from the table in the space indicated on the form.

Next the B value for 8°42′ (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 3191; this is shown on the form as an A value. We run through the tables until 3192 (the number nearest 3191) 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 38817; 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. 78.)

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 67 is N. 96°22′ E. which means that the body is 96°22′ toward the east from true north. An azimuth of N. 96°22′ *W* means that the body is 96°22′ 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° (see p. 29). An azimuth of N. 96°22′ W. could be entered in this space as 263°38′. 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.

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 Nautical 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 probable positions of the plane 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. (See pp. 155 to 158.)

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 two or three stars are printed on the same graph; 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 two 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 Nautical 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 only a 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 77, the altitude of the celestial pole is equal to the latitude of the place from which it is observed: however,

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[6] For a discussion of sidereal time, see "Additional Stars," p. 99.

Polaris is not exactly at the pole, but moves about it in a small circle with a radius of about 1°2′.5. (See fig. 69.) 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 Nautical Almanac there is a special table (see p. 117) giving the GHA of Polaris for 0^h GCT for each day of the year. Just as with any other star, a correction may be applied from the tables illustrated on page 110 to obtain the GHA for the GCT of observation. The LHA is then found, as before, by combining the GHA and the longitude of the assumed position.

Having obtained the LHA, either east or west, the table on page 118, from the Nautical Almanac is entered and a correction obtained

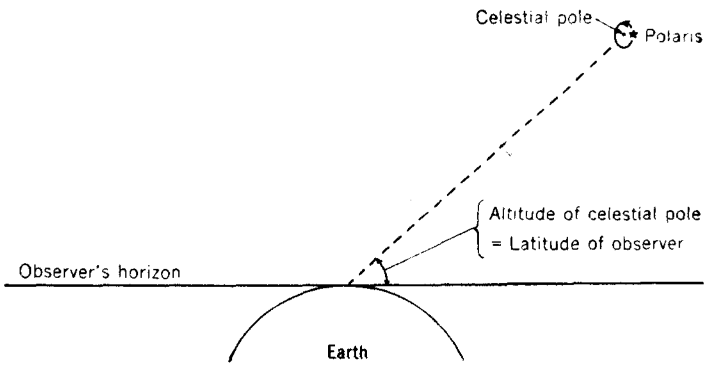


FIGURE 69.—Latitude from Polaris.

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 plane, 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 plane 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 plane 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 68. 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 plane. 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 plane 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 brightness of Polaris (second 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 Nautical Almanac. By some method, the star must be identified before the line of position can be computed.

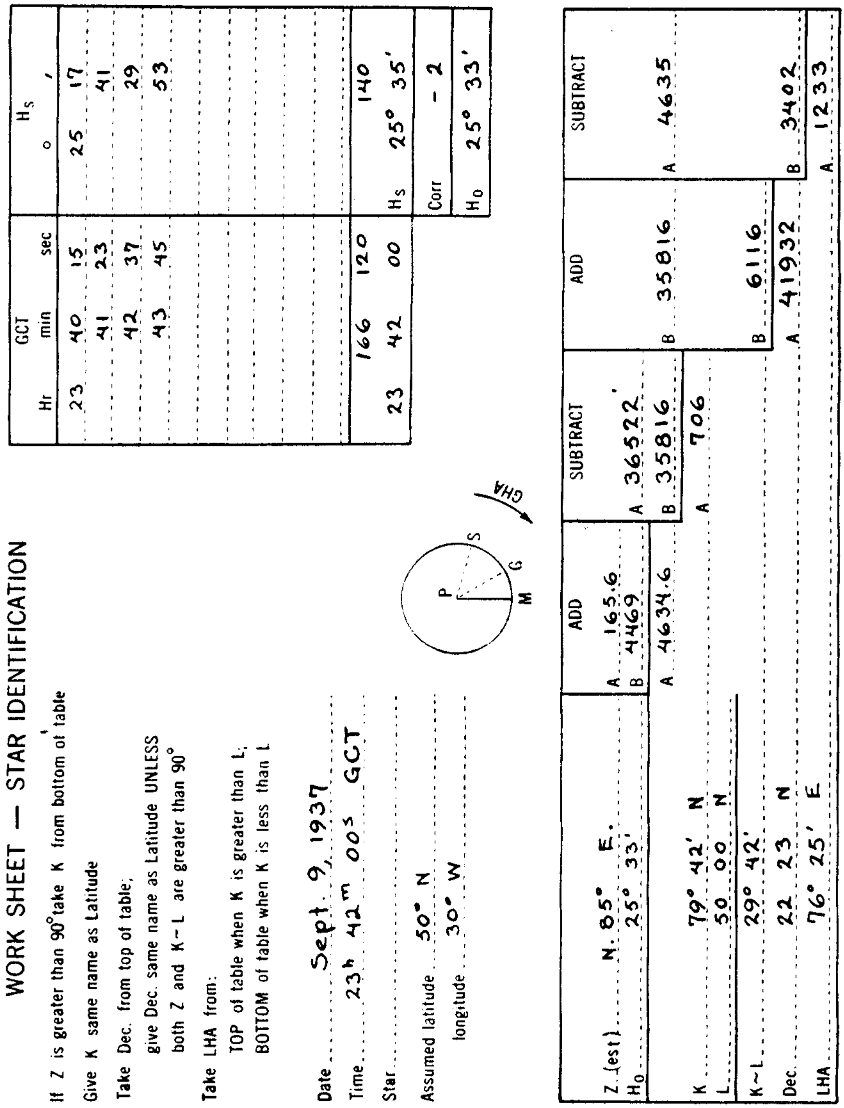
There are available several star finders from which, after the approximately known data are set up, the star may be identified. Perhaps the most accurate of these is The Rude Star Finder and Identifier, published by the United States Hydrographic Office as H. O. No. 2102a. There are also Special Star 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. 182 to 194) 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 Nautical Almanac, and the problem is then worked in the usual way (as in fig. 67) 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 70, 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, September 9, 1938; the corrected sextant altitude H_o, was 25°33′; 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* 4634.6 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. 67) and the *B* and 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.



WORK SHEET — STAR IDENTIFICATION

If Z is greater than 90° take K from bottom of table

Give K same name as Latitude

Take Dec. from top of table; give Dec. same name as Latitude UNLESS both Z and K ~ L are greater than 90°

Take LHA from:
TOP of table when K is greater than L;
BOTTOM of table when K is less than L

Date Sept. 9, 1937
Time 23h 42m 00s GCT
Star
Assumed latitude 50° N
longitude 30° W

GCT Hr	GCT min	GCT sec	Hs °	Hs ′
23	40	15	25	17
	41	23		41
	42	37		29
	43	45		53
	166	120		140
23	42	00	Hs 25°	35′
			Corr	− 2
			Ho 25°	33′

		ADD	SUBTRACT	ADD	SUBTRACT
Z (est)	N. 85° E.	A 165.6			
Ho	25° 33′	B 4469	A 36522		
		A 4634.6	B 35816	B 35816	A 4635
K	79° 42′ N		A 706		
L	50 00 N				
K~L	29° 42′			B 6116	
Dec.	22 23 N			A 41932	B 3402
LHA	76° 25′ E				A 1233

FIGURE 70.—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 76° east of *M*. From the relationship pictured, the GHA is 360° minus the angle *GPS*, and the angle *GPS* is equal to the LHA minus the angle *GPM* (longitude); hence the GHA is 313°35′.

76° 25′ LHA		360° 00′	
−30 0 long.		−46 25	angle GPS
46° 25′ angle GPS		313° 35′ GHA	

The GHA just obtained is for 23^h42^m GCT, and in the Nautical Almanac the GHA is tabulated for 0^h. In order to obtain the GHA for 0^h, the correction that would normally be added for 23^h42^m must be subtracted from the above:

GHA for 23^h42^m GCT 9–9–38	313°	35′	+360° = 673°	35′
Corr. for 23^h42^m	−356	28.4	−356	28.4
GHA for 0^h, 9–9–38			317°	6′.6

Since the correction is greater than the GHA, 360° must be added to the latter before the subtraction can be performed. We now have the GHA as about 317° and the declination as 22°23′: in the Nautical Almanac, under "Stars, September 1938," for September 9 we find the second magnitude star Hamal (α Arietis) with a GHA of 316°26′.9 and a declination of 23°10′.4. No other star even approaches these values, and it is therefore safe to assume that Hamal was the star observed. Its GHA and declination are entered on the form shown in figure 67, and the line of positive computed as illustrated therein.

ADDITIONAL STARS

As already described, the Nautical Almanac in its present form provides an easy method for finding the GHA of 55 stars. These stars are so well distributed over the celestial sphere that there is

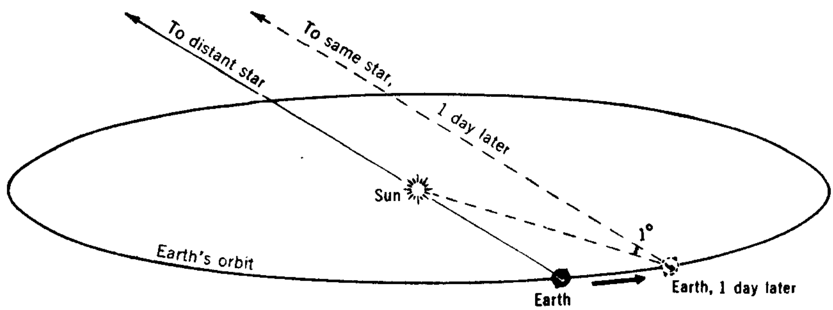


FIGURE 71.—The civil day and sidereal time. Less time is required for rotation of the earth with respect to a star than to the sun.

seldom a time when there are not two or more available for observation, if conditions are at all favorable.

For those occasions when clouds may shut out the stars ordinarily used, but still leave a fairly bright star visible here and there, the Nautical Almanac gives the celestial coordinates (but not the GHA) of 110 additional stars. In order to find the GHA of these stars we must resort to sidereal time; this is usually confusing to the beginner, and it is hoped that some day the GHA of these additional stars will also be tabulated in the Nautical Almanac, making all reference to sidereal time unnecessary in air navigation. In the meantime, the rules given below may be followed easily, although a knowledge of sidereal time is helpful.

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 71, 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. 71) are in direct line with a distant star, which we will suppose is 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° further 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,

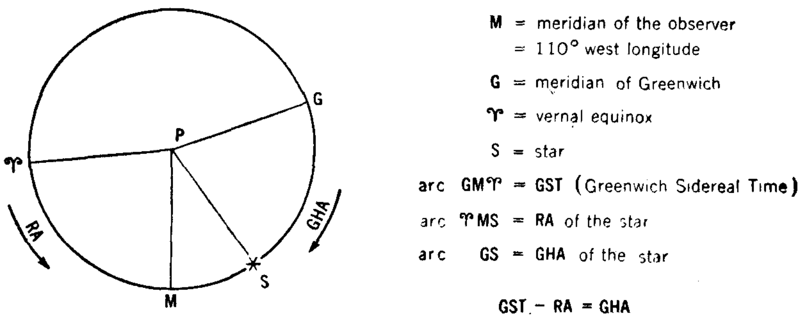


FIGURE 72.—The Greenwich hour angle and sideral time.

that the civil day is longer than the sidereal day, the difference amounting to about 3^m56^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.

If the additional stars referred to are to be used, the simplest method is to carry an additional chronometer rated to sidereal time for the meridian of Greenwich. In this case, the Greenwich sidereal time (GST) of the observation is recorded, instead of GCT, and the GHA is found from the equation GHA=GST−RA (right ascension of the star). This relationship is apparent in the time diagram of figure 72.

The GHA so obtained is in terms of time, and must still be converted into arc; a special table is provided for this purpose, near the back of the Nautical Almanac.

If the chronometer rated to sidereal time is not available, the process is a little more complicated. The first table in the Nautical

[7] Strictly speaking, with respect to the *mean* sun.

Almanac is labeled, "Sun, 1938" (or for the current year). This table gives the sidereal time of 0^h GCT for each day in the year. At the bottom of the same page there is a second table called, Correction for longitude from Greenwich; it might just as appropriately have been called, "Correction for converting civil time to sidereal time." From this second table, a correction is added to the civil hours, minutes, and seconds, past midnight, thus converting them to sidereal time. This total (sidereal time past midnight) is then added to the sidereal time of 0^h (midnight) in order to obtain the GST of the observation; then, as before, GHA = GST − RA.

To illustrate, suppose that the GHA of ε Cygni is desired, for $22^h45^m0^s$ GCT, October 15, 1937:

GST of 0^h, 10–15–37 (From 1st table of Nautical Almanac.)	1^h	32^m	$25^s.6$
GCT of observation	22	45	0.0
Corr. for 22^h45^m (From bottom of same page in Almanac.)		+3	44.2
GST of $22^h45^m0^s$ GCT	24^h	21^m	$9^s.8$
RA of ε Cygni (From Nautical Almanac, "addl. stars.")	−20	43	39.6
GHA of ε Cygni (in terms of time).	3^h	37^m	$30^s.2$

The GHA is now converted from time to arc, by means of the table near the back of the Nautical Almanac:

$$3^h36^m = 54°$$
$$1^m28^s = 22'$$
$$2^s.2 = 33''$$
$$3^h37^m30^s.2 = 54°22'33''.\ \text{GHA in terms of arc.}$$

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 Nautical Almanac for 1938 lists 55 principal navigational stars, and 110 additional 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 map. 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, every one 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 two pointer stars are named Dubhe and 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 2.

Table 2.—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.	ο	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 Nautical 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 the 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 never 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,[8] 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,[8] passing from view in the daytime only because of the greater brightness of the sun. As the distance from Polaris increases, the radii of the circles increase until, near the southern horizon, stars describe only flattened arcs not very high above the horizon.

Aside from this nightly passage of the stars across the sky, their apparent motion in space with respect to each other is 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. It is for this reason that the process of determining positions from the sun, moon, or planets, is

[8] For an observer in the United States.

slightly more complicated than in the case of the fixed stars; however, with the present arrangement of the Nautical Almanac it is very little more difficult. This is all the more important since they are the brighter and more easily observed bodies.

Some of the subjects discussed in this final section, such as the motion of the stars and planets, may be considered in the light of 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. 195).

THE NAUTICAL ALMANAC

The pages next following are from the Nautical Almanac for 1938. They are included here to illustrate the use of the Almanac in the solution of the typical examples presented herein.

CORRECTIONS TO BE APPLIED TO THE OBSERVED ALTITUDE OF A STAR OR OF THE SUN'S LOWER LIMB, TO FIND THE TRUE ALTITUDE 281

TABLE A

Observed Altitude	☉ Sun's Corr.	★ Star's Corr.
° ′	′	′
6 30	+ 8.2	-7.9
6 40	8.4	7.7
6 50	8.6	7.6
7 0	8.7	7.4
7 10	8.9	7.2
7 20	+ 9.0	-7.1
7 30	9.2	7.0
7 40	9.3	6.8
7 50	9.5	6.7
8 0	9.6	6.6
8 10	+ 9.7	-6.4
8 20	9.8	6.3
8 30	10.0	6.2
8 40	10.1	6.1
8 50	10.2	6.0
9 0	+10.3	-5.9
9 20	10.5	5.7
9 40	10.6	5.5
10 0	10.8	5.3
10 20	11.0	5.2
10 40	+11.2	-5.0
11 0	11.3	4.9
11 30	11.5	4.7
12 0	11.7	4.5
12 30	11.9	4.3
13 0	+12.0	-4.1
13 30	12.2	4.0
14 0	12.3	3.8
15 0	12.6	3.6
16 0	12.8	3.4
17 0	+13.0	-3.2
18 0	13.2	3.0
19 0	13.3	2.8
20 0	13.5	2.6
22 0	13.7	2.4
24 0	+14.0	-2.2
26 0	14.1	2.0
28 0	14.3	1.8
30 0	14.4	1.7
32 0	14.6	1.6
34 0	+14.7	-1.4
36 0	14.8	1.3
38 0	14.9	1.3
40 0	15.0	1.2
45 0	15.1	1.0
50 0	+15.3	-0.8
55 0	15.4	0.7
60 0	15.5	0.6
65 0	15.6	0.5
70 0	15.7	0.4
75 0	+15.8	-0.3
80 0	15.8	0.2
85 0	15.9	-0.1
90 0	+16.0	0.0

TABLE B

Date	☉ Additional Sun's Corr.
	′
Jan. 1	+0.3
15	+0.3
Feb. 1	+0.3
15	+0.2
Mar. 1	+0.2
15	+0.1
Apr. 1	0.0
15	0.0
May 1	-0.1
15	-0.1
June 1	-0.2
15	-0.2
July 1	-0.2
15	-0.2
Aug. 1	-0.2
15	-0.2
Sept. 1	-0.1
15	-0.1
Oct. 1	0.0
15	+0.1
Nov. 1	+0.2
15	+0.2
Dec. 1	+0.3
15	+0.3
31	+0.3

TABLE C

Correction for Height of Eye			
Height of Eye (feet)	Corr.	Height of Eye (feet)	Corr.
	′		′
0	0.0	100	- 9.8
1	-1.0	150	12.0
2	1.4	200	13.9
3	1.7	250	15.5
4	2.0	300	17.0
5	-2.2	350	-18.3
6	2.4	400	19.6
7	2.6	450	20.8
8	2.8	500	21.9
9	2.9	550	23.0
10	-3.1	600	-24.0
11	3.2	650	25.0
12	3.4	700	25.9
13	3.5	750	26.8
14	3.7	800	27.7
15	-3.8	850	-28.6
16	3.9	900	29.4
17	4.0	950	30.2
18	4.1	1000	31.0
19	4.3	1050	31.8
20	-4.4	1100	-32.5
21	4.5	1150	33.2
22	4.6	1200	34.0
23	4.7	1250	34.6
24	4.8	1300	35.3
25	-4.9	1350	-36.0
26	5.0	1400	36.7
27	5.1	1450	37.3
28	5.2	1500	38.0
29	5.3	1550	38.6
30	-5.4	1600	-39.2
31	5.4	1650	39.8
32	5.5	1700	40.5
33	5.6	1800	41.6
34	5.7	1900	42.7
35	-5.8	2000	-43.8
37	6.0	2100	44.9
39	6.1	2200	46.0
41	6.3	2300	47.0
43	6.4	2400	47.9
45	-6.6	2500	-49.0
47	6.7	2600	50.0
49	6.9	2700	50.9
51	7.0	2800	51.9
53	7.1	2900	52.8
55	-7.3	3000	-53.7
60	7.6	3100	54.6
65	7.9	3200	55.4
70	8.2	3300	56.3
75	8.5	3400	57.1
80	-8.8	3500	-58.0
85	9.0	3600	58.8
90	9.3	3700	59.6
95	9.6	3800	60.4
100	-9.8	4000	-62.0

162915°—39——8

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TABLE E

BUBBLE SEXTANT CORRECTION TO OBSERVED ALTITUDE OF SUN OR STAR

FOR REFRACTION AND PARALLAX

Observed Altitude	Sun's Correction	Star's Correction	Observed Altitude	Sun's Correction	Star's Correction	Observed Altitude	Sun's Correction	Star's Correction
° ′	′	′	° ′	′	′	° ′	′	′
6 30	−7.8	−7.9	10 0	−5.2	−5.3	24 0	−2.0	−2.2
6 40	7.6	7.7	10 20	5.0	5.2	26 0	1.9	2.0
6 50	7.4	7.6	10 40	4.9	5.0	28 0	1.7	1.8
7 0	7.3	7.4	11 0	4.7	4.9	30 0	1.6	1.7
7 10	7.1	7.2	11 30	4.5	4.7	32 0	1.4	1.6
7 20	−7.0	−7.1	12 0	−4.3	−4.5	34 0	−1.3	−1.4
7 30	6.8	7.0	12 30	4.1	4.3	36 0	1.2	1.3
7 40	6.7	6.8	13 0	4.0	4.1	38 0	1.1	1.2
7 50	6.5	6.7	13 30	3.8	4.0	40 0	1.0	1.2
8 0	6.4	6.6	14 0	3.7	3.8	45 0	0.9	1.0
8 10	−6.3	−6.4	15 0	−3.4	−3.6	50 0	−0.7	−0.8
8 20	6.2	6.3	16 0	3.2	3.3	55 0	0.6	0.7
8 30	6.1	6.2	17 0	3.0	3.1	60 0	0.5	0.6
8 40	5.9	6.1	18 0	2.8	3.0	65 0	0.4	0.5
8 50	5.8	6.0	19 0	2.7	2.8	70 0	0.3	0.4
9 0	−5.7	−5.9	20 0	−2.5	−2.6	75 0	−0.2	−0.3
9 20	5.5	5.7	21 0	2.4	2.5	80 0	0.1	0.2
9 40	5.3	5.5	22 0	2.3	2.4	85 0	−0.1	−0.1
10 0	−5.2	−5.3	24 0	−2.0	−2.2	90 0	0.0	0.0

TABLE F

BUBBLE SEXTANT CORRECTION TO OBSERVED ALTITUDE OF MOON

FOR REFRACTION AND PARALLAX

Obs. Altitude	Horizontal Parallax							
	54′	55′	56′	57′	58′	59′	60′	61′
°	′	′	′	′	′	′	′	′
5.5	+44.6	+45.6	+46.6	+47.6	+48.6	+49.6	+50.6	+51.6
6.0	45.2	46.2	47.2	48.2	49.2	50.2	51.2	52.2
6.5	45.8	46.8	47.8	48.8	49.7	50.7	51.7	52.7
7.0	46.2	47.2	48.2	49.2	50.2	51.2	52.2	53.2
7.5	46.6	47.6	48.6	49.6	50.6	51.6	52.6	53.6
8.0	+46.9	+47.9	+48.9	+49.9	+50.9	+51.9	+52.9	+53.9
8.5	47.2	48.2	49.2	50.2	51.2	52.2	53.2	54.2
9.0	47.5	48.5	49.4	50.4	51.4	52.4	53.4	54.4
9.5	47.7	48.7	49.7	50.6	51.6	52.6	53.6	54.6
10.0	47.9	48.9	49.9	50.8	51.8	52.8	53.8	54.8
11	+48.2	+49.2	+50.1	+51.1	+52.1	+53.1	+54.1	+55.1
12	48.4	49.4	50.3	51.3	52.3	53.3	54.2	55.2
13	48.5	49.5	50.4	51.4	52.4	53.4	54.4	55.3
14	48.6	49.6	50.5	51.5	52.5	53.4	54.4	55.4
15	48.6	49.6	50.5	51.5	52.5	53.4	54.4	55.4
16	+48.6	+49.5	+50.5	+51.5	+52.4	+53.4	+54.3	+55.3
17	48.5	49.5	50.4	51.4	52.3	53.3	54.3	55.2
18	48.4	49.4	50.3	51.3	52.2	53.2	54.1	55.1
19	48.3	49.2	50.2	51.1	52.1	53.0	54.0	54.9
20	48.1	49.0	50.0	50.9	51.9	52.8	53.8	54.7
21	+47.9	+48.8	+49.8	+50.7	+51.7	+52.6	+53.5	+54.5
22	47.7	48.6	49.6	50.5	51.4	52.3	53.3	54.2
23	47.5	48.4	49.3	50.2	51.1	52.0	53.0	53.9
24	47.2	48.1	49.0	49.9	50.8	51.7	52.7	53.6
25	46.9	47.8	48.7	49.6	50.5	51.4	52.3	53.2
26	+46.6	+47.5	+48.4	+49.3	+50.2	+51.1	+52.0	+52.9
27	46.2	47.1	48.0	48.9	49.8	50.7	51.6	52.5
28	45.9	46.8	47.6	48.5	49.4	50.3	51.2	52.1
29	45.5	46.4	47.2	48.1	49.0	49.9	50.8	51.6
30	45.1	46.0	46.8	47.7	48.6	49.4	50.3	51.2
31	+44.7	+45.6	+46.4	+47.3	+48.1	+49.0	+49.8	+50.7
32	44.3	45.1	46.0	46.8	47.7	48.5	49.4	50.2
33	43.8	44.7	45.5	46.3	47.2	48.0	48.8	49.7
34	43.4	44.2	45.0	45.8	46.7	47.5	48.3	49.2
35	42.9	43.7	44.5	45.3	46.2	47.0	47.8	48.6
36	+42.4	+43.2	+44.0	+44.8	+45.6	+46.4	+47.2	+48.0
37	41.9	42.7	43.5	44.3	45.1	45.9	46.6	47.4
38	41.3	42.1	42.9	43.7	44.5	45.3	46.0	46.8
39	40.8	41.6	42.3	43.1	43.9	44.7	45.4	46.2
40	40.2	41.0	41.8	42.5	43.3	44.1	44.8	45.6
41	+39.7	+40.4	+41.2	+41.9	+42.7	+43.4	+44.2	+44.9
42	39.1	39.8	40.6	41.3	42.0	42.8	43.5	44.3
43	38.5	39.2	39.9	40.7	41.4	42.1	42.9	43.6
44	37.9	38.6	39.3	40.0	40.7	41.5	42.2	42.9
45	+37.2	+37.9	+38.6	+39.4	+40.1	+40.8	+41.5	+42.2

Obs. Altitude	Horizontal Parallax							
	54′	55′	56′	57′	58′	59′	60′	61′
°	′	′	′	′	′	′	′	′
46	+36.6	+37.3	+38.0	+38.7	+39.4	+40.1	+40.8	+41.5
47	35.9	36.6	37.3	38.0	38.7	39.4	40.0	40.7
48	35.3	35.9	36.6	37.3	37.9	38.6	39.3	40.0
49	34.6	35.2	35.9	36.6	37.2	37.9	38.5	39.2
50	33.9	34.5	35.2	35.8	36.5	37.1	37.8	38.4
51	+33.2	+33.8	+34.5	+35.1	+35.7	+36.4	+37.0	+37.6
52	32.5	33.1	33.7	34.3	35.0	35.6	36.2	36.8
53	31.8	32.4	33.0	33.6	34.2	34.8	35.4	36.0
54	31.1	31.6	32.2	32.8	33.4	34.0	34.6	35.2
55	30.3	30.9	31.5	32.0	32.6	33.2	33.8	34.3
56	+29.6	+30.1	+30.7	+31.2	+31.8	+32.4	+32.9	+33.5
57	28.8	29.3	29.9	30.4	31.0	31.5	32.1	32.6
58	28.0	28.5	29.1	29.6	30.2	30.7	31.2	31.7
59	27.2	27.7	28.3	28.8	29.3	29.8	30.3	30.8
60	26.4	26.9	27.5	28.0	28.5	29.0	29.5	29.9
61	+25.6	+26.1	+26.6	+27.1	+27.6	+28.1	+28.6	+29.0
62	24.8	25.3	25.8	26.3	26.7	27.2	27.7	28.1
63	24.0	24.5	24.9	25.4	25.9	26.3	26.8	27.2
64	23.2	23.7	24.1	24.5	25.0	25.4	25.8	26.3
65	22.4	22.8	23.2	23.7	24.1	24.5	24.9	25.4
66	+21.5	+22.0	+22.4	+22.8	+23.2	+23.6	+24.0	+24.4
67	20.7	21.1	21.5	21.9	22.3	22.7	23.0	23.4
68	19.8	20.2	20.6	21.0	21.4	21.7	22.1	22.5
69	19.0	19.4	19.7	20.1	20.4	20.8	21.1	21.5
70	18.1	18.5	18.8	19.2	19.5	19.8	20.2	20.5
71	+17.3	+17.6	+17.9	+18.2	+18.6	+18.9	+19.2	+19.5
72	16.4	16.7	17.0	17.3	17.6	17.9	18.2	18.5
73	15.5	15.8	16.1	16.4	16.7	17.0	17.3	17.5
74	14.6	14.9	15.2	15.4	15.7	16.0	16.3	16.5
75	13.7	14.0	14.2	14.5	14.8	15.0	15.3	15.5
76	+12.8	+13.1	+13.3	+13.5	+13.8	+14.0	+14.3	+14.5
77	11.9	12.2	12.4	12.6	12.8	13.1	13.3	13.5
78	11.0	11.2	11.4	11.6	11.9	12.1	12.3	12.5
79	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.5
80	9.2	9.4	9.6	9.7	9.9	10.1	10.2	10.4
81	+ 8.3	+ 8.5	+ 8.6	+ 8.8	+ 8.9	+ 9.1	+ 9.2	+ 9.4
82	7.4	7.5	7.6	7.8	8.0	8.1	8.2	8.4
83	6.5	6.6	6.7	6.8	7.0	7.1	7.2	7.3
84	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3
85	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.2
86	+ 3.7	+ 3.8	+ 3.8	+ 3.9	+ 4.0	+ 4.0	+ 4.1	+ 4.2
87	2.8	2.8	2.9	2.9	3.0	3.0	3.1	3.1
88	1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1
89	+ 0.9	+ 0.9	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE D

CORRECTION TO THE OBSERVED ALTITUDE OF THE MOON

FOR REFRACTION, PARALLAX, AND SEMIDIAMETER

Lower Limb									Upper Limb								
Obs. Alt. Lower Limb	Horizontal Parallax								Obs. Alt. Upper Limb	Horizontal Parallax							
	54′	55′	56′	57′	58′	59′	60′	61′		54′	55′	56′	57′	58′	59′	60′	61′
°	′	′	′	′	′	′	′	′	°	′	′	′	′	′	′	′	′
5.5	+59.6	+60.9	+62.1	+63.4	+64.7	+66.0	+67.3	+68.5	5.5	+29.4	+30.2	+30.9	+31.6	+32.3	+33.0	+33.7	+34.4
6.0	60.2	61.4	62.7	64.0	65.3	66.5	67.8	69.1	6.0	30.1	30.8	31.5	32.3	33.0	33.7	34.4	35.1
6.5	60.7	61.9	63.2	64.5	65.8	67.0	68.3	69.6	6.5	30.7	31.4	32.1	32.8	33.5	34.3	35.0	35.7
7.0	61.1	62.4	63.6	64.9	66.2	67.4	68.7	70.0	7.0	31.2	31.9	32.6	33.3	34.0	34.8	35.5	36.2
7.5	61.5	62.7	64.0	65.3	66.5	67.8	69.1	70.4	7.5	31.6	32.3	33.0	33.7	34.5	35.2	35.9	36.6
8.0	+61.8	+63.1	+64.3	+65.6	+66.9	+68.1	+69.4	+70.7	8.0	+32.0	+32.7	+33.4	+34.1	+34.8	+35.5	+36.3	+37.0
8.5	62.1	63.3	64.6	65.9	67.1	68.4	69.7	70.9	8.5	32.3	33.0	33.7	34.4	35.1	35.9	36.6	37.3
9.0	62.3	63.6	64.8	66.1	67.4	68.6	69.9	71.1	9.0	32.6	33.3	34.0	34.7	35.4	36.1	36.8	37.5
9.5	62.5	63.8	65.0	66.3	67.6	68.8	70.1	71.3	9.5	32.8	33.5	34.2	34.9	35.6	36.3	37.1	37.8
10.0	62.7	64.0	65.2	66.5	67.7	69.0	70.3	71.5	10.0	33.0	33.7	34.4	35.1	35.8	36.5	37.3	38.0
11	+63.0	+64.2	+65.5	+66.7	+68.0	+69.3	+70.5	+71.8	11	+33.3	+34.0	+34.7	+35.4	+36.2	+36.9	+37.6	+38.3
12	63.2	64.4	65.7	66.9	68.2	69.5	70.7	72.0	12	33.6	34.3	35.0	35.7	36.4	37.1	37.8	38.5
13	63.3	64.6	65.8	67.0	68.3	69.6	70.8	72.1	13	33.7	34.4	35.1	35.8	36.5	37.2	37.9	38.6
14	63.4	64.6	65.9	67.1	68.4	69.6	70.9	72.1	14	33.8	34.5	35.2	35.9	36.6	[illegible]	38.0	38.7
15	63.4	64.6	65.9	67.1	68.4	69.6	70.9	72.1	15	33.8	34.5	35.2	35.9	36.6	37.3	38.0	38.7
16	+63.4	+64.6	+65.8	+67.1	+68.3	+69.6	+70.8	+72.0	16	+33.8	+34.5	+35.2	+35.9	+36.6	+37.3	+38.0	+38.6
17	63.3	64.5	65.8	67.0	68.2	69.5	70.7	71.9	17	33.8	34.5	35.1	35.8	36.5	37.2	37.9	38.6
18	63.2	64.4	65.6	66.9	68.1	69.3	70.6	71.8	18	33.7	34.3	35.0	35.7	36.4	37.1	37.7	38.4
19	63.1	64.3	65.5	66.7	67.9	69.2	70.4	71.6	19	33.5	34.2	34.9	35.6	36.2	36.9	37.6	38.2
20	62.9	64.1	65.3	66.5	67.8	69.0	70.2	71.4	20	33.4	34.0	34.7	35.4	36.0	36.7	37.4	38.1
21	+62.7	+63.9	+65.1	+66.3	+67.5	+68.7	+70.0	+71.2	21	+33.2	+33.9	+34.5	+35.2	+35.8	+36.5	+37.2	+37.8
22	62.5	63.7	64.9	66.1	67.3	68.5	69.7	70.9	22	33.0	33.6	34.3	34.9	35.6	36.3	36.9	37.6
23	62.2	63.4	64.6	65.9	67.0	68.2	69.4	70.6	23	32.7	33.4	34.0	34.7	35.3	36.0	36.6	37.3
24	62.0	63.1	64.3	65.5	66.7	67.9	69.1	70.3	24	32.5	33.1	33.7	34.4	35.0	35.7	36.3	37.0
25	61.7	62.9	64.0	65.2	66.4	67.6	68.8	69.9	25	32.2	32.8	33.4	34.1	34.7	35.4	36.0	36.6
26	+61.3	+62.5	+63.7	+64.9	+66.0	+67.2	+68.4	+69.6	26	+31.9	+32.5	+33.1	+33.7	+34.4	+35.0	+35.6	+36.2
27	61.0	62.2	63.3	64.5	65.7	66.8	68.0	69.2	27	31.5	32.1	32.8	33.4	34.0	34.6	35.2	35.9
28	60.7	61.8	63.0	64.1	65.3	66.4	67.6	68.8	28	31.2	31.8	32.4	33.0	33.6	34.2	34.9	35.5
29	60.3	61.4	62.6	63.7	64.9	66.0	67.2	68.4	29	30.8	31.4	32.0	32.6	33.2	33.8	34.4	35.0
30	59.9	61.0	62.2	63.3	64.4	65.6	66.7	67.9	30	30.4	31.0	31.6	32.2	32.8	33.4	34.0	34.6
31	+59.5	+60.6	+61.7	+62.9	+64.0	+65.1	+66.3	+67.4	31	+30.0	+30.6	+31.2	+31.8	+32.3	+32.9	+33.5	+34.1
32	59.0	60.2	61.3	62.4	63.5	64.7	65.8	66.9	32	29.6	30.1	30.7	31.3	31.9	32.5	33.0	33.6
33	58.6	59.7	60.8	61.9	63.1	64.2	65.3	66.4	33	29.1	29.7	30.3	30.8	31.4	32.0	32.5	33.1
34	58.1	59.2	60.3	61.4	62.5	63.6	64.8	65.9	34	28.7	29.2	29.8	30.3	30.9	31.5	32.0	32.6
35	57.7	58.7	59.8	60.9	62.0	63.1	64.2	65.3	35	28.2	28.7	29.3	29.8	30.4	30.9	31.5	32.0
36	+57.2	+58.2	+59.3	+60.4	+61.5	+62.6	+63.7	+64.7	36	+27.7	+28.2	+28.8	+29.3	+29.8	+30.4	+30.9	+31.5
37	56.7	57.7	58.8	59.8	60.9	62.0	63.1	64.2	37	27.2	27.7	28.2	28.8	29.3	29.8	30.3	30.9
38	56.1	57.2	58.2	59.3	60.4	61.4	62.5	63.6	38	26.7	27.2	27.7	28.2	28.7	29.2	29.7	30.3
39	55.6	56.6	57.7	58.7	59.8	60.8	61.9	62.9	39	26.1	26.6	27.1	27.6	28.1	28.6	29.1	29.6
40	55.0	56.1	57.1	58.1	59.2	60.2	61.3	62.3	40	25.6	26.1	26.6	27.1	27.6	28.0	28.5	29.0
41	+54.4	+55.5	+56.5	+57.5	+58.6	+59.6	+60.6	+61.6	41	+25.0	+25.5	+26.0	+26.4	+26.9	+27.4	+27.9	+28.4
42	53.9	54.9	55.9	56.9	57.9	59.0	60.0	61.0	42	24.4	24.9	25.4	25.8	26.3	26.8	27.2	27.7
43	53.3	54.3	55.3	56.3	57.3	58.3	59.3	60.3	43	23.8	24.3	24.7	25.2	25.6	26.1	26.6	27.0
44	52.7	53.7	54.6	55.6	56.6	57.6	58.6	59.6	44	23.2	23.6	24.1	24.6	25.0	25.4	25.9	26.3
45	52.0	53.0	54.0	55.0	56.0	56.9	57.9	58.9	45	22.6	23.0	23.4	23.9	24.3	24.7	25.2	25.6
46	+51.4	+52.4	+53.3	+54.3	+55.3	+56.2	+57.2	+58.2	46	+21.9	+22.4	+22.8	+23.2	+23.6	+24.0	+24.5	+24.9

For Height of Eye Correction see Table C

STARS, JUNE 1938

GREENWICH CIVIL TIME

Star	Alphecca α Cor. Bor Mag. 2 3	Dschubba δ Scorpii Mag 2 5	Antares α Scorpii Mag 1 2	α Tri. Aus Mag 1 9	Subik η Ophiuchi Mag. 2 6	Shaula λ Scorpii Mag 1 7	Rasalague α Ophiuchi Mag 2 1	Etamin γ Draconis Mag 2 4	Kaus Austr ε Sagittarii Mag 2.0
Date	Greenwich Hour Angle for 0ʰ Greenwich Civil Time								
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
13	27 37 2	21 27 9	14 13 8	10 5 5	3 55 6	358 16 7	357 37 2	351 50 6	345 36 9
14	28 36 3	22 27 1	15 12 9	11 4.6	4 54 7	359 15 9	358 36 3	352 49.7	346 36 0
15	29 35 5	23 26 2	16 12 1	12 3.8	5 53 8	0 15 0	359 35 5	353 48 9	347 35 2
16	30 34 6	24 25 3	17 11 2	13 2 9	6 53 0	1 14.2	0 34 6	354 48 0	348 34.3
17	31 33 7	25 24.5	18 10.3	14 2.0	7 52.1	2 13.3	1 33 7	355 47.1	349 33.4
18	32 32 9	26 23 6	19 9.5	15 1.2	8 51.3	3 12 4	2 32 9	356 46.3	350 32 6
19	33 32 0	27 22 8	20 8.6	16 0.3	9 50.4	4 11.6	3 32 0	357 45.4	351 31.7
20	34 31.2	28 21 9	21 7.7	16 59.4	10 49 5	5 10.7	4 31 1	358 44 6	352 30 8
21	35 30.3	29 21 0	22 6 9	17 58 6	11 48 7	6 9.8	5 30 3	359 43 7	353 30 0
22	36 29.4	30 20.2	23 6.0	18 57.7	12 47.8	7 8.9	6 29 4	0 42.8	354 29.1
23	37 28.6	31 19.3	24 5.2	19 56 9	13 46.9	8 8.1	7 28 6	1 42.0	355 28.2
24	38 27.7	32 18.4	25 4.3	20 56.0	14 46 1	9 7.2	8 27 7	2 41.1	356 27 3
25	39 26 9	33 17 6	26 3.4	21 55.1	15 45 2	10 6.4	9 26.8	3 40.2	357 26 5
26	40 26 0	34 16 7	27 2 6	22 54.3	16 44.4	11 5.5	10 26.0	4 39.4	358 25 6
27	41 25 1	35 15.9	28 1.7	23 53.4	17 43.5	12 4.6	11 25.1	5 38.5	359 24.8
28	42 24 3	36 15 0	29 0 8	24 52 5	18 42.6	13 3 8	12 24 2	6 37 7	0 23 9
29	43 23 4	37 14 1	29 59 9	25 51 7	19 41 8	14 2 9	13 23 4	7 36 8	1 23 0
30	44 22 6	38 13 3	30 59 1	26 50 8	20 40 9	15 2 1	14 22 5	8 35 9	2 22 2

Star	Vega α Lyræ Mag. 0.1	Nunki σ Sagittarii Mag. 2.1	Altair α Aquilæ Mag. 0 9	Peacock α Pavonis Mag. 2.1	Deneb α Cygni Mag. 1.3	Enif ε Pegasi Mag. 2.5	Al Na'ir α Gruis Mag. 2.2	Fomalhaut α Pis. Aus. Mag. 1.3	Markab α Pegasi Mag. 2.6
June 1	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s
R. A.	18 34 53 3	18 51 29 1	19 47 48.5	20 20 49 7	20 39 21.6	21 41 10 8	22 4 22.7	22 54 15 7	23 1 42 2
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
Dec.	+38 43 5	−26 22 3	+8 42 3	−56 55 7	+45 3 5	+9 35 5	−47 15 3	−29 56 7	+14 52 4
	h m	h m	h m	h m	h m	h m	h m	h m	h m
Transit	1 59	2 16	3 12	3 45	4 3	5 5	5 28	6 18	6 25
Date	Greenwich Hour Angle for 0ʰ Greenwich Civil Time								
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
1	330 5.9	325 56 9	311 52 1	303 36 7	298 58 8	283 31.5	277 43 5	265 15 2	263 23 6
2	331 5 0	326 56 0	312 51 2	304 35 9	299 57 9	284 30.6	278 42.6	266 14 4	264 22 7
3	332 4.1	327 55 2	313 50 3	305 35.0	300 57 0	285 29.7	279 41.8	267 13 5	265 21.9
4	333 3 3	328 54 3	314 49.5	306 34.1	301 56.2	286 28.9	280 40.9	268 12.6	266 21.0
5	334 2.4	329 53.4	315 48.6	307 33.3	302 55.3	287 28.0	281 40.0	269 11.8	267 20.1
6	335 1 5	330 52.6	316 47.7	308 32.4	303 54.4	288 27.1	282 39.1	270 10.9	268 19 3
7	336 0.7	331 51 7	317 46 9	309 31.5	304 53 6	289 26.2	283 38.3	271 10.0	269 18 4
8	336 59.8	332 50 8	318 46.0	310 30.6	305 52.7	290 25.4	284 37 4	272 9.2	270 17 5
9	337 58.9	333 50 0	319 45 1	311 29.8	306 51 8	291 24.5	285 36.5	273 8.3	271 16 7
10	338 58.1	334 49 1	320 44.3	312 28.9	307 51 0	292 23.6	286 35.7	274 7.4	272 15 8
11	339 57.2	335 48 2	321 43.4	313 28.0	308 50.1	293 22.8	287 34.8	275 6.5	273 14 9
12	340 56.4	336 47 4	322 42 5	314 27.2	309 49.2	294 21.9	288 33.9	276 5.7	274 14 1
13	341 55.5	337 46 5	323 41 7	315 26.3	310 48.3	295 21.0	289 33.0	277 4.8	275 13 2
14	342 54 6	338 45.6	324 40 8	316 25.4	311 47.5	296 20.2	290 32.2	278 3.9	276 12 3
15	343 53.8	339 44 8	325 39 9	317 24.6	312 46.6	297 19.3	291 31.3	279 3.1	277 11 4
16	344 52.9	340 43.9	326 39 1	318 23 7	313 45.8	298 18.4	292 30 4	280 2.2	278 10 6
17	345 52.0	341 43.0	327 38.2	319 22.8	314 44.9	299 17 6	293 29 6	281 1.3	279 9.7
18	346 51.2	342 42.2	328 37.3	320 21.9	315 44.0	300 16.7	294 28.7	282 0.5	280 8 8
19	347 50.3	343 41.3	329 36.5	321 21.1	316 43.1	301 15.8	295 27.8	282 59.6	281 8 0
20	348 49.4	344 40.4	330 35.6	322 20.2	317 42.3	302 15.0	296 26.9	283 58.7	282 7 1
21	349 48.6	345 39.6	331 34.7	323 19.3	318 41.4	303 14.1	297 26.1	284 57.9	283 6 2
22	350 47 7	346 38.7	332 33.9	324 18.5	319 40.5	304 13.2	298 25 2	285 57.0	284 5 4
23	351 46 8	347 37.8	333 33.0	325 17.6	320 39.7	305 12.4	299 24 3	286 56 1	285 4 5
24	352 46.0	348 37.0	334 32.1	326 16.7	321 38.8	306 11.5	300 23.5	287 55.2	286 3 6
25	353 45.1	349 36.1	335 31.3	327 15.8	322 37.9	307 10.6	301 22.6	288 54.4	287 2 8
26	354 44.3	350 35.2	336 30.4	328 15.0	323 37.1	308 9.8	302 21.7	289 53.5	288 1 9
27	355 43.4	351 34.4	337 29.5	329 14.1	324 36.2	309 8.9	303 20 8	290 52 6	289 1 0
28	356 42 6	352 33.5	338 28.7	330 13.2	325 35.3	310 8.0	304 20.0	291 51.8	290 0.1
29	357 41.7	353 32.6	339 27.8	331 12.4	226 34.5	311 7.2	305 19.1	292 50.9	290 59.3
30	358 40.8	354 31.8	340 26.9	332 11.5	327 33.6	312 6.3	306 18.2	293 50.0	291 58.4

214 CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF STARS

Min.	Hours of Greenwich Civil Time							
	0h	1h	2h	3h	4h	5h	6h	7h
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 0.0	15 2.5	30 4.9	45 7.4	60 9.9	75 12.3	90 14.8	105 17.2
1	0 15.0	15 17.5	30 19.9	45 22.4	60 24.9	75 27.4	90 29.8	105 32.3
2	0 30.1	15 32.5	30 35.0	45 37.5	60 39.9	75 42.4	90 44.9	105 47.3
3	0 45.1	15 47.6	30 50.1	45 52.5	60 55.0	75 57.4	90 59.9	106 2.4
4	1 0.2	16 2.6	31 5.1	46 7.6	61 10.0	76 12.5	91 14.9	106 17.4
5	1 15.2	16 17.7	31 20.1	46 22.6	61 25.1	76 27.5	91 30.0	106 32.5
6	1 30.2	16 32.7	31 35.2	46 37.6	61 40.1	76 42.6	91 45.0	106 47.5
7	1 45.3	16 47.8	31 50.2	46 52.7	61 55.1	76 57.6	92 0.1	107 2.5
8	2 0.3	17 2.8	32 5.3	47 7.7	62 10.2	77 12.6	92 15.1	107 17.6
9	2 15.4	17 17.8	32 20.3	47 22.8	62 25.2	77 27.7	92 30.2	107 32.6
10	2 30.4	17 32.9	32 35.3	47 37.8	62 40.3	77 42.7	92 45.2	107 47.7
11	2 45.5	17 47.9	32 50.4	47 52.8	62 55.3	77 57.8	93 0.2	108 2.7
12	3 0.5	18 3.0	33 5.4	48 7.9	63 10.3	78 12.8	93 15.3	108 17.7
13	3 15.5	18 18.0	33 20.5	48 22.9	63 25.4	78 27.9	93 30.3	108 32.8
14	3 30.6	18 33.0	33 35.5	48 38.0	63 40.4	78 42.9	93 45.4	108 47.8
15	3 45.6	18 48.1	33 50.5	48 53.0	63 55.5	78 57.9	94 0.4	109 2.9
16	4 0.7	19 3.1	34 5.6	49 8.0	64 10.5	79 13.0	94 15.4	109 17.9
17	4 15.7	19 18.2	34 20.6	49 23.1	64 25.6	79 28.0	94 30.5	109 32.9
18	4 30.7	19 33.2	34 35.7	49 38.1	64 40.6	79 43.1	94 45.5	109 48.0
19	4 45.8	19 48.2	34 50.7	49 53.2	64 55.6	79 58.1	95 0.6	110 3.0
20	5 0.8	20 3.3	35 5.7	50 8.2	65 10.7	80 13.1	95 15.6	110 18.1
21	5 15.9	20 18.3	35 20.8	50 23.3	65 25.7	80 28.2	95 30.6	110 33.1
22	5 30.9	20 33.4	35 35.8	50 38.3	65 40.8	80 43.2	95 45.7	110 48.2
23	5 45.9	20 48.4	35 50.9	50 53.3	65 55.8	80 58.3	96 0.7	111 3.2
24	6 1.0	21 3.4	36 5.9	51 8.4	66 10.8	81 13.3	96 15.8	111 18.2
25	6 16.0	21 18.5	36 21.0	51 23.4	66 25.9	81 28.3	96 30.8	111 33.3
26	6 31.1	21 33.5	36 36.0	51 38.5	66 40.9	81 43.4	96 45.8	111 48.3
27	6 46.1	21 48.6	36 51.0	51 53.5	66 56.0	81 58.4	97 0.9	112 3.4
28	7 1.1	22 3.6	37 6.1	52 8.5	67 11.0	82 13.5	97 15.9	112 18.4
29	7 16.2	22 18.7	37 21.1	52 23.6	67 26.0	82 28.5	97 31.0	112 33.4
30	7 31.2	22 33.7	37 36.2	52 38.6	67 41.1	82 43.6	97 46.0	112 48.5
31	7 46.3	22 48.7	37 51.2	52 53.7	67 56.1	82 58.6	98 1.1	113 3.5
32	8 1.3	23 3.8	38 6.2	53 8.7	68 11.2	83 13.6	98 16.1	113 18.6
33	8 16.4	23 18.8	38 21.3	53 23.7	68 26.2	83 28.7	98 31.1	113 33.6
34	8 31.4	23 33.9	38 36.3	53 38.8	68 41.2	83 43.7	98 46.2	113 48.6
35	8 46.4	23 48.9	38 51.4	53 53.8	68 56.3	83 58.8	99 1.2	114 3.7
36	9 1.5	24 3.9	39 6.4	54 8.9	69 11.3	84 13.8	99 16.3	114 18.7
37	9 16.5	24 19.0	39 21.4	54 23.9	69 26.4	84 28.8	99 31.3	114 33.8
38	9 31.6	24 34.0	39 36.5	54 39.0	69 41.4	84 43.9	99 46.3	114 48.8
39	9 46.6	24 49.1	39 51.5	54 54.0	69 56.5	84 58.9	100 1.4	115 3.9
40	10 1.6	25 4.1	40 6.6	55 9.0	70 11.5	85 14.0	100 16.4	115 18.9
41	10 16.7	25 19.1	40 21.6	55 24.1	70 26.5	85 29.0	100 31.5	115 33.9
42	10 31.7	25 34.2	40 36.7	55 39.1	70 41.6	85 44.0	100 46.5	115 49.0
43	10 46.8	25 49.2	40 51.7	55 54.2	70 56.6	85 59.1	101 1.5	116 4.0
44	11 1.8	26 4.3	41 6.7	56 9.2	71 11.7	86 14.1	101 16.6	116 19.1
45	11 16.8	26 19.3	41 21.8	56 24.2	71 26.7	86 29.2	101 31.6	116 34.1
46	11 31.9	26 34.4	41 36.8	56 39.3	71 41.7	86 44.2	101 46.7	116 49.1
47	11 46.9	26 49.4	41 51.9	56 54.3	71 56.8	86 59.2	102 1.7	117 4.2
48	12 2.0	27 4.4	42 6.9	57 9.4	72 11.8	87 14.3	102 16.8	117 19.2
49	12 17.0	27 19.5	42 21.9	57 24.4	72 26.9	87 29.3	102 31.8	117 34.3
50	12 32.1	27 34.5	42 37.0	57 39.4	72 41.9	87 44.4	102 46.8	117 49.3
51	12 47.1	27 49.6	42 52.0	57 54.5	72 56.9	87 59.4	103 1.9	118 4.3
52	13 2.1	28 4.6	43 7.1	58 9.5	73 12.0	88 14.5	103 16.9	118 19.4
53	13 17.2	28 19.6	43 22.1	58 24.6	73 27.0	88 29.5	103 32.0	118 34.4
54	13 32.2	28 34.7	43 37.1	58 39.6	73 42.1	88 44.5	103 47.0	118 49.5
55	13 47.3	28 49.7	43 52.2	58 54.6	73 57.1	88 59.6	104 2.0	119 4.5
56	14 2.3	29 4.8	44 7.2	59 9.7	74 12.2	89 14.6	104 17.1	119 19.5
57	14 17.3	29 19.8	44 22.3	59 24.7	74 27.2	89 29.7	104 32.1	119 34.6
58	14 32.4	29 34.8	44 37.3	59 39.8	74 42.2	89 44.7	104 47.2	119 49.6
59	14 47.4	29 49.9	44 52.4	59 54.8	74 57.3	89 59.7	105 2.2	120 4.7
60	15 2.5	30 4.9	45 7.4	60 9.9	75 12.3	90 14.8	105 17.2	120 19.7

Sec.	Corr.
	′
0	0.0
1	0.3
2	0.5
3	0.8
4	1.0
5	1.3
6	1.5
7	1.8
8	2.0
9	2.3
10	2.5
11	2.8
12	3.0
13	3.3
14	3.5
15	3.8
16	4.0
17	4.3
18	4.5
19	4.8
20	5.0
21	5.3
22	5.5
23	5.8
24	6.0
25	6.3
26	6.5
27	6.8
28	7.0
29	7.3
30	7.5
31	7.8
32	8.0
33	8.3
34	8.5
35	8.8
36	9.0
37	9.3
38	9.5
39	9.8
40	10.0
41	10.3
42	10.5
43	10.8
44	11.0
45	11.3
46	11.5
47	11.8
48	12.0
49	12.3
50	12.5
51	12.8
52	13.0
53	13.3
54	13.5
55	13.8
56	14.0
57	14.3
58	14.5
59	14.8
60	15.0

SUN, JUNE 1938

G. C. T.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.
	Wednesday 1			**Sunday 5**			**Thursday 9**		
h	m s	° ′	° ′	m s	° ′	° ′	m s	° ′	° ′
0	+2 29.1	+21 56.0	180 37.3	+1 51.1	+22 26.9	180 27.8	+1 8.0	+22 51.5	180 17.0
2	2 28.4	21 56.7	210 37.1	1 50.3	22 27.5	210 27.6	1 7.0	22 52.0	210 16.8
4	2 27.6	21 57.4	240 36.9	1 49.4	22 28.0	240 27.4	1 6.1	22 52.4	240 16.5
6	2 26.9	21 58.1	270 36.7	1 48.6	22 28.6	270 27.1	1 5.1	22 52.8	270 16.3
8	2 26.1	21 58.8	300 36.5	1 47.7	22 29.2	300 26.9	1 4.2	22 53.3	300 16.1
10	2 25.4	21 59.5	330 36.4	1 46.9	22 29.7	330 26.7	1 3.2	22 53.7	330 15.8
12	2 24.7	22 0.2	0 36.2	1 46.0	22 30.3	0 26.5	1 2.3	22 54.1	0 15.6
14	2 23.9	22 0.9	30 36.0	1 45.1	22 30.9	30 26.3	1 1.3	22 54.6	30 15.3
16	2 23.2	22 1.6	60 35.8	1 44.3	22 31.4	60 26.1	1 0.4	22 55.0	60 15.1
18	2 22.4	22 2.2	90 35.6	1 43.4	22 32.0	90 25.8	0 59.4	22 55.4	90 14.9
20	2 21.7	22 2.9	120 35.4	1 42.5	22 32.5	120 25.6	0 58.4	22 55.8	120 14.6
22	2 20.9	22 3.6	150 35.2	1 41.7	22 33.1	150 25.4	0 57.5	22 56.3	150 14.4
H. D.	0.4	0.3	... ...	0.4	0.3	... ...	0.5	0.2	... ...

G. C. T.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.
	Thursday 2			**Monday 6**			**Friday 10**		
0	+2 20.1	+22 4.3	180 35.0	+1 40.8	+22 33.6	180 25.2	+0 56.5	+22 56.7	180 14.1
2	2 19.4	22 5.0	210 34.9	1 39.9	22 34.2	210 25.0	0 55.6	22 57.1	210 13.9
4	2 18.6	22 5.6	240 34.7	1 39.0	22 34.7	240 24.8	0 54.6	22 57.5	240 13.6
6	2 17.8	22 6.3	270 34.5	1 38.1	22 35.3	270 24.5	0 53.6	22 57.9	270 13.4
8	2 17.1	22 7.0	300 34.3	1 37.3	22 35.8	300 24.3	0 52.6	22 58.3	300 13.2
10	2 16.3	22 7.6	330 34.1	1 36.4	22 36.3	330 24.1	0 51.7	22 58.7	330 12.9
12	2 15.5	22 8.3	0 33.9	1 35.5	22 36.9	0 23.9	0 50.7	22 59.1	0 12.7
14	2 14.8	22 8.9	30 33.7	1 34.6	22 37.4	30 23.7	0 49.7	22 59.5	30 12.4
16	2 14.0	22 9.6	60 33.5	1 33.7	22 37.9	60 23.4	0 48.7	22 59.9	60 12.2
18	2 13.2	22 10.3	90 33.3	1 32.8	22 38.4	90 23.2	0 47.8	23 0.3	90 11.9
20	2 12.4	22 10.9	120 33.1	1 31.9	22 39.0	120 23.0	0 46.8	23 0.7	120 11.7
22	2 11.6	22 11.6	150 32.9	1 31.0	22 39.5	150 22.8	0 45.8	23 1.0	150 11.4
H. D.	0.4	0.3	... ...	0.4	0.3	... ...	0.5	0.2	... ...

G. C. T.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.
	Friday 3			**Tuesday 7**			**Saturday 11**		
0	+2 10.8	+22 12.2	180 32.7	+1 30.1	+22 40.0	180 22.5	+0 44.8	+23 1.4	180 11.2
2	2 10.0	22 12.9	210 32.5	1 29.2	22 40.5	210 22.3	0 43.8	23 1.8	210 11.0
4	2 9.2	22 13.5	240 32.3	1 28.3	22 41.0	240 22.1	0 42.8	23 2.2	240 10.7
6	2 8.4	22 14.1	270 32.1	1 27.4	22 41.5	270 21.9	0 41.9	23 2.6	270 10.5
8	2 7.6	22 14.8	300 31.9	1 26.5	22 42.0	300 21.6	0 40.9	23 2.9	300 10.2
10	2 6.8	22 15.4	330 31.7	1 25.6	22 42.5	330 21.4	0 39.9	23 3.3	330 10.0
12	2 6.0	22 16.0	0 31.5	1 24.7	22 43.0	0 21.2	0 38.9	23 3.7	0 9.7
14	2 5.2	22 16.6	30 31.3	1 23.8	22 43.5	30 20.9	0 37.9	23 4.0	30 9.5
16	2 4.4	22 17.3	60 31.1	1 22.9	22 44.0	60 20.7	0 36.9	23 4.4	60 9.2
18	2 3.6	22 17.9	90 30.9	1 21.9	22 44.5	90 20.5	0 35.9	23 4.7	90 9.0
20	2 2.8	22 18.5	120 30.7	1 21.0	22 45.0	120 20.3	0 34.9	23 5.1	120 8.7
22	2 2.0	22 19.1	150 30.5	1 20.1	22 45.5	150 20.0	0 33.9	23 5.4	150 8.5
H. D.	0.4	0.3	... ...	0.5	0.2	... ...	0.5	0.2	... ...

G. C. T.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.
	Saturday 4			**Wednesday 8**			**Sunday 12**		
0	+2 1.2	+22 19.7	180 30.3	+1 19.2	+22 46.0	180 19.8	+0 32.9	+23 5.8	180 8.2
2	2 0.3	22 20.4	210 30.1	1 18.3	22 46.4	210 19.6	0 31.9	23 6.1	210 8.0
4	1 59.5	22 21.0	240 29.9	1 17.3	22 46.9	240 19.3	0 30.9	23 6.5	240 7.7
6	1 58.7	22 21.6	270 29.7	1 16.4	22 47.4	270 19.1	0 29.9	23 6.8	270 7.5
8	1 57.8	22 22.2	300 29.5	1 15.5	22 47.8	300 18.9	0 28.9	23 7.1	300 7.2
10	1 57.0	22 22.8	330 29.3	1 14.5	22 48.3	330 18.6	0 27.9	23 7.5	330 7.0
12	1 56.2	22 23.4	0 29.0	1 13.6	22 48.8	0 18.4	0 26.9	23 7.8	0 6.7
14	1 55.4	22 24.0	30 28.8	1 12.7	22 49.2	30 18.2	0 25.8	23 8.1	30 6.5
16	1 54.5	22 24.5	60 28.6	1 11.7	22 49.7	60 17.9	0 24.8	23 8.5	60 6.2
18	1 53.7	22 25.1	90 28.4	1 10.8	22 50.2	90 17.7	0 23.8	23 8.8	90 5.9
20	1 52.8	22 25.7	120 28.2	1 9.9	22 50.6	120 17.5	0 22.8	23 9.1	120 5.7
22	+1 52.0	+22 26.3	150 28.0	+1 8.9	+22 51.1	150 17.2	+0 21.8	+23 9.4	150 5.4
H. D.	0.4	0.3	... ...	0.5	0.2	... ...	0.5	0.2	... ...

NOTE.—The Equation of Time is to be applied to the G. C. T. in accordance with the sign as given

SUN, MAY 1938

G. C. T.	Equation of Time	Sun's Declination	Sun's G. H. A.	Equation of Time	Sun's Declination	Sun's G. H. A.
	Wednesday 25			**Sunday 29**		
h	m s	° ′	° ′	m s	° ′	° ′
0	+3 19.3	+20 47.3	180 49.8	+2 53.4	+21 28.8	180 43.4
2	3 18.8	20 48.3	210 49.7	2 52.8	21 29.6	210 43.2
4	3 18.4	20 49.2	240 49.6	2 52.2	21 30.4	240 43.0
6	3 17.9	20 50.1	270 49.5	2 51.5	21 31.2	270 42.9
8	3 17.5	20 51.0	300 49.4	2 50.9	21 32.0	300 42.7
10	3 17.0	20 51.9	330 49.2	2 50.3	21 32.8	330 42.6
12	3 16.5	20 52.8	0 49.1	2 49.6	21 33.5	0 42.4
14	3 16.0	20 53.7	30 49.0	2 49.0	21 34.3	30 42.2
16	3 15.5	20 54.7	60 48.9	2 48.3	21 35.1	60 42.1
18	3 15.1	20 55.6	90 48.8	2 47.7	21 35.9	90 41.9
20	3 14.6	20 56.5	120 48.6	2 47.0	21 36.7	120 41.8
22	3 14.1	20 57.4	150 48.5	2 46.4	21 37.5	150 41.6
H. D.	0.2	0.5	... ...	0.3	0.4	... ...
	Thursday 26			**Monday 30**		
0	+3 13.6	+20 58.2	180 48.4	+2 45.7	+21 38.2	180 41.4
2	3 13.1	20 59.1	210 48.3	2 45.1	21 39.0	210 41.3
4	3 12.6	21 0.0	240 48.1	2 44.4	21 39.8	240 41.1
6	3 12.1	21 0.9	270 48.0	2 43.7	21 40.5	270 40.9
8	3 11.6	21 1.8	300 47.9	2 43.1	21 41.3	300 40.8
10	3 11.0	21 2.7	330 47.8	2 42.4	21 42.0	330 40.6
12	3 10.5	21 3.6	0 47.6	2 41.7	21 42.8	0 40.4
14	3 10.0	21 4.4	30 47.5	2 41.0	21 43.6	30 40.3
16	3 9.5	21 5.3	60 47.4	2 40.4	21 44.3	60 40.1
18	3 8.9	21 6.2	90 47.2	2 39.7	21 45.1	90 39.9
20	3 8.4	21 7.1	120 47.1	2 39.0	21 45.8	120 39.7
22	3 7.9	21 7.9	150 47.0	2 38.3	21 46.6	150 39.6
H. D.	0.3	0.4	... ...	0.3	0.4	... ...
	Friday 27			**Tuesday 31**		
0	+3 7.3	+21 8.8	180 46.8	+2 37.6	+21 47.3	180 39.4
2	3 6.8	21 9.7	210 46.7	2 36.9	21 48.0	210 39.2
4	3 6.3	21 10.5	240 46.6	2 36.2	21 48.8	240 39.1
6	3 5.7	21 11.4	270 46.4	2 35.5	21 49.5	270 38.9
8	3 5.1	21 12.2	300 46.3	2 34.8	21 50.2	300 38.7
10	3 4.6	21 13.1	330 46.1	2 34.1	21 51.0	330 38.5
12	3 4.0	21 13.9	0 46.0	2 33.4	21 51.7	0 38.3
14	3 3.5	21 14.8	30 45.9	2 32.7	21 52.4	30 38.2
16	3 2.9	21 15.6	60 45.7	2 32.0	21 53.1	60 38.0
18	3 2.3	21 16.5	90 45.6	2 31.3	21 53.8	90 37.8
20	3 1.8	21 17.3	120 45.4	2 30.5	21 54.6	120 37.6
22	3 1.2	21 18.1	150 45.3	-2 29.8	+21 55.3	150 37.4
H. D.	0.3	0.4	... ...	0.4	0.4	... ...
	Saturday 28					
0	+3 0.6	+21 19.0	180 45.2			
2	3 0.0	21 19.8	210 45.0			
4	2 59.4	21 20.6	240 44.9			
6	2 58.9	21 21.5	270 44.7			
8	2 58.3	21 22.3	300 44.6			
10	2 57.7	21 23.1	330 44.4			
12	2 57.1	21 23.9	0 44.3			
14	2 56.5	21 24.7	30 44.1			
16	2 55.9	21 25.6	60 44.0			
18	2 55.2	21 26.4	90 43.8			
20	2 54.6	21 27.2	120 43.7			
22	+2 54.0	+21 28.0	150 43.5			
H. D.	0.3	0.4	... ...			

SEMIDIAMETER

		′
May	1	15.90
	11	15.87
	21	15.83
	31	15.80

Corr. to G. H. A.

Min or Sec.	Corr. for Minutes	Corr. for 1 Hour + Minutes	Corr. for Sec's.
	° ′	° ′	′
0	0 0.0	15 0.0	0.0
1	0 15.0	15 15.0	0.3
2	0 30.0	15 30.0	0.5
3	0 45.0	15 45.0	0.8
4	1 0.0	16 0.0	1.0
5	1 15.0	16 15.0	1.3
6	1 30.0	16 30.0	1.5
7	1 45.0	16 45.0	1.8
8	2 0.0	17 0.0	2.0
9	2 15.0	17 15.0	2.3
10	2 30.0	17 30.0	2.5
11	2 45.0	17 45.0	2.8
12	3 0.0	18 0.0	3.0
13	3 15.0	18 15.0	3.3
14	3 30.0	18 30.0	3.5
15	3 45.0	18 45.0	3.8
16	4 0.0	19 0.0	4.0
17	4 15.0	19 15.0	4.3
18	4 30.0	19 30.0	4.5
19	4 45.0	19 45.0	4.8
20	5 0.0	20 0.0	5.0
21	5 15.0	20 15.0	5.3
22	5 30.0	20 30.0	5.5
23	5 45.0	20 45.0	5.8
24	6 0.0	21 0.0	6.0
25	6 15.0	21 15.0	6.3
26	6 30.0	21 30.0	6.5
27	6 45.0	21 45.0	6.8
28	7 0.0	22 0.0	7.0
29	7 15.0	22 15.0	7.3
30	7 30.0	22 30.0	7.5
31	7 45.0	22 45.0	7.8
32	8 0.0	23 0.0	8.0
33	8 15.0	23 15.0	8.3
34	8 30.0	23 30.0	8.5
35	8 45.0	23 45.0	8.8
36	9 0.0	24 0.0	9.0
37	9 15.0	24 15.0	9.3
38	9 30.0	24 30.0	9.5
39	9 45.0	24 45.0	9.8
40	10 0.0	25 0.0	10.0
41	10 15.0	25 15.0	10.3
42	10 30.0	25 30.0	10.5
43	10 45.0	25 45.0	10.8
44	11 0.0	26 0.0	11.0
45	11 15.0	26 15.0	11.3
46	11 30.0	26 30.0	11.5
47	11 45.0	26 45.0	11.8
48	12 0.0	27 0.0	12.0
49	12 15.0	27 15.0	12.3
50	12 30.0	27 30.0	12.5
51	12 45.0	27 45.0	12.8
52	13 0.0	28 0.0	13.0
53	13 15.0	28 15.0	13.3
54	13 30.0	28 30.0	13.5
55	13 45.0	28 45.0	13.8
56	14 0.0	29 0.0	14.0
57	14 15.0	29 15.0	14.3
58	14 30.0	29 30.0	14.5
59	14 45.0	29 45.0	14.8
60	15 0.0	30 0.0	15.0

NOTE.—The Equation of Time is to be applied to the G. C. T. in accordance with the sign as given.

MOON, 1938

GREENWICH CIVIL TIME

JUNE 10

G. C. T.	Right Ascension	Declination	Greenwich H. A.
h	h m s	° ′	° ′
0	14 50 24	−17 27.5	35 5.3
1	14 52 30	17 33.7	49 36.4
2	14 54 36	17 39.9	64 7.4
3	14 56 42	17 46.0	78 38.4
4	14 58 48	17 52.0	93 9.4
5	15 0 54	17 57.9	107 40.3
6	15 3 0	18 3.7	122 11.3
7	15 5 6	18 9.5	136 42.2
8	15 7 12	18 15.1	151 13.1
9	15 9 18	18 20.7	165 44.0
10	15 11 25	18 26.2	180 14.9
11	15 13 31	18 31.6	194 45.7
12	15 15 38	18 36.8	209 16.6
13	15 17 44	18 42.0	223 47.4
14	15 19 51	18 47.2	238 18.2
15	15 21 58	18 52.2	252 49.0
16	15 24 4	18 57.1	267 19.8
17	15 26 11	19 1.9	281 50.5
18	15 28 18	19 6.7	296 21.3
19	15 30 25	19 11.3	310 52.0
20	15 32 32	19 15.9	325 22.7
21	15 34 39	19 20.4	339 53.4
22	15 36 46	19 24.7	354 24.1
23	15 38 54	−19 29.0	8 54.7

Multiples of Variation per Minute

m	R.A.	Dec.	H. A.
	s	′	′
1	2	−0.1	14.5
2	4	0.2	29.0
3	6	0.3	43.5
4	8	0.3	58.1
5	11	0.4	72.6
6	13	0.5	87.1
7	15	0.6	101.6
8	17	0.7	116.1
9	19	0.8	130.6
10	21	0.9	145.1
20	42	1.7	290.3
30	63	2.6	435.4
40	84	3.5	580.6
50	105	−4.4	725.7

JUNE 11

G. C. T.	Right Ascension	Declination	Greenwich H. A.
0	15 41 1	−19 33.2	23 25.4
1	15 43 8	19 37.3	37 56.0
2	15 45 15	19 41.3	52 26.6
3	15 47 23	19 45.2	66 57.2
4	15 49 30	19 49.0	81 27.8
5	15 51 38	19 52.7	95 58.4
6	15 53 45	19 56.3	110 29.0
7	15 55 53	19 59.8	124 59.6
8	15 58 1	20 3.2	139 30.1
9	16 0 8	20 6.6	154 0.7
10	16 2 16	20 9.8	168 31.2
11	16 4 24	20 12.9	183 1.8
12	16 6 31	20 16.0	197 32.3
13	16 8 39	20 18.9	212 2.8
14	16 10 47	20 21.7	226 33.3
15	16 12 55	20 24.5	241 3.8
16	16 15 3	20 27.1	255 34.3
17	16 17 11	20 29.7	270 4.8
18	16 19 19	20 32.1	284 35.2
19	16 21 27	20 34.4	299 5.7
20	16 23 35	20 36.7	313 36.2
21	16 25 43	20 38.8	328 6.6
22	16 27 51	20 40.9	342 37.1
23	16 29 59	20 42.8	357 7.6
24	16 32 7	−20 44.7	11 38.0

Multiples of Variation per Minute

m	R.A.	Dec.	H. A.
	s	′	′
1	2	0.0	14.5
2	4	−0.1	29.0
3	6	0.1	43.5
4	9	0.2	58.0
5	11	0.2	72.5
6	13	0.3	87.1
7	15	0.3	101.6
8	17	0.4	116.1
9	19	0.4	130.6
10	21	0.5	145.1
20	43	1.0	290.2
30	64	1.5	435.3
40	85	2.0	580.3
50	106	−2.5	725.4

Greenwich Civil Time	Moon's Semidiameter	Moon's Horizontal Parallax
d h	′	′
10 0	15.0	55.0
11 0	14.9	54.6

JUNE 12

G. C. T.	Right Ascension	Declination	Greenwich H. A.
h	h m s	° ′	° ′
0	16 32 7	−20 44.7	11 38.0
1	16 34 15	20 46.4	26 8.5
2	16 36 23	20 48.1	40 38.9
3	16 38 31	20 49.7	55 9.4
4	16 40 39	20 51.1	69 39.8
5	16 42 47	20 52.5	84 10.3
6	16 44 55	20 53.7	98 40.7
7	16 47 3	20 54.9	113 11.2
8	16 49 11	20 55.9	127 41.6
9	16 51 19	20 56.9	142 12.1
10	16 53 27	20 57.8	156 42.6
11	16 55 35	20 58.5	171 13.0
12	16 57 43	20 59.2	185 43.5
13	16 59 51	20 59.7	200 14.0
14	17 1 59	21 0.2	214 44.5
15	17 4 7	21 0.5	229 14.9
16	17 6 15	21 0.8	243 45.4
17	17 8 23	21 1.0	258 15.9
18	17 10 30	21 1.0	272 46.5
19	17 12 38	21 1.0	287 17.0
20	17 14 46	21 0.9	301 47.5
21	17 16 54	21 0.6	316 18.0
22	17 19 1	21 0.3	330 48.6
23	17 21 9	−20 59.9	345 19.1

Multiples of Variation per Minute

m	R.A.	Dec.	H. A.
	s	′	′
1	2	0.0	14.5
2	4	0.0	29.0
3	6	0.0	43.5
4	9	0.0	58.0
5	11	−0.1	72.5
6	13	0.1	87.0
7	15	0.1	101.6
8	17	0.1	116.1
9	19	0.1	130.6
10	21	0.1	145.1
20	43	0.2	290.2
30	64	0.3	435.2
40	85	0.4	580.3
50	107	−0.5	725.4

JUNE 13

G. C. T.	Right Ascension	Declination	Greenwich H. A.
0	17 23 17	−20 59.3	359 49.7
1	17 25 24	20 58.7	14 20.3
2	17 27 32	20 58.0	28 50.9
3	17 29 39	20 57.1	43 21.5
4	17 31 46	20 56.2	57 52.1
5	17 33 54	20 55.2	72 22.7
6	17 36 1	20 54.1	86 53.4
7	17 38 8	20 52.8	101 24.1
8	17 40 15	20 51.5	115 54.8
9	17 42 22	20 50.1	130 25.4
10	17 44 29	20 48.6	144 56.2
11	17 46 36	20 47.0	159 26.9
12	17 48 43	20 45.3	173 57.6
13	17 50 50	20 43.5	188 28.4
14	17 52 57	20 41.6	202 59.2
15	17 55 3	20 39.6	217 30.0
16	17 57 10	20 37.5	232 0.8
17	17 59 16	20 35.3	246 31.7
18	18 1 23	20 33.1	261 2.5
19	18 3 29	20 30.7	275 33.4
20	18 5 35	20 28.2	290 4.3
21	18 7 41	20 25.7	304 35.3
22	18 9 47	20 23.0	319 6.2
23	18 11 53	20 20.3	333 37.2
24	18 13 59	−20 17.4	348 8.2

Multiples of Variation per Minute

m	R.A.	Dec.	H. A.
	s	′	′
1	2	0.0	14.5
2	4	+0.1	29.0
3	6	0.1	43.5
4	8	0.1	58.1
5	11	0.1	72.6
6	13	0.2	87.1
7	15	0.2	101.6
8	17	0.2	116.1
9	19	0.3	130.6
10	21	0.3	145.1
20	42	0.6	290.3
30	63	0.9	435.4
40	85	1.2	580.5
50	106	+1.5	725.6

Greenwich Civil Time	Moon's Semidiameter	Moon's Horizontal Parallax
d h	′	′
12 0	14.8	54.3
13 0	14.8	54.1

GREENWICH CIVIL TIME

Date	Right Ascension 0h		Declination 0h		Greenwich H. A. 0h	Var. per Min.	Transit Merid. of Greenwich
	APRIL						
	h m s	s	° ′	′	° ′	′	h m
1	21 42 42	46	-14 26.9	3.7	223 1.3	15.0330	9 7
2	21 43 28	46	14 23.2	3.7	223 48.9	15.0331	9 4
3	21 44 14	45	14 19.5	3.7	224 36.6	15.0332	9 0
4	21 44 59	45	14 15.8	3.6	225 24.4	15.0332	8 57
5	21 45 44	45	14 12.2	3.6	226 12.2	15.0333	8 54
6	21 46 29	44	-14 8.6	3.6	227 0.2	15.0333	8 51
7	21 47 13	44	14 5.0	3.6	227 48.2	15 0334	8 48
8	21 47 57	44	14 1.4	3.6	228 36.4	15.0334	8 44
9	21 48 41	43	13 57.8	3.5	229 24.6	15.0335	8 41
10	21 49 24	43	13 54.3	3.5	230 13.0	15.0336	8 38
11	21 50 7	42	-13 50.8	3.5	231 1.4	15.0337	8 35
12	21 50 49	42	13 47.3	3.4	231 50.0	15.0338	8 32
13	21 51 31	42	13 43.9	3.4	232 38.6	15.0338	8 28
14	21 52 13	41	13 40.5	3.4	233 27.3	15.0339	8 25
15	21 52 54	41	13 37.1	3.4	234 16.2	15.0340	8 22
16	21 53 35	40	-13 33.7	3.3	235 5.1	15.0340	8 18
17	21 54 15	40	13 30.4	3.3	235 54.2	15.0341	8 15
18	21 54 55	30	13 27.1	3.3	236 43.3	15.0342	8 12
19	21 55 34	39	13 23.8	3.2	237 32.6	15.0342	8 9
20	21 56 13	39	13 20.6	3.2	238 22.0	15.0343	8 5
21	21 56 52	38	-13 17.4	3.2	239 11.5	15.0344	8 2
22	21 57 30	38	13 14.2	3.1	240 1.1	15.0345	7 59
23	21 58 8	37	13 11.1	3.1	240 50.8	15.0346	7 56
24	21 58 45	37	13 8.0	3.1	241 40.6	15.0346	7 52
25	21 59 22	36	13 4.9	3.0	242 30.6	15.0347	7 49
26	21 59 58	36	-13 1.9	3.0	243 20.6	15.0348	7 46
27	22 0 34	35	12 58.9	2.9	244 10.8	15.0349	7 42
28	22 1 9	35	12 56.0	2.9	245 1.1	15.0350	7 39
29	22 1 44	35	12 53.1	2.9	245 51.6	15.0351	7 36
30	22 2 19	33	-12 50.2	2.8	246 42.1	15.0352	7 32
	MAY						
1	22 2 52	34	-12 47.4	2.8	247 32.8	15.0352	7 29
2	22 3 26	32	12 44.6	2.7	248 23.6	15.0353	7 25
3	22 3 58	33	-12 41.9	2.7	249 14.5	15.0354	7 22
4	22 4 31	31	12 39.2	2.6	250 5.6	15.0355	7 19
5	22 5 2	32	12 36.6	2.6	250 56.8	15.0356	7 15
6	22 5 34	30	12 34.0	2.6	251 48.1	15.0357	7 12
7	22 6 4	30	12 31.4	2.5	252 39.6	15.0358	7 8
8	22 6 34	30	-12 28.9	2.4	253 31.2	15.0359	7 5
9	22 7 4	29	12 26.5	2.4	254 23.0	15.0360	7 2
10	22 7 33	29	12 24.1	2.4	255 14.8	15.0361	6 58
11	22 8 2	27	12 21.7	2.3	256 6.9	15.0362	6 54
12	22 8 29	28	12 19.4	2.3	256 59.1	15.0363	6 51
13	22 8 57	27	-12 17.1	2.2	257 51.4	15.0364	6 48
14	22 9 24	26	12 14.9	2.1	258 43.8	15.0365	6 44
15	22 9 50	25	12 12.8	2.1	259 36.4	15.0366	6 41
16	22 10 15	25	12 10.7	2.1	260 29.1	15.0367	6 37
17	22 10 40		-12 8.6		261 22.0	15.0368	6 34

Date	Right Ascension 0h		Declination 0h		Greenwich H. A. 0h	Var. per Min.	Transit Merid. of Greenwich
	MAY						
	h m s	s	° ′	′	° ′	′	h m
16	22 10 15	25	-12 10.7	2.1	260 29.1	15.0367	6 37
17	22 10 40	25	12 8.6	2.0	261 22.0	15.0368	6 34
18	22 11 5	24	12 6.6	1.9	262 15.1	15.0369	6 30
19	22 11 29	23	12 4.7	1.9	263 8.2	15.0370	6 26
20	22 11 52	22	12 2.8	1.8	264 1.6	15.0371	6 23
21	22 12 14	22	-12 1.0	1.8	264 55.1	15.0372	6 19
22	22 12 36	22	11 59.2	1.7	265 48.7	15.0373	6 16
23	22 12 58	20	11 57.5	1.7	266 42.5	15.0374	6 12
24	22 13 18	21	11 55.8	1.6	267 36.5	15.0375	6 9
25	22 13 39	19	11 54.2	1.5	208 30.6	15.0376	6 5
26	22 13 58	19	-11 52.7	1.5	269 24.9	15.0378	6 1
27	22 14 17	18	11 51.2	1.4	270 19.3	15.0370	5 58
28	22 14 35	17	11 49.8	1.3	271 13.9	15.0379	5 54
29	22 14 52	17	11 48.5	1.3	272 8.7	15.0381	5 50
30	22 15 9	16	11 47.2	1.2	273 3.6	15.0382	5 47
31	22 15 25	16	-11 46.0	1.2	273 58.7	15.0383	5 43
	JUNE						
1	22 15 41	14	-11 44.8	1.1	274 54.0	15.0385	5 40
2	22 15 55	15	-11 43.7	1.0	275 49.4	15.0386	5 36
3	22 16 10	13	11 42.7	1.0	276 45.1	15.0387	5 32
4	22 16 23	13	11 41.7	0.9	277 40.8	15.0388	5 28
5	22 16 36	12	11 40.8	0.8	278 36.8	15.0389	5 25
6	22 16 48	11	11 40.0	0.8	279 32.9	15.0391	5 21
7	22 16 59	11	-11 39.2	0.7	280 29.2	15.0392	5 17
8	22 17 10	10	11 38.5	0.7	281 25.7	15.0393	5 14
9	22 17 20	9	11 37.8	0.5	282 22.4	15.0394	5 10
10	22 17 29	8	11 37.3	0.5	283 19.2	[illegible].0395	[illegible] 6
11	22 17 37	8	11 36.8	0.5	284 16.2	15.0397	5 2
12	22 17 45	7	-11 36.3	0.3	285 13.4	15.0398	4 58
13	22 17 52	6	11 36.0	0.3	286 10.8	15.0399	4 54
14	22 17 58	6	11 35.7	0.3	287 8.4	15.0400	4 51
15	22 18 4	5	11 35.4	0.1	288 6.1	15.0401	4 47
16	22 18 9	4	11 35.3	0.1	289 4.0	15.0403	4 43
17	22 18 13	4	-11 35.2	0.1	290 2.1	15.0404	4 39
18	22 18 17	2	11 35.1	0.1	291 0.4	15.0406	4 35
19	22 18 19	2	11 35.2	0.1	291 58.8	15.0407	4 31
20	22 18 21	2	11 35.3	0.2	292 57.4	15.0408	4 27
21	22 18 23	0	11 35.5	0.2	293 56.3	15.0409	4 24
22	22 18 23	0	-11 35.7	0.3	294 55.3	15.0411	4 20
23	22 18 23	1	11 36.0	0.4	295 54.5	15.0412	4 16
24	22 18 22	2	11 36.4	0.5	296 53.9	15.0413	4 12
25	22 18 20	2	11 36.9	0.5	297 53.4	15.0414	4 8
26	22 18 18	3	11 37.4	0.6	298 53.2	15.0416	4 4
27	22 18 15	4	-11 38.0	0.7	299 53.1	15.0417	4 0
28	22 18 11	5	11 38.7	0.7	300 53.2	15.0418	3 56
29	22 18 6	5	11 39.4	0.8	301 53.5	15.0419	3 52
30	22 18 1	6	11 40.2	0.9	302 54.0	15.0421	3 48
31	22 17 55		-11 41.1		303 54.7	15.0422	3 44

Hor. Parallax: Jan. 1, 0′.02; Feb. 1, 0′.02; Mar. 1, 0′.02; Apr. 1, 0′.03; May. 1, 0′.03; June 1, 0′.03; July 1, 0′.03

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF PLANETS

159

Hrs.		Variation of Hour Angle per Minute																				Hrs.
		15'.020	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031	.032	.033	.034	.035	.036	.037	.038	.039	
	°	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	
1	15	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.3	1
2	30	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.2	3.4	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.4	4.6	4.7	2
3	45	3.6	3.8	4.0	4.1	4.3	4.5	4.7	4.9	5.0	5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.7	6.8	7.0	3
4	60	4.8	5.0	5.3	5.5	5.8	6.0	6.2	6.5	6.7	7.0	7.2	7.4	7.7	7.9	8.2	8.4	8.6	8.9	9.[illegible]	9.4	4
5	75	6.0	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9.0	9.3	9.6	9.9	10.2	10.5	10.8	11.1	11.4	11.7	5
6	90	7.2	7.6	7.9	8.3	8.6	9.0	9.4	9.7	10.1	10.4	10.8	11.2	11.5	11.9	12.2	12.6	13.0	13.3	13.7	14.0	6
7	105	8.4	8.8	9.2	9.7	10.1	10.5	10.9	11.3	11.8	12.2	12.6	13.0	13.4	13.9	14.3	14.7	15.1	15.5	16.0	16.4	7
8	120	9.6	10.1	10.6	11.0	11.5	12.0	12.5	13.0	13.4	13.9	14.4	14.9	15.4	15.8	16.3	16.8	17.3	17.8	18.2	18.7	8
9	135	10.8	11.3	11.9	12.4	13.0	13.5	14.0	14.6	15.1	15.7	16.2	16.7	17.3	17.8	18.4	18.9	19.4	20.0	20.5	21.1	9
10	150	12.0	12.6	13.2	13.8	14.4	15.0	15.6	16.2	16.8	17.4	18.0	18.6	19.2	19.8	20.4	21.0	21.6	22.2	22.8	23.4	10
11	165	13.2	13.9	14.5	15.2	15.8	16.5	17.2	17.8	18.5	19.1	19.8	20.5	21.1	21.8	22.4	23.1	23.8	24.4	25.1	25.7	11
12	180	14.4	15.1	15.8	16.6	17.3	18.0	18.7	19.4	20.2	20.9	21.6	22.3	23.0	23.8	24.5	25.2	25.9	26.6	27.4	28.1	12
13	195	15.6	16.4	17.2	17.9	18.7	19.5	20.3	21.1	21.8	22.6	23.4	24.2	25.0	25.7	26.5	27.3	28.1	28.9	29.6	30.4	13
14	210	16.8	17.6	18.5	19.3	20.2	21.0	21.8	22.7	23.5	24.4	25.2	26.0	26.9	27.7	28.6	29.4	30.2	31.1	31.9	32.8	14
15	225	18.0	18.9	19.8	20.7	21.6	22.5	23.4	24.3	25.2	26.1	27.0	27.9	28.8	29.7	30.6	31.5	32.4	33.3	34.2	35.1	15
16	240	19.2	20.2	21.1	22.1	23.0	24.0	25.0	25.9	26.9	27.8	28.8	29.8	30.7	31.7	32.6	33.6	34.6	35.5	36.5	37.4	16
17	255	20.4	21.4	22.4	23.5	24.5	25.5	26.5	27.5	28.6	29.6	30.6	31.6	32.6	33.7	34.7	35.7	36.7	37.7	38.8	39.8	17
18	270	21.6	22.7	23.8	24.8	25.9	27.0	28.1	29.2	30.2	31.3	32.4	33.5	34.6	35.6	36.7	37.8	38.9	40.0	41.0	42.1	18
19	285	22.8	23.9	25.1	26.2	27.4	28.5	29.6	30.8	31.9	33.1	34.2	35.3	36.5	37.6	38.8	39.9	41.0	42.2	43.3	44.5	19
20	300	24.0	25.2	26.4	27.6	28.8	30.0	31.2	32.4	33.6	34.8	36.0	37.2	38.4	39.6	40.8	42.0	43.2	44.4	45.6	46.8	20
21	315	25.2	26.5	27.7	29.0	30.2	31.5	32.8	34.0	35.3	36.5	37.8	39.1	40.3	41.6	42.8	44.1	45.4	46.6	47.9	49.1	21
22	330	26.4	27.7	29.0	30.4	31.7	33.0	34.3	35.6	37.0	38.3	39.6	40.9	42.2	43.6	44.9	46.2	47.5	48.8	50.2	51.5	22
23	345	27.6	29.0	30.4	31.7	33.1	34.5	35.9	37.3	38.6	40.0	41.4	42.8	44.2	45.5	46.9	48.3	49.7	51.1	52.4	53.8	23

Hrs.		Variation of Hour Angle per Minute																		Hrs.
		15'.040	.041	.042	.043		15'.044	.045	.046	.047	.048	.049		15'.050	.051	.052	.053	.054	.055	
	°	'	'	'	'	°	'	'	'	'	'	'	°	'	'	'	'	'	'	
1	15	2.4	2.5	2.5	2.6	15	2.6	2.7	2.8	2.8	2.9	2.9	15	3.0	3.1	3.1	3.2	3.2	3.3	1
2	30	4.8	4.9	5.0	5.2	30	5.3	5.4	5.5	5.6	5.8	5.9	30	6.0	6.1	6.2	6.4	6.5	6.6	2
3	45	7.2	7.4	7.6	7.7	45	7.9	8.1	8.3	8.5	8.6	8.8	45	9.0	9.2	9.4	9.5	9.7	9.9	3
4	60	9.6	9.8	10.1	10.3	60	10.6	10.8	11.0	11.3	11.5	11.8	60	12.0	12.2	12.5	12.7	13.0	13.2	4
5	75	12.0	12.3	12.6	12.9	75	13.2	13.5	13.8	14.1	14.4	14.7	75	15.0	15.3	15.6	15.9	16.2	16.5	5
6	90	14.4	14.8	15.1	15.5	90	15.8	16.2	16.6	16.9	17.3	17.6	90	18.0	18.4	18.7	19.1	19.4	19.8	6
7	105	16.8	17.2	17.6	18.1	105	18.5	18.9	19.3	19.7	20.2	20.6	105	21.0	21.4	21.8	22.3	22.7	23.1	7
8	120	19.2	19.7	20.2	20.6	120	21.1	21.6	22.1	22.6	23.0	23.5	120	24.0	24.5	25.0	25.4	25.9	26.4	8
9	135	21.6	22.1	22.7	23.2	135	23.8	24.3	24.8	25.4	25.9	26.5	135	27.0	27.5	28.1	28.6	29.2	29.7	9
10	150	24.0	24.6	25.2	25.8	150	26.4	27.0	27.6	28.2	28.8	29.4	150	30.0	30.6	31.2	31.8	32.4	33.0	10
11	165	26.4	27.1	27.7	28.4	165	29.0	29.7	30.4	31.0	31.7	32.3	165	33.0	33.7	34.3	35.0	35.6	36.3	11
12	180	28.8	29.5	30.2	31.0	180	31.7	32.4	33.1	33.8	34.6	35.3	180	36.0	36.7	37.4	38.2	38.9	39.6	12
13	195	31.2	32.0	32.8	33.5	195	34.3	35.1	35.9	36.7	37.4	38.2	195	39.0	39.8	40.6	41.3	42.1	42.9	13
14	210	33.6	34.4	35.3	36.1	210	37.0	37.8	38.6	39.5	40.3	41.2	210	42.0	42.8	43.7	44.5	45.4	46.2	14
15	225	36.0	36.9	37.8	38.7	225	39.6	40.5	41.4	42.3	43.2	44.1	225	45.0	45.9	46.8	47.7	48.6	49.5	15
16	240	38.4	39.4	40.3	41.3	240	42.2	43.2	44.2	45.1	46.1	47.0	240	48.0	49.0	49.9	50.9	51.8	52.8	16
17	255	40.8	41.8	42.8	43.9	255	44.9	45.9	46.9	47.9	49.0	50.0	255	51.0	52.0	53.0	54.1	55.1	56.1	17
18	270	43.2	44.3	45.4	46.4	270	47.5	48.6	49.7	50.8	51.8	52.9	270	54.0	55.1	56.2	57.2	58.3	59.4	18
19	285	45.6	46.7	47.9	49.0	285	50.2	51.3	52.4	53.6	54.7	55.9	285	57.0	58.1	59.3	60.4	61.6	62.7	19
20	300	48.0	49.2	50.4	51.6	300	52.8	54.0	55.2	56.4	57.6	58.8	301	0.0	1.2	2.4	3.6	4.8	6.0	20
21	315	50.4	51.7	52.9	54.2	315	55.4	56.7	58.0	59.2	60.5	61.7	316	3.0	4.3	5.5	6.8	8.0	9.3	21
22	330	52.8	54.1	55.4	56.8	330	58.1	59.4	60.7	62.0	63.4	64.7	331	6.0	7.3	8.6	10.0	11.3	12.6	22
23	345	55.2	56.6	58.0	59.3	346	0.7	2.1	3.5	4.9	6.2	7.6	346	9.0	10.4	11.8	13.1	14.5	15.9	23

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF PLANETS

Time	Variation of Hour Angle per Minute 14'.98	14'.99	15'.00	15'.01	15'.02	15'.03	15'.04	15'.05	15'.06	15'.07	Sec.	Corr.
m	° '	° '	° '	° '	° '	° '	° '	° '	° '	° '		
0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0	0.0
1	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.1	0 15.1	1	0.3
2	0 30.0	0 30.0	0 30.0	0 30.0	0 30.0	0 30.1	0 30.1	0 30.1	0 30.1	0 30.1	2	0.5
3	0 44.9	0 45.0	0 45.0	0 45.0	0 45.1	0 45.1	0 45.1	0 45.1	0 45.2	0 45.2	3	0.8
4	0 59.9	1 0.0	1 0.0	1 0.0	1 0.1	1 0.1	1 0.2	1 0.2	1 0.2	1 0.3	4	1.0
5	1 14.9	1 14.9	1 15.0	1 15.0	1 15.1	1 15.2	1 15.2	1 15.2	1 15.3	1 15.4	5	1.3
6	1 29.9	1 29.9	1 30.0	1 30.1	1 30.1	1 30.2	1 30.2	1 30.3	1 30.4	1 30.4	6	1.5
7	1 44.9	1 44.9	1 45.0	1 45.1	1 45.1	1 45.2	1 45.3	1 45.3	1 45.4	1 45.5	7	1.8
8	1 59.8	1 59.9	2 0.0	2 0.1	2 0.2	2 0.2	2 0.3	2 0.4	2 0.5	2 0.6	8	2.0
9	2 14.8	2 14.9	2 15.0	2 15.1	2 15.2	2 15.3	2 15.4	2 15.4	2 15.5	2 15.6	9	2.3
10	2 29.8	2 29.9	2 30.0	2 30.1	2 30.2	2 30.3	2 30.4	2 30.5	2 30.6	2 30.7	10	2.5
11	2 44.8	2 44.9	2 45.0	2 45.1	2 45.2	2 45.3	2 45.4	2 45.5	2 45.7	2 45.8	11	2.8
12	2 59.8	2 59.9	3 0.0	3 0.1	3 0.2	3 0.4	3 0.5	3 0.6	3 0.7	3 0.8	12	3.0
13	3 14.7	3 14.9	3 15.0	3 15.1	3 15.3	3 15.4	3 15.5	3 15.6	3 15.8	3 15.9	13	3.3
14	3 29.7	3 29.9	3 30.0	3 30.1	3 30.3	3 30.4	3 30.6	3 30.7	3 30.8	3 31.0	14	3.5
15	3 44.7	3 44.8	3 45.0	3 45.2	3 45.3	3 45.4	3 45.6	3 45.7	3 45.9	3 46.0	15	3.8
16	3 59.7	3 59.8	4 0.0	4 0.2	4 0.3	4 0.5	4 0.6	4 0.8	4 1.0	4 1.1	16	4.0
17	4 14.7	4 14.8	4 15.0	4 15.2	4 15.3	4 15.5	4 15.7	4 15.8	4 16.0	4 16.2	17	4.3
18	4 29.6	4 29.8	4 30.0	4 30.2	4 30.4	4 30.5	4 30.7	4 30.9	4 31.1	4 31.3	18	4.5
19	4 44.6	4 44.8	4 45.0	4 45.2	4 45.4	4 45.6	4 45.8	4 45.9	4 46.1	4 46.3	19	4.8
20	4 59.6	4 59.8	5 0.0	5 0.2	5 0.4	5 0.6	5 0.8	5 1.0	5 1.2	5 1.4	20	5.0
21	5 14.6	5 14.8	5 15.0	5 15.2	5 15.4	5 15.6	5 15.8	5 16.0	5 16.3	5 16.5	21	5.3
22	5 29.6	5 29.8	5 30.0	5 30.2	5 30.4	5 30.7	5 30.9	5 31.1	5 31.3	5 31.5	22	5.5
23	5 44.5	5 44.8	5 45.0	5 45.2	5 45.5	5 45.7	5 45.9	5 46.1	5 46.4	5 46.6	23	5.8
24	5 59.5	5 59.8	6 0.0	6 0.2	6 0.5	6 0.7	6 1.0	6 1.2	6 1.4	6 1.7	24	6.0
25	6 14.5	6 14.8	6 15.0	6 15.2	6 15.5	6 15.7	6 16.0	6 16.2	6 16.5	6 16.8	25	6.3
26	6 29.5	6 29.7	6 30.0	6 30.3	6 30.5	6 30.8	6 31.0	6 31.3	6 31.6	6 31.8	26	6.5
27	6 44.5	6 44.7	6 45.0	6 45.3	6 45.5	6 45.8	6 46.1	6 46.3	6 46.6	6 46.9	27	6.8
28	6 59.4	6 59.7	7 0.0	7 0.3	7 0.6	7 0.8	7 1.1	7 1.4	7 1.7	7 2.0	28	7.0
29	7 14.4	7 14.7	7 15.0	7 15.3	7 15.6	7 15.9	7 16.2	7 16.4	7 16.7	7 17.0	29	7.3
30	7 29.4	7 29.7	7 30.0	7 30.3	7 30.6	7 30.9	7 31.2	7 31.5	7 31.8	7 32.1	30	7.5
31	7 44.4	7 44.7	7 45.0	7 45.3	7 45.6	7 45.9	7 46.2	7 46.5	7 46.9	7 47.2	31	7.8
32	7 59.4	7 59.7	8 0.0	8 0.3	8 0.6	8 1.0	8 1.3	8 1.6	8 1.9	8 2.2	32	8.0
33	8 14.3	8 14.7	8 15.0	8 15.3	8 15.7	8 16.0	8 16.3	8 16.6	8 17.0	8 17.3	33	8.3
34	8 29.3	8 29.7	8 30.0	8 30.3	8 30.7	8 31.0	8 31.4	8 31.7	8 32.0	8 32.4	34	8.5
35	8 44.3	8 44.6	8 45.0	8 45.4	8 45.7	8 46.0	8 46.4	8 46.7	8 47.1	8 47.4	35	8.8
36	8 59.3	8 59.6	9 0.0	9 0.4	9 0.7	9 1.1	9 1.4	9 1.8	9 2.2	9 2.5	36	9.0
37	9 14.3	9 14.6	9 15.0	9 15.4	9 15.7	9 16.1	9 16.5	9 16.8	9 17.2	9 17.6	37	9.3
38	9 29.2	9 29.6	9 30.0	9 30.4	9 30.8	9 31.1	9 31.5	9 31.9	9 32.3	9 32.7	38	9.5
39	9 44.2	9 44.6	9 45.0	9 45.4	9 45.8	9 46.2	9 46.6	9 46.9	9 47.3	9 47.7	39	9.8
40	9 59.2	9 59.6	10 0.0	10 0.4	10 0.8	10 1.2	10 1.6	10 2.0	10 2.4	10 2.8	40	10.0
41	10 14.2	10 14.6	10 15.0	10 15.4	10 15.8	10 16.2	10 16.6	10 17.0	10 17.5	10 17.9	41	10.3
42	10 29.2	10 29.6	10 30.0	10 30.4	10 30.8	10 31.3	10 31.7	10 32.1	10 32.5	10 32.9	42	10.5
43	10 44.1	10 44.6	10 45.0	10 45.4	10 45.9	10 46.3	10 46.7	10 47.1	10 47.6	10 48.0	43	10.8
44	10 59.1	10 59.6	11 0.0	11 0.4	11 0.9	11 1.3	11 1.8	11 2.2	11 2.6	11 3.1	44	11.0
45	11 14.1	11 14.6	11 15.0	11 15.4	11 15.9	11 16.3	11 16.8	11 17.2	11 17.7	11 18.2	45	11.3
46	11 29.1	11 29.5	11 30.0	11 30.5	11 30.9	11 31.4	11 31.8	11 32.3	11 32.8	11 33.2	46	11.5
47	11 44.1	11 44.5	11 45.0	11 45.5	11 45.9	11 46.4	11 46.9	11 47.3	11 47.8	11 48.3	47	11.8
48	11 59.0	11 59.5	12 0.0	12 0.5	12 1.0	12 1.4	12 1.9	12 2.4	12 2.9	12 3.4	48	12.0
49	12 14.0	12 14.5	12 15.0	12 15.5	12 16.0	12 16.5	12 17.0	12 17.4	12 17.9	12 18.4	49	12.3
50	12 29.0	12 29.5	12 30.0	12 30.5	12 31.0	12 31.5	12 32.0	12 32.5	12 33.0	12 33.5	50	12.5
51	12 44.0	12 44.5	12 45.0	12 45.5	12 46.0	12 46.5	12 47.0	12 47.5	12 48.1	12 48.6	51	12.8
52	12 59.0	12 59.5	13 0.0	13 0.5	13 1.0	13 1.6	13 2.1	13 2.6	13 3.1	13 3.6	52	13.0
53	13 13.9	13 14.5	13 15.0	13 15.5	13 16.1	13 16.6	13 17.1	13 17.6	13 18.2	13 18.7	53	13.3
54	13 28.9	13 29.5	13 30.0	13 30.5	13 31.1	13 31.6	13 32.2	13 32.7	13 33.2	13 33.8	54	13.5
55	13 43.9	13 44.4	13 45.0	13 45.6	13 46.1	13 46.6	13 47.2	13 47.7	13 48.3	13 48.8	55	13.8
56	13 58.9	13 59.4	14 0.0	14 0.6	14 1.1	14 1.7	14 2.2	14 2.8	14 3.4	14 3.9	56	14.0
57	14 13.9	14 14.4	14 15.0	14 15.6	14 16.1	14 16.7	14 17.3	14 17.8	14 18.4	14 19.0	57	14.3
58	14 28.8	14 29.4	14 30.0	14 30.6	14 31.2	14 31.7	14 32.3	14 32.9	14 33.5	14 34.1	58	14.5
59	14 43.8	14 44.4	14 45.0	14 45.6	14 46.2	14 46.8	14 47.4	14 47.9	14 48.5	14 49.1	59	14.8
60	14 58.8	14 59.4	15 0.0	15 0.6	15 1.2	15 1.8	15 2.4	15 3.0	15 3.6	15 4.2	60	15.0

GREENWICH HOUR ANGLE OF POLARIS, 1938 265

FOR 0^h GREENWICH CIVIL TIME

	° ′		° ′		° ′		° ′		° ′		° ′
Jan. 1	74 26 3	Mar. 1	132 51 8	May 1	193 2 9	July 1	252 56 3	Sept. 1	313 44 6	Nov. 1	13 44 5
2	75 25.8	2	133 51 2	2	194 1 9	2	253 55.2	2	314 43 5	2	14 43.6
3	76 25 2	3	134 50.5	3	195 1.0	3	254 54.0	3	315 42 4	3	15 42.8
4	77 24 6	4	135 49.9	4	196 0.0	4	255 52.8	4	316 41 4	4	16 42.0
5	78 24 0	5	136 49.2	5	196 59.0	5	256 51 6	5	317 40 3	5	17 41 1
6	79 23 5	6	137 48 6	6	197 58 0	6	257 50 5	6	318 39 2	6	18 40.3
7	80 22.9	7	138 47 9	7	198 57 0	7	258 49.3	7	319 38.1	7	19 39.5
8	81 22.3	8	139 47 2	8	199 56.0	8	259 48.1	8	320 37 0	8	20 38.7
9	82 21 7	9	140 46 5	9	200 55.0	9	260 47.0	9	321 35 9	9	21 37.8
10	83 21 1	10	141 45 8	10	201 54 0	10	261 45 8	10	322 34.9	10	22 37 0
11	84 20 6	11	142 45 2	11	202 53 0	11	262 44 6	11	323 33.8	11	23 36 2
12	85 20 0	12	143 44 5	12	203 52 0	12	263 43.4	12	324 32 7	12	24 35 4
13	86 19 4	13	144 43 8	13	204 50 9	13	264 42 3	13	325 31 7	13	25 34 7
14	87 18 9	14	145 43 1	14	205 49 9	14	265 41 1	14	326 30 6	14	26 33 9
15	88 18.3	15	146 42 4	15	206 48 9	15	266 39.9	15	327 29 5	15	27 33 1
16	89 17 7	16	147 41 6	16	207 47.8	16	267 38.7	16	328 28.5	16	28 32 3
17	90 17 2	17	148 40 9	17	208 46 8	17	268 37.6	17	329 27 4	17	20 31 5
18	91 16 6	18	149 40.2	18	209 45 7	18	269 36 4	18	330 26 4	18	30 30 8
19	92 16.0	19	150 39 5	19	210 44 6	19	270 35 2	19	331 25 3	19	31 30 0
20	93 15 4	20	151 38 7	20	211 43 6	20	271 34.1	20	332 24 3	20	32 29 3
21	94 14.9	21	152 38 0	21	212 42 5	21	272 32 8	21	333 23.3	21	33 28.5
22	95 14 3	22	153 37 3	22	213 41 5	22	273 31 7	22	334 22 2	22	34 27 8
23	96 13.7	23	154 36.5	23	214 40.4	23	274 30 5	23	335 21.2	23	35 27 0
24	97 13.2	24	155 35.8	24	215 39 3	24	275 29.4	24	336 20.2	24	36 26 3
25	98 12.6	25	156 35.0	25	216 38.3	25	276 28.2	25	337 19.2	25	37 25.5
26	99 12 0	26	157 34.3	26	217 37.2	26	277 27.0	26	338 18.1	26	38 24.8
27	100 11.5	27	158 33.5	27	218 36 1	27	278 25.9	27	339 17 1	27	39 24.1
28	101 10.9	28	159 32 7	28	219 35.0	28	279 24.7	28	340 16 1	28	40 23 4
29	102 10 3	29	160 31 9	29	220 33.9	29	280 23 5	29	341 15 1	29	41 22 7
30	103 9.8	30	161 31 1	30	221 32 8	30	281 22 4	30	342 14.1	30	42 21 9
31	104 9 2	31	162 30.3	31	222 31 7	31	282 21 2	Oct. 1	343 13 1	Dec. 1	43 21 2
Feb. 1	105 8 6	Apr. 1	163 29.6	June 1	223 30 6	Aug. 1	283 20 0	2	344 12 1	2	44 20.5
2	106 8.1	2	164 28.7	2	224 29 5	2	284 18 8	3	345 11.1	3	45 19 9
3	107 7.5	3	165 27.9	3	225 28 4	3	285 17.7	4	346 10 2	4	46 19 2
4	108 6.9	4	166 27 1	4	226 27 3	4	286 16 5	5	347 9 2	5	47 18.5
5	109 6 4	5	167 26.3	5	227 26 2	5	287 15 3	6	348 8.2	6	48 17.8
6	110 5.8	6	168 25.4	6	228 25 1	6	288 14 2	7	349 7 2	7	49 17 1
7	111 5.2	7	169 24.6	7	229 23 9	7	289 13 0	8	350 6 3	8	50 16 5
8	112 4 6	8	170 23.8	8	230 22.8	8	290 11 8	9	351 5.3	9	51 15 8
9	113 4.1	9	171 22 9	9	231 21 7	9	291 10 7	10	352 4 3	10	52 15 1
10	114 3.5	10	172 22 1	10	232 20 6	10	292 9.5	11	353 3 4	11	53 14 5
11	115 2.9	11	173 21 2	11	233 19 4	11	293 8 4	12	354 2 4	12	54 13.8
12	116 2 3	12	174 20 4	12	234 18 3	12	294 7 2	13	355 1 5	13	55 13.2
13	117 1.7	13	175 19 5	13	235 17 2	13	295 6 1	14	356 0 6	14	56 12 5
14	118 1.1	14	176 18 6	14	236 16 0	14	296 4 9	15	356 59 6	15	57 11 9
15	119 0.5	15	177 17.8	15	237 14 9	15	297 3 8	16	357 58 7	16	58 11 2
16	120 0.0	16	178 16.9	16	238 13.7	16	298 2 6	17	358 57 8	17	59 10 6
17	120 59 3	17	179 16 0	17	239 12 6	17	299 1 5	18	359 56 9	18	60 9.9
18	121 58.7	18	180 15.1	18	240 11 4	18	300 0 3	19	0 55.9	19	61 9 3
19	122 58 1	19	181 14.2	19	241 10.3	19	300 59 2	20	1 55.0	20	62 8 7
20	123 57 5	20	182 13.3	20	242 9.1	20	301 58.1	21	2 54.1	21	63 8 1
21	124 56.9	21	183 12 4	21	243 8.0	21	302 56.9	22	3 53 2	22	64 7 4
22	125 56 3	22	184 11.4	22	244 6.8	22	303 55.8	23	4 52 3	23	65 6 8
23	126 55 6	23	185 10 5	23	245 5.6	23	304 54.7	24	5 51 4	24	66 6 2
24	127 55.0	24	186 9 6	24	246 4.5	24	305 53.6	25	6 50.6	25	67 5 6
25	128 54 4	25	187 8.6	25	247 3.3	25	306 52.4	26	7 49 7	26	68 5 0
26	129 53 7	26	188 7 7	26	248 2 2	26	307 51.3	27	8 48.8	27	69 4.4
27	130 53.1	27	189 6 8	27	249 1.0	27	308 50.2	28	9 47 9	28	70 3.8
28	131 52.5	28	190 5 8	28	249 59.8	28	309 49 1	29	10 47.1	29	71 3.2
29	132 51.8	29	191 4.8	29	250 58 7	29	310 48 0	30	11 46.2	30	72 2.6
30	133 51.2	30	192 3.9	30	251 57.5	30	311 46 9	31	12 45 3	31	73 2.0
31	134 50 5	31	193 2.9	31	252 56.3	31	312 45 8	32	13 44 5	32	74 1 4

TABLE III

FOR FINDING LATITUDE BY AN OBSERVED ALTITUDE OF POLARIS, 1938

HOUR ANGLE, ARGUMENT

Correction for Local Hour Angle to be Applied to True Altitude

L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.
°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′
0	-1 1.6	60	-0 30.4	120	+0 31.2	180	+1 1.6	240	+0 31.2	300	-0 30.4
1	1 1.6	61	0 29.4	121	0 32.1	181	1 1.6	241	0 30.3	301	0 31.3
2	1 1.5	62	0 28.5	122	0 33.0	182	1 1.5	242	0 29.3	302	0 32.2
3	1 1.5	63	0 27.5	123	0 33.9	183	1 1.5	243	0 28.4	303	0 33.2
4	1 1.4	64	0 26.6	124	0 34.8	184	1 1.4	244	0 27.4	304	0 34.1
5	-1 1.3	65	-0 25.6	125	+0 35.7	185	+1 1.4	245	+0 26.5	305	-0 35.0
6	1 1.2	66	0 24.6	126	0 36.6	186	1 1.3	246	0 25.5	306	0 35.8
7	1 1.1	67	0 23.6	127	0 37.4	187	1 1.1	247	0 24.5	307	0 36.7
8	1 1.0	68	0 22.6	128	0 38.3	188	1 1.0	248	0 23.5	308	0 37.6
9	1 0.8	69	0 21.6	129	0 39.1	189	1 0.8	249	0 22.5	309	0 38.4
10	-1 0.6	70	-0 20.6	130	+0 39.9	190	+1 0.7	250	+0 21.5	310	-0 39.3
11	1 0.4	71	0 19.6	131	0 40.7	191	1 0.5	251	0 20.5	311	0 40.1
12	1 0.2	72	0 18.5	132	0 41.5	192	1 0.3	252	0 19.5	312	0 40.9
13	1 0.0	73	0 17.5	133	0 42.3	193	1 0.0	253	0 18.5	313	0 41.7
14	0 59.7	74	0 16.5	134	0 43.1	194	0 59.8	254	0 17.5	314	0 42.5
15	-0 59.5	75	-0 15.4	135	+0 43.8	195	+0 59.5	255	+0 16.5	315	-0 43.3
16	0 59.2	76	0 14.4	136	0 44.6	196	0 59.2	256	0 15.4	316	0 44.0
17	0 58.8	77	0 13.3	137	0 45.3	197	0 58.9	257	0 14.4	317	0 44.8
18	0 58.5	78	0 12.3	138	0 46.0	198	0 58.6	258	0 13.3	318	0 45.5
19	0 58.2	79	0 11.2	139	0 46.7	199	0 58.3	259	0 12.3	319	0 46.2
20	-0 57.8	80	-0 10.2	140	+0 47.4	200	+0 57.9	260	+0 11.2	320	-0 47.0
21	0 57.4	81	0 9.1	141	0 48.1	201	0 57.6	261	0 10.2	321	0 47.6
22	0 57.0	82	0 8.0	142	0 48.7	202	0 57.2	262	0 9.1	322	0 48.3
23	0 56.6	83	0 7.0	143	0 49.4	203	0 56.8	263	0 8.0	323	0 49.0
24	0 56.2	84	0 5.9	144	0 50.0	204	0 56.4	264	0 7.0	324	0 49.6
25	-0 55.7	85	-0 4.8	145	+0 50.6	205	+0 55.9	265	+0 5.9	325	-0 50.3
26	0 55.2	86	0 3.7	146	0 51.2	206	0 55.5	266	0 4.8	326	0 50.9
27	0 54.8	87	0 2.7	147	0 51.8	207	0 55.0	267	0 3.8	327	0 51.5
28	0 54.2	88	0 1.6	148	0 52.4	208	0 54.5	268	0 2.7	328	0 52.1
29	0 53.7	89	-0 0.5	149	0 52.9	209	0 54.0	269	0 1.6	329	0 52.7
30	-0 53.2	90	+0 0.6	150	+0 53.5	210	+0 53.5	270	+0 0.6	330	-0 53.2
31	0 52.7	91	0 1.6	151	0 54.0	211	0 52.9	271	-0 0.5	331	0 53.7
32	0 52.1	92	0 2.7	152	0 54.5	212	0 52.4	272	0 1.6	332	0 54.2
33	0 51.5	93	0 3.8	153	0 55.0	213	0 51.8	273	0 2.7	333	0 55.8
34	0 50.9	94	0 4.8	154	0 55.5	214	0 51.2	274	0 3.7	334	0 55.2
35	-0 50.3	95	+0 5.9	155	+0 55.9	215	+0 50.6	275	-0 4.8	335	-0 55.7
36	0 49.6	96	0 7.0	156	0 56.4	216	0 50.0	276	0 5.9	336	0 56.2
37	0 49.0	97	0 8.0	157	0 56.8	217	0 49.4	277	0 7.0	337	0 56.6
38	0 48.3	98	0 9.1	158	0 57.2	218	0 48.7	278	0 8.0	338	0 57.0
39	0 47.6	99	0 10.2	159	0 57.6	219	0 48.1	279	0 9.1	339	0 57.4
40	-0 47.0	100	+0 11.2	160	+0 57.9	220	+0 47.4	280	-0 10.2	340	-0 57.8
41	0 46.2	101	0 12.3	161	0 58.3	221	0 46.7	281	0 11.2	341	0 58.2
42	0 45.5	102	0 13.3	162	0 58.6	222	0 46.0	282	0 12.3	342	0 58.5
43	0 44.8	103	0 14.4	163	0 58.9	223	0 45.3	283	0 13.3	343	0 58.8
44	0 44.0	104	0 15.4	164	0 59.2	224	0 44.6	284	0 14.4	344	0 59.2
45	-0 43.3	105	+0 16.5	165	+0 59.5	225	+0 43.8	285	-0 15.4	345	-0 59.5
46	0 42.5	106	0 17.5	166	0 59.8	226	0 43.1	286	0 16.5	346	0 59.7
47	0 41.7	107	0 18.5	167	1 0.0	227	0 42.3	287	0 17.5	347	1 0.0
48	0 40.9	108	0 19.5	168	1 0.3	228	0 41.5	288	0 18.5	348	1 0.2
49	0 40.1	109	0 20.5	169	1 0.5	229	0 40.7	289	0 19.6	349	1 0.4
50	-0 39.3	110	+0 21.5	170	+1 0.7	230	+0 39.9	290	-0 20.6	350	-1 0.6
51	0 38.4	111	0 22.5	171	1 0.8	231	0 39.1	291	0 21.6	351	1 0.8
52	0 37.6	112	0 23.5	172	1 1.0	232	0 38.3	292	0 22.6	352	1 1.0
53	0 36.7	113	0 24.5	173	1 1.1	233	0 37.4	293	0 23.6	353	1 1.1
54	0 35.8	114	0 25.5	174	1 1.3	234	0 36.6	294	0 24.6	354	1 1.2
55	-0 35.0	115	+0 26.5	175	+1 1.4	235	+0 35.7	295	-0 25.6	355	-1 1.3
56	0 34.1	116	0 27.4	176	1 1.4	236	0 34.8	296	0 26.6	356	1 1.4
57	0 33.2	117	0 28.4	177	1 1.5	237	0 33.9	297	0 27.5	357	1 1.5
58	0 32.2	118	0 29.3	178	1 1.5	238	0 33.0	298	0 28.5	358	1 1.5
59	0 31.3	119	0 30.3	179	1 1.6	239	0 32.1	299	0 29.4	359	1 1.6
60	-0 30.4	120	+0 31.2	180	+1 1.6	240	+0 31.2	300	-0 30.4	360	-1 1.6

Chapter VI.—METEOROLOGY

THE WEATHER BUREAU'S METEOROLOGICAL SERVICE IN AID OF AIR NAVIGATION

AUTHORITY FOR THE SERVICE

By authority of the Air Commerce Act of 1926 and the Civil Aeronautics Act of 1938 the Weather Bureau is charged with the responsibility of furnishing an adequate meteorological service for aviation in order "to promote the safety and efficiency of air navigation in the United States and above the high seas."

AIRWAY WEATHER SERVICE

A successful solution of the weather problem for aviation requires, first of all, a dense network of surface and upper-air observation stations, manned by trained observers, and the rapid transmission of frequent reports from these. Secondly, it requires a technical staff of employees at terminal airports to prepare frequent weather maps, upper-air charts, and diagrams from which a picture of the changing weather situations may be presented; and, thirdly, it requires competent meteorologists to analyze the current weather conditions, anticipate the development of new situations, compute the movement of pressure systems, and to issue, on the basis of these, short-period forecasts for the route to be flown. In constantly endeavoring to maintain as complete a service as possible the Weather Bureau has established about 550 stations at fairly regular distances apart along the civil airways in the United States, Alaska, and Hawaii, and, in addition, over 250 stations rather uniformly distributed off the airways for reporting weather. Reports are collected by teletype and radio from airway stations and by telegraph and telephone from off-airway stations, and are relayed to required points along the airways by the Civil Aeronautics Authority radio and teletype systems. There are 114 well-distributed stations, equipped for taking upper-air wind observations, and additional stations at which upper-air observations are made by instruments which are carried aloft by balloons and report conditions through the medium of radio signals (radiosonde). At 150 important airway terminals, qualified meteorologists of the Weather Bureau are on duty 24 hours a day, charting and analyzing weather reports and discussing the meteorological conditions with pilots.

Supervision of the airway weather service in the field is exercised by 15 general supervising stations, each one of which has a certain district for which it issues forecasts, maintains an inspectional service, and has general authority in regard to supervision of stations in that district, while the central office at Washington, D. C., has administrative control and exercises supervision of the service as a whole.

SURFACE WEATHER OBSERVATIONS

Weather observations are taken hourly throughout the 24 hours at most of the stations located on civil airways. Special observations are taken at these stations whenever marked changes in weather conditions occur. At stations located off the airways, observations are taken every 6 hours, and every 3 hours at a few designated to do this. Reports from ships at sea, made twice daily, are also available. Observations generally consist of ceiling (height of cloud layers above the ground) in feet; sky conditions; visibility in miles; weather conditions (including precipitation, squalls, etc.); obstruction to vision (fog, haze, etc.); temperature; dew point; wind direction and velocity; barometric pressure; pressure change tendency; amount, type, and direction of clouds; and miscellaneous information (thunderstorms, line-squalls, etc.). To facilitate the transmission of the reports, they are put into a symbol or figure code, depending upon the type of observation and whether the station making the report is on an airway, is an "off-airway" station, or a ship at sea. The symbol reports are described in Plate III, "Explanation of Symbol Weather Reports," which may be obtained from the Aerological Division of the Weather Bureau.

UPPER-AIR OBSERVATIONS

Weather Bureau first-order stations at airway terminals and a number of stations off the airways are equipped to take observations of directions and velocities of upper-air winds. These are called "pilot-balloon observations." They are made at 6-hour intervals and are accomplished by means of a strong, but light, rubber balloon, which is inflated with the proper amount of hydrogen or helium to make it rise at a known rate of speed. This balloon is released and its progress in the upper air followed by means of a theodolite, which is a special telescope devised to enable the reading of the horizontal and vertical angles from the observer of the object being sighted. These angles, representing the path of the balloon, are read at regular intervals until the balloon passes from sight, reaches a sufficient height for a satisfactory report, or bursts, due to the excess of internal over external pressure. The readings thus obtained, when computed in connection with the rate of ascent, readily give the velocity and direction of the wind at the various desired altitudes. Such information is broadcast by radio to pilots. It is also transmitted by figure code on teletype and radio circuits and, when charted for a number of stations, gives the pilot a picture of the winds he will encounter.

CV11 02318 2422 22625 2728 42832 2844 62852 2967 83078 3087 03194 8202*

Cleveland, Ohio

Time—11:00 a. m., 75th Meridian

Elevation (feet above sea level)	Wind direction (to nearest 10°, true)	Wind velocity (m. p. h.)
Surface	230°	18
1,000	240	22
2,000	·260	25
3,000	270	28
4,000	280	32
5,000	280	44
6,000	280	52
7,000	290	67
8,000	300	78
9,000	300	87
10,000	310	94
11,000	320	102

* Velocities of 100 miles per hour or over are indicated by adding 50 to the direction figures.

FIGURE 73.—Typical symbol report of pilot ballon observations with interpretation.

Upper-air observations are also made by means of radiosondes attached to rubber sounding balloons at approximately 30 Weather Bureau, one Navy and two Army stations. Several additional radiosonde stations are expected to be established by the Navy during the fiscal year beginning July 1, 1939. These instruments are miniature radio transmitters, from which are obtained records of free-air temperature, pressure, and humidity from the earth's surface to heights of between 50,000 and 75,000 feet. Radiosonde observations have recently replaced airplane observations in both the Weather Bureau and the Army. The Navy still makes airplane observations at a few points.

Radiosonde observations are made at about 4:00 a. m., E. S. T., and the data are evaluated and the reports transmitted over the teletype circuits in time for their receipt at the various forecast centers by 7:30 a. m., E. S. T.

The data secured from the radiosondes each day are plotted at the various Weather Bureau stations on appropriate charts. The barometric pressure prevailing at the levels, 5,000, 10,000, and 14,000 feet above sea level are plotted and isobars are drawn. Pictures of the high and low pressure areas existing at those elevations are thereby obtained. From a comparison of these charts and the weather map constructed to represent meteorological conditions at the surface of the earth and near sea level, the weather forecaster is enabled to make improved predictions regarding expected movements of meteorological conditions over the country.

The data obtained from the radiosondes also provide information regarding the characteristics of air masses existing over the various parts of the earth. A knowledge of these characteristics makes it possible to determine the moisture content of cold and warm air masses which interact to form cyclonic systems which so greatly determine our weather. Similarly, it is possible to determine from the data the levels at which clouds will form and the likelihood of precipitation as well as whether it will probably be rain, snow, or some other form.

A valuable means of portraying and analyzing the information secured by the radiosonde is the isentropic chart. Several of these are prepared every day. Each of the charts is used to represent certain meteorological conditions existing on a selected surface in the atmosphere wherein the flow of unsaturated air generally occurs. One chart pertains to a single selected surface, so that the different charts represent the respective selected surfaces. In making an isentropic chart, the meteorologist plots for each radiosonde station the barometric pressure in the selected surface and also the pressure to which a particle of air from that surface must be lifted in order that condensation of the water vapor in that particle may occur. Isobars are then drawn for the pressures represented in each surface. A day by day comparison of these isentropic charts shows the flow and interactions of moist and dry tongues of air in the given surfaces, and in addition, indications are obtained regarding regions where cloudiness, precipitation, and possibly thunderstorms will occur.

Other charts with various meteorological applications are also prepared to aid in the analysis and forecasting of weather on the basis of the data rendered by the radiosonde observations.

The analysis of the temperature data provided by the instruments also makes it possible to estimate the probable minimum and maximum temperatures likely to occur during the day. Moreover, it is similarly possible to estimate the intensity of warm and cold waves which may affect various regions of the country.

The indications regarding the elevation at which freezing temperature and saturated or cloudy air occur are of extreme value to aviation interests by showing levels at which the hazard of ice formation on aircraft is a maximum. Aviators are thereby warned to avoid the levels at which such temperatures and wet conditions occur in the atmosphere. One of the principal advantages of the radiosonde over other means of upper-air meteorological observations (for example, airplane) is that it provides information to greater heights than the other means in question.

The radiosonde, therefore, affords a method whereby information for the protection of stratosphere flying may be readily secured. Since this phase of aviation is rapidly approaching the stage where regular aerial transport in the stratosphere may be contemplated, the new tool of meteorologists is a valuable asset for the progress of aeronautics.

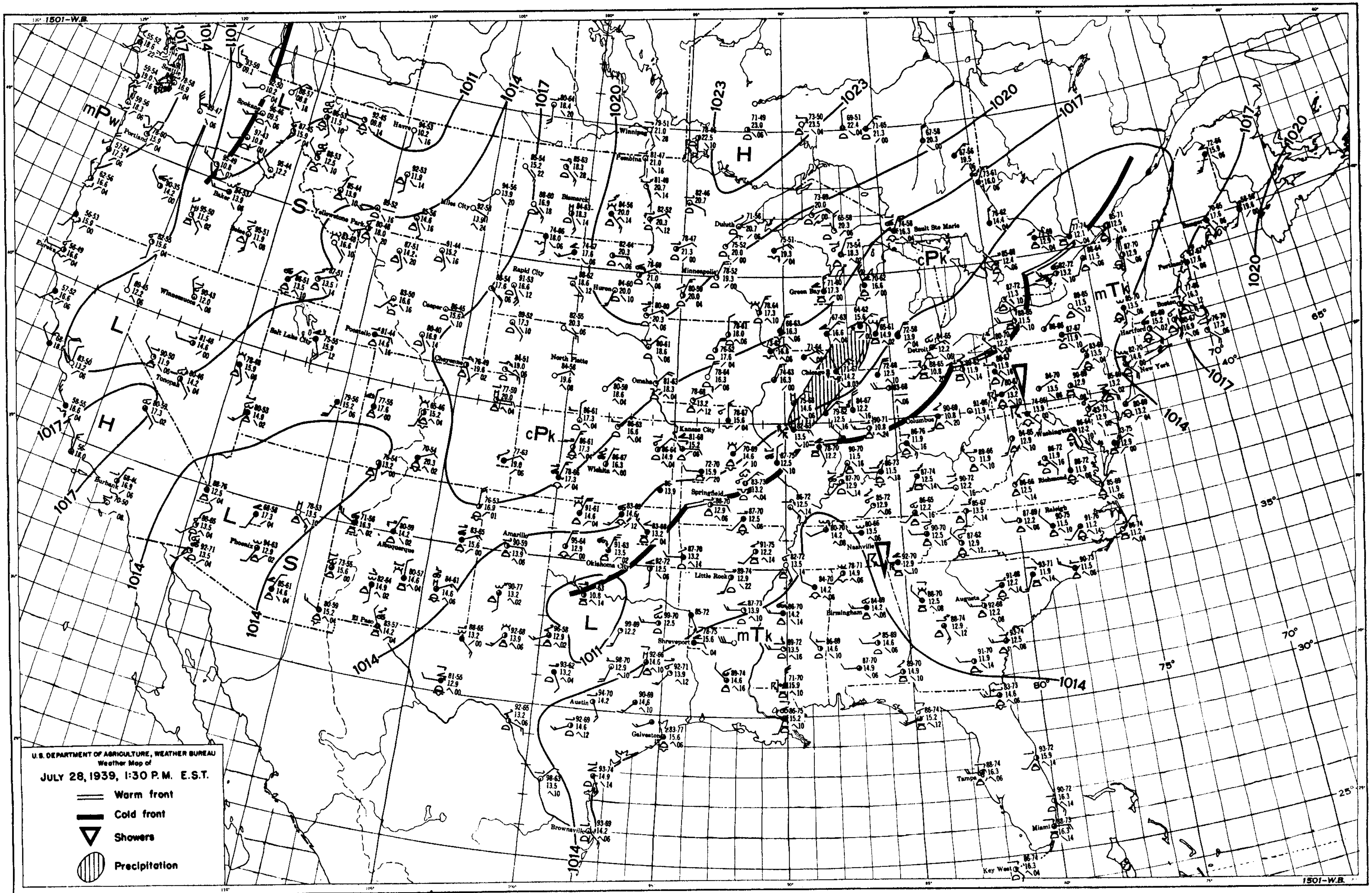


FIGURE 74.—Typical airport weather map (greatly reduced).

162915—39 (Face p. 122)

When observations of upper-air wind directions and velocities cannot be obtained by means of pilot balloons, the distribution of barometric pressures in the three levels referred to above gives an accurate indication of probable wind conditions in those levels.

The radiosonde is proving of great aid by quickly furnishing data regarding meteorological changes at levels above those ordinarily reached by airplanes (16,500 ft.). It is thus furthering the advance of meteorology through the disclosure of the connection which exists between movements and characteristics of the stratosphere and the sequence of weather phenomena which we experience at the surface of the earth.

COMMUNICATIONS

A system of teletype and radio circuits is provided by the Civil Aeronautics Authority for the rapid collection and distribution of weather information. Such a communication system is essential for an effective airway weather service. The weather observations are collected in groups. The reports of each circuit are then automatically relayed to such other circuits as require them. Complete weather information is thus made available at every important airway terminal as soon as the collections and relays have been completed, which is only a few minutes after the meteorological observations represented by the report have been made. The reports are broadcast by radio to pilots in the air, posted on Weather Bureau bulletin boards, entered on meteorological charts and maps, and disseminated by telephone and interphone systems as they are received, so that pilots and air-line dispatchers have a constant knowledge of the latest developments in meteorological conditions.

Stations off the airways report by telephone and telegraph and these reports are collected at designated centers and relayed to teletype circuits for distribution to all stations where required. Maps showing the teletype and radio circuits in the United States may be obtained upon request from the Civil Aeronautics Authority.

WEATHER MAPS AND CHARTS

In order that the information received from a collection of hundreds of weather reports may be transformed from a picture of instantaneous weather conditions at each station to a picture of the general conditions over a large area, the reports are entered on maps, covering large areas of the country and adjacent regions, and are also plotted on various other meteorological charts. From these maps, drawn for surface observations, and charts plotted from the information received from radiosonde and pilot-ballon observations, the trained meteorologist is enabled to make his analysis of weather conditions pertinent to aviation. Airport weather maps are prepared every 6 hours, with special maps at shorter intervals when conditions warrant.

A typical weather map, with the analysis of air masses and fronts indicated thereon, is given in figure 74. Numerous symbols are used for brevity, and a description of them is given in figure 75.

FIGURE 75.

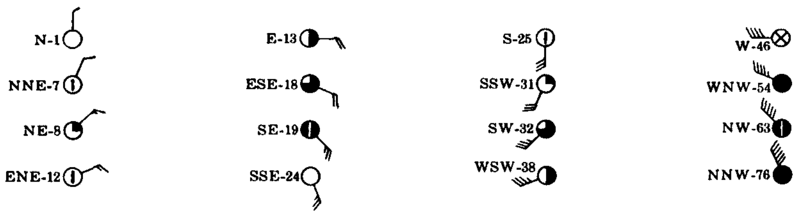
EXPLANATION OF METEOROLOGICAL DATA AND SYMBOLS ENTERED ON WEATHER MAPS

TOTAL AMOUNT OF ALL CLOUDS

Proportion of sky covered (in tenths)

- Absolutely no clouds in sky.
- One tenth.
- Two or three tenths.
- Four, five, or six tenths.
- Seven or eight tenths.
- Nine tenths.
- Sky completely covered with clouds.
- Sky obscured by fog, duststorm, or other phenomenon

WIND DIRECTION AND VELOCITY



ABBREVIATED DESCRIPTION OF SKY AND SPECIAL PHENOMENA

- Low fog, whether on ground or at sea.
- Haze (but visibility greater than 2,200 yds.)
- Dust devils seen.
- Distant lightning.
- Light fog (visibility between 1,100 yds. and 2,200 yds.)
- Fog at a distance, but not at station (or ship)
- Precipitation within sight.
- Thunder, without precipitation at station (or ship)
- Dust storm within sight, but not at station (or ship)
- Ugly, threatening sky.
- Squally weather.
- Heavy squalls } ... in last 3 hours
- Waterspouts seen } ... in last 3 hours
- Visibility reduced by smoke or volcanic ashes.
- Dust storm (visibility greater than 1,100 yds.)
- Signs of tropical storm (hurricane)

PRECIPITATION IN LAST HOUR BUT NOT AT TIME OF OBSERVATION

- Precipitation (rain, drizzle, hail, snow, or sleet)
- Drizzle } ... other than showers
- Rain } ... other than showers
- Snow } ... other than showers
- Rain and snow mixed
- Rain shower (s)
- Snow shower (s)
- Hail or rain and hail shower(s)
- Slight thunderstorm
- Heavy thunderstorm

DUST STORMS AND STORMS OF DRIFTING SNOW
(VISIBILITY LESS THAN 1,000 METERS, 1,100 YARDS)

- Dust or sand storm.
- Dust or sand storm has decreased.
- Dust or sand storm, no appreciable change.
- Dust or sand storm has increased.
- Line of dust storms.
- Storm of drifting snow.
- Slight storm of drifting snow } ... generally low.
- Heavy storm of drifting snow } ... generally low.
- Slight storm of drifting snow } ... generally high.
- Heavy storm of drifting snow } ... generally high.

FIGURE 75.—Continued.

FOG (VISIBILITY LESS THAN 1,000 METERS, 1,100 YARDS)

Fog.

Moderate fog in last hour } but not at time
Thick fog in last hour } of observation.

Fog, sky discernible } has become thinner
Fog, sky not discernible } during last hour.

Fog, sky discernible } no appreciable change
Fog, sky not discernible } during last hour.

Fog, sky discernible } has begun or become thicker
Fog, sky not discernible } during last hour.

Fog in patches.

DRIZZLE (PRECIPITATION CONSISTING OF NUMEROUS MINUTE DROPS

Drizzle.

Intermittent } ...slight drizzle.
Continuous }

Intermittent } ... moderate drizzle.
Continuous }

Intermittent } ... thick drizzle.
Continuous }

Drizzle and fog.

Slight or moderate } ... drizzle and rain.
Thick }

RAIN

Rain.

Intermittent } ... slight rain.
Continuous }

Intermittent } ... moderate rain.
Continuous }

Intermittent } ... heavy rain.
Continuous }

Rain and fog.

Slight or moderate } ... rain and snow, mixed.
Heavy }

SNOW

Snow (or snow and rain, mixed).

Intermittent } ... slight snow in flakes.
Continuous }

Intermittent } ... moderate snow in flakes.
Continuous }

Intermittent } ... heavy snow in flakes.
Continuous }

Snow and fog.

Grains of snow (frozen drizzle).

Ice crystals; or frozen raindrops (Sleet - U. S. definition).

SHOWER(S)

Shower(s).

Shower(s) of slight or moderate } ... rain.
Shower(s) of heavy }

Shower(s) of slight or moderate } ... snow.
Shower(s) of heavy }

Shower(s) of slight or moderate } ... rain and snow.
Shower(s) of heavy }

Shower(s) of snow pellets (soft hail).

Shower(s) of slight or moderate } hail, or rain
Shower(s) of heavy } and hail.

THUNDERSTORM

Thunderstorm.

Rain at time } thunderstorm during last hour but not at time of observation.
Snow, or rain and snow mixed, at time }

Thunderstorm, slight without hail, but with rain (or snow). } at time of observation.
Thunderstorm slight with hail. }

Thunderstorm moderate without hail, but with rain (or snow). } at time of observation.
Thunderstorm moderate with hail. }
Thunderstorm heavy without hail, but with rain (or snow) }
Thunderstorm combined with dust storm. }
Thunderstorm heavy with hail. }

FIGURE 75.—Continued.

CHARACTERISTIC OF BAROMETRIC TENDENCY DURING 3-HOUR PERIOD ENDING AT TIME OF OBSERVATION

Barometer now higher than or the same as 3 hours ago:

- Rising, then falling
- Rising, then steady; or rising, then rising more slowly.
- Unsteady.
- Steady or rising.
- Falling or steady, then rising; or rising, then rising more quickly.

Barometer now lower than 3 hours ago:

- Falling, then rising.
- Falling, then steady; or falling, then falling more slowly.
- Unsteady.
- Falling.
- Steady or rising, then falling; or falling, then falling more quickly.

FORM OF LOW CLOUD

- No lower clouds (no symbol)
- Cumulus of fine weather
- Cumulus heavy and swelling, without anvil top
- Cumulonimbus
- Stratocumulus formed by the flattening of cumulus clouds
- Layer of stratus or stratocumulus
- Low broken up clouds of bad weather
- Cumulus of fine weather and stratocumulus
- Heavy or swelling cumulus, or cumulonimbus, and stratocumulus
- Heavy or swelling cumulus (or cumulonimbus) and low ragged clouds of bad weather

FORM OF MIDDLE CLOUD

- No middle clouds (no symbol)
- Typical altostratus, thin
- Typical altostratus, thick (or nimbostratus)
- Altocumulus, or high stratocumulus, sheet at one level only
- Altocumulus in small isolated patches; individual clouds often show signs of evaporation and are more or less lenticular in shape
- Altocumulus arranged in more or less parallel bands, or an ordered layer advancing over sky
- Altocumulus formed by a spreading out of the tops of cumulus
- Altocumulus associated with altostratus or altostratus with partially altocumulus character
- Altocumulus castellatus, or scattered cumuliform tufts
- Altocumulus in several sheets at different levels, generally associated with thick fibrous veils of cloud and a chaotic appearance of the sky

FORM OF HIGH CLOUD (CIRRUS CLOUD)

- No upper clouds (no high clouds; no symbol)
- Cirrus, delicate, not increasing, scattered and isolated masses
- Cirrus, delicate, not increasing, abundant but not forming a continuous layer
- Cirrus of anvil clouds, usually dense
- Cirrus, increasing, generally in the form of hooks ending in a point or in a small tuft
- Cirrus (often in polar bands) or cirrostratus advancing over the sky but not more than 45° above the horizon
- Cirrus (often in polar bands) or cirrostratus advancing over the sky and more than 45° above the horizon
- Veil of cirrostratus covering the whole sky
- Cirrostratus not increasing and not covering the whole sky
- Cirrocumulus predominating, associated with a small quantity of cirrus

CLOUD FORMS-ABBREVIATIONS

Ci = Cirrus	St = Stratus	Fc = Fractocumulus
Cc = Cirrocumulus	Ns = Nimbostratus	Acc = Altocumulus castellatus
Cs = Cirrostratus	Cu = Cumulus	Cm = Cumulonimbus mammatus (Mammato cumulus)
Ac = Altocumulus	Cb = Cumulonimbus	
Sc = Stratocumulus	Fs = Fractostratus	

U. S. DEPARTMENT OF AGRICULTURE
WEATHER BUREAU

EXPLANATION OF SYMBOL WEATHER REPORTS

(based on instructions contained in Weather Bureau Circular N 1939)

[To illustrate the method used in transmission and deciphering of symbol weather reports, the following example of such a report is given. Each element of the report is connected by a line with a description of all symbols and conditions which might be used in that particular phase of the report. Elements of observations are always transmitted in the same order; therefore all symbol weather reports may be deciphered by reference to this chart]

WA7 C SPL 1624E E30⊕15⦶2VT-R-BD- 152/68/60→↘18-↑1618E 996 +⊕NW

Station

Lists of station names and their representative call letters are posted on Weather Bureau airport station bulletin boards for the information of all concerned.

A figure, 0 to 9, representing the total extent of sky covered by clouds, is entered immediately following the call letters for station names, in accordance with the following:

0 No clouds.
1 Less than 0.1.
2 0.1.
3 0.2 to 0.3.
4 0.4 to 0.6.
5 0.7 to 0.8.
6 0.9.
7 More than 0.9 but with breaks.
8 Overcast (solid).
9 Sky obscured.

Classification of report

The symbols C, N, or X are used immediately following, after 1 space, the station letters to classify weather conditions at airports specifically designated as controlled airports.

If no classification letter is used the station is not located at a controlled airport.

C: Satisfactory for contact flight.
N: Requiring observance of instrument flight rules.
X: Take-off and landing suspended.

Type of report

"SPL," meaning "special report," appears when crucial changes have occurred in weather conditions since the last report.

The absence of the observation-type letter group "SPL" indicates an observation where no crucial changes have occurred since the last transmitted observation.

"LCL," meaning "local extra observation," appears only on reports sent over local circuits. Such reports are made every 15 minutes during periods of low ceiling and/or visibility.

Time of report

Time groups are in figures based on the 24-hour clock, with following letters showing the standard of time used, e. g., "1440E" means 2:40 p. m., Eastern Standard Time; "0030C" means 12:30 a. m., Central Standard Time; "2359M" means 11:59 p. m., Mountain Standard Time; "2015P" means 8:15 p. m., Pacific Standard Time, etc.

"SPL" reports which are sent alone and all "LCL" reports bear the time of observation immediately following, after 1 space, the observation-type letter group "SPL" or "LCL."

"SPL" reports appearing in sequences do not show the time-of-report group and the time of observation is considered as the time of all other reports in the sequence as indicated in the sequence heading.

Ceiling

The absence of a "ceiling" group indicates an "unlimited" ceiling (above 9,750 feet).

Figures representing the number of *hundreds* of feet which apply are used to indicate the height of the ceiling between 51 and 9,750 feet, inclusive, above the station, e. g., "35" indicates 3,500 feet, "3" indicates 300 feet, etc.

The figure naught (0) is used when the ceiling is zero (below 51 feet).

When the height is estimated the letter "E" precedes the ceiling figures.

A plus sign (+) is used preceding the ceiling figures to indicate the ceiling balloon was blown from sight at the height represented by the figures and before reaching the clouds.

The letter "V" is used, immediately following the figures for ceiling, if the height of the ceiling is changeable and below 2,000 feet.

Sky

The absence of a symbol for sky indicates that precipitation or obstructions to vision are present and reduce the ceiling to zero and/or the visibility to one-fifth mile or less and make the sky unobservable.

The sky condition is indicated by the following symbols unless the condition given above is present:

○ Clear.
⦶ Scattered clouds.
⦷ Broken clouds.
⊕ Overcast.
⦶/ High scattered.
⦷/ High broken.
⊕/ High overcast.
⊕⦷ Overcast, lower broken.
⊕⦶ Overcast, lower scattered.
⦷⦷ Broken, lower broken.
⦷⦶ Broken, lower scattered.
⦶⦷ Scattered, lower broken.
⦶⦶ Scattered, lower scattered.
⊕/⦷ High overcast, lower broken.
⊕/⦶ High overcast, lower scattered.
⦷/⦷ High broken, lower broken.
⦷/⦶ High broken, lower scattered.
⦶/⦷ High scattered, lower broken.
⦶/⦶ High scattered, lower scattered.

The plus (+) or minus (−) sign *preceding* the cloudiness symbol indicates "dark" and "thin," respectively.

Height of lower scattered clouds is indicated by the entry of a figure, representing the hundreds of feet applying, immediately preceding the scattered clouds symbol.

Visibility

The absence of a figure for visibility indicates that the visibility is 10 miles or more.

The value of the visibility below 10 miles is indicated by figures representing the number of miles and/or fractions of miles.

The letter "V" is used, immediately following the figure for visibility, if the visibility is fluctuating rapidly and is 2 miles or less.

Weather

The "weather" element of the report is indicated, when appropriate, by the following symbols:

R− Light rain.
R Moderate rain.
R+ Heavy rain.
S− Light snow.
S Moderate snow.
S+ Heavy snow.
ZR− Light freezing rain.
ZR Moderate freezing rain.
ZR+ Heavy freezing rain.
L− Light drizzle.
L Moderate drizzle.
L+ Heavy drizzle.
ZL− Light freezing drizzle.
ZL Moderate freezing drizzle.
ZL+ Heavy freezing drizzle.
E− Light sleet.
E Moderate sleet.
E+ Heavy sleet.
A− Light hail.
A Moderate hail.
A+ Heavy hail.
AP− Light small hail.
AP Moderate small hail.
AP+ Heavy small hail.
OP− Light snow pellets.
OP Moderate snow pellets.
OP+ Heavy snow pellets.
SQ− Mild snow squall.
SQ Moderate snow squall.
SQ+ Severe snow squall.
RQ− Mild rain squall.
RQ Moderate rain squall.
RQ+ Severe rain squall.
T− Mild thunderstorm.
T Moderate thunderstorm.
T+ Severe thunderstorm.
SW− Light snow showers.
SW Moderate snow showers.
SW+ Heavy snow showers.
RW− Light rain showers.
RW Moderate rain showers.
RW+ Heavy rain showers.
TORNADO (always written out in full).

Obstructions to vision

The "obstructions to vision" element of the report is indicated, when appropriate, by the following symbols:

F−− Damp haze.
F− Light fog.
F Moderate fog.
F+ Thick fog.
FF Dense fog.
GF− Light ground fog.
GF Moderate ground fog.
GF+ Thick ground fog.
GFF Dense ground fog.
IF− Light ice fog.
IF Moderate ice fog.
IF+ Thick ice fog.
IFF Dense ice fog.
H Hazy.
K− Light smoke.
K Moderate smoke.
K+ Thick smoke.
D− Light dust.
D Moderate dust.
D+ Thick dust.
BS− Light blowing snow.
BS Moderate blowing snow.
BS+ Thick blowing snow.
GS− Light drifting snow.
GS Moderate drifting snow.
GS+ Thick drifting snow.
BD− Light blowing dust.
BD Moderate blowing dust.
BD+ Thick blowing dust.
BN− Light blowing sand.
BN Moderate blowing sand.
BN+ Thick blowing sand.

Barometric pressure

The barometric pressure is indicated by a group of 3 figures; tens, units, and tenths of millibars involved. Thus a pressure of 1015.2 millibars would be written as "152"; 999.9 as "999"; 1025.7 as "257"; etc. Sent only by stations equipped with mercurial barometers.

Temperature

Temperature is indicated by figures giving its value to the nearest degree Fahrenheit.

Values below zero Fahrenheit are indicated by the entry of a minus sign (−) immediately preceding the figures for temperature. Zero is entered as "0."

Dew point

Dew point is indicated by figures giving its value to the nearest degree Fahrenheit.

Values below zero Fahrenheit are indicated by the entry of a minus sign (−) immediately preceding the figures for dew point.

Wind

The wind *direction* is indicated by arrows, as follows:

↓ North.
↓↙ North-northeast.
↙ Northeast.
←↙ East-northeast.
← East.
←↖ East-southeast.
↖ Southeast.
↑↖ South-southeast.
↑ South.
↑↗ South-southwest.
↗ Southwest.
→↗ West-southwest.
→ West.
→↘ West-northwest.
↘ Northwest.
↓↘ North-northwest.

The *velocity* is indicated by figures representing its value in miles per hour, "calm" being indicated by the letter "C." If estimated, this is indicated by the entry of the letter "E" immediately following the velocity figures.

The *character* of the wind is indicated, when appropriate, by entry, immediately following the velocity, of a minus sign (−) for "fresh gusts" and a plus sign (+) for "strong gusts." No indication of character means the wind is steady.

Wind shifts which have occurred at the reporting station are indicated, immediately following the other wind data, by an arrow showing the direction (to 8 points only) *from which* the wind was blowing prior to the shift, followed by the local time, on the 24-hour clock, at which the shift occurred, with following letter showing the standard of time used. The intensity of the shift is indicated by the minus sign (−) for "mild," the absence of a sign for "moderate," and the plus sign (+) for "severe," the signs being entered immediately following the standard-of-time letter.

Altimeter setting

Indicated by a group of 3 figures representing the inch and hundredths of an inch of pressure involved. Thus, 30.00 would be written as "000"; 29.98 as "998"; etc. Sent only by designated stations equipped with mercurial barometers.

Remarks

Remarks are transmitted in authorized English abbreviations and teletype symbols. Lists of the abbreviations are available for inspection at all Weather Bureau Airport Stations. The teletype symbols used are shown on this chart.

Special data

Special data comprising pressure change and characteristic, 5,000-foot pressure at selected stations, cloud, thunderstorm, and snow depth data, Great Lakes water temperature, etc., data from selected stations, etc., are entered in code at certain times by the stations designated to do this, as separate groups, immediately following the report proper. These data are intended primarily for the preparation of maps for forecasting.

Missing data

Elements normally sent, but for *some reason missing from* the transmission, will be indicated by the letter "M" entered in the report in place of the missing data.

For example, the report given above would be deciphered as follows: **Washington—sky more than nine-tenths covered but with breaks; satisfactory for contact flight; special report at 4:24 p. m., Eastern Standard Time; ceiling estimated at 3,000 feet; overcast, lower scattered clouds at 1,500 feet; visibility 2 miles, variable; mild thunderstorm; light rain; light blowing dust; barometric pressure 1015.2 millibars; temperature 68° F.; dew point 60° F.; wind west-northwest 18 miles per hour, fresh gusts; moderate wind shift from the south at 4:18 p. m., Eastern Standard Time; altimeter setting, 29.96 inches; dark to the northwest.**

162915°—39

AIRWAY FORECASTS

From careful study and analysis of meteorological charts and maps the forecasts are made. Airway forecasters are on duty 24 hours a day at the fifteen general supervising stations, which are also forecast centers for their respective districts. At these stations airway forecasts are made every six hours for periods of eight hours in advance for all airways and all terminals within the district. Such forecasts include ceiling heights, visibility, sky conditions, precipitation, fog, smoke, haze, icing, thunderstorms, squalls, etc., expected to occur over the airways or at the terminal within the district during the period of the forecast. Special forecasts are issued when conditons change rapidly. In some instances, forecasts for a period longer than eight hours in advance are made, when required, for long cross-country flights. The following is an example of such a forecast issued by a supervising station:

Warm front extending Springfield to Tarkio to North Platte to Dickinson with warm moist air to south and west overrunning cold surface air to north and east will advance slowly north and eastward causing scattered to broken clouds with ceiling 8,000 feet or more ahead of it and overcast 5,000 feet or more in few mild thundershowers. Visibility 6 miles or more all stations except in rain areas and smoke at Chicago where visibilities of 3 miles or more will be experienced. Increasing high scattered to broken clouds and increasing lower clouds becoming overcast during afternoon in mild to moderate thundershowers within warm air mass in Iowa and southern Minnesota. Ceiling 3,000 feet and visibility very low at times during afternoon in shower areas, otherwise visibility more than 6 miles.

MISCELLANEOUS SERVICES RENDERED

The Weather Bureau has also special and miscellaneous duties in regard to aviation, such as maintaining meteorological service for air meets, air races, and massed flights of Army and Navy planes. In addition, meteorological data are compiled for airline and aircraft companies and Government agencies to be used in helping to solve the problems of aviation as affected by the weather. Pilots or operators may consult with trained meteorologists for information concerning their weather problems. This consultation service is available at important airway terminals at all hours of the day or night, and is of great value, particularly in regard to avoiding weather disturbances or choosing the most desirable altitude with respect to upper air winds.

INTERPRETATION OF THE WEATHER MAP

IMPORTANCE OF UNDERSTANDING WEATHER MAPS

The preceding section was prepared by the United States Weather Bureau, and describes the collection and dissemination of this most important information. While it is not expected that a pilot should be his own forecaster, under some circumstances a knowledge of the weather may become a matter of life or death. Certainly an understanding of fundamental meteorological principles renders the advice of the meteorologist more intelligible and may prove of great value when such services are not available. The brief treatment which follows is necessarily general and suggestive only, but it is hoped that it may be of some assistance, and may make reference to the standard texts on meteorology a bit easier. Those desiring a more complete and detailed treatment are referred to the bibliography on page 195.

METEOROLOGICAL SYMBOLS

In order to depict aeronautical data clearly on the charts of the Coast and Geodetic Survey, special aeronautical symbols are required; similarly, numerous symbols are used to record the various meteorological data. By comparing the weather map of figure 74 with the symbols and descriptions of figure 75, the wealth of information which it contains may be more fully appreciated.

The amount and type of cloudiness at any of the reporting stations on the map; temperature and dew point; precipitation of various kinds and degree (light, moderate, or heavy); fog, thunderstorms, barometric pressure and pressure changes; wind direction and velocity—all and more are clearly indicated by symbols and figures.

Figure 76 may be called a "station model." It is simply an enlargement of the conventional circle representing a city or Weather Bureau station on a weather map, and shows the standard placing of the various data around the circle. This standard placing of data is departed from only when compelled by congestion.

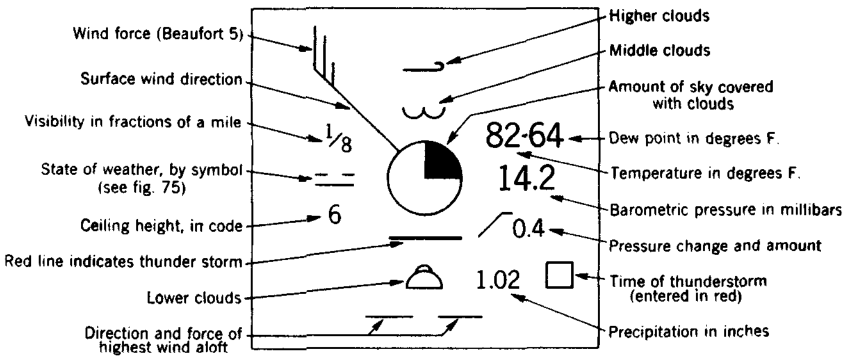


FIGURE 76.—Station model, showing placing of meteorological data.

Wind directions are indicated by arrows; "the arrows fly with the wind," the wind always blowing along the shaft of the arrow, toward the city. The wind velocity is indicated by the number and length of the barbs on the feather end of the arrow. Referring to the Beaufort scale of wind force (table 6, p. 177), it may be seen that a number has been assigned to each wind velocity defined and tabulated. Wind of force 1 is represented by one short barb on the arrow; wind of force 2, by one long barb; force 3 by one long and one short barb, force 4 by two long barbs, and so on. Thus, the second arrow of the fourth line under "Wind Direction and Velocity" (fig. 75) shows two long barbs and one short, and corresponds to a wind of force 5, which ranges from 19 to 24 m. p. h.; in figure 75 this is interpreted as 24 m. p. h.

Lines known as **isobars** *are also shown, connecting points* where the barometric pressure is the same, and the boundaries or fronts between the diverse air masses are indicated.

THE AIR OCEAN

In order to understand the various meteorological actions and reactions and their interpretation from the weather maps, it should be realized that "man is a deep-air animal." We live at the bottom of an air ocean, and our fastest planes are those which have been streamlined so that they resemble a great fish, or a whale, and are able to pass through the air ocean with the least resistance.

Even though it is invisible, the ocean of air is just as real, just as tangible, as the ocean of water. In it there are currents (winds), some of which flow with the regularity of the Gulf Stream, while others are "as changeable as the wind." Near the surface of the earth, wind is restrained and deflected by ridges and other obstructions, resulting in gusts and bumpy air. "Airfalls" exist over the top of a ridge or hangar, just as waterfalls exist where the stream plunges over a ledge; the reverse situation also exists, the wind being deflected upward for a considerable distance when it meets an obstacle. The greatest care must be exercised, therefore, when flying near the ground.

ATMOSPHERIC PRESSURE

The air ocean is substantial enough to support ships weighing many tons, and possesses weight, exerting a pressure of nearly 15 pounds per square inch at sea level. This means that at sea level the body of an adult is subject to an atmospheric pressure of approximately 30 tons.

The weight of the air ocean may be measured with a barometer. As we ascend there is less air above us, and hence less weight, or atmospheric pressure; the altimeter is simply a barometer which has been graduated to record this pressure difference directly in feet.

Atmospheric pressure is generally measured in terms of the height of the column of mercury which it will support in an ordinary mercurial barometer; aneroid barometers are so graduated that they may also be read in these same terms. The extreme variation in barometric pressure recorded in the United States ranges from about 27.40 inches to 31.50 inches of mercury at sea level. The normal variation, of course, is much less. As shown in figure 74, barometric pressure is now reported and shown on weather maps in terms of millibars, 1 inch of mercury being equal to 33.86 millibars. Thus the pressure at a given time and place may be expressed either as 29.93 inches of mercury, or as 1013.4 millibars.

On the manuscript weather maps prepared at the airports, the last three figures of the barometric pressure are recorded immediately to the right of the circle representing a city. For example, with a pressure of 1013.4 millibars, the figures 13.4 would be entered immediately to the right of the circle.

In order to have a uniform basis of comparison, the pressures observed at various places are reduced to pressure at sea level before being recorded on the map. The isobars are then drawn through points having the same barometric pressure. In figure 74 the isobars are drawn for every three millibars of difference in pressure. Intervals of two and of four millibars are also used, depending chiefly on the scale of the map. The centers of areas of low barometric pressure are indicated by the word "LOW," or by the letter "L"; the centers of high barometric pressure by the word "HIGH," or the letter "H." Several areas of both high and low pressure may be noted in figure 74.

CAUSES OF WEATHER CHANGES

Comparison has already been made between the air ocean and the ocean of water. Between the warm water of the equatorial regions and the cold water near the poles some interchange and admixture are continually taking place, and definite physical reactions occur. Similarly, when a mass of air from the warm equatorial regions meets an air mass from the cold polar regions there occur physical reactions which may be readily understood.

Most of the phenomena associated with weather changes occur in this way, a familiar illustration being found in the escaping steam from the exhaust of a locomotive or power plant (fig. 77).

All air contains a certain amount of water vapor; the warmer the air, the greater the amount of moisture it can contain. As the steam (which is essentially very warm, moist air) rises into the cooler and drier atmosphere, it is cooled until it can no longer retain all its moisture; some of it condenses into the minute water droplets which we see as steam, and a small cloud is formed; an occasional drop of water, or "rain," may even fall to the ground. The wind imparts horizontal motion, but the miniature cloud never attains any great size, since around its edges the water vapor is again being absorbed by the drier and "thirstier" surrounding air.

In this one illustration, as a result of the reactions between two different air masses, we have seen vertical currents set up, horizontal movement, condensation and precipitation, and cloud formation. In a general way, this is the process of all weather phenomena.

In latitudes near the equator, because of the more nearly perpendicular rays from the sun and the comparatively dark covering of foliage in these areas, a much greater amount of heat is received than in the polar regions, where the sun's rays are quite oblique and the white surface of snow and ice tends to reflect the sun's heat. At the same time, the snow and ice covering is more favorable for radiation than the green vegetation, and the radiation of heat by the earth is nearly as great at the poles as at the equator. Due to these inequalities of heating by the sun and of radiation by the earth, an excess of heat is accumulated in equatorial regions, while a deficiency is set up in polar regions. Practically all meteorological phenomena—such as winds, clouds, and precipitation—result from the tendency to equalize these heat differences.

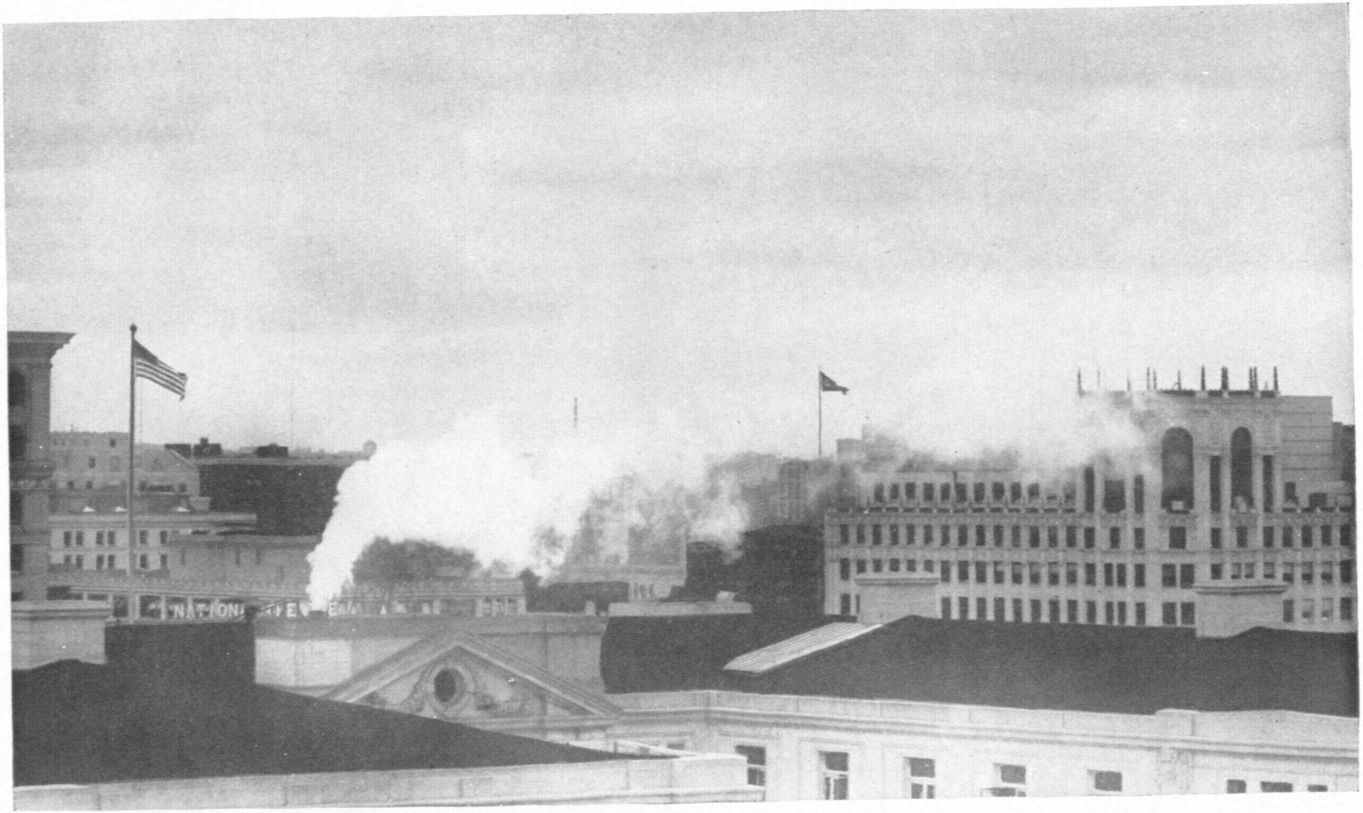


FIGURE 77.—Cloud formation illustrated by escaping steam.

The higher temperatures and predominating ocean areas in the tropics result in warm air masses with high moisture content. The broad expanse of land area to the north of the United States is protected from the moisture-laden winds of the Pacific by high coastal mountains; in conjunction with the low temperatures of northern Canada and Alaska, this results in cold air masses with very little moisture.

In studying the distribution of pressure over the earth, it is found that there are more or less permanent pressure belts. While areas of low and high pressure are constantly in motion (see p. 138), high pressures are fairly constant at the poles. Also, on each side of the equator, close to the tropics, there is a belt of high pressure known as the "horse latitudes." Between these tropical belts of high pressure near the equator, is the region known as the "doldrums," where the pressure remains nearly uniform and winds are light and variable. It is supposed that cold, dry air is expelled southward by the high pressure area near the north pole, while warm, moist air moves northward from the tropical belt of high pressure.

When, in our latitudes, warm moist air from the tropics—for example, from the Gulf of Mexico—comes in contact with the cold polar air, the warm air is chilled to the point where it can no longer retain all its moisture; some of it condenses, just as in the case of the warm, moist steam meeting the colder and drier air, and cloudiness or precipitation and other meteorological reactions take place.

AIR MASS DESIGNATIONS

On weather maps (see fig. 74) the air masses are divided into two principal classes, according to their source regions—polar, or cold, and tropical, or warm. These are again subdivided, on the general basis of moisture, into two main classes, depending on whether the source is land and dry, or water and moist; these two classes are designated as continental and maritime, respectively. A third classification, designated as "superior," is applied to high-level air masses of the middle and upper troposphere (see p. 140). The identification of the source regions of the air masses, and the tracing of the boundaries or "fronts" between them, are important parts of the work of the meteorologist.

An air mass that has acquired characteristic properties is designated by the name or abbreviation of its source region. As it moves onward over the changing surface of the earth, different thermal and moisture characteristics are acquired, especially in the lower layers. These changes in the original properties of the air mass are caused by the radiation of heat from the earth's surface, by mixing, by condensation or evaporation, and other causes. When the original characteristics have become somewhat modified because of such reasons, the designation of the air mass is also modified by prefixing the letter *N* (Neutralized—transitional or modified). The following table defines the source regions used on weather maps and lists the abbreviations commonly employed to designate them.

Table 3.—Air mass classification and designations

Source by—		Local source region	Corresponding air-mass name	Classification after Bergeron*
Latitude	Nature			
Polar	Continental	Alaska, Canada, and Arctic.	Polar Canadian or continental, Pc.	cA or cAw, winter. cP or cPk, summer.
		Modified in southern and central United States.	Transitional polar continental, Npc.	cPw or cPk, winter. cPk, summer.
	Maritime	Colder portions of North Pacific Ocean.	Polar Pacific, Pp.	mAk or mPk, winter. mP or mPw, summer.
		Modified in central and western United States.	Transitional polar Pacific, Npp.	cPw, winter. cPk, summer.
		Modified over warm portions of Pacific.	Transitional polar Pacific, Npp.	mP or mPk, winter. mP or mPk, summer.
		Colder portions of North Atlantic Ocean.	Polar Atlantic, Pa.	mPk, winter. mPw, spring and summer.
		Modified over warm portions of Atlantic.	Transitional polar Atlantic, Npa.	mPk, winter, spring, and summer.
Tropical	Maritime	Gulf of Mexico, Caribbean Sea, Sargasso Sea, and Middle Atlantic (also southern United States in summer).	Tropical Atlantic, Ta.	mT or mTk, winter. mTk, summer.
		Modified over northern U. S. or North Atlantic.	Transitional tropical Atlantic, Nta.	mTw, winter and summer
		Northern part Pacific trade-wind belt.	Tropical Pacific, Tp (usually not found in summer).	mT or mTk, winter.
		Modified in U. S. or over North Pacific.	Transitional tropical Pacific, Ntp.	mTw, winter.
Tropical and sub-polar	High-level	Middle and upper troposphere.	Superior, S.	S, winter and summer.

*Explanation of symbols:
A is Arctic.
P is Polar.
T is Tropical.
m is maritime.
c is continental.
w means the air mass is warmer than the surface over which it is traveling.
k means the air mass is colder than the surface over which it is traveling.

Bergeron's classification not only tells the source region of the air mass but it also gives some idea of the thermal stratification. The source region of the air is designated as follows: *A*, arctic; *P*, polar; *T*, tropical. The natural source regions are designated by *m* for maritime and *c* for continental. The letters *w* and *k* give a differential thermal value of the air mass. The letter *w* does not mean that the air is warm itself, but means that it is warmer than the surface (ground, ocean, or snow cover) over which it is passing. Because it is warmer than the surface over which it is traveling it is cooled from below and becomes a stable air mass. The weather properties of such an air mass are poor visibility, and possibly stratus clouds and fog. Likewise, the letter *k* means that the air is colder than the surface over which it is passing; it is therefore heated from below and becomes unstable resulting in the formation of cumulus clouds and possibly showers and thunderstorms.

In the weather map of figure 74, the eastern and southeastern portions of the United States are covered by maritime tropical air. This is a warm moist air with temperatures close to 90° F. and dew points in the lower seventies. Because it is colder than the surface over which it is traveling, it is conditionally unstable and most of the stations report swelling cumulus clouds and a few report cumulonimbus clouds with an active thunderstorm.

The north and central Plain states, and the Lake region is covered by continental polar air. It is relatively cool and dry, with temperatures near 80° F. and the dew points in the middle sixties. It is also colder than the surface over which it is traveling. In the central part of the air mass it will be noted that most stations report clear or scattered clouds which are "fair weather" cumulus.

Between these two air masses a front exists. The heavy line represents a cold front; the double line a warm front. Along this front are several waves or slight depressions. It will be noted that the most cloudy and rainy weather (shaded area) occurs just north of the front. This bad weather is caused by lifting of the moist tropical air over the wedge of cooler continental polar air. This lifting causes the tropical air to cool adiabatically (see p. 139) to a temperature below the dew point, and results in condensation and precipitation.

In the northwest is a cold front (heavy line). To the west of this front there is maritime polar air; because it is stable, few cumulus clouds are reported. East of the cold front Superior air is found at the ground. General sinking brought this air within several hundred meters of the ground and heating and turbulence over the Plateau brought the air to the surface. This Superior air is relatively so dry that only scattered clouds exist in the air mass and along the front.

THE DEVELOPMENT OF A DEPRESSION

The way in which the meeting of dissimilar air masses produces the various meteorological reactions is further illustrated in figure 78. At the left of the figure cold air is shown flowing from the northeast,

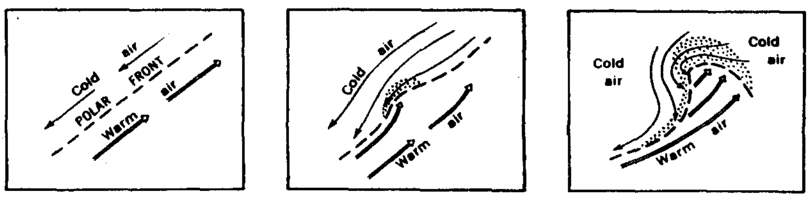


FIGURE 78.—Development of a depression.

with warm air flowing from the southwest. The surface between the two air masses and along which they move is referred to as "the surface of discontinuity," and the line representing this surface on the weather map is called the "polar front." Depressions (areas of low barometric pressure) form along this front as described below, and constitute the means by which interchange takes place between the cold and warm air.

Along the front between the two air masses, the usual tendency is for the cold air to push southward and for the warm air to move northward, causing a bulge toward the north, as shown in the central part of the figure. This movement having once started, the cold air tends to swing around still farther at the back, emphasizing the protruding tongue of warm air as illustrated in the right section of the figure. This exaggerated bulge is the newly born depression, which is shown on a larger scale and in more detail in figure 79.

In the upper part of the figure the broken line representing the polar front is divided into two sections, marked respectively as the "warm front" and the "cold front." The area within the bulge of the polar front, between the warm and cold fronts, contains warm air, while the rest of the area shown is covered by cold air.

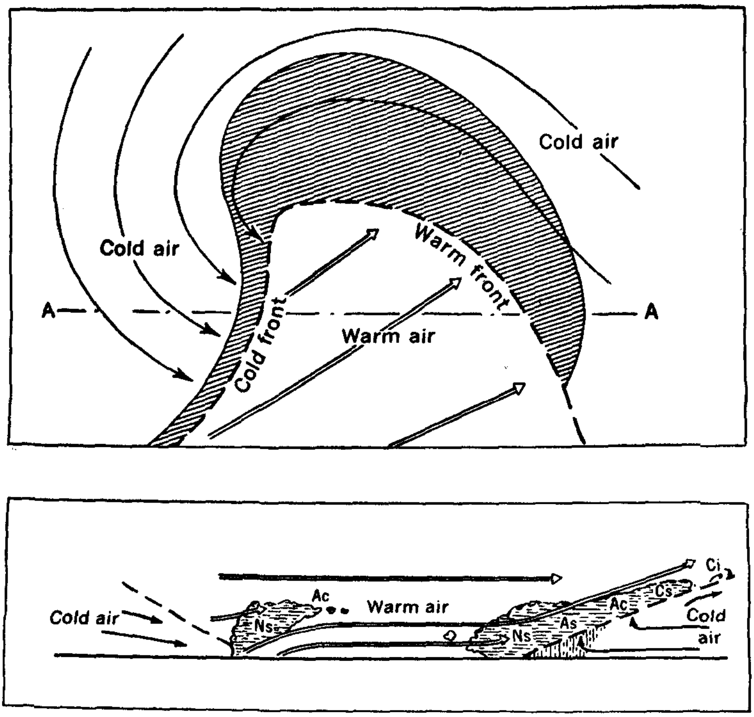


FIGURE 79.—Typical depression, with section through fronts.

In the lower part of figure 79 there is shown a cross section through the depression along the line *AA*, each part of the section lying directly beneath the corresponding part of the depression in the upper portion of the figure.

Along the warm front, the warm air, being lighter, ascends and is forced forward over the gradually sloping surface of the colder underlying air. Just as the warm, moist steam coming in contact with the colder air resulted in condensation and precipitation, so in this case the ascent of the warm air over the colder air beneath it results in the cloud sequence shown. The approach of the warm front, then, is marked by increasing and lowering clouds, and finally by rain, which becomes heavier as the front approaches and the clouds get lower. Rain is represented in the lower part of the figure by vertical shading. The passing of the warm front is followed by a rise in temperature, as the cold air is replaced by the warmer air behind the front. Relatively clear sky and sunshine are to be expected, although cumulus clouds and scattered showers are not infrequent, because of ascending currents in the warm, moist air.

As the cold front approaches (see left part of cross section, fig. 79) the warm air is again lifted as the colder air pushes in under it. Altocumulus or cumulonimbus clouds form, and are usually accompanied by brief but heavy rainfall of a squally, showery type. A narrow band of nimbostratus clouds and showers is pictured along the cold front, but in many cases these are entirely absent.

As the cold front passes and the colder air behind it comes in contact with the surface of the area so recently occupied by the warm air, the air near the surface is heated, and strong vertical currents are set up. The warm air meeting the cold air at higher levels results in the formation of clouds—usually cumulus or cumulonimbus. The resulting weather characteristics of such areas are clear periods alternating with occasional showers.

With the passage of a front there is usually a pronounced change in wind direction. This is illustrated in figure 79, from which it

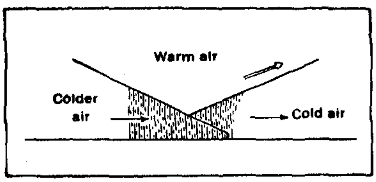


FIGURE 80.—Occlusion (cold-front type).

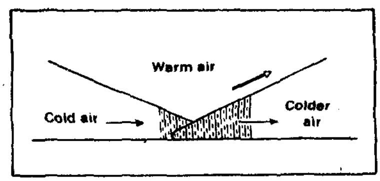


FIGURE 81.—Occlusion (warm-front type).

may also be seen that this change is more pronounced along the cold front, where wind direction may change 90° in as little as a minute. For this reason the cold front has sometimes been referred to as the "wind shift line."

The shaded area in the upper part of figure 79 represents the area of the depression in which precipitation (rain, snow, etc.) is taking place. The area of precipitation preceding the warm front is usually quite broad, while the precipitation following the cold front as a rule is quite narrow.

Ordinarily the cold front advances more rapidly than the warm front, and overtakes it. When the cold air from the back of the depression overtakes the cold air before it, the warm air is lifted entirely from the ground, and is said to be **occluded.** If the overtaking air is colder than the cold air in front of the depression, because of a different path of travel or other reason, the situation is as shown in figure 80, and is known as a cold-front type of occlusion; if the reverse is true, a warm-front type results (fig. 81). The cold-front type is characterized by squally rain and falling temperature, the warm-front type by low cloud and continuous rain or drizzle.

It has already been suggested that the apex of the northward bulge of the polar front is the center of the depression. The relatively high original temperature of the warm air mass at this point is further increased by the "latent heat of condensation," especially in the upper layers. This is the reverse process of the escaping steam illustration: heat was applied to the water to change it from liquid to vapor form, as steam; when water vapor is condensed to liquid form, the heat it originally received is given up, and is known as the heat of condensation. Since the air at this point is warmer, and therefore lighter, than elsewhere (for this and other reasons), the barometric pressure (weight of the air ocean) is lower here. As we progress away from the center of the low pressure area to points where the air is colder and heavier, the barometric pressure increases until, where the air is coldest, a high pressure area (or HIGH) is located. Figure 82 shows the depression of figure 79, with the addition of a system of typical isobars.

A general rule may be given here, known as Buys Ballot's law, which may prove useful at times: in the northern hemisphere, if you face the wind the area of lower pressure will be to your right, the higher pressure to your left. This may be readily visualized from figure 79.

Generally speaking, the western part of a LOW and the eastern part of a HIGH may be considered as similar air masses; conversely, the eastern part of a LOW and the western part of a HIGH may be so considered. In the first case (west of the LOW, east of the HIGH) surface temperatures are low or falling, and the pressure rising; in the second case, temperatures are high or rising, and the pressure is falling.

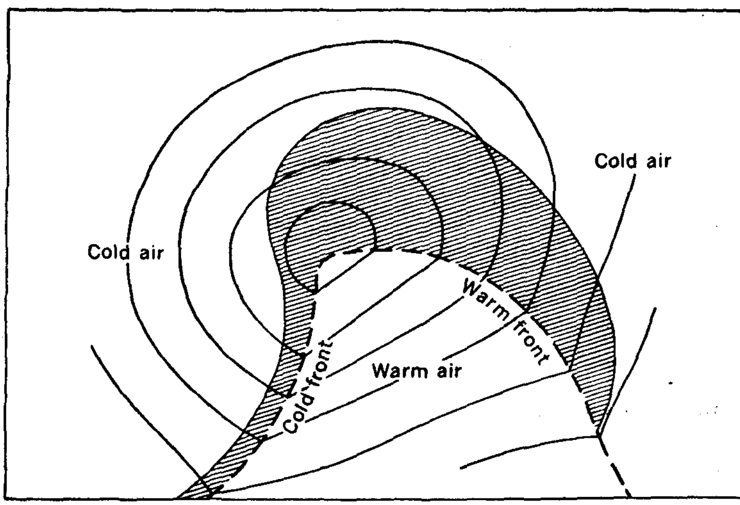


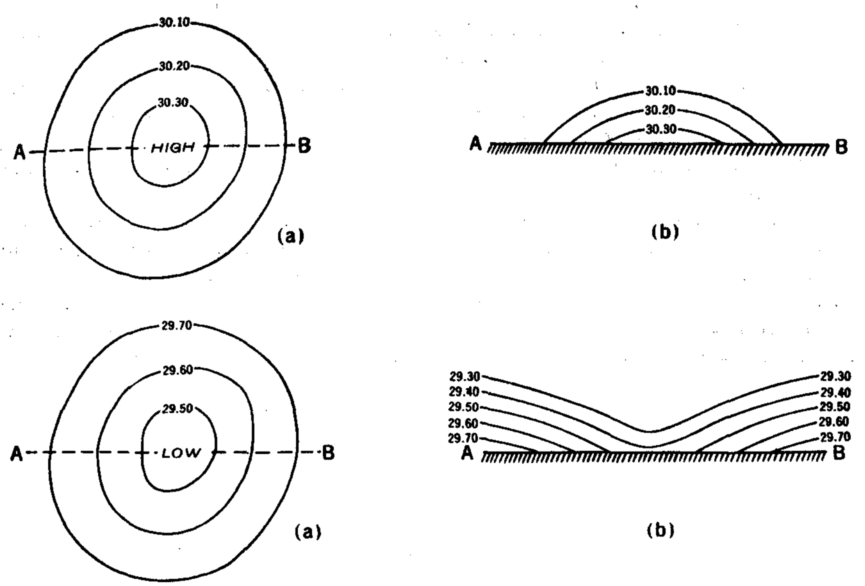
FIGURE 82.—Typical depression, showing isobars.

ISOBARS

More than anything else, the system of isobars on a weather map resembles the system of contours on a topographic map. As a matter of fact, they are very similar, as may be seen from the following comparisons.

A contour is a line at every point of which the elevation above sea level is the same; at every point on an isobar the barometric pressure is the same.

If we think of the isobars as contours depicting the atmospheric topography, the area represented by a HIGH represents a hill of air; the area represented by a LOW represents a depression, or valley. This conception is further suggested by the use of the words HIGH (for the hill of air) and LOW (for the valley). It has also been well brought out in an article on "The Technique of Drawing Isobars on Weather Maps," which appeared on the back of the Pilot Chart of the Upper Air—North Atlantic,[1] for December 1938. Figures 83 and 84 are reprinted from that article.



FIGURES 83 AND 84.—High pressure area (or "hill" of air) and low pressure area (or "valley" of air) are represented (*a*) in horizontal plane by isobars and (*b*) in vertical plane by cross section.

On a topographic map, contours close together indicate a steep slope; on a weather map, isobars close together represent a steep hill of air, or "gradient." In contrast with the topographic feature, an air hill is fluid, and therefore tends to flow down into the valleys—the closer the isobars, the faster the rate of flow (wind velocity). We find, then, surface winds always blowing out from a HIGH, and in toward a LOW. If the earth were stationary, this flow might follow a direct line between the two centers; however, because of friction, the rotation of the earth, and related factors, wind in the northern hemisphere is always deflected toward the right and approaches the trend of the isobars, blowing more or less along them. This may be seen by comparing the directions of the wind as shown in figure 79 with the isobars of figure 82. Wind therefore blows spirally outward from a HIGH in a generally clockwise direction, and spirally inward toward a LOW, in a counterclockwise direction (fig. 85). While individual exceptions may be noted in

[1] Chart 1400a, published by the U. S. Hydrographic Office, Washington, D. C.; 10 cents.

figure 74, for the most part the arrows indicating wind direction follow this rule.

This regular circulation of the winds about a pressure center is more pronounced near the surface; it becomes less definite as the altitude increases, due to the effect of the prevailing winds at higher levels. The HIGHS and LOWS themselves move across the United States from west to east, at a rate usually in excess of 500 miles a day (from about 20 to 30 miles an hour). Lows usually move in an easterly or north of east direction, and HIGHS in an easterly or south of east direction. Summer LOWS and HIGHS are of less energy and of slower movement than those of the winter season.

Technically, a low pressure area with its system of winds is known as a **cyclone,** a high pressure area as an **anticyclone.** "Cyclone" as used here should not be confused with the destructive storm so often given that name, but properly known as a tornado.

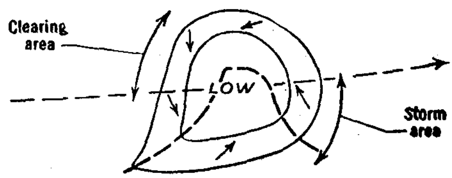


FIGURE 85.—Wind system of a LOW.

As already stated, the altimeter is simply a form of barometer. It is well to remember that in flying from a high pressure area into a low pressure area the instrument indicates an altitude higher than the true altitude; the same is true, of course, if the pressure falls during flight, before the plane returns to the point of departure. For this reason altimeters are provided with a barometric scale, by which they may be adjusted to the pressure in the vicinity of flight, so that they indicate actual heights, and not dangerously misleading altitudes.

For example, in figure 74 the barometric pressure at Pembina, North Dakota, is 1021.0 millibars, and at Havre, Montana, it is 1010.2 millibars. These pressures correspond to altimeter settings of about 30.15 and 29.83 inches, respectively. Under these conditions, if a pilot left Pembina with his altimeter adjusted to the pressure there, upon landing at Havre his altimeter would indicate that he was still more than 300 feet in the air.

Pressure differences of this magnitude are quite common, and differences of twice this amount are not unusual. The difference of altitude in feet corresponding to the difference in barometric pressure should be considered approximate only, since this varies somewhat with the temperature. As a general rule, however, it may be said that each tenth of an inch of difference in pressure corresponds to an apparent difference in altitude of 100 feet. The important thing is that the altimeter should always be adjusted for the barometric pressure prevailing at the time in the region of flight. The necessary information for making this adjustment is given in the hourly weather broadcasts (see plate III).

TEMPERATURE AND DEW POINT

If a glass of cold water is placed in a warm room, tiny drops of moisture form on the outside of the glass. This is another everyday illustration of the meeting of dissimilar air masses: the warm air coming in contact with the chilled glass is cooled to the point where it can no longer retain all its moisture, and condensation takes place. The temperature at which condensation begins is known as the **dew point.**

The name "dew point" was probably used in this connection because it is in this manner that dew is formed. After sunset on a clear night the earth rapidly radiates the heat which it has stored up during the day; finally the surface of the earth becomes cold enough that air coming in contact with it is chilled to the point where condensation must take place, and the drops of dew are formed. A layer of clouds serves to retain the heat near the surface, and so prevents the condensation of dew.

Temperature and dew point are among the most important items of information appearing on the weather map. On the manuscript maps prepared at the airports, barometric pressure is recorded immediately to the right of the circle representing a city, and the temperature and dew point are recorded just above the pressure. The dew point is also given in weather reports (see plate III), and should be especially noted in reports received by radio while in flight. When the dew point comes within about a degree of the air temperature, fog may usually be expected within an hour. There are many instances when the expected fog fails to materialize, but safety demands that pilots should recognize the danger and plan accordingly.

TEMPERATURE AND STABILITY

Air is said to be in stable equilibrium if it tends to remain at its original level or to return to that level after vertical displacement. If it tends to assist vertical displacement and to move further away from its original level, it is said to be in unstable equilibrium. If it neither assists nor resists vertical displacement, but tends to remain at any level to which it may be moved, it is said to be in neutral equilibrium.

The chief factor determining stability is the vertical distribution of temperature. Although widely different conditions may be noted at any given time, the average decrease of temperature with altitude is about 1° F. for each 300 feet. The decrease of temperature with altitude is known as the **lapse rate.**

When a body of air is caused to rise—because it has become warmer (and hence lighter) than the surrounding air; because of being lifted over a mountain range or underrunning mass of air, or for other reasons—it meets continuously decreasing atmospheric pressure, and therefore continues to expand. As it expands it becomes cooler, and is said to cool at the **adiabatic rate** if its cooling is due to expansion alone, and it neither gains nor loses heat from its surroundings. The adiabatic rate of cooling for dry air (which in this case means anything drier than saturated air) is about 1.6° F. for each 300 feet of increase in elevation (1° C. for each 100 meters). When saturated air rises, some condensation of moisture must take place, and the heat of condensation is added to the air. Due to this addition of heat, the temperature falls off less rapidly; that is, the lapse rate for saturated air is less than for dry air.

An ascending mass of air which cools at the adiabatic rate (1.6° for 300 feet) because of expansion, is cooling more rapidly than the normal decrease of temperature with altitude (1° for 300 feet); under these conditions the ascending air soon reaches a level where it is as cool as the surrounding air and ceases to rise. If the ascending air continues to rise until it is cooled to the dew point (because of expansion) and cloud formation begins, it continues to rise because the less rapid cooling rate for saturated air causes it to remain warmer than its surroundings.

Under certain conditions (as on clear nights, when there is little or no wind) the air becomes appreciably colder at the surface than at higher altitudes. Such an increase of temperature with altitude is known as a **temperature inversion,** since the normal condition is inverted, or upside down. If a considerable amount of moisture is present, the chilling of the air near the surface may result in condensation and the formation of fog.

The normal temperature decrease with height continues to a level known as the tropopause. Below that level lies the troposphere, with its turbulence and infinite variety of weather; above it lies the stratosphere, in which temperature variations are very small, and ideal flying weather prevails. The height of the tropopause varies with the season and latitude, being higher over the equator than over the poles, and higher in summer than in winter. On the average, it may be said to vary from about 25,000 feet above the earth at the north pole to about 50,000 feet at the equator.

CLOUDS

The general process of cloud formation has already been illustrated by the escaping steam, the glass of cold water, and the meeting of dissimilar air masses. A study of the various cloud forms is of very practical value. From the weather map we may learn the temperature, dew point, wind direction and velocity, and other related data, at or near the ground level; from a study of the clouds we may visualize the unseen air currents, and may know something of flying conditions—wind direction and velocity, temperature, and humidity—at the cloud levels. Within limits, we may even predict the weather from them.

As an aid to cloud study and identification of cloud types, a chart of cloud forms, published by the United States Weather Bureau has been included in the back of this book. Additional copies of the cloud chart may be obtained from the Superintendent of Documents, Washington, D. C., for 5 cents.

Those desiring more complete information may obtain from the same source a 25-page bulletin entitled "Cloud Forms According to the International System of Classification" (W. B. No. 956); or Circular S, a 100-page booklet of cloud pictures and descriptions entitled "Codes for Cloud Forms and States of the Sky" (W. B. No. 1249), for 10 and 15 cents, respectively.

The sequence of cloud types is illustrated in figure 79. The cirrus clouds are the highest of all, at times reaching altitudes of 40,000 feet. At their altitude it is so cold that the condensed water droplets are frozen, and these clouds always consist of minute ice crystals.

The flat, darker bases of the cumulus clouds indicate the altitude at which the dew point is reached as the vertical current of air ascends. If the mass of rising air is of considerable proportions, these clouds may develop into the familiar "thunder head," or cumulonimbus, and the condensation soon becomes sufficient to cause precipitation. It has been said that "cumulus clouds are the visible tops of ascending columns of air."

At times the towering heads of thunderstorms reach the regions of high winds, where the cloud tops are whipped off and driven on well in advance of the storm. These cloud tops, driven by the wind, resemble cirrus clouds, and are often referred to as "false cirrus."

Stratus clouds are defined as "a uniform layer of cloud resembling a fog but not resting on the ground." When such a layer occurs at greater altitudes, it takes on something of the form of the clouds ordinarily found at those levels, and a combined name is given to the layer, as cirrostratus. Clouds of the stratus type ("layer clouds") often mark the temperature inversion which exists when a warm air mass overruns colder air.

FOG

Fogs are stratus clouds that have formed at or near the surface of the ground. Various classifications of fog are given by different writers; the following are among the types listed by Byers:[1]

a. Radiation fogs.
b. Advection fogs.
c. Upslope fogs.
d. Frontal fogs.

Mention has already been made of the rapid radiation of heat from the surface of the earth on a clear night, and the resultant cooling of the lower layers of air in contact with the earth when calm conditions prevail. If surface temperatures fall to the dew point, condensation takes place and a radiation fog is formed. Being colder and heavier than the overlying air, it first fills up the valleys and low places, and is often called ground fog. If there is little or no wind, the fog will be shallow; light winds cause the air to be chilled to a greater height, through mixing, and the fog will therefore be deeper. Winds in excess of 5 or 6 miles per hour usually cause such thorough mixing of the warm and cold air that the temperature inversion is destroyed and fog does not form. When the sun rises, the earth's surface and the air in contact with it are warmed and fog of this type is dissipated (or "burns off") within an hour or two.

Advection fogs are usually caused by the passage of warm moist air over a colder surface. The simplest case of this type results from comparatively warm sea air drifting in over colder land surfaces in winter; such fog is usually quite shallow and, like radiation fog, burns off quickly under the influence of the sun.

A truer type of advection fog forms in summer, when air from the heated land surfaces is caused to flow out over the cooler surface of the ocean. By midafternoon, due to the increased heat over the land surfaces, a light sea breeze springs up and the dense fog which has formed over the sea is carried inland. Later at night, when the land breeze again prevails, the fog moves back over the sea. In some cases, when winds are light, fog formed in this way may persist for

[1] Byers, Horace Robert: Synoptic and Aeronautical Meteorology.

a day or more. In the same manner, although on a smaller scale. advection fogs form over and around inland lakes and rivers.

Advection fogs also form at sea, when comparatively warm air moves over a colder ocean current or the colder inshore waters emptying from large rivers. If temperature differences are slight, conditions are not greatly different from those resulting in radiation fog; only a shallow fog is formed, which soon burns off under the action of the sun. When temperature differences are greater, fog may form even in the face of high winds; under these conditions the fog may even lift somewhat above the surface, becoming, in effect, a low lying stratus cloud.

A less frequent type of advection fog is caused by the passage of cold air over a warmer surface.

Upslope fogs form chiefly on the great plains of the west, which rise gradually from about 1,000 feet elevation at the Missouri River to 5,000 feet at the eastern foot of the Rockies. An easterly wind in this area results in mechanical lifting, during which adiabatic cooling of the air results in a heat loss of about 5.5° F. for each 1,000 feet. Air moving westward from the eastern boundary of Nebraska and cooling adiabatically should therefore be about 22° colder when it reaches the western boundary of the State. The greater the wind velocity, the more rapid is the cooling. Dense fogs often form in these regions, even with fairly strong winds. They are, of course, often increased by conditions which would of themselves result in radiation fog.

Frontal fogs may form at any stage of the passing of a front. As rain falls into the cold air just ahead of a warm front, the moisture content is increased and the dew point is raised so that fog sometimes forms almost instantaneously. Surface cooling resulting from a heavy shower contributes to the formation of such fog. It may also form temporarily because of the mixing of warm air with the colder air behind a cold front as the front passes.

There are many other classifications of fog, modified more or less by local conditions in each case. The foregoing is not intended as a complete treatment of the subject, but has been presented as typical. Until complete safety of instrument landing has been achieved, every effort should be made to avoid being caught in the air by fog. It has been said that "anyone can be taught to fly blind in a month, and then it takes the rest of a lifetime to teach him when not to fly."

THUNDERSTORMS

The common thunderstorms of summer are the result of temperature differences and ascending air currents caused by uneven heating within a given body of air. A concrete or macadam road becomes appreciably hotter than a grassy meadow; a ploughed field absorbs more heat than the shady woods, and the sandy beach becomes much hotter than the sea. Air in contact with these warmer surfaces is heated by conduction; as it becomes hotter it also becomes lighter and is forced to rise by the cooler and heavier air around and above it. As the dew point is reached and condensation takes place, the heat of condensation is added to the air within the cloud, raising its temperature still higher and causing still stronger vertical currents. From the rising currents of air thus set up, the cumulonimbus clouds are formed as described in the preceding section, and a thunderstorm is soon in progress.

The vertical currents and temperatures present in a thunderstorm are often such as to cause the formation of hail. Hailstones may be said to be nothing more nor less than frozen rain drops, often with many successive layers of water frozen around the original drop as it has been carried up and down within the cloud. Some believe they can tell whether or not a cloud contains hail by its peculiar color and "boiling" characteristics. Probably experience has proved that such clouds do carry hail, but the fact is that any fully developed thunderstorm is more than likely to carry a dangerous load of hail, and should be avoided.

Many rules have been given for flying in a thunderstorm; the only safe rule is to avoid one. Aside from the hazards of hail and lightning, the vertical currents are frequently so strong that an aircraft cannot be controlled in them; also, they often extend to such heights that it is doubtful if a plane can climb above them. Even if the plane is able to fly above the storm, the time lost in climbing would enable the pilot to fly many miles in level flight around the storm—which is a much safer procedure.

It should be remembered that whenever a column of air ascends, an equal amount of air must descend. Just preceding a cumulo-nimbus cloud (thunder head) a strong upward current of air is found; just behind this current is a compensating down draft, which is more dangerous, since, if flying low, a plane may be carried all the way to the ground.

As a rule, a thunderstorm of the thermal type just described is comparatively local in character, and it is quite practical to fly around it with little delay. There is another type of thunderstorm, however, associated with the passage of a cold front and known as a **line squall,** which may prove more serious. Not only are the vertical currents often stronger, but the storm may extend along a front for several hundred miles, making it impractical to fly around it.

If, along a cold front, the cold air *underruns* the warmer air which it replaces, the warm, moist air is forced up to levels where condensation and all the other characteristics of the ordinary thunderstorm occur; the only difference in this case is that the thunderstorm is produced by mechanical lifting of the warm air. When the cold air *overruns* the warmer air, violent vertical currents are set up as the lighter air breaks through the colder and heavier air above it. In either case a series of thunderstorms is developed almost simultaneously along a line several hundred miles in length.

The violent motions associated with the line squall usually extend only to an altitude of about 6,000 feet, and it is sometimes possible to fly above them; however, the vertical currents common to all thunderstorm clouds may extend up to 15,000 or 20,000 feet, and may exceed velocities of 100 m. p. h. There are also many line squalls of more moderate intensity, but it may be seen that attempts to fly through or over such a disturbance are hazardous.

At best, ascending and descending air currents and gusts result in turbulence and bumpy air. Ordinarily, this is not of great importance, aside from the personal discomfort involved, yet occasionally serious injury to passengers has resulted from this cause, even on heavy transport planes. When rough air is encountered it is often possible to find relatively smooth air at another level—sometimes at lower altitudes, if the terrain permits, and sometimes by flying as high as possible, where the vertical currents have already spent much of their energy and a comparative state of balance has again been established.

VERTICAL CURRENTS AND SOARING

Knowledge of ascending and descending currents as revealed by cloud forms is important to pilots of powered craft, but it becomes of first importance to glider pilots. Clouds of the cumulus type do not float—rather, the minute drops of water are falling in a current of rising air; any drops of water that do fall below the cloud base are quickly absorbed or evaporated by the drier air beneath the cloud. Similarly, a turkey buzzard has no secret formula for escaping the law of gravity and soaring to higher levels without flapping a wing; he is falling all the time with respect to the air, but has learned to do his falling in air currents that ascend faster than he falls.

As already suggested, rising currents of air may be found beneath a cumulus cloud, particularly just ahead of it; up the windward slope of a ridge or mountain; over a sandy beach, desert, ploughed ground, or paved highway; over a smokestack or factory; updrafts may also result from other causes or combinations of causes. Descending currents may be found over the leeward edge of a ridge or other obstruction; over a large lake or river; over wooded areas, etc.

These few instances are only suggestive of the possibilities in this field, and a more detailed study of the subject will be well repaid.

ICE

In spite of the progress that has been made toward overcoming the formation of ice, condensation near freezing temperatures still remains one of the greatest hazards of flight. This is due not only to the increase in weight, but also to the loss of efficiency resulting from the deformation of the wings by the encrusted ice. The Safety and Planning Division of the Civil Aeronautics Authority has warned that an apparently inconsequential amount of ice or snow adhering to the upper surface of a wing may render the airplane hazardous. Pilots are urged to make sure that all traces of snow, ice, or frost are removed from the wings of an airplane before attempting to take off. Ice may also form around the controls and make the airplane unmanageable.

In general, ice does not form on an aircraft unless the temperature of the air is 34° or less, and moisture is present in the air in visible form (rain, fog, snow, etc.). Frost sometimes forms in clear air when a cold airplane enters a warm, moist air mass, but it usually disappears as the temperature of the airplane reaches the temperature of the surrounding air. Ice seldom forms in any considerable quantity at temperatures below 0° F., because of the small amount of water vapor present in air at such low temperatures.

In the laboratory, water may be cooled appreciably below the freezing point and yet remain liquid; under these conditions, however, the least disturbance changes it at once to ice. Similarly, the atmosphere often contains drops of water which have been cooled below freezing and which change immediately to ice (in part, at least) upon coming into collision with the cold airplane.

The size of the water droplets seems to be an important factor in the formation of ice. Small drops are carried around the plane by air currents, and are kept from striking it by a cushion of compressed air which is built up in front of the plane by its rapid movement; larger drops, because of their greater weight and inertia, break through this cushion of air and flow over the surface, a considerable portion of them freezing quickly. Within limits, the stronger the vertical currents, the larger are the drops of water that may be supported; therefore it may be said that maximum icing conditions are found in regions of strong vertical currents, such as are present in heavy cumulus or cumulonimbus clouds. Such areas should be avoided if at all possible. Stratiform clouds are subject only to slight vertical currents, and carry small water drops; except for the stratus itself, ice formed in them is less hazardous. In the case of the stratus cloud, while the water droplets are small they are so numerous that a heavy load of ice is quickly accumulated.

With respect to temperature, maximum icing occurs between 26° and 34° F. The latter temperature is slightly above the freezing point, but when drops of water at this temperature strike the speeding airplane, they are further chilled by the evaporation which results from its rapid motion.

When icing conditions are encountered in the cold air ahead of a warm front, they may sometimes be avoided by climbing into the warmer overrunning air. This may be better visualized by referring to the section in the lower part of figure 79; a pilot meeting with icing conditions in the cold air at the right of the figure might climb through the altostratus clouds into the warmer air above. The airplane, of course, has already acquired the freezing temperature of the cold air mass, and may take on considerable ice in climbing through the warm moist cloud. The maximum rate of climb should be maintained in order to accumulate the minimum amount of ice. Also, if the cold air mass extends to any great height, even the warmer overrunning air may have been cooled by expansion until it is below the freezing point, and severe icing conditions may again be met. This is particularly likely if the direction of flight is such as to take one up the sloping surface between the two air masses, when it is necessary to climb higher and higher in order to stay in the warm air mass. However, if temperatures in the warm air mass are sufficiently high, the pilot may not only escape further icing, but may even melt off or evaporate ice that has already formed.

It might be well to remark here that the vertical scale of the section of figure 79 is greatly exaggerated, for the sake of illustration. The sloping surface between the two air masses rises only about 1 mile in 100 miles, and if shown true to scale would almost coincide with the line representing the surface of the ground.

Under some conditions, icing may be avoided by flying low. For example, suppose that a pilot is flying from the warm area of figure 79 into the cold area to the west of the cold front. As he approaches the cold front (see section, bottom of fig. 79) ceiling and visibility are still such that he can fly beneath the altocumulus and also beneath the nimbostratus. Although this is the "warm sector," temperature is just about freezing, and in the precipitation beneath the nimbostratus light ice is formed. Deicing equipment is able to take care of this amount of ice, however, and it is known that behind the cold front clear skies prevail. Flight is therefore continued beneath the clouds, and the little ice adhering to the airplane is slowly evaporated after passing the front, even though the temperature there is below freezing. Any effort to climb through the nimbostratus would probably have resulted in the formation of a dangerous amount of ice.

CONCLUSION

While a knowledge of the general principles of meteorology leads to a better understanding of the weather map and may prove useful in an emergency, it should always be remembered that the most approved theories have their exceptions and may be wrong in any given instance. Also, weather often changes very quickly—sometimes in ways entirely unexpected even on the part of the most experienced meteorologists. To keep informed of these constantly changing conditions pilots should be careful to listen in on all weather broadcasts during flight and should not depend for too long a period on reports and forecasts received before taking off.

Conclusions based only on general principles may be very misleading. For example, knowing the general wind system accompanying a LOW (see fig. 85), it is sometimes suggested that when flying in a northerly direction it is preferable to fly to the east or southeast of a LOW because of favoring winds. This is theoretically correct, yet the LOW itself is moving in an easterly direction and the worst weather is found along the easterly or southeasterly edge, while better or clearing weather may be expected west of the LOW; to fly to the east of the LOW, then, would mean flying through bad weather, or flying so far east to avoid it that better time would be made by facing the headwinds in the safer weather west of the LOW. For an east-west flight, better weather might be expected north of the LOW.

With the necessary knowledge and experience, very helpful results can be obtained from local observations of pressure, temperature, winds, and clouds; however, except in emergencies, conclusions based on observations at a single point should not be relied upon. Far more definite and reliable forecasts can be made from reports from a well-organized network of stations, since more complete information is available regarding the size, rate, and direction of movement of disturbances, or of air masses and the fronts that attend them. It is for this reason that the regular weather maps are prepared and expert advice is made available. Whenever possible, therefore, consult the airport meteorologist.

Chapter VII.—PRACTICAL EXAMPLES

If, for any of the methods of air navigation described herein, the procedure seems complicated or in any way involved, it is only because of the difficulty of finding words as simple as the operations required. Most of the mystery can be removed from the subject by just a little practice. Even working out a few typical problems will help to correlate the various steps and to demonstrate the natural procedure from one step to another; at the same time, more efficient operation and the personal satisfaction and safety of the pilot make it well worth while. With this in mind, the following practical examples are offered:

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).

Known data: Cruising speed of plane, 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 plane 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 degrees 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 20. 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 plane; 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 of the plane 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 plane should pass the town of Jacobsburg, which is near the top of a ridge, and at the end of a railroad. 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.

Known data: Cruising speed of plane 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:

	(*a*)	(*b*)	(*c*)
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.
Distance from Pittsburgh	136 miles	268 miles	434 miles.
Time from Pittsburgh	48 minutes	1 hour, 35 minutes	2 hours, 34 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. Figure 86 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 plane in this case is relatively low, and the flight will be chiefly for pleasure. Navigation will consist in large measure of piloting, and the sectional charts will therefore be used.

Since the Lambert projection affords a perfect junction between any number of charts, if space is available the charts required may be carefully fitted together and a straight line drawn across all of them, from starting point to destination.

However, when more than two or three charts are involved, it is often easier to plot the route first as a straight line, or series of straight lines, on a small-scale control chart, such as Coast and Geodetic Survey chart No. 3060a or 3074 (see p. 28). The points at which the straight line crosses meridians and parallels on the small-scale chart are then measured and transferred to the large-scale charts, and connected on each of them with straight lines. The portion of

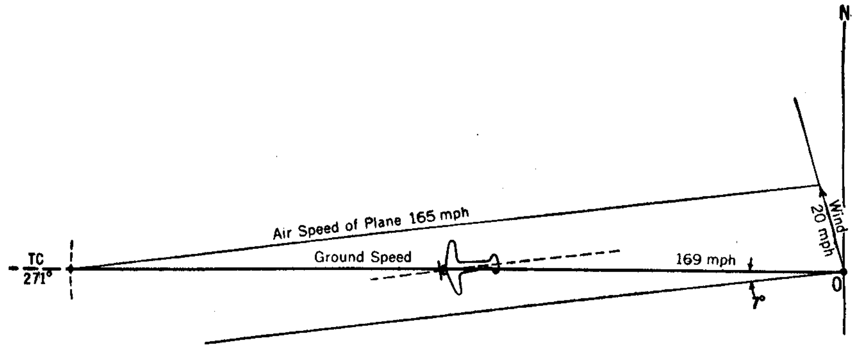


FIGURE 86.—Graphic determination of wind correction and ground speed.

the route appearing on each of the large-scale charts is treated as in the two preceding examples, in order to obtain the required distance and compass headings.

Following this procedure, we find that the straight line between the two airports on chart 3074 crosses longitude 84° (the western limit of the Cleveland sectional chart), at latitude 40°48′. This point is plotted on the Cleveland chart, using the marginal scale of minutes of latitude, and connected with Pittsburgh-Allegheny Airport by a straight line.

The portion of the route on the Cleveland chart crosses 4° of longitude, and is therefore divided into two sections crossing 2° of longitude each. The true course for each section is then obtained as in example 1, and magnetic variation, compass deviation, and correction for the effect of wind are applied in order to find the required compass heading for each section. The total distance on the Cleveland chart is 215 miles.

In the same way the portions of the route crossing the Chicago, Des Moines, and Lincoln sectional charts are subdivided into sections of practical length, and the compass heading for each section determined. The distances from the various charts are totaled, of course, to obtain the distance for the entire route.

Example 4.—After leaving Burgess Field, Uniontown, Pa., under conditions of poor visibility, a plane is flown for 40 minutes on a compass heading of 55° and at an air speed of 120 m. p. h. Compass deviation on this heading is 3° east; average magnetic variation in this vicinity as noted on the chart, 6° west; wind as reported at Burgess Field, 30 m. p. h., from 315°. (Cleveland sectional chart, or regional chart 9M.)

Required: The track of the plane (the "course made good"), and the dead reckoning position of the plane at the end of the 40 minutes.

55° compass heading.
+3° easterly deviation (to rectify, add easterly deviation).
58° magnetic heading.
—6° westerly variation (to rectify, subtract westerly variation).
52° true heading.

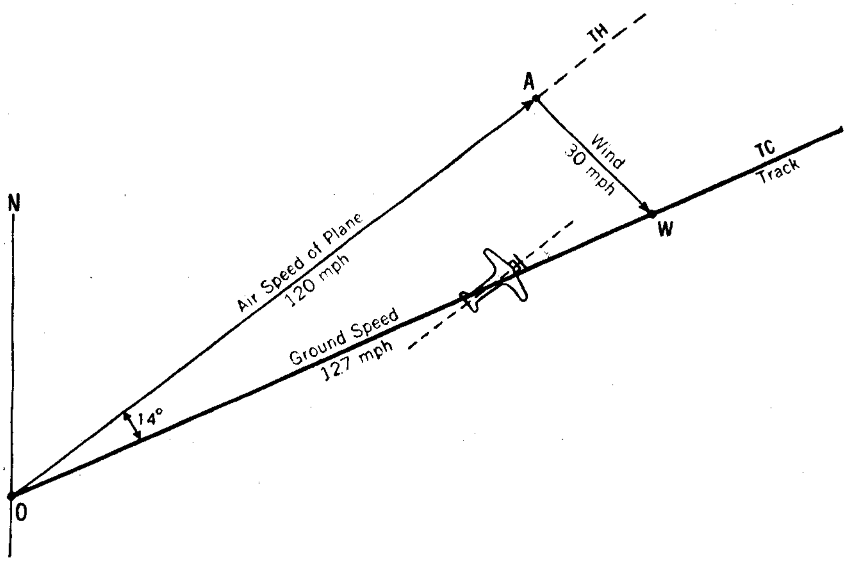


FIGURE 87.—Graphic determination of track and ground speed.

Because of poor visibility it was impossible to obtain drift observations, and therefore the true heading must be rectified for wind by means of a triangle of velocities, from the data obtained at Burgess Field.

From *O* (fig. 87) lay off *OA* on the true heading of 52° and equal to the air speed of 120 m. p. h.; from *A* lay off *AW* to represent the direction (from 315° true) and velocity (30 m. p. h.) of the wind. Draw *OW*, which represents the track of the plane over the ground, and also the ground speed. *OW* is measured and found to be 127 m. p. h., and the angle *AOW* (the drift angle) is found to be 14°.

52° true heading (see above).
+14° drift (to rectify, add for wind from left).
66° true course (track).

In 40 minutes, at a ground speed of 127 m. p. h., the plane will have covered 85 miles. Here it must be remembered that we are plotting a course, not a bearing, and that the true course made good must be plotted with the meridian nearest halfway. Roughly estimating the distance of 85 miles on a true course of 66°, it is seen that the meridian of 79° is about in the center of the route already flown. From any convenient intersection on the seventy-ninth meridian the true course of 66° is laid off (lightly), and a line parallel thereto is drawn from Burgess Field. This final line represents the track of the plane, and a point along this line 85 miles from Burgess Field is the dead reckoning position of the plane.

Example 5.—While flying the radio range course between Columbus and Cleveland, Ohio, in heavy fog, a pilot became uncertain as to his position along the course. He was able to tune in the Goshen radio range station and, by means of a direction finder on his own plane, the true bearing of that station from his position was determined as 294°. See chart 9M.

Required: The position of the plane.

In this case we are working with a bearing, not a course, and the angle must be plotted with the meridian nearest which it was determined; no correction for distortion is necessary when using the Lambert projection. The pilot supposed himself to be somewhere near Mount Vernon; consequently, the bearing was plotted with the meridian of 82°30′, at its intersection with latitude 40°30′. It was found that this plotted bearing passed slightly to the north of the Goshen radio station, so a second line was drawn, through the Goshen station and parallel to the first line. The intersection of the second line with the northerly course of the Columbus radio range, about 6 miles north of Mount Vernon, marks the position of the plane at the moment the bearing was measured.

If the Cleveland sectional chart were being used on this flight, it would be easier to plot the bearing directly from the Goshen radio range station on the Chicago chart, transferring the bearing to the Cleveland chart at the point where it crosses the meridian between the two charts. The bearing to be plotted from the radio station is obtained as follows (see p. 69):

294° bearing observed at plane.
—180°
114° reciprocal bearing.

The difference of longitude between the plane and the radio range station is 3°. Multiplying this number by the convergence of $0\overset{\circ}{.}6$ per degree of longitude (see p. 32), we obtain $3\times0\overset{\circ}{.}6=1\overset{\circ}{.}8$ or, to the nearest whole degree, 2°. The correction is to be subtracted, since the plane is east of the station.

114°
—2° to be subtracted, since plane is east of station.
112° bearing to be plotted from Goshen radio range station.

The bearing of 112° is plotted from Goshen and crosses the 84th meridian at $40°58\overset{\prime}{.}5$ of latitude, the bearing at that point being measured as 113°. This bearing is laid off from the same latitude on the 84th meridian of the Cleveland chart, and its intersection with the northerly course of the Columbus radio range determines the position of the plane in the same location as before.

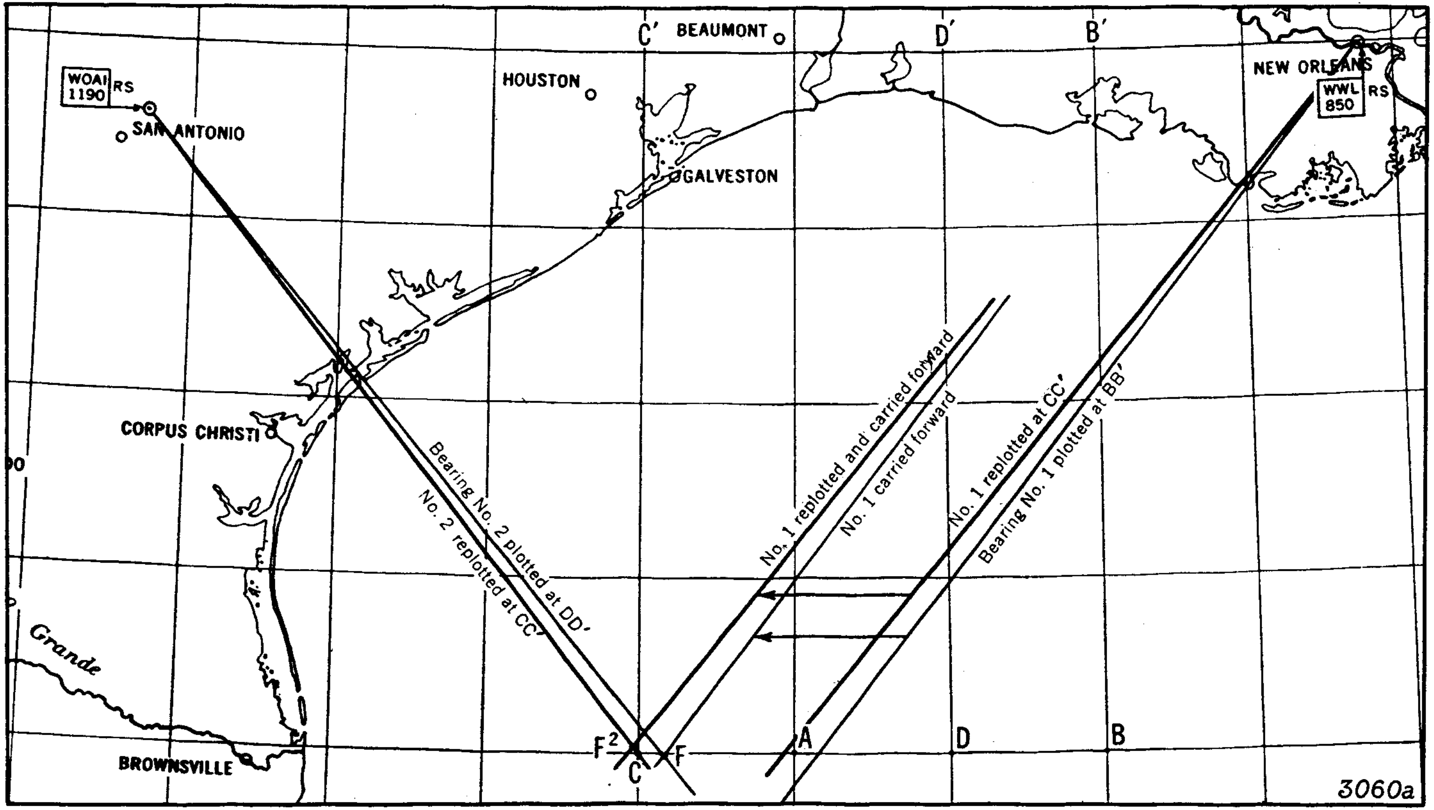


FIGURE 88.—A fix from radio bearings when the assumed position is considerably in error.

Example 6.—In the preceding example, if the Goshen radio station had been equipped with the necessary apparatus (as are the naval radio direction finder stations along our coasts), the pilot might have called Goshen and requested that his bearing from that station be determined. 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 plane), and its intersection with the Columbus radio range course would have determined his position as in example 5.

Example 7.—On a direct flight from Key West, Fla., to Brownsville, Tex., a pilot was approximately at position *A*, figure 88, but by dead reckoning believed himself to be in the vicinity of *B*. By radio compass he determined the bearing of WWL (New Orleans) as 39°, which was plotted on the 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*, result-

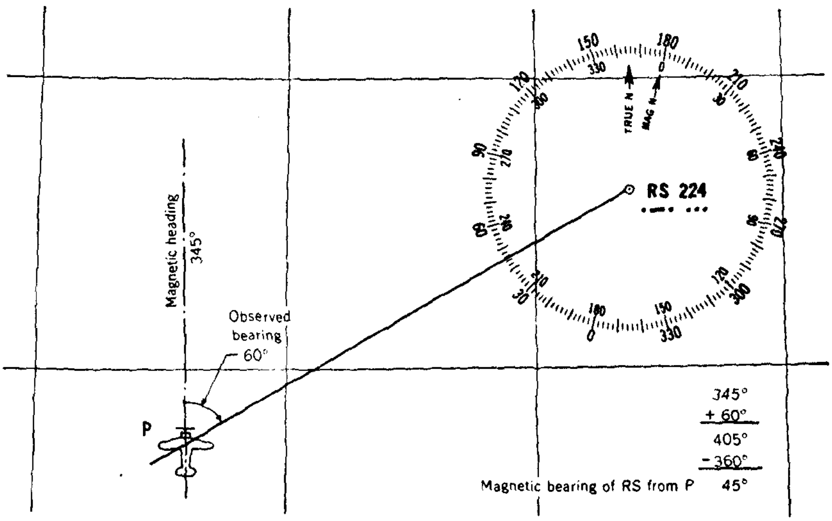


FIGURE 89.—Plotting a radio bearing on a radio direction-finding chart.

ing 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 plane 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 plane so much farther ahead than was supposed.

162915°—39——11

Example 8.—A pilot was flying in the vicinity of *P* (fig. 89 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 plane'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. 44), 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 plane'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 plane was located when the bearing was observed.

Example 9.—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 40°19′, longitude 83°44′.

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

By means of the marginal scale showing minutes of latitude, on the adjacent meridians (83°30′, and 84°) lay off northward from latitude 40° a distance equal to 19 minutes of latitude and draw a straight line through the points so obtained. This line represents the latitude of the radio station.

In the lower margin are scales showing minutes of longitude for each parallel of latitude printed on the chart. Lay off along latitude 40°30′, westward from longitude 83°30′, a distance of 14 minutes measured from the scale for latitude 40°30′; along latitude 40° lay off 14 minutes measured from the scale for latitude 40°, and draw a straight line between the points so obtained. This line represents the longitude of the radio station (83°30′ + 14′ = 83°44′), and its intersection with the line representing the latitude is the position of the tower.

In practice it should not be necessary to measure the 14 minutes along both parallels. Instead, having drawn the line representing the latitude of the station, the 14 minutes may be laid off along it, if the value of this measurement has been scaled at the correct proportionate position on the scales of minutes of longitude.

On some sectional charts the meridians and parallels themselves are subdivided into minutes, and in this case positions can be plotted directly as outlined above.

Example 10.—After an extended period of flying above fog, it is desired to check the position of a plane 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.

Example 11.—A pilot flying "over the top" by dead reckoning, believed his position to be about latitude 37°15′, 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 plane. 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, or on the marginal scale, 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.

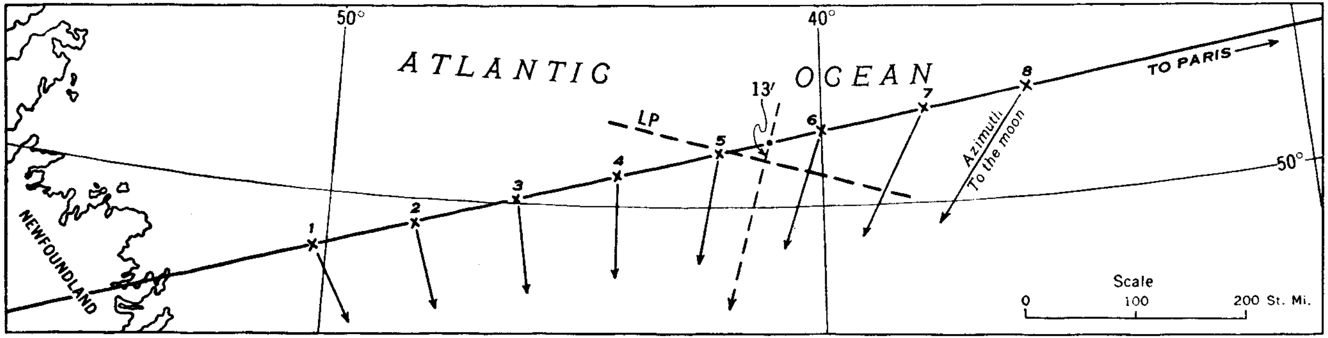
The intersection of this line of position with a second line obtained by observing the moon (if visible by daylight), or the intersection of lines of position from two stars at night, fixes the location of the plane.

Example 12.—A flight is planned from New York to Paris, along the great-circle route. It is desired to leave New York on May 13, 1938. From the best data available, a ground speed of 190 m. p. h. is expected (165 m. p. h. air speed plus 25 m. p. h. westerly wind). The distance is a little more than 3,600 statute miles, and approximately 19 hours are required for the flight. It is planned to leave New York about 1:30 p. m. eastern standard time ($=18^h30^m$ GCT), arriving at Paris at about 1:30 p. m. the following day ($=13^h30^m$ GCT).

From the Nautical Almanac it is learned that the moon will be full on May 14, and will be favorably situated for observation. The dead-reckoning positions of the plane from about the end of evening twilight, May 13, to about the beginning of morning twilight, May 14, are as indicated in figure 90.

Using the latitude, longitude, and GCT corresponding to each dead-reckoning position, the altitude and azimuth of the moon for each position are computed by means of the line of position table, pages 182 to 194. In the Nautical Almanac it is noted that the horizontal parallax for the moon on May 14 is 55′.1. From the table on page 107, the bubble sextant corrections for refraction and parallax are found and applied to the computed altitudes, with reversed sign. The azimuths are then plotted on the chart of the route (fig. 90), and the precomputed altitude curve of figure 91 is drawn. During flight, the only correction to be applied to the sextant altitude of the moon is that for index error (if any).

To illustrate the use of the method in flight, suppose that at 3^h30^m GCT a sextant altitude of 18°59′ is obtained. Applying a known



D. R. POSITION	LATITUDE	LONGITUDE	G.C.T.	AZIMUTH	ALTITUDE	ALTITUDE (corr. for ref. & par.)
1	49° 17′	50° 18′	1^h 15^m	153° 4′	18° 26′	17° 37′
2	49 42	48 16	1 45	162 10	20 18	19 29
3	50 4	46 14	2 15	171 33	21 15	20 26
4	50 24	44 11	2 45	181 1	21 17	20 28
5	50 42	42 4	3 15	190 29	20 19	19 30
6	50 58	40 0	3 45	199 42	18 29	17 40
7	51 12	37 51	4 15	208 39	15 49	15 0
8	51 24	35 42	4 45	217 12	12 25	11 36

FIGURE 90.—Portion of great-circle route, New York to Paris.

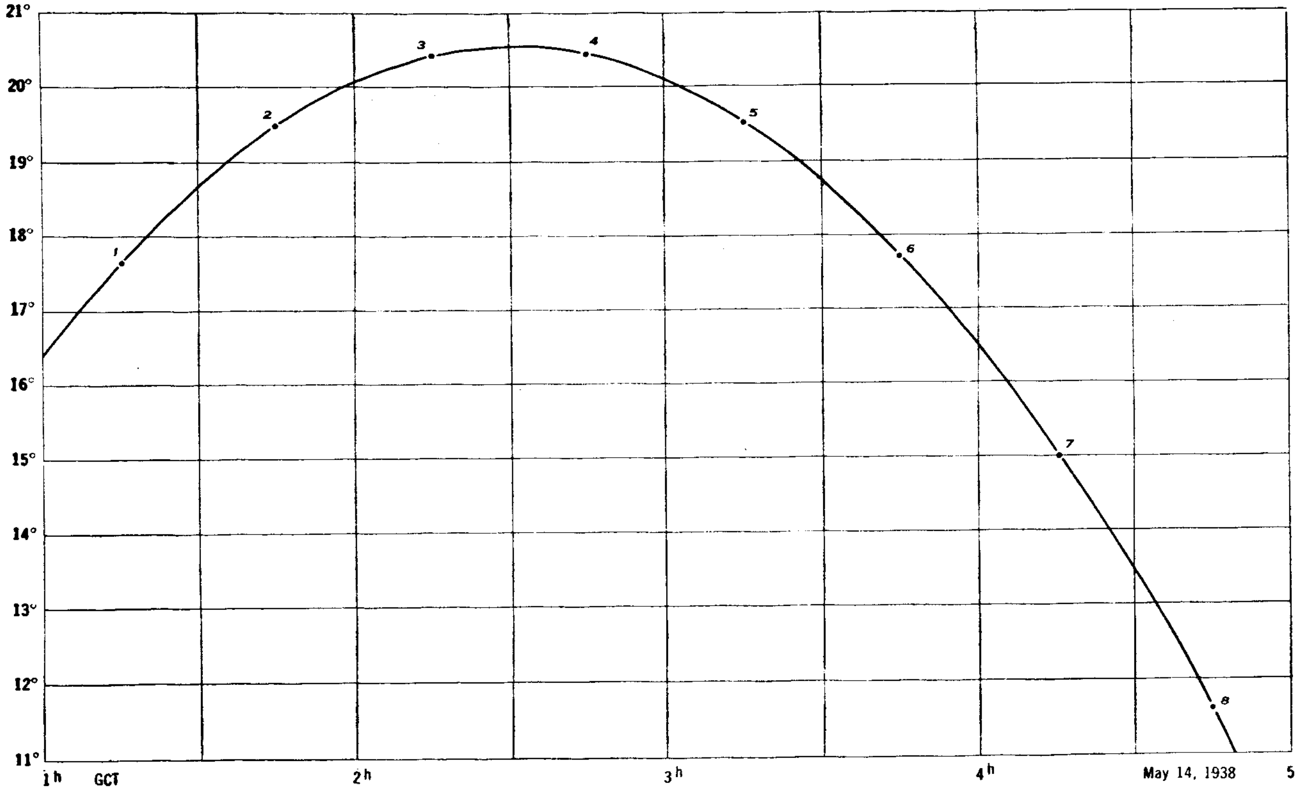


FIGURE 91.—Precomputed altitude curve for the moon.

index correction of $-3'$, the corrected sextant altitude is 18°56'. From the curve of figure 91 the altitude of the moon for 3^h30^m is read as 18°43'. Since the observed altitude is 13' greater, the position at the time of observation is 13' closer to the moon. At 3^h30^m the dead reckoning position of the plane is halfway between positions 5 and 6; the approximate azimuth of the moon is laid off through that point, as indicated by the light broken line, and the line of position *LP* is drawn, 13' toward the body from the dead-reckoning position.

A curve of altitudes can also be precomputed and plotted for some other celestial body, differing from the moon in azimuth by about 90° if possible. The intersection of a line of position from the moon with a line from this second body, obtained as described above,[1] fixes the position of the plane.

For other examples in celestial navigation, see pages 88 to 101.

Additional examples, involving time—speed—distance relations, and simpler methods of correcting for the effect of wind, are included in the Appendix which follows.

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[1] With due regard to the course and distance made good between observations.

APPENDIX

In the preceding examples all problems pertaining to wind effect have been solved graphically by means of a triangle of velocities. This principle is essential to a clear understanding of the factors involved; however, 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 simple 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 planes 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. The first of the graphs which follow, therefore, is for the conversion of percentage velocities into miles per hour and vice versa.

In all the graphs it is immaterial whether statute miles or nautical miles are used; the answers will be obtained from the graphs in the same terms with which they are entered.

CONVERSION OF PERCENTAGE VELOCITIES AND MILES-PER-HOUR VELOCITIES

[See fig. 92]

This graph is intended to facilitate the conversion from miles per hour to percentage velocities, as well as 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 95 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.).

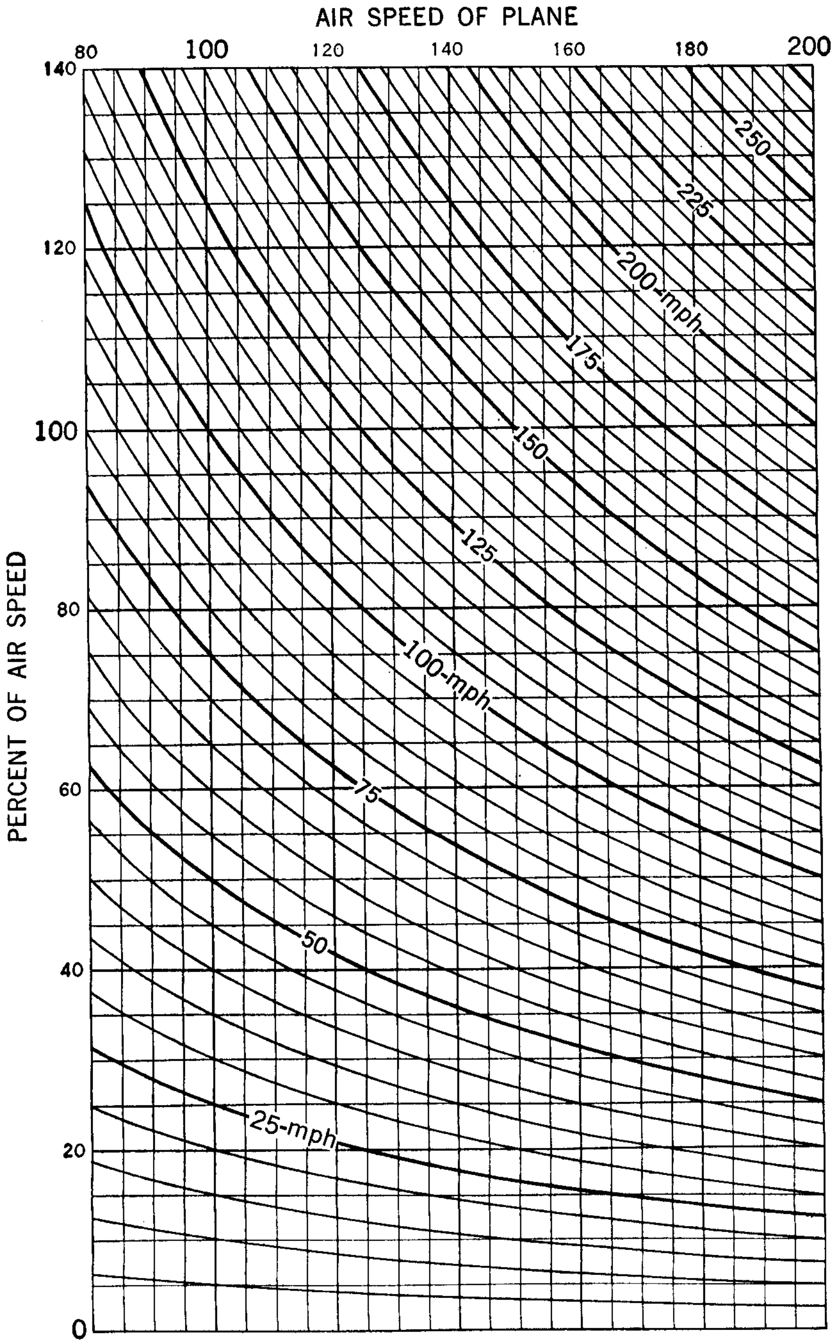

Figure 92.—Graph for converting miles-per-hour velocities and percentage velocities.

FINDING THE TRUE AIR SPEED

[See fig. 93]

For many problems of piloting and dead reckoning a knowledge of the true air speed is essential. The air speed 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 93.

In using the graph it is assumed that the air speed 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). The following example illustrates the use of the graph.

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 92, 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.

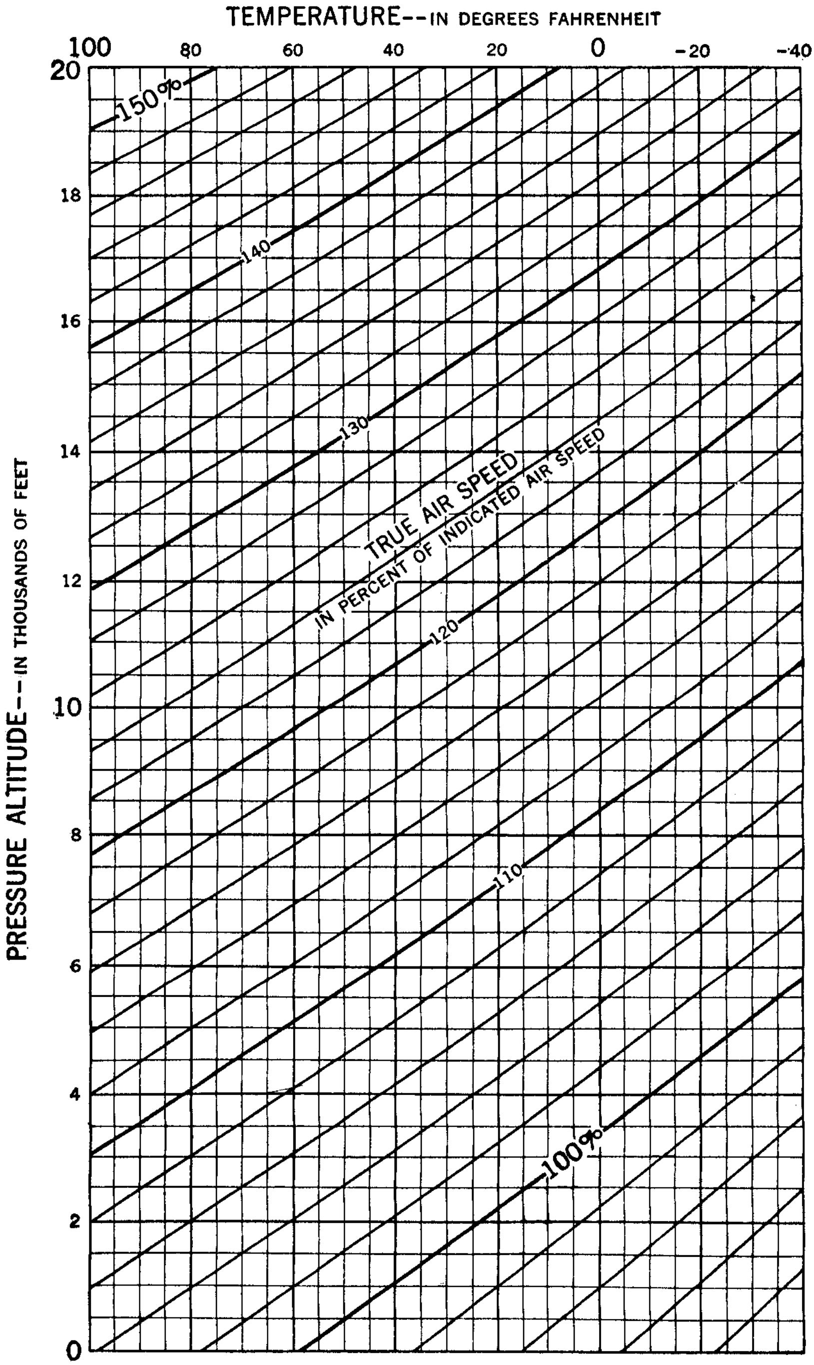

FIGURE 93.—Graph for finding the true air speed.

TIME—SPEED—DISTANCE PROBLEMS

[See fig. 94]

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.—A plane 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. See example 1, page 174.

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 become 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.

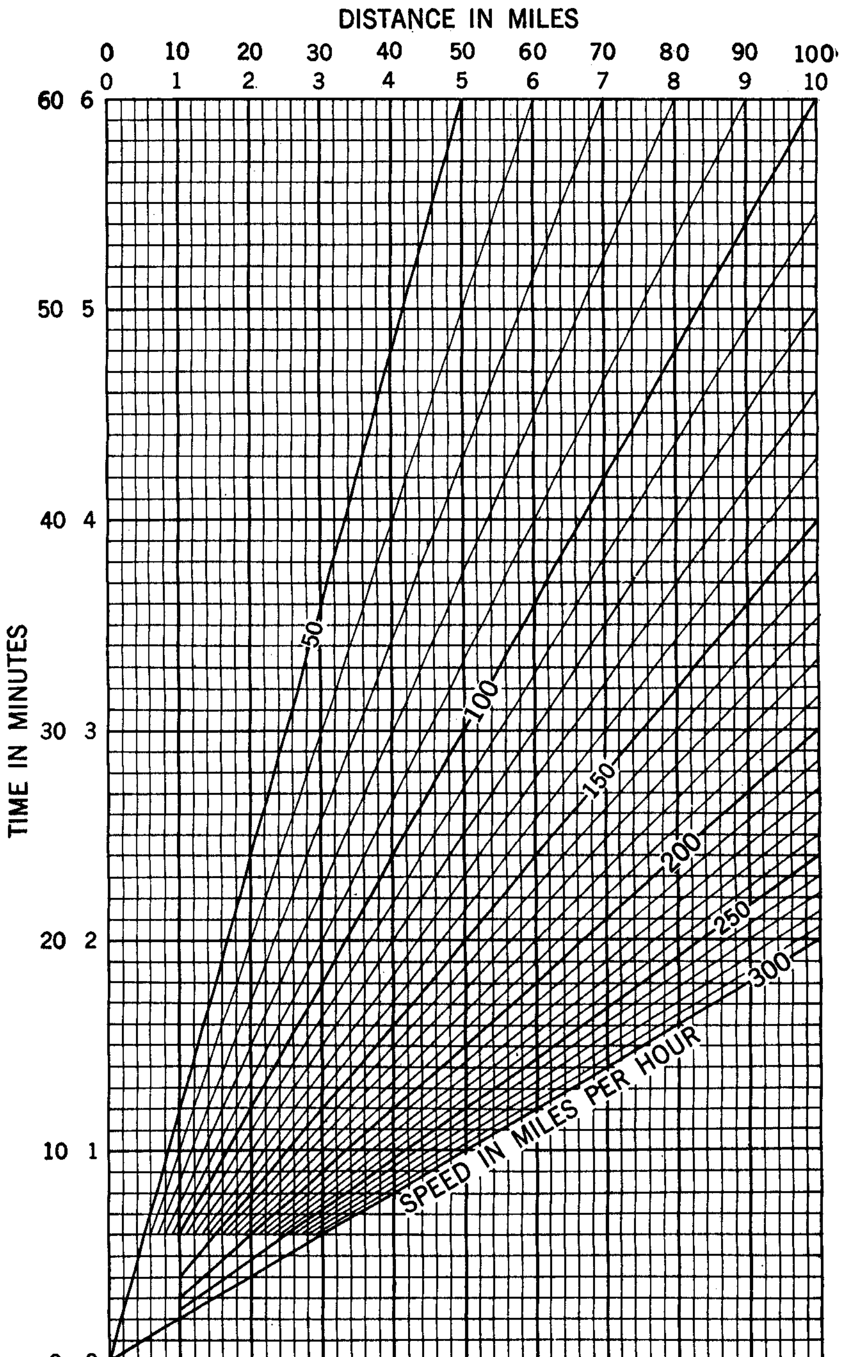

FIGURE 94.—Time—Speed—Distance graph.
For distance under 10 miles or time under 6 minutes use the inner scales.
For distances over 10 miles or time over 6 minutes use the outer scales.

CORRECTION TO COURSE FOR WIND AND DETERMINATION OF GROUND SPEED

[See fig. 95]

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.

As explained on page 41, 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 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 98 or figure 100.

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 92.

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 plane is 160 m p. h.; true course, 85°; wind, 25 m. p. h., from 45°. Find the correction to the course for wind, and the ground speed that will be made good along the intended track while flying the corrected course (compass heading).

The angle between the wind and the true course is 85° − 45°, or 40°. By reference to figure 92 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 95, 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 plane 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 96 will guard against errors.

From figure 92 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 95 fol-

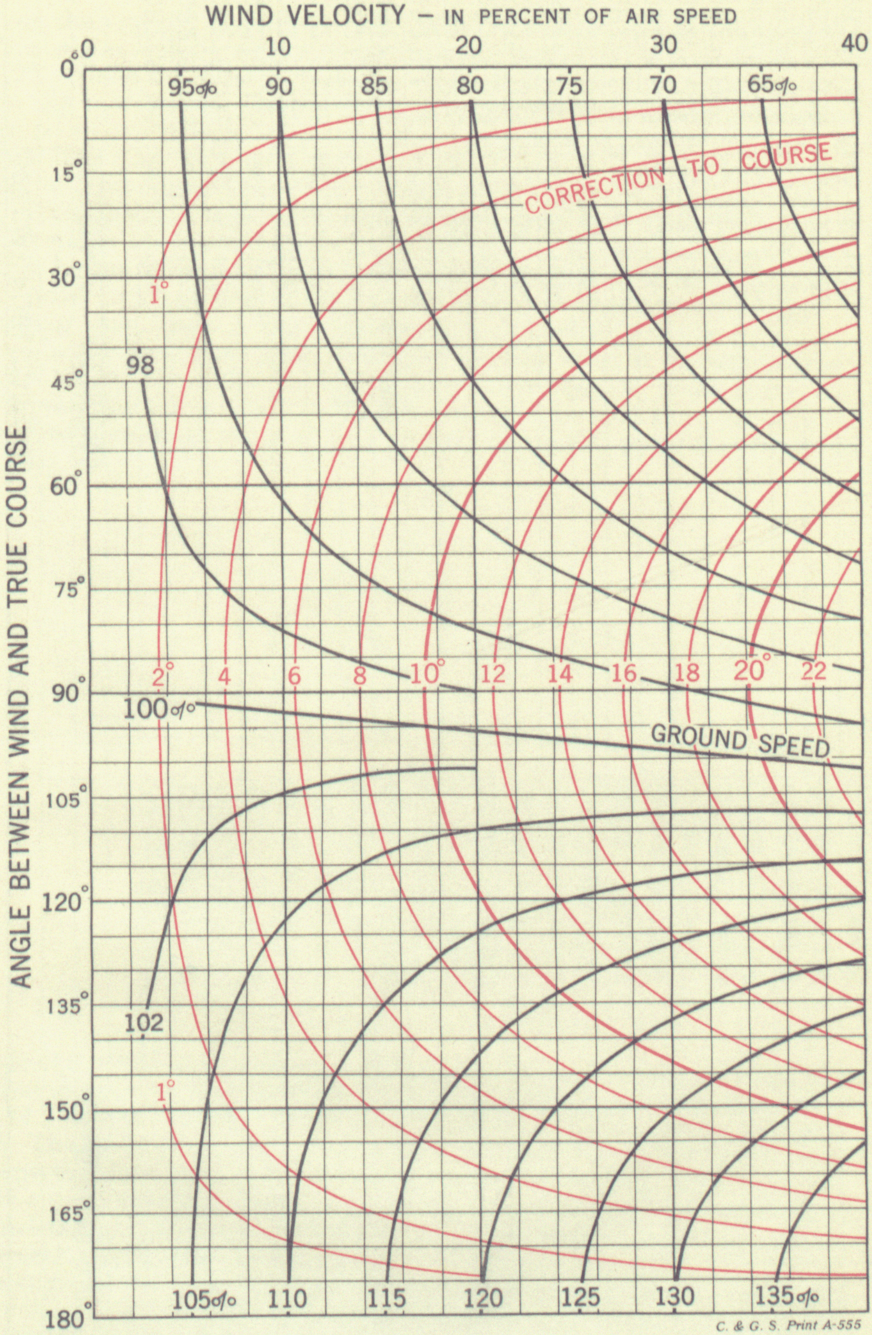

FIGURE 95.—Graph for finding the wind correction angle and ground speed when the wind direction and velocity are known.

low 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 92 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 strong cross winds. Find the direction and velocity of the wind.

The 10° which the pilot must head into the wind is the wind correction angle. In figure 95, 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

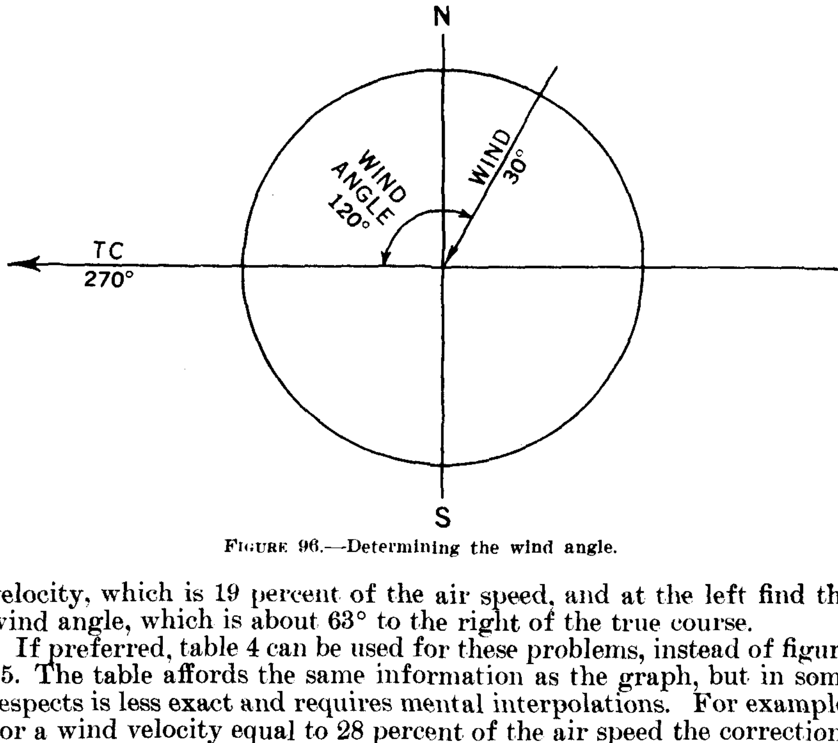

FIGURE 96.—Determining the wind angle.

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 4 can be used for these problems, instead of figure 95. 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 plane, 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.

Table 4.—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

CORRECTION TO COURSE AND DETERMINATION OF GROUND SPEED BY THE DOUBLEDRIFT METHOD

[See fig. 98]

Figure 95 and table 4 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 98, 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 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 (defined on pp. 40 and 41)—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.

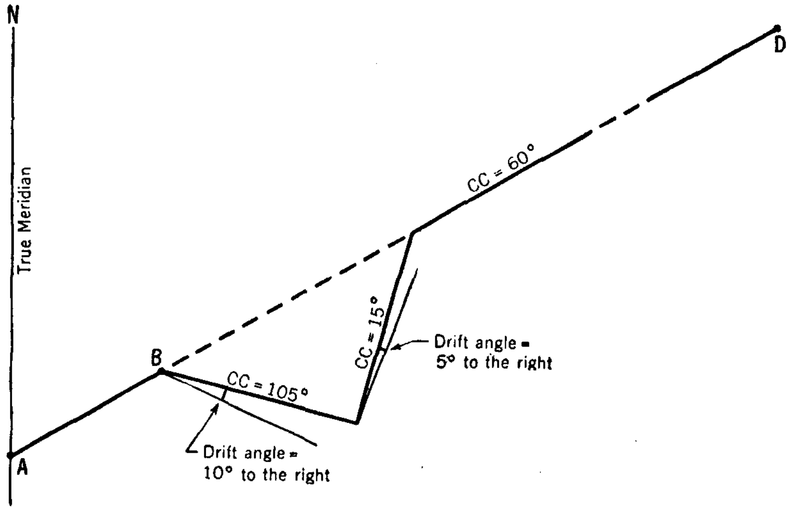

FIGURE 97.—Measuring the two drift angles.

Figure 97 further illustrates the procedure. The compass course from *A* 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 plane 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.

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 new corrections to course and ground speed 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 previously computed and incorporated in the graph, and the pilot reads from it only the corrections therefor. 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. 171.

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 123° (45° to the right), then on a course of 33° (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,

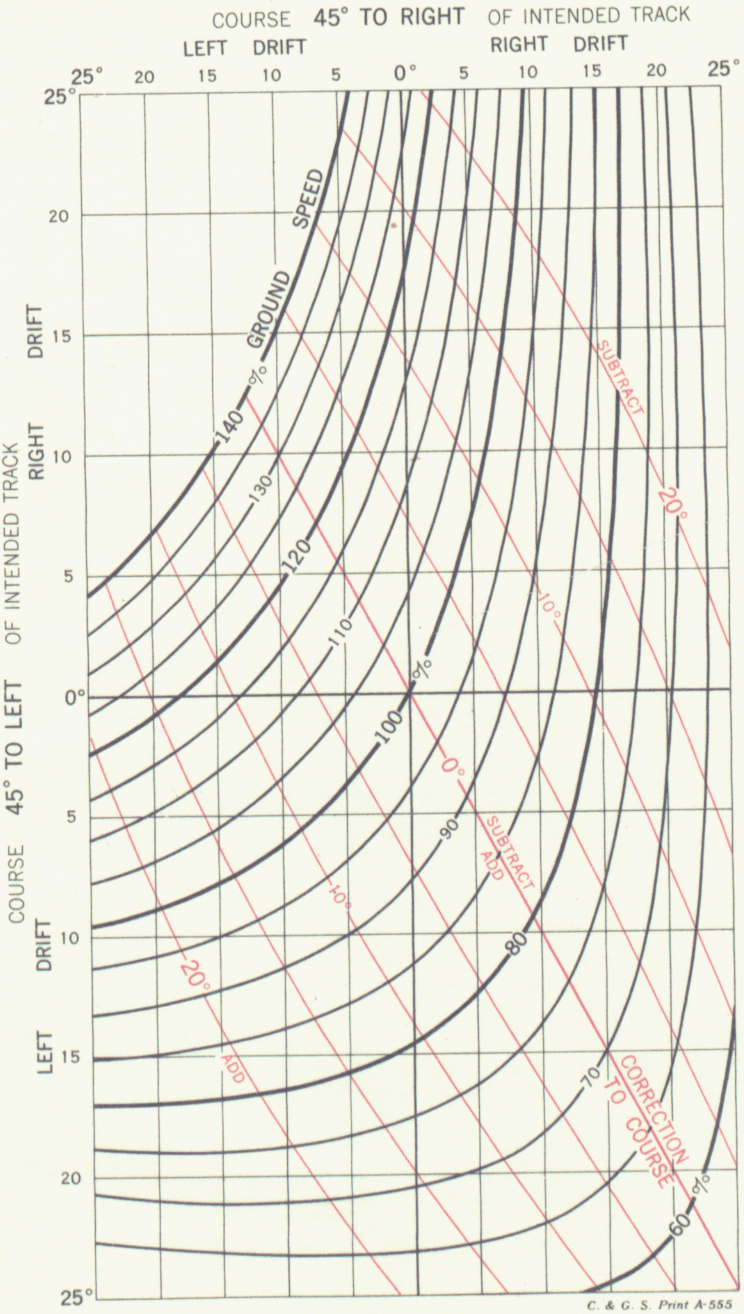

FIGURE 98.—Graph for finding the wind correction angle and ground speed by the double drift method.

and a ground speed of 136 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 corrections to course and ground speed should be redetermined.

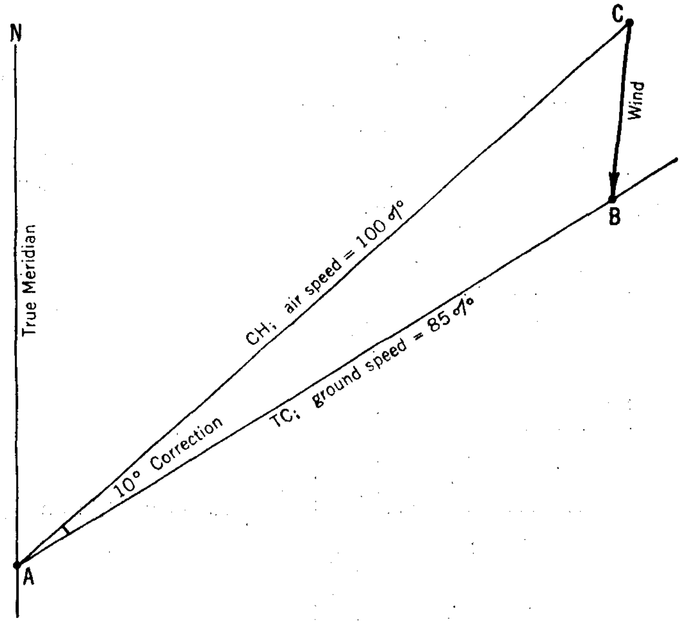

FIGURE 99.—Finding the wind direction and velocity from figure 98.

Example 3.—A pilot, having obtained from figure 98 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 *AN* (fig. 99) lay off the true course *AB* and plot the correction to the course. The air speed is in the direction of the compass heading *AC*, which is therefore plotted = 100 percent; the ground speed is in the direction of *AB*, which is plotted = 85 percent. *CB* 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 101; see example 3, page 173.

FINDING WIND CORRECTION AND GROUND SPEED IN FLIGHT FROM ONE OBSERVATION WITH A DRIFT INDICATOR

[See fig. 100]

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 plane 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.

As with the preceding graph, the correction to the course will be the drift angle that will be observed as long as the corrected compass heading is maintained and wind conditions do not change. If at any time during flight an appreciable difference is noted, it is only necessary to head the plane once more on the no-wind compass course, observe the new drift angle and ground speed, and read the desired corrections from the graph.

Example 1.—A plane 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 and a ground speed of 153 m. p. h. are observed with a drift indicator. Find the correction to the course and the ground speed that will be made good along the intended track.

By reference to figure 92 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 92, 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.

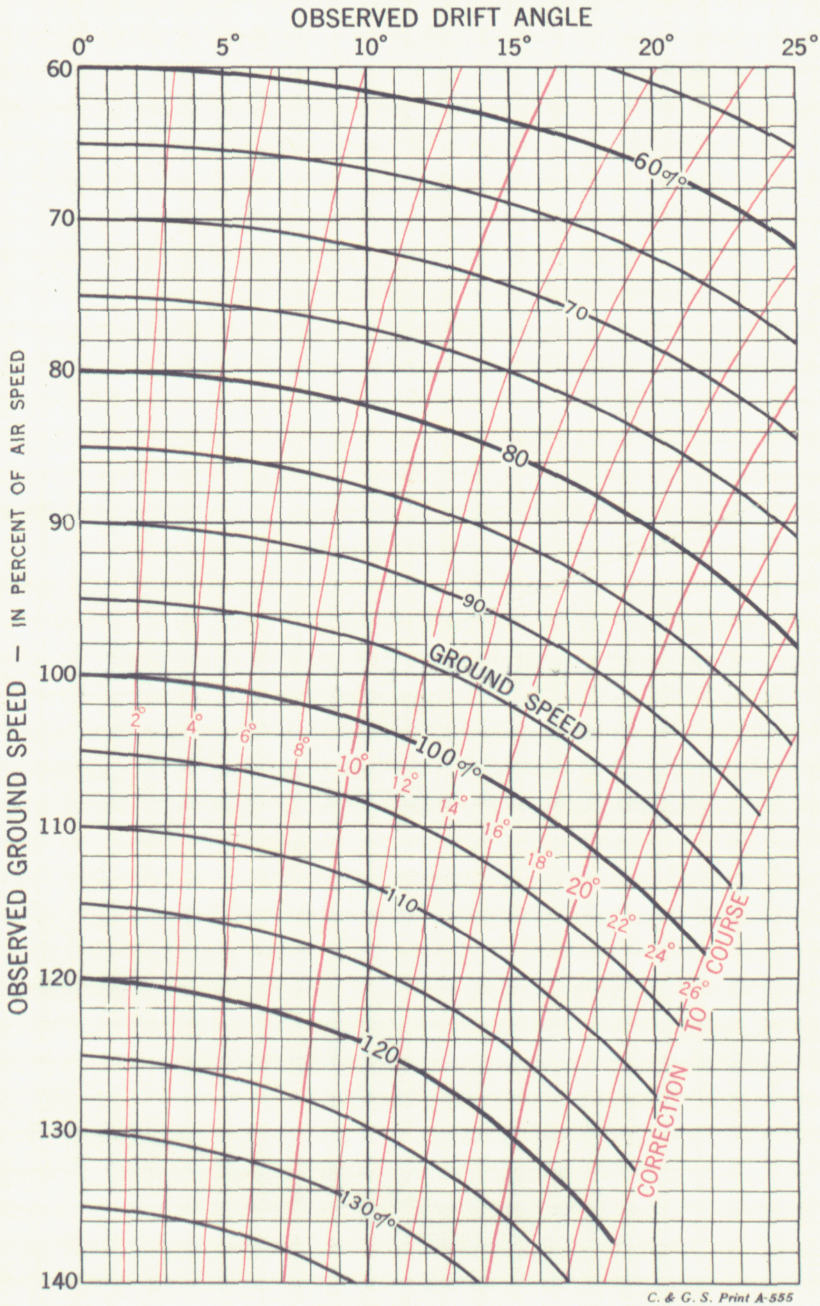

FIGURE 100.—Graph for finding the wind correction angle and ground speed from one observation with a drift indicator.

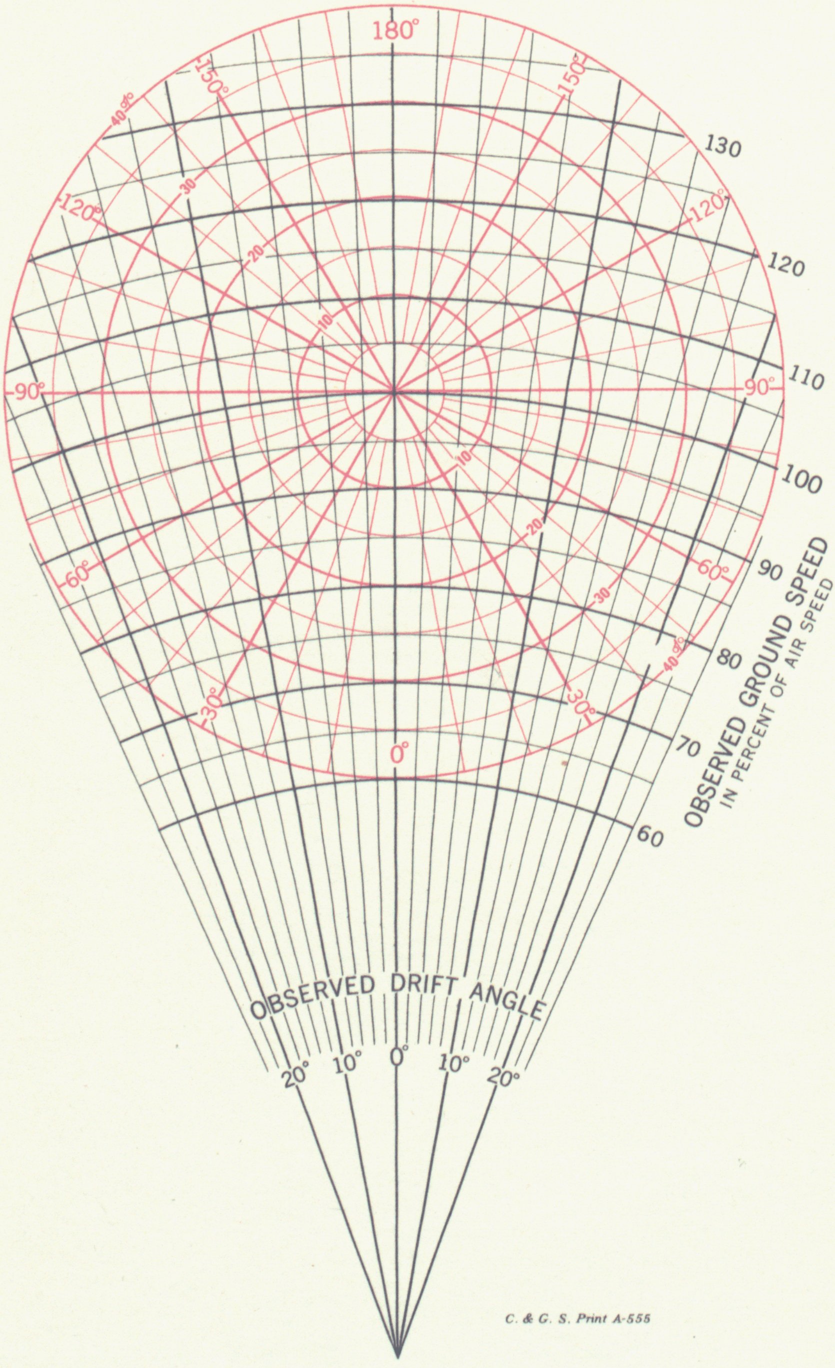

FIGURE 101.—Graph for rectifying heading and ground speed for wind.

RECTIFYING THE HEADING AND GROUND SPEED FOR THE EFFECT OF WIND

[See fig. 101]

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; p. 44). 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 101 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 speeds.

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 plane.

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 plane, according to the problem. The black arcs are spaced at intervals of 5 percent of the air speed, and provide a convenient scale for reading ground speeds.

Example 1.—A pilot flying in fog 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.

It is seen that the wind is from the right of the plane and 135° from the plane's head, and the wind velocity of 20 m. p. h. is 20 percent of the air speed of the plane. 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 plane'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 plane's air speed, or 121 m. p. h.

Example 3.—A plane 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 plane's air speed. 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 air speed, 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 plane's head. Since the heading of the plane 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. 102]

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 plane will then parallel the original intended track; or that if double the error is applied the plane 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 102 shows the course errors for any departure from the track and any distance flown. As already pointed out, this error applied to the compass heading will not give the correct heading to steer. 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 94 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 100. Or if wind direction and velocity are required, these may be obtained from figure 101 with the same data.

Example 1.—In flying from Cedar Lawn Airport, near Kenton, Ohio, to Springfield Airport (pl. I), on a true heading of 189° and at an air speed of 120 m. p. h., a pilot passes directly over the town of Rushsylvania 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 Rushsylvania is 10.5 miles from Cedar Lawn Airport and 2 miles west of the intended track. He notes, from figure 102, that this corresponds to a drift angle of 11°, and from figure 94 that the ground speed is 140 m. p. h., which is 117 percent of the plane's air speed. (See example 5, p. 164.) Referring to figure 100 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 steered.

If he should wish to know the direction and velocity of the wind, he may enter figure 101 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 plane, or 189° − 125° = 64° true.

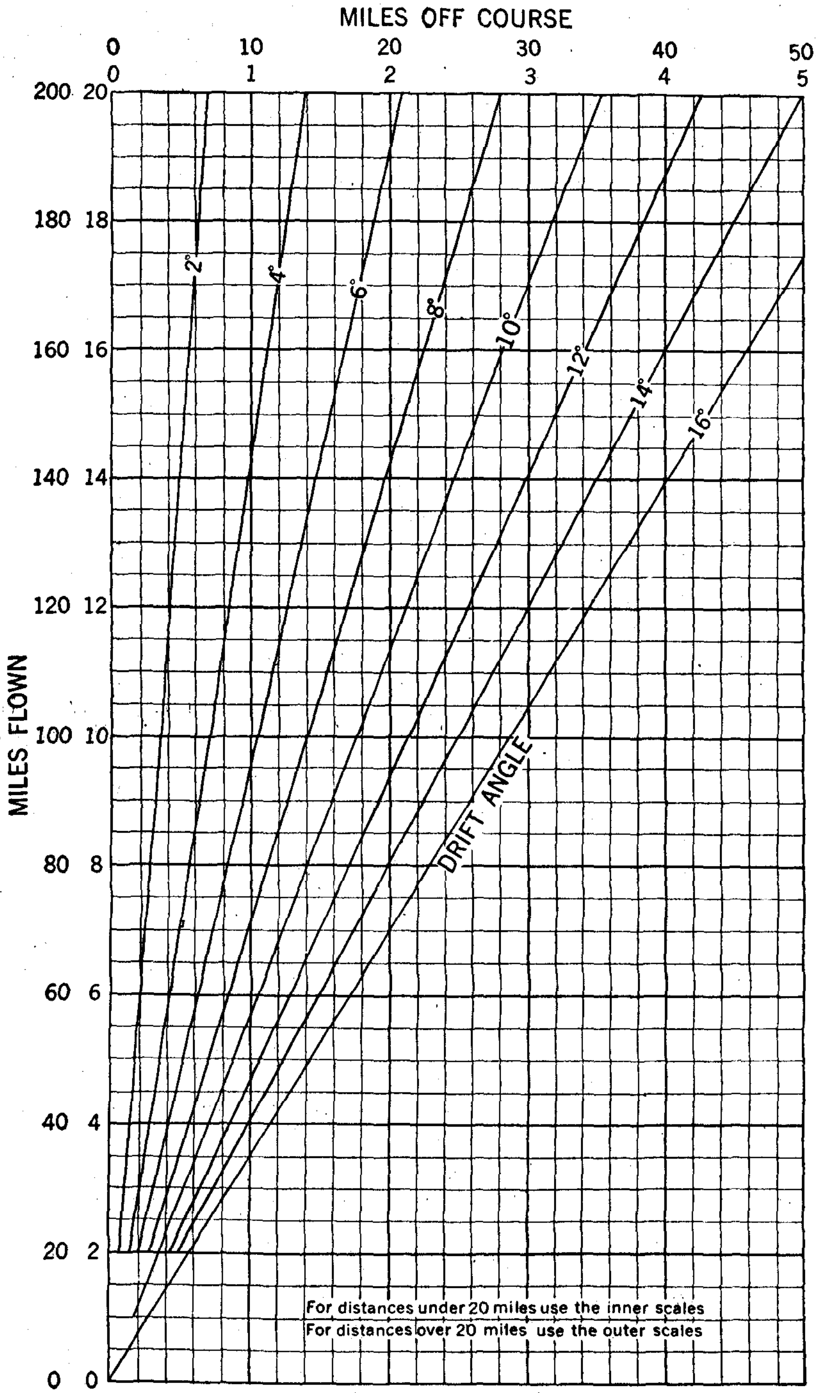

FIGURE 102.—Graph for finding the drift angle.

RADIUS OF ACTION

Radius of action problems are treated on pages 47 to 51. 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 a plane may fly under given wind conditions and still return to the point of departure.

Table 5.—Approximate radius of action for each hour of flying time available

Air speed 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

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 thereto. The difference between maximum and minimum is surprisingly small, amounting to only:

10% for a 40% wind (wind 40% of plane's air speed)
5% for a 30% wind
3% for a 25% wind, and
2% for a 20% wind.

The values given in table 5 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. Thus, for a plane 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 from 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.

THE BEAUFORT SCALE

In the preceding pages various methods have been given for correcting the course of a plane 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 6.—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	
2	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4–7	
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	
8	Breaks twigs off trees; generally impedes progress.	39–46	Gale.
9	Slight structural damage occurs (chimney pots and slate removed).	47–54	
10	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	55–63	Whole gale.
11	Very rarely experienced; accompanied by widespread damage.	64–75	
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 (see p. 128), 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.

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 JUNE 30, 1939

WITHOUT TIME LIMIT

Location	Name	Location	Name
Akron, Ohio	Municipal Airport.	Nogales, Ariz	Nogales International Airport.
Ajo, Ariz	Do.		
Albany, N. Y	Albany Airport.	Ogdensburg, N. Y	Ogdensburg Harbor.
Brownsville, Tex	Brownsville-Pan American Airport.	Pembina, N. Dak	Fort Pembina Airport.
		Portal, N. Dak	Portal Airport.
Buffalo, N. Y	Buffalo Airport.	Port Angeles, Wash	Port Angeles Airport.
Caribou, Maine	Municipal Airport.	Port Townsend, Wash	Port Townsend Airport.
Cleveland, Ohio	Do.	Put-in-Bay, Ohio	Erie Isle Airways Airport.
Detroit, Mich	Do.	Rouses Point, N. Y	Rouses Point Seaplane Base.
Do	Ford Airport.		
Do	Wayne County Airport.	San Diego, Calif	Lindbergh Field.
Douglas, Ariz	Douglas International Airport.	San Juan, P. R	Isla Grande Airport.
		Seattle, Wash	Boeing Field.
Duluth, Minn	Williamson-Johnson Airport.	Do	Lake Union Seaplane Base.
Do	Duluth Boat Club Seaplane Base.	Skagway, Alaska	Skagway Municipal Airport.
Eagle Pass, Tex	Eagle Pass Airport.	Swanton, Vt	Missisquoi Airport.
El Paso, Tex	El Paso Airport.	West Palm Beach, Fla	Roosevelt Flying Service Base (Currie Common Park).
Fairbanks, Alaska	Weeks Municipal Airport.		
Juneau, Alaska	Juneau Airport.		
Ketchikan, Alaska	Ketchikan Airport.	Wrangell, Alaska	Wrangell Seaplane Base.
Key West, Fla	Meacham Airport.		
Laredo, Tex	Laredo Airdrome.		
Miami, Fla	Dinner Key Seaplane Base.		
Do	Pan American Airport (or 36th St. Airport).		

TEMPORARY (1 YEAR)

Location	Name	Date designated
Bangor, Maine	Bangor Airport	June 26, 1939
Bellingham, Wash	Graham Airport	Apr. 18, 1939
Buffalo, N. Y	Buffalo Marine Airport	July 29, 1938
Burlington, Vt	Burlington Airport	June 29, 1939
Calexico, Calif	Calexico Airport	Jan. 10, 1939
Cape Vincent, N. Y	Cape Vincent Harbor	Apr. 25, 1939
Crosby, N. Dak	Crosby Airport	June 28, 1939
Fort Yukon, Alaska	Fort Yukon Airfield	July 6, 1939
Great Falls, Mont	Great Falls Airport	June 2, 1939
Havre, Mont	Havre Airport	Do.
Malone, N. Y	Malone Airport	Apr. 18, 1939
Miami, Fla	Chalks Flying Service Airport	Sept. 17, 1938
Niagara Falls, N. Y	Niagara Falls Airport	July 2, 1939
Plattsburg, N. Y	Plattsburg Airport	June 2, 1939
Rochester, N. Y	Rochester Airport	Nov. 7, 1938
Sandusky, Ohio	John G. Hinde Airport	June 1, 1939
Sault Ste. Marie, Mich	Sault Ste. Marie Airport	Aug. 4, 1938
Spokane, Wash	Spokane Airport (Felts Field)	June 2, 1939
Warroad, Minn	Warroad Seaplane Base	Sept. 2, 1938
Watertown, N. Y	Walling Airport	June 2, 1939
Wellesley I., N. Y	Wellesley Farms Airport Wellesley I. Seaplane Base	May 1, 1939

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 Recognized Dealers at the principal airports of the United States. A list of Recognized Dealers and their places of business 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), 40 cents.
Regional aeronautical charts (1:1,000,000), 75 cents.
Aeronautical radio direction-finding charts (1:2,000,000), 75 cents.
3060a. Aeronautical planning chart, United States, Lambert projection (1:5,000,000); shows principal airports and broadcasting stations, index to sectional 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 issued 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.

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.

A discount of 25 percent is allowed on orders for 100 or more copies of Special Publication No. 197 (Practical Air Navigation and the Use of the Aeronautical Charts of the U. S. Coast and Geodetic Survey), in one shipment to one address.

PUBLICATIONS OF THE CIVIL AERONAUTICS AUTHORITY

The Civil Aeronautics Authority, under its obligations to promote and regulate air commerce, publishes pamphlets and bulletins of general and specific interest to the aircraft industry, airmen, and the public. Some of these are on special phases of aeronautics, both technical and nontechnical in character, and are known as Aeronautics Bulletins. In addition to these publications, airway bulletins and reports of committees and conferences are published. Requests for publications should be addressed to the Civil Aeronautics Authority, Washington, D. C., except in the case of the Air Commerce Bulletin, which has been placed on a sales basis, and may be ordered from the Superintendent of Documents, United States Government Printing Office, Washington, D. C., at 50 cents a year, or 5 cents a single copy; and in the case of the Flight Instructors Manual, which may be ordered from the Superintendent of Documents at 25 cents a copy.

A description of the printed publications follows:

Air Commerce Bulletin.

The Air Commerce Bulletin, published on the 15th of each month, carries articles, news items, and statistics dealing with civil aeronautics; information as to certificates and approvals issued by the Civil Aeronautics Authority; and notice of issuance of any new or revised regulations and publications issued by the Civil Aeronautics Authority. News of Civil Aeronautics Authority projects is emphasized, but other information also is carried, particularly with reference to scheduled and miscellaneous aircraft operations, accidents, and aircraft production.

Civil Aeronautics bulletins:

No. 3. Aircraft Accidents and Casualties, September 1, 1938.
No. 5. Flight Instructor's Manual (25 cents, from Superintendent of Documents).
No. 10. Airport Lighting, September 1, 1938.
No. 11. Airport Directory, July 1, 1939.
No. 12. Air Marking, October 1, 1938.

Development reports:

No. 1. The Radiotelemeter and Its Importance to Aviation, September 1938.
No. 2. An Ultra-High Frequency Aircraft Receiver, September 1938.
No. 3. Aeronautical Light Nomenclature, October 1938.
No. 4. The Alfaro Engine, January 1939.
No. 5. Development and Use of the Airport Orientator, December 1938.

Civil Air Regulations, 334 pp.

Digest of Regulations . . . for solo and private pilots certificates, 55 pp.

Publications of the former Bureau of Air Commerce.

In addition to the above, the Authority has available for distribution a limited number of publications issued by the former Bureau of Air Commerce of the Department of Commerce. This Bureau went out of existence in August 1938 when its personnel and property were transferred to the Civil Aeronautics Authority in accordance with the Civil Aeronautics Act of 1938.

Some of these publications are now being revised; or are scheduled for revision in the near future. These publications are as follows:

Aeronautics bulletins:

No. 1. Civil Aeronautics in the United States, August 1, 1937.
No. 18. State Aeronautical Legislation Digest and Uniform State Laws.
No. 27. Aeronautic Radio.

Airport Bulletin:

No. 1. Airport Grading and Drainage, June 1, 1935.

Map:

Airway Map of the United States, November 1, 1938.

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.
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CONVENIENT ABBREVIATIONS

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).
- AP = Airport.
- AS = Air speed.
- Bn = Beacon.
- 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).
- HD = Hourly difference.
- HE = Height of eye.
- H_o = Observed altitude (sextant altitude corrected for refraction, etc.).
- HP = Horizontal parallax.
- H_s = Sextant altitude (uncorrected).
- IC = Index correction.
- Lat = Latitude.
- LHA = Local hour angle.
- Long = Longitude.
- LP = Line of position.
- M = Meridian of observer.
- MC = Magnetic course.
- MH = Magnetic heading.
- mph = Miles per hour.
- NA = Nautical Almanac.
- 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.
- 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).

THE LINE OF POSITION TABLE

The Line of Position Table is an abridged form of the Dead Reckoning Altitude and Azimuth Table, prepared by Lt. 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.

Table 9.—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 9.—Line of position table—Continued

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′		7°00′		8°00′		9°00′		10°00′		11°00′		′
	A	B	A	B	A	B	A	B	A	B	A	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 9.—Line of position table—Continued

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

	12°00′		13°00′		14°00′		15°00′		16°00′		17°00′		
	A	B	A	B	A	B	A	B	A	B	A	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	60979	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 9.—Line of position table—Continued

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	3763	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 9.—Line of position table—Continued

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

′	24°00′ A	24°00′ B	25°00′ A	25°00′ B	26°00′ A	26°00′ B	27°00′ A	27°00′ B	28°00′ A	28°00′ B	29°00′ A	29°00′ 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 9.—Line of position table—Continued

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	8631	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	7584	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 9.—Line of position table—Continued

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM OF TABLE

	36°00′		37°00′		38°00′		39°00′		40°00′		41°00′		
	A	B	A	B	A	B	A	B	A	B	A	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	10970	19163	11596	18277	12244	58
3	23026	9232	22003	9794	21017	10376	20066	10980	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 9.—Line of position table—Continued

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	13076	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 9.—Line of position table—Continued

WHEN LHA (E OR W) IS GREATER THAN 90°, TAKE "K" FROM BOTTOM 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 9.—Line of position table—Continued

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	28837	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	7666	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 9.—Line of position table—Continued

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 9.—Line of position table—Continued

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	41564	3157	43432	2865	45399	2588	47472	2325	49664	35
26	3782	39814	3459	41594	3152	43464	2860	45433	2583	47508	2321	49702	34
27	3777	39843	3454	41625	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	3335	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 9.—Line of position table—Continued

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	60538	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′		

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*For sale by the Superintendent of Documents, Washington, D. C.
†For sale by the Hydrographic Office, Washington, D. C.

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[1] Now known as Aeronautics Bulletin No. 11.

CUT ON THIS LINE

PUBLICATION NOTICES

To make immediately available the results of its various activities to those interested, the Coast and Geodetic Survey maintains mailing lists of persons and firms desiring to receive notice of the issuance of charts, Coast Pilots, maps, and other publications.

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O

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU

CLOUD FORMS

This chart has been prepared with a view of aiding observers in the identification of the several cloud forms according to the INTERNATIONAL SYSTEM OF CLASSIFICATION of 1932

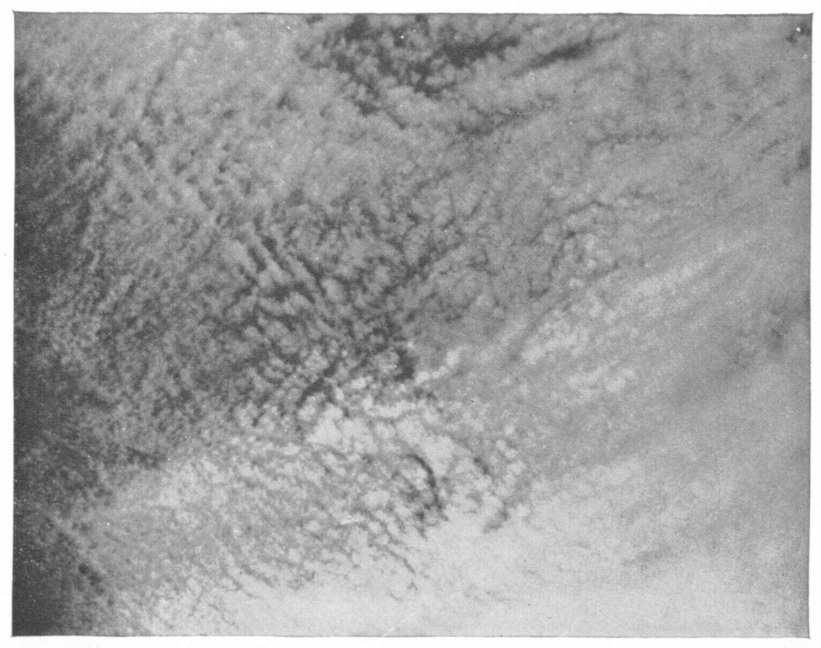
An edition containing a larger number of photographs and more detailed descriptions may be obtained from the Superintendent of Documents, Washington, D. C.

F. Ellerman.

1. Cirrus in parallel trails and small patches.

H. T. Floreen.

2. Cirrus with an irregular arrangement of filaments.



H. T. Floreen.

3. Cirrocumulus. There is some cirrus in lower right portion of picture.

A. J. Weed.

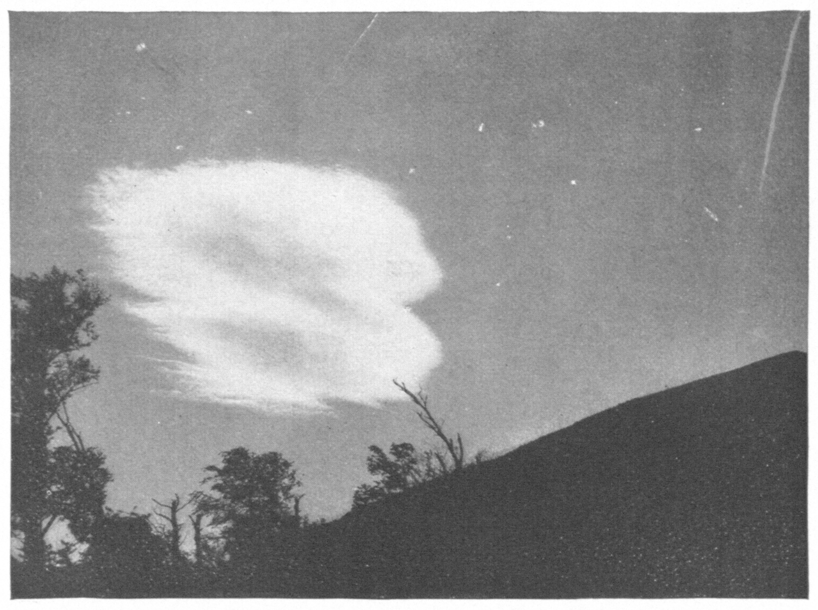
4. Cirrus, in upper part of picture, merging into cirrostratus at bottom of picture. Some of the filaments of cirrus have small tufts or upturned ends.

G. A. Clarke.

5. Cirrostratus in a thin fibrous sheet, with halo.

F. Ellerman.

6. Turreted altocumulus (*castellatus*) above and tall cumulus (*castellatus*) below (at left).



C. F. Brooks.

7. Lenticular altocumulus.

C. F. Brooks.

8. Altocumulus, active form.

A. C. Lapsley.

9. Altocumulus, laminated form resulting from degeneration of cloud sheet.

G. A. Clarke.

10. Thin altostratus with fractostratus (or fractocumulus) below.

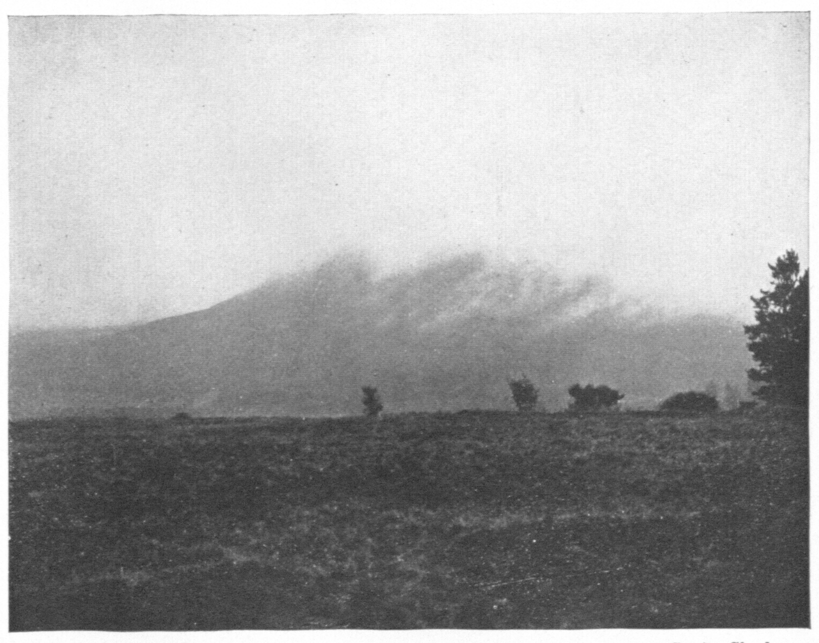
11. Altostratus, with thin altocumulus at a lower level.

F. Ellerman.

12. Stratocumulus, photographed from an altitude of 1,750 meters. To an observer at sea level they would be higher and appear smaller and perhaps be called altocumulus.

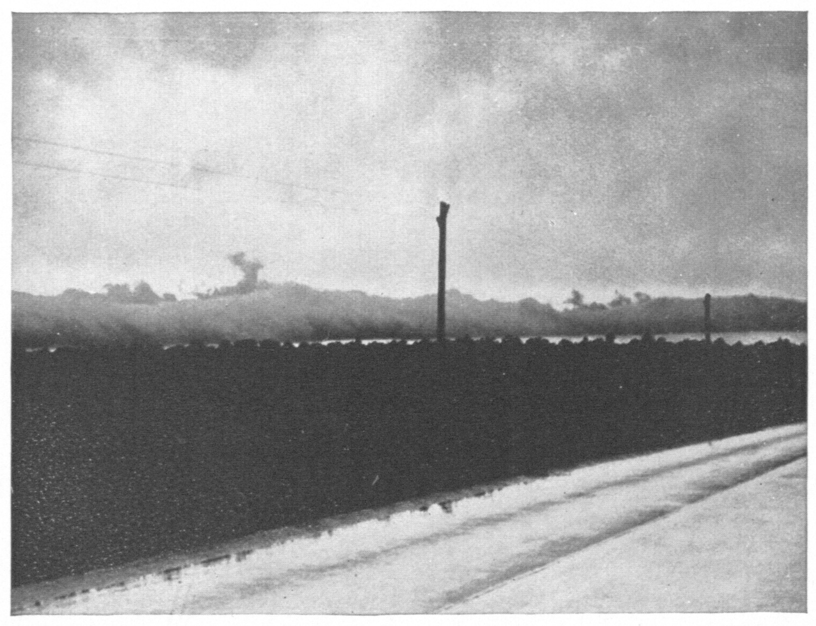
W. J. Humphreys.

13. Stratocumulus, irregular rolls.



G. A. Clarke.

14. Stratus, in a uniform sheet below the level of the hilltop, with shreds of fractostratus along the hillside.

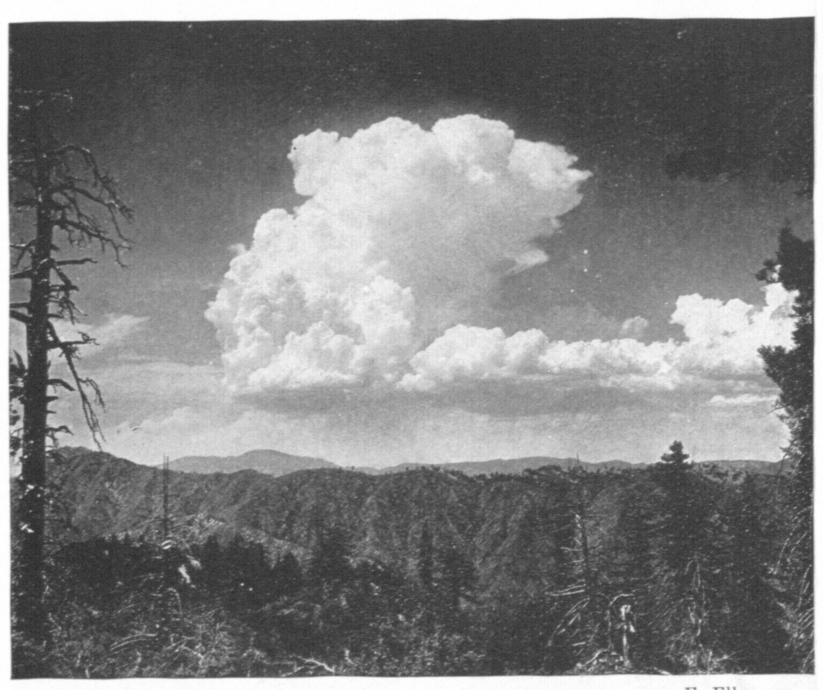


J. C. Hagan.

15. Nimbostratus, with fractocumulus roll near horizon.

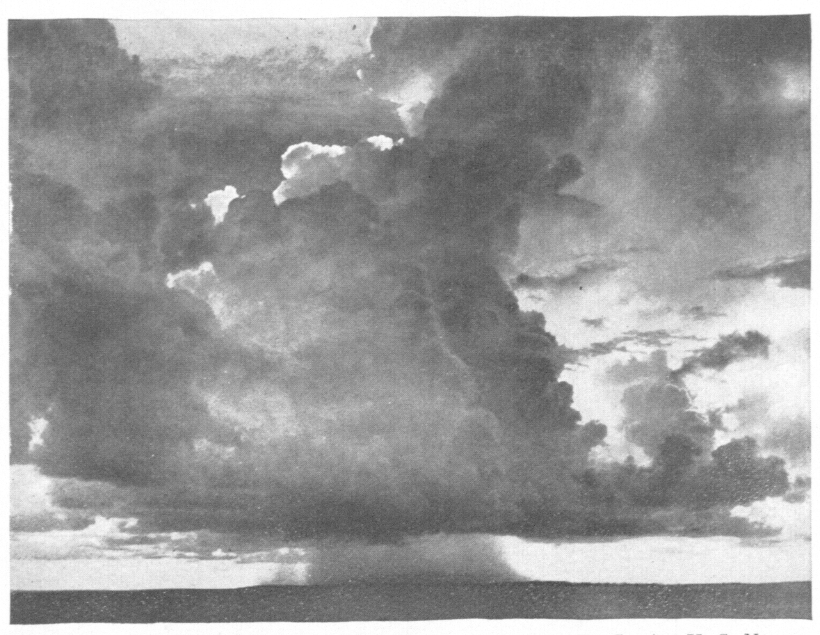
H. T. Floreen.

16. Cumulus of fair weather.



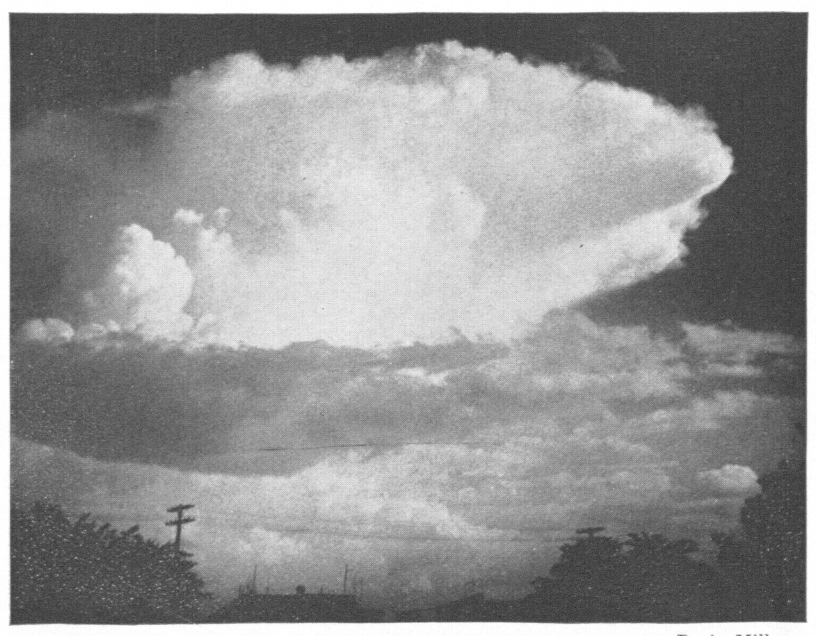
F. Ellerman.

17. Cumulus and cumulonimbus. The large cloud has just grown into cumulonimbus.



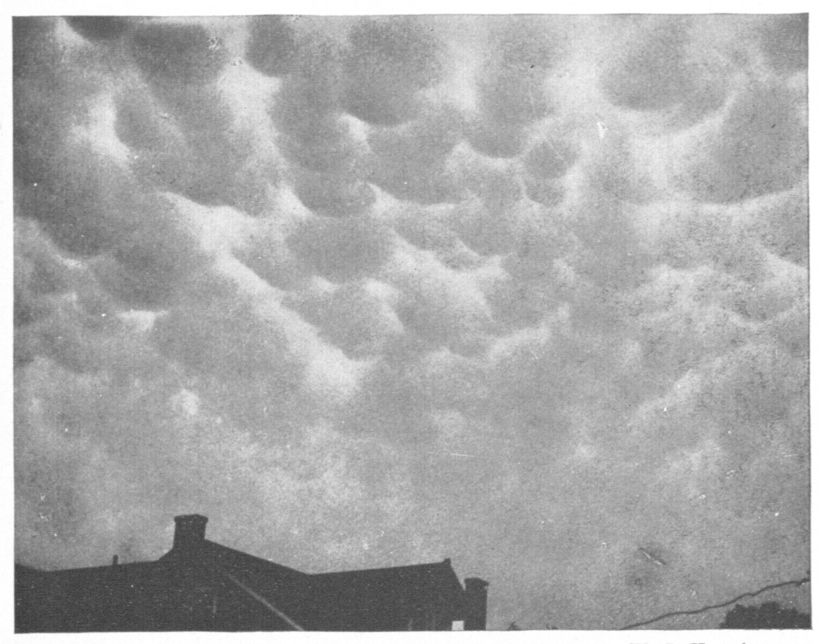
Air Service U. S. Navy.

18. Cumulonimbus.



P. A. Miller.

19. Cumulonimbus.



W. J. Humphreys.

20. Cumulonimbus mammatus.

The following definitions are derived from the "International Atlas of Clouds and of States of the Sky, 1932." The international abbreviations are given in parentheses after the cloud names, followed by numbers which refer to the illustrations:

Cirrus (Ci) 1, 2, 4.—*Detached clouds of delicate and fibrous appearance, usually without shading, generally white in color, and often of a silky appearance.* Cirrus appears in the most varied forms, such as isolated tufts, lines drawn across a blue sky, branching featherlike plumes, curved lines ending in tufts, etc. Cirrus is often arranged in bands which cross the sky and, owing to perspective, converge toward opposite points on horizon. Cirrus clouds are composed of ice crystals. Except when unusually dense, they are transparent and, as a rule, when they cross the sun's disc they hardly diminish its brightness.

Cirrocumulus (Cc) 3.—*A cirriform layer or patch of white flakes, or of globular masses, usually very small and without shadows.* The cloudlets are arranged in groups or lines, or more often in ripples resembling those of the sand on the seashore. Cirrocumulus can usually be differentiated from small altocumulus by the association of fine altocumulus with larger cloudlets elsewhere in the same layer, by the slightly more grayish appearance of altocumulus, and by the connection of cirrocumulus with cirrus or cirrostratus.

Cirrostratus (Cs) 4, 5.—*A thin, whitish veil which does not blur the outlines of the sun or moon but usually gives rise to halos.* Sometimes it is quite diffuse and merely gives the sky a milky aspect; sometimes it more or less distinctly shows a fibrous structure with disordered filaments. During the day, when the sun is sufficiently high above the horizon, the sheet is never thick enough to prevent shadows of objects on the ground.

Altocumulus (Ac) 6, 7, 8, 9.—*A layer (or patches) composed of laminae or nearly globular masses.* The smallest elements of the regularly arranged units may be fairly small and thin, with or without shading. These elements are arranged in groups, lines or waves, following one or two directions, and are sometimes so close together that their edges join. The thin and translucent edges often show irisations, which are rather characteristic of altocumulus. A cloud sheet which is continuous, at least over the greater part of the layer, and consists of dark and more or less irregular elements, with sharp relief on the under surface of the sheet, is classed as altocumulus rather than altostratus.

Small cumuliform clouds with vertical development, arranged in a line and resting on a common horizontal base, which gives them a crenellated appearance, are called *castellatus* (pl. 6). Clouds of an ovoid shape, produced by the arching upward of a humid layer, usually caused by a mountain or by obstructing air (as in a convectional column), are named *lenticularis* (pl. 7).

Altostratus (As) 10, 11.—*A striated, fibrous, or smooth veil, more or less gray or bluish in color like thick cirrostratus but without halo phenomena; the sun or moon usually shows vaguely with a faint gleam as through ground glass.* Sometimes, however, it is very thick and dark, even completely hiding the sun or moon. The differences of thickness may cause relatively light patches between very dark parts, but the under surface never shows sharp relief, although there is usually a striated or fibrous structure in places and occasionally a mammillated appearance.

Stratocumulus (Sc) 12, 13.—*A layer (or patches) composed of laminae, globular masses or rolls; the smallest of the regularly arranged elements are fairly large; they are soft and gray with darker parts; also, a low, continuous sheet, thick or thin, with distinct irregularities of large size.* The elements are arranged in groups, lines or waves, aligned in one or two directions. Very often the rolls are so close that their edges join; when they cover the whole sky, they may have a wavy appearance. Stratocumulus is distinguished from altocumulus by the criterion that the cloud is altocumulus if the smallest, well defined and regularly arranged elements (leaving out the detached elements, which are generally seen on the edges) are not greater than 10 solar diameters in their smallest diameters, i. e., approximately the width of three fingers when the arm is held extended.

Stratus (St) 14.—*A low, uniform layer of cloud, resembling fog, but not resting on the ground.* When this very low layer is broken up into irregular shreds it is designated fractostratus (Fs). Stratus is often a local cloud, and when it breaks up the blue sky is seen. A veil of true stratus generally gives the sky a hazy appearance, which is very characteristic. Rain from stratus clouds is in the form of a drizzle, that is, small drops very close together. When there is no precipitation, stratus shows some contrasts and some lighter transparent parts.

Nimbostratus (Ns) 15.—*A low, amorphous, usually nearly uniform, rainy layer of a dark-gray color, feebly illuminated, seemingly from the inside.* When it gives precipitation it is usually in the form of continuous rain or snow. Precipitation alone is not a sufficient criterion to distinguish the cloud, which should be called nimbostratus, even when no rain or snow falls from it. The usual evolution is as follows: A layer of altostratus grows thicker and lower (sometimes assuming a hazy, ragged aspect) until it becomes a layer of nimbostratus. Beneath the layer there is generally a progressive development of very low, ragged clouds, isolated at first, then fusing together into an almost continuous layer. These low clouds are called fractostratus or fractocumulus.

Cumulus (Cu) 6, 16, 17.—*Thick clouds with vertical development; the upper surface is dome-shaped and exhibits rounded protuberances, while the base is nearly horizontal.* When the cloud is opposite the sun the surfaces normal to the observer are brighter than the edges of the protuberances. When the light comes from the side, the cloud exhibits strong contrasts of light and shade; against the sun, on the other hand, they look dark with a bright edge. True cumulus is definitely limited above and below; its surface often appears hard and clear-cut. But one may also observe ragged cumulus in which the different parts show constant change. This cloud is designated fractocumulus (Fc). Cumulus, whose base is generally of a gray color, has a uniform structure, that is, composed of rounded parts right up to its summit with no fibrous structure. Even when large, cumulus usually produces only light precipitation.

Cumulonimbus (Cb) 17, 18, 19, 20.—*Heavy masses of clouds, with great vertical development, whose cumuliform summits rise in the form of mountains or towers, the upper part having a fibrous texture and often spreading out in the shape of an anvil.* Cumulonimbus clouds generally produce showers of rain or snow and sometimes of hail, and often thunderstorms as well. Masses of cumulus, however heavy they may be and however great their vertical development, should not be classed as cumulonimbus unless the whole, or a part of their tops, is transformed or is in the process of transformation into a cirrus mass. When a quick, heavy shower occurs it may be assumed that the cloud is cumulonimbus, even though low clouds may hide the fibrous summit.

A mammillated structure often appears in cumulonimbus, either quiescent on the lower surface of the lateral parts of the anvil (pl. 20), or boiling under the low storm collar just after the squall arrives and before the shower begins.

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