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PRACTICAL AIR NAVIGATION

and

THE USE OF THE AERONAUTICAL CHARTS OF THE DEPARTMENT OF COMMERCE

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By

THOBURN C. LYON
ASSISTANT CARTOGRAPHIC ENGINEER

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NOTE.—With reference to the Regional Aeronautical Charts mentioned in this publication, 9–M and 10–M have been published. Progress on the remainder of this series has been indefinitely postponed by circumstances beyond the control of the U. S. Coast and Geodetic Survey.

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PRACTICAL AIR NAVIGATION

INTRODUCTION

The Air Commerce Act of 1926 provided for the charting of airways and the publication of aviation maps necessary for safety in flying. At that time there were no such maps of the country, and no maps were available which could serve even as an adequate base for the addition of aeronautical data. A new type of map for aerial needs was urgently required, and to the United States Coast and Geodetic Survey of the Department of Commerce was assigned the technical work of investigating this field, and of compiling and publishing the new maps of the airways.

The first air maps published by the Coast and Geodetic Survey for the Bureau of Air Commerce 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 quickly found favor, they were little more than accurate 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 coming of more advanced methods of navigation, features that once were considered essential have been replaced with others of greater relative importance. Certain items which should be included in a topographic map now are 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 have gradually assumed the character of the nautical charts so essential for safety at sea, and recently the designation of these highly specialized publications has been changed to aeronautical charts.

Even today the development of the aeronautical chart cannot be considered complete. Changing conditions of flight (such as higher speeds, longer flights, and higher altitudes) are fairly certain to result in changed methods of navigation. Such changes the chart should not merely keep pace with, but should anticipate.

Maps in general may be looked upon 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. 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 the Department is even looking toward the early extension of its aids for the navigation of air routes across the oceans. The frequent correction of its charts to show these changes as they occur is a most important function of

the Government, and is imperative for safety in all forms of air transportation.

Two series of aeronautical charts are now being published by the Coast and Geodetic Survey:

* **Sectional charts,** covering 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,** covering the whole country, in 17 sheets, at a scale of 1:1,000,000, or about 16 miles to the inch (fig. 2).

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 were made necessary by faster planes flying greater distances.

Because of the larger scale and more detailed 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 resorted to. 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.

CHART READING

THE IMPORTANCE OF CHART READING

A chart is a small-scale representation 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.

Not all of the cultural and topographic features described are included in the regional series, because of their smaller scale; however, all are included in the sectional series, and such as can be shown on the regional charts are in conformity therewith.

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.

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* Fifty-six sectional and 2 regional aeronautical charts were available November 1935.

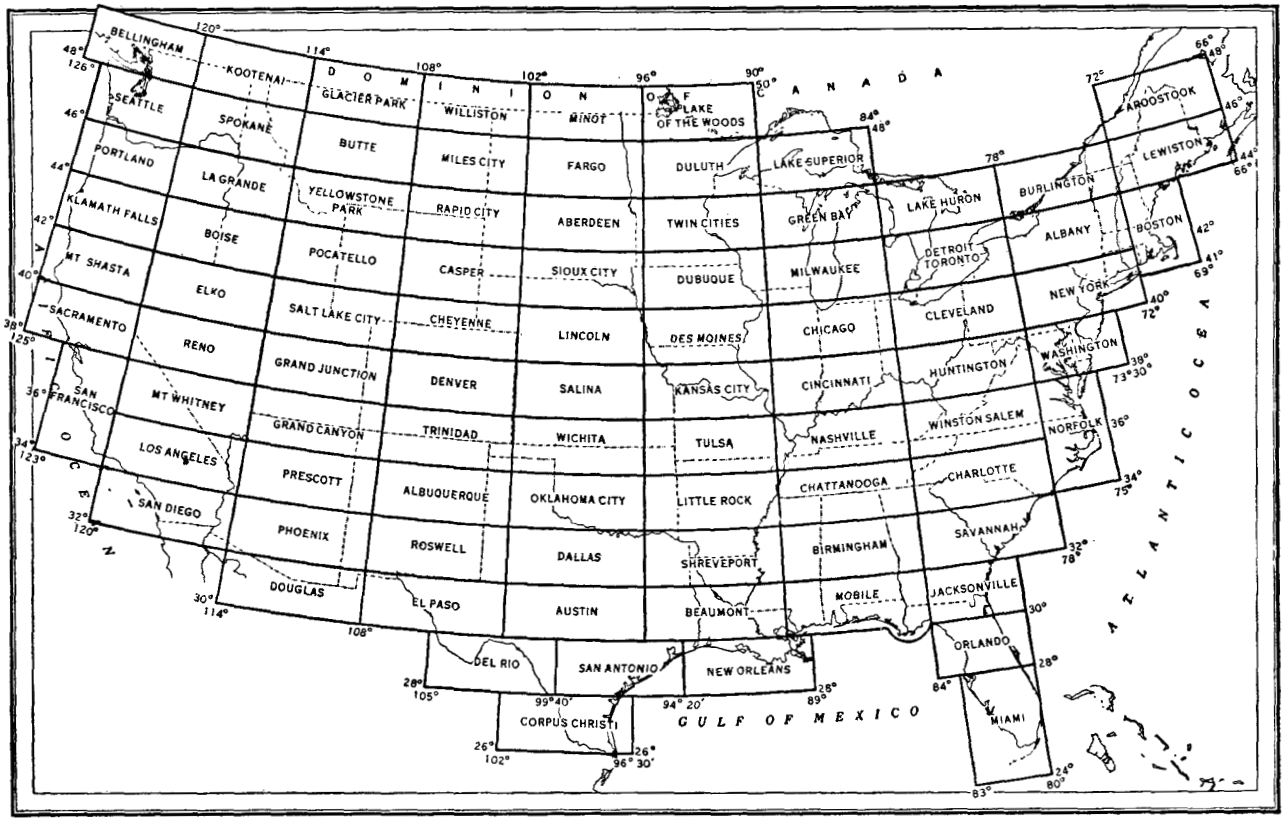


FIGURE 1.—Index to sectional aeronautical charts.

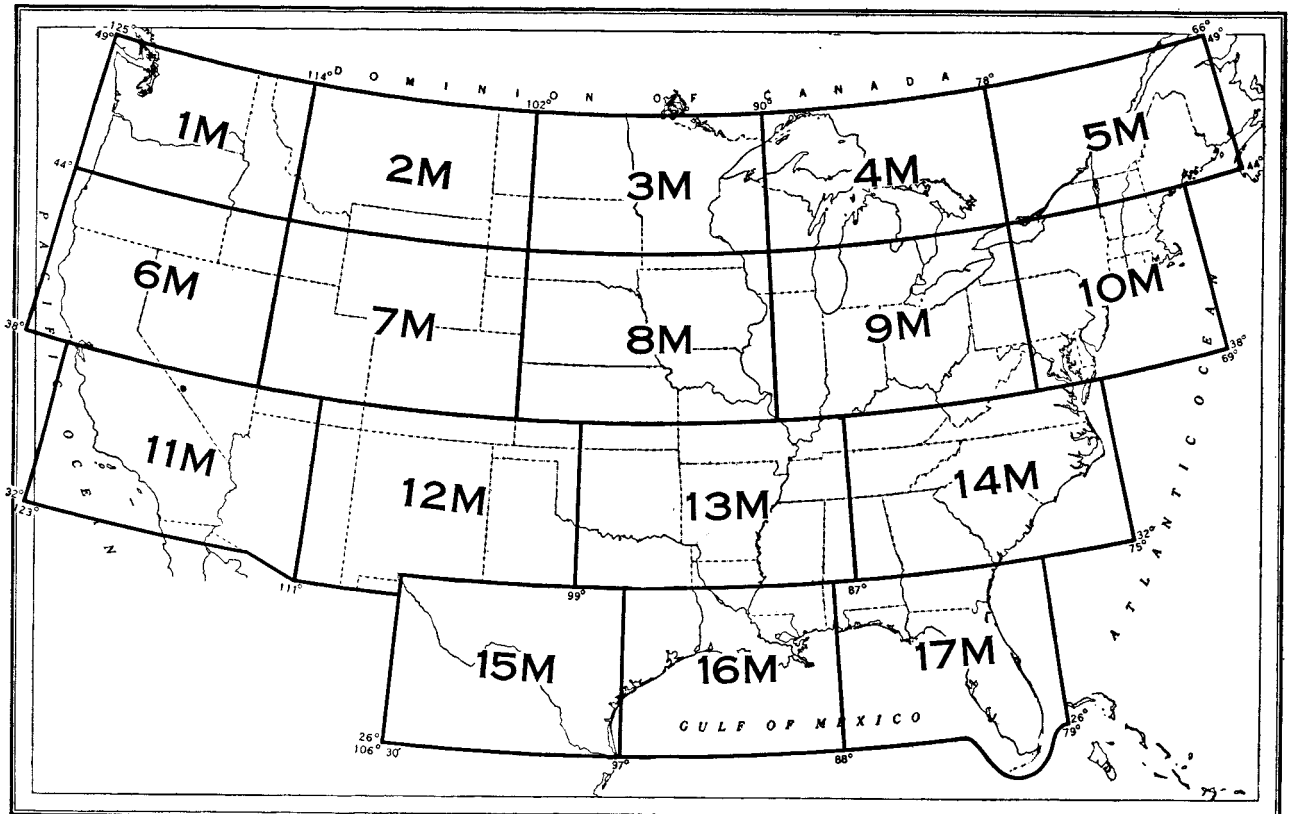


FIGURE 2.—Index to regional aeronautical charts.

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

Relief, including mountains, hills, valleys, and other features of the terrain.

WATER FEATURES

[See fig. 3.]

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.

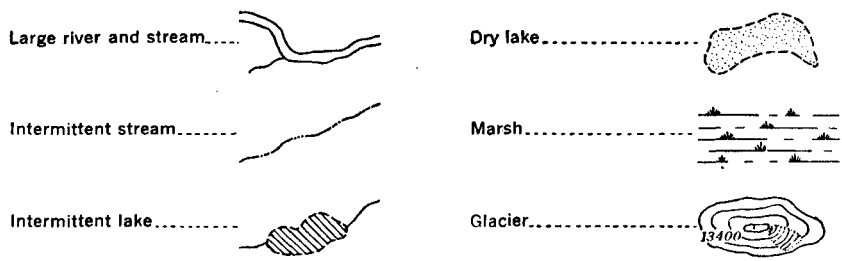


Figure 3.—Water features.

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.

CULTURAL FEATURES

[See figs. 4 and 5]

Cultural features are generally indicated in black. Towns of less than 1,000 in population are indicated by a conventional black circle. Towns 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 by lighter black lines with crossties at 2½-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 because they are also 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 seldom is 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.

"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

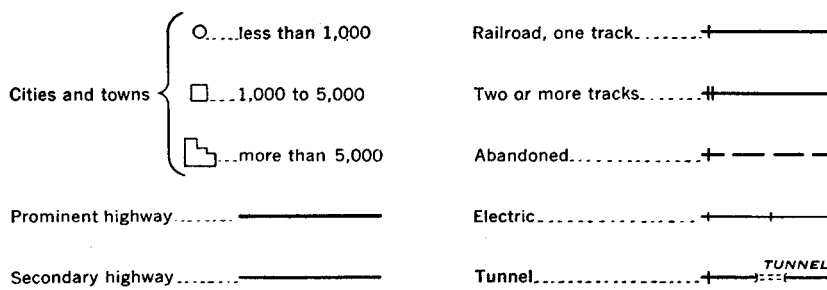


FIGURE 4.—Cultural features.

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 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. 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.

Oil derricks are represented by a symbol suggestive of their structural framework. Oil tanks are shown by small black dots, or circles. Where there are just a few scattered derricks or tanks, a

symbol often represents an individual well or tank; where they are very numerous, the symbols are distributed at convenient intervals and indicate an area, rather than individual derricks or tanks.

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. If there is a telephone available at a tower, this fact is also indicated on the chart, as it may prove of value in the event of a forced landing.

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.

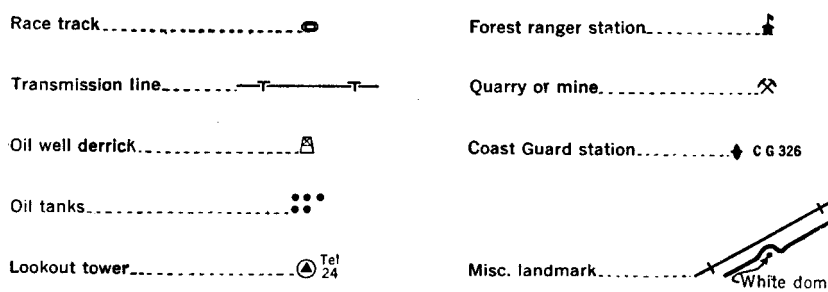


FIGURE 5.—Cultural features (landmarks).

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 series, 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 3 features may occupy a space no more than 75 feet in width, yet on the chart, showing the 3 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 as a double line, and in length enough to preserve in a general way, at least, the shape of the lake. As far as possible, symbols are centered on their true locations and exaggerated only as much as may be essential to a clear representation.

RELIEF

[See fig. 6.]

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.

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 also are shown.

A contour represents an imaginary line on the ground, every point of which is at the same height above sea level, and the varied curves of the contour show the ridges, valleys, canyons, bluffs, and other topographic 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 7 represents

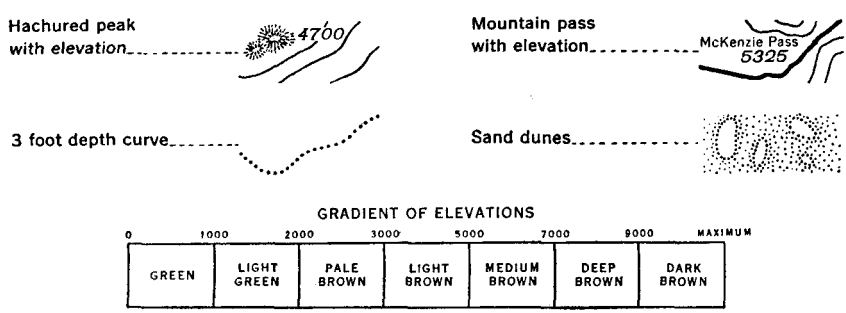


FIGURE 6.—Relief (elevation).

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 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 8 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 curving 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. 9). 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

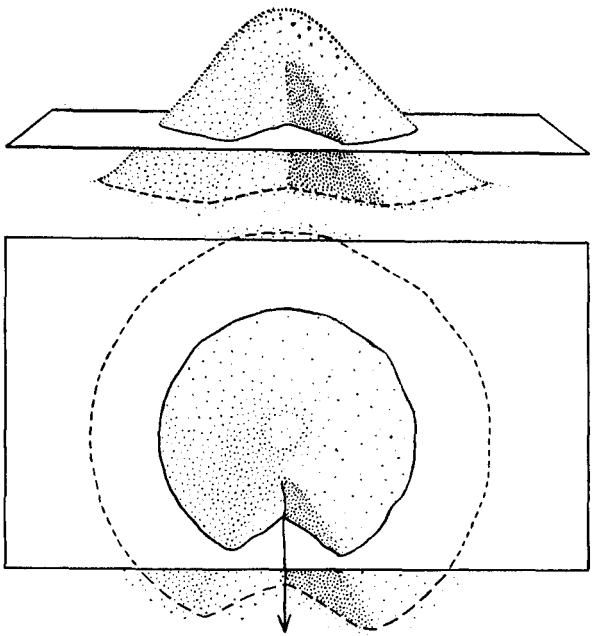


FIGURE 7.—Contours illustrated by a sand pile.

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

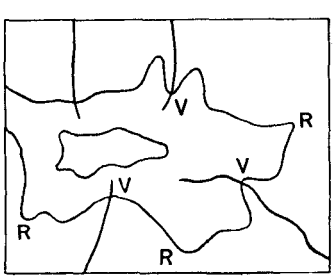


FIGURE 8.—Ridges and valleys shown by contours.

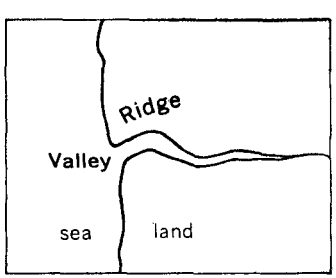


FIGURE 9.—The seashore as a contour.

close to the shore. If the terrain should rise from the coast in a long gentle slope, the 1,000-foot contour would be 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 10. 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 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 in-

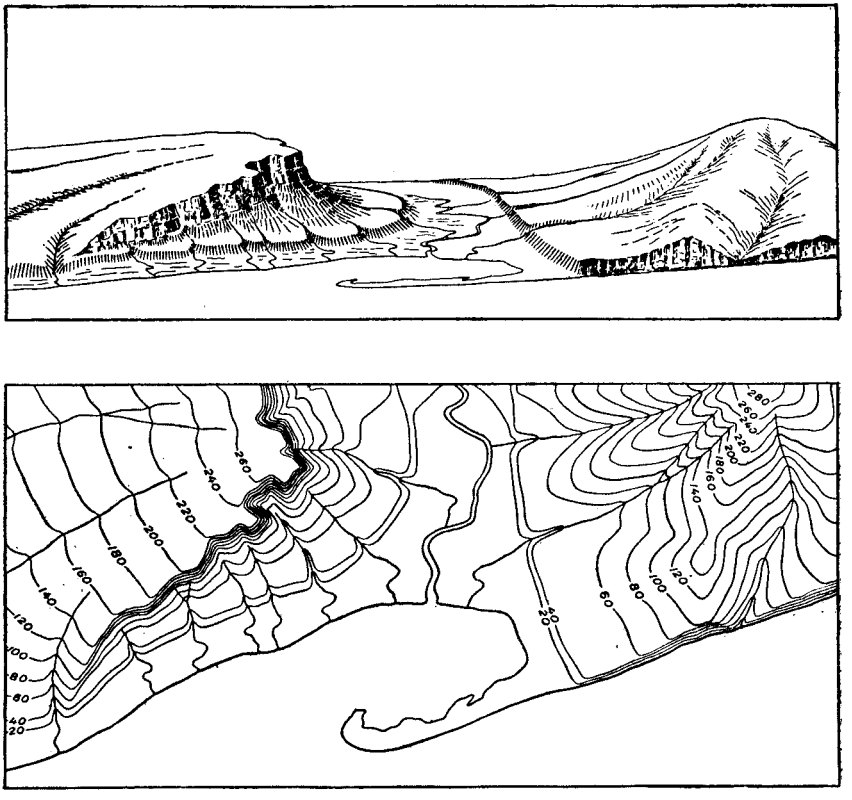


FIGURE 10.—Altitude, form, and slope expressed by contours.

clined 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.

It should be noted that in figure 10 the contours represent successive increases of 20 feet in elevation—that is, the "contour interval" is 20 feet. For the aeronautical charts a contour interval of 1,000 feet[1] has been adopted.

The 3-foot depth curve, in water areas (fig. 6), may be thought of as an under-water contour, and every point along the curve is 3 feet

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

below low water. It is shown by a row of brown dots, and serves as a sort of danger line within which seaplanes should not attempt to land.

Sand and sand dunes are indicated by brown dots (fig. 6).

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. 11 and 12.]

Aeronautical information and features of interest chiefly for air navigation—airports, beacon lights, radio ranges, etc.—are shown in red. 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 issue printed in red in the lower left corner of each

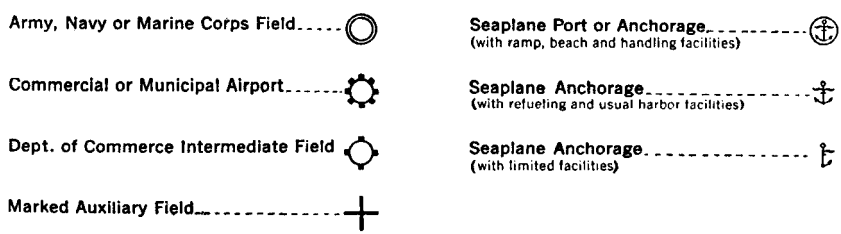


FIGURE 11.—Airport classification.

chart. The pilot's own interests and the safety of the public make it imperative to discard obsolete charts and to obtain new editions as soon as they become available.

Airport and airway changes subsequent to the date of printing are listed in the Air Commerce Bulletin (which is published monthly by the Department, and may be had free upon request), 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. 11). 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.

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

The letters *LF*, in red, adjacent to an airport symbol indicate that the field is equipped with night lighting facilities. 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 Airway Bulletin No. 2, or obtain local information.

A rotating airway beacon light is indicated by a red star with open center. Red arrows in conjunction with the beacon symbol indicate that the beacon is equipped with course lights and show the directions in which they are pointed; the number of the beacon (which is painted at the base of the beacon for daylight identification, and flashed by the course lights in Morse code for identification at night), with the corresponding Morse signal, is placed adjacent to the symbol.

A flashing beacon light is indicated by a smaller solid red star.

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

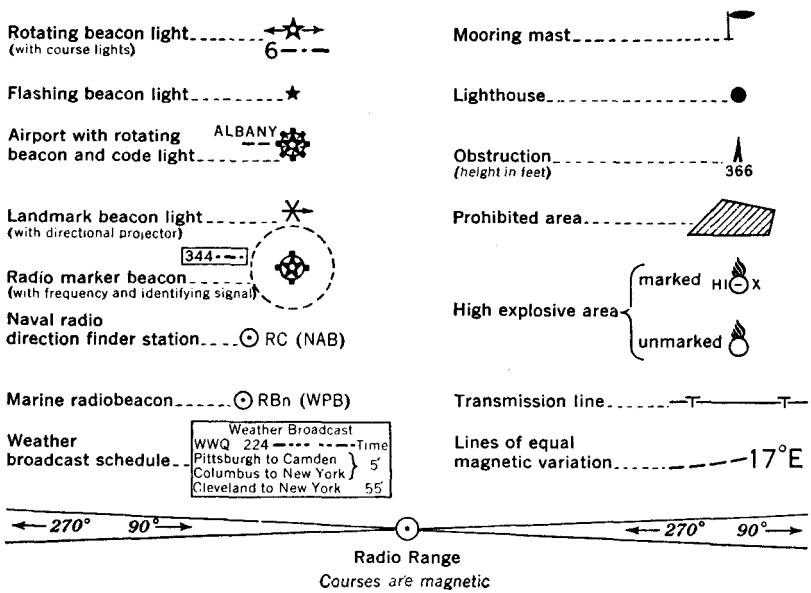


FIGURE 12.—Aeronautical data (miscellaneous).

is also equipped with a code light, red rays are added to the beacon symbol, and the Morse signal flashed by the code light is shown adjacent to the airport.

A landmark beacon light, operated by a commercial establishment for advertising purposes as well as for the benefit of airmen, is indicated by a heavy red asterisk. An arrow in conjunction with this symbol indicates that the beacon is equipped with a stationary bearing projector pointing to the nearest airport.

A mooring mast is indicated by a symbol suggesting a dirigible at its moorings.

A lighthouse is shown by a heavy red dot.

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.

Certain areas near naval proving grounds and test-firing ranges are prohibited to aircraft. These areas are indicated by prominent red ruling.

There are other more limited areas where quantities of high explosives are stored. Pilots are forbidden to fly over such areas, and they are marked on the chart as shown in figure 12.

Radio range stations are localized by a red circle-and-dot symbol, and the positions of the range courses are shown by a pink tint. Magnetic compass courses toward the station are indicated in red, and large red letters mark the *A* and *N* quadrants of the system. The method of flying the radio ranges will be treated in detail in a later section.

Radio marker beacons are usually located at an airport, and in these cases the airport is enclosed in a red circle.

Naval radio direction finder stations are seldom used by aircraft today. However, these stations are indicated by a red circle-and-dot symbol and the initials *RC*.

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

Places at which the magnetic variation is the same in direction and magnitude, are connected on the charts by broken red lines known as lines of equal magnetic variation, or isogonic lines. The amount and direction of variation are shown in red figures.

Compass roses (fig. 13), oriented to true north, are printed on the charts in red. In the absence of a protractor 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 degrees of longitude away. Therefore, compass roses are printed at intervals sufficiently close that courses may be measured with practical accuracy, and one is usually available no matter how the chart is folded.

PROJECTION AND SCALES

Both series of charts are based on the Lambert conformal projection, which affords many advantages for air navigation in the United States. In this projection, variations in scale are so small that distances can be measured as if the scale of the charts were constant. Therefore, in the borders of both series 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.

In the margins of the sectional charts (1:500,000) are scales subdivided into minutes of latitude, and into minutes of longitude. These scales provide convenient means of plotting points when their geographic coordinates (latitude and longitude) are known, or of determining the geographic coordinates of points from their positions on the charts. Their use will be discussed in a later section. In some instances, 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.

2080°—35——2

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.

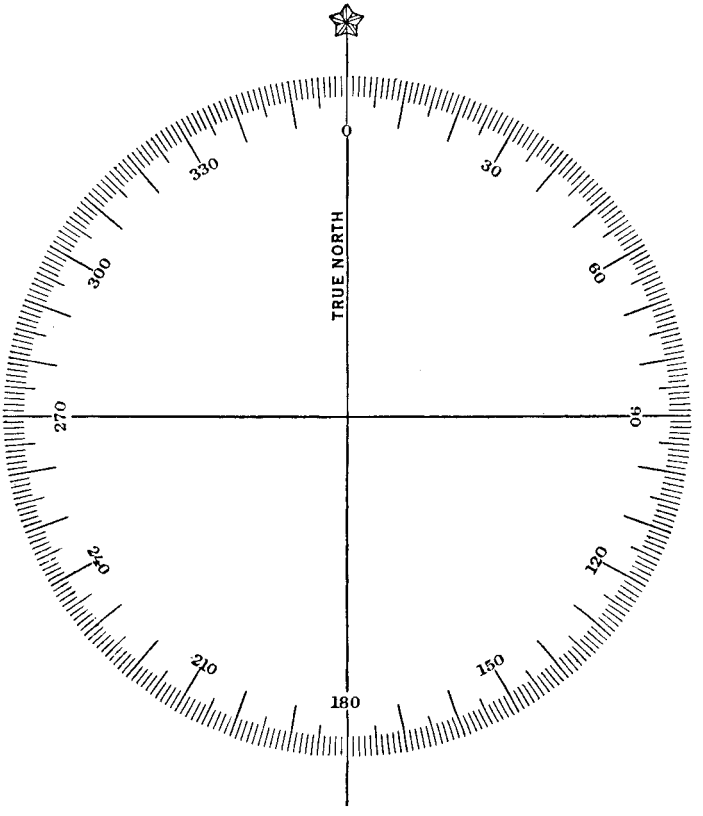


FIGURE 13.—Compass rose.

Should a scale of nautical miles be desired, the scale of minutes of latitude, i. e., the subdivisions along the meridians, will serve, since a minute of latitude is very nearly a nautical mile.

NIGHT FLYING CHARTS

To meet an ever-increasing need, the regional charts are also contemplated in a special edition, with a night flying chart printed on the reverse side. All detail that is lost to view with the coming of darkness has been eliminated from these charts, and there are shown only those features of interest in night flying: Major drainage, principal cities, radio aids to navigation, obstructions, and beacon lights and airports at which all-night operation of lighting

facilities is assured. The night flying charts are based on the Mercator projection, at a scale of 1:1,000,000 at latitude 40°. (See back of plate 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.

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 head winds; 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 directing the plane from place to place by reference to visible landmarks which can be identified on the chart.

Directing a plane from one place to another solely by reference to visible landmarks is known in this country as **piloting.**

LANDMARKS

The cultural features of the terrain constitute a most important class of landmarks. For example (plate 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.

The topographic features are frequently of outstanding importance in steering a course. 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.

STEERING A RANGE

In order to keep on the desired course, 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, suppose a flight is planned from the airport at McMinnville, Oreg., to Swim auxiliary field, just south of Mount Hood (Portland sectional chart). After taking off, the plane is steered so that the southerly slope of Mount Hood is kept lined up with the U-bend of the Willamette River, about 8 miles east of McMinnville. Soon after passing the river the race track north of Canby is seen, and the plane is headed so as to keep the track slightly to the north of the direct line to Mount Hood. Shortly before coming abreast of Canby, the course is checked by noting that the plane passes directly over the Department of Commerce beacon at Aurora. The power station south of Estacada and the lookout tower about 15 miles east of Estacada, in conjunction with the southerly slope of Mount Hood, furnish the next 2 ranges. By this time State highway no. 50 is seen, and its general trend is followed in to Swim field.

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, and for this reason 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 (plate I), the route from Springfield Airport to Marion Airport lies between and roughly parallel to the Erie Railroad and State highway no. 4. Flying this route, when a plane was about opposite Marysville a compass heading of 35° was noted. Shortly afterward an area of thick fog was encountered unexpectedly, but the compass heading of 35° was maintained; on running

out of the fog 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 straight line 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 straight line 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.

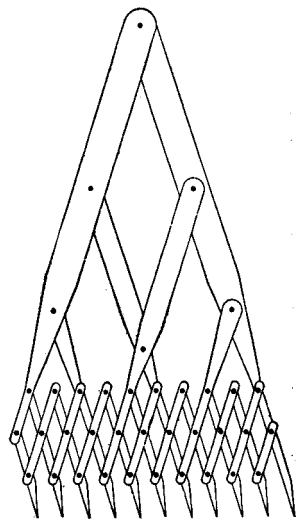


FIGURE 14.—Spacing dividers.

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

The spacing dividers (fig. 14) 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 num-

bered 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.

Some will prefer, no doubt, to combine the two methods, dividing the straight line 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 that 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. 38, p. 50), 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 beneath it may be read from the bottom 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 from the bottom 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 up 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 maps, 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

Charts of both series will be found very convenient for use in the air when properly folded. It is intended that the charts be folded once, back to back, along the line *AB* (fig. 15), 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.

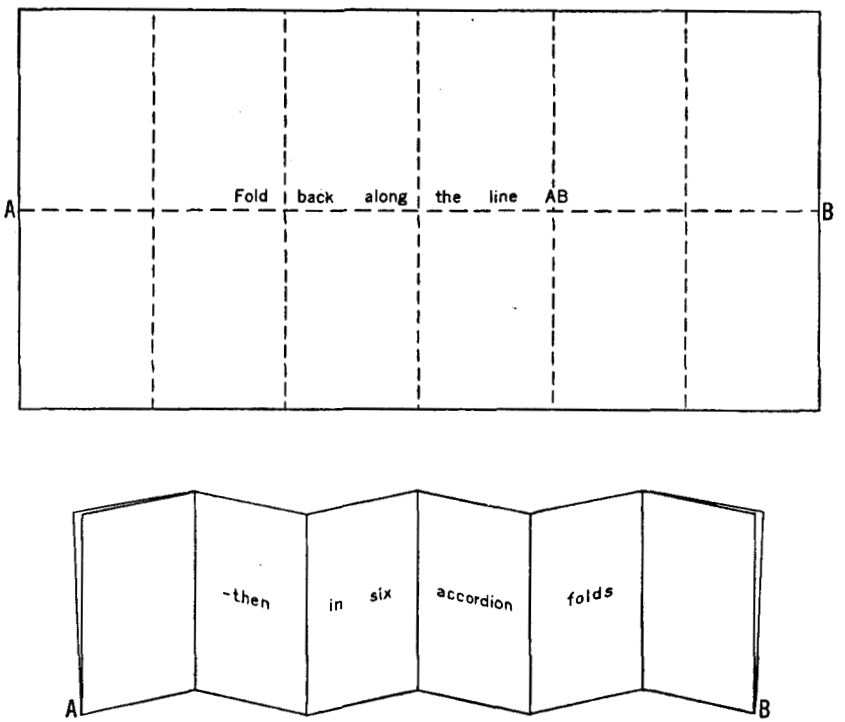


FIGURE 15.—Folding the chart for use in flight.

If it is desired to make a strip chart covering a certain route (as the route *CD*, fig. 16), 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 15.

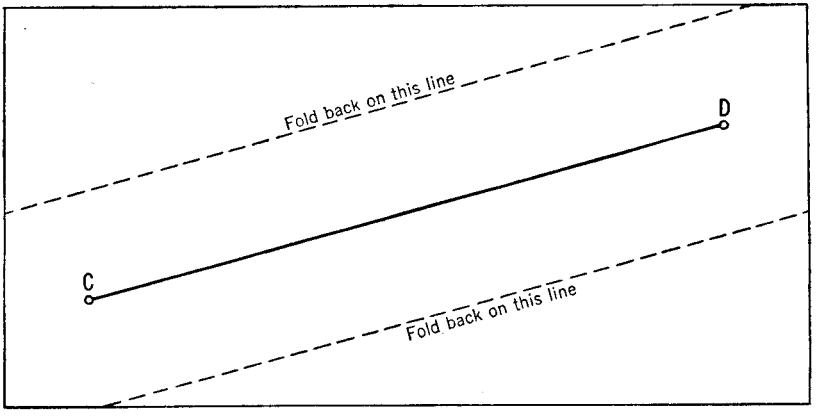


FIGURE 16.—Folding the chart as a strip.

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. The ability to navigate by more advanced methods is certain to result in greater operating efficiency and will give considerable 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, and the Lambert conformal conic projection was chosen for both series of aeronautical charts. This projection was devised nearly 200 years ago, but it did not come into prominence until the World War, when it was adopted for the military maps of the Allied Forces because it afforded a maximum accuracy 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 have been reached as the result of 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 supposed 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. On a chart of the country as a whole, the maximum (total) scale error for nearly 90 percent of the area of the United States is within ½ 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 might 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, the following brief comparison states the special properties of each.

Chart no. 3060a is on the same projection as the two series of aeronautical charts and is at a scale of 1:5,000,000, or about 80 miles to the inch. It affords a high degree of accuracy in the measurement of distances between widely separated points, and in the plotting of radio bearings. About 40 of the principal broadcasting stations and 160 of the country's leading airports are shown in red, facilitating radio compass navigation and the plotting of routes between principal airports. Courses also may be measured thereon, although in general they should be measured on one of the larger-scale series, as recommended in a later section. 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 approximately at 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.

There are two basic problems in navigation, 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 28 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 17 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*.

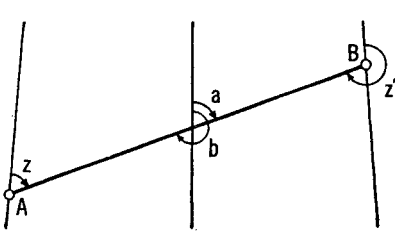


FIGURE 17.—Courses and bearings.

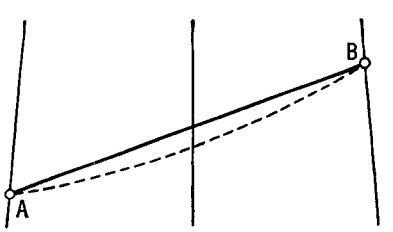


FIGURE 18.—Course and track.

It should be noted, further, 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]

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

[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.

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).

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.

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. 17), 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 18. 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 degrees of longitude the true course may be measured with the meridian nearest halfway, as described above and as illustrated in figure 17, and the entire distance flown as one course.

When the difference of longitude between the two points is more than 3 or 4 degrees the straight line on the chart should be divided into sections crossing approximately 2 degrees 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 19 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 degrees, which is too great to be flown satisfactorily in one course. The route is therefore divided into five sections crossing approximately 2 degrees of longitude each, the two end sections being slightly longer than the others. 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.

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).

2. TO FIND THE MAGNETIC COURSE

As explained above, the true course is measured with reference to the true meridian printed on the chart, or true north. However, magnetic compasses are commonly 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, and the angular difference between them at any place is known in navigational circles as the magnetic variation of the place. It is

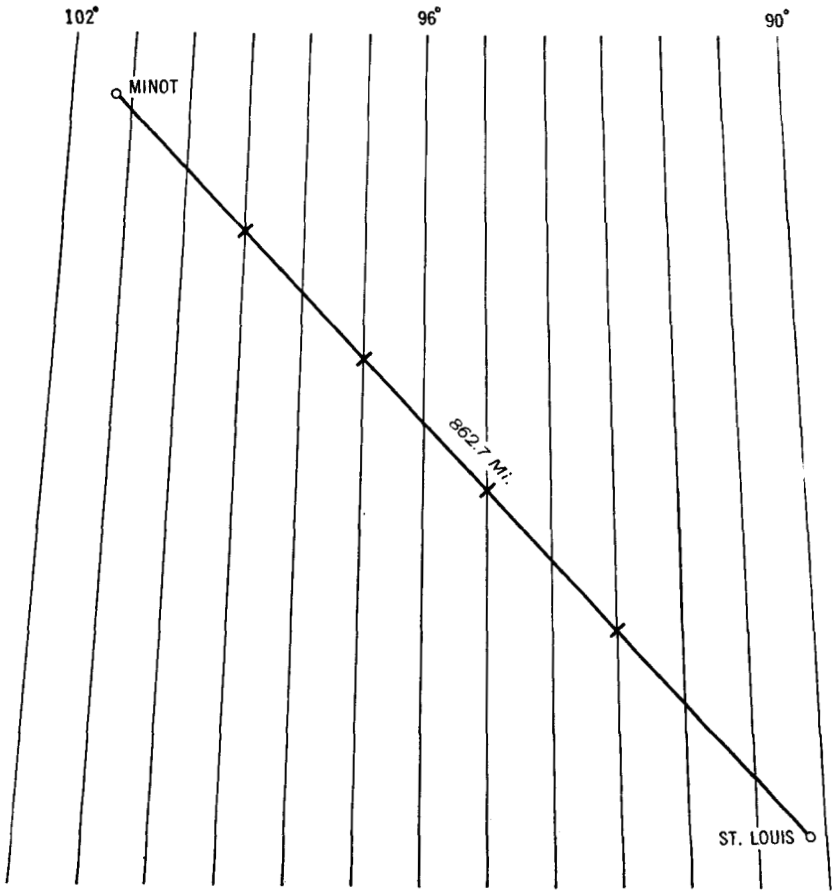


FIGURE 19.—Subdividing a long route.

called westerly variation or easterly variation, according as magnetic north lies to the west or to the east of true north.

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

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

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

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

Numerous rhymes and jingles have been contrived to help navigators remember this rule, but often the rhymes have proved more confusing and harder to remember than the rule itself. It is believed that if the pilot can fix in his mind the relation pictured in figure 20, there will never be any question as to the proper application of magnetic variation.

In figure 20, *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.

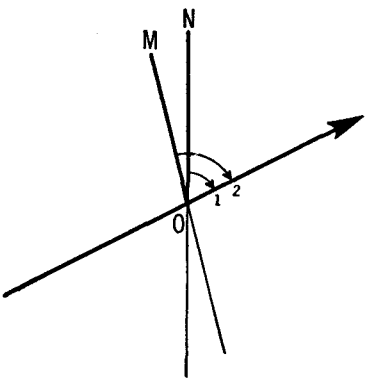


FIGURE 20.—Magnetic variation.

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 20° west, resulting in the condition shown in figure 21.

Near Portland, Oreg., the variation is about 22° east, as in figure 22.

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 23 shows the conditions actually existing 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 course 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

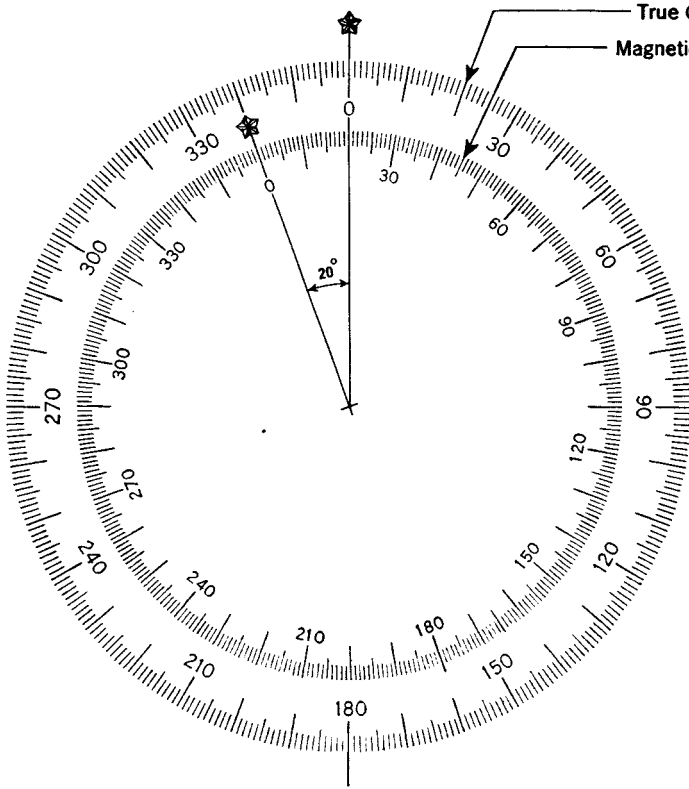


FIGURE 21.—At Portland, Maine, magnetic variation is about 20° west, and the magnetic compass reading is 20° greater than the true direction for any chosen course.

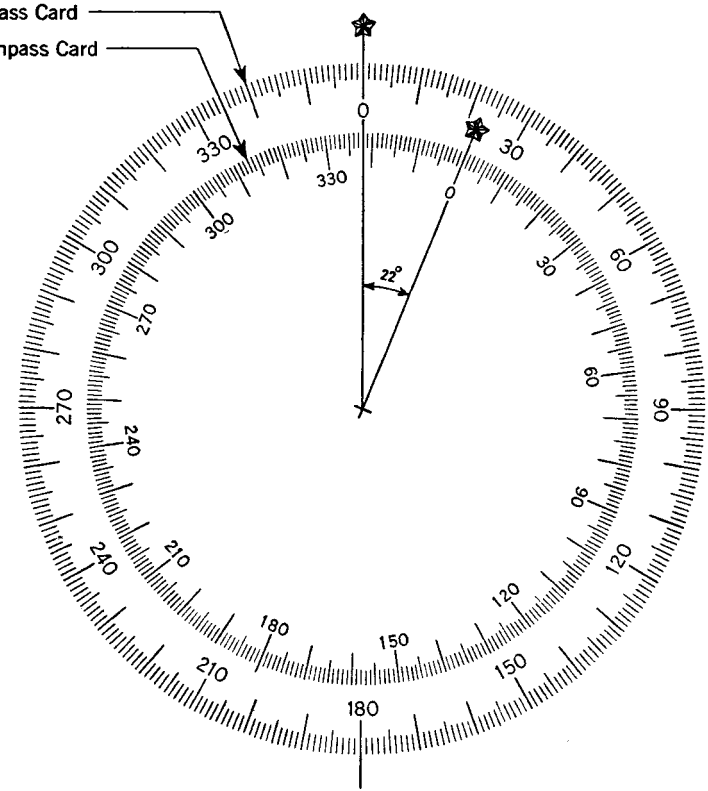


FIGURE 22.—At Portland, Oreg., magnetic variation is about 22° east, and the magnetic compass reading is 22° less than the true direction for any chosen course.

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.

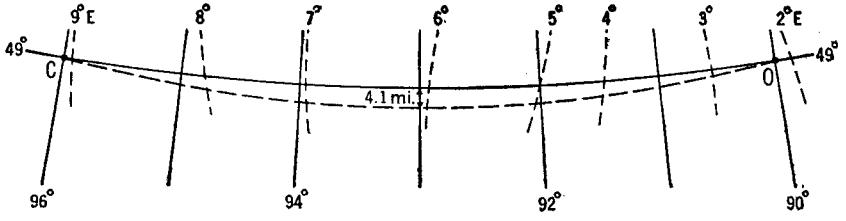


FIGURE 23.—Departure from intended track due to flying a mean magnetic course.

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. The angular difference between magnetic north and the north indication of the compass on any particular heading is known as the compass deviation for that heading. It is different, of course, for each compass, and even for each new location of a compass in the same airplane; it also differs in magnitude and direction as the airplane is pointed on different headings. 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. 28). It is simply another step in the process of finding the compass heading, and may be defined further as the **true course plus or minus magnetic variation and compass deviation.**

By proper adjustments, deviation on the various headings may be greatly reduced, but a reduction of the deviation is less important than knowing exactly the amount of deviation on the respective headings. It is desirable to 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, 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.**

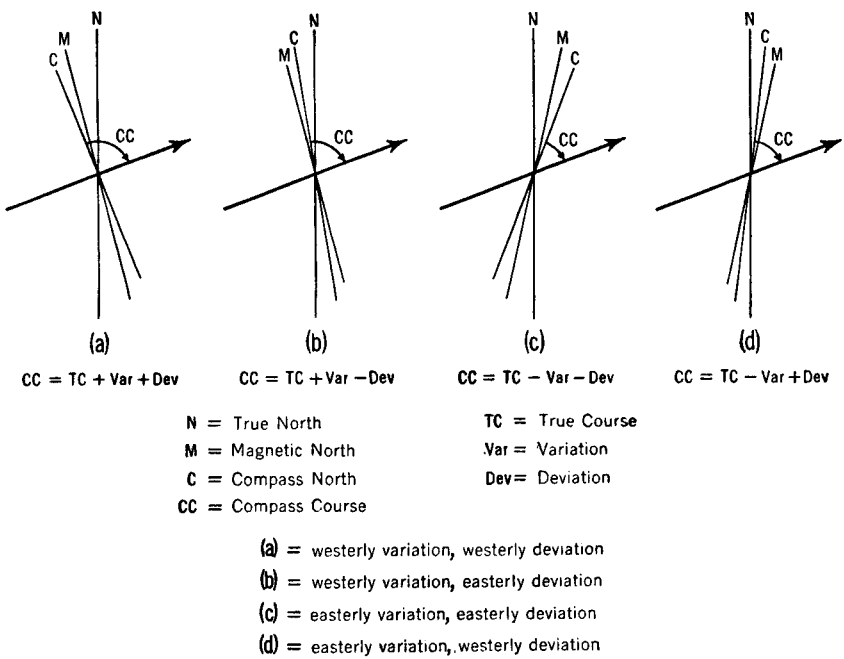


FIGURE 24.—Applying variation and deviation to find the compass course.

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

Figure 24 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 often is 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 28 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. 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 in an entirely different direction under its own power.

For example, a plane headed due east from *A* (fig. 25), flying at an air speed of 100 m.p.h., should reach *B* (100 miles distant) in 1 hour; but, during the hour of flight the plane has also been subject

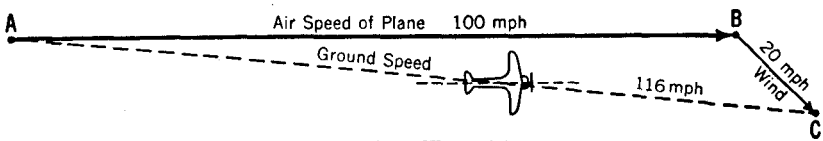


FIGURE 25.—Wind drift.

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 116 m.p.h.

Air speed is the speed of the plane with reference to the air, and is the speed registered by the air speed indicator (when corrected for altitude and temperature). It is represented by the line *AB* in the figure.

Ground speed is the speed made good over the ground, and is the resultant of the course 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 25 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, when the wind direction and velocity are known a pilot can determine graphically the number of degrees the plane must be headed into the wind (the "wind correction angle"),

in order to make good the intended course and to reach the destination with precision. The procedure is as follows:

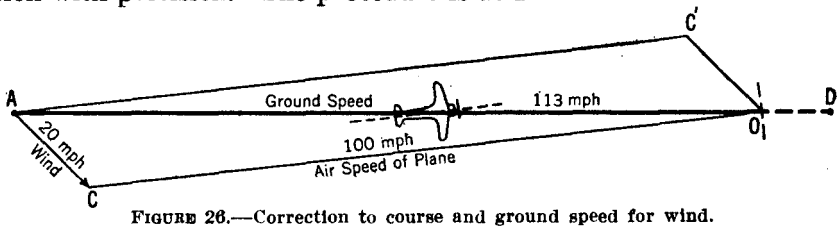


FIGURE 26.—Correction to course and ground speed for wind.

The true course from A to a distant point, D (fig. 26), 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.

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 plane's heading 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.

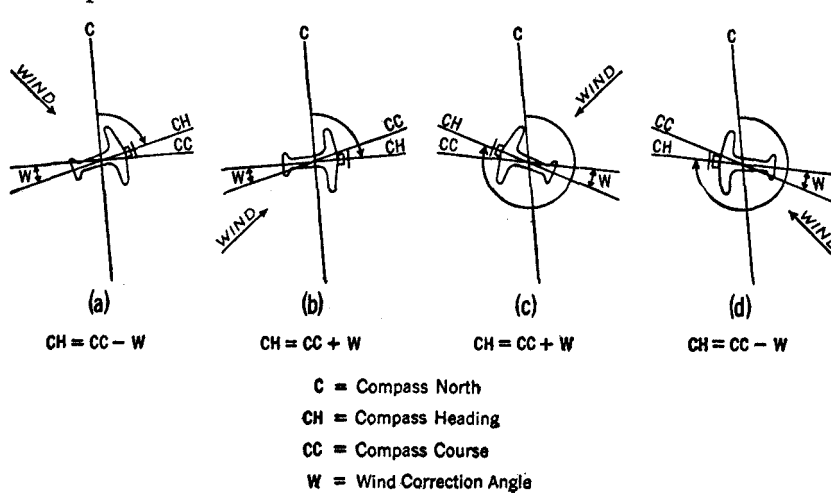


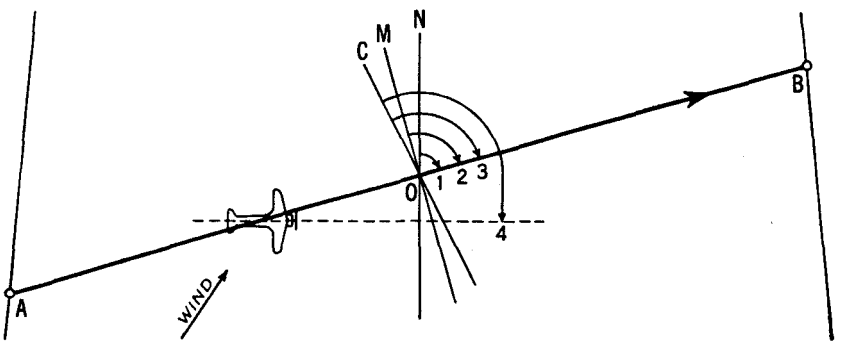
FIGURE 27.—Combining compass course and wind correction to find the compass heading.

Figure 27 illustrates the application of the allowance, or correction, for wind effect under varying conditions. For any particular case it is believed that a rough sketch similar to one of those in the figure will remove any doubt the pilot may have as to whether the allowance for wind should be added or subtracted.

By comparing the various parts of figure 27 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 graphic 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).



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

FIGURE 28.—Graphic definition of terms used in dead reckoning.

By way of summary, figure 28 affords a graphic definition of the terms commonly used in navigation by dead reckoning, and of their inter-relation.[1]

CASE II

In the preceding discussion only the first of the two cases 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.

1. TO RECTIFY THE COMPASS HEADING FOR DEVIATION

If we remember the rule laid down under Case I, that to convert a magnetic course to a compass course we **ADD WESTERLY DEVIA-**

[1] 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. Also, if the compass is properly compensated the difference in deviation between adjacent headings ordinarily should be so small as to be negligible in practice.

TION, 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 Case I and subtracting in Case II, it should be necessary only to remember that problem one, finding the compass heading from the chart, is normally the first and basic operation, and for this we must **ADD WESTERLY** variation or deviation. For the second operation, performed in the air (infrequently), we simply reverse the procedure.

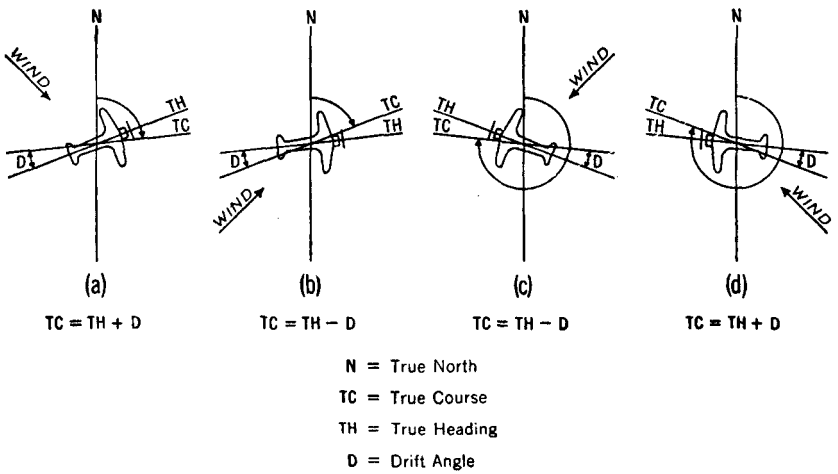


FIGURE 29.—Combining the true heading and drift to find the track (true course made good).

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 29 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, page 45), 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 30, *A* marks the last known position of a plane and the known data are as follows:

Compass heading in flight	55°
Ground speed (approx.)	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.

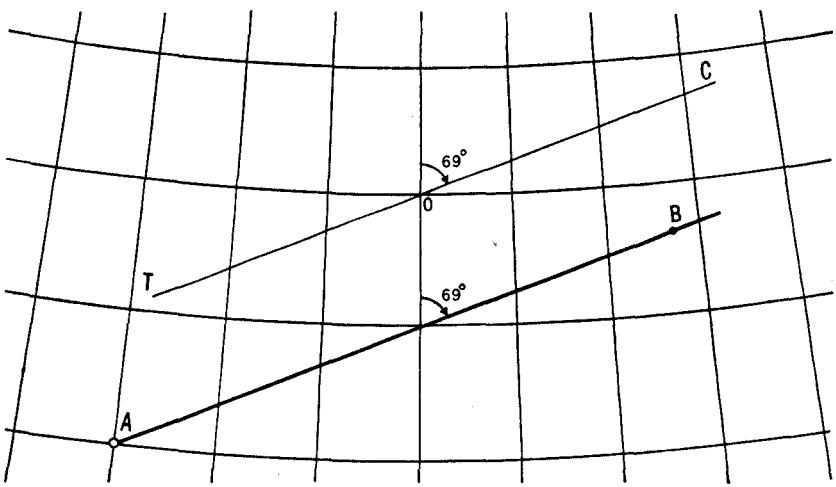


FIGURE 30.—Plotting on the chart the track, or true course made good.

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 (fig. 29a).
   =59°+10°=69°.
4. The approximate distance covered in 1^h 20^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.

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

Case I: Chart to compass heading:
1. Measure the true course.
2. ADD WESTERLY VARIATION.
3. ADD WESTERLY DEVIATION.
4. ADD WIND RIGHT, i. e,. add the correction for wind from right)

Case II: Compass heading to chart:
1. Subtract westerly deviation.
2. Subtract westerly variation.
3. Subtract wind right, i. e., for wind from the right.
4. Plot true course on chart.

RADIO NAVIGATION

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 fog flying, when all other methods fail or become very uncertain.

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 or 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 Department of Commerce, illustrated in figure 31.

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. The four courses from each station are obtained as follows:

Into two diagonally opposite quadrants (fig. 32) 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 series of long dashes. Thus, a pilot will hear the series of long dashes while he is on course; if he deviates to one side he will hear the dot-dash (*A*) signal, and if he deviates to the other 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 in conspicuous red 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.

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.

At an early date the letter *I* (· ·) will replace the letter *N* (— ·) at all range stations. The operation of the radio range system otherwise will remain unchanged for the aural signals described above, but this slight change will permit also the use of the new visual indicators which enable the pilot to keep on course simply by flying so as to keep the pointer of the indicator centered. If the pilot deviates from the course, the movement of the pointer indicates the side to which he has moved. One of the great advantages of this system is that it relieves pilots from the strain of constant listening. The on-course (equisignal) zone is about 3° in width, depending largely upon the orientation of the courses, the receiving equipment used, and

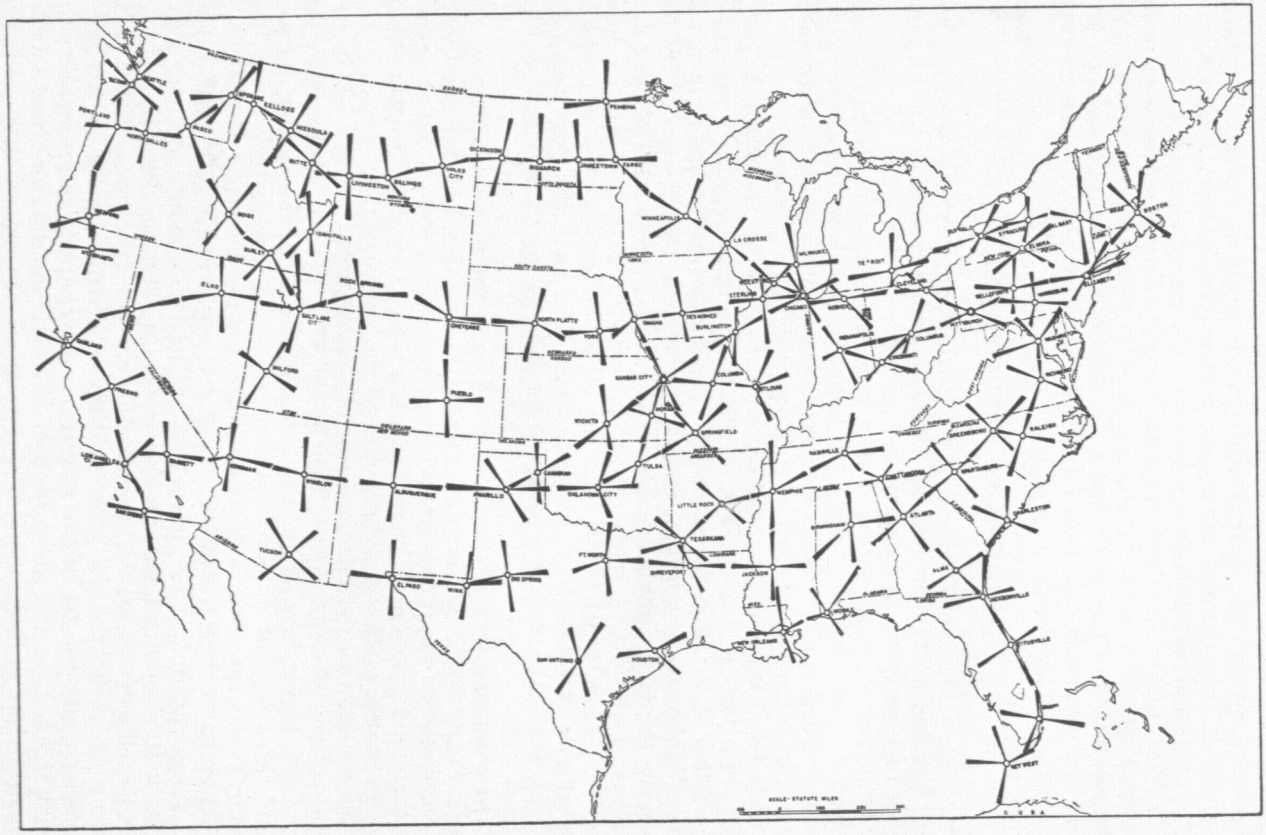


FIGURE 31.—The radio range system of the Department of Commerce.

the technique of the observer. Maximum sharpness of course is obtained with the receiving set tuned to the minimum practical volume.

The range signals are interrupted several times each minute for the transmission of the identifying signal of the station; with the change to *I–A* this will be changed to about once every 2½ minutes. 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, or the identifying signal which is transmitted into the *A* quadrants.

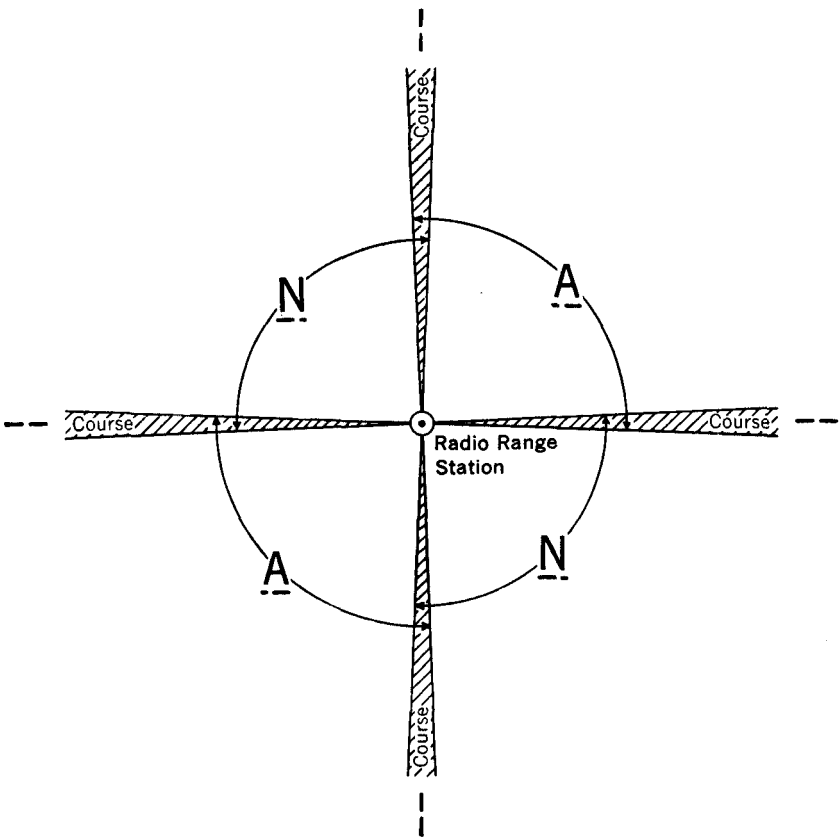


FIGURE 32.—Typical radio range station.

If he is on course, after the series of long dashes (the *A* and *N* signals interlocked), he will hear the identifying signal transmitted into the *N* quadrants, immediately followed by the same signal transmitted 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. 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.

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.

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.

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 32 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.

Then, 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 have been found to exist in some cases—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. 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.

The most difficult problem that may arise is that of quadrant identification. 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.

Now let us suppose that, flying under conditions of poor visibility, a pilot finds himself off the radio range course and receiving an *A* signal. From the identification signal he knows that he is listening to the station shown in figure 33, but does not know whether he is in the northeast or the southwest quadrant of that station.

To determine in which of the two quadrants he is flying, the procedure is as follows:

Fly a course at right angles to the bisector of the quadrants involved—in this case, either toward the northwest or toward the southeast. Suppose that the northwest heading is chosen: the route of the plane will be as indicated by m^1 or m^2.

Continue at right angles to the bisector (which may be either m^1 or m^2), until the on-course signals are heard, then make a 90° turn to the right.

If the pilot finds himself in the quadrant he has just left, i. e., if he again hears the *A* signal, he knows he has intercepted the northerly course from the station (route m^1), and makes a 90° turn to the left until the on-course signals are heard again. He then follows the range course away from the station until he is able to check his compass heading, makes a 180° turn, and follows the course back to the station, where he continues on the proper course toward his destination.

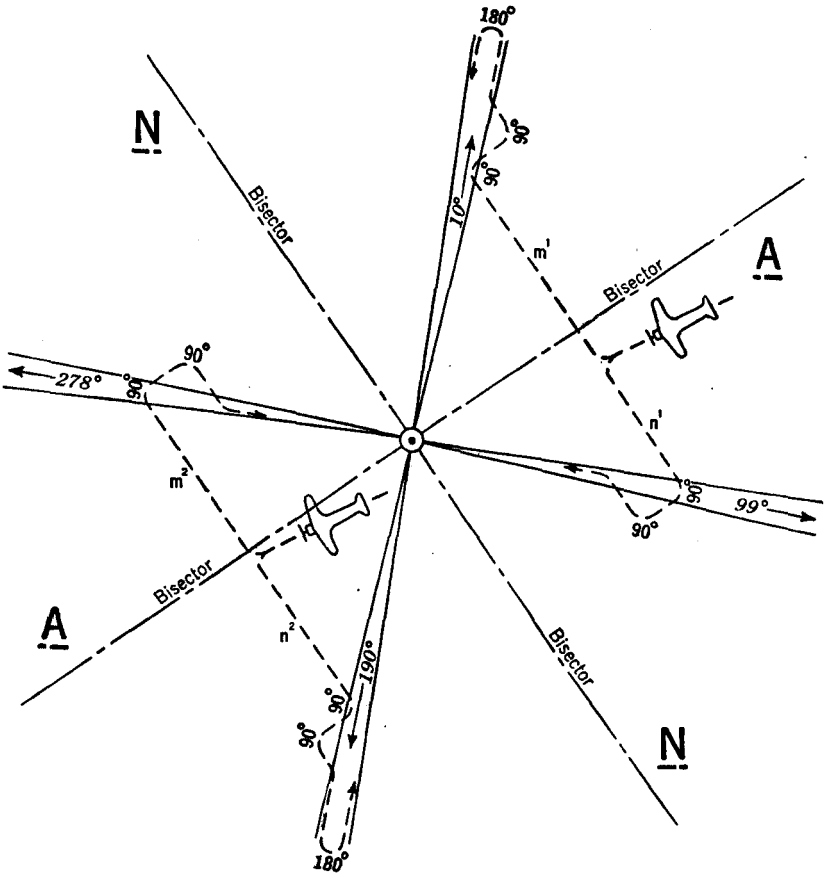


FIGURE 33.—Quadrant identification, radio range system.

If, after making his 90° turn to the right, the pilot finds himself in an *N* quadrant, he knows he has intercepted the westerly course of the station (route m^2), makes another 90° turn to the right until he picks up the course again, then checks his compass heading and follows the course in to the station.

If the pilot chooses the southeasterly heading instead of the northwesterly, the procedure will still be identical with the two cases outlined above, as shown by the routes n^1 and n^2 in the figure.

Another very similar—and perhaps simpler—method is as follows:

Fly a course at right angles to the bisector of the quadrants whose signals are heard until the on-course signals are received.

Identify the radio range course intercepted by making a 90° turn to the right and noting the signals heard, as in the first method.

A turn of approximately 270° to the left then brings the plane back to the range course and headed in the general direction of the station; the compass heading is checked, and the course followed in to the station.

Still other methods of quadrant identification are used and advocated by various pilots, but all are essentially the same as those just described.

With the visual indicators of the radio compass type, quadrant identification generally is 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. Errors of 180° are possible, but any doubt as to whether the plane is flying toward or away from the station may be removed by flying for a few minutes at right angles to the original course, and noting the change in bearing of the station.

Obviously, certain other rules are essential also. 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, pilots of the various transport companies also have arranged to fly their craft at definite altitudes.

Due to the effect of wind, as well as irregularities in steering, it seldom is possible to hold steadily to the course marked out by the range. Instead, if the pilot is slightly to the right of the range 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 courses marked out by the radio ranges, there are also radio marker beacons. These are low power transmitters, emitting a distinctive signal on the same frequency as that of the range on which they are located, and serving 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 before him.

All radio marker beacons 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.

THE RADIO COMPASS

The visual indicators of the radio compass type referred to, when used with charts on the Lambert projection, are as useful for direction finding and position determination off the airways as on the radio range system itself. By their use pilots are enabled to tune in the programs and broadcasts of any station whose 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 indica-

tor 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 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 the method is illustrated in figure 34. A pilot flying in the vicinity of *P* measures the bearing, *X*, of the radio station *RS*. From the meridian nearest the approximate position, *P*, the observed bearing is measured and the line *PR* drawn; a line from the radio station parallel to *PR* makes the same angle with the meridian near *P*, and is a radio line of position, at some point on which the aircraft is located.

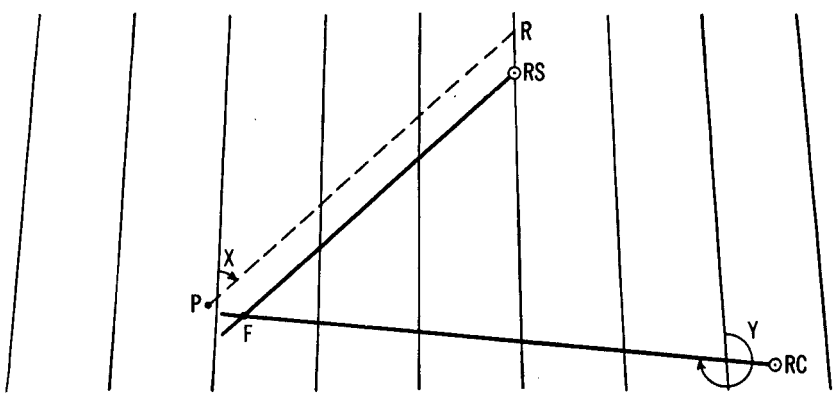


FIGURE 34.—Radio compass navigation (radio bearings).

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 lines of position, *F*, fixes the location of the plane.

RADIO AND THE CORRECTION FOR WIND

In this problem, as in all other problems of air navigation, wind is the principal complicating factor. Even though the pilot heads his plane directly for the radio station *RS*, under the effect of strong cross winds the plane will follow the round-about broken line of figure 35, instead of the direct route.

This can be overcome by checking the position of the plane at frequent intervals and noting whether the successive positions indicate a departure from the intended track. The amount and direc-

tion of the departure provide the means of determining the direction and velocity of the wind from which, in accordance with rules already given, the necessary correction to the heading of the plane can be found.

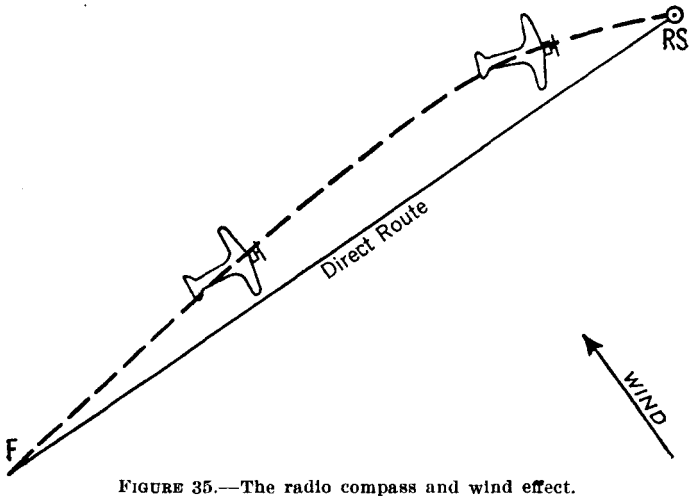


FIGURE 35.—The radio compass and wind effect.

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 40°.

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 17. By inspection it is seen that the meridian of 81°30′ is nearest half-way.

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 40°, in this case, is 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 36 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.

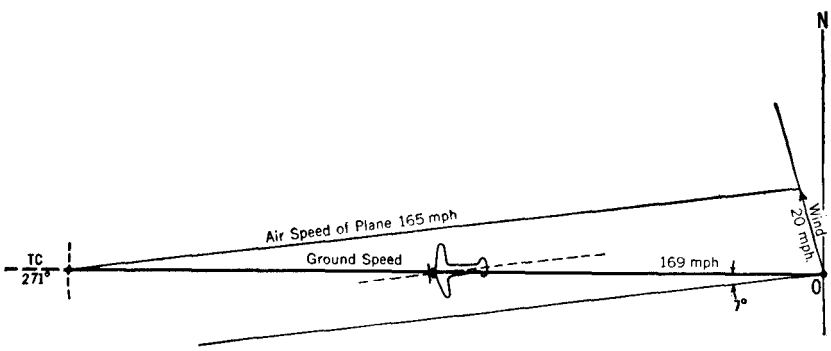


FIGURE 36.—Graphic determination of wind correction and ground speed.

Example 3.—A flight is proposed from Pittsburgh-Allegheny 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 C. & G. S. chart no. 3060a or 3074 (see p. 21). 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 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 totalled, 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.

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. 37) 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.

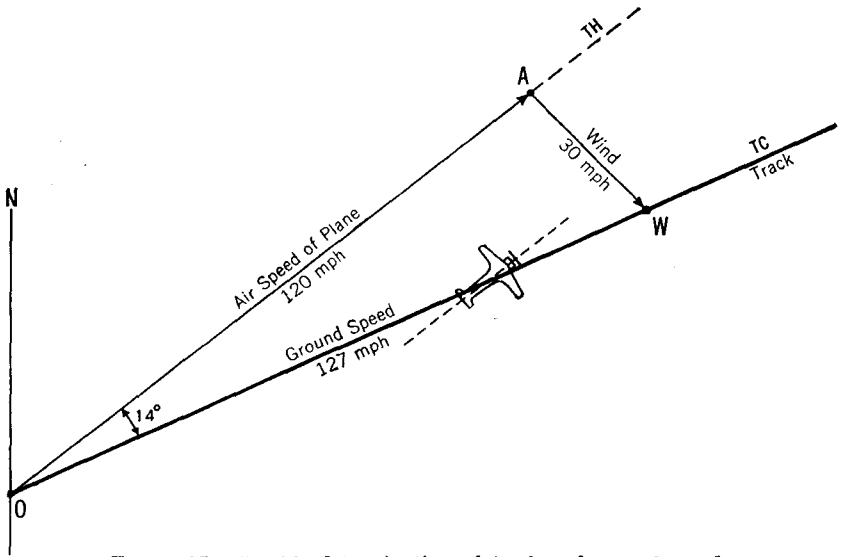


FIGURE 37.—Graphic determination of track and ground speed.

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.

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.—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 (plate 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 8.—After an extended period of flying above fog, it is desired to check the position of a plane by celestial observations. The method employed is worked from the dead reckoning position, and the latitude and longitude of this position are therefore required.

On the regional charts (plate 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 9.—A pilot flying "over the top" by dead reckoning, believed his position to be about latitude 40°30′, longitude 83°30′, when he was able to obtain an altitude of the sun.

Having solved the "astronomical triangle" by any chosen method, the pilot has these data:

Azimuth (bearing) of the body	235°
Observed altitude	42°34′
Computed altitude	42°20′
Altitude difference	14′

The azimuth, or bearing, of the body 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 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, passing through Indian Lake and the northeast corner of Bellefontaine, is the required line of position.

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

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

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 elements 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 problems involving the effect of wind, or time-speed-distance relations.

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.

TIME—SPEED—DISTANCE PROBLEMS

[See fig. 38.]

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 on graph), follow the vertical line corresponding to 6 miles up 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 on graph), follow the vertical line corresponding to 95 miles up 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 beneath 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) up 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.

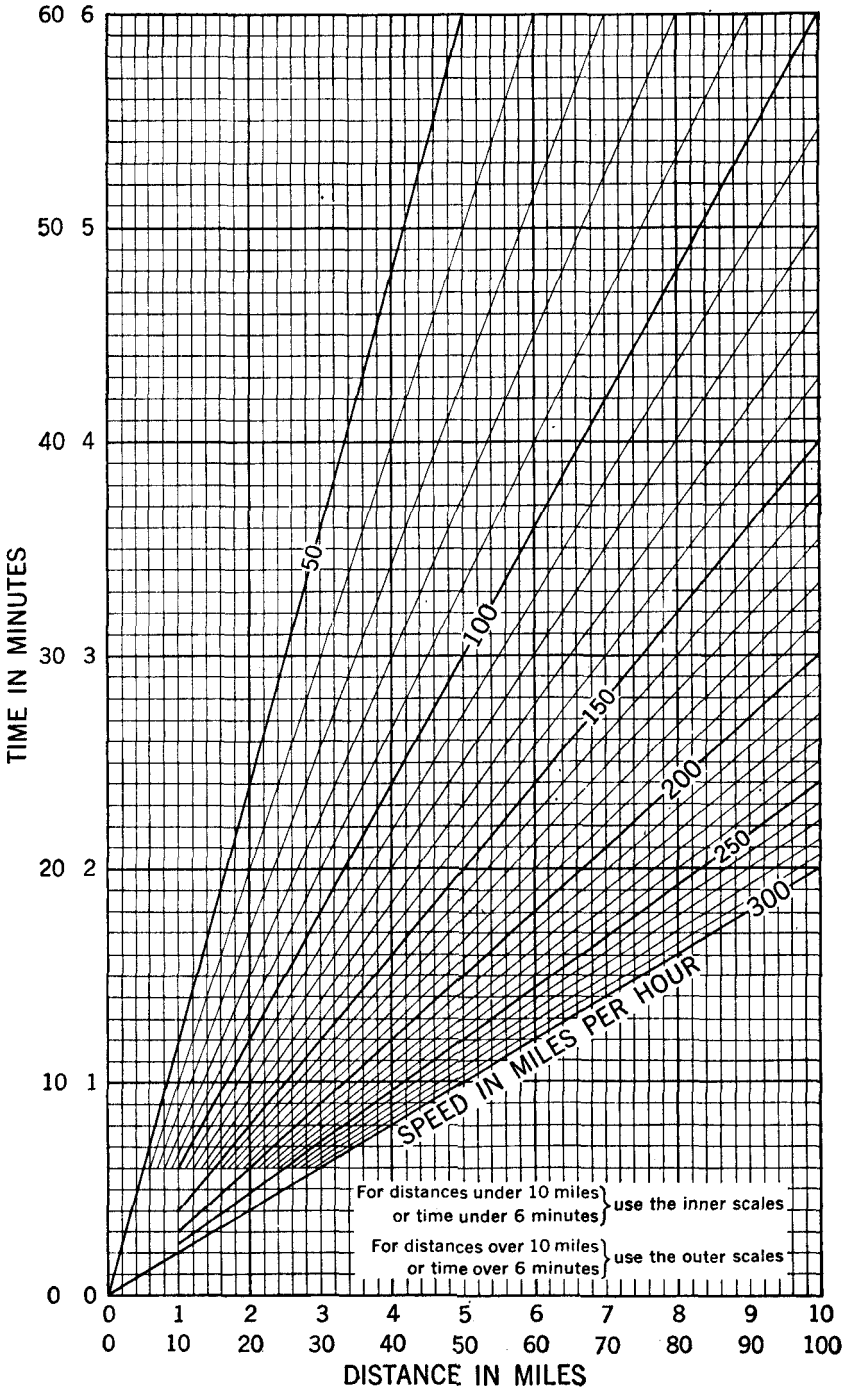


FIGURE 38.—Time—speed—distance graph.

FINDING WIND CORRECTIONS TO COURSE AND GROUND SPEED

[See figs. 39 and 40.]

In order to make these graphs useful for planes of all cruising speeds, it was necessary to compute them for wind velocities and ground speeds based on percent of air speed.

To adapt them for use with your plane, in "Line X" of both figures write under each percentage velocity the indicated percent of the cruising speed of your plane. That is, if your plane cruises at 120 m.p.h., under the figure 10 write 10 percent of 120, or 12; under 20 write 20 percent of 120, or 24, etc. Similarly, in the boxes marked "Y", of figure 40, write the ground speeds corresponding to the indicated percent. If your plane cruises at 120 m.p.h., the 95-percent curve would be marked 95 percent of 120, or 114, and so on.

All examples of the use of these graphs are based on cruising speeds of 100 m.p.h., since only the percentage velocities appear on the graphs as printed, and in this case they may be read as miles per hour. The graph must be adapted to the cruising speed of your plane as outlined above, but otherwise the procedure is identical in all cases.

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 100 m.p.h.; true course, 85°; wind, 27 m.p.h., from 45°. Find the correction to the course for wind, and the ground speed that will be made good along the corrected course.

The angle between the wind and the true course is 85°−45°, or 40°. In figure 39, follow the (interpolated) vertical line corresponding to a wind velocity of 27 m.p.h. down to its intersection with the horizontal line for 40° wind angle and find the curve for the correction to the course, which is 10°. Since the wind is from the left, 10° must be subtracted from the true course. Following the same procedure in figure 40, the ground speed of 78 m.p.h. is found by interpolation between the curves for 75 and 80 m.p.h. This is the ground speed that will be made good along the corrected course.

Example 2.—The cruising speed of plane is 100 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 corrected course.

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 41 will guard against errors.

In figure 39, follow the vertical line for 32 m.p.h. down to its intersection with the horizontal line for 120° and read the correction to the course, which is 16°. Since the wind is from the right, this correction must be added to the true course.

Following the same procedure in figure 40, the ground speed of 112 m.p.h. is interpolated between the curves for 110 and 115 m.p.h.

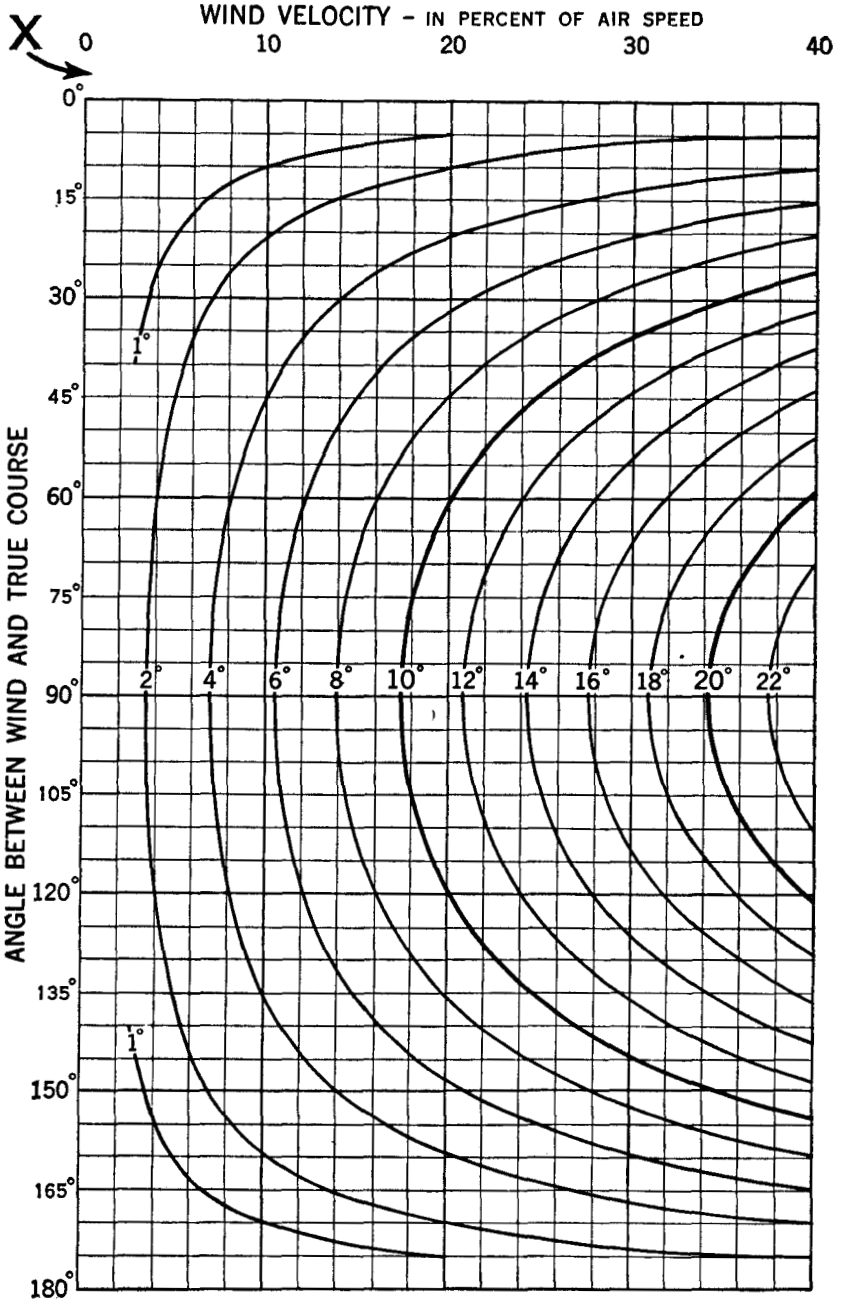


FIGURE 39.—Graph for finding the wind correction angle. **Important:** To adapt this graph for use with your plane, write in "Line X" the wind velocities corresponding to the indicated percent of the cruising speed of your plane. See p. 51.

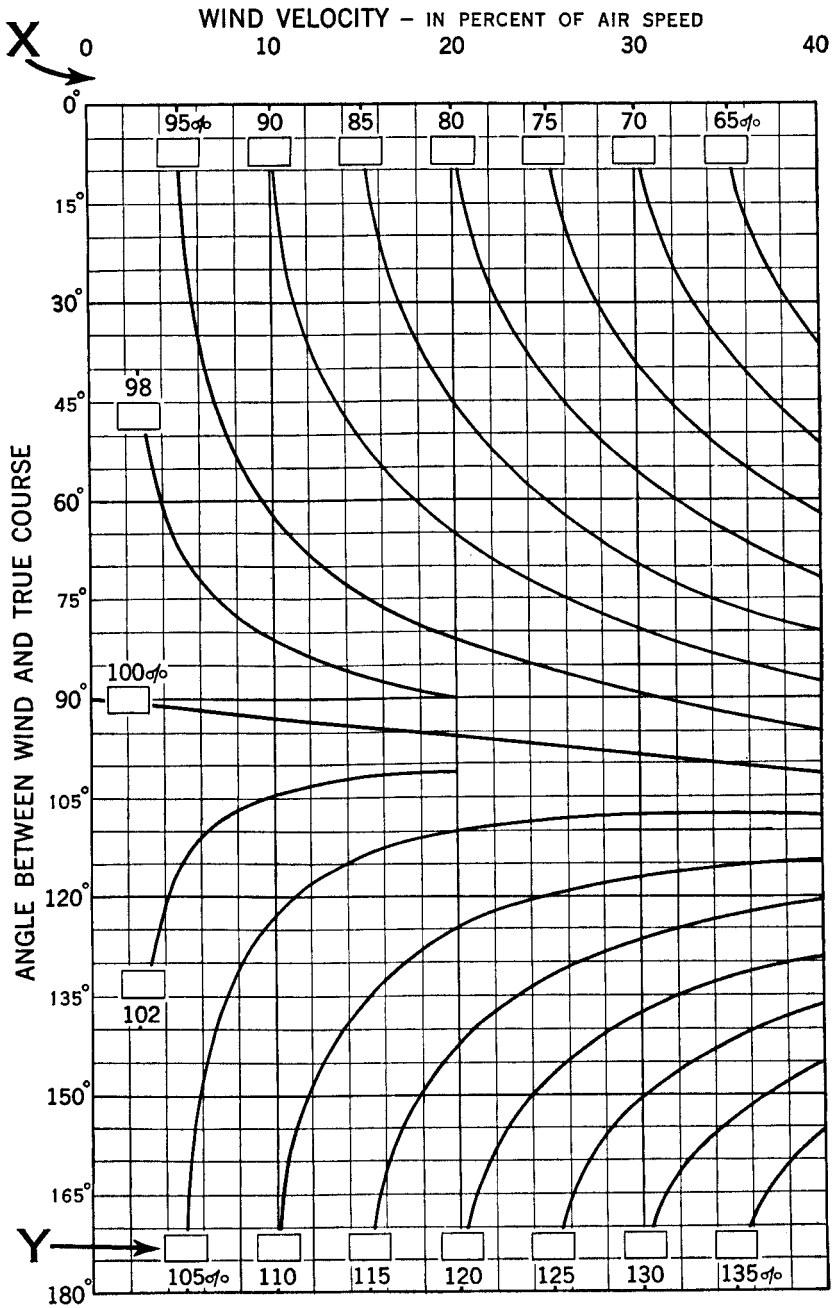


FIGURE 40.—Graph for finding the corrected ground speed. **Important:** To adapt this graph for use with your plane, (1) write in "Line X" the wind velocities corresponding to the indicated percent of the cruising speed of your plane; (2) write in "Boxes Y" the ground speeds corresponding to the indicated percent of the cruising speed of your plane. See p. 51.

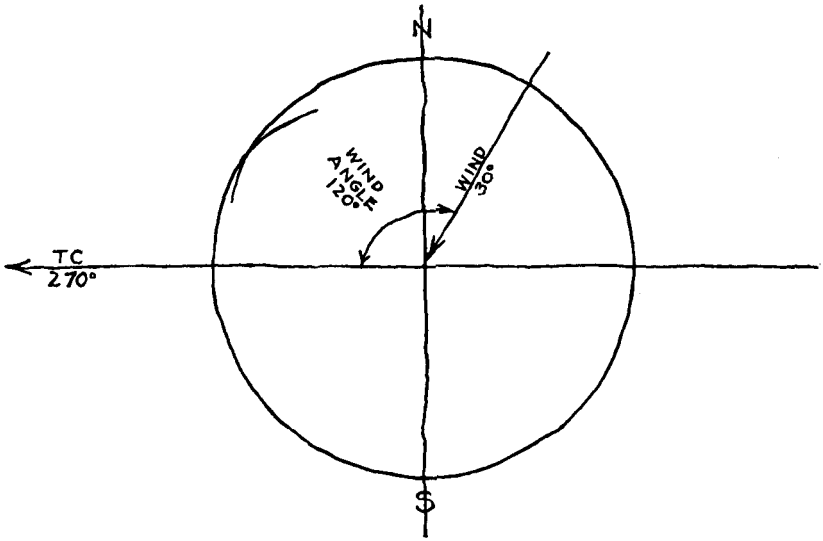


FIGURE 41.—Determining the wind angle.

RECTIFYING THE COURSE AND GROUND SPEED FOR THE EFFECT OF WIND

[See fig. 42.]

In effect, this graph 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 are drawn at 5-mile distances from the center for reading wind velocities.

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 5 miles apart and provide a convenient scale for reading ground speeds.

Figures 39 and 40 are for use in dead reckoning, case I (p. 22); this graph is for use in case II (p. 32).

As in figures 39 and 40, wind velocities and ground speeds indicated in this figure are in percent of air speed. To adapt it for use with your plane, write in "Line X" the indicated percent of the cruising speed of your plane; in each red "Box Y" write the wind velocity for the indicated percent of the cruising speed.

In this case, also, a cruising speed of 100 m.p.h. will be used in the examples to permit reading the percentage velocities in miles per hour. However, when adapted as suggested above, it is equally suitable for use with any cruising speed.

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. Following the (interpolated) red line for

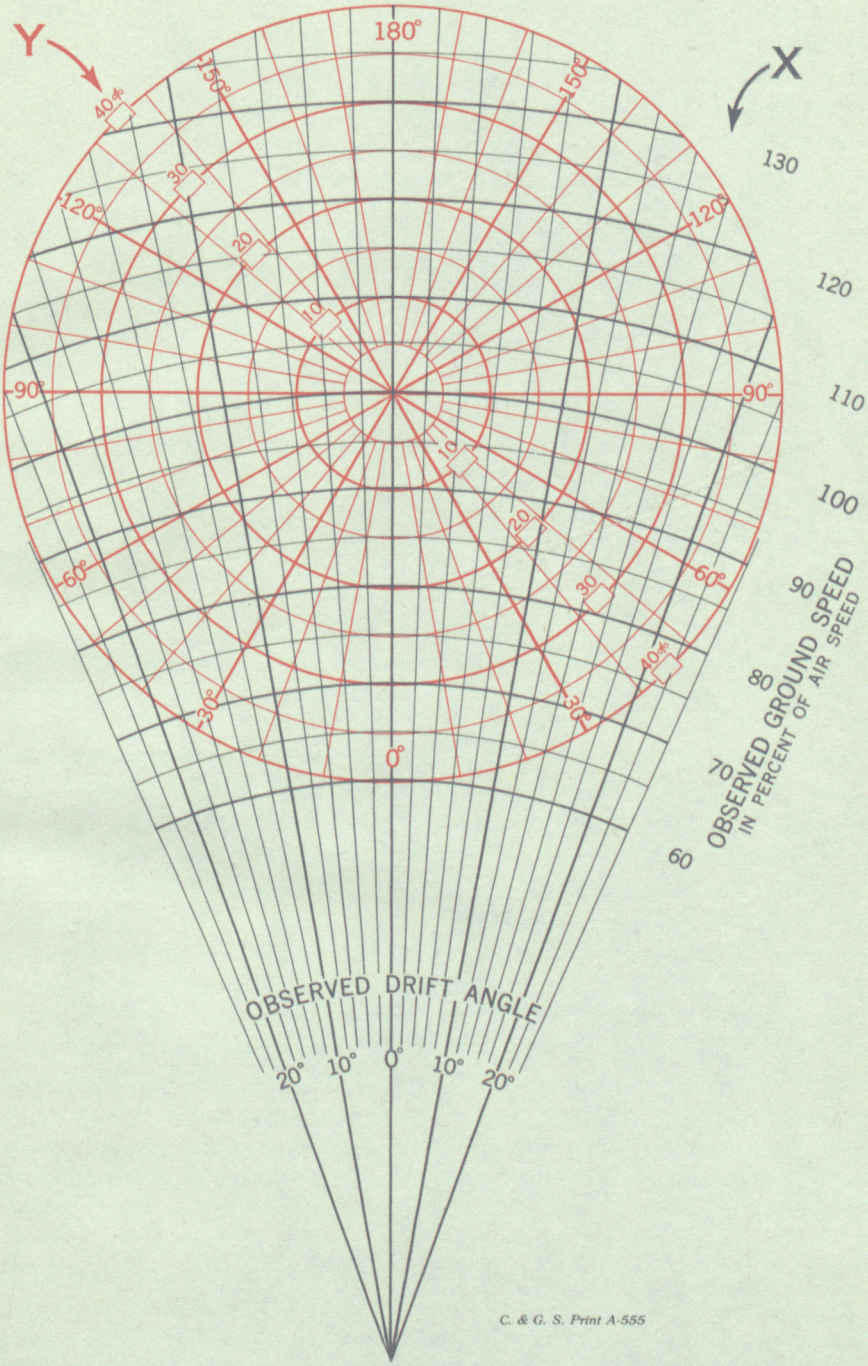


FIGURE 42.--Graph for rectifying course and ground speed for wind.

135° from the center to its intersection with the circle for 20 m.p.h., it is seen that the ground speed is 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 a cruising speed of 100 m.p.h. and on a true heading of 90° was able to determine a drift angle of 12° 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 12° drift to the right, we find a wind velocity of 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 12° must be added: 90°+12°=102°, the track made good. The ground speed of 102 m.p.h. is also read from the graph.

Example 3.—A plane cruising at a speed of 100 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 113 m.p.h. are observed. Find the wind direction and velocity.

Follow the black drift line marked 10° (to the right of 0°) out to its intersection with the (interpolated) black ground speed arc representing 113 m.p.h. The position of this intersection between the red circles for 20 and 25 m.p.h. indicates the velocity of the wind, which is 23 m.p.h., and the nearest 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.

The usual method of obtaining wind direction and velocity in flight consists of steering the plane on two different compass headings and noting the drift angle on each; with these data a "wind rose" is plotted, and the wind direction and velocity are scaled. This new method, using the graph shown in figure 42, affords these data from one observation.

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

[See fig. 43.]

Figures 39 and 40 are intended largely for determining the corrections to course and ground speed 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 the conditions predicted.

Figure 42 is of use chiefly for finding the track and ground speed or for finding the wind direction and velocity while in flight.

By the use of figure 43 the pilot is no longer concerned with wind direction and velocity, provided visibility permits the use of a drift indicator. From one observation he may read directly from the graph the correction to the course for wind and the ground speed that will be made good along the corrected course.

One of the chief advantages of this method is that corrections are based on conditions experienced at the moment, not on predicted

conditions. In addition, if at any time during flight it is believed that wind conditions have materially changed, the corrections may be quickly checked or redetermined simply by heading the plane once more on the original (no-wind) compass course, noting the new drift angle and ground speed and reading the corrections directly from the graph.

In this graph the observed ground speed and the corrected ground speed are both in percent of air speed. To adapt it for use with your plane, write in "Column X" and in "Boxes Y" the indicated percent of the cruising speed of your plane.

Example 1.—A plane having a cruising speed of 100 m.p.h. is headed on the no-wind compass course, when a drift angle of 8° to the right and a ground speed of 123 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 corrected course.

Follow the vertical line corresponding to an 8° drift angle down to its intersection with the horizontal line for 123 m.p.h. ground speed and read, from the nearest red curve, 10°, the correction to the course for wind; the nearest black curve, 120 m.p.h., indicates the ground speed along the corrected course. Since the drift is to the right, the wind is from the left, and the 10° must be subtracted from the compass course.

DRIFT DETERMINATION WITHOUT A DRIFT INDICATOR

[See fig. 44.]

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 44 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 38 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 corrected course can be obtained at a glance from figure 43. Or if wind direction and velocity are required, these may be obtained from figure 42 with the same data.

Example 1.—In flying from Cedar Lawn Airport, near Kenton, Ohio, to Springfield Airport (plate I), on a true heading of 189° and at a cruising speed of 100 m.p.h., a pilot passes directly over the town of Rushsylvania just five minutes after taking off. Knowing that this town is west of his intended track, he wishes to find the

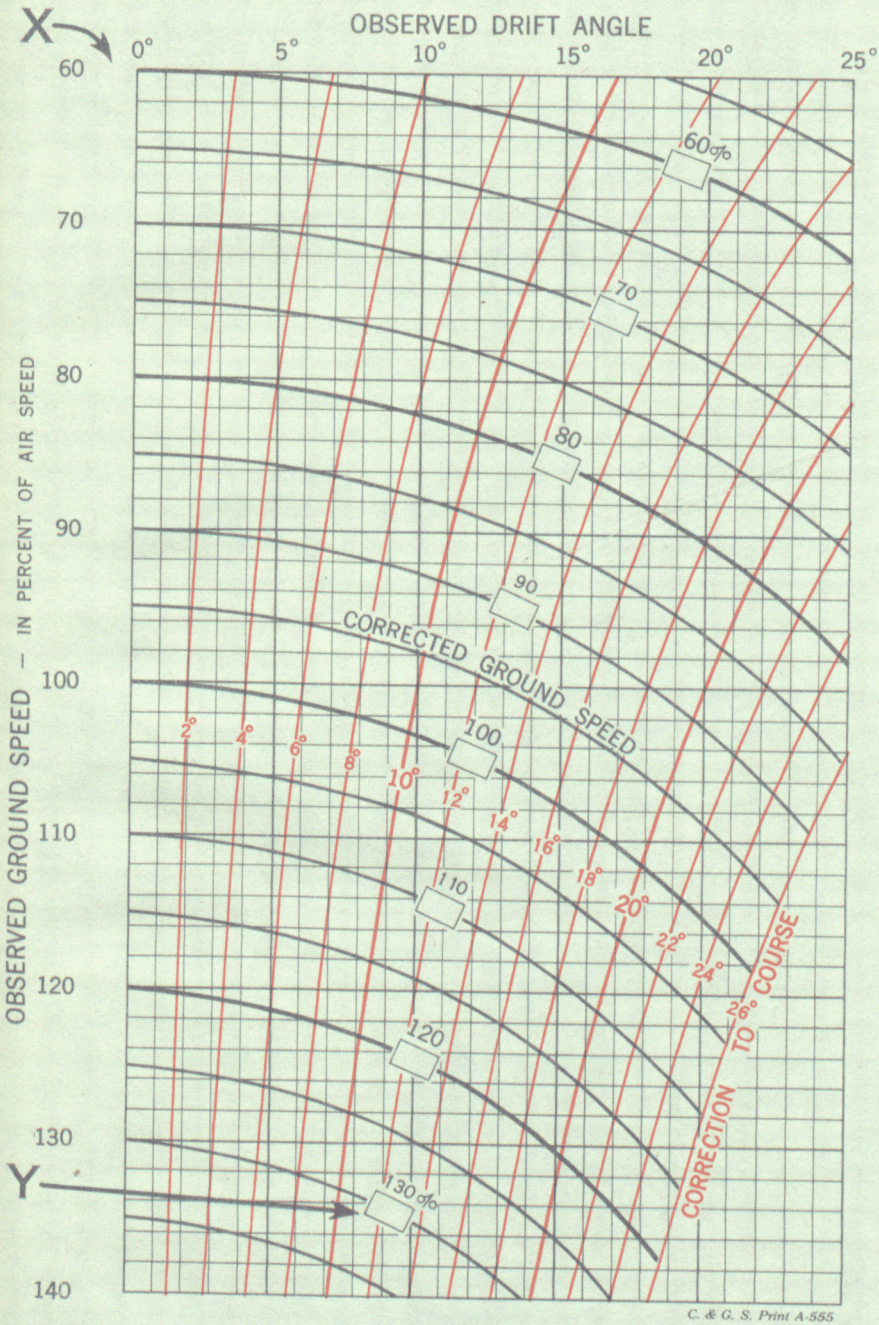


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FIGURE 43.–Graph for finding wind correction and ground speed from one observation with a drift indicator.

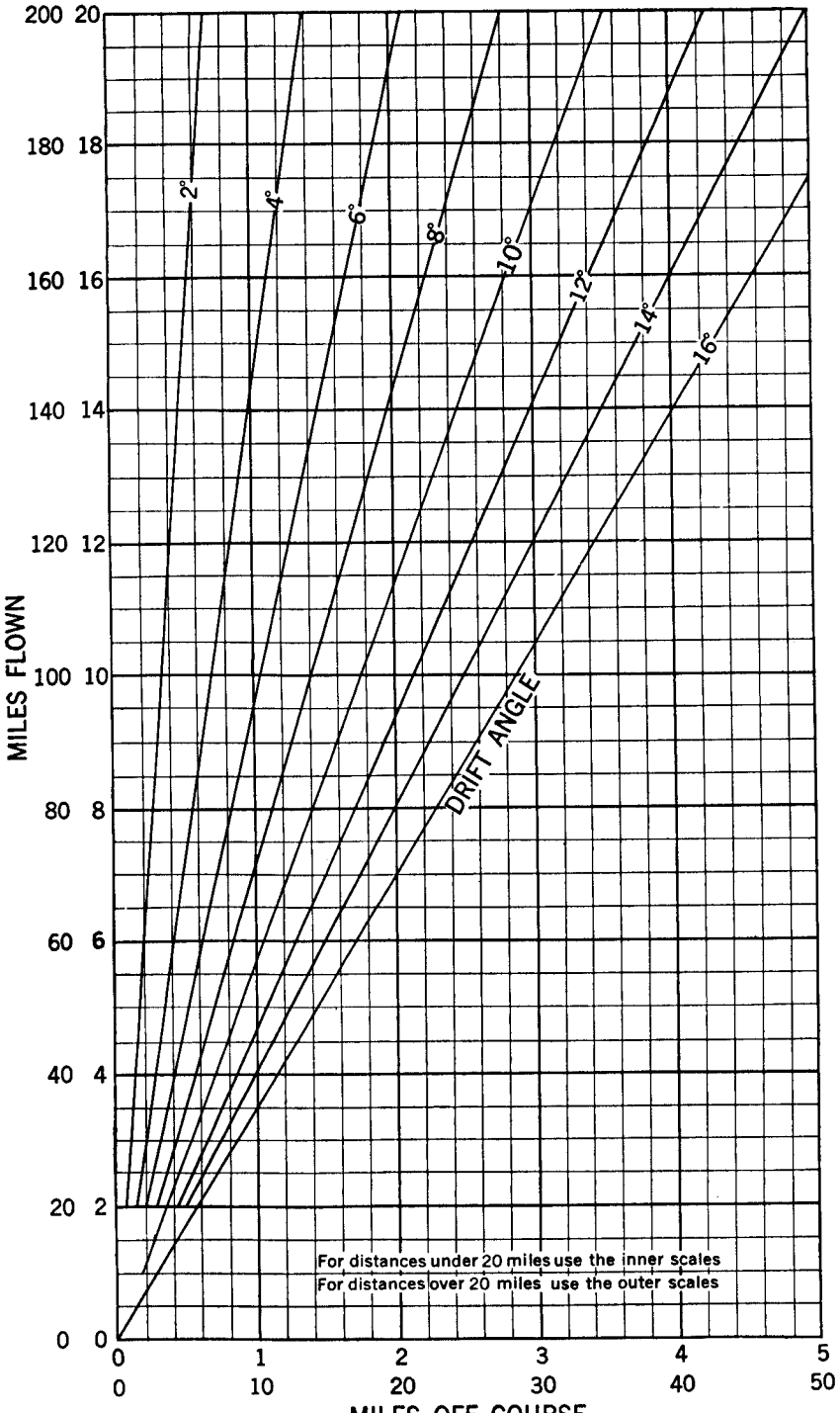

FIGURE 44.—Graph of drift angles.

correction to be made to his course, and the ground speed that will be made good along the corrected course.

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 44, that this corresponds to a drift angle of 11°, and from figure 38, that the ground speed is 126 m.p.h. Referring to figure 43 with these data he reads the correction to his course as 14°, and the ground speed that will be made good along the corrected course as 120.5 m.p.h. Since the wind is from the left, the correction of 14° must be subtracted from the heading: 189°−14°= 175°, the true heading to be steered.

If he should wish to know the direction and velocity of the wind, he may enter figure 42 with a drift angle of 11° to the right and a ground speed of 126 m.p.h., and read the wind velocity as 34 m.p.h., and the wind direction as 135° from the heading of the plane, or 189°−135°=54° true.

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.

AP=Airport.
AS=Air speed.
Bn=Beacon.
CC=Compass course.
CH=Compass heading.
D=Drift angle.
Dev=Deviation, Compass.
GS=Ground speed.
MC=Magnetic course.
MH=Magnetic heading.
mph=Miles per hour.
O=Origin, or starting point.
RA=Radio range station.
RBn=Marine radiobeacon.
RC=Radio compass (naval radio direction finder station).
RM=Radio marker beacon.
RS=Radio station.
SP=Seaplane port.
TC=True course.
TH=True heading.
Var=Variation.
W=Wind (direction and velocity).
Z=Azimuth or bearing.

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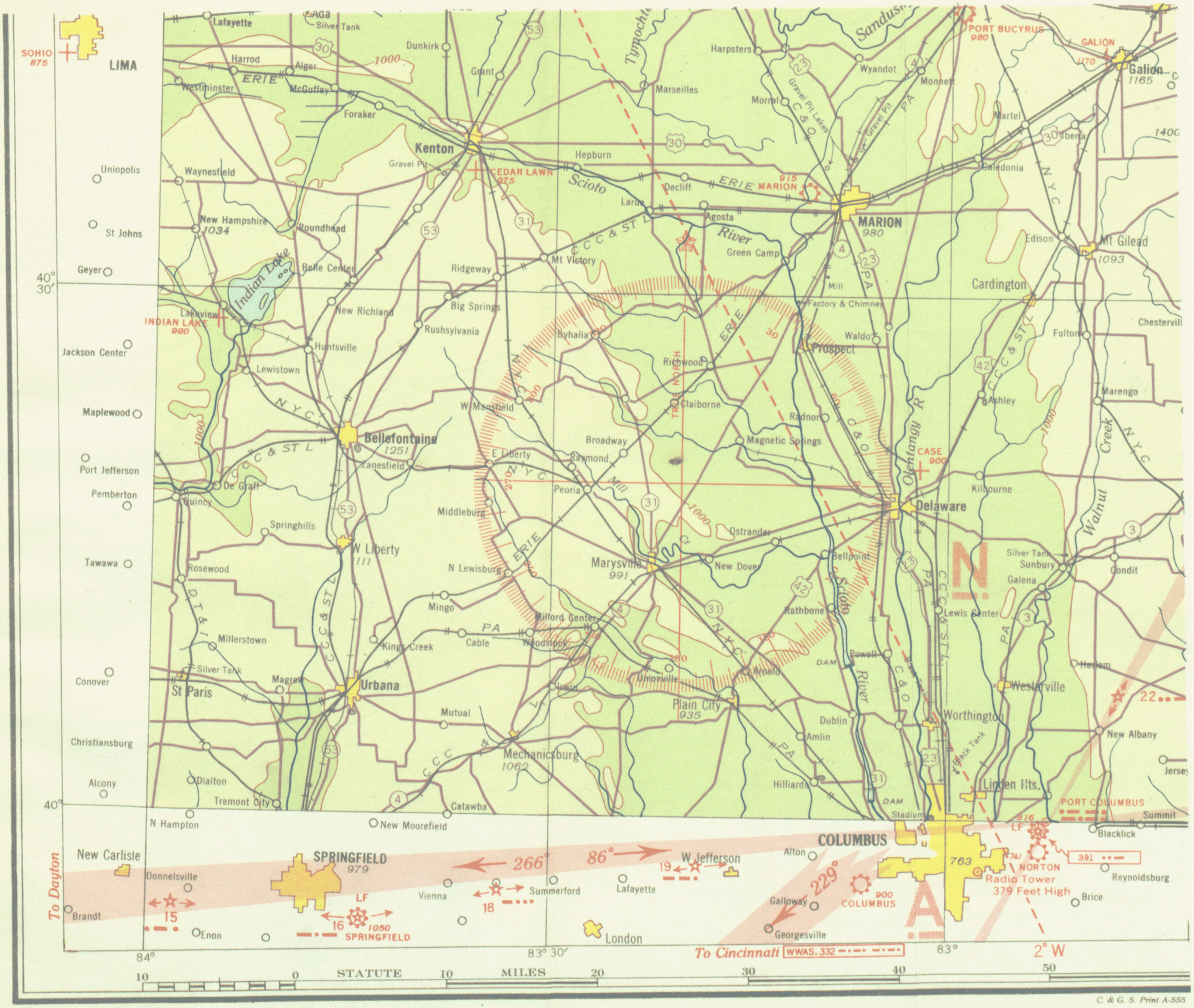
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SOHIO 875
Lafayette
Silver Tank
Dunkirk
Harrod
Alger
Westminster
McGuffey
Foraker
Grant
Kenton
Gravel Pit
CEDAR LAWN 975
Hepburn
Scioto
Tymochtee
Marseilles
Harpsters
Morral
Wyandot
Monnett
Sandusky
PORT BUCYRUS 980
GALION 1170
Galion 1165
Martel
Iberia
Galedonia
Uniopolis
Waynesfield
St Johns
New Hampshire 1034
Roundhead
Belle Center
Indian Lake
Geyer
Lakeview
INDIAN LAKE 980
Jackson Center
Huntsville
Lewistown
New Richland
Ridgeway
Big Springs
Rushsylvania
Mt Victory
Larue
Decliff
Agosta
Green Camp
ERIE
915 MARION
MARION 980
Edison
Mt Gilead 1093
Cardington
Chesterville
Fulton
Marengo
Maplewood
Bellefontaine 1251
Zanesfield
W Mansfield
Byhalia
Richwood
Claiborne
Prospect
Waldo
Factory & Chimney
Mill
Ashley
Radnor
Magnetic Springs
Broadway
Raymond
E Liberty
Peoria
Port Jefferson
Pemberton
De Graff
Quincy
Middleburg
Springhills
W Liberty 111
Rosewood
N Lewisburg
Marysville 991
Ostrander
New Dover
Bellpoint
Delaware
CASE 900
Kilbourne
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Walnut Creek
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Alcony
Dialton
Tremont City
Catawba
N Hampton
New Moorefield
Stadium
PORT COLUMBUS
Summit
Blacklick
COLUMBUS
New Carlisle
SPRINGFIELD 979
266°
86°
W Jefferson
Alton
229°
763
741
NORTON
Radio Tower
379 Feet High
391
Reynoldsburg
Donnelsville
Vienna
Summerford
Lafayette
Galloway
900 COLUMBUS
Brice
To Dayton
Brandt
Enon
LF
1050 SPRINGFIELD
London
Georgesville
To Cincinnati
WWAS. 332
2° W
40° 30′
40°
84°
83° 30′
83°
STATUTE MILES
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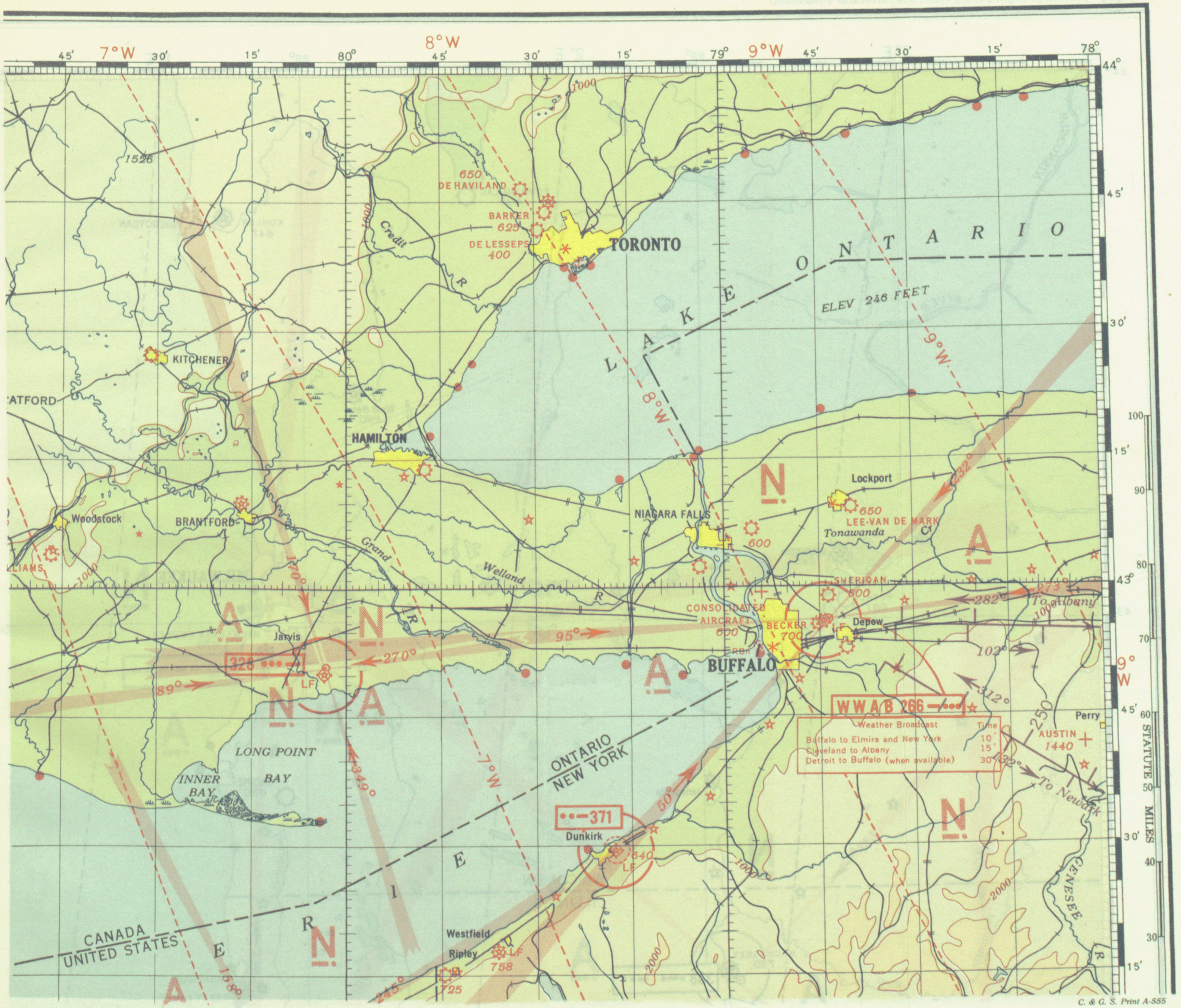
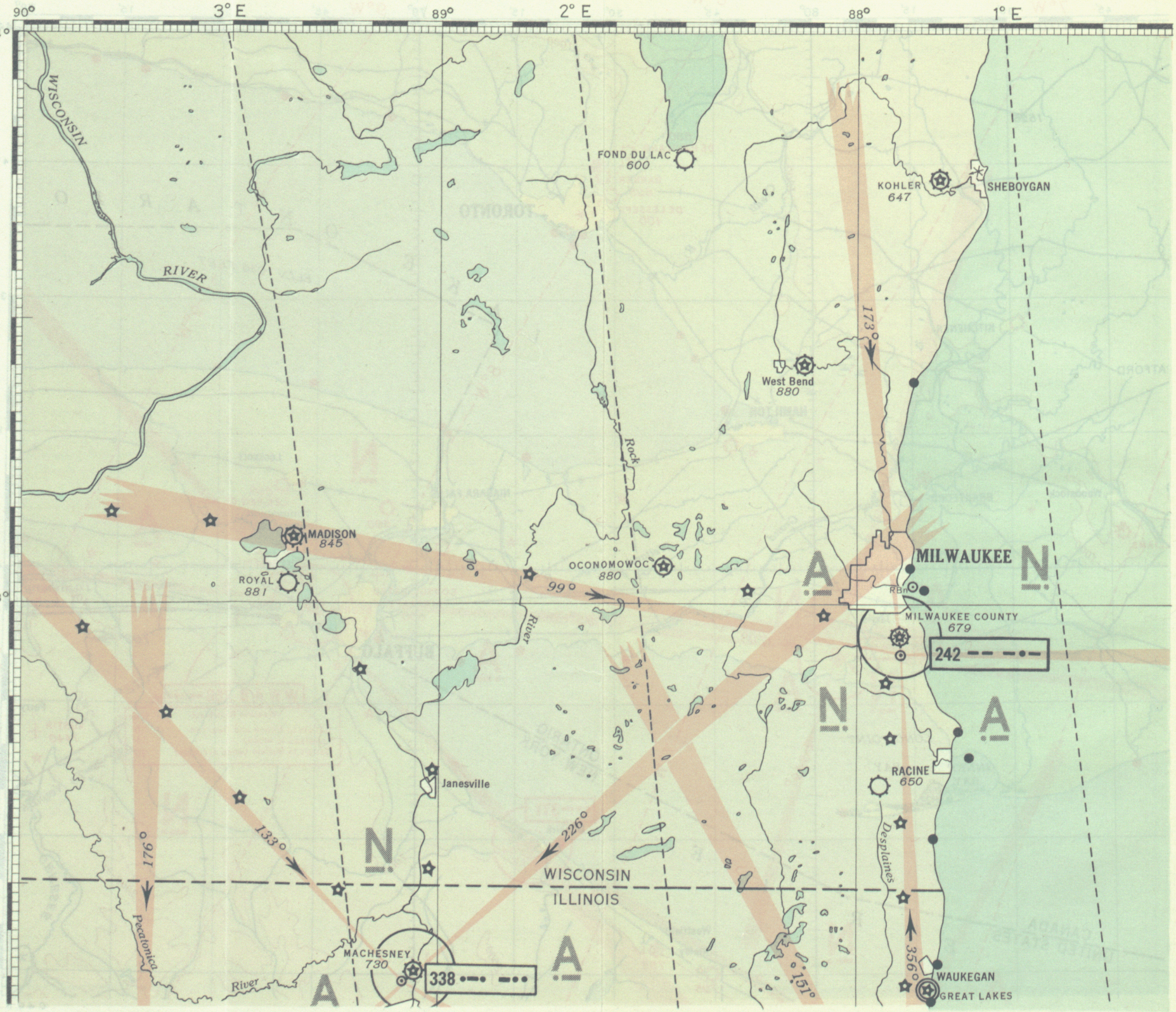
PLATE II
(Portion of Regional Chart 9M)




90°
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89°
2° E
88°
1° E
44°
43°
WISCONSIN
RIVER
FOND DU LAC
600
KOHLER
647
SHEBOYGAN
173°
West Bend
880
Rock
River
MADISON
845
ROYAL
881
OCONOMOWOC
880
99°
MILWAUKEE
RBn
MILWAUKEE COUNTY
679
242
Janesville
RACINE
650
Desplaines
133°
226°
176°
WISCONSIN
ILLINOIS
Pecatonica
River
MACHESNEY
730
338
151°
356°
WAUKEGAN
GREAT LAKES

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