TM 1–205

WAR DEPARTMENT

TECHNICAL MANUAL

AIR NAVIGATION

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CHANGES No. 1 } WAR DEPARTMENT, WASHINGTON 25, D. C., 6 October 1943.

TM 1–205, 25 November 1940, is changed as follows:

170.1. (Added.) Drift by timing and bearings.—*a. General.*—(1) This method of reading drift is designed specifically for use when flying with a solid undercast. However, mountain tops must be showing above such an undercast. It is not necessary to know the geographical position of the mountains nor is it necessary to know their distance from the airplane. In fact, the greater the distance from the airplane the greater the accuracy of the drift reading.

(2) Such conditions as described are prevalent in the Alaskan theater of operations. Heretofore, a navigator flying under these conditions found it impossible to determine his drift. Therefore, it was impossible for him to keep his airplane on course resulting in great danger to equipment and personnel.

b. Equipment required.—(1) A pelorus, astro compass, or any other instrument by which a relative bearing can be taken.

(2) An accurate watch and preferably a stop watch especially when the airplane is a short distance (1 to 5 miles) from the mountain top.

c. Procedure.—The first step in determining drift is to set the pelorus to a relative bearing of 45° and wait for the object to come into the sight, at which instant the time is recorded. The pelorus is then set to a relative bearing of 90° and the instant the mountain comes into the sight the time is again recorded. The same procedure is used with a bearing of 135°.

d. Example.—(1) Figure 109.1 represents a case in which the time interval necessary to change the relative bearing from 45° to 90° is the same as that necessary to change the bearing from 90° to 135°. *A* is the position of the airplane when the relative bearing of the mountain is 45°; *B* is the position when the relative bearing is 90°; and *C* is the position when the relative bearing is 135°. Line *ABC* represents the true heading and the track since there is no drift. T_1 is the time interval necessary to change the relative bearing from 45° to 90°. T_2 is the interval necessary to change the relative bearing from 90° to 135°. When there is no drift, T_1 equals T_2.

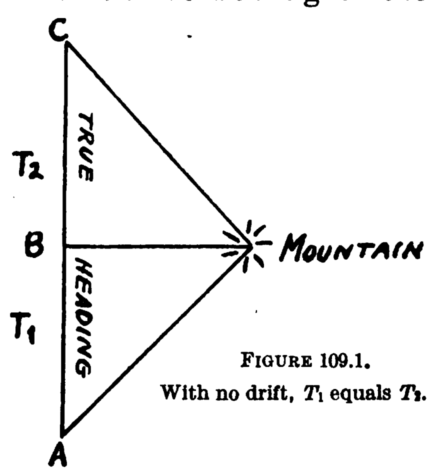
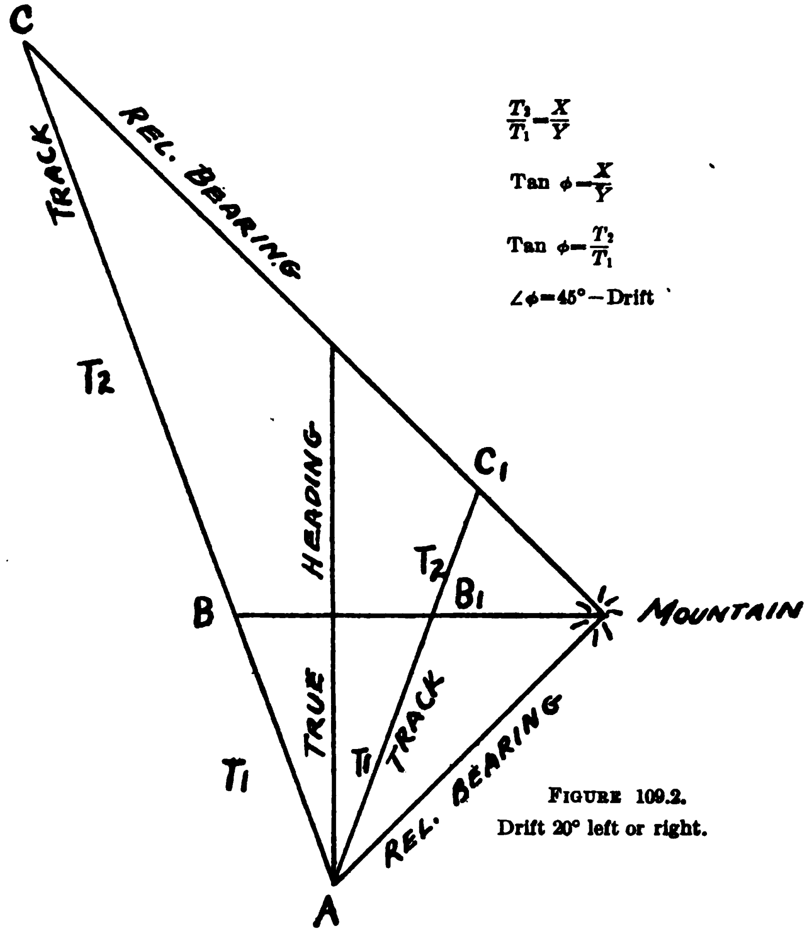


FIGURE 109.1.
With no drift, T_1 equals T_2.

(2) In figure 109.2, assume that the airplane is on the same true heading, 360°. The drift is 20° left or right and the track, therefore, 340° or 20°.



$\frac{T_2}{T_1}=\frac{X}{Y}$

Tan $\phi=\frac{X}{Y}$

Tan $\phi=\frac{T_2}{T_1}$

$\angle\phi=45°-$Drift

FIGURE 109.2.
Drift 20° left or right.

(*a*) Consider the first case, a drift 20° left. *A* again represents the airplane's position when the relative bearing is 45°; *B* is the position when the relative bearing is 90°; *C* is the position when the relative bearing is 135°. T_2 is greater than T_1.

(*b*) Now consider the second case, a drift 20° right. *A* is still the position of the airplane when the relative bearing is 45°; B_1 is the position when the relative bearing is 90°; C_1 is the position when the relative bearing is 135°. T_2 is less than T_1.

(*c*) After T_1 and T_2 are recorded, the latter is divided by the former. The quotient is a factor which necessitates reference to certain tables. Table A is used when the object from which the relative bearing was taken is on the right side of the airplane; table B when the object is on the left side. Opposite the factor is found the drift correction.

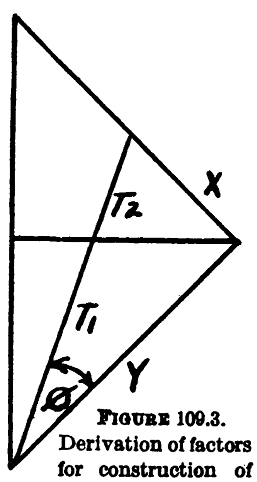


FIGURE 109.3.
Derivation of factors for construction of tables A and B.

(*d*) When the object is on the left side of the airplane, the relative bearings are in turn 315°, 270°, and 225°. The factors are derived from the geometric construction shown in figure 109.3.

e. Disadvantages of method.—(1) Since drift alone is obtainable, if the course must be changed, the navigator is not aware of the new drift.

(2) If the landmark is a considerable distance away (50 miles or more), by the time the relative bearing of 135° or 225° is reached, the object may be obscured.

(3) If the landmark is very close (5 miles or less), the relative bearing changes so quickly that the navigator will experience difficulty in obtaining accurate T_1 and T_2 values. If these values are inaccurate, the resultant factor may be in considerable error.

TABLE A.—*Drift by timing*

If object on which bearing is taken is to the *right* of the airplane, use this table.
Divide T_2 by T_1 to determine factor.

Drift correction	Factor	Drift correction	Factor
+1	1. 0355	−1	0. 9657
2	1. 0724	2	. 9325
3	1. 1106	3	. 9004
4	1. 1504	4	. 8693
5	1. 1918	5	. 8391
6	1. 2349	6	. 8098
7	1. 2799	7	. 7813
8	1. 3270	8	. 7536
9	1. 3764	9	. 7265
+10	1. 4281	−10	. 7002
11	1. 4826	11	. 6745
12	1. 5399	12	. 6494
13	1. 6003	13	. 6249
14	1. 6643	14	. 6009
15	1. 7321	15	. 5774
16	1. 8040	16	. 5543
17	1. 8807	17	. 5317
18	1. 9626	18	. 5095
19	2. 0503	19	. 4877
+20	2. 1445	−20	. 4663
21	2. 2460	21	. 4452
22	2. 3559	22	. 4245
23	2. 4751	23	. 4040
24	2. 6051	24	. 3839
25	2. 7475	25	. 3640
26	2. 9042	26	. 3443
27	3. 0777	27	. 3249
28	3. 2709	28	. 3057
29	3. 4874	29	. 2867
+30	3. 7321	−30	. 2679
31	4. 0108	31	. 2493
32	4. 3315	32	. 2309
33	4. 7046	33	. 2126
34	5. 1446	34	. 1944
35	5. 6713	35	. 1763
36	6. 3138	36	. 1584
37	7. 1154	37	. 1405
38	8. 1443	38	. 1228
39	9. 5144	39	. 1051
40	11. 4301	40	. 0875

TABLE B.—*Drift by timing*

If object on which bearing is taken is to the *left* of the airplane, use this table.
Divide T_2 by T_1 to determine factor.

Drift correction	Factor	Drift correction	Factor
+1	0. 9657	−1	1. 0355
2	. 9325	2	1. 0724
3	. 9004	3	1. 1106
4	. 8693	4	1. 1504
5	. 8391	5	1. 1918
6	. 8098	6	1. 2349
7	. 7813	7	1. 2799
8	. 7536	8	1. 3270
9	. 7265	9	1. 3764
+10	. 7002	−10	1. 4281
11	. 6745	11	1. 4826
12	. 6494	12	1. 5399
13	. 6249	13	1. 6003
14	. 6009	14	1. 6643
15	. 5774	15	1. 7321
16	. 5543	16	1. 8040
17	. 5317	17	1. 8807
18	. 5095	18	1. 9626
19	. 4877	19	2. 0503
+20	. 4663	−20	2. 1445
21	. 4452	21	2. 2460
22	. 4245	22	2. 3559
23	. 4040	23	2. 4751
24	. 3839	24	2. 6051
25	. 3640	25	2. 7475
26	. 3443	26	2. 9042
27	. 3249	27	3. 0777
28	. 3057	28	3. 2709
29	. 2867	29	3. 4874
+30	. 2679	−30	3. 7321
31	. 2493	31	4. 0108
32	. 2309	32	4. 3315
33	. 2126	33	4. 7046
34	. 1944	34	5. 1446
35	. 1763	35	5. 6713
36	. 1584	36	6. 3138
37	. 1405	37	7. 1154
38	. 1228	38	8. 1443
39	. 1051	39	9. 5144
40	. 0875	40	11. 4301

[A. G. 300.7 (1 Oct 43).] (C 1, 6 Oct 43.)

BY ORDER OF THE SECRETARY OF WAR:

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OFFICIAL:
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AIR NAVIGATION

Prepared under direction of the
Chief of the Air Corps

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CHAPTER 1

PILOTAGE AND ELEMENTARY DEAD RECKONING

SECTION I

GENERAL

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1. Purpose and scope.—The purpose of this manual is to describe and illustrate the various methods of air navigation used by pilots of the Army Air Corps. Pilotage, elementary dead reckoning, and the use of the Federal aids to air navigation will be covered in detail in this chapter, so that this manual may be used as a text for students undergoing flying instruction.

2. Definition and development of air navigation.—*a.* Air navigation is the art of determining the geographical position and maintaining the desired direction of an aircraft, relative to the earth's surface, by means of pilotage, dead reckoning, radio aids, or celestial observations. It is not an exact science.

b. The basic principles of air navigation are very similar to those used centuries ago by mariners. Present day navigators depend upon the magnetic compass for direction as did Columbus when he sailed the Atlantic. Gradually, through the centuries, better instruments have been developed, and methods have been refined. When airplanes were developed to the point where they could fly for short distances on cross-country flights, there was an immediate need for navigation methods suitable for use in the air. Following the path made by rivers, railroads, and highways was one of the earliest methods, but with improvement of airplanes and engines, overwater flights were made and a better method of navigation was required. It became necessary to borrow methods from the marine navigator. The air surrounding the earth is simply an ocean through which aircraft may cruise, guided by navigational methods very similar to those used to guide boats over the surface of the sea. With long flights, many of them over water, now a routine thing, it is apparent that there is need for a scientific method of air navigation. This must include one or more ways of flying accurate courses when—

(1) Over poorly mapped country.

(2) Over water.

(3) Over fog and in any condition of poor visibility.

(4) Making flights at night.

3. Methods used in air navigation.—There are four general methods used in air navigation: pilotage, dead reckoning, radio navigation, and celestial navigation. Two or more of these methods are usually combined in actual practise, but for purposes of instruction they are treated separately. An explanation of their combined use during flight conditions will be made in section X.

4. Pilotage.—Pilotage is the method of conducting an aircraft from one point to another by observation of landmarks either previously known or recognized from a map. This method is, therefore, very limited when navigating over poorly mapped country, over bodies of water, at night, off regularly established airways where no beacons exist, or during weather when visibility is poor. However, pilotage is always used, whenever possible, in conjunction with the other methods of navigation. The use of ranges and cross bearings is included in this method and can often be used to good advantage. This method is analogous to that used by the motorist, where the highway is equivalent to the compass course and towns passed through are the check points.

5. Dead reckoning.—Dead reckoning (D. R.) is the method of determining the geographical position and maintaining the required course by applying the ground speed and track, as estimated or calculated, over a certain period of time from the point of departure or from the last known position. It is deduced reckoning and is the basic method of navigation, being used at all times, by itself, and in conjunction with the other methods of navigation. The use of this method allows flights to be made with very little or no reference to outside objects. It is used extensively on over-water flights where pilotage methods fail because of the lack of check points.

6. Radio navigation.—Radio navigation is the method of conducting an aircraft from one point to another by radio aids, such as the radio beacon, radio direction finder, or radio bearings. Development of this method of navigation is receiving considerable attention. Its possibilities are great due to the fact that no view of the ground is necessary and that instrument landings are made possible. The reliability, accuracy, and power of radio equipment in the hands of a skilled operator constitute the only limiting factors of this method.

Should this equipment fail or the radio signals be interfered with, some other method of navigation must be relied upon. It is likewise used in conjunction with other methods. This method has a doubtful value in time of war, due to radio interference or to restrictions imposed by "radio silence."

7. **Celestial navigation.**—Celestial navigation is the method of determining the geographical position of an aircraft by observation of celestial bodies. The use of celestial bodies for determining position is as old as history, and although the basic principles have been unchanged for some time, constant improvements in methods and procedure have made celestial observations a fairly simple and yet accurate means of navigation.

8. **Marine and air navigation compared.**—The ocean currents are plotted on charts so that the navigator can refer to them and can accurately gage their effect on the vessel. In the air this is not the case; there are variable currents moving in many directions, so that it is impossible to plot them on a map. It is necessary to resort to some other method to determine the effect of air currents. There is a great difference in the relative speeds of the currents; in the ocean they seldom exceed 4 knots, while in the air they may move more than 90 knots. On board a ship the visibility is usually about 8 or 10 miles, while in the air at 5,000 feet the calculated visibility is 81 miles, although under normal conditions, depending upon the atmosphere, it is usually about 20 miles. The heading of an airplane cannot be as accurately maintained due to the smaller compass that is used. The patent log of the mariner is much more accurate for determining distance traveled on a course than is the determination of ground speed from the air. The mariner can fix his position by celestial bodies to within 1 mile, while in the air 5 to 10 miles is average under normal air conditions. The modern airplane travels at speeds of more than 200 miles per hour as compared to the 30 knots of the modern ocean liner. The ocean vessel may be stopped completely when danger threatens in conditions of poor visibility, while the airplane must continue to travel at relatively high speeds in order to maintain its altitude.

Section II

MAPS AND CHARTS

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9. Definitions.—*a. Map and chart.*—A map is a representation of a sphere or a portion of a sphere on a flat surface. The term "map" is used for areas that are mostly land. Ordinarily, the term "chart" is used for representations of areas that are mostly water; however, the Civil Aeronautics Administration applies the term to publications prepared by them, although many of these charts cover only land areas. In order to represent a sphere or a portion of a sphere on a flat surface it must of necessity be distorted. The methods of representing portions of the earth on a map or chart are known as "projections." There are four main types of projections in general use: the Mercator, Lambert conformal (conic), gnomonic, and polyconic. Each type of projection has its use, and no one projection has every feature which is desirable in a map.

b. Sphere.—A sphere is a body bounded by a surface all points of which are equidistant from a point called the "center." For the purposes of navigation the earth is usually considered to be a sphere. Actually it is an ellipsoid whose polar diameter is 7,899.7 and equatorial diameter is 7,926.5 statute miles. It is apparent that the earth's deviation from the spherical is slight.

c. Great circle.—A great circle is a circle on the earth's surface whose plane passes through the center of the earth. The great circle equidistant from the two poles is known as the Equator. Great circles passing through the two poles are known as meridians.

d. Small circle.—A small circle is a circle on the earth's surface whose plane does not pass through the center of the earth. Small circles whose planes are parallel to the great circle plane of the Equator are known as parallels of latitude.

e. Rhumb line.—A rhumb line is a line which crosses all meridians at the same angle. It does not necessarily represent the shortest distance between points. Any two points on the earth's surface may be connected by a rhumb line. The rhumb line drawn on the sphere is known as a loxodromic curve. According to the foregoing definition, the meridians, the Equator, and the parallels are rhumb lines, but the meridians and the Equator being also great circles are usually not considered rhumb lines. The parallels are a special type of rhumb line since they intersect every meridian at 90°. All other rhumb lines are curves which approach but never reach the poles. The path of an airplane maintaining a constant course is a rhumb line. Rhumb lines appear as straight lines on the Mercator projection. This is true of no other projection.

10. Latitude and the Equator.—Latitude (Lat.) is the angular distance north or south of the Equator, as subtended at the center of the earth, measured from the Equator as a plane of origin. Latitude is measured in degrees, minutes, and seconds of arc, and may have any value from 0° at the Equator to 90° north or south, which would indicate the North or South Pole. North latitude is sometimes designated by the + sign and south latitude by the − sign; it is better practice, however, to use the letters N. or S. to designate the latitude of a point.

11. Longitude and the prime meridian.—Longitude (Long.) is the angular distance, at the axis of the earth, between the plane of a meridian and the plane of the prime meridian of Greenwich, England, measured to the eastward or westward. Longitude is measured in degrees, minutes, and seconds of arc, and may have any value from 0° at Greenwich, England, up to 180° east or west. The area of the United States is in latitude north (of the Equator) and longitude west (of the prime meridian).

12. Latitude and the nautical mile.—The angular distance between the Equator and the North or the South Pole is 90° or 5,400 minutes. If we use the actual length of a minute of latitude as a unit of linear distance, we have 5,400 of these units as the distance between the Equator and either the North or South Pole. This unit of distance is called a nautical mile and is 6,080 feet in length. The statute mile, an arbitrarily selected unit of measure, is 5,280 feet in length. The relationship between latitude and distance, 1 minute of arc of latitude equaling 1 nautical mile, makes the nautical mile very useful in navigation and led to its adoption as the standard measure of distance in marine navigation. Although 1 minute of arc of latitude equals 1 nautical mile, the same relationship does not exist between arc of longitude and the nautical mile except at the Equator.

13. Longitude, arc and distance.—Although arc of latitude may be converted directly into distance as shown above, arc of longitude may be directly converted into nautical miles only at the Equator. There, and there only, 1 minute of arc of longitude equals 1 nautical mile. Methods of determining the linear distance represented by arc of longitude at various other points on the surface of the earth are described in section IX, chapter 2.

14. Conversion, nautical and statute units.—The nautical mile is longer than the statute mile, the ratio being as 115 is to 100. This relationship makes it possible to convert a specified distance, known in one of these units, to the other unit by use of one of the following formulas:

$$\text{(Distance in) statute miles} = \text{nautical miles} \times 1.15$$

$$\text{(Distance in) nautical miles} = \frac{\text{statute miles}}{1.15}$$

Thus if the distance from *A* to *B* is 100 nautical miles we have

$$\text{Statute miles} = 100 \times 1.15 \text{ or}$$

$$100 = \frac{\text{statute miles}}{1.15}$$

15. Mercator, Lambert conformal, gnomonic, and polyconic projections.—*a. Mercator.*—A map made on the Mercator projection has all meridians of longitude represented by parallel vertical lines and all parallels of latitude shown as parallel horizontal lines. Thus the straight lines representing meridians and parallels all cross each other at right angles. It is used extensively in marine navigation and in air navigation when the airplane carries a navigator as a member of the crew. Most of the hydrographic office charts for the U. S. Navy and the U. S. Coast and Geodetic Survey charts are constructed on this projection.

b. Lambert conformal projection.—(1) In the Lambert conformal projection, the meridians of the earth are represented by straight lines converging toward a common point outside the borders of the chart, and the parallels by curved lines which are sections of concentric circles whose center is at the point of intersection of the meridians. Meridians and parallels intersect at right angles.

(2) The scale error of any chart is small, and distances may be measured directly by means of the graphic scales printed on the border. If the entire United States is shown in a single chart, the maximum scale error for nearly 90 percent of the chart is about ½ of 1 percent—an error quite negligible in practice.

c. Gnomonic.—A map or chart made with this projection has all meridians shown as converging straight lines and the parallels of latitude shown as curved lines with the exception of the Equator which appears as a straight line. Charts made on this projection are sometimes called "great circle charts" because a straight line drawn on such a chart will indicate a great circle, which is the shortest distance between points. Courses drawn on the gnomonic chart are transferred to another kind of chart or map for actual use in navigation.

d. Polyconic.—A map made on this projection has the central meridian shown as a straight line and all other meridians shown as curved lines. The parallels are arcs of circles, each with a different radius. This type of projection is not used for navigation maps in the United States but is used for Geological Survey, engineer, and many military maps. Maps based on the polyconic are sometimes the only ones available when navigating over land areas outside the United States.

e. Reference.—A more complete description of these and other projections is given in section III, chapter 2.

16. Aeronautical charts of the United States.—*a. List.*—The following aeronautical charts of the United States are now being published or prepared. All but the last two are based on the Lambert-conformal projection.

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

(2) *Regional charts* to cover the United States, in 17 sheets, at a scale of 1: 1,000,000, or about 16 miles to the inch.

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

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

(5) *Great circle chart* of the United States (chart No. 3074), at approximately the same scale as chart No. 3060a.

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

b. History.—(1) The Air Commerce Act of 1926 provided for the charting of airways and the publication of aviation maps necessary for safety in flying and for the further development of air transportation. At that time there were no suitable maps of the country as a whole, nor even maps which could serve as an adequate base for the addition of aeronautical data. A new type of map, especially designed to meet the needs of a new industry, was urgently required, and the technical work of investigating this field and of compiling and publishing the new maps of the airways was assigned to the United States Coast and Geodetic Survey of the Department of Commerce, with instructions "to provide as adequate charts for air navigation as it now provides for ocean navigation."

(2) In order to satisfy the most immediate and pressing demands,

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

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

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

(5) Maps in general may be thought of as containing information which is subject to comparatively little change even over a considerable period of time. 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 are being rebuilt for more efficient operation; improved equipment is being installed; and aids are even being provided for the navigation of air routes across the oceans. The frequent correction of these charts to show the changes as they occur is a most important function of the Government and is imperative for safety in all forms of cross-country flying.

17. Chart reading.—*a. Importance.*—(1) An aeronautical chart is a small scale representation of a portion of the earth and its culture, presenting to the trained eye a description of the charted region more nearly perfect than could be obtained from the pages of a book. It depicts the landmarks and other information found of value by pilots long familiar with the region. Consequently, any time spent in learning to read and interpret its detailed information will be well repaid; that this is beginning to be appreciated is evidenced by the growing demand for these charts.

(2) 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 recently and therefore are not as well known. The following description of these symbols and their significance has been prepared as an aid to chart reading. It applies primarily to sectional charts, since the scale of that series permits the charting of fairly complete information. On the smaller scale charts many details must be omitted, but with few exceptions those that can be included are shown by the same symbols.

b. Features.—Features shown on these charts may be divided into two groups:

(1) Those necessary to a clear and accurate topographic representation of the region, such as—

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

(*b*) *Cultural*, such as towns, cities, roads, railroads, and other works of man.

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

(2) Aeronautical data and information of interest chiefly for use in air navigation.

c. Water features.—(1) 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.

(2) 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.

(3) Intermittent lakes and ponds are shown with broken shore lines and cross ruling in blue.

(4) 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.

(5) 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.

(6) Glaciers are indicated by blue shading, representing the form lines of the glacial area, superimposed on the conventional brown.

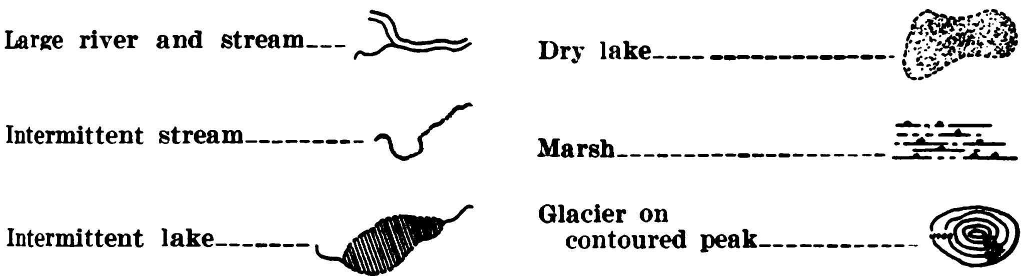


FIGURE 1.—Water features.

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

(2) (*a*) Prominent highways are indicated by a heavy purple line, secondary highways by lighter lines in purple. In a few instances very poor roads are charted because of unusual landmark value, and such roads are shown by a broken purple line (the conventional symbol for a trail).

(*b*) Prominent highways and secondary highways must be understood as only relative terms. In some of the thinly settled 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 sections there are so many roads that it is impossible 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.

(3) Railroads are represented by fairly heavy lines with cross ties at 5-mile intervals, electric railways (trolleys) by lighter black

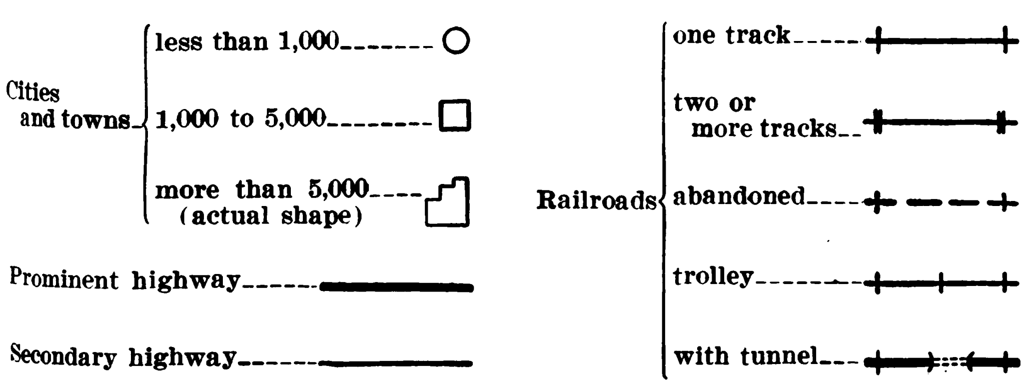


FIGURE 2.—Cultural features.

lines with cross ties at 2½-mile intervals. Thus, when the route parallels a railroad or electric railway, the spacing of cross ties provides a convenient check on ground speed and distance covered.

(4) Single-track railroads are shown with single cross ties, while for railroads of two or more tracks the cross ties are in pairs.

(5) 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.

(6) Tunnels are indicated not only because they serve as landmarks but also because they are a source of potential danger. If a pilot is following a railroad through territory with which he is not familiar and the railroad enters a tunnel, he may find himself suddenly confronted by a mountainside without sufficient space either to turn or to climb above it. This difficulty is seldom encountered

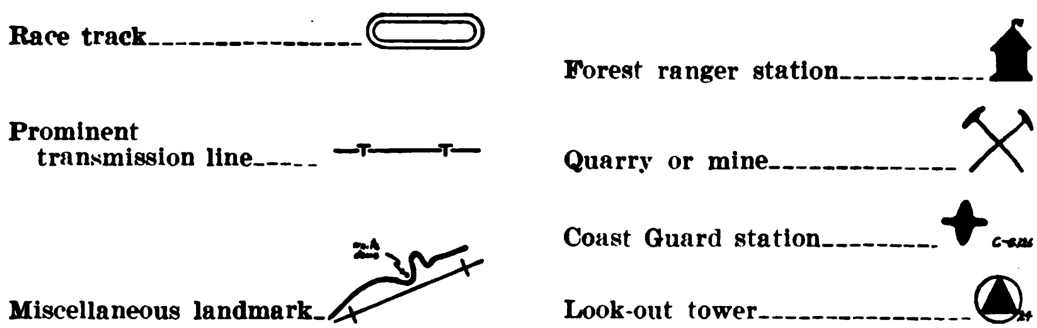


FIGURE 3.—Cultural features (landmarks).

in the case of highways, but any highway tunnels are shown by the same symbol.

(7) 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.

(8) Prominent transmission lines are shown by a symbol representing the poles or towers with wires between. These lines may be considered either as landmarks or as obstructions, and because of their importance to air traffic they are shown in red (fig. 10). 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.

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

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

(11) 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.

(12) 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.

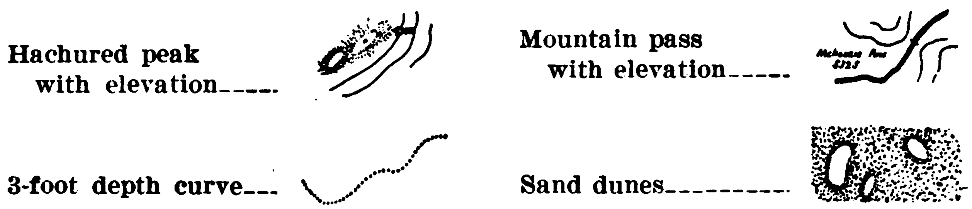
(13) In addition to the foregoing, there are in many localities a number of unclassified distinctive landmarks which are of great assistance in identifying position. These are usually indicated on the sectional charts with a dot and descriptive note.

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

f. Relief.—(1) 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.

(2) Some prominent peaks or steep cliffs are also accentuated by hachuring or shading with elevations in black italic figures.

(3) Many other critical elevations—mountain passes and high



GRADIENT OF ELEVATIONS

0	1000	2000	3000	5000	7000	9000 Maximum
Green	Light green	Pale brown	Light brown	Medium brown	Deep brown	Dark brown

FIGURE 4.—Relief (elevation).

points—are shown on the charts with a dot to designate the location. The elevations of a number of cities and towns are also shown.

g. Contours.—(1) A contour represents an imaginary line on the ground every point of which is at the same height above sea level.

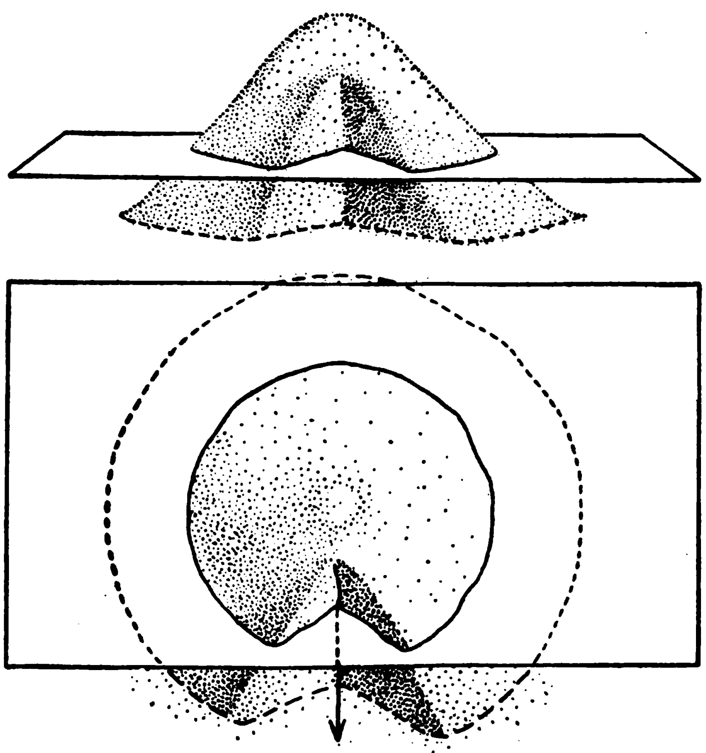


FIGURE 5.—Contours illustrated by a sand pile.

The varied curves of the contour show the ridges, valleys, canyons, bluffs, and other details. With a little practise, 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.

(2) Any contour is the intersection of an imaginary horizontal plane with the surface of the terrain. To illustrate, figure 5 represents a pile of sand from the nearer side of which sand has been carried away until a "valley" has been formed. The top of the sand pile is 5 feet above the pavement, and an imaginary plane is passed through the pile at a height of 2 feet. In the lower part of the figure 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.

(3) 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.

(4) In figure 6 the curves at *V*, *V*, *V*, represent valleys of varying width and depth, while *R*, *R*, *R*, represent ridges or hills.

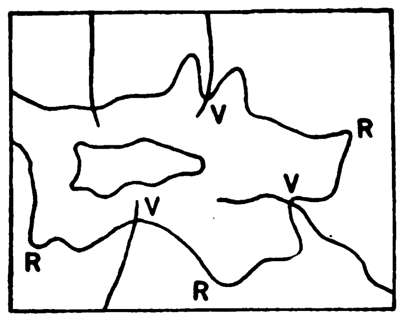


FIGURE 6.—Ridges and valleys shown by contours.

(5) One way of visualizing more readily the significance of the contours is to think of them as successive shore lines if the sea should rise to the levels indicated by the respective contours. The line of the seacoast itself is a contour, every point thereon having the same altitude (zero) with respect to mean high water. Valleys sloping down toward the shore line are represented by a curve or indentation landward. Ridges result in a curve seaward (fig. 7). Now if the sea should rise 1,000 feet, the 1,000-foot contour would become the shore line; valleys would still be indicated by a curve toward the higher ground (which could now be called landward), and ridges would be indicated by a curve toward the lower ground (seaward).

(6) If a cliff should rise almost vertically above the shore line for 1,000 feet, the 1,000-foot contour would appear on the chart very close to the shore. When the terrain slopes gently upward from the coast, the 1,000-foot contour is a considerable distance inland. Thus, contour lines that are far apart on the chart indicate a gentle slope, while lines that are close together indicate a steep slope; contours that run together indicate a cliff.

(7) The manner in which contours express altitude, form, and de-

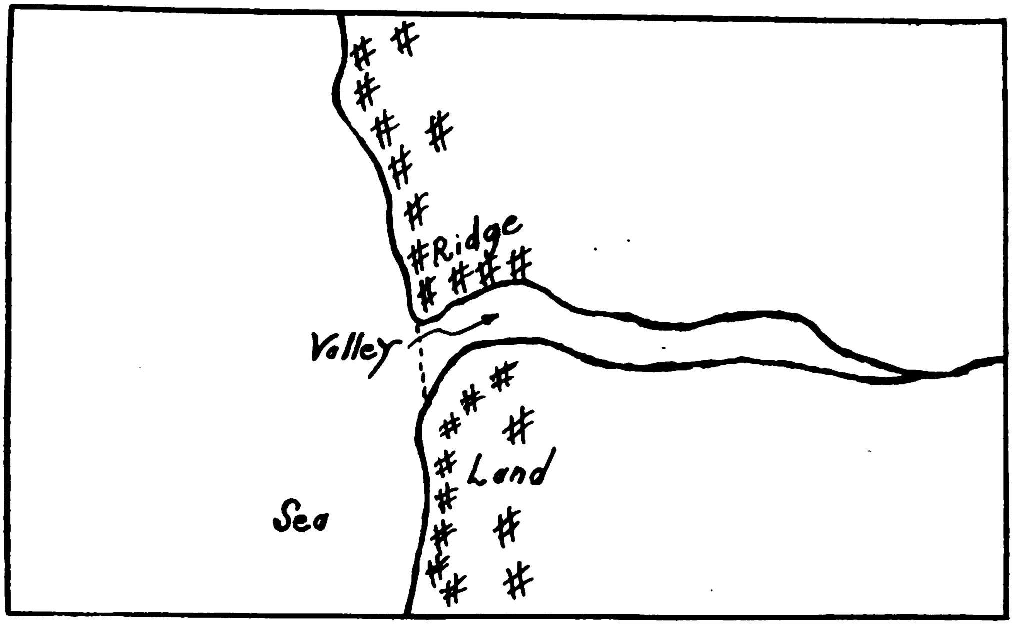


FIGURE 7.—Seashore as contour.

gree of slope is shown in figure 8. 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 inclined tableland that is traversed by a few shallow gullies. In the lower part of the figure, each of these features is represented directly beneath its position in the sketch by contour lines.

(8) In figure 8 the contours represent successive differences in elevation of 20 feet—that is, the "contour interval" is 20 feet. For the sectional and regional aeronautical charts a contour interval of 1,000 feet has been adopted. (On a few of the charts, because of unusual local conditions, intermediate contours at 500-foot intervals are shown.)

h. Safe altitude.—(1) In order to maintain a safe flying altitude, unless the elevation of the top of a ridge or peak is given in figures, it should be assumed that the elevation is a full thousand feet above the highest contour shown. For example, the highest charted contour along a ridge may be only 2,000 feet, yet the ridge may be topped by minor summits rising to 2,800 feet or more. Assuming trees approximately 100 feet in height, the extreme elevation of the ridge may be almost 3,000 feet, yet the addition of the 3,000-foot contour is not warranted. It should be noted that the gradient tint used in this case (pale brown, see fig. 4) indicates not merely an elevation of 2,000 feet but includes any elevation short of 3,000 feet. Unless absolutely certain of their position, whenever visibility is poor, pilots should be careful to fly at a safe margin above the highest ground in the entire region.

(2) The 3-foot-depth curve in water areas (fig. 4) may be thought of as an under water contour, and every point along the curve is 3 feet below low water. It is shown by a row of black dots, and serves as a sort of danger line within which seaplanes should not attempt to land. Three feet of water is not sufficient for large flying boats. On new editions the 3-foot curve is being replaced by a 6-foot curve.

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

(4) All the foregoing features are combined by the cartographer

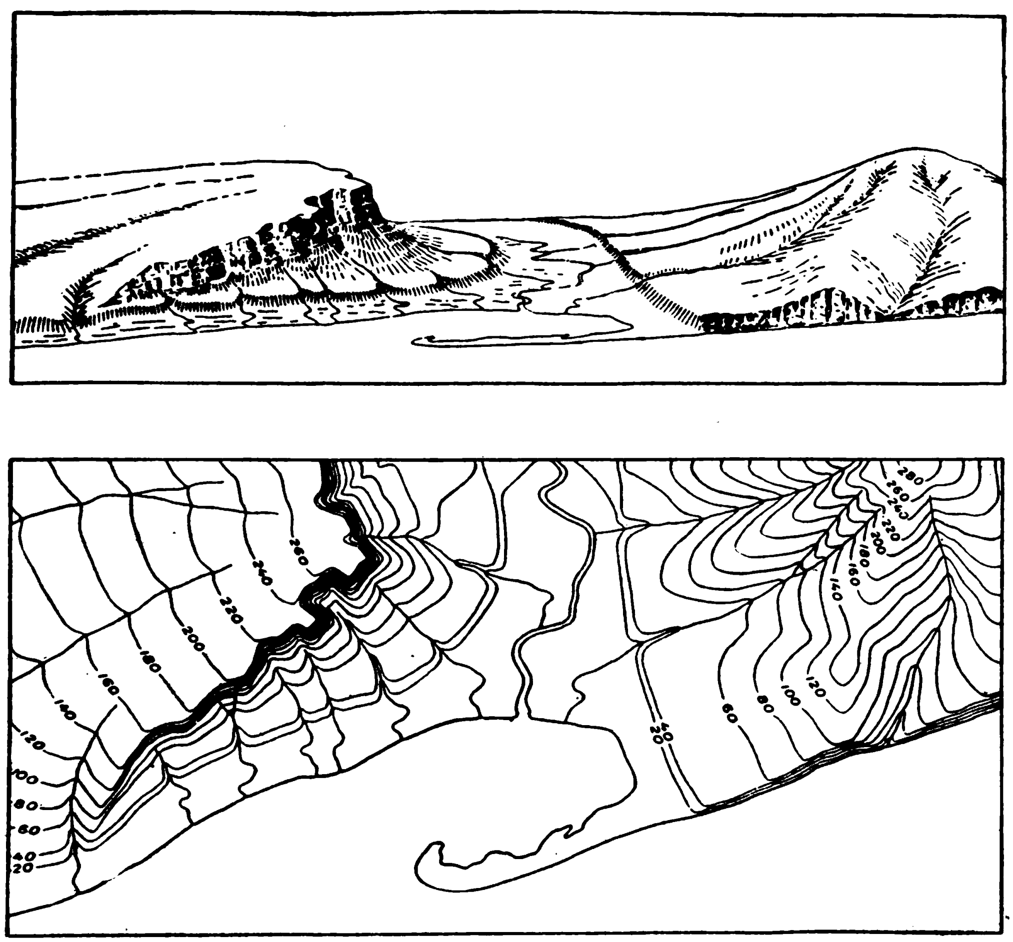


FIGURE 8.—Altitude, form, and slope expressed by contours.

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.

i. Aeronautical information.—(1) Aeronautical information and features of interest chiefly for use in air navigation, such as airports, beacon lights, radio ranges, and radio identification signals, are usually shown in red print. The data are subject to constant change, and it is well to remember that charts are safe only as long as their data are correct. The elimination of certain airports, with changes in beacon lights or radio aids to navigation, makes the use of an obsolete chart as dangerous in the air as at sea. For this reason, new editions are frequently printed, showing the latest information available, with the date of the edition printed in red in the lower left corner of each chart.

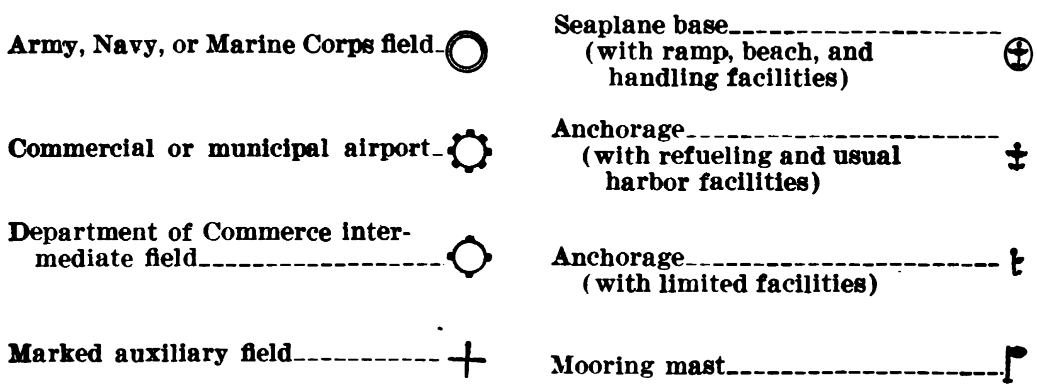


FIGURE 9.—Airport classifications.

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

(3) Airport and airway changes subsequent to the date of printing are listed in the Air Commerce Bulletin (published monthly) and in the weekly "Notices to Airmen." All such changes are kept on file in the various operations offices together with other pertinent data concerning Army fields. 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.

(4) Airports are classified as to their operation (whether commercial, municipal, Army, etc.) and are shown in accordance with the accompanying legend (fig. 9). It is important to consider the classification of a field before landing in order to know what supplies or services may be obtained there.

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

(6) Elevations of airports above sea level are indicated by slanting numerals adjacent to the airport.

(7) The letters LF adjacent to an airport symbol indicate that the field is equipped with lighting facilities for landing at night. Sometimes these facilities are operated only at certain hours or on request. The same is true of certain other beacon lights and aids, and for complete information on these points pilots should refer to the information on file at the local operations office.

j. Beacons.—(1) A rotating beacon is indicated by a star with an open center. Arrows in conjunction with the beacon symbol indicate that the beacon is equipped with course lights, and show the direction in which they are pointed. Adjacent to the symbol are placed the number of the beacon and the corresponding code signal which is flashed by the course lights for identification at night. When there is a power shed at the beacon, the site number is also painted on the shed roof for daylight identification.

(2) The number of any intermediate field or beacon is obtained by dropping the final digit of the mileage from the origin of the airway on which it is located.

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

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

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

(6) A light for marine navigation is shown by a large dot. It should be noted that a powerful light of this kind is often incon-

spicuous from the air, because its light is directed along the surface for the benefit of surface navigation.

(7) A landmark beacon, operated by private interests or by a commercial establishment for advertising purposes as well as for the benefit of airmen, is represented by the proper beacon symbol (rotating or flashing) as described above. As a rule these beacons are located neither on an established air route nor at an airport, but they serve to identify a point from which a pilot may proceed to his

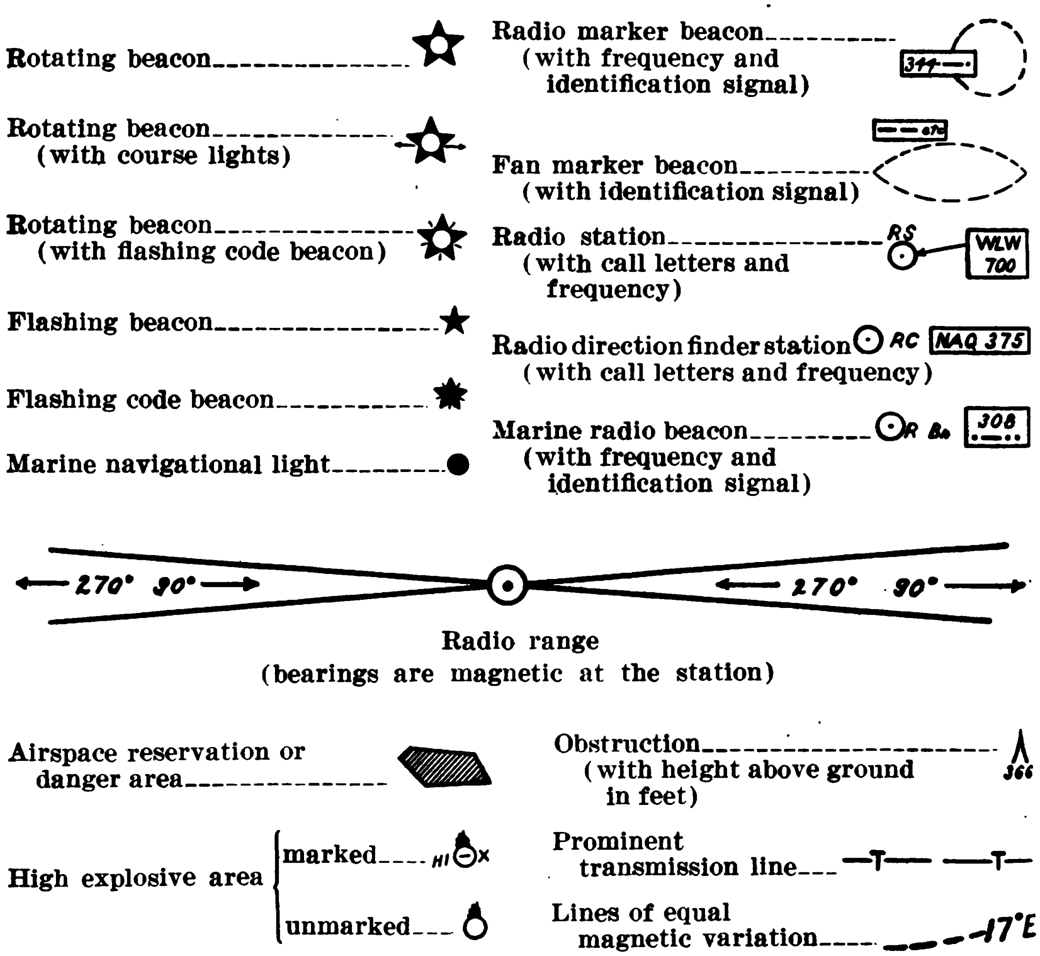


FIGURE 10.—Aeronautical data (miscellaneous).

destination. A rotating landmark beacon usually rotates at two revolutions per minute, in order to distinguish it from an airway beacon which makes six revolutions per minute. An arrow in conjunction with this symbol indicates that the beacon is equipped with a course light; on the chart the arrow is placed so that it points to the airport toward which the course light is directed.

k. Reserved area.—(1) Air space reservations and danger areas are indicated by prominent cross ruling and appropriate notes. The former have been designated by Executive order and may not be flown over at any altitude. Danger areas are shown by request of the Army and Navy and should not be flown over at altitudes below 5,000 feet.

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

(3) Flying is also prohibited in other limited areas for special reasons—for example, in the vicinity of the White House and the Capitol in Washington. In such localities the charts are already too congested to indicate the restricted area, and pilots should keep informed of such matters through the Air Commerce Bulletin, Notice to Airmen, and through local sources.

(4) Isolated obstructions are shown as indicated in figure 10, 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.

l. Radio ranges.—(1) A radio range station is indicated by a dot within a small circle, and the positions of the range courses are shown by a pink tint. Magnetic courses toward or away from the station are indicated, and large letters mark the A and N quadrants of the system. Smaller letters are placed adjacent to and near the end of many of the range courses to avoid any confusion as to quadrant designation. The method of flying the radio ranges is treated in detail in section VIII.

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

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

(4) A number of commercial broadcasting stations are shown on the charts. Originally, they were included chiefly because of their danger as obstructions. With the development of the aircraft radio compass, however, these stations have also become of navigational importance. Radio stations suitable for this purpose are shown by the conventional circle and dot symbol, the initials R. S., and the frequency. Stations operating at less than 500 watts are not charted.

For stations with power between 500 and 1,000 watts, the power is indicated on the chart as some guide to the distance at which satisfactory reception may be expected. For stations of 1 kilowatt or more, the power is omitted.

(5) Radio direction-finder stations are seldom used by aircraft today. However, these stations are indicated by a circle and dot symbol and the initials R. C. (from their former designation as radio compass

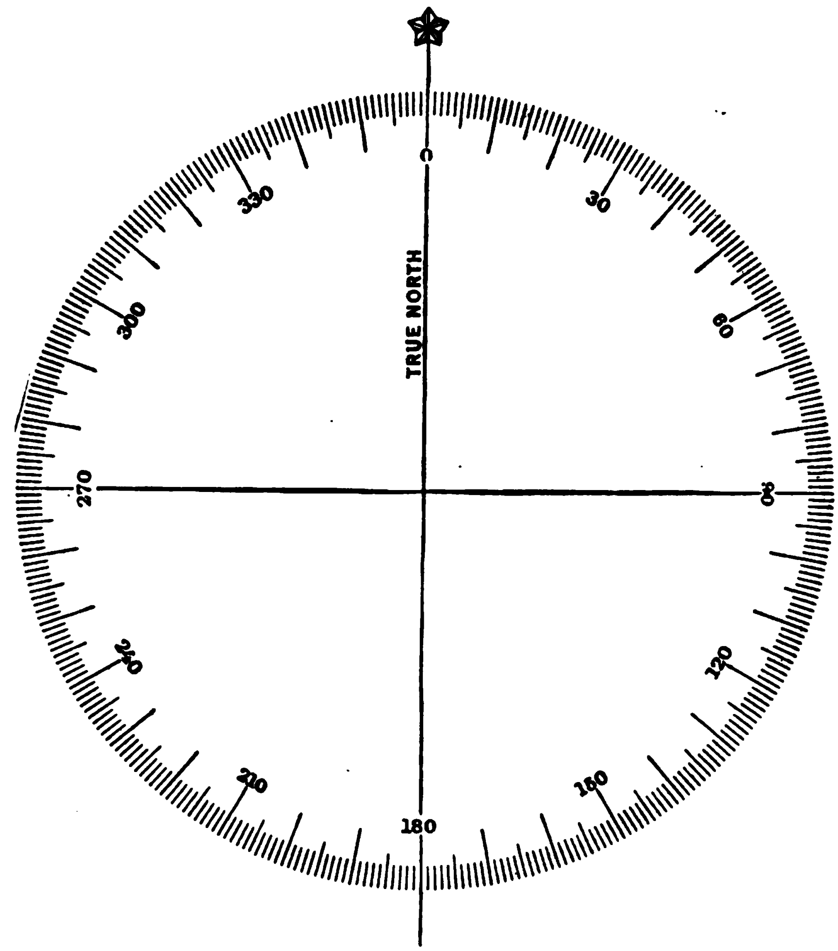


FIGURE 11.—True compass rose.

stations). Marine radio beacon stations are indicated by the same symbol and the initials R. Bn.

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

n. Compass rose.—Compass roses (fig. 11), oriented to true north, are printed on the sectional and regional charts. If a protractor is not available, these roses may be used for the approximate measurement of courses and bearings. Because of the convergence of meridians in the Lambert projection, some inaccuracy is introduced if a compass rose is used for the measurement of direction at a point more than 1° or 2° of longitude away. Therefore, compass roses are printed at intervals sufficiently close that courses may be measured from them with practical accuracy, and one is usually available no matter how the chart is folded. On some charts, the direction and amount of magnetic variation are represented on the compass roses, in addition to their representation by isogonic lines.

18. Sectional aeronautical charts.—*a. Scale.*—The expressions 1:500,000 and 1:1,000,000 used to denote the scale of a chart are read as "one to five hundred thousand" and "one to one million." They represent the proportion existing between the chart and the portion of the earth represented thereon. In the first case, 1 inch on the chart represents 500,000 inches on the ground; similarly, any other unit, as 1 foot, 1 yard, or 1 centimeter, represents 500,000 of the same units on the ground. Such a proportion is sometimes written as a fraction as $\frac{1}{500,000}$, and is occasionally referred to as the fractional scale or representative fraction of the chart to which it applies. The scale of the sectional charts is one to five hundred thousand, or about 8 miles to the inch.

b. Number.—The area of the United States has been divided into 87 sections, each of which is shown on one of the charts. (See fig. 12.)

c. Use.—Sectional charts are suitable for all forms of navigation. They show all of the detail needed for use when pilotage methods are used. They are somewhat bulky and on long flights many of them are usually required, but no other maps now available are as well suited for filling the pilot-navigator's requirements when flying over the United States.

19. Regional aeronautical charts.—*a. Scale.*—The scale of the regional charts is one to one million, or about 16 miles to the inch.

b. Area.—These charts cover such area that the United States is represented on 17 sheets. (See fig. 13.)

c. Use.—The regional charts are designed to be used in methods of air navigation other than pilotage or in conjunction with that method. They are more convenient than the sectional charts for comparatively long flights with faster planes, since pilots do not need to change charts as often while in the air. They are also convenient for planning routes which extend beyond the limits of a sectional chart, one regional chart often covering the route which would require two or three sectional charts. Because of the larger scale and the more complete

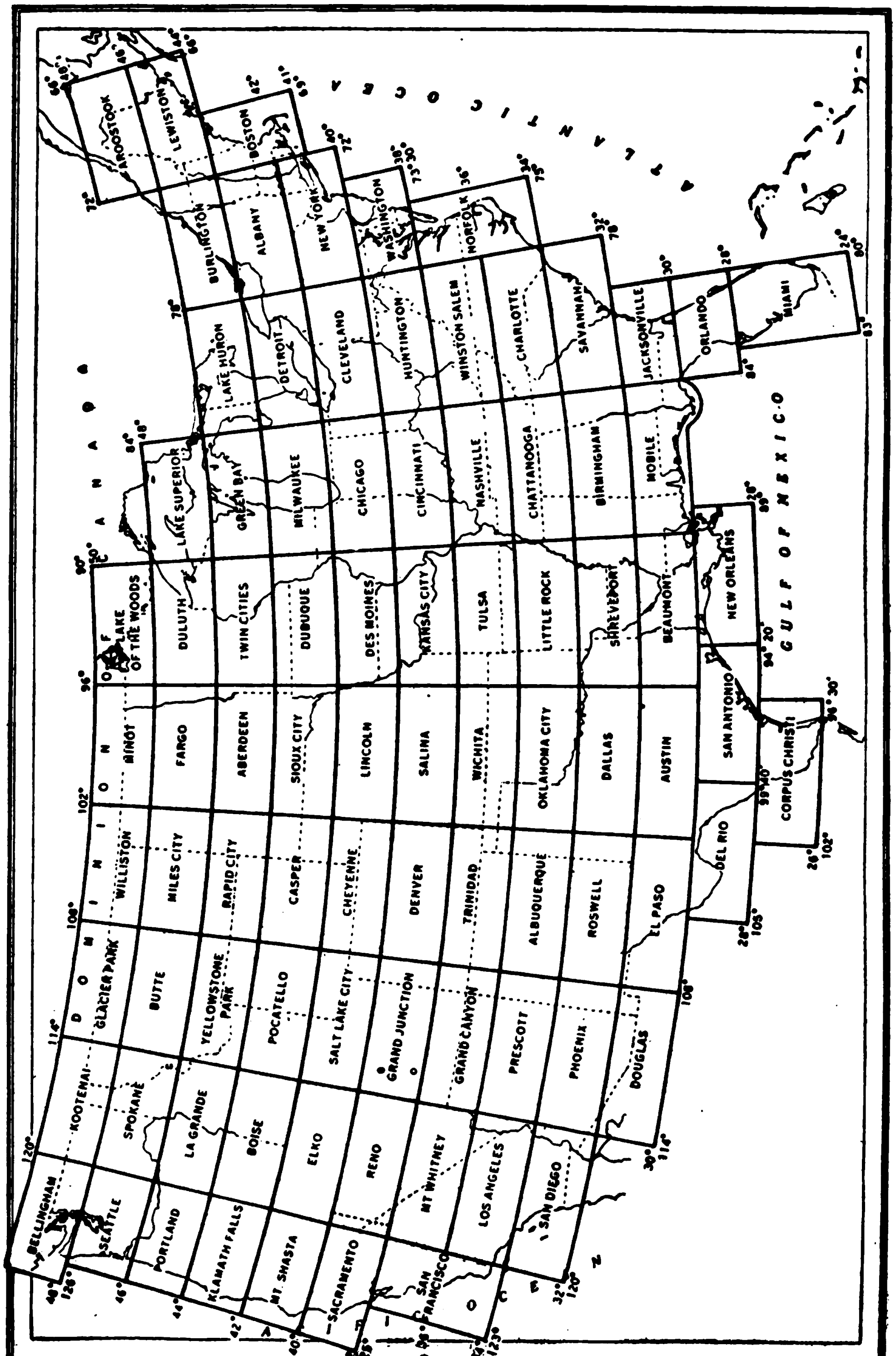


FIGURE 12.—Index of sectional aeronautical charts.

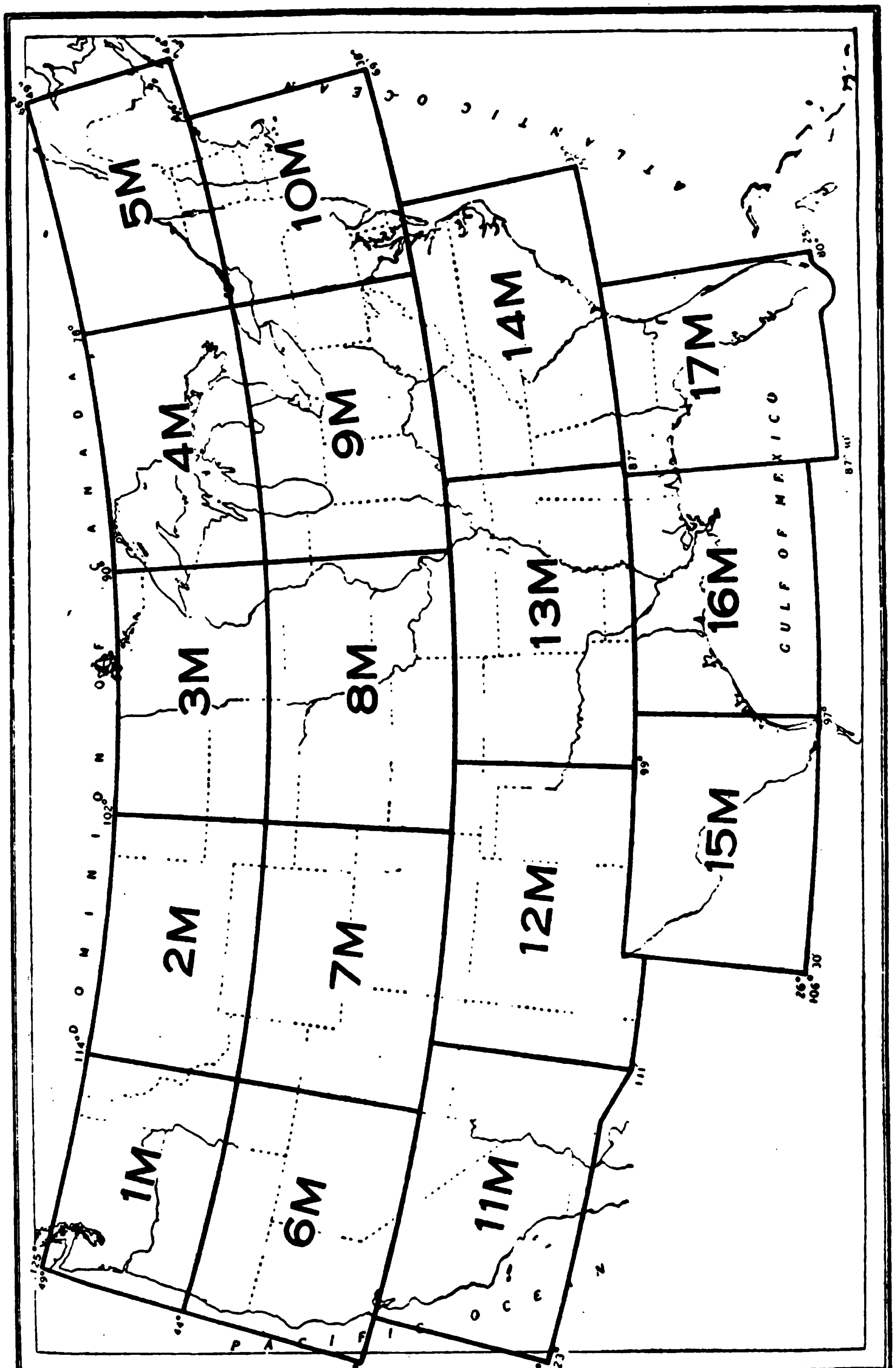


FIGURE 13.—Index of regional aeronautical charts.

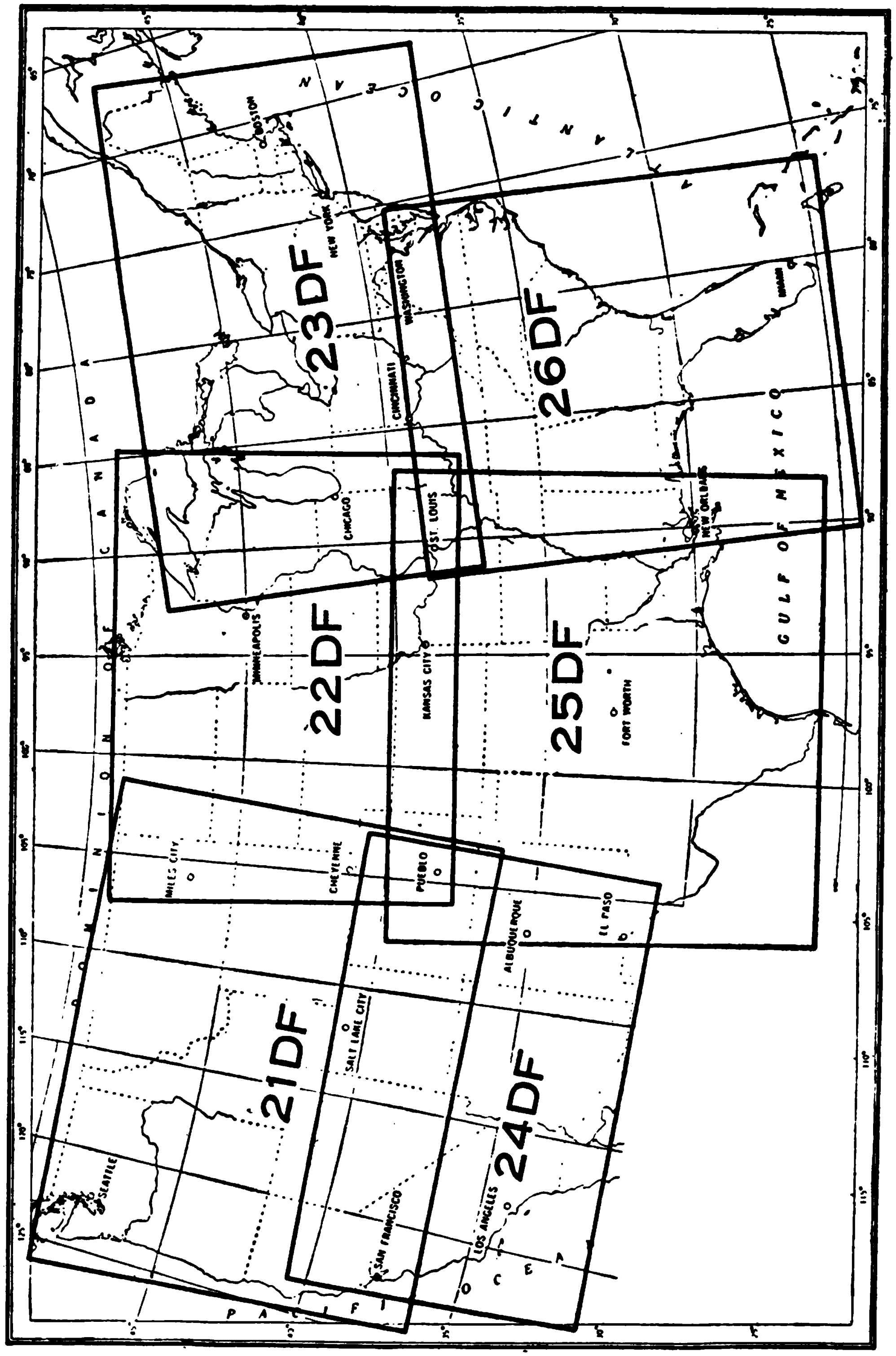


FIGURE 14.—Index of aeronautical charts for radio direction finding.

information shown on the sectional charts they are necessary supplements to the regional series. They will always be required for detailed studies of an area. 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.

20. Other aeronautical charts of the United States.—*a. Radio direction-finding charts* (fig. 14).—(1) These charts show the area of the United States on six sheets and use a scale of one to two million, or about 32 miles to the inch. They are designed especially for use in the plotting of radio bearings. Their smaller scale and wider extent make it possible to plot bearings from radio stations which would frequently be outside the limits of the local chart when using either of the larger scale series of charts. The method of plotting bearings on these charts which are constructed on the Lambert conformal projection is treated in detail in section X, chapter 2.

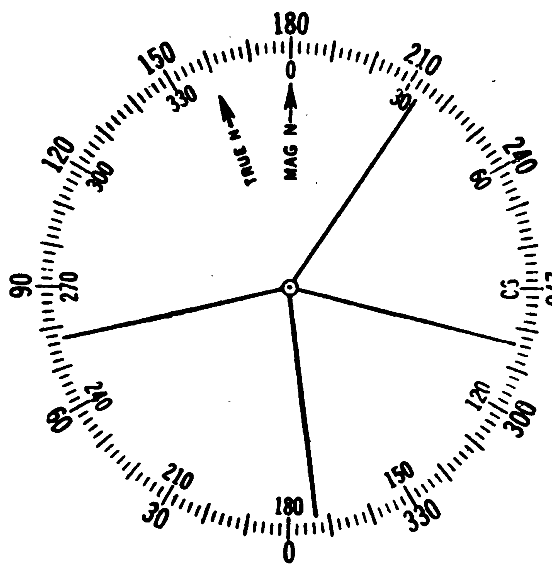


FIGURE 15.—Magnetic compass rose.

(2) Specially designed compass roses (fig. 15), oriented to magnetic north, are used on the radio direction finding charts. These roses are graduated to read both from magnetic south and from magnetic north. The outer figures are ordinarily used and are therefore larger; they are sometimes used to plot reciprocal bearings (the radio compass bearing observed at the plane plus or minus 180°), and for that reason read from 0 at magnetic south. For certain other problems a rose reading from 0 at magnetic north is more convenient, and for such problems the inner (smaller) figures are also available. These magnetic compass roses should be used to plot bearings taken by an airplane only when the airplane is relatively close to the transmitting station, i. e., close enough so that the difference in variation existing at the airplane and at the station is negligible. Otherwise a correction is necessary to account for this difference in variation. These roses should not be confused with the conventional compass roses appearing on the sectional and regional charts, nor used in the same manner. (See sec. VIII.)

b. Aeronautical planning chart (*No. 3060a*).—This chart shows the entire area of the United States on one sheet, with a scale of one to five million, or about 80 miles to the inch. This is exactly one-tenth the scale of the sectional charts. It affords a high degree of accuracy in the measurement of distances between widely separated points and may also be used for the plotting of radio bearings, the necessary instructions for performing these operations being printed on the chart itself. About 40 of the principal broadcasting stations and 250 of the most important airports are shown in red, facilitating radio compass navigation and the plotting of routes. The plotting of routes is further simplified by an overprint showing the limits of each sectional chart; in this way the pilot may see at once which sectional charts will be required for a projected flight, and also the approximate location of the intended route on each chart. Lines of equal magnetic variation are shown. Courses may also be measured thereon, although in general they should be measured on one of the larger scale charts. 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.

c. Great circle chart (*No. 3074*).—The sectional, regional, radio direction finding, and aeronautical planning charts are constructed on the Lambert-conformal projection. The great circle chart is constructed on the gnomonic projection and is on approximately the same scale as No. 3060a. It is not suitable for the measurement of navigation courses, bearings, or distances, but any straight line on this projection represents a precise great circle track. 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.

d. Magnetic chart (*No. 3077*).—This chart shows the entire area of the United States on one sheet, with a scale of one to seven and one-half million, or about 115 miles to the inch. Lines of equal magnetic variation at 1° intervals are shown on this chart.

SECTION III

TIME, DIRECTION, AND BEARING

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Time and longitude	23
Time zones	24

	Paragraph
The 24-hour system	25
Direction and bearing	26
Directions on a map	27

21. Time.—Time is of primary importance to the navigator. By its use he can calculate the distance traveled along his course or in celestial navigation he can calculate his longitude. There are three different kinds of time:

a. Mean or civil time.—Mean time is based on the travel of an imaginary or fictitious sun. This is the time as kept by watches or chronometers, and the time we use in our time zones. At the same instant the civil times of two points of different longitude are never the same. Mean or civil time is not to be confused with standard or zone time which is based on the civil time of certain selected meridians. Standard time is described in paragraph 24.

b. Apparent or solar time.—Solar time is time based on the travel of the real sun. The real sun is also known as the true sun or apparent sun. The time read from a sun dial is apparent time. Solar time is used extensively in celestial navigation.

c. Sidereal or star time.—This time is used in celestial navigation when determining the relationship between time and the position of the stars. It is based on the travel of the stars.

22. Day.—The time interval between two successive transits of a heavenly body is a day. The civil day, solar day, and sidereal day are not of the same duration. The difference between these various kinds of days is described in TM 1-206. The civil day is the only one of particular interest to the pilot and is the interval between two successive transits of the mean sun, not the real sun. The interval between transits is divided into 24 hours, each of 60 minutes.

23. Time and longitude.—*a.* There is a definite relationship between time and longitude—24 hours of time is equal to 360° of arc of longitude. Thus each hour of time equals 15° of longitude. Other subdivisions are shown as follows:

Time:	Arc of longitude
24 hours	360°
1 hour	15°
4 minutes	1°
1 minute	15′
4 seconds	1′
1 second	15″

Using the above relationship, if the longitude and time of one place are known and the longitude of a second place is known, the time of the second place may be determined.

b. (1) ***Problem.***—**If it were 10:00 A. M. at longitude 98°30′ W., find the time at longitude 115°20′ W., at the same moment.**

(2) *Solution.*—The difference of longitude (DLo) is found by subtracting 98°30′ from 115°20′, the result being 16°50′. Converting this arc to time, it is found that 16°50′ of longitude is equivalent to 1 hour 7 minutes and 20 seconds of time. The second location is west of longitude 98°30′ W., and so the difference in time is subtracted from the original time given. *Answer:* $8^h\ 52^m\ 40^s$ A. M.

24. Time zones.—*a. Division.*—For our own convenience in everyday life we use time zones which are areas using the same civil time throughout. These zones are 15° wide over the ocean areas. Over land areas, limits of the time zones are adjusted arbitrarily to suit the convenience of population centers. The standard meridians used to determine the time zones in the United States and Canada are the 60th, 75th, 90th, 105th, and 120th meridians west from Greenwich. Actually, the boundaries between these zones are very irregular. The 60th meridian, together with the area up to 7½° of longitude on each side, comprises the zone known as "intercolonial." Likewise the eastern standard time zone is based on the area on each side of the 75th meridian. Thus, eastern standard time is the mean or civil time of the 75th meridian, and this same time is used for convenience between longitudes 67½° W. and 82½° W., roughly. The central standard time zone centers on the 90th meridian, mountain standard time on the 105th, and Pacific standard time on the 120th.

b. Sunset tables.—(1) *General.*—Sunset tables (figs. 16 and 17) are printed in the handbook Radio Data and Aids to Airways Flying, which is carried on each cross-country flight. These tables enable the pilot to determine the time of sunset for any position of latitude and longitude.

(2) *Problem.*—Find the sunset time for May 20 at latitude 33°00′ N. and longitude 94°30′ W. (Follow instructions printed with the table.)

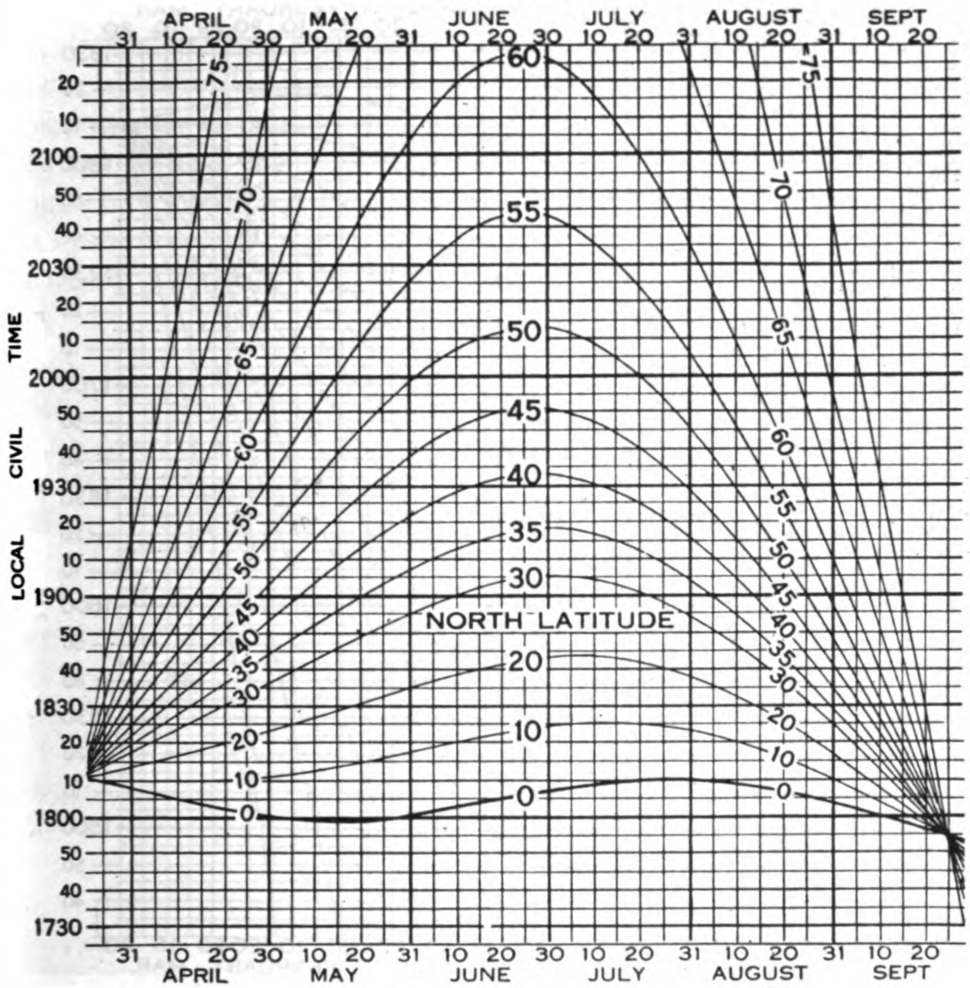
(*a*) Enter the top or bottom scale with the proper date, May 20.

(*b*) Move vertically down or up to the curve for observer's latitude, 33°00′. Interpolate between 30° and 35°.

(*c*) Move horizontally to the right or left and read the local civil time on the vertical scales at the side, or 1855 hour (24-hour system of keeping time, par. 25).

(*d*) To find exact zone or standard time as carried by your watch add 4 minutes for each degree west of the standard meridian, etc. The longitude given, 94°30′, is 4°30′ west of the standard 90th meridian (central standard time), so $4\frac{1}{2} \times 4$ or 18 minutes is added to 1855 for the sunset time. *Answer:* 1913 hour, CST.

SUNSET



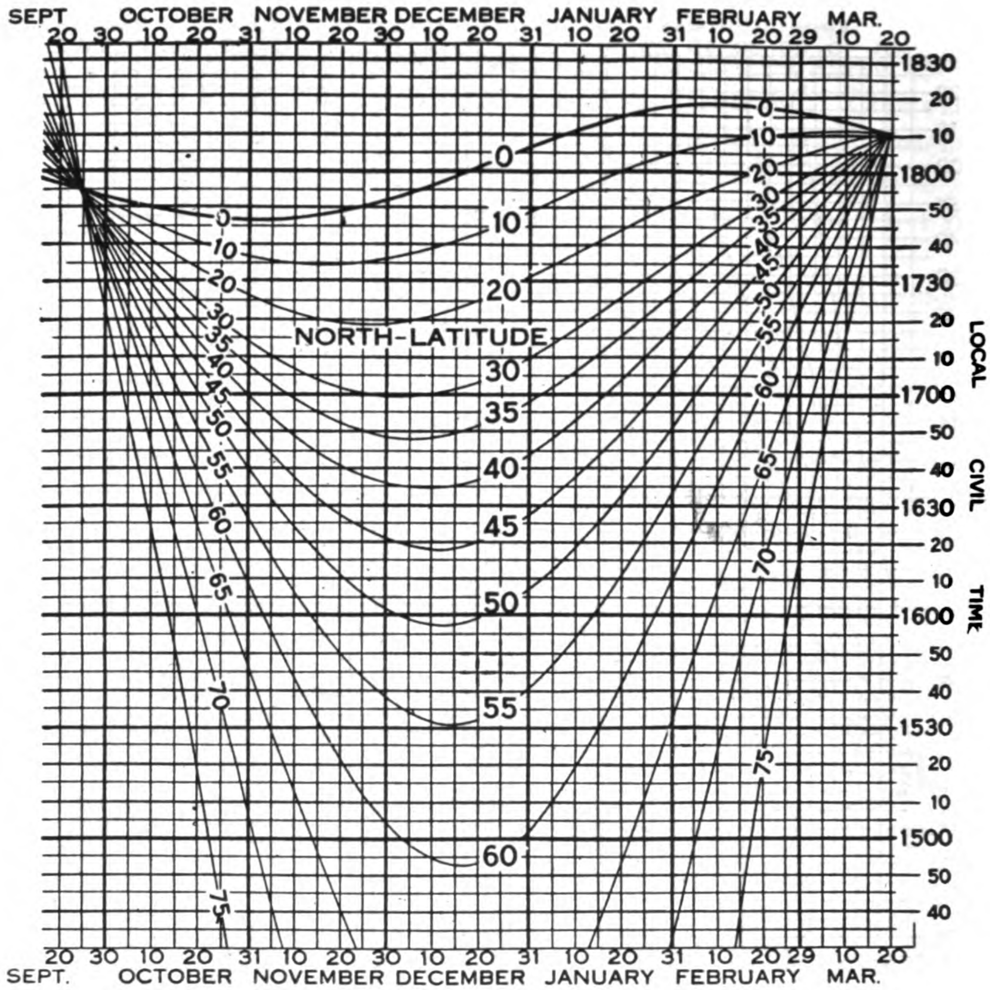
INSTRUCTIONS FOR USE

1. Enter the top or bottom scale with proper date.
2. Move vertically down or up to the curve for observer's latitude.
3. Move horizontally to right or left and read local civil time on vertical scales at the side.
4. To find exact zone or standard time as carried by your watch, add 4 minutes for each degree west of standard meridian and subtract 4 minutes for each degree east of standard meridian.

FIGURE 16.—Sunset table, summer.

25. The 24-hour system.—This system of keeping time eliminates the use of the abbreviations A. M. and P. M. The values for A. M. time are unchanged except that four figures are always used: 8:00 A. M. becomes 0800 hour; 3:15 A. M. becomes 0315 hour; and 11:38 A. M. becomes 1138 hour. The value of P. M. time is increased by 1200, hence 1:15 P. M., 7:42 P. M., and 11:19 P. M. become 1315 hour, 1942 hour, and 2319 hour, respectively. The use of this system

SUNSET



INSTRUCTIONS FOR USE

1. Enter the top or bottom scale with proper date.
2. Move vertically down or up to the curve for observer's latitude.
3. Move horizontally to right or left and read local civil time on vertical scales at the side.
4. To find exact zone or standard time as carried by your watch, add 4 minutes for each degree west of standard meridian and subtract 4 minutes for each degree east of standard meridian.

FIGURE 17.—Sunset table, winter.

decreases the chances of making errors by eliminating the A. M. and P. M. abbreviations, and for this reason it has been adopted for use in Air Corps operations.

26. Direction and bearing.—*a. Marine method.*—The mariner divides the circle into 32 equal parts called "points," each point equaling 11°15′. To sail two points east of north means, therefore, to sail 22°30′ east of north, or north northeast (N.N.E.), etc. This system is not used in air navigation and is becoming outdated in surface navigation.

b. Second system.—In a second system somewhat similar to the above, the circle is divided into four equal parts, indicating the four cardinal directions, N, E, S, and W. The direction from *A* to *B*, in figure 18, is called "North 30° East"; *A* to *F* is "South 60° East"; *A* to *C* is "South 30° West"; *A* to *D* is "North 60° West." Each direction in this system is referred to as north (or south) so many degrees east (or west). This way of designating direction has a special use in calculating courses and distances. These calculations are described in section IX, chapter 2.

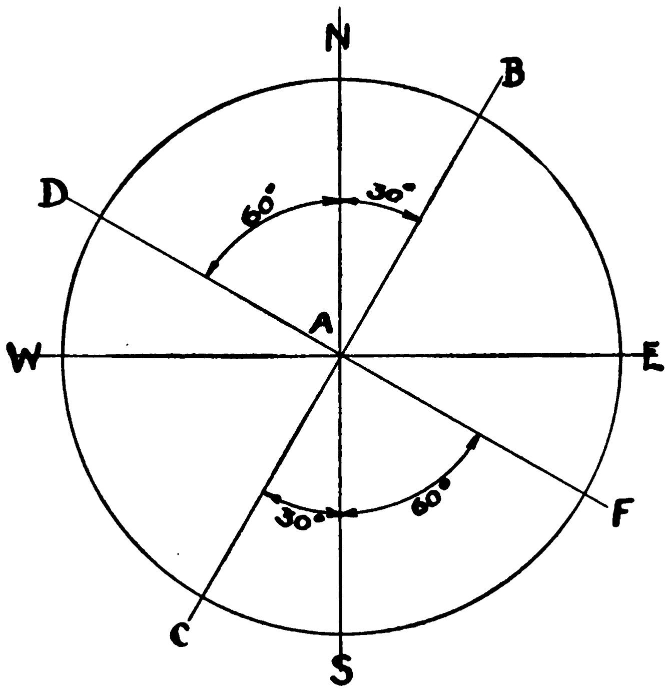


FIGURE 18.—Directions and bearings.

c. Air navigation system.—(1) The system of measuring and naming directions used in air navigation is easier to use than either of the above. It consists of designating directions in relation to north by measuring them clockwise from north through any arc up to 360°. In this system it is not necessary to refer to north, east, south, or west, as the numerical value shows the exact direction. Thus in figure 18, $AN=360°$ or 0°, $AB=30°$, $AE=90°$, $AF=120°$, $AS=180°$, $AC=210°$, $AW=270°$, and $AD=300°$. To measure the direction from a point *A* to a point *B*, the angle between the meridian which passes through *A* and the line connecting *A* and *B* is measured clockwise from north. If this angle equals 30°, it may be said that—

(*a*) The bearing from *A* to *B* is 30°.

(*b*) *B* bears 30° from *A*, or *A* bears 210° from *B*.

(*c*) The direction from *A* to *B* is 30°.

(*d*) The true course from *A* to *B* is 30°.

(2) Another example of the difference between a direction (or course) and a bearing (or azimuth) may be seen by referring to figure 19.

(*a*) Angle *a* is the course angle from *A* to *B*.

(*b*) Angle *b* is the course angle from *B* to *A*.

(*c*) Angle *Z* is the bearing or azimuth of *B* as measured at the point *A*.

(*d*) Angle *Z′* is the bearing or azimuth of *A* as measured at the point *B*.

27. Directions on a map.—*a. How measured.*—(1) When it is desired to find the course or direction between two points on a map, a connecting line is drawn between these points. Then, if the map is based on the Lambert projection, the angle between the connecting line and the meridian which is nearest to midway between the points is measured. Thus, in figure 19 (Lambert projection) the course angle between *A* and *B* is angle *a* rather than angle *Z* or angle *b* rather than angle *Z′*. For usual flights the use of an ordinary protractor to measure the angle will give sufficient accuracy.

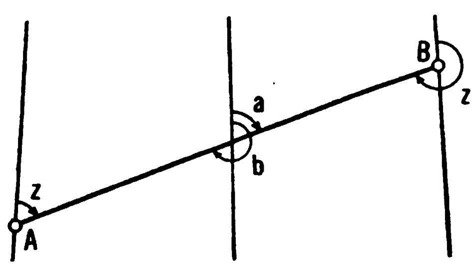


FIGURE 19.—Courses and bearings.

(2) It should be explained that when the course is measured on the meridian nearest halfway, a plane following that course will not exactly follow the straight line on the chart but will slightly depart therefrom near the middle of the route. 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 track the straight line throughout its entire length.

b. Long courses.—(1) When the two points are separated by not more than 3° or 4° of longitude, the true course may be measured on the meridian nearest halfway as described above and as illustrated in figure 19. The entire distance is then flown as one course.

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

(3) *Example.*—(*a*) Figure 20 illustrates the method of determining the series of true courses to be flown between St. Louis and Minot. The distance is 862.7 statute miles. The difference of longitude is nearly 12° which is too great to be flown satisfactorily in one course. The route is therefore divided into three sections cross-

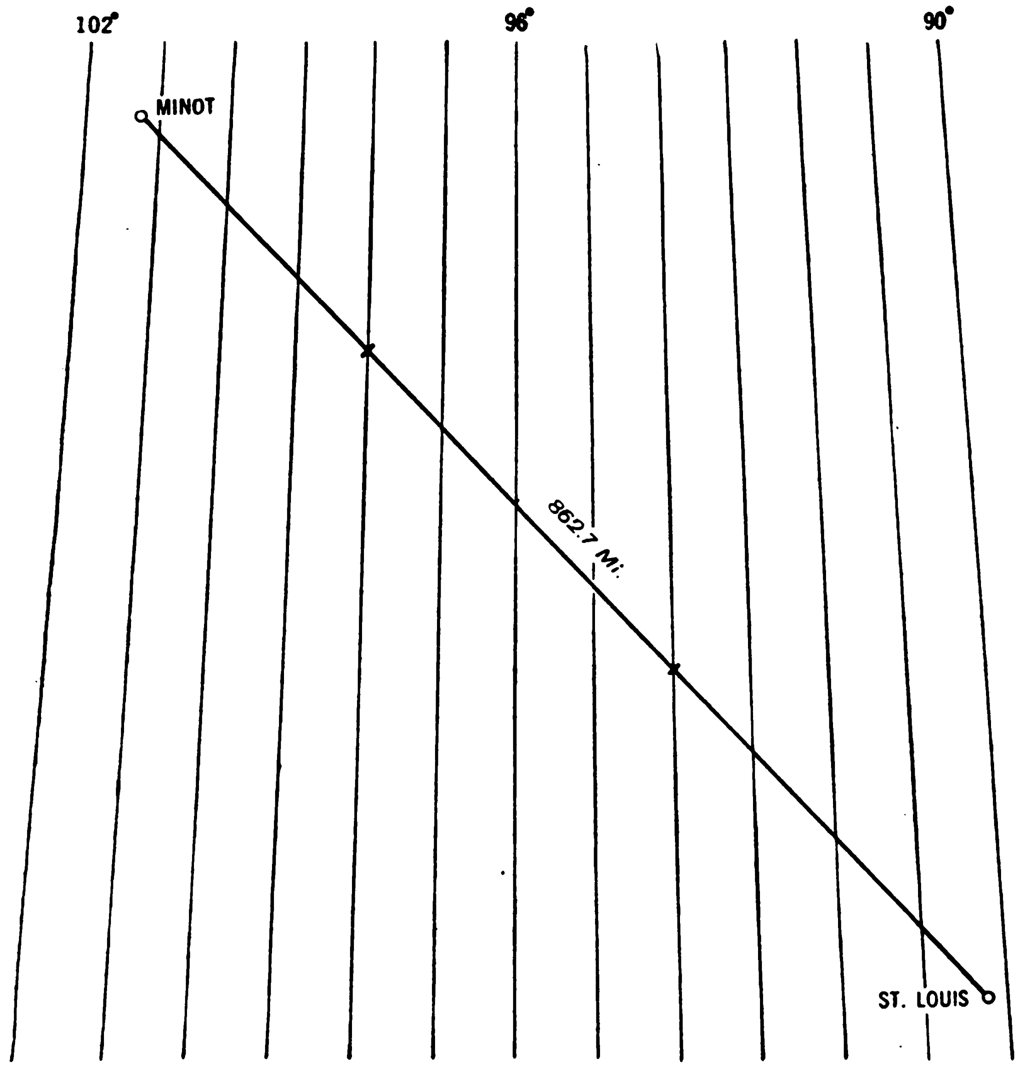


FIGURE 20.—Subdividing long route.

ing approximately 4° of longitude each. The true course to be flown throughout the total length of each section is measured on the middle meridian of that section, and the course is changed in flight as the end of each succeeding section is reached.

(*b*) For the flight from St. Louis to Minot only two regional charts are required. It is a simple matter to join these two charts and draw the straight line between the two places. When using the sectional series, six charts are necessary, and it is inconvenient to join so many charts; in this case, therefore, the route should first be plotted on one of the small-scale planning charts and then transferred to the regional and sectional charts.

c. Computing course and distance.—The course and distance between two points may be computed mathematically with great accuracy. The methods are described in section IX, chapter 2.

SECTION IV

COMPASSES AND COMPASS ERRORS

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Magnetism	29
Magnetic compass	30
Aperiodic or Air Corps type D compass	31
Earth-inductor compass	32
Variation	33
Compass installation errors	34
Magnetic deviation	35
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28. Need for compass.—Human beings do not have that sense which will allow them to move in any direction without some outside means of orientation. Certain animals, such as pigeons, the wild duck, and the domesticated cat, have this sense highly developed and their exploits are well known. Man, however, must depend on some mechanical means or must use the celestial bodies to find his way along the surface of the earth. Even the ancient mariners depended upon the sun and stars to give them directions when at sea. When the sky was covered with fog or clouds they were forced to anchor if they were out of sight of land. It was not until the 12th century that the use of the magnetic compass became known in Europe.

29. Magnetism.—*a. Lodestone.*—It was discovered that a certain ore called "lodestone" had the particular property of always pointing in the same direction when freely suspended in space. This discovery led to the development of the first instrument for indicating direction. It was discovered that this peculiar property of lodestone was due to magnetic influence, and this in turn brought the further discovery that the earth is a huge magnet.

b. Some laws of magnetism.—(1) The general law applying to all magnets is that like magnetic poles repel and unlike poles attract.

(2) The field is the space surrounding a magnet in which the magnetic forces act.

(3) The poles of a magnet are the places where the lines of force enter the magnet.

(4) Dip is the vertical angle between the longitudinal axis of a magnetized needle, freely suspended, and the horizontal. The dip angle is zero at the magnetic equator. As the compass is carried north or south, the angle increases until the maximum dip is reached at the magnetic poles. The magnetic equator is an imaginary, irregular line circumventing the earth. It does not coincide with the geographic Equator.

(5) A bar magnet freely suspended in a magnetic field will take a position parallel to the magnetic lines of force.

(6) A compass is simply a magnetized steel needle which is suspended to allow it to rotate freely in a horizontal plane. The compass needle will aline itself with the earth's magnetic field when it is not influenced by local magnetism.

(7) The earth being a huge magnet has a north magnetic pole and a south magnetic pole. The earth's north magnetic pole is the one situated in the Northern Hemisphere. To avoid confusion it is customary to refer to that end of the compass needle which points to the earth's north magnetic pole as the "north seeking" end of the needle. The other end is the "south seeking" end of the needle. The north seeking end of the needle or a bar magnet is said to have "red" magnetism and the south seeking end is said to have "blue" magnetism.

(8) Unfortunately the geographical poles and the magnetic poles do not coincide, thus the compass needle does not usually point toward true north. This discrepancy in direction is known as "variation."

30. Magnetic compass.—*a. Methods.*—There are four general methods by means of which direction is established without visual reference to the surface of the earth:

(1) Some type of magnetic compass which reacts to the magnetic lines of force of the earth.

(2) A gyro compass which keeps its axis lined up with the rotational axis of the earth. This type has not yet been developed for use in aircraft.

(3) Radio reception, using a radio compass or a radio range.

(4) Celestial observations, using an instrument such as a sun compass.

b. Classes.—There are two general classes of magnetic compasses which depend upon the magnetic field of the earth for their operation:

(1) A type having a magnetic needle which tends to line up parallel to the earth's magnetic field. The Air Corps types B and D operate on this principle.

(2) A type in which a generator rotates, using the earth's magnetic lines of force for its field. The earth inductor compass operates on this principle.

c. Air Corps type B compass.—(1) This type of magnetic compass is the one in general use by pilots. It may be mounted on the instrument panel with the other instruments and its card is read through a window on the rear side of the case or bowl. (See fig. 21.)

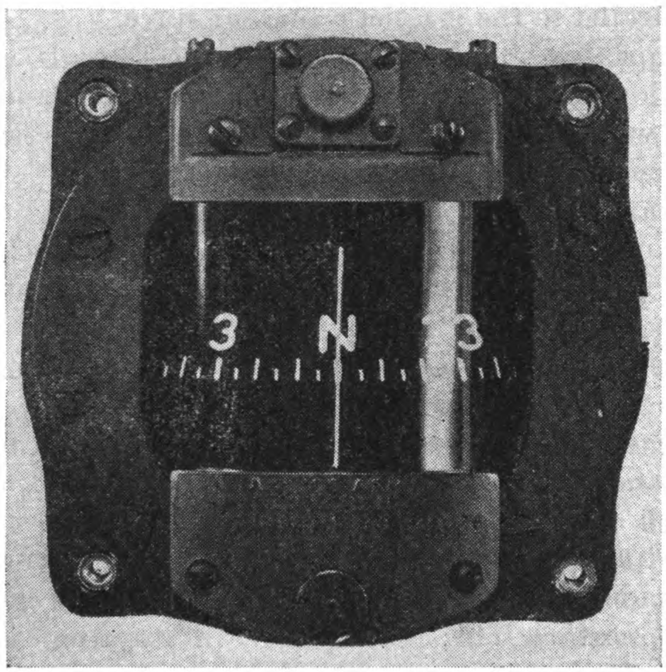

FIGURE 21.—Type B-15 magnetic compass.

(2) The card has a mark or graduation for each 5°. (Some new compasses have 1° graduations.) There is a number or a letter at each 30° interval on the card. Each cardinal direction, north, east, south, and west, is designated by its first letter. Other directions are numbered, with the final zero of the actual value omitted. For example, the direction of 240° would be indicated by the number 24. If the entire card could be removed from the compass and be split in half near the letter N, and then could be unrolled into a straight band, the letters and numerals would appear in the following order (there would be only one N):

N 33 30 W 24 21 S 15 12 E 6 3 N

Each of the 30° markings is divided into smaller graduations (fig. 22). Each smallest subdivision represents 5°.

d. Parts.—The principal parts of the magnetic aircraft compass are as follows:

(1) Bowl, which is usually spherical or cylindrical in shape and made of a nonmagnetic material.

(2) Card assembly, which comprises the card, card magnets, spider, pivot, and float when one is used.

(3) Lubber line, which is a wire or thin piece of material fixed with reference to the compass and by which the compass card is read.

(4) Damping fluid, a water white, acid free kerosene which completely fills the bowl.

(5) Compensating chamber, where the compensating magnets are held.

(6) Expansion and contraction device, which allows for temperature changes of the liquid.

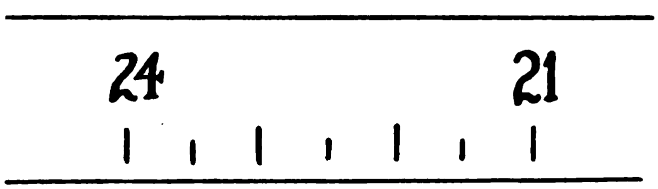

FIGURE 22.—Section of compass card.

(7) Antivibration mount, which is the frame by which the compass is attached to the airplane.

(8) Light for illumination of the card at night.

e. Construction.—(1) A magnetic compass is actuated by one or more bar magnets held parallel in a common frame. This frame or card assembly is pivoted at a point above its center of gravity in such a manner that it will balance horizontally. The movement of the card assembly is damped by a liquid in order to minimize the effects of vibration and the relative unsteadiness of the airplane. A shock-absorbing system, consisting usually of springs and felt pads, is also provided to take up a certain amount of vibration in the interest of preserving the pivot and jewel. The liquid serves two other functions: one to prevent corrosion of the pivot and the other parts inside of the bowl; and the other to keep the jewel washed clean of insoluble particles which tend to settle to the bottom of the bowl. A cross-sectional diagram of a magnetic compass is shown in figure 23. The card, which varies in diameter in different types, carries two cylindrical bar magnets of tungsten steel mounted on the under side. The outside rim of the card is marked in 5° graduations. The cardinal points are indicated by the letters N, E, S, and W.

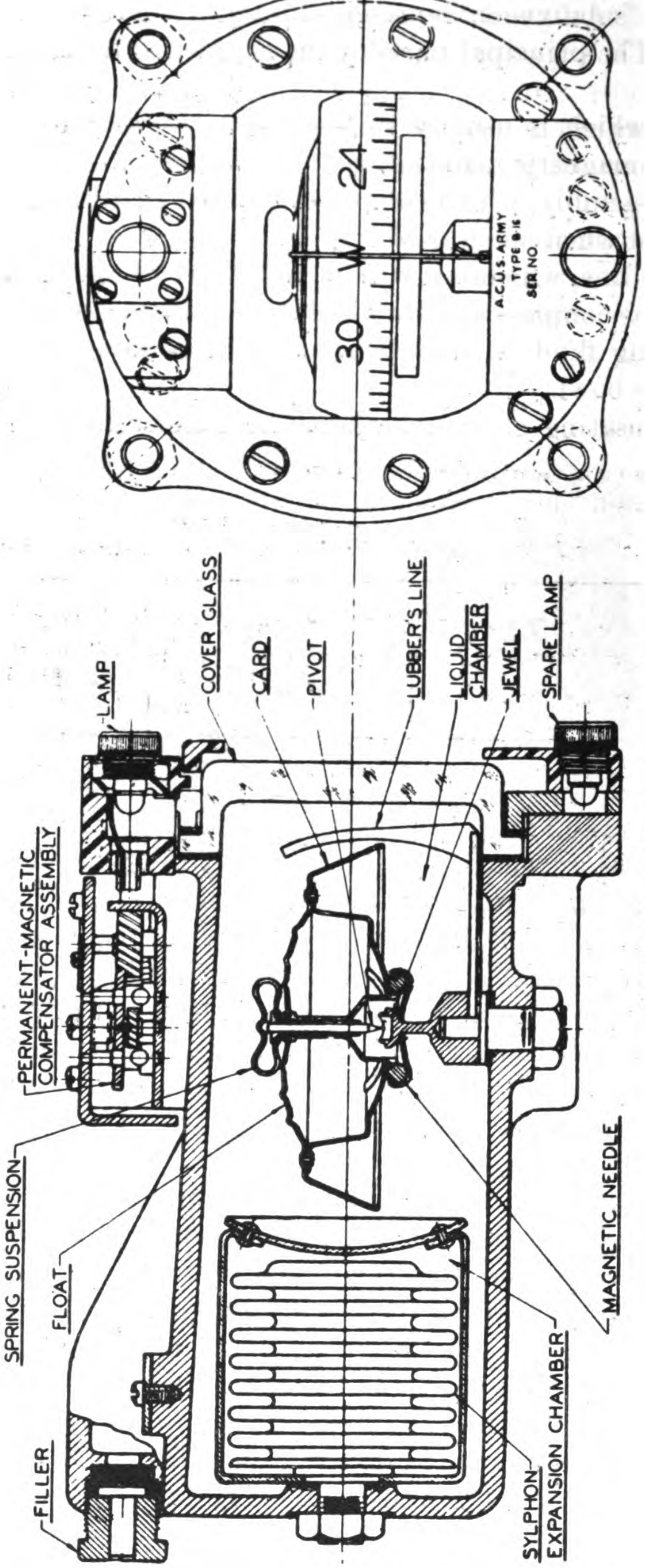

FIGURE 23.—Diagram of magnetic compass.

(2) From the center of the card a pivot points downward, and when the card is in place it rests in a jewel cup at the top of a post extending into the bowl from the bottom. The card is kept in place by a cage and hemisphere, forming a retaining device which prevents the pivot from leaving the cup. The pivot is made of steel. Owing to vibration it becomes somewhat blunt with use, but this does not affect the performance appreciably. Sapphire is used for the jewel cup. The vertical lubber line is mounted inside the bowl so as to be close to the glass face. In addition to the liquid, the damping system consists of a mechanical combination of springs and cushions to help absorb vibration.

f. Operation.—If a bar magnet is suspended so as to turn in any direction about its center of gravity, it will take a position with one end pointing northerly and the other end pointing southerly. For this reason the ends of the magnets are known as the north seeking or N end, and the south seeking or S end, respectively. Since the magnetic force acting on the N end is equal and opposite to the force on the S end, the effort on the N end only is considered. The position taken by the magnets in the usual compass is parallel to the earth's magnetic field. Hence, the needles hold the card in one position (errors will be discussed later), so that the direction of the longitudinal axis of the airplane with respect to magnetic north may be determined by reading that part of the card which is designated by the lubber line. When the airplane is turned, and the card comes to rest, the magnetic needles hold the card in the same previous directional position. The window and lubber line have been moved around the card to show a different section of it, and hence a different direction is indicated by the lubber line.

31. **Aperiodic or Air Corps type D compass.**—This type of compass is used extensively in airplanes which carry a member of the crew designated as navigator. Its description and operation are contained in section III, chapter 2.

32. **Earth-inductor compass.**—*a.* This type of compass is essentially a magnetic compass. It is actuated by the force of the earth's magnetic field and therefore indicates magnetic directions. It differs from the conventional magnetic compass in that magnetized needles are not employed to detect the earth's field. It operates upon the principle of the electric direct-current generator. An armature rotated by mechanical means cuts the earth's magnetic lines of force, thus generating an electric potential which is used to operate an indicating instrument. The indicator is a small galvanometer which is arranged to show a deflection when the aircraft is steered from the course for which it is set. The controller is set for a given course to

be flown, and as long as the aircraft is headed directly upon the course the indicator points to zero. It points to left or right when the airplane is headed off the course. The indicator also points to zero when a course 180° from that set is being flown. In this case a turn to the right causes a deflection of the pointer to the left and vice versa.

b. The earth-inductor compass is heavier and has more working parts than the magnetic-needle type compass. It has a few minor advantages over the magnetic-needle type, but these advantages have been largely offset by the development of the directional gyro to assist in holding a steady heading when using the magnetic-needle compass. The earth-inductor compass is used but little today.

33. Variation.—*a. Definition.*—The magnetic compass needle if operating perfectly and undisturbed by outside forces will point to the magnetic north pole. The earth's magnetic poles, with the magnetic field which controls the compass, are not located at the geographic poles of the earth. The magnetic pole in the Northern Hemisphere is at approximately lat. 71° N. and long. 96° W., while the southern pole is at lat. 73° S. and long. 156° E. Variation (Var.) is the angle between the plane of the true meridian and a line passing thru a freely suspended compass needle which is influenced solely by the earth's magnetism. It is named east or west according to the direction of the compass needle from true north. Variation changes with time and place.

b. Isogonic lines.—If the earth's crust were composed of a homogeneous material, the magnetic lines of force would be great circles joining the magnetic poles. The composition of the earth's crust is such, however, that in most localities the direction of the magnetic lines of force deviates considerably from the great circle. Fortunately, science not only has accurately located the magnetic poles but has also determined, with sufficient accuracy for the navigator, the direction of the magnetic lines of force at all places on the earth's surface; furthermore, the small changes in the direction which are gradually taking place have also been computed. An imaginary line connecting points of equal variation is called an "isogonic line." At all points along any given isogonic line the magnetic variation is the same. Figure 24 shows the lines of equal magnetic variation in the United States in 1935 at 5° intervals. Referring to the figure, it may be seen that in the eastern part of the United States the magnetic compass points west of true north (that is, the variation is westerly); in the western part of the country the magnetic compass points east of true north (easterly variation). The dividing line between these two areas of opposite variation, the line of 0° variation, is known as the "agonic line." At all points along this line the direction of magnetic north and true north are the same. Minor bends and turns in the isogonic lines are chiefly the result of local attraction. The isogonic lines shown in the figure are not magnetic meridians and should not be so called.

c. Importance.—When a course is referred to magnetic north rather than true north it is known as a magnetic course. The magnetic course is the true course with variation applied, or the true course plus or minus variation. 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 it must have some name for

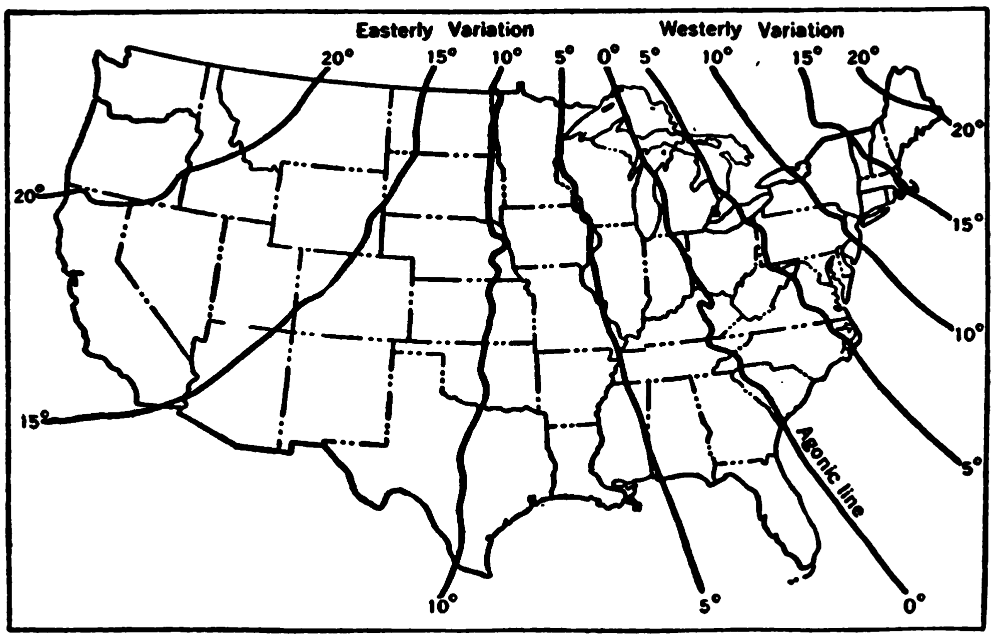

FIGURE 24.—Magnetic variation in United States, 1935.

reference. The correct application of variation is, however, one of the most important steps in navigation. Ships have been piled on the rocks and airplanes have become completely lost because of misapplication of magnetic variation.

d. Rule.—In applying variation it is necessary to learn the following rule so thoroughly that a wrong application is impossible: To convert a true course into a magnetic course, *add westerly variation.* Many pilots have found it helpful to remember the rhymes "East is least, west is best" or "East is minus, west is plus." It is important to note that the rule applies only when changing from true to magnetic course. It must be reversed to change from magnetic to true course. If the pilot can fix in his mind the relation pictured in figure 25, there will be no question as to the correct application of magnetic variation. In the figure, *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 point *O* and is west of true north as indicated. Angle *NOM* is the magnetic variation which is westerly. When magnetic north lies to the west of true north, the angle *NOM* must be added to the true course (angle 1) to obtain the magnetic course (angle 2), or the magnetic direction of the route. If westerly variation is to be added, easterly variation must be subtracted; but by always remembering the rule, *add westerly variation*, there will never be any danger of an erroneous treatment. For instance, near Portland, Maine, the variation is about 17° west, and the compass reading is 17° greater than the corresponding true course; near Portland, Oregon, the variation is about 22° east, and the compass reading is 22° less than the true course for any chosen course.

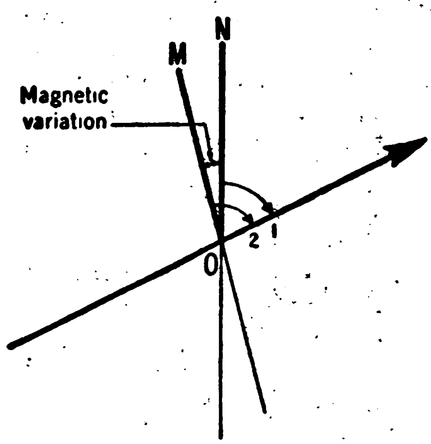

FIGURE 25.—Magnetic variation.

e. How variation is applied.—(1) In order to use the magnetic compass in air navigation, it is necessary to measure the course angle to get the true course, and then to make the correction for variation in order to know the magnetic course which will correspond to the true course. This magnetic course is later converted to compass course as will be described in the following paragraphs. For long flights, after dividing the route into sections of practical length and determining the series of true courses, the average magnetic variation for each section is applied in order to find the series of magnetic courses. (This is unnecessary on short flights in United States latitudes.)

(2) If the above procedure is disregarded and a long route is flown on one mean magnetic course, considerable departure from the intended track may result. For example, figure 26 shows the conditions actually existing in 1935 along the Canadian border between longitudes 90° and 96°, a distance of 273 miles. The true course for the route from point *O* to point *C* is 270°, the magnetic course at the point *O* is 268°. While the mean magnetic course is flown for the entire distance beginning at *O*, the course is in error by about 4°, and the plane will track the broken line south of the parallel. At

the center of the route the track will be 4.1 miles south of the parallel, gradually returning to meet it at *C*. The departure from this course is greatest where the greatest differences in magnetic variation occur. The maximum departure does not always occur at the midpoint of the route. It will only occur at the midpoint when the isogons are equally spaced.

(3) Variation cannot be reduced or eliminated, but it is constant for all headings of the aircraft in any one locality.

34. Compass installation errors.—One of the reasons why a compass fails to indicate correct magnetic direction is faulty installation. The compass must be installed so that the lubber line is parallel to the fore-aft axis of the airplane. Lubber-line error may be totally eliminated or it may be partially but satisfactorily eliminated. The total elimination is a difficult task which must be performed by an installation expert. The partial elimination may be accomplished

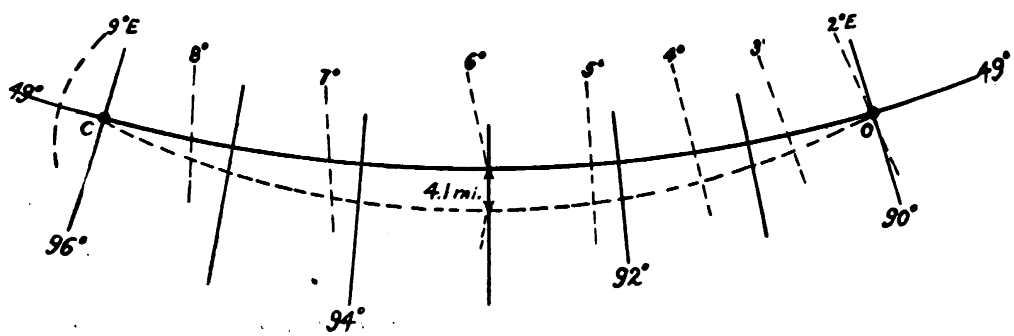

FIGURE 26.—Departure from intended track.

by the pilot just before he compensates the compass as described in paragraph 36. The fact that the lubber-line error is not totally eliminated is taken into account when the compass is swung to determine deviations.

35. Magnetic deviation.—*a. Definition.*—Another reason why the compass fails to indicate correct magnetic direction is due to magnetic deviation. The earth's lines of force are deflected from their normal path by the magnetic properties of the aircraft itself. All aircraft of necessity contain a certain amount of magnetic material; any iron in the structure is either permanently magnetized or has magnetism temporarily induced into it by the earth's magnetic field. In addition, wires carrying electric current produce magnetic fields of their own. This local magnetism disturbs the earth's magnetic field in the vicinity of the airplane. Thus the indication of any compass installed in an aircraft will be in error an angular amount equal to the number of degrees that the earth's lines of magnetic force are deflected from their normal path by the magnetic properties of the airplane. This error is known as deviation. Deviation is defined as the error caused by the aircraft's magnetism and is the angle between the magnetic meridian and the axis of the compass needle when the latter is deflected by the aircraft's magnetism. Since the magnetism in an airplane is not symmetrically distributed with respect to the compass, deviation will vary with the heading of the aircraft. Deviation is referred to as east or west according to the direction in which the needle is deflected.

b. Determination.—Deviation may be determined and tabulated by the process known as calibrating the compass (par. 36). The record of the compass deviations is posted in the airplane, and therefore the pilot must usually wait until he is actually in the airplane before he can know the deviations of the compass in that airplane.

c. How deviation is applied; rule.—(1) When a magnetic course is corrected for deviation it becomes a compass course. The compass course has no importance of its own as it is merely one of the steps in the process of arriving at a final compass heading.

(2) The application of deviation to the magnetic course is the same as the application of variation to the true course (par. 33*d*.) When changing from true to magnetic to compass, add westerly variation or deviation. Use the rhyme "East is least, west is best" or any other reminder. To avoid any possibility of a misunderstanding, the sequence shown here applies when changing from true to compass course, and the large arrow indicates that the correction for east is minus and for west is plus when changing from true toward compass course.

E−	True Course ↓
	Variation E or W ↓
W+	Magnetic course ↓
	Deviation E or W ↓
	Compass course

(3) Since the amount and direction of deviation change as the heading of the airplane is changed, each new heading of the aircraft requires a check to see what allowance must be made for deviation. The values for making this correction are obtained from the compass correction card posted in the airplane.

(4) It should be remembered that variation is measured from true north and is named with respect to north, while deviation is measured from magnetic north and is named with respect to the magnetic meridian.

36. Compass calibration on ground.—*a. Definitions.*—Compass calibration is the process of determining the magnetic deviation of the compass. It consists of three steps: removal of lubber line error; compensation; and swinging. Compass compensation is defined as a practical method of applying magnets or other correctors to neutralize the magnetic forces exerted on a compass by the aircraft and its equipment. Swinging the compass is the process of determining the compass deviation after it has been compensated.

b. Frequency of calibration.—The calibration of a compass installed in an aircraft cannot be expected to remain accurate for a very long time, as it has been found that gunfire, engine vibration, rough landings, etc., change the residual magnetism of the aircraft to an appreciable extent. Also the compensating magnets lose strength with age. Where accuracy for a particular flight is required, the aircraft compass should be swung before the flight and the deviations recharted. All compasses are swung and compensated at regular intervals of time or of flying hours of the aircraft, and also after the change of an engine or any electrical equipment which is likely to affect the compass.

c. Master compass and swinging base.—In order to calibrate an airplane's compass it is necessary to have available a master compass or a compass swinging base. A master compass is one from which all compensating magnets have been removed, which is in excellent working order, and which is portable, so that it may be located at a spot unaffected by any magnetic properties other than those of the earth. A compass base is a magnetic compass rose laid out on the ground. These compass bases are arranged so that the airplane may be accurately headed in magnetic directions from zero degrees magnetic through 360° at 15° intervals. Each Air Corps station has a compass swinging base. The master compass and the magnetic base serve to establish the correct magnetic direction of the longitudinal axis of the airplane. The reading of the airplane's compass while on any given magnetic heading (determined from the master compass or the swinging base) is compared with the correct magnetic direction of the airplane to determine the deviation on that heading.

d. Instructions preparatory to calibrating.—The following general instructions apply to the calibration of all magnetic aircraft compasses:

(1) See that compass is properly filled with liquid. This may be accomplished by removing compass from mount and turning it face up. If a bubble appears, it is an indication that more liquid is required.

(2) Remove all compensating magnets from slots, if compass has removable magnets.

(3) See that airplane is as far as possible from other aircraft, and any steel structure, underground cables, and drainage pipes.

(4) With wheels securely locked, elevate tail wheel on a support so that airplane is in flying position, with tail secured or weighted down to prevent nosing over when engine is started.

(5) See that there is no lateral inclination of airplane.

(6) Keep all unused magnets at least 2 feet away from compass.

(7) Cause compass card to deflect through a small angle, using small permanent magnet for this purpose, and insure that card rotates freely on pivot.

(8) Place all controls, guns, etc., in flying position except that, when engine is running, elevators will be used to assist in keeping tail of airplane down.

(9) See that compass card does not list, that is, that its path of rotation is in a horizontal plane.

(10) With engine or engines running and speeded up so that maximum charge is shown on ammeter, head airplane toward magnetic north and then to magnetic east to determine error caused by vibration and induced magnetic influences.

e. Removing lubber line error.—The method of finding and reducing the lubber line error, when a compass is first installed in the airplane, is as follows:

(1) Head airplane, in turn, on headings of magnetic north, east, south, and west, recording deviations on these headings.

(2) Add easterly deviations together and westerly deviations together. Subtract smaller from greater and divide by four. The result, named east or west for the larger value, gives the angular error of the lubber line or the lubber line error.

(3) The correction for this error, necessary only if it is more than 1°, is made by changing the installation of the compass mounting in the airplane. The base of the compass is provided with slots or other means of rotating the entire compass on the mount.

f. Compensation.—After the correction has been made for the lubber line error, the compass is ready for compensation. This is accomplished as follows:

(1) Head airplane toward magnetic north. Insert required number of compensating magnets in the *athwartship* compensating chamber (so that magnets are at right angles to compass needle) to obtain a reading of exactly N.

(2) Head magnetic east and insert required number of magnets in fore and aft compensating chamber (at right angle to compass needle) to obtain a reading of exactly E.

(3) Head magnetic south and note error. Reduce error by one-half by reducing or changing magnets inserted in (1) above. This throws one-half of the error back to north reading. *Example:* If the reading on magnetic south is 184°, the magnets will be changed to make the reading equal 182°.

(4) Head magnetic west and reduce error by one-half by changing magnets inserted in (2) above. This throws one-half of the error back to east.

g. Swinging.—Swing airplane at 15° intervals, around the complete circle. Make a record of the deviations, at each position, under conditions of radio "on" and "off" and lights "on" and "off." Record these deviations on the compass correction card or, in lieu of the deviations, record the compass courses which must be steered to make good the various magnetic courses. This card is posted in a suitable holder near the compass.

37. Errors of compass in flight.—*a. General.*—Whenever the compass card is tilted to the eastward or westward it is acted upon by the vertical component of the earth's magnetic force and is rotated so as to give a false reading. In the magnetic compass the vertical component exerts its greatest downward pull at the north-seeking end of the card in north latitudes and at the south-seeking end in south latitudes. In either case the force causing rotation will be the greatest when the card is tilted about the N–S line; that is, when either the east or west side of the card is depressed.

b. Acceleration errors.—Compass cards are held level under normal conditions, due to the fact that the card is designed with its center of gravity below the pivot, and it therefore acts like a pendulum. When acceleration forces act upon the pendulum compass card assembly, it will swing away from the vertical like any other pendulum, and the plane of the compass needles will be tilted with respect to the horizontal. As stated before, the resulting rotation of the card will be a maximum when the acceleration forces cause the card to tilt about its N–S line; in other words, when the acceleration is in an east or west direction. Such accelerations occur when a plane headed east or west speeds up or slows down (speed error), and when a plane headed north or south turns toward the east or west (northerly turning error). In every case in northern latitudes the north side of the card will rotate from north toward the low side of card. In south latitudes the south side of the card will rotate from south toward the low side of the card. At the magnetic equator, where there is no vertical component, there will be no errors due to acceleration.

(1) *Northerly turning error.*—When making a turn, the forces of acceleration act at right angles to the heading of the plane. Thus, in northern latitudes, if the aircraft is headed in a northerly direction but is making a turn to the east, the pendulous assembly will be pulled to the west by the forces of acceleration, and the east side of the card will be depressed below the horizontal. The vertical component of the earth's magnetism will then cause the north point of the card to rotate toward the east or low side. Thus, the compass reading will be less than it should be and may, in certain cases, even falsely indicate that a turn is being made to the westward. When flying blind this is a dangerous thing as the pilot applying sufficient rudder to make the compass indicate a turn to the eastward may place the aircraft in a spinning attitude. This same action occurs when a turn is made to the westward from a northerly heading, in that the compass will read less than it should and may even indicate a turn in the opposite direction. On southerly headings in north latitudes a turn is not so dangerous, because the card indicates the turn in the correct direction but of greater magnitude than actually made. In southern latitudes the situation is reversed, and a turn from southerly headings is the most dangerous, since here the compass will indicate a turn of less magnitude than is being made, or may even indicate a turn in the opposite direction.

(2) *Speed errors.*—Speed errors due to acceleration or deceleration of speed are maximum on east and west headings. In normal flight, speed accelerations are small. The accelerations become large when entering and pulling out of a dive, however, and if the dives are made on east or west headings large deviations of the compass will be noted. The compasses will also be slightly deflected during take-offs and landings on east and west headings.

(3) *Swirl errors.*—Swirl errors occur whenever turns are made. They are caused by the fact that the liquid in the compass is rotated a certain amount due to the friction with the compass case. The movement of this liquid rotates the card in the direction the turn is made, the amount of rotation being dependent upon the design of the compass, the liquid used, and the magnitude of the turn.

c. Vibration error.—A certain engine speed may cause vibrations which affect the compass. Instances have been recorded when compasses have begun spinning due to vibration and continued to spin until the "period" of the vibration was changed. A change in engine speed will usually break the period of the vibration.

d. Minimizing errors.—It will be apparent from the above that the compass should be read only when the airplane is flying straight and level at a constant speed. By reading the compass only under these conditions, acceleration errors can be held to a minimum. The compass is not a satisfactory instrument for determining the rate of a turn or even the direction when acceleration is taking place.

38. **Summary.**—*a*. The compass is the most important navigational instrument in the aircraft and its use is essential except for short flights in excellent weather. The magnetic compass is subject to the laws of magnetism.

b. Compass readings should be taken while the airplane is flying straight and level at a constant speed. The compass will not record correctly when the airplane is accelerating or decelerating as occurs when the airplane is turning, diving, or climbing. Nor will the compass indicate correct magnetic direction when the needle is vibrating.

c. Variation cannot be reduced or eliminated but it is constant for all headings in any one locality.

d. Deviation error may be either eliminated or reduced and is different for different headings in the same locality. The deviations of the compass are determined by a process called calibration. Since these deviations are determined with the airplane in flying position, the deviations will only hold good when the airplane is flying straight and level.

e. When changing a true course to a magnetic course use the rule "East is least, west is best." Subtract easterly and add westerly variation.

f. Use the same rule for applying deviations when changing from a magnetic course to a compass course.

Section V

TIME, SPEED, AND DISTANCE

	Paragraph
Time, speed, and distance	39
Knots and miles per hour	40
Air speed and ground speed	41
Triangular scale	42

39. **Time, speed, and distance.**—*a*. *Relationship.*—There is a definite relationship between time, speed, and distance. Speed is a rate of motion or a ratio between time and distance.

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{Time} = \frac{\text{distance}}{\text{speed}}$$

$$\text{Distance} = \text{time} \times \text{speed}$$

These formulas may be used as shown above, but care should be taken to use the correct units. If speed is given in miles per hour, then distance should be in miles, and time should be in hours.

b. Example.—(1) Using the formula

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

and substituting numerical values might result in

$$180 \text{ m. p. h.} = \frac{45 \text{ miles}}{.25 \text{ hours}}$$

This formula is correct numerically. If the time is changed to 15 minutes it would appear to be

$$180 = \frac{45}{15}$$

which would be incorrect. It could be changed to read

$$3 \text{ miles per minute} = \frac{45 \text{ miles}}{15 \text{ min.}}$$

and it would again be correct. As a rule it is better to use miles and hours (m. p. h.) as the units.

(2) If any two of the above values are known, the third one may be found by using the suitable formula. Thus, if the time is required when the distance is known to be 134 miles and the speed to be 170 m. p. h., the formula would be

$$\text{Time} = \frac{\text{distance}}{\text{speed}}$$

or

$$\begin{aligned} \text{Time} &= \frac{134}{170} \\ &= .788 \text{ hours} \\ &= .788 \times 60 \text{ minutes} \\ &= 47.28 \text{ minutes} \end{aligned}$$

40. Knots and miles per hour.—*a. Definition.*—A knot is a unit of speed equal to 1 nautical mile per hour. (It is equivalent to 1.15 statute miles per hour.) It is frequently used by navigators of airplanes which have a crew member designated as such. The word "knot" is complete without the additional words "per hour"; for example, 120 knots is the same as 120 nautical miles per hour.

b. Use.—The formulas given in paragraph 14 for statute miles also apply to nautical miles. For example, if distances and speeds are given in nautical miles and knots, the same formulas would be used. (Par. 14 gives the conversion factors for changing one of these units to the other.) No attempt should be made to work a problem without insuring that the distances and rates of travel are in the same units.

41. Air speed and ground speed.—The air speed of an airplane depends on its rate of movement in the air, while the ground speed is its speed in relation to the ground. (See sec. VI.) The difference between the two is caused by the movement of the air or the wind.

42. Triangular scale.—*a. Type.*—The triangular engineer (not architect) scale, which is useful in constructing vector triangles, has six different edges and six scales on it (K & E #1631 P or similar). These scales are very useful in constructing vector diagrams which represent velocities and distances to scale. (See sec. VI.) The 12-inch scale allows the rapid and accurate use of scales ranging from 1 inch=10 units to 1 inch=60 units.

b. The six scales.—(1) Scale 10, the scale edge of which is designated by the figure 10 at the left end (or in the center), is the scale which is best used for a diagram where the values are represented by 1 inch=10 miles. Each smallest subdivision then represents 1 mile, and the figure 1=10 miles, 2=20 miles, etc., up to 12=120 miles. By mentally adding a zero to each printed figure, any required value is instantly determined.

(2) Scale 20 likewise is divided into small subdivisions, and each one may represent 1 mile. By adding the final zero to each figure printed on this scale, any distance up to 240 miles may be quickly determined without shifting the position of the scale.

(3) Scale 30 shows, by the smallest subdivisions, 1 mile up to 360 miles.

(4) Scale 40 shows from 1 mile up to 480 miles.

(5) Scale 50 is divided to show from 1 to 600 miles.

(6) Scale 60 is divided to show from 1 to 720 miles.

c. Example.—To insure that each student thoroughly understands the use of the triangular scale, the following example is given:

(1) Draw a straight line with cross marks exactly 8½ inches apart. Then, in order, place the six edges of the scale along this line and note the number of units represented by this 8½-inch distance.

(2) As the rule edges indicate the scale as shown in the first column, the distances shown in the second column will be indicated:

Scale, 1 inch	Distance, 8½-inch line
Miles	*Miles*
10	85
20	170
30	255
40	340
50	425
60	510

SECTION VI

EFFECT OF WIND

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43. Definitions.—*a.* (1) *Air speed.*—True speed of an aircraft relative to the air. It is the true air speed unless otherwise stated. Air speed is obtained by correcting the calibrated air speed for density, using temperature and pressure altitude corrections.

(2) *Ground speed.*—Actual speed relative to the earth's surface.

(3) *Drift.*—Angle between the heading and the track. It is named right or left according to the way the airplane is drifted.

(4) *Drift correction.*—Angle added to or subtracted from an aircraft's course (true) to obtain heading. In case of a right drift the angle is subtracted from the course to obtain the heading, and in case of a left drift it is added. A 5° drift correction to the right would be written as +5°; the drift would be L.5°. A 5° drift correction to the left would be written −5°; the drift would be R. 5°.

(5) *Course* (C.).—Direction over the surface of the earth, expressed as an angle, with respect to true north, that an aircraft is intended to be flown. It is the course laid out on the chart or map and is always the true course unless otherwise designated.

(6) *Magnetic course* (M. C.).—Course (true) with variation applied.

(7) *Compass course* (C. C.).—Magnetic course with deviation applied.

(8) *Course made good.*—Resultant true direction the aircraft bears from the point of departure. (All courses are measured from north through east of 360°.)

(9) *Track.*—Actual path of an aircraft over the surface of the earth. Track is the path that has been flown. Course (true) is the path intended to be flown.

(10) *Heading.*—Angular direction of the longitudinal axis of the aircraft with respect to true north. It is the course with the drift correction applied. It is true heading unless otherwise designated.

(11) *Magnetic heading.*—Heading with variation applied.

(12) *Compass heading.*—Magnetic heading with deviation applied.

(13) *Wind direction and force.*—Wind is designated by the direction from which it blows. Force of the wind is expressed as the speed in miles per hour or knots.

(14) *Velocity.*—Rate of change of position in a given direction. It involves both speed and direction.

(15) *Line.*—A straight line may represent a velocity; direction is represented by the position of the line; speed by the length of the line.

b. No wind.—(1) *General.*—An airplane in flight, when there is no wind, will have the same air speed and ground speed. It will also have the same heading and course. This condition seldom prevails, so the effect of the wind must usually be taken into consideration. The change in rate of travel (air speed or ground speed) and the change in direction (course or heading) may be solved by the same vector diagram. There are two simple cases which do not need a diagram, and these are the rare occasions when the airplane course is exactly downwind or into the wind.

(2) *Example.*—(*a*) An airplane, air speed 150 m. p. h., is flown directly into a 20 m. p. h. head wind. The ground speed then equals 130 m. p. h. and the heading is the same as the course.

(*b*) An airplane, air speed 150 m. p. h., is flown directly down wind in a 20 m. p. h. wind. The ground speed then equals 170 m. p. h. and the course and heading are the same.

44. Vector diagrams.—*a. Velocities.*—A velocity may be represented in a vector diagram by a straight line. The direction of the line is drawn in the same direction as the motion, and the length of the line represents the rate of motion. Two component velocities may be resolved into the resultant velocity.

b. Wind diagrams.—In the wind vector diagram the heading and air speed are drawn as one component and the wind direction and wind speed as the second component. The resultant then indicates the course and ground speed. (In the actual movement of the airplane over the earth, the resultant is the track.)

45. Usual problem, type 1.—*a. To determine heading and ground speed.*—(1) The type of diagram described in this paragraph will hereafter be called type 1 in order to shorten the nomenclature. This type of diagram is constructed when it is desired to determine the heading and the ground speed, knowing the course, the air speed, and the wind velocity. A diagram of this type may be drawn directly on a map, using the map scale, or it may be constructed on an ordinary sheet of paper.

(2) 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. If we substitute for the cork a toy motorboat which requires a minute to cross a small stream, and the stream is flowing at the rate of 10 feet per minute, even though the boat is headed directly across stream it will still feel the full effect of the current. During the minute of its crossing it will be swept 10 feet downstream and will reach the opposite bank at a point 10 feet below the point of departure. The solid line of figure 27 represents the path of the boat in crossing the stream. In exactly the same way an airplane in flight is subject to

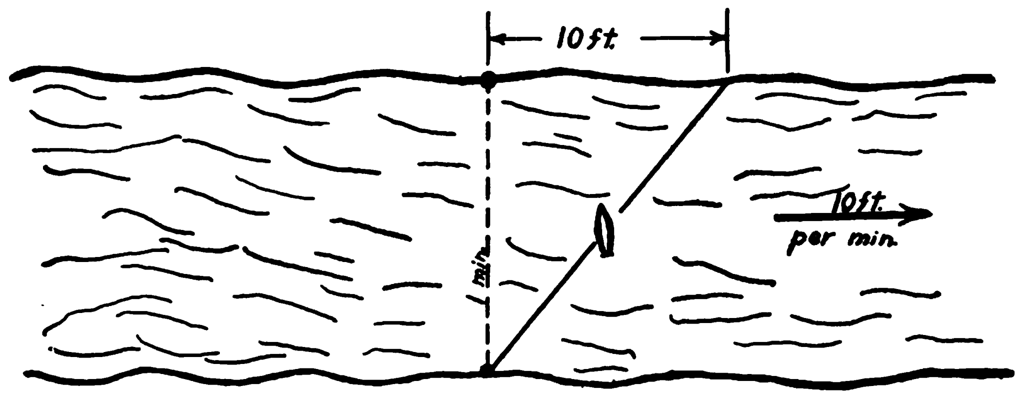

FIGURE 27.—Effect of current on a boat.

the full effect of the wind, even though the plane may be moving under its own power in an entirely different direction.

(3) For example, if a plane were headed due east from *A* at an air speed of 100 m. p. h., it would reach a point *B* 100 miles away in just 1 hour if there were no wind. If a wind were blowing from the north the plane would actually arrive in 1 hour at a point to the south of point *B*. In order to be able to make good the desired course to the east, the airplane must be headed *into* the wind by an amount which will counteract the tendency of the wind to cause the airplane to be drifted south of the 90° course. This change of heading (the heading will be less than 90°) will also cause a change in the ground speed. The example in *b* below shows how the heading and ground speed are determined by constructing a diagram.

b. Type 1 diagram.—(1) *First example.*—To find heading and ground speed.

(*a*) Given: Desired course 90°.
Air speed 100 m. p. h.
Wind velocity 20 m. p. h. from 315°.
Required: Heading.
Ground speed.

(*b*) The first step is the construction of a north-south line. A mental calculation or rough sketch indicates that this line may be placed close to the left side of the paper, as all of the diagram will be on the right side of it. So it is drawn close to the left border of the paper and then a starting point *A* is chosen.

(*c*) From *A* the course line 90° is drawn as *AX*. (See fig. 28.)

(*d*) From *A* the wind line *AB* is drawn down wind from 315°.

(*e*) The distance *AB* is made equal to 20 units of the scale it is desired to use.

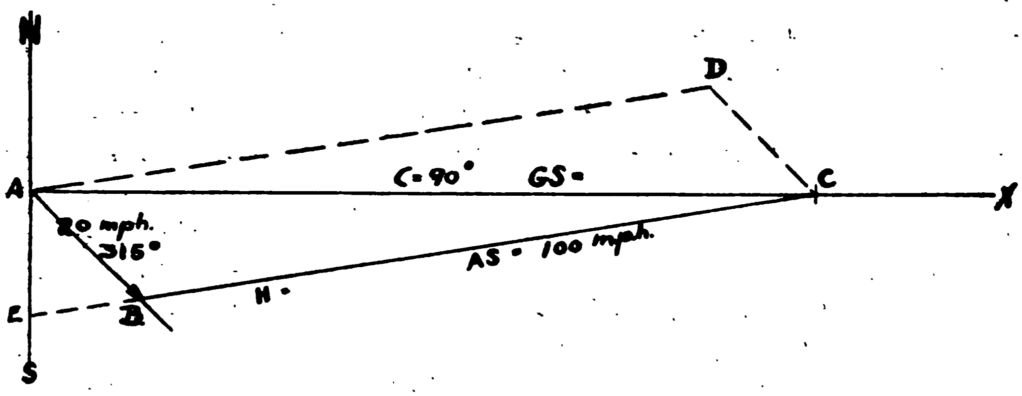

FIGURE 28.—First example of type 1 diagram.

(*f*) From *B* the point *C* is located so that by construction the distance *BC* equals the air speed for 1 hour or 120 m. p. h.

(*g*) The triangle *ADC* is constructed in this example so that *ABCD* is a parallelogram.

(*h*) The required heading will be the direction indicated by the line *AD* (same as shown by line *BC*).

(*i*) The required ground speed will be shown by the number of units in the length of the line *AC*.

(*j*) It usually is not necessary to complete the parallelogram, as the required heading and ground speed may be determined from the triangle *ABC*. Note that the angle *NAD*, which is the heading angle, is the same as the angle *NEC* (*CB* is continued through *B* to *E*). The heading may therefore be determined by finding the direction of *BC* and so the side *AD* is not actually needed.

(2) *Second example.*—To find heading, ground speed, and time.

(*a*) Given: Course 243°.
Air speed 140 m. p. h.
Wind 20 m. p. h. from 278°.
Distance *A* to *M* 248 miles.
Required: Ground speed out.
True heading out.
Time for flight.

(*b*) Determine the position of the north-south line and point *A*. (See fig. 29.)

(*c*) Draw *AX* 243°.

NOTE.—This line need be only long enough to help complete a 1-hour diagram. In this type of problem it does not have to extend all the way to the point *M*.

(*d*) Draw *AB*, wind velocity 20 m. p. h. from 278°.

(*e*) Draw *BC*, air speed 140 m. p. h.

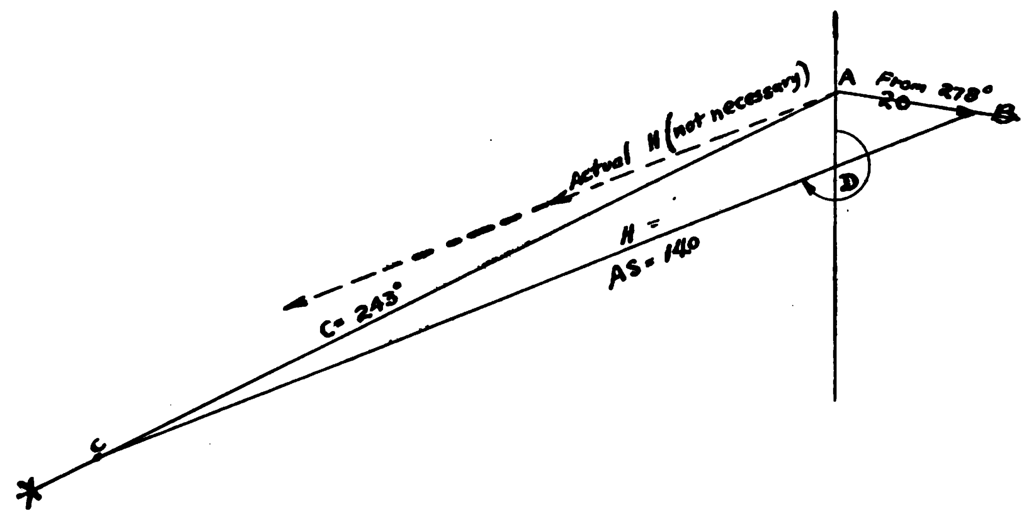

FIGURE 29.—Second example of type 1 diagram.

(*f*) Measure *AC*, ground speed.

(*g*) Measure angle *D*, heading angle.

(*h*) Divide distance 248 by ground speed 123.

(*i*) Change resulting hours and fractions to hours and minutes.

(*j*) The required answers are given in (*f*), (*g*), and (*i*) above.

46. Rules and helps.—*a*. The principal source of accuracy in diagrammatical solutions is neatness. Lines should be drawn with a hard lead pencil sharpened to a fine point. The paper should be placed on a hard surface and in sufficient light.

b. To avoid mistakes, all lines should be labeled as soon as they are drawn. This will insure easier checking of the diagram after completion.

c. Read the problem through two or three times so that there is no doubt as to what is required and the methods to use. It is helpful to make a rough approximate sketch before starting the detailed accurate diagram.

d. Place the diagram correctly in the available space. If the diagram will all be done on one side of the N–S line, do not draw this line down the center of the paper.

e. Use 1 hour units unless there is a reason for using more or less than this amount.

f. There are sometimes several ways to work some types of diagrammatical solutions. The ones shown in this manual are best for all types of such problems.

g. Wind always blows the aircraft from the heading to the course.

h. Course and ground speed are always on the same line.

i. Heading and air speed are always on the same line.

j. In all diagrams illustrated in this section of the manual the wind is always plotted *downward.*

k. Only true directions are used in diagrams. If the data give a compass course, change it to a true course, using arithmetic, before drawing the diagram. If the problems give a compass heading, change it to a true heading, arithmetically, before starting to draw.

47. Compass heading.—*a. Course and heading.*—(1) It has already been shown that 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 was also defined as the true course plus or minus variation and deviation but with no allowance for wind. To avoid any confusion at this point remember that—

(*a*) *Compass course* is the true course plus or minus variation and deviation but without allowance for wind effect.

(*b*) *Compass heading* is the true course plus or minus variation and deviation and including allowance for wind. It is the direction by compass in which the plane is pointed.

(2) Another method of illustrating the differences between course and heading is to enumerate them as follows:

1. True course.	1. True course.
2.	2. Drift correction.
3.	3. True heading.
4. Variation.	4. Variation.
5. Magnetic course.	5. Magnetic heading.
6. Deviation.	6. Deviation.
7. Compass course.	7. Compass heading.

In the first group of seven lines there has been no correction for drift, while in the second group the drift correction has been made. Each starts with true course and each ends with a compass direction. If the drift correction is applied to line 5 of the first group it will then become line 5 of the second group. Line 7 may be changed in the same manner.

b. Application.—(1) In actual use the true heading is changed to the compass heading before it is used by a pilot. To do this, he applies variation and deviation to the true heading which then becomes the compass heading.

Example: If the problem illustrated in paragraph 45 *b* (2) had included, in the data given, variation 11° east and deviation 2° west, it would be possible to complete it for a required compass heading. The true heading was determined to be 247½° or 248°. Taking the latter figure, the next steps would be—

True heading 248°.
Variation 11° east (subtract).
Magnetic heading 237°.
Deviation 2° west (add).
Compass heading 239° (answer).

(2) In order to make good a course of 243°, with the wind and air speed as shown in paragraph 45*b*(2), and variation and deviation as shown above, the pilot would head the airplane so that the compass reading would be 239°. The resulting compass heading in this case would not be many degrees different from the original course. Often in actual practice this difference will be quite large.

48. Reverse problem, type 2.—*a. To find course and ground speed.*—(1) In the preceding discussion the usual type of problem has been considered, namely, determining from the chart and from the wind data, when planning a flight and before taking off, the distance between points, the compass heading to be followed, and the ground speed.

(2) 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 compass heading, approximate ground speed, and elapsed time.

(3) Essentially, this problem is the reverse of the first. In type 1 we start with the true course measured on the chart and apply the

drift correction, variation, and deviation in order to obtain the compass heading. In type 2, 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 type 1 must be reversed. Whatever would have been added then must be subtracted now, and vice versa.

(4) (*a*) This process of taking away or changing may be called "rectifying," and to do so requires three steps:

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.

(*b*) The first two steps are done by arithmetic in order to obtain the true heading. The last step may be done graphically or by mechanical means, by use of tables, by using a computer, or even by mathematical means.

b. Type 2 diagram.—(1) *First example.*

(*a*) Given: Compass heading 82°.
Air speed 100 m. p. h.
Wind 20 m. p. h. from 315°.
Variation 10° east.
Deviation 2° west.

Required: Course (or track) being made good.
Ground speed.

(*b*) By arithmetic find the true heading. This may be done by reversing the rule of "East is least, west is best," or it may be done by filling in the known values as follows:

	A	*B*
E−	True heading=?	=*90*° (*answer*)
W+	Variation=10° E. or −	=−10
	Magnetic heading=?	=80°
	Deviation=2° W. or +	=+2
	Compass heading=82°	=82°

(*c*) Although this may seem longer than the method of reversing a previously learned rule, it has the advantage of allowing a rapid check of the arithmetic by using, from top to bottom of column *B*, the same rule used before.

(*d*) The diagram is now drawn as follows (fig. 30): From point *A* on the N–S line draw *AB* equal to the true heading 90° in direction and to the air speed in length. Then from point *B* draw *BC* equal to the wind velocity. Connect *A* and *C*, and *AC* will represent the course (or track) and also the ground speed.

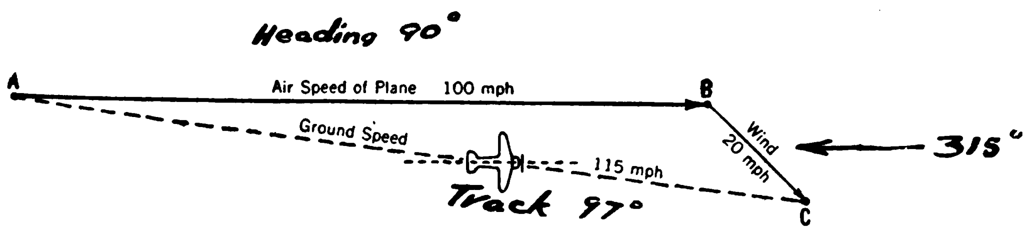

FIGURE 30.—First example of type 2 diagram.

(*e*) Note that in this diagram, type 2, the wind is drawn from a point 1 hour's air speed away from the starting point. Also that the rule of the wind blowing the airplane from heading to track applies as it should.

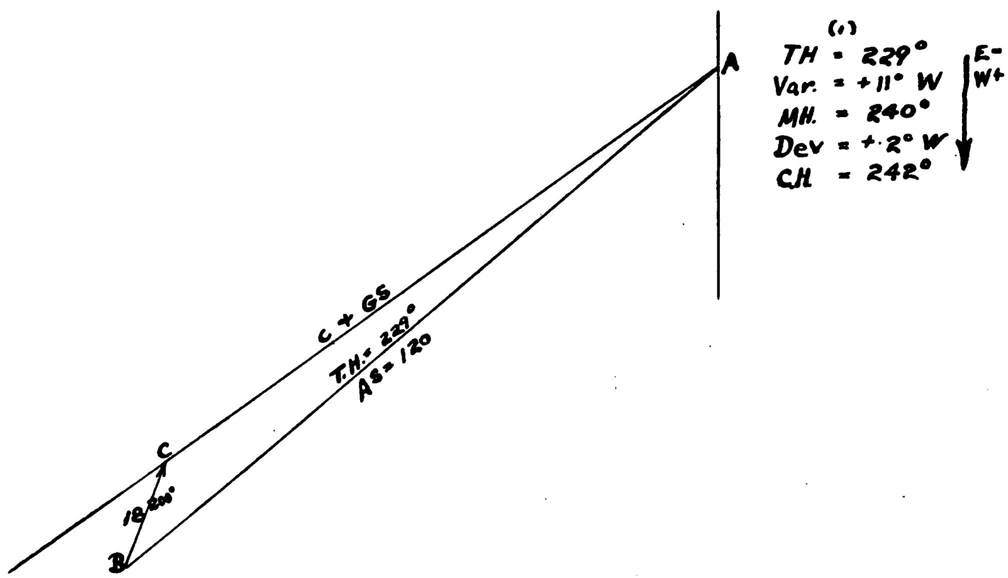

FIGURE 31.—Second example of type 2 diagram.

(2) *Second example.*

(*a*) Given: Compass heading 242°.
Air speed 100 m. p. h.
Wind 18 m. p. h. from 200°.
Variation 11° west.
Deviation 2° west.

Required: Course (or track).
Ground speed.

(*b*) Change compass heading to true heading.
(*c*) Draw *AB* (fig. 31) equal to heading and air speed.
(*d*) Draw *BC* equal to the wind velocity.
(*e*) Draw *AC*, which equals the course (track) and the ground speed.

49. Solving for wind.—Another type of wind diagram may be used if the heading and air speed and also the course and ground speed are known.

Example (fig. 32): Let *AB* equal the true heading and air speed. Let *AC* equal the course and ground speed. Then *BC* will represent the wind velocity, and the wind would be blowing in the direction from *B* to *C* with speed equal to the length *BC*.

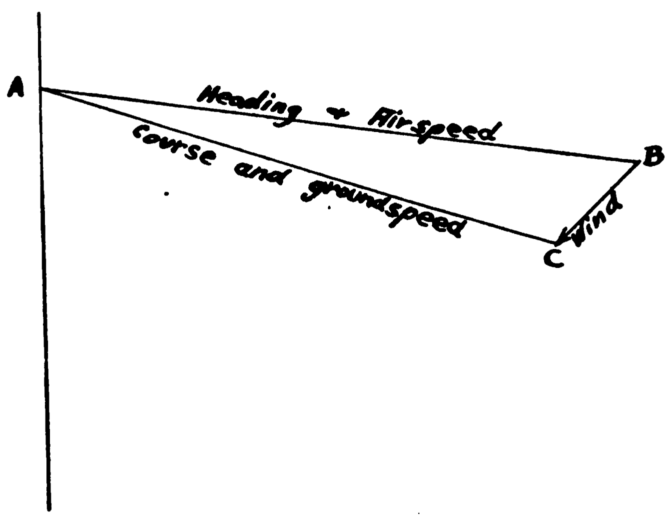

FIGURE 32.—Solving for wind.

SECTION VII

ELEMENTARY DEAD RECKONING

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50. Advantages of dead reckoning (D. R.).—*a. Definition.*—Dead reckoning is the method of determining the geographical position of an aircraft by applying the track and ground speed, as estimated or calculated, over a certain period of time from the point of departure or from the last known position.

b. Use.—(1) Cross-country flying by elementary methods of piloting is simple under conditions of good visibility. Piloting a plane by reference to visible landmarks is fundamental and must be combined with any other form of navigation that may be used; however, when a pilot is limited to flying by landmarks alone, he loses the saving in distance of the direct air route. Furthermore, if the weather should close in unexpectedly during the flight and the familiar landmarks could not be found, the results might be extremely serious not only to the pilot but to the life and property of others as well.

(2) By means of dead reckoning between check points, a pilot can fly directly to or fairly close to the landmarks for which he is looking. Because he knows when and where to look for them, he will often succeed in finding them when a pilot without such training would miss them altogether. If he has an accurate knowledge of his own course and speed, and of wind direction and force, he may proceed even under adverse weather conditions with more certainty than an untrained pilot might in clear weather. In any event, the ability to navigate by more advanced methods results in increased safety and greater operating efficiency, gives considerable confidence and mental satisfaction to the pilot, and is essential for the missions required of military personnel.

(3) Dead reckoning, or deduced reckoning as it was originally called, consists of keeping the position of the aircraft known by means of estimating the path and distance traveled since a last known check point. This method is really the basis of all navigation. All other methods may be said to supplement dead reckoning.

(4) A pilot can fly cross country with no instruments and equipment except a map, and even without that if he has sufficient knowledge of the terrain to be covered, but only very foolish and inexperienced pilots attempt such flights. Elementary dead reckoning methods require the use of several instruments.

51. Air speed meter.—*a. Definitions.*—(1) Air speed is the true speed of an aircraft relative to the air. It is the true air speed unless otherwise stated. Air speed is obtained by correcting the calibrated air speed for density, using temperature and pressure altitude corrections.

(2) Indicated air speed is the reading of the air speed indicator.

(3) Calibrated air speed is the reading of the air speed indicator, corrected for instrumental and installation errors.

b. Relationship.—(1) The air speed indicator indicates the calibrated air speed of the airplane traveling through the air only when the instrumental and installation errors are so small that they may be ignored. Instrumental errors are usually so small that they may be neglected, but the installation error is so large that the air speed installation is always calibrated when precision results are desired. In elementary dead reckoning the difference between indicated air speed and calibrated air speed is ordinarily ignored or estimated. In nearly all air speed indicator installations, it will be found that the indicated air speed is less than the calibrated air speed by an amount varying considerably between different airplanes and also at different speeds in the same airplane. The calibration of air speed meters is described in paragraph 154.

(2) Except in still air at normal sea level temperature and atmospheric pressure, the calibrated air speed is different from the true air speed. However, the pilot may calculate the true air speed from the calibrated air speed if he knows the pressure altitude at which he is flying and the free air temperature. The conversion of calibrated air speed to true air speed may be accomplished by formula. However, the conversion is usually made by using the type D-3, E-6B, or E-1 dead reckoning computers. The procedure when using the D-3 is described in paragraph 55. The procedure when using the other two computers is described in paragraph 145. If a computer is not available, the air speed may be obtained from calibrated air speed by the following rule: For every 1,000 feet of altitude above sea level, increase the calibrated air speed by 2 percent. For example, at 10,000 feet above sea level, the true air speed is 20 percent greater than the calibrated air speed.

c. Use.—Specific uses of the air speed indicator are as follows:

(1) To aid in estimating the actual ground speed of the airplane. This is necessary in cross-country flying when the time required to reach a landing field must be determined, during bomb sighting and gunnery missions, and in aerial camera work.

(2) To aid in determining the best throttle setting for the most efficient flying speed.

(3) To aid in determining the best climbing and gliding angles.

(4) To determine whether the speed attained in a dive is within the limits of safety for the structure of the airplane.

(5) To indicate to the pilot when the airplane has attained flying speed during the take-off and when the stalling speed is being approached when landing. This is especially true when flying closed cabin airplanes. Pilots are trained to judge these speeds without the aid of instruments, and in open cockpit airplanes this is easily done. In large, enclosed types, the air speed indicator is a very essential aid.

270209°—40——5

d. Principle of operation.—The air speed meter is operated by changes in air pressure, introduced into the instrument through tubing. If leaks or stoppages develop in the tubing the result will be a lower instrument reading. The indicator is a sealed unit with a pressure sensitive cell inside. The cell is a hollow circular box made of thin sheet bronze. It is capable of expanding and contracting as the pressure is varied on its surfaces. The movement of the cell is transmitted to a pointer through a system of levers and gears, and this pointer registers the rate of travel on the scale on the instrument face.

52. Altimeter.—*a. Purpose and use.*—Altimeters are used for two distinct purposes in an aircraft:

(1) To measure the elevation of the aircraft above some point on the ground (regardless of its elevation above sea level). This method of altitude measurement is used in instrument landing procedure and will give a zero altimeter reading upon landing. It is called the "zero setting" system.

(2) To measure the elevation of the aircraft above sea level. This method of altitude measurement is used for cross-country and airways flights and is called the "altimeter setting" system. Specific uses of the altimeter setting system are as follows:

(*a*) To show at all times elevation of the airplane above sea level so that the indication can be compared with maps for the purpose of clearing critical points and mountain peaks safely.

(*b*) To use advantageously meteorological data which is supplied by weather stations, such as wind velocities and directions, and cloud and storm formations which are to be avoided in flight when possible.

(*c*) To observe and follow correctly airways traffic regulations.

b. Principle of operation.—Altimeters and barometers operate on the same principle. The mechanism is actuated by changes in atmospheric pressure. Atmospheric pressure varies with altitude, decreasing as altitude increases. Air is compressible so the atmospheric pressure does not decrease uniformly with a uniform increase of altitude. In the standard atmosphere at sea level the atmospheric pressure is 14.7 pounds per square inch; at 10,000 feet it is 10.8 pounds per square inch; at 20,000 feet it is 7.06 pounds per square inch; and at 30,000 feet the pressure is only 4.9 pounds per square inch. Atmospheric pressure is usually determined by measuring the height of the column of mercury it will support. This height at sea level in the standard atmosphere is 29.92 inches; at 10,000 feet it is 20.73 inches; at 20,000 fet it is 14.38 inches; and at 30,000 feet it is 9.97 inches. Any instrument which will indicate variations in pressure can be calibrated to indicate the approximate altitude. It cannot, however, always indicate the exact altitude, because the temperatures and the pressures, and therefore the pressure altitude relation, change with time and place. Consequently the altitude pressure relation in the standard atmosphere is assumed, and the altimeter is adjusted to conform to it.

c. Description.—(1) The altimeter in most common use is a modification of the aneroid barometer. The dial, instead of being graduated in units of pressure, is graduated in units of height. All of the altimeters used on military aircraft are the sensitive type. Standard models for tactical operation have a calibrated range of from −1,000

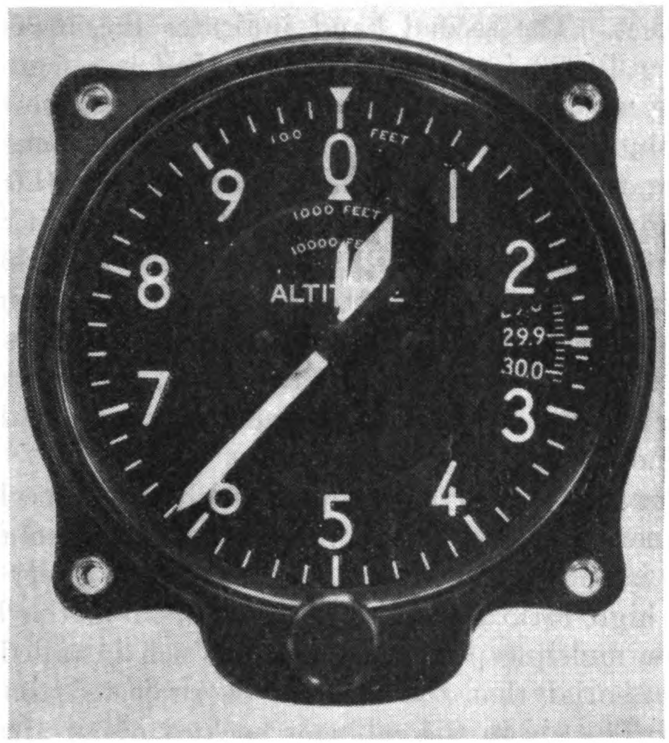

FIGURE 33.—Sensitive altimeter with barometric setting.

feet below sea level to +35,000 feet above. By use of a multiple pointer system, the instrument can be accurately read to at least one-half the smallest unit graduation on the scale which is 20 feet. Late types of altimeters have one altitude scale, one barometric scale and index marker, two reference markers, and three pointers. A setting knob located at the bottom front of the instrument case drives two pinions in opposite directions. One of these pinions rotates the barometric scale and reference markers and the other pinion rotates the aneroid mechanism assembly and the pointers. The altitude scale is graduated from 0 to 10. This scale is fixed, and all the pointers, the reference markers, and the barometric scale rotate and indicate with reference to it.

(2) The aneroid mechanism is exceptionally well built. It is very sensitive and well balanced. A temperature compensator is included in the mechanism to correct for any mechanical error from this source that results when changing from one altitude to another.

(3) The minute hand makes one revolution for a change of 1,000 feet, each numeral being 100 feet, and the small graduations correspond to 20 feet. Due to the wide spacing between the 20-foot graduations a change of 5 feet is readily apparent. The hour hand makes one revolution for a change in altitude of 10,000 feet, each numeral being 1,000 feet. The second hand indicates the 10,000 feet, each numeral being 10,000 feet. To cover the full range of the instrument the long hand makes a total of 36 revolutions, the intermediate hand 3.6 revolutions, and the small hand 0.36 revolution. The standard range for the barometric scale is from 28.1 to 31.0 inches *Hg*, with unit graduations of 0.02 inch *Hg*. When the limit of the range of the barometric scale is reached at either extreme, a shutter blanks out the indication of the barometric dial, and the barometric pressure is read from the position of the reference markers. Thus, by introducing a limited range barometric scale, the actual unlimited possibilities of setting barometric pressure by means of the reference markers are not in any way affected.

d. Operation.—(1) *General.*—Since the altimeter mechanism consists of an aneroid which is designed to measure absolute pressure, its operation is entirely automatic. Extreme sensitivity is obtained by use of a high ratio multiplying mechanism in the linkage and the use of the multiple pointer system. When installed on an airplane it is essential that the aneroid be subjected to undisturbed (static) air. The air in the cabin or cockpit of an airplane under flight conditions is highly disturbed and if allowed to enter the case of the altimeter would cause serious errors in the instrument's indication. The extent of these errors varies; on high-speed airplanes they may be as much as 500 feet. Consequently, for correct operation and indication, the altimeter must be vented to the static line, and the instrument case and entire static system must not have any leaks.

(2) *Definitions.*—(*a*) Altimeter setting is a pressure in inches of mercury, and is the existing station pressure reduced to sea level in accordance with the United States standard atmosphere. Altimeter setting is also the standard atmosphere pressure corresponding to pressure altitude variation.

(*b*) Station pressure is the existing atmospheric pressure at the elevation of the mercurial barometer located in the weather station.

(*c*) Field elevation pressure is the existing atmospheric pressure at a point 10 feet above the mean elevation of the runway and is obtained by applying a suitable correction to the station pressure. It is assumed that the altimeter in an airplane is 10 feet higher than the landing surface.

(*d*) Pressure altitude is the altitude in the standard atmosphere corresponding to the existing barometric pressure.

(*e*) Pressure altitude variation is the algebraic difference between the existing pressure altitude and the surveyed elevation of the field. The pressure altitude variation is also the equivalent in feet of the altimeter setting in accordance with the standard atmosphere.

(*f*) Meteorological sea-level pressure is the station pressure reduced to sea level in a manner dependent upon the prevailing conditions of station temperature. Meteorological sea level pressure should not be confused with altimeter setting, should never be broadcast to aircraft, and should never be used in connection with aircraft altimeters. It is designed to give smooth, consistent isobars on the sea level plane for the purpose of drawing weather maps.

(3) *Zero setting system.*—(*a*) When it is desired to set the altimeter so that the pointers indicate the height of the airplane above the ground or runway at some specific point, regardless of its elevation above sea level, the pilot in the airplane will contact the ground station at that point by radio and ask for the pressure altitude at that station.

(*b*) On late type altimeters which have the barometric scale, the pilot would call for the field elevation pressure.

(*c*) After the pilot sets these on his altimeter, his altimeter pointers would then indicate the elevation of the airplane above the runway and upon landing would read zero within the tolerance of the instruments. (See fig. 34.)

(*d*) The accuracy of this system on properly maintained instruments will be very close, normally, within + 30 feet; however, it is not recommended to depend on the altimeter for an indication accuracy closer than + 75 feet.

(*e*) For stations below an elevation of approximately 1,200 feet, either field elevation pressure or pressure altitude setting of the zero setting system will give a zero altimeter reading upon landing, and one may be used as a check against the other within the operating limits of the instrument. For elevations above approximately 1,200 feet, only pressure altitude can be set on the zero setting system due to the limited range of the zero setting scale graduated in pressure.

(4) *Altimeter setting system.*—(*a*) Upon receipt of altimeter setting by radio, the zero setting scale graduated in inches of mercury pressure is set to correspond. For example, if the altimeter setting received from a nearby ground station is 30.03 inches of mercury, this should be set on the zero setting scale by turning the knob. The altimeter will then read altitude above sea level (uncorrected for atmospheric temperature) within the operating limits of the instrument and the accuracy of measurement of the altimeter setting. If the air-

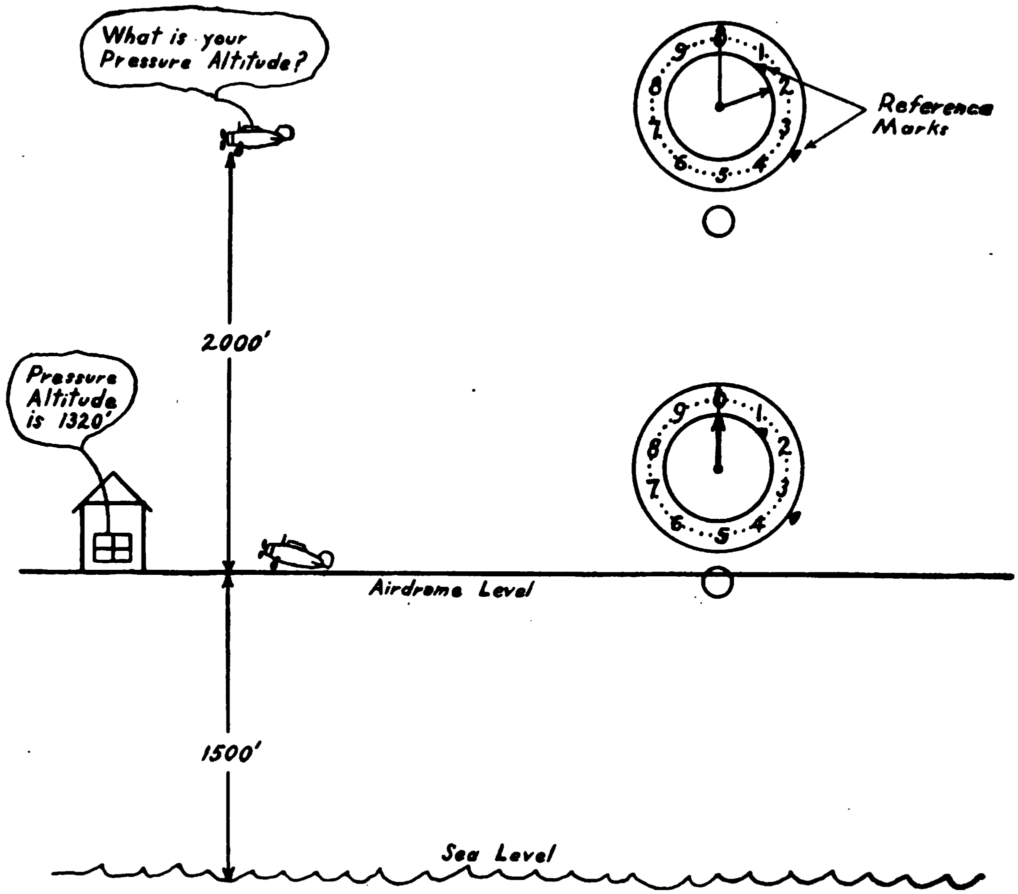

FIGURE 34.—Use of pressure altitude.

craft is landed, the instrument will read the surveyed elevation of the field within the operating limits of the instruments.

(*b*) The older types of Air Corps altimeters (type C-7 and earlier) are not equipped with a zero setting scale graduated in inches of mercury pressure but are provided only with reference marks reading on the altitude dial. These instruments may readily be used with the altimeter setting received by radio by referring to a table (par. 148) to obtain the pressure altitude variation, which is the altitude in feet corresponding to the altimeter setting, and by setting the reference marks on the altimeter to correspond. The pressure altitude variation may be plus or minus, depending upon existing conditions. Care should be taken in setting negative pressure altitude variations because the numerals on the dial do not apply in this case.

(*c*) For example, if the altimeter setting received is 30.03, then from the table the pressure altitude variation is found to be −100 feet. The hundred-foot zero reference mark is rotated counterclockwise from zero until it reads 9, and the thousand-foot zero reference mark is slightly to the left of zero.

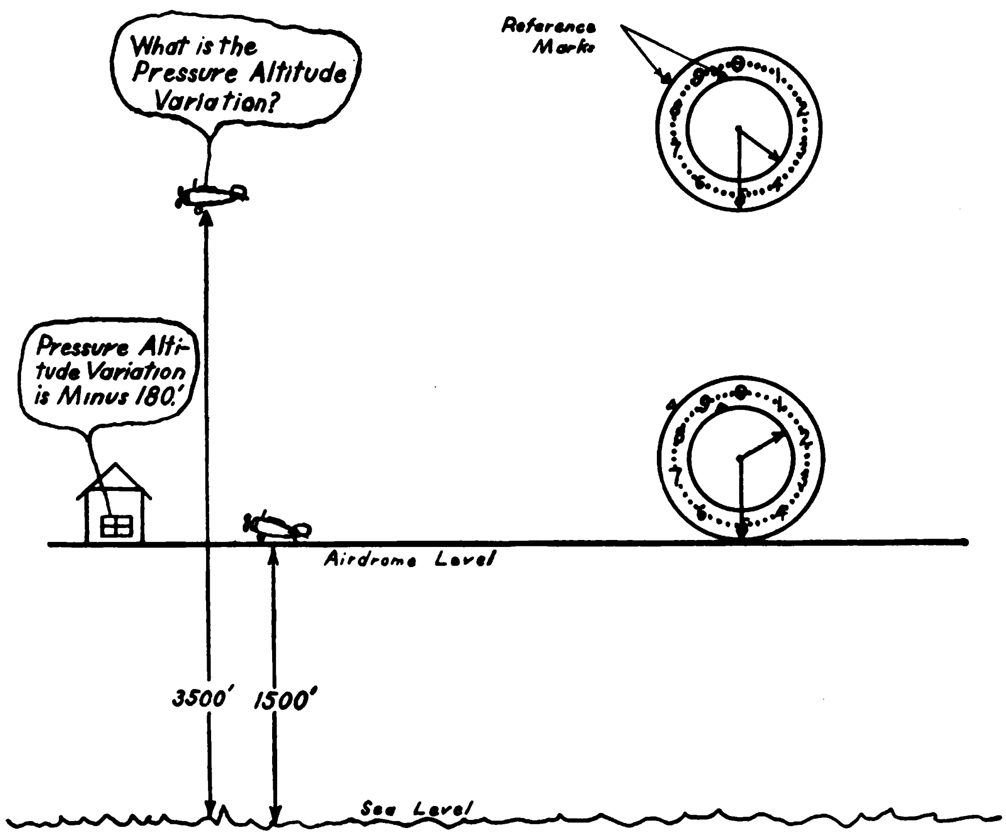

FIGURE 35.—Use of pressure altitude variation.

(*d*) Altimeter settings are continuously changing and as a rule are never the same at any two stations. It is therefore imperative that the pilot obtain the altimeter setting by radio at every scheduled broadcast from the ground station nearest his location at the time in order to permit the safe execution of traffic control.

(*e*) For accuracy in clearing mountains, elevations, and critical points along a route it is necessary to correct the altimeter reading for atmospheric temperature. This may readily be done by using the type C-1 true altitude computer or the E-6B dead reckoning computer. *Caution:* It should be noted that for obtaining the prescribed flight level for the purpose of traffic control, all aircraft operators must use the altimeter reading uncorrected for atmospheric temperature or all operators must correct their altimeter readings for atmospheric temperature. It is considered impracticable to require altimeter readings to be corrected by all operators at the present time for traffic control purposes. Therefore, prescribed flight levels will be altitudes uncorrected for atmospheric temperatures. Flight and traffic control personnel must realize that adequate margin of clearance must be allowed over mountains, etc., in order to use indicated altitudes uncorrected for atmospheric temperature. In preparing and maintaining flight plans, this should be carefully considered.

1. The latter case is one which may bring real danger to a pilot in case of bad weather. When the barometer reading is low the visibility is often poor. Under these conditions the altimeter, if not properly set, will indicate an altitude above the actual height of the airplane. A pilot, depending on the altimeter reading in such a case, might think his altitude is 1,000 feet above sea level when it is actually several hundred feet (or more) below the 1,000 foot level he desires to use.

2. Many accidents have been caused by the failure to allow properly for the above adjustment of the altimeter. Safety demands that under conditions of poor visibility the pilot will allow a *big* margin of clearance when judging what altitude he should use. Without knowledge of the barometric pressure, increase this allowance to make up for a possible low pressure.

53. Turn indicator.—*a. Purpose and use.*—The purposes and uses of the turn indicator are—

(1) To determine accurately the magnitude of any turn made by the airplane.

(2) To relieve the pilot of the strain and mental fatigue resulting in attempting to maintain a directional bearing with a magnetic compass.

(3) To provide a positive azimuth indication at all times.

(4) To help locate radio beacons.

(5) For straight course keeping and for exact course changes when necessary.

(6) To show bank, by showing turn, and by movement of the inclinometer.

(7) To keep the airplane out of acrobatics under instrument flight conditions.

(8) To direct the pilot in bombing exercises.

(9) To keep a straight course on photographic mapping missions.

b. Description.—The type A-2 turn indicator is a two in one instrument. It contains a gyroscopic rotor for showing turn, and a ball, in a glass inclinometer, for showing bank. The gyro turn mechanism consists of a small rotor, spun by means of a moving column of air striking small cups on the rotor wheel. A circular card graduated in degrees is attached to the vertical ring in which the rotor and its gimbal ring are mounted. The vertical ring and card are free to turn in vertical bearings, and a rectangular opening in the front of the instrument case permits a view of an ample section of the card. The rotor is horizontal in normal operation. This entire assembly is placed inside of a sealed case. A lubber line painted on the window is used as a fixed reference mark with which to aline and read the instrument. The gimbal ring which carries the gyro and card is mounted so that it can be set to any degree in azimuth. This is accomplished by means of a caging knob which meshes with the azimuth gear. In the bottom at the rear of the case two vents are provided for connection of the instrument to the vacuum system of the airplane. An atmospheric vent located in the bottom of the instrument case is covered with a screen. The air passing through this vent is directed onto the gyro which causes its spin. At the top and in front of the window in the rectangular opening a small 12-volt light bulb is inserted into a recess, providing light for use at night.

c. Operation.—(1) To use the turn indicator the pilot determines the course which he desires to follow. He gets on this course by means of the magnetic compass. He sets the turn indicator to the same reading as the compass, or to zero if he desires. Now every turn, however great or small, will be indicated instantly by this instrument. Each 10 or 15 minutes it should be checked with the magnetic compass and reset if necessary. Any time that a change of course is desired it can be accomplished accurately with this instrument. It neither lags, swings, nor oscillates, and it is therefore an accurate and safe indicator of directions and turns. The gyro will maintain its fixity in banks, climbs, and dives up to 55°. Any maneuver in excess of this amount is beyond the operating limits of the instrument. Such turns may cause the gyro to upset, with the result that its indications cannot be depended upon until level flight is resumed, the gyro caged, and the instrument reset by compass.

(2) The following points must be understood and observed to use the instrument properly:

(*a*) It is *not* a direction seeking instrument.

(*b*) It does not contain any magnets and can only be used to maintain a direction after the course has been found by means of the magnetic compass.

(*c*) It will not perform satisfactorily when maneuvers of the airplane exceed its operating limits.

(*d*) Due to the torque of the rotor and slight friction in the bearing, it will drift slightly from a set plane. This drift will not exceed 5° in 15 minutes on any properly operative indicator.

54. Clock.—An accurate timepiece is essential to navigation. Time is the basis for all computations in determining ground speed and subsequently estimated time of arrival, or in determining position from terrestrial bearings or dead reckoning methods. Standard equipment in Air Corps airplanes is the 8-day, sweeping second-hand clock. It is mounted with the other instruments on the instrument board. There are many types of navigation watches issued by the Air Corps. One that incorporates a "stop watch" feature has some advantages over the usual watch.

55. D-3 computer.—*a. Description and use.*—The D-3 computer is for the use of the pilot in solving speed, time, distance problems and altitude, temperature, air speed problems. It is of convenient pocket size and consists of a circular slide rule about 3½ inches in diameter with a suitable scale on each side.

b. Front side.—(1) Using the front face of the computer, if any two of the three factors of speed, time, and distance are known, the third factor can be obtained with one setting. The following are examples of typical problems of this type:

(2) Given: Time 12 minutes.
Distance 35 miles.
Required: Speed.
Solution: Set the time (12 minutes) on the inner scale (smaller disk) opposite the distance (35 miles) on the outer scale. The speed will then be shown on the outer scale opposite the large arrow (1 hour or 60 minutes) which is printed on the inner disk. *Answer:* 175 m. p. h.

(3) Given: Distance 360 miles.
Speed 148 m. p. h.
Required: Time.
Solution: Set the large arrow (1 hour) of the inner disk opposite the speed 148 on the outer scale. Then find the distance 360 on the outer scale and read the time opposite this figure on the inner scale. *Answer:* 2 hours 26 minutes.

(4) Any such problems may be quickly worked by using the inner disk for time and the outer scale for distance and speed.

c. Back side.—(1) On the reverse side of the computer are scales for applying the pressure altitude and temperature correction to the calibrated air speed in order to obtain the true air speed. To use, rotate the transparent disk until the calibrated air speed on the disk is opposite the free air temperature scale, which is printed on the background so as to be read through the disk. Then read the true air speed opposite the mark which agrees with the altitude of the airplane. Note that the altitude used is the pressure altitude and not the altitude above the terrain. Also that the air speed used is the calibrated and not the indicated air speed. The temperature used is the temperature of the free air outside the airplane and not the ground temperature.

(2) The transparent disk is constructed with a roughened surface so that the corresponding indicated air speeds may be penciled on it; the data being transcribed from the air speed meter calibration card, or the estimated calibrated air speed if no calibration card is available.

56. Thermometer.—The air thermometer shows the temperature of the air at the altitude being maintained by the aircraft. Ground temperature is the temperature of the air at a ground station. All Air Corps thermometers installed in airplanes read degrees Centigrade. Free air temperature is used to correct air speed readings as well as altimeter readings, and also to determine if icing conditions are present.

57. Elementary methods.—*a. General.*—Very accurate results from dead reckoning methods may be obtained when a well-trained navigator with a complete set of instruments and equipment is present in the airplane. The pilot in the smaller airplanes does not have the drift meter, the aperiodic compass, the pelorus, and the other aids to precise navigation. He usually does not have the range for long over-water flights, or for long periods of flight during instrument flying conditions.

b. Desired accuracy.—(1) The pilot navigator usually combines elementary dead reckoning with pilotage methods, together with aids from radio. He uses dead reckoning for short periods of time when he maintains a certain heading for a definite period and then expects to be within sight of the next check point.

(2) The following example illustrates how elementary dead reckoning is used. In figure 36 a pilot is flying along an easily followed course *A*, *B*, to *C*. At *C* the combination of highway and railroad, which has provided his check points, changes direction toward the south. The pilot wishes to go on to *D*, but the terrain between *C* and *D* is such that no check points are available, so he uses simple dead

reckoning methods to proceed from *C* to *D*. He checks his exact compass heading along the course from *A*, through *B*, to *C*, and also determines his ground speed on this part of his course. When he passes *C*, he merely continues the same compass heading and figures his estimated time of arrival (E. T. A.) at *D*, using the figure for his known speed.

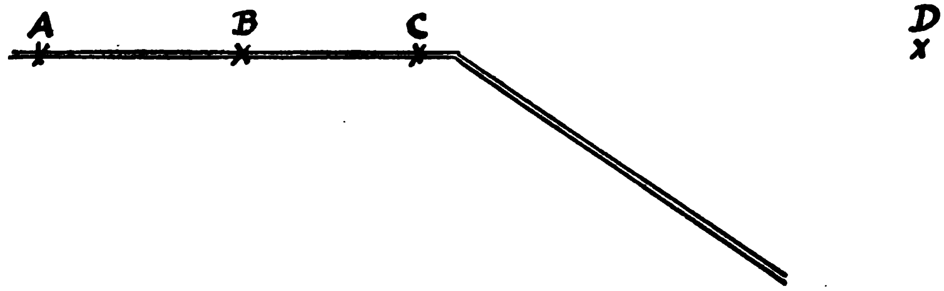

FIGURE 36.—Elementary dead reckoning.

(3) Using the above method, the pilot may arrive at his destination a minute or two early or late. Also, he may be a mile or two to the right or left of *D* when he comes within sight of it. For this method, such accuracy is sufficient, and in actual practice it frequently gives very precise results.

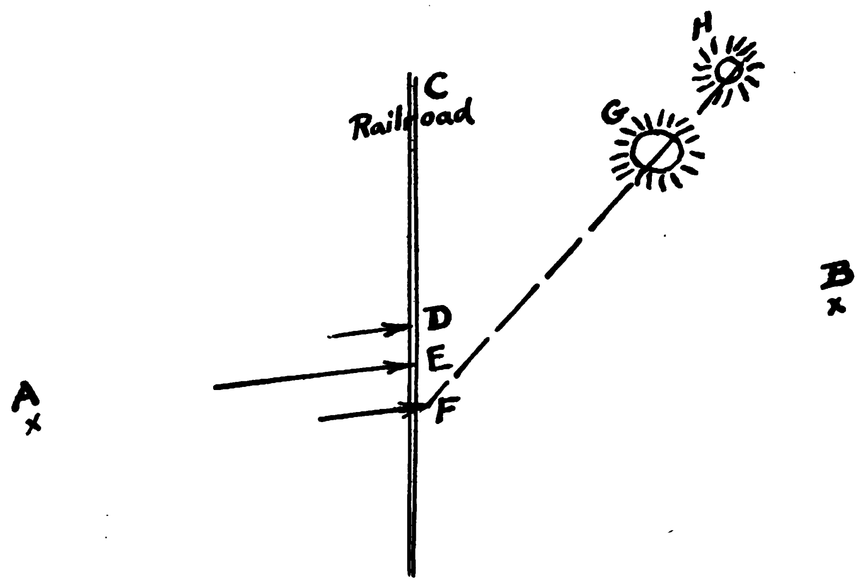

FIGURE 37.—Line of position.

58. Line of position and fix.—*a*. The "line of position" is a line on which the aircraft is observed to be. The intersection of two lines of position determines a "fix." The following example shows clearly a line of position. In Figure 37 a pilot proceeds from *A* to *B*, flying over terrain which offers little chance for him to identify his position positively. He knows that his course is approximately due east but cannot check his ground speed. When he comes to the *C* railroad it gives him a chance to identify his position as being *somewhere* along the railroad, as shown on his map. He cannot be sure whether he is at *D*, *E*, or *F*, but by knowing that he is on the line of position (the railroad) he has an excellent check on his ground speed.

b. If, in the above example, the pilot had been able as he crossed the railroad to see that he was in line with the tops of the two hills *G* and *H*, he would have had a second line of position *F*, *G*, *H*. The intersection of the two, or in this case the point *F*, would then be a fix. Then he would know his position as well as his speed.

59. Steering a range.—*a*. In order to keep on a desired course it is good practice, when convenient, to select two landmarks ahead, which are known to be on the course, and to 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 may be selected and a second range steered.

b. Sometimes the selection of a range is very easy, as when a road or railroad parallels the route; at other times, the selection of a continuous series of ranges may prove difficult. For this reason, and also as an added factor of safety, it is desirable to use the magnetic compass for keeping a constant direction. 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.

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

SECTION VIII

FEDERAL AIDS TO NAVIGATION

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Radio fixes	76
Wind effect when homing	77
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60. Federal aids.—*a. Present facilities.*—Facilities provided on the Federal airways usually consist of the following:

(1) Radio range beacons for directional guidance.

(2) Radio marker beacons for assistance in locating strategic points, such as intermediate landing fields, and in many cases giving directional guidance over short distances.

(3) Rotating beacon lights at approximately 15-mile intervals.

(4) Intermediate landing fields so located, relative to airports, that established landing areas are available at intervals of approximately 50 miles.

(5) Radio communication stations for weather broadcasts and emergency messages to aircraft.

(6) Weather reporting service, involving the use of teletypewriter circuits and point to point radio. The teletypewriter circuits are used not only for transmission of weather reports and forecasts but also for transmission of reports on progress of aircraft en route along the airways.

(7) Airway traffic control.

b. Radio aids.—(1) 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 during instrument flying, when other methods fail or become very uncertain.

(2) Data concerning radio ranges is kept up to date in Technical Orders, Handbook of Instructions: Radio Data and Aids to Airways Flying; and Air Corps Radio Facility Charts. A copy of each is carried in the airplane as part of the cross-country equipment.

c. Advantages and disadvantages.—(1) The advantage of the use of radio in navigation is that it greatly simplifies the effort in good weather, and in conditions of instrument flying it is the only means of navigation available. It not only enables a cross-country flight to be performed in fog or under conditions of zero visibility, but it is the only means of allowing the pilot to make an "instrument landing" at his destination.

(2) Its chief disadvantage is that under certain bad-weather flight conditions the pilot is wholly dependent upon his radio. Should the radio reception fail, he might then be in a dangerous situation which, had he not depended on the use of radio, he would have avoided.

61. Radio range system.—In the United States are numerous radio ranges located adjacent to important landing fields and spaced at intervals along the important airways. (See fig. 38). The distance between these ranges, and the power output of the radio equipment used is such that several nearby ranges may usually be received from any point along an airway. These ranges serve as a directional guide for approaching toward and also for departing from the station.

62. A and N zones.—*a.* Each radio range station marks four courses or equisignal zones which are normally 90° apart, although this spacing is often varied in order that the courses may coincide with the established airways. For example (fig. 39), the northerly course of the Nashville radio range station is directed along the Nashville-Louisville airway; the southeasterly course is directed along the airway to Chattanooga; and the southwesterly course serves the airway from Memphis. The easterly course serves no particular airway.

b. Into two diagonally opposite quadrants (fig. 39) the letter N (— .) is transmitted in Morse code, and into the remaining pair of quadrants the letter A (. —) is transmitted. Each quadrant slightly overlaps the neighboring quadrants, and in the narrow wedge formed by the overlap the two signals are heard with equal intensity, the dots and dashes of the two signals interlocking to produce a continuous signal or monotone. Thus, a pilot will hear the continuous dash while he is on course. If he deviates to one side of the course he will hear

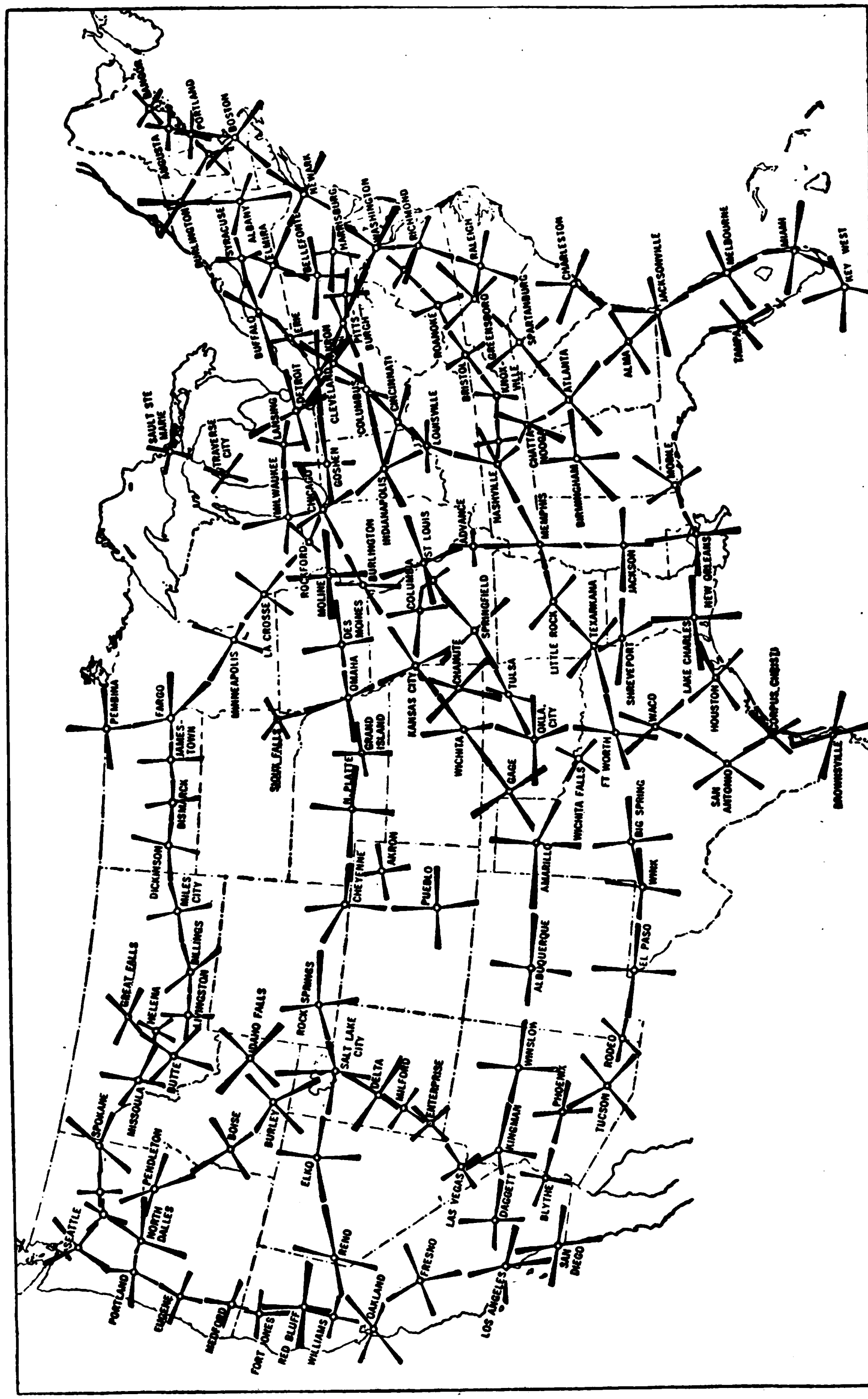

FIGURE 38.—Radio range system in the United States, 1938.

the dot-dash (A) signal, and if he deviates to the other side he will hear the dash-dot (N) signal.

c. On the aeronautical charts, the radio range system is shown in pink tint, and the A and N zones of each station are indicated in conspicuous red letters. On the radio facilities charts, the A zones are indicated by inking in the angle at the station. By reference to the chart, pilots may know from the signals received whether they are on course or to the right or left of the course. The range signals are interrupted about twice each minute for the transmission of the station identifying signal. If a pilot is near the bisector of an N zone, he will hear the dash-dot (N) signal, followed by the station identifying

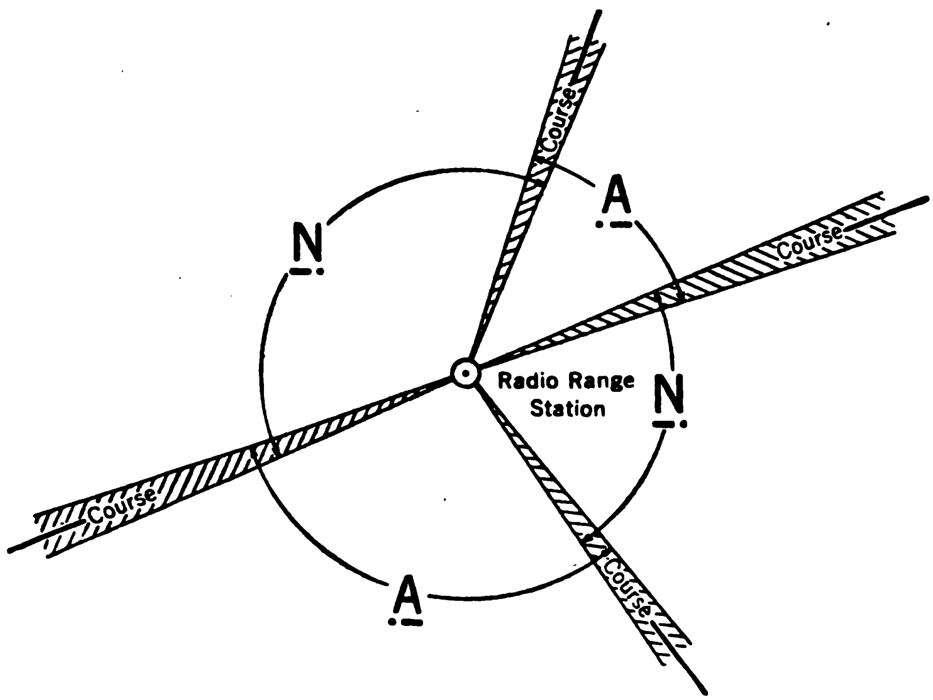

FIGURE 39.—Nashville radio range station.

signal, but will not hear the dot-dash (A) signal, or the identifying signal which is transmitted into the A zones. If he is on the beam, he will hear the identifying signal transmitted into the N zones, immediately followed by the same signal transmitted into the A zones and at the same signal strength. If the first of the two station identification signals is weaker, the pilot knows he is favoring the A zone; if the second is weaker, he knows he is favoring the N zone.

d. The Air Corps radio facility charts are published each month and should always be used to ascertain the location of ranges and the directions of the legs. These numerical directions are printed on the legs as magnetic bearings toward the station. The radio facility charts are drawn to accurate scale and can be used, if necessary, the same as a map. The name of each radio range station, the frequency upon which it broadcasts, and the identifying code letters are listed on these charts.

e. 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.

63. On-course signal.—*a. Change of signal.*—(1) The on-course (equisignal) zone is about 3° in width, depending largely upon the orientation of the courses, the receiving equipment used, and the technique of the observer. Maximum sharpness of course is obtained with the receiving set tuned to the minimum practical volume.

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

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

b. Weather reports.—Brief weather reports are transmitted at scheduled intervals for information to those flying the airway on which the station is located. On some ranges the weather reports cause an interruption of the range signals. In order to provide continuous range operation in emergencies, weather broadcasts may be omitted on request; for the same reason, provision has been made at some stations for broadcasting all voice communications on a standard frequency of 236 kilocycles. Equipment providing for simultaneous transmission of range signals and broadcasts on the same frequency is now being installed, thus eliminating the necessity of omitting either the range or voice service.

c. Radio range stations.—(1) 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.

(2) In addition to the airway radio range stations operated by the Civil Aeronautics Administration, a number of important terminal airports are also equipped with privately operated airport radio range stations. These are exactly similar to the radio range stations already described, except that they are of quite limited power and range. They are always so located as to localize the landing area very definitely and provide a positive control of landings in bad weather. The courses from the airport radio range stations are shown by a pink tint on the aeronautical charts. To avoid confusion in the congested area surrounding major airports, full information is not indicated on the charts. Pilots desiring complete data should obtain them from the "Tabulation of Air Navigation Radio Aids" which is issued by the Civil Aeronautics Administration and may be had free upon request.

(3) 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.

(4) 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 39 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.

64. Cone of silence and twilight zone.—*a. Cone of silence.*—(1) Directly above the antenna or towers of the radio range station there is a cone of silence, a limited area shaped like an inverted cone, in which all signals fade out. Just before entering the cone of silence the volume of the signals increases rapidly; as the plane enters the cone, the signals fade out abruptly for a few seconds, the length of time depending on the speed of the plane and the diameter of the cone at the level of flight. When the plane first leaves the cone, the signals surge back with great volume before they begin to fade as the distance from the station increases. If the plane passes over the station a bit to one side of the cone, and the receiver is not kept to minimum volume, the signals do not entirely fade out.

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

b. Twilight zone.—In flying across a radio range beacon beam, an airplane flies from an A or N zone toward and through the beam. As the plane approaches the beam or equisignal zone, the pilot begins to hear, along with the zone and identifying signal of his zone, a faint beam signal, and a faint identifying signal from the opposite zone. As the plane continues to move into the equisignal zone, those faint signals increase in intensity until, when the aircraft is within the beam, the A and N signals interlock to form a continuous monotone beam signal, and the A and N zone identifying signals will be of equal intensity. Crossing through the equisignal zone and entering the new quadrant, the new zone signal and identifying signal will be heard with increasing volume along with the weakening beam signal. As the aircraft proceeds out of the equisignal zone into the new zone, the beam signal will fade away and disappear, and only the new zone signal and its identifying signal will be heard. These areas of fading signals, where both beam and zone signals are heard together, located on each side of the equisignal zone, are termed twilight zones. A pilot flying the radio range beacons has several uses for the twilight zones. A Civil Aeronautics Administration airways regulation requires aircraft to fly on the right hand side of an established airway or radio range. While flying "on instruments" on the radio range, a pilot may comply with this regulation by following the outer edge of the twilight zone on the right-hand side of the range, keeping well clear of the beam. In orientating himself over a radio beacon, a pilot recognizes that he is approaching a beam when he enters the twilight zone.

65. Reliability; errors.—*a.* (1) When flying away from a radio range station it is important to check the magnetic course being made good (the compass heading plus or minus deviation and wind effect) at frequent intervals, as multiple courses exist at some locations—

particularly in mountainous country. If the condition of multiple courses does exist, the effect will be that the equisignal zone, which is normally about 3° in width, may be broken up into a number of narrow on-course bands with a total spread of 10° or 15° or even more. Between the on-course bands the proper quadrant signal is usually heard, although an A signal is often found in an N quadrant, and vice versa. 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. A multiple course can often be recognized by its narrow width in comparison with the true range course. This item is of less importance when flying toward the station, since even a false range course would serve perfectly as a homing device. In this case it should be remembered that such a course may lead over terrain that is dangerous because of high mountain peaks.

(2) A related difficulty is found in bent courses. As a rule, the bend is relatively small and is of little importance since it bends away from and around the obstruction that causes it. In mountainous country, bends of as much as 45° have been noted. Several such bends may occur in a short distance, and to attempt to follow them without a thorough knowledge of their relation to the terrain, previously gained under conditions of good visibility, might prove impossible. If the plane continues in straight flight under these conditions, the range courses seem to be swinging from side to side. Courses from range stations using the old loop antenna usually swing excessively at night beyond 25 miles from the station. This phenomenon is known as "night effect," and has been practically eliminated in recent installations by using four vertical radiators instead of two crossed loop antennas. In view of the difficulties mentioned, when flying on instruments it is important to maintain an altitude well above any nearby peaks or obstructions; and in interpreting the word "nearby" a generous allowance should be made for any possible uncertainty as to the position of the plane.

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

c. Some of these difficulties may be greatly reduced as the result of development work now being conducted by the Civil Aeronautics Administration. For example, a supplementary range service on ultrahigh frequencies has already been made available at some stations, resulting in definitely improved performance. An experimental installation has been made of a two-course radio range, also on ultrahigh frequency, which is expected to afford simpler means of orientation as well as certain other advantages. Considerable work has been done on an omnidirectional radio beacon, which is intended to give the equivalent of a range course from any direction toward the transmitter.

66. Bad weather use.—The maximum use of radio aids occurs during flights in conditions of poor visibility or at night when there is no lighted airway to guide the pilot. For most effective use, the radio range system should be regarded as an aid to dead reckoning. With any form of radio navigation there is always the possibility of excessive static and of mechanical failure, either in transmission or reception. In such cases the pilot who has neglected other methods of navigation may find himself hopelessly lost and without the information necessary for safely completing the flight.

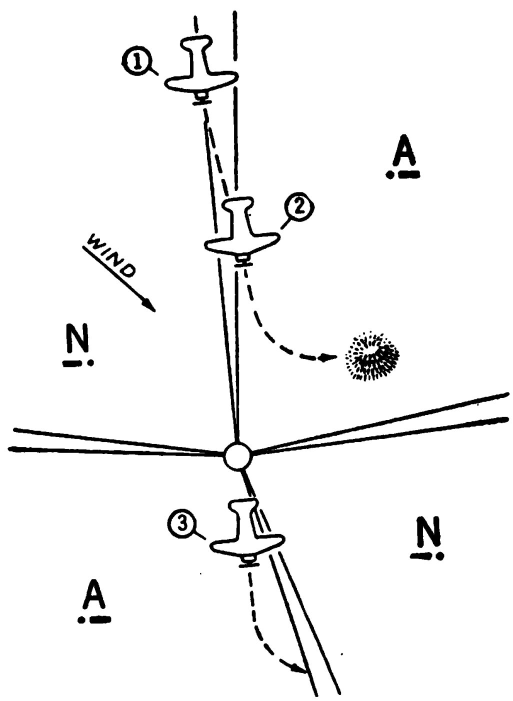

FIGURE 40.—Danger of neglecting drift.

67. Effect of wind on use of radio range.—*a. Drift.*—It has been remarked that pilots need not be concerned with corrections for drift when flying the radio ranges. In a general way this is true, but it should not be taken to mean that drift may be safely neglected. As long as the airplane is kept along the right side of the equisignal zone the track over the ground is known; but it may be necessary to head the airplane into the wind at an appreciable angle in order to stay on course. It is important that this angle be observed and that every possible check should be made of current wind conditions and the proper allowance therefor.

b. Example.—Figure 40 illustrates what actually happened in one case through failure to make the proper allowance for wind. A pilot was flying south along the right side of the equisignal zone at position 1. Due to a pronounced change in wind direction which had not yet been detected, no allowance was made for the northwest wind. Under the action of this wind the aircraft drifted into the northeasterly A quadrant as shown at position 2. The pilot supposed he had crossed the westerly course of the range and that he was in the southwesterly A quadrant at position 3. He therefore turned toward the east with the idea of getting on the southerly course of the range but struck the side of a mountain near position 2 as indicated.

68. Systems of orientation.—*a. Accurate data.*—Ordinarily, the most difficult problem that may arise is that of quadrant identification and of finding the range course as quickly as possible from an unknown position. For the solution of this problem an accurate radio range 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. For this reason radio facility charts are always carried by the military cross-country pilot.

b. Methods.—There are several favored methods of quadrant identification and of finding the range course as quickly as possible. No one method is suitable for all conditions, and the pilot should become thoroughly familiar with each of them in order to solve any given problem with the least delay. In the following discussion of the various methods, it will be assumed in each case that the pilot knows, from the signals received, that he is in one of the two A quadrants of the Harrisburg radio range station, but that he does not know which one. (See fig. 41.)

69. 90° turn method.—This was the first method of orientation to be developed. It is still popular because of its simplicity and uniformity, and is probably as good as any when within reasonable distance of a range with quadrants which have angles of about 90°.

a. Under this system a course is flown at right angles to the average bisector of the two possible quadrants (fig. 41). When the course pattern of a station is not symmetrical, it is important to use the average bisector since it is equally suitable for either of the two quadrants in which the plane may be located. In this case, a course at right angles to the average bisector may be either 337° or 157°.

b. (1) If the course of 337° is chosen, then it is certain that courses 2 and 3 are somewhere behind the plane.

(2) The pilot continues on the course of 337° until the on-course signal is received; through the equisignal zone until the first N signal on the other side is heard; then makes a 90° turn to the right.

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

(4) In either case, the pilot makes a general turn to the left, away from the station, and gradually eases into the equisignal zone, as

shown; he then follows the range course in to the station, and from that point on to the local airport or a more distant destination. When close to the radio range station and approaching it, pilots may fly in the on-course zone; pilots flying *from* a station are definitely required to fly on the right of the equisignal zone.

c. If the course of 157° is chosen, rather than 337°, the procedure will still be the same as before (fig. 41).

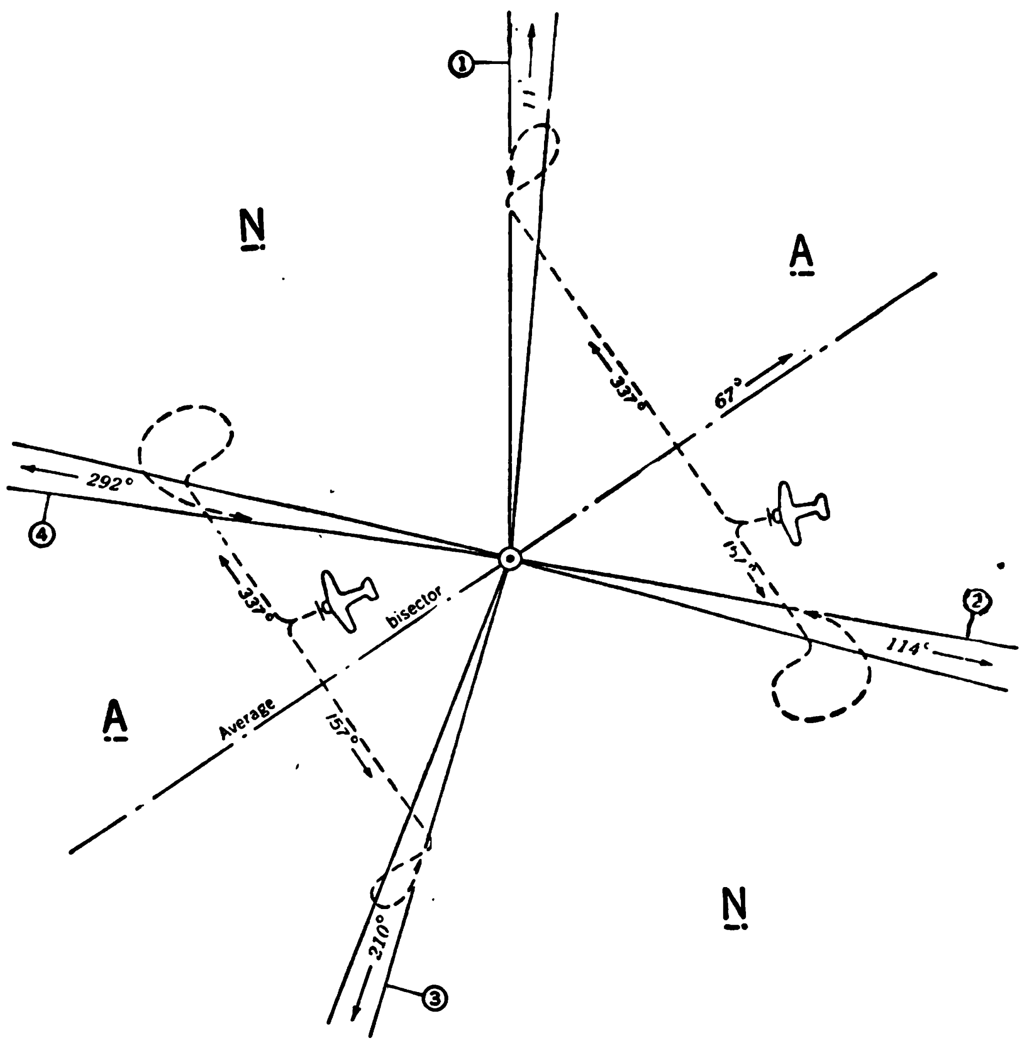

FIGURE 41.—Identification, 90° method.

d. Where multiple courses are known to exist, instead of making the 90° turn as soon as the first N signal is heard, it is advisable to fly for some little distance before making the turn, selecting the true range course from among the several false ones encountered, if possible.

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

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

(1) If he flies the 337° course at right angles to the average bisector of the quadrants and the faint signal begins to fade, he knows he is flying away from the nearest on-course zone, and that he is therefore just north of course 2 or course 3. He makes a 180° turn, approaching the equisignal zone on the 157° course, and the procedure from this point is identical with that illustrated in figure 40.

(2) If he flies the 337° course and the faint signal becomes stronger, the pilot knows he is approaching the equisignal zone, and that his position is therefore just south of course 4 or course 1. He therefore continues on the same heading, his further procedure being exactly as shown in the figure.

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

h. This is a very dependable method under favorable conditions. Its chief disadvantage may be seen by looking at figure 39. If the airplane is in a quadrant where the angle is greatly in excess of 90°, (as the northwest quadrant) on a course at right angles to the average bisector of the quadrants, it may be necessary to fly a considerable distance before picking up the on-course signals. This might be especially true in case of a large drift due to wind.

70. Fade-out method.—*a.* Under this system the pilot flies a course paralleling the average bisector of the two quadrants (instead of at right angles thereto), with the volume of his receiver as low as possible. If the signal fades out he knows that he is flying away from the station; if the volume increases he knows that he is approaching it. This procedure identifies the particular quadrant in which he is flying, unless some of the difficulties mentioned later prevent.

b. (1) For example, referring to figure 42, if the pilot is flying a course of 67° and the signal fades out, he knows he is in the easterly A quadrant with the station behind him. He makes a 180° turn and flies to and through an equisignal zone. As soon as the first N signal is received, he turns left not more than 180° until the on-course signal is again received.

(2) Then with volume as low as practical, he straightens out along the right side of the range course and flies until the volume fades out or builds up appreciably. If it is increasing, he follows it in to the station; if it fades out, he makes a 180° turn and then follows it in to the station as a new point of departure.

c. One weakness of this system is that for some stations the signal strength is variable due to irregularities of the terrain or night effect. The signals from these stations alternately increase and fade so that it is difficult to decide definitely, without undue loss of time, whether the volume is increasing or fading out. In the case of "squeezed courses" (that is, when the courses are not 90° apart), it is possible to fly away from a station and have the signals become stronger instead of weaker.

d. Several combinations of the 90° and the fade-out method will suggest themselves. For example, after intercepting an equisignal zone, the range course may be identified and followed in to the station by essentially the same procedure as that illustrated in figure 41. As in the 90° method, if the two identification signals are heard, one loud and one weak, and the weak one begins to fade out, it is evident that the pilot is flying away from the nearest range course as well as from the station. The 180° turn is made at once, and the procedure is then as shown.

e. The individual conditions at any one station must be considered in choosing the method to be used. For example, for a pilot in one of the N quadrants at Newark, it would be generally desirable to fly the average bisector toward the northwest. If he were in the southeast quadrant, either the reverse course or a course at right angles to the bisector might carry him out to sea.

f. It should be understood that under any conditions the greatest signal strength is found along the bisectors of the quadrants, the lowest signal strength along the edges, where the on-course zones are located. Therefore, flying parallel to the bisector but at a considerable distance from it, the signal strength may decrease as the on course is approached, even though the station is nearer. If the decreased signal strength is due to approaching an on-course zone, the double signals of the twilight zone should be heard upon turning up the volume. If the twilight signals are not heard with the increased volume, it is

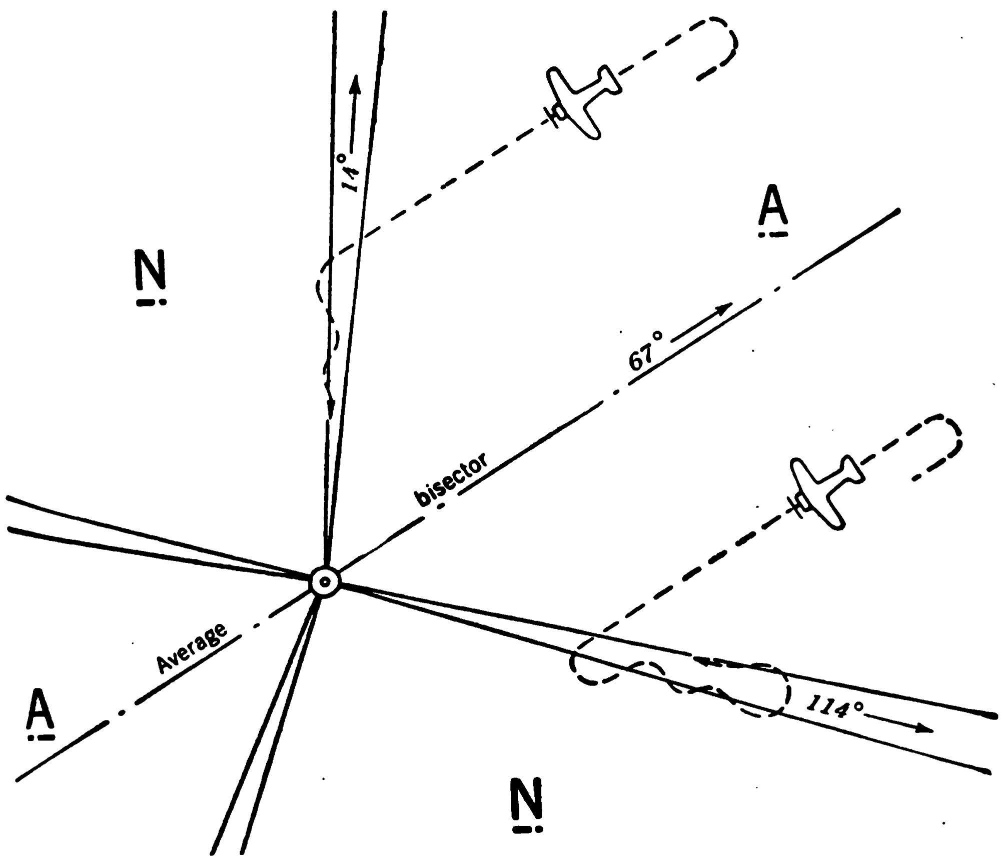

FIGURE 42.—Identification, fade-out method.

definitely known that the airplane is proceeding away from the station. In either case, the quadrant is identified, the direction with respect to the station is known, and the pilot may proceed as outlined above and as illustrated in figure 42.

71. **Standard method.**—For a particular situation, one procedure may have certain advantages; at another time a different method is preferable. To prevent confusion and loss of time in trying to choose the most suitable method when the position of the aircraft is uncertain, some standard procedure is desirable—one that will fit *any*

conditions that may arise. It has already been pointed out that the 90° turn method first described is not practical under some conditions. Others object to the fade-out method because of the excessive turning required after intercepting a course. The following method—in principle at least—has been adopted as standard by some of the major air lines, since it may be used satisfactorily on any and all ranges.

a. First, the quadrant is identified by the fade-out method described above, and the airplane is headed parallel to the bisector of the quadrant, toward the station (fig. 43). It will intercept either course 1 or course 2.

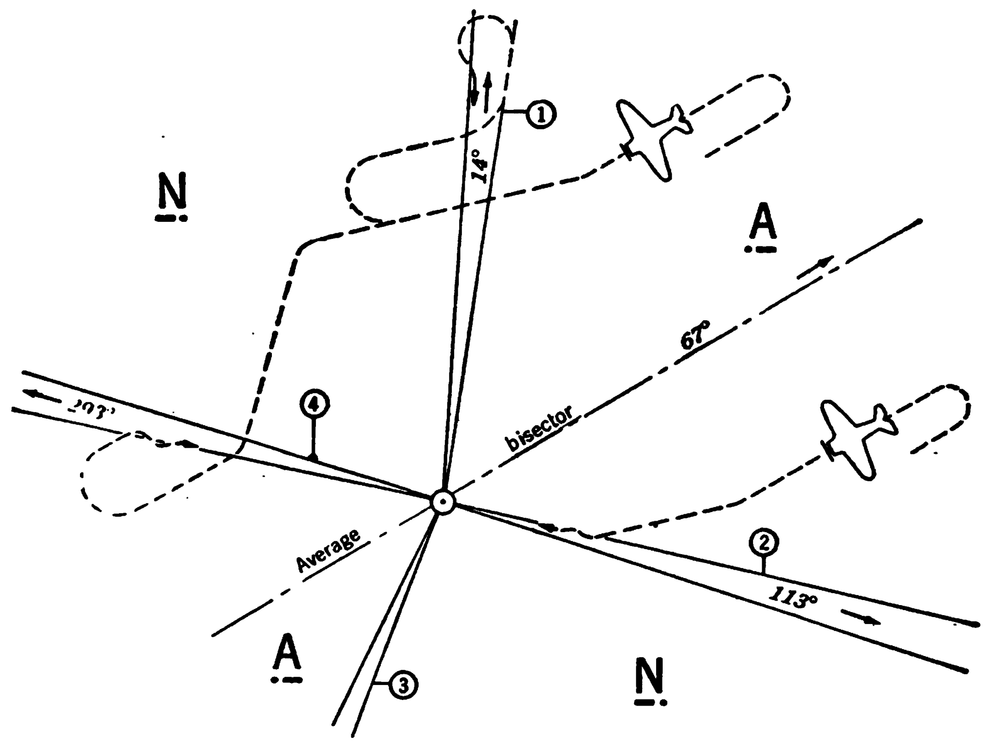

FIGURE 43.—Identification, standard method.

b. On the Harrisburg range (fig. 43), the final approach should be made from the west over course 4. It would be desirable, therefore, to intercept course 2 rather than course 1, continuing on course 2 past the cone of silence and out on course 4, then making a 180° turn for the final approach. Under this standard method, the pilot assumes that he actually will intercept the desired course (course 2). As he enters the twilight zone he changes heading so as to approach course 2 (if his assumption is correct) at an angle of 30°; an easy turn on reaching the equisignal zone then brings him on course. If his assumption is wrong (a fifty-fifty chance), he will intercept course 1 and pass quickly through it. The fact that the course was crossed so quickly is notice that he has intercepted course 1, rather than course 2. He may either turn back to course 1 and by a series of turns settle down on that course ultimately following it in to the station, or he may fly on into the northwest N quadrant for a time, then turn toward course 4 at an angle of 90° thereto, and follow it in to the station upon reaching the on-course zone. In a narrow quadrant this latter method (approaching a known course at right angles) materially reduces the time required for identifying an equisignal zone and beginning the approach.

72. Parallel method.—*a. Description.*—Under this system the quadrant is identified by flying along the average bisector and noting the fading or increase in volume. Then, if it is desired to reach the station over a particular course of the range, the pilot flies parallel to the other range course limiting that quadrant until the desired on-course zone is reached, and follows it in to the station.

b. Example of use.—A pilot determines his position as being some place in the northeast quadrant of figure 43. He desires to approach the station by way of the easterly leg, 113° out or 293° in, magnetic. Noting that the northerly leg out is 14°, he flies parallel to it (194°) until the easterly leg is intercepted and then he follows it in to the station.

73. Other methods.—Various other methods of quadrant identification have been used but it is believed that those just described represent the simplest and most practical methods yet developed.

a. Radio compass (par. 75).—With a radio compass which has a visual indicator, quadrant identification is generally unnecessary. The pilot may determine the direction of the station and fly directly to it, setting a new course from that point toward his destination.

b. Orientator.—The airport orientator is a valuable aid in all problems of quadrant and range course identification. In this instrument a circular chart showing the airport in relation to the courses of the radio range, with other pertinent data, is directly attached to a disk member on the top of the directional gyro. Once the chart of the orientator has been properly alined with the corresponding features on the ground, it remains so as the result of gyroscopic action. Thereafter, regardless of the number of turns, a faithfully oriented picture of the attitude of the airplane with respect to the range courses is given by the orientator chart—without mental effort on the part of the pilot.

c. Quadrant identification.—(1) It is possible at times to identify the quadrant of a radio range by tuning in on one or more adjacent ranges. In many cases, the A or N signal heard from the second or third station will conclusively prove that the position of the aircraft is in one certain quadrant of the original station.

(2) An example of the use of this method is shown in figure 44. A pilot tuned in on the Atlanta range and received an N signal. Not knowing whether he was in the north or south N quadrant, he tuned his receiver to the frequency of the Birmingham station. This station gave him an N signal, which showed that he was in the south N

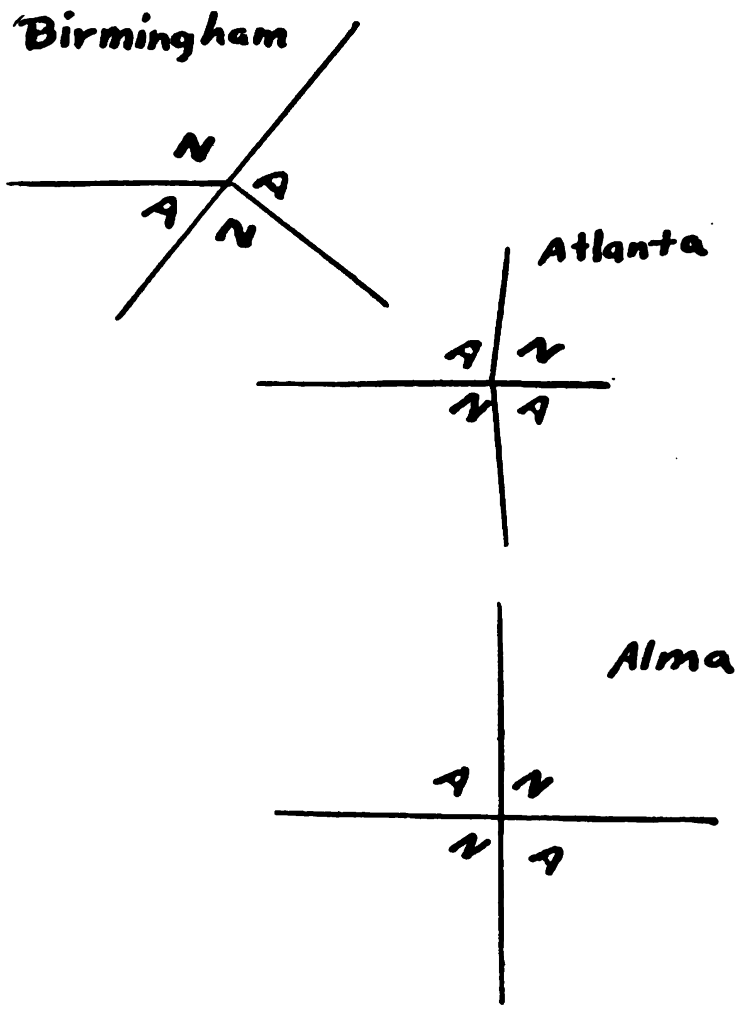

FIGURE 44.—Identification from adjacent ranges.

quadrant of Atlanta. To make sure, however, he tuned in on the Alma station. This time he received an A signal, again showing that he was in the south N quadrant of Atlanta.

d. Precautions.—In addition to the general problem of the identification of radio range quadrants, certain other rules must be observed.

(1) For example, in order to prevent meeting aircraft flying in the opposite direction, it is important that pilots fly to the right of the

radio range courses. As an added safeguard, the Civil Air Regulations require that flights along an airway be made at definite altitudes—in one direction at the odd thousand-foot levels (as 1,000, 3,000, or 5,000 feet above sea level) and in the opposite direction at the even thousand-foot levels (as 2,000, 4,000, or 6,000 feet). This insures that there will always be at least 1,000 feet vertical separation between planes flying in opposite directions. Definite altitudes are fixed for crossing another airway, and other restrictions have been placed upon instrument flying within 10 miles of the center of an established civil airway by pilots not engaged in scheduled air transportation. All these requirements are set forth in detail in the Civil Air Regulations and in War Department regulations. Air Corps pilots will comply with all Civil Air Regulations, in addition to those published by the War Department.

(2) During conditions of poor visibility, irregularities in steering and the drift caused by wind will make it difficult for the pilot to hold exactly on the right edge of the on-course signal. Instead, if he is slightly to the right of the course he heads a few degrees to the left until the on-course signals are heard, then a few degrees to the right until the off-course signals again predominate, etc. In this way he "weaves" along the right-hand edge of the equisignal zone, making frequent checks of the course by means of his compass.

74. Marker beacons.—*a. General.*—At critical points along the radio range courses there are also radio marker beacons. These are low-power transmitters which emit a distinctive signal on the same frequency as that of the range on which they are located, and serve to inform the pilot of his progress along the route. When located at the intersection or junction of courses from two radio range stations, marker beacons operate on the frequencies of both stations. When the pilot receives the signal of a marker beacon so located, it serves as a reminder to tune his set to the frequency of the radio range next ahead of him.

b. Installations.—(1) All radio beacons of this type are equipped for two-way voice communication and are prepared to furnish weather reports and other emergency information, or to report the passage of a plane, on request. In case the plane is not equipped with a transmitter, if the pilot circles the marker beacon the operator will come on the air with the weather for that particular airway. The pilot indicates that he has received the information by a series of short blasts of his engine and proceeds on his way.

(2) More recent installations of marker beacons are of the ultrahigh frequency "fan type." These beacons operate on a frequency of 75

megacycles (75,000 kilocycles) and have no facilities for voice communication. From one to four fan markers may be located around any given range station, usually at distances of about 20 miles. Beacons of this type are in operation on three of the four courses of the Newark range (fig. 45). The remaining course has no fan marker since it serves no airway but is directed out to sea. Each such marker beacon transmits a fan-shaped radio pattern across the equisignal zone. The markers around a given radio range station are identified by a succession of single dashes or by groups of two, three, or four dashes. The single-dash identification is always assigned to a course directed true north from a station, or to the first course in a clockwise direction

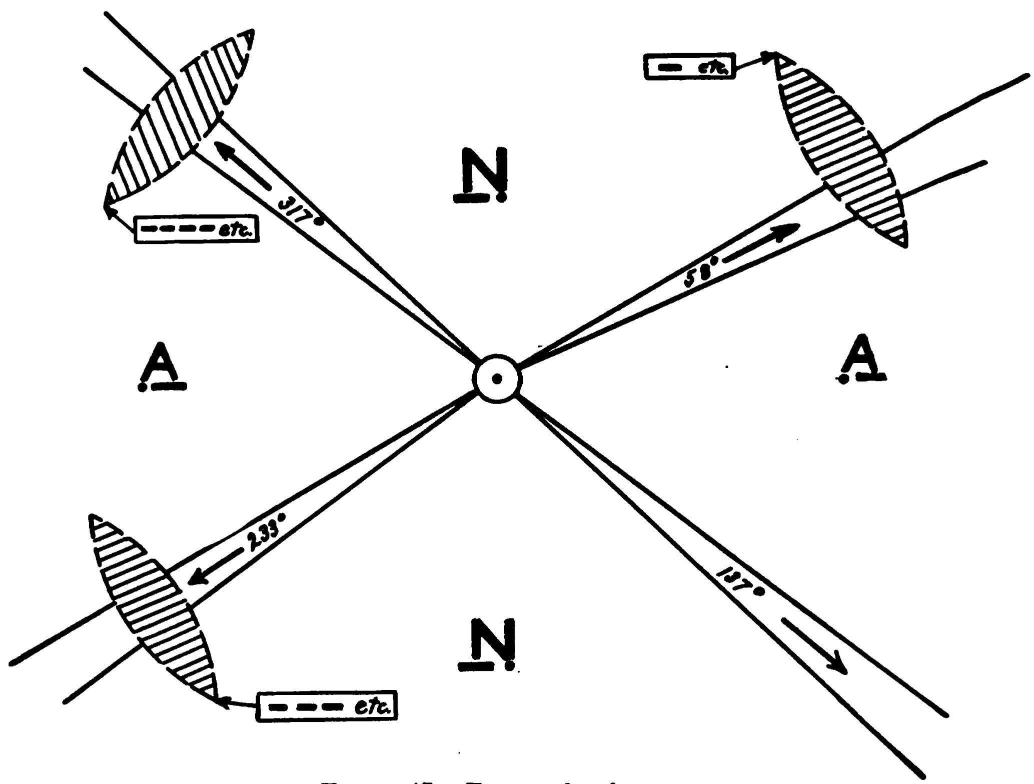

FIGURE 45.—Fan marker beacons.

therefrom; the groups of two, three, or four dashes are assigned respectively to the second, third, and fourth courses of the station, proceeding clockwise from true north. The identifying signals assigned to the fan markers around the Newark range illustrate this practice. The signal of a fan marker beacon, then, identifies a particular course of a range, and also a position along that course; it therefore definitely fixes the location of the plane. The fan marker beacons also constitute an important link in the system of airways traffic control.

(3) In weather such that visual observations of the ground cannot be used, ground speed can be determined by noting the time required

to reach a given marker beacon, or from the elapsed time between passing successive marker beacons, range stations, or cross beams from other radio range stations.

75. Radio compass.—There are several types of equipment under the general head of radio compass. Signals may be received aurally or visually or both by means of a loop antenna which may be either fixed or rotatable. Strictly speaking, the radio compass refers to installations employing a fixed loop and a visual indicator. The radio compass used by the Army is a radio receiver equipped with a loop antenna and a pilot indicator which shows a zero indication when headed directly toward or away from the station. In order to eliminate any possibility of 180° ambiguity, when the station is tuned in the pilot starts a turn to the right and continues until the pointer moves from the right to the center. This places the pilot in only one possible position and that is toward the station. From this point on to the station, a right pointer indication is corrected by a right turn and a left-hand pointer indication by a left turn.

a. Use.—(1) The radio compass is chiefly used as a "homing device," and bearings of radio stations off the line of flight may be obtained only by turning the airplane toward the station and noting the compass heading when the indicator is centered.

(2) With the rotatable loop, bearings may be obtained without turning the airplane. Instead, the loop is rotated until the position of minimum signal strength or "null" is obtained; the bearing of the station may then be read from a graduated dial. By means of separate dials on recent installations, allowance may be made for variation and deviation so that true bearings, magnetic bearings, or bearings relative to the head of the airplane may be read directly from the instrument. This equipment is properly referred to as a radio direction finder.

b. Sense antenna.—(1) Under certain atmospheric conditions it is sometimes necessary to disconnect the "sense antenna." In this event it is impossible to determine directly whether a radio station is before or behind the airplane, that is, whether the station is in the direction of the indicated bearing or of its reciprocal. It then becomes necessary to work an orientation problem in much the same manner as that used with the radio ranges.

(2) In figure 46, suppose that an airplane is being flown on a heading of 310° true when, at 1, the radio compass bearing of the station *RS* is determined as either 75° (station behind) or 255° (station ahead). In either case, with the loop in homing position a 90° turn is made to the left of the homing course, as at 2. This

heading is maintained for a period of from 3 to 10 minutes, depending on the ground speed and the distance from the station. A 90° turn to the right is then made, returning the airplane to the original homing course, as at 3. If the new bearing indicates that the station is now to the right of the original bearing (4a) the station is still ahead; if to the left of the original bearing (4b) the station is behind.

c. Other uses.—(1) Both the radio compass and the direction finder are valuable aids when flying the radio range system. For example, if a pilot is flying a range course and is able at the same time to obtain the bearing of some off-course radio station, the intersection of this bearing with the range course plotted on the chart definitely

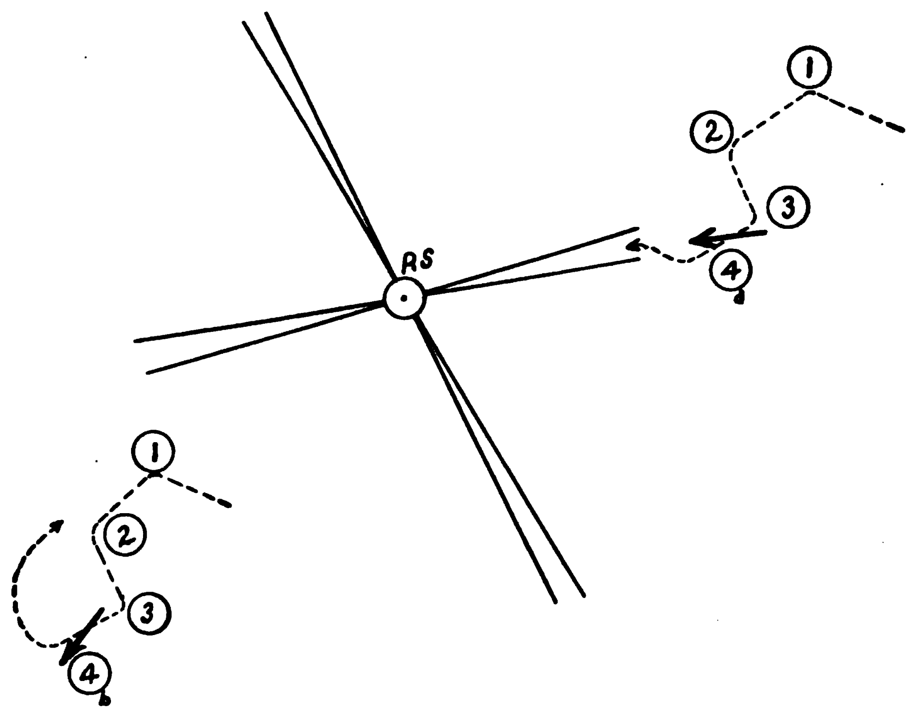

FIGURE 46.—Orientation with radio compass.

fixes the position of the airplane along the course at the moment the observation was made. Or if the pilot is appreciably off course he may identify the quadrant in which he is flying by means of the observed bearing to the radio station. This also informs him of the location of the equisignal zones, and he may proceed to the station without the extra flying required by other methods.

(2) The main use of the radio compass or direction finder is that of determining the direction to any broadcasting station. It is as useful for direction finding and the determining of position when off of the airways as it is when on the radio range system itself. By its use pilots are enabled to tune in any broadcasting station of

which the position is known—commercial or Government—and fly directly to the station selected merely by heading the airplane so as to keep the pointer of the indicator centered. A straight line drawn on the chart from any given position to the radio station in question represents the course required, with no wind, in flying to that station.

76. **Radio fixes.**—*a.* The pilot of an airplane equipped with a radio compass may fix his position by taking bearings on two or more transmitting stations.

b. If the compass is of the fixed-loop type, the radio compass must be tuned to each station in turn and the following procedure taken:

(1) Turn airplane until sensing indicator is on zero and airplane headed toward station.

(2) Holding airplane on a steady heading with sensing indicator on zero, read magnetic compass. This is the compass bearing of the station from the airplane.

(3) Convert compass bearing of station to true bearing by applying magnetic deviation and variation with proper sign.

(4) Find true bearing of airplane from station by adding or subtracting 180°.

(5) Plot bearing from station.

c. The intersection of two simultaneous bearing lines will fix the position of the airplane. It is obvious from the foregoing that the two bearings cannot be taken simultaneously. Hence, a running fix must be made. Running fixes are described in section VI, chapter 2.

d. If the airplane is equipped with a rotatable loop compass, the airplane need not be turned so that it is headed toward the station. The method of taking and plotting radio fixes with a rotatable loop compass is described in detail in section X, chapter 2.

e. It is apparent from the foregoing that the pilot of an airplane not equipped with an automatic pilot can make little use of radio bearings to find his position because he cannot release the controls long enough to perform the many mechanical and computational steps necessary to plot the lines to position upon his map. Some mechanical plotters have been made which eliminate such of the work connected with plotting the bearings. Even with a mechanical device, the pilot navigator will find the taking and plotting of radio bearings an extremely difficult task. Fixes by radio bearings can be accomplished with any degree of accuracy only in those airplanes which carry a navigator. It is for this reason that the detailed procedure of fixing the airplane's position by bearings taken from the aircraft is given in chapter 2 rather than in this chapter.

f. The position of an airplane may be fixed by bearings taken by two or more ground direction finder stations. Nothing more is required of the pilot than to depress the transmitting key long enough for the ground stations to take their bearings. Sometimes these ground stations are so coordinated that the bearings are taken simultaneously. Ground personnel plot the bearings and radio the position indicated by the intersection to the airplane. The complete procedure is described in section X, chapter 2.

77. Wind effect when homing.—*a.* When the radio compass or direction finder is used as the sole means of navigation, the effect of wind is the principal complicating factor. Once understood, however, the proper allowance for wind can be made and the pilot may proceed with certainty even though the ground is not visible.

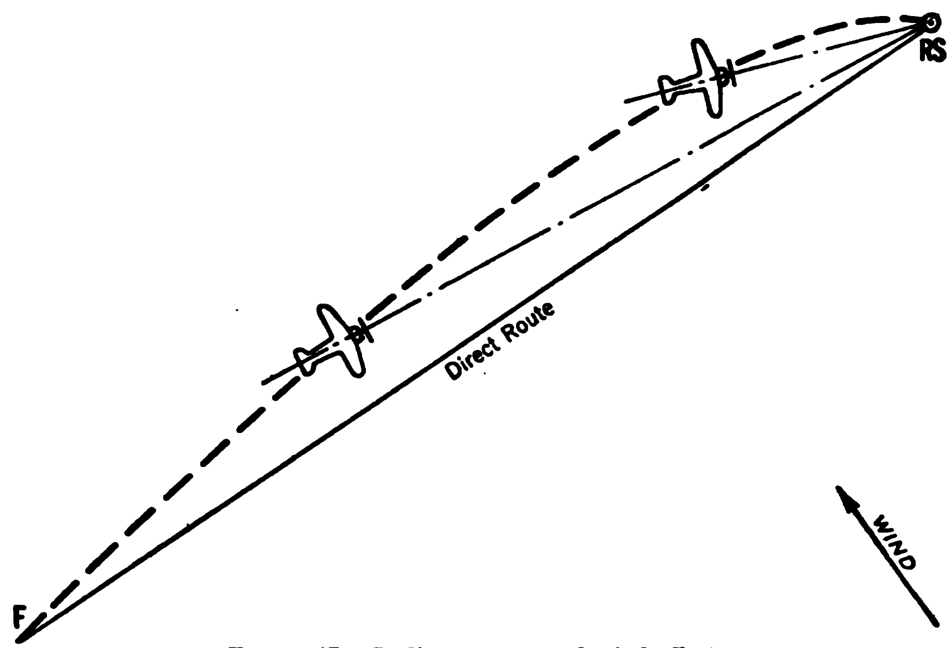

FIGURE 47.—Radio compass and wind effect.

b. When using the radio compass solely as a homing device, even though the pilot heads his airplane directly for the radio station (*RS*, fig. 47), under the effect of cross winds the airplane will follow the roundabout broken line of the figure instead of the direct route. From the standpoint of the added distance alone, this is often unimportant, since it would seldom require appreciably more time to fly the round-about course than to head into the wind and crab along the intended track at reduced ground speed. On the other hand, it is always desirable to know with reasonable precision the track being made good. At times this is absolutely essential in order to keep the airplane over favorable terrain or to avoid dangerous flying conditions.

Furthermore, more precise methods of navigation do result in some saving of flying time.

c. In view of the wind factor, precise navigation with the radio compass is possible only in conjunction with a stable magnetic compass or with a gyro-compass. To illustrate, suppose a pilot leaves a point *A* and proceeds toward a distant radio station *B*. (See fig. 48.) From the chart he knows that the true course from *A* to *B* is 90°. With a true heading of 90° he soon finds from his radio compass that he has drifted to the left. Heading slightly into the wind after another period of flying he finds he has now returned to the direct route. This means that he has made more allowance for wind than is necessary in order only to maintain the intended track, so he assumes a heading between the first and second. After a period of flight on this inter-

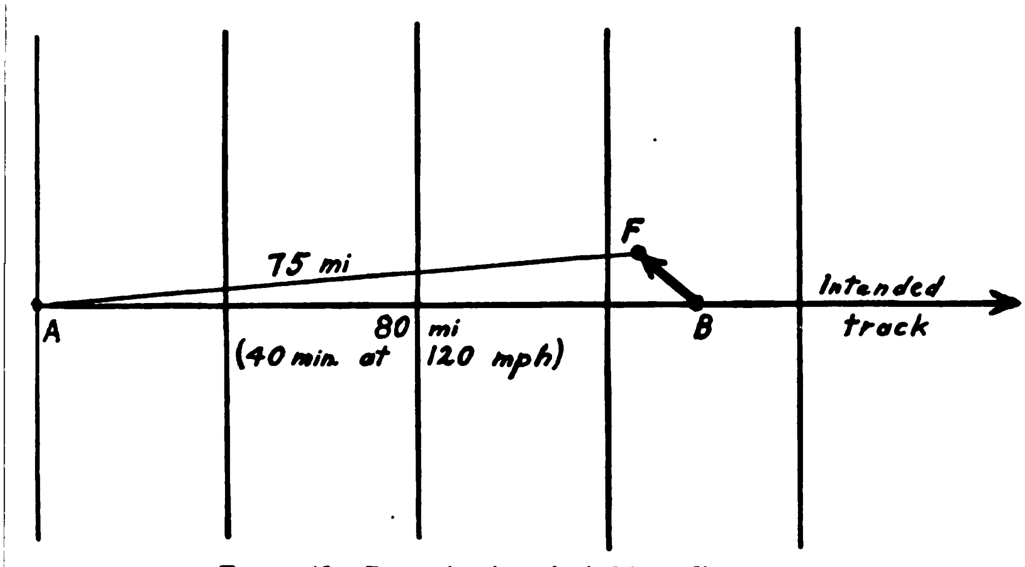

FIGURE 48.—Determination of wind by radio compass.

mediate heading, he turns momentarily to the original heading of 90° just long enough to determine from the radio compass that he is still on the direct line to the station at *B*. This indicates that he is making the proper allowance for wind and he returns to the intermediate heading. Subsequent checks made by turning the airplane momentarily to the original heading of 90° will keep him advised of any deviation from the direct route and enable him to make any further changes in heading that may prove necessary. The procedure is the same whether flying toward a radio station or flying away from a station.

d. The process of finding the correct heading to steer in order to make good the direct route to the station may be somewhat simplified if the pilot is able to determine the drift angle. By heading into the wind at an angle just a little greater than the observed drift angle, the approximate heading is found at once. Subsequent checks as outlined in *e* above will provide the data for any further modification that may be necessary.

e. The foregoing applies to the nonrotatable loop antenna; when using the rotatable loop the procedure is simpler. If a deviation to the left is noted, the airplane is turned slightly into the wind as before and the loop rotated the same number of degrees in the opposite direction. The indicator will then show the same amount of deviation from the route as before, but if enough allowance has been made this will gradually decrease to zero. This indicates that the airplane is again over the intended track, and a slightly smaller allowance for wind should keep it there. Each time the heading is changed the loop is rotated an equal number of degrees in the opposite direction. A heading is then found on which the indicator will remain centered as long as the heading is maintained. While this condition exists, the airplane is making good the direct route toward the station.

f. With the rotatable loop of the automatic type, the procedure is still simpler. If a departure to the left is noted, as in the previous instances, the pilot turns toward the right until the original bearing is again indicated. It is then only necessary, by trial and error, to find a heading such that the original bearing is indicated continuously without changing. As long as the compass heading and the indicated bearing both remain constant, the direct track toward the station is being made good. The difference between the compass heading and the bearing in this case is the drift angle. As pointed out below, this provides the necessary information for determining wind direction and velocity.

g. Under unusual conditions, if the airplane is already close to dangerous topography, instead of returning to the intended track as described above it may even be desirable to circle back and reach the plotted route at a position nearer the starting point. The arrival over the intended route must be determined by the radio compass in conjunction with the gyro or magnetic compass.

h. If the airplane is proceeding from a radio station as a point of departure, using the radio compass as a homing device (flying away from home), and the visual indicator shows a deviation from the direct route, the drift angle may be determined simply by heading the airplane so as to center the indicator and noting the difference in degrees from the original heading. While one drift angle cannot determine a position, if this angle is plotted on the chart and the estimated distance made good is scaled along it, an approximate position is obtained which may be of some assistance.

78. Errors of radio compass bearings.—*a.* The radio compass is subject to deviation error due to the heading effect which the mass metal of the airplane has upon the incoming radio waves. The calibration of the radio compass to determine these deviations is described in section X, chapter 2.

b. Radio compass bearings are subject to night effect, refraction, and various other effects. See section X, chapter 2, for a complete discussion on the vagaries of radio waves.

79. Night flying aids.—*a. Lighted airways.*—(1) Most of the main airways are equipped with beacon lights for use in night navigation. On aeronautical charts the letters LF adjacent to an airport symbol indicate that the field is equipped with lighting facilities for landing at night. Sometimes these facilities are operated only at certain hours or on request. The same is true of certain other beacon lights and aids, and for complete information on these points pilots should obtain information from the local operations office.

A	· —	M	— —	Y	— · — —
B	— · · ·	N	— ·	Z	— — · ·
C	— · — ·	O	— — —	0	— —
D	— · ·	P	· — — ·	1	· — —
E	·	Q	— — · —	2	· · —
F	· · — ·	R	· — ·	3	· · · —
G	— — ·	S	· · ·	4	· · · ·
H	· · · ·	T	—	5	· — ·
I	· ·	U	· · —	6	— · —
J	· — — —	V	· · · —	7	— · ·
K	— · —	W	· — —	8	— · · ·
L	· — · ·	X	— · · —	9	— — ·

FIGURE 49.—Code adopted for airway use.

(2) A rotating beacon is indicated by a star with an open center. Arrows in conjunction with the beacon symbol indicate that the beacon is equipped with course lights and show the direction in which they are pointed. Adjacent to the symbol are placed the number of the beacon and the corresponding code signal which is flashed by the course lights for identification at night. When there is a power shed at the beacon, the site number is also painted on the shed roof for daylight identification.

(3) The number of any intermediate field or beacon is obtained by dropping the final digit of the mileage from the origin of the airway on which it is located. For example, beacon No. 19 on any airway is approximately 190 miles from the origin of the airway. The course lights flash the code for only the last figure of the beacon number, the code signals being the same for beacons numbered 9, 29, etc. Beacons having the same signal are approximately 100 miles apart, and a pilot should know on which 100-mile section of the airway he is flying. For convenient identification the code used along the airways is shown in figure 49. It should be noted that, although the code used for the

letters of the alphabet is the standard International Morse Code, the numerals are designated by symbols which also represent a letter in that code.

(4) The following sentence, arranged so that the first letter in each word corresponds to the code for the successive numbers in the series, has been suggested as an aid in memorizing the sequence of letters:

1	. — —	W hen
2	. . —	U ndertaking
3	. . . —	V ery
4	. . . .	H ard
5	. — .	R outes
6	— . —	K eep
7	— . .	D irections
8	— . . .	B y
9	— — .	G ood
10	— —	M ethods

b. Beacon lights.—(1) The original standard airways beacon is a 24-inch rotating unit of the searchlight type developing approximately 1,000,000 candlepower. The new standard airway beacon is a 36-inch rotating unit showing two beams of light separated by an angle of 180°, each beam having a maximum of about 1,250,000 candlepower. The airway beacons are so operated as to show six clear flashes per minute. A directional arrow 70 feet in length which points to the next higher numbered beacon light is constructed on the ground at the base of the beacon tower. On the feather end of the arrow, or on one side of the roof of the small powerhouse, the beacon light site number is painted. Beacons are numbered from *west* to *east* and from *south* to *north* between terminal cities, the numbers corresponding in each case to the nearest 10-mile interval.

(2) When rotating beacon lights are used without color screens, only clear flashes are shown. Auxiliary course lights are generally installed in such cases to provide the color flashes. The presence of landing facilities is indicated by green flashes and the absence of such facilities by red flashes. Two course lights are mounted on each beacon tower, one pointing forward and the other pointing backward along the airway. These course lights are searchlight projectors fitted with aviation red or green lenses. They give a beam of 15° horizontal and 6° vertical spread and of about 100,000 candlepower. Each course light flashes its code signal which corresponds to the number of the beacon on the airway. The course lights flash code numbers running from 1 to 10, as illustrated above, and thus indicate successive 100-mile sections of the airway. In order for a pilot to identify positively the number of a beacon site or the miles he has flown along

the airway from the code characteristic, it is necessary for him to know on which 100-mile section he is flying.

80. Landing fields.—*a*. Civil Aeronautics Bulletin No. 11, "Directory of Airports and Sea Plane Bases," published by the Civil Aeronautics Administration, lists and describes all airports and landing fields of consequence in the United States.

b. The Civil Aeronautic Administration's "Weekly Notices to Airmen" is the source from which airport information is kept up to date. It carries information as to new airports, discontinuance of airports, changes at existing airports, and changes in the aids to air navigation, on the Federal airways system, including landing fields, lights, radio, and weather reporting facilities, and special notices.

81. Weather broadcasts.—*a*. For the purpose of keeping aircraft in flight acquainted with prevailing weather conditions in their flight area, radio communication stations have been established at frequent intervals along the airways of the nation. Hourly weather reports come into these radio communication stations by teletypewriter and are broadcast on regular schedule. (Air Corps pilots will find the schedules for each broadcast station in the radio facilities chart provided in each airplane.) In addition, each station broadcasts a brief report of weather conditions at its own location at hourly intervals. Most radio beacons operate in conjunction with radio broadcast stations which announce weather reports on regular schedules. Where a station provides both directional signals and weather broadcasts, both are transmitted on the same frequency. This is necessary because of the limited number of channels available, and has the advantage that the pilot does not have to retune his receiver to get weather information.

b. All airway radio broadcast stations equipped to broadcast on the frequency of 236 kilocycles will broadcast the Weather Bureau terminal forecasts applicable to the station location; also the airway forecast applicable to the airway or airways upon which the stations are located. The forecasts are broadcast at the end of the broadcast of local weather at 4:29 and 10:29 a. m. and p. m., eastern standard time. For broadcast of winds aloft see radio facilities chart.

c. The radio marker beacon radio telephone stations also transmit weather information when special occasions arise on a frequency of 278 kilocycles.

SECTION IX

AIR TRAFFIC RULES

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82. Publications containing rules.—Regulations governing the navigation of Army aircraft are published by the War Department. Military aircraft are required to comply with Civil Air Regulations insofar as is consistent with military operations. The rules and regulations governing flying may be found in the following publications:

Army Regulations No. 95-15 and No. 95-35.

Air Corps circulars: 5-10, Notices to Pilots.
15 series, Blank Forms and Reports.
60 series, Flying.
85 series, Airdromes, Flying Fields, and Airways.
90 series, Aids to Navigation.

Air Corps circular letters.

Air Corps technical publications.

Civil Air Regulations.

83. Army Regulations.—AR 95-15 and AR 95-35 apply to pilots of the Regular Army, the Organized Reserves, and to the National Guard when in the Federal service. They cover the operation of aircraft in general. They are divided into sections with the following headings: (AR 95-15) general provisions; use of aircraft; passengers in Army aircraft; air rules; lights and streamers; signals; flying over populous areas and assemblages of people; parachutes; use of Army aircraft by the Reserve Corps; cross-country flights; experimental engineering; and (AR 95-35) airdromes; general provisions; markings. (See also FM 1-25.)

84. Air Corps circulars.—Air Corps circulars are published by the Chief of the Air Corps, under authority of Army Regulations, for the purpose of issuing information and instructions of an administrative nature pertaining solely to the Air Corps and which are subject to more or less frequent change. The circulars which are of special interest to the pilot-navigator are as follows:

a. A. C. Cir. 5-10, Notices to Pilots.—These notices give information concerning the condition of airdromes and other pertinent data.

b. A. C. Cir. 15 series, Blank Forms and Reports.—Flight Envelope, 15-9; W. D., A. C. Form No. 15, Invoice (for purchases), 15-15; Radio and Telegraphic Reports of Aircraft Accidents, 15-16; W. D., A. C. Form No. 23, Clearance for Aircraft, 15-23; W. D., A. C. Form No. 24, Flight Performance Record, 15-24; and Forced Landing Report, 15-30 and 15-30B.

c. A. C. Cir. 45-7, Pilots' Information File.—In each station operations office a Pilots' Information File is maintained. It is divided into two sections:

(1) The general section contains a copy of those instructions and regulations, general in nature and application, that should be brought to the attention of all flying personnel. (See A. C. Cir. O-2, par. 2.) This section also contains pertinent Army Regulations and Air Corps circulars, circular letters, and technical publications.

(2) The special section contains local flying rules and regulations; local facilities; and operating and flight instructions for equipment.

d. A. C. Cir. 60 series, Flying.—This series covers many rules pertaining to flying, such as flights to sea; oxygen use at altitudes; restriction on acrobatic flying; smoke grenades; design and flight limitations; night flying equipment; air space reservations; and piloting of aircraft absent from home station.

85. Air Corps circular letters and technical publications.—Air Corps circular letters and technical publications which apply to the pilot-navigator will be found in the Pilots' Information File.

86. Civil Air Regulations.—Rules and regulations governing flying in general, and cross-country flying on the civil airways in particular, have been published by the Civil Aeronautics Administration. All pilots, including Army pilots, are subject to these rules, and to possible penalties if the rules are not followed. Part 60, Civil Air Regulations, contains air traffic rules. Each pilot, before going cross country, is required to read and understand the pertinent rules which apply to this type of flying. The difference between "contact" flight rules and "instrument" flight rules will be noted especially.

87. Handbook of Instructions.—*a. Air Corps Radio Facility Charts.*

(1) A copy of this Technical Order is carried in each airplane during cross-country flights. Up-to-date charts showing the name, location, frequency, call letters, A and N zones, and magnetic bearings of the range courses are given for each radio range station in the United States and for those in some foreign areas.

(2) Radio range stations are listed in tables, together with pertinent data, including the weather broadcast schedules.

(3) Air Corps radio stations are listed, with important information concerning them.

(4) A mileage chart showing the distances between radio range stations; a time zone and mileage chart showing the distances between important stations; and the areas of the time zones are included.

b. Radio Data and Aids to Airways Flying.—A copy of this Technical Order is also carried on each cross-country flight. It contains—

(1) General instructions of value to the pilot-navigator.

(2) Index of aeronautical charts, showing the sectional chart divisions of the United States.

(3) Sunset tables, with instructions for use.

(4) Civil airways and air traffic control centers, together with the more important rules as to altitudes to use for various courses, both for on and off airways flying; data for instrument flights; Civil Air Regulations—Air Traffic Rules, listing the rules applying to cross-country flights; and broadcasting stations of the United States, together with pertinent data concerning them.

88. Flight plan and clearance.—All Air Corps pilots are required to obtain a clearance before departing on cross-country flights. Detailed instructions pertaining to the clearance are found in A. C. Cir. 15-23.

SECTION X

NAVIGATION FLIGHTS

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89. Relation of pilotage and elementary dead reckoning.—*a.* "Air pilotage is the method of conducting an aircraft from one point to another by observation of landmarks either previously known or recognized from a map." Although this sounds very simple, there are many chances for careless errors to cause the inexperienced pilot to get lost or to waste much time during a comparatively easy cross-country flight. The poor method of merely taking off and heading in the general direction of the destination, relying entirely upon excellent visibility and numerous landmarks is not good pilotage although it will frequently give fair results. Pilotage and dead reckoning are closely related in actual practice, and usually on a flight made mainly with pilotage methods there are many chances to use dead reckoning methods to good advantage for short periods of time.

b. Theoretically, on a pilotage flight, it is not necessary to have a magnetic compass. Most experienced pilots, however, would not attempt to make a cross-country flight without a reliable compass. Even on a flight where there is a main river or shore line to follow, there is some chance of having to leave the easily followed course due to weather or some other cause. In such a case, especially if the visibility is poor, the magnetic compass is indispensable.

c. As the cross-country experience of a pilot is increased, some of the steps which follow may be eliminated. The beginner should remember that he develops his ability during flights made in good weather and on easily followed courses. Then later on if he is faced with a difficult and possibly unexpected situation he will have the correct background and the habit of using the proper methods. This will enable him to know his exact position at all times and to reach his destination even under adverse conditions.

90. Preparation of maps.—Many maps used by Air Corps personnel have already been prepared for the most used flight paths. When this has been done the map will show, as straight lines, the courses between the various turning points. These lines will be marked off at 20-mile intervals for an easily used distance scale. The *magnetic course* will be indicated by its numerical value for each direction along the course lines.

a. Marking for cross-country use.—If it is necessary to use a map which has not been marked for cross-country use, prepare it as follows:

(1) Draw a straight line between the starting point and the destination. (If desired to fly from *A* to *D* by way of *B* and *C* then draw *AB*, *BC*, and *DC*.) Examine the paths shown by these course lines. From knowledge of the terrain or from information shown on the map, decide whether or not it would be best to follow these straight courses. If, on any leg, a slightly longer distance would

enable the pilot to avoid flying over large bodies of water, mountains, or other hazardous terrain, then divide this leg into two or more sections so that the path outlined will be safer to use.

(2) When the course lines are completed, measure each leg for distance and then mark off 10- or 20-mile intervals on the course line. Write in, on the map, each 50- and 100-mile numerical value.

(3) Then on those legs which extend over only 3° or 4° of longitude, or less, measure the course line with a protractor. Use the meridian which is nearest the middle of the leg. Correct the protractor reading for variation and print the value for the magnetic course on the map. On a longer leg of 6° or 8° of longitude, first divide the leg in half and then obtain the magnetic course for each half by using the variation nearest the middle of each section.

b. Folding aeronautical charts.—(1) For laying out routes before taking off, for all detailed studies of a region, and for all general use, a flat chart, free from folds and wrinkles, is very desirable. During actual flight, even in the larger transport planes, lack of space usually prevents the use of an unfolded chart. As a result, many methods of folding the charts have been devised, while those flying regular routes have made up strip charts or books from the published charts. In order to avoid the handling of numerous charts on all navigational flights, even short ones, both sectional and regional charts have been designed to cover fairly large areas. Nevertheless charts of both series will be found very convenient for use in the air when properly folded. It is recommended that the charts be folded once, back to back, along the line *AB* (fig. 50), then in four or six "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.

(2) Strip charts are very convenient for those flying frequently over the same route; however, as already suggested, they cannot fully satisfy the need even for this type of flying. A pilot may be compelled to leave the charted airway because of adverse weather conditions or other reasons and will find himself over unfamiliar territory with no chart of the ground below. If a strip chart or book is prepared showing only the region immediately adjacent to the route, complete sectional charts showing a wider area, folded for most convenient reference in case of need, should also be carried.

(3) Some very ingenious folds and route books have been devised, by means of which the entire route, or even whole charts, can be followed from point to point by the flip of a page; however, if such folds are made by pasting portions of the chart together, they cannot be

considered satisfactory for all purposes, since the chart cannot be spread flat again for the plotting of new courses, etc. Folds of this sort should by all means be supplemented by a flat chart or one so folded that it may again be opened out flat.

(4) If a strip chart is desired, the chart can be folded as a strip without destroying or cutting away any part of it. For example, if it is desired to make a strip chart covering the route *CD* (fig. 51), 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 50.

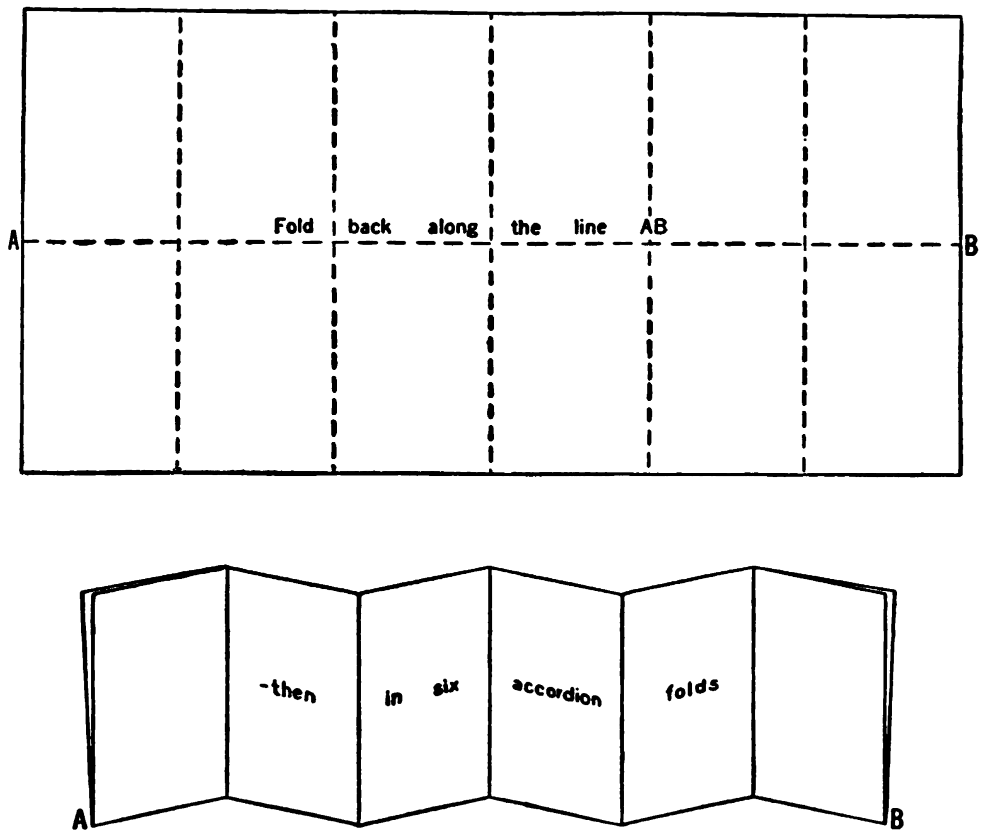

FIGURE 50.—Folding the chart for use in flight.

By this method the folded-back portions of the chart are still available if they should be needed.

91. Other preflight preparation.—*a*. Although the Form 1 always has a pencil attached, it is far more convenient to use a separate pencil, with eraser, which may be carried in a holder or a pocket. A writing pad consisting of a pad placed on a small piece of plywood (held to the leg, above the knee, by rubber bands) has been successfully used and endorsed by pilots of small airplanes. Some pilots prefer to use paper clips to attach their extra paper directly to the map.

b. After the necessary cross-country request has been approved, and the maps prepared, the equipment, such as flares for night flying, cross-country tool kit, stakes and covers, smoke candles, etc., should be placed in the airplane.

c. Master charts in the operations office should be checked to insure that all pertinent data are also on the charts to be used on the flight.

d. The Pilots' Information File and Notice to Pilots should be checked for recent additions.

92. Simple log sheet.—It is a good policy for the pilot to study his map before he goes into the air for a navigation flight. One excellent method is to make a list of all possible check points along the route, with the distance from the starting point and the distance between consecutive points listed against them, somewhat in the manner of road

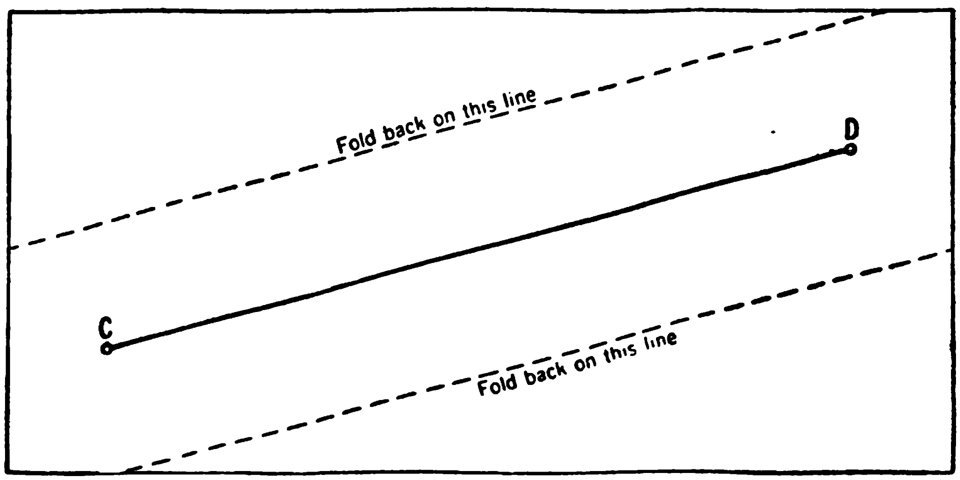

FIGURE 51.—Folding the chart as a strip.

logs for automobile touring. The time should be computed to each check point, using the average air speed. The time should be listed as take-off time plus the number of minutes computed. This time can then be checked against the actual time in flight to determine whether the wind is hindering or helping on the flight. During the flight the pilot can refer to this list and check the points off as he goes along. An example of such a simple log is shown in figure 52. Assume that easily recognized check points are located as listed above and distances from the starting point are as shown. The planned air speed is to be 140 m. p. h. Using the D-3 computer (par. 55), the E. T. A. (estimated time of arrival) of the first three or four check points is recorded. (All may be computed, if desired.) This simple log may be carried (as stated in par. 91) clipped along the edge of the map or on a separate pad of some sort.

93. Flight plan, clearance, weather.—Before take-off, the pilot must procure a clearance from the operations office. This clearance includes a flight plan for the trip and certain other pertinent data. It also includes a space for the weather report, and this part is retained by the pilot for use during the flight.

94. Handbooks and XC envelope.—Before take-off, the pilot must insure that the airplane carries the two Technical Orders—Radio Facility Charts and Radio Data and Aids to Airways Flying—and also a cross-country envelope. These Technical Orders were discussed in paragraph 87. The cross-country envelope contains a number of blank forms and certain regulations and orders. These are listed, together with a description of the use of the envelope, in A. C. Cir. 15-9.

CHECK POINTS	DISTANCE FROM START	140 mph E.T.A.	ACTUAL T.A.	REMARKS
Start	0	Take off +		
Pt. A	12	5 +		
Pt. B	21	9		
Pt. C	38	16 +		
Pt. D	61	26 +		
Pt. E	88-			
Pt. F	105			
Pt. G	130			
Pt. H	165			

FIGURE 52.—Pilot log form.

95. Radio check on ground.—Before the actual take-off, the pilot (of radio equipped airplanes) will call the control tower and complete a radio check-in. He will receive the correct time, data relative to altimeter setting, wind velocity, and take-off instructions, during the check-in.

96. Initial procedure.—*a.* The pilot gains the altitude which he is to use, before starting on the desired course. He then passes directly over his starting point or some definite check point nearby (listed as "Start" on his log) and notes the *exact* time he passes over it, writing this time on the log. If it is undesirable to climb to the cruising altitude, before starting, it may be gained on the way. Note that this will mean a slower ground speed during the period of climbing. In any event he *writes down* on the log sheet the exact time of departure.

b. The pilot figures out his desired compass course as soon as he sees the compass correction card. If wind data are not available he estimates the drift correction. (Usually the correction by the inexperienced pilot will be too large.) This correction, applied by heading the airplane into the wind the required number of degrees, is applied to the compass course and thus the original compass heading is obtained. He uses this heading and watches for the first check point, meanwhile holding the map so that it is properly oriented in relation to the ground. As he looks at the chart, the course line he intends to follow is held parallel to the longitudinal axis of the airplane, and his desired course as shown on the chart is along this line from bottom to top as he looks at it. Held in this position all of the printed matter may be upside down, but it is the correct position for the map.

c. The method of steering a range (par. 59) may be used at this time in conjunction with others.

d. During the first few minutes the pilot checks the map against the ground repeatedly. He also glances frequently at the compass to see that a constant heading is maintained. He may use the directional gyro set to zero, and this is usually easier to keep centered than the magnetic compass.

e. Knowing the E. T. A. of the first real check point, the pilot starts looking for it a little ahead of time. When he passes over it, he has a check on his ground speed and also on his estimate of the drift. If he passes very far to the right or left of the check point, he should make a correction in his heading. This correction is difficult to judge at first but becomes easy after a few flights. One easily remembered relationship is that a change of 1° of heading will make about 1 mile difference to right or left, in 60 miles of travel, or 2° will make a mile of difference in 30 miles, and 4° will change 1 mile to the side in 15 miles forward.

f. If the course is such that a radio range may be used, the proper station is tuned in and the compass heading checked against the radio signals.

g. Usually railroads and highways are excellent check objects to use at the start of and throughout the trip. Rivers, lakes, quarries, water towers, race tracks, adjacent towns, etc., are all very useful in aiding the pilot to maintain the proper position and direction.

h. It cannot be overemphasized that the time to start checking the heading, and also the map with the objects on the ground, is *immediately* after the start. If they both indicate that the desired course is being made good, there is hardly a chance of starting in the wrong direction even without the use of radio.

97. Written record vs. memory.—One of the most serious of the mistakes an inexperienced pilot may make is that of trying to remember some of the things he should write. The rule is: *write*, do not try to *remember*. Even if the course seems so easy that a log seems unnecessary, write the time of passing each check point opposite the position of the place on the map. It is well to have an eraser handy, in case the map is already marked with the check times of another pilot.

98. Altitude; traffic rules.—The cross-country pilot will keep in mind that there is a specified altitude to use, depending on the course; that there are certain traffic rules and safety precautions to be observed; that certain radio reports may be required; and that the original flight plan must be followed out unless the change is immediately reported. These are but a few of the things he must keep in mind, in addition to his duty as pilot-navigator.

99. Time and ground speed.—*a. Method.*—With the use of the simple log, already described, the pilot may easily keep track of his time and ground speed at all check points. As each check point is passed and identified, the time will be written down and the estimate of the ground speed revised. The use of the D-3 computer makes the figuring of ground speed the work of but a moment. A good check on ground speed enables the pilot to know his position at all times and serves to differentiate between two check points which may have points in common. Knowing his ground speed and the distance, he will know which check point it is. The ground speed may change considerably if the airplane passes through a wind shift.

b. Position for noting time.—The pilot waits until the check point is directly underneath the airplane or directly abeam before noting the time. For accuracy, each of his observations is done in the same way, and the results are then uniform.

c. Three things to check.—By constantly checking the following three items the pilot will insure his flight against errors involving uncertainty as to position. Knowing position and direction of travel he cannot become lost. He checks—

(1) The compass heading to see that the airplane is kept on the correct and straight course.

(2) The time and distance flown, from which he estimates his ground speed.

(3) His position, by means of check points on the ground, ground speed, elapsed time, and radio. The time and ground speed will help identify check points having similar features.

100. Use of radio.—The use of the radio is not emphasized in this section as the pilot may have to navigate at times without its use. He will be able to do so by following the methods outlined. The use of radio greatly simplifies air navigation in the United States, but there is always a chance that it may fail. By training himself to navigate without depending too much on the radio, the pilot insures himself against becoming confused if it ceases to operate. By using proper methods in good weather and not depending on one method alone, he develops his technique to the point where the failure of one or more instruments or the radio will not cause him to become lost.

101. Dead reckoning between check points.—After the pilot determines the compass heading which keeps him on course, he may fly

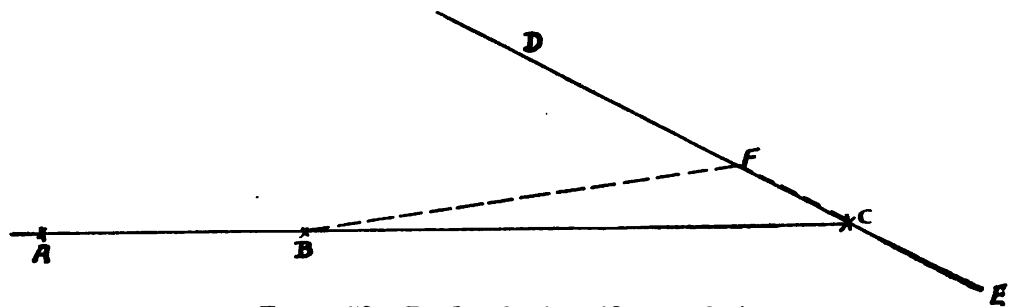

FIGURE 53.—Dead reckoning aid, example 1.

for periods across terrain which offers no good reference points and still arrive very close to his next check point. Frequently a case will come up when he may insure his arrival by going a slightly longer distance. In the following examples, assume that the visibility has been cut down by the presence of dust.

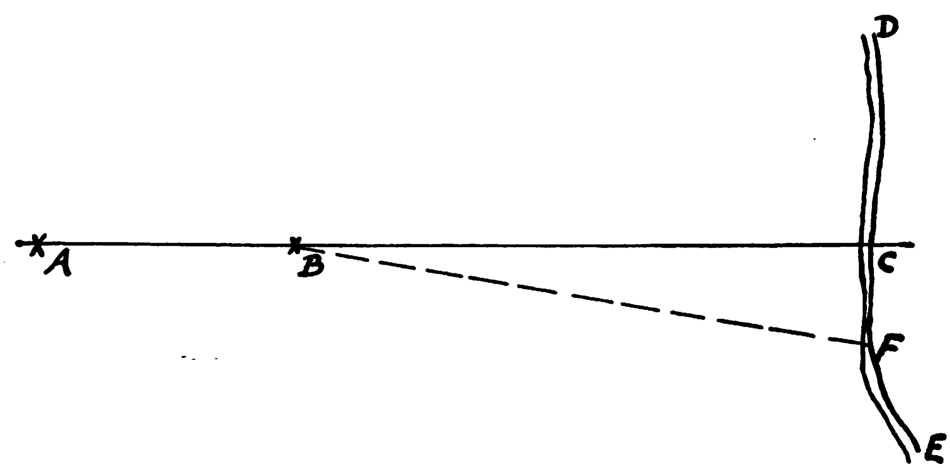

FIGURE 54.—Dead reckoning aid, example 2.

a. Example 1.—A pilot, en route from *A* to *C* (fig. 53) navigates easily from *A* to *B* and then comes to a stretch from *B* to *C* which offers no check points. He notes that a railroad passes through *D*, *C*, and *E*. Knowing the compass heading which he followed from *A* to *B*, the pilot swings several degrees to the left and follows the course *BF*. When he comes to the railroad he turns to the right and quickly arrives at *C*. He also uses the time and ground speed for the distance

BF as an additional check. This method enables the pilot to know for sure which way to turn when he reaches the railroad. In conditions of poor visibility he might otherwise have to guess, if he did not arrive within sight of *C*.

b. Example 2.—Figure 54 illustrates another example, where the railroad (or river, etc.) is approximately at right angles to the course. In this case the pilot swings to either side (right, shown) and then knows which way to turn to reach the point *C*.

102. If position becomes uncertain.—A pilot who is flying over a strange course may, during periods of dead reckoning, become uncertain as to his exact position. There is a definite distinction between being uncertain as to position and being lost.

a. Example.—(1) If the pilot knows his exact place and time of departure and, after checking several check points, finds that the next point fails to come in view at the proper time, his position is uncertain, but he is not lost. He has definite information on all the work that he has done thus far and can establish an approximate position. On the other hand, if he does not know his time of departure and has not checked his ground speed against the check points, he will be lost when his check point fails to come in view. This is true because he will have no data to use in establishing an approximate position. With no written record to use, his memory will soon make him doubt some of his previous check points.

(2) To avoid remaining uncertain as to position, the pilot knows exactly what he has done up to the point where his position becomes uncertain. Assuming that he has written the data as to starting time, kept an accurate compass heading, and checked both direction and ground speed by means of check points, he has a record of his flight up to the last recognized check point. Knowing that the flight had progressed satisfactorily up to that time, the first question for him to consider is the missing check point itself. Is it a feature that he could easily miss, or is it possible that the map is in error? A careful check of the time and the ground speed will tell him whether he has gone the proper distance from the last check point. It may be that he has passed the point without seeing it, due to poor visibility. His progress up to that time will give an idea as to which side he may have passed it on.

(3) The best plan to follow is for the pilot to look ahead on the map and see what possible check points lie ahead, both on the course and to either side of the course. The time needed to reach these points should be computed from the last recognized check point, and the airplane should be held on the proper compass heading. It is seldom

that this procedure will not apply. When he reaches and identifies the new object, it is important that he identify his exact location, particularly when it is a railroad. He should not go on unless he is sure of his location. If there is no other way, he may try to identify the name of the nearest town from a sign on a water tank or on the roof of a building and then take a new departure from that point. It is not unusual for him to fly as much as half an hour without a definite check point, but this should cause no trouble if the flight has been started properly and the compass heading flown accurately.

b. Each flight different.—(1) Each navigation flight is an individual problem. The country passed over and the weather cause variations in procedure. For example, in good weather the pilot may be able to check on a series of towns along a railroad 5 or 10 miles to the side, but when the visibility is poor he cannot see them and will have to depend upon points he passes over or close to. When the visibility is poor the available check points are reduced in number, and it is very important that those which are seen are used to the utmost. For this reason the pilot should practice close adherence to the principles stated so that he will be familiar with the procedure when the visibility is limited. It is quite easy to fly a navigation problem when the visibility is good, but the pilot does not get the benefit from the practice if he does not check accurately as he goes along. Then, when bad weather arrives, the points he can see are limited and he does not have confidence in his ability to navigate with them. This is particularly true of night flights as there are fewer check points that can be used unless the lighted airways are followed.

(2) Repeating some of the above points, if the pilot has not kept a close check on the time and ground speed and has not flown an accurate compass heading he is lost when a check point fails to appear. He does not know exactly how far he has gone, and he does not know the direction closely enough to establish a position. The best that he can do is to proceed with the same compass heading that he has been flying and as soon as he comes to a railroad, town, or other object locate himself before he leaves it. The essential point is that he should know what he has done previously. If he has flown an accurate compass heading and has properly checked the time, he is able to determine quite closely where he should be. On the other hand, if he has wandered over the country, using several different compass headings, and has failed to keep track of the time and ground speed, he has nothing on which to base an estimate of position.

c. Lost.—In the event the pilot becomes lost and is unable, using all available methods, to identify any check point, he will proceed as follows:

(1) *General.*—From an examination of his map, he will try to decide what area he is in. He will search the map for some important river, railroad, highway, or other prominent feature which may be reached and followed. If sufficient gasoline and daylight are available and the weather is suitable, he will choose the compass heading which will be most likely to allow him to reach such a feature. He will start on this heading and maintain it unless, for reasons of safety or the discovery of a check point, he decides to change. When he arrives at a "position line" he will follow it until he can identify his position, turning in the direction most likely to bring him to an airport.

(2) *Important rules when lost.*—As a rule, a person becomes lost only through extreme carelessness. Having made mistakes in getting lost, the pilot may still redeem himself by using good judgment afterward. His actions should be governed by the word "safety" as applied to available fuel supply, daylight time remaining, conditions of weather, terrain beneath airplane, terrain to be flown over if he takes the best compass heading available, and so on. For such a pilot, some things to do and some things to avoid are listed below:

(*a*) With good weather, plenty of gasoline, and plenty of daylight left, follow instructions in (1) above. The only exception to this rule might be when a large smooth, hard, field is found; so good that there is no doubt about being able to make a safe landing, and located near a habitation, or to persons who will be able to tell the pilot his location.

(*b*) If the gasoline supply is low, it is imperative that the best field available be located immediately and that a landing be made in it while there is sufficient gasoline to "go around again" if necessary. Nothing may be said here which will determine for the pilot when the "best available field" is still not good enough. Needless to say, if there is no place to land, the remaining fuel will be used to obtain or maintain an altitude safe for parachute use, while the search continues for a suitable field.

(*c*) The approach of darkness may make a landing necessary. The pilot will have to decide this, but he must not wait until it is too dark if he does decide to land. The type of airplane, its equipment, the amount of experience of the pilot, and the availability of a landing area are all factors affecting this decision.

(*d*) The weather may influence the choice of whether to land or to continue on the best compass heading. The availability of a suitable landing area is also an important item in this decision.

(*e*) The terrain beneath the airplane is one of the most important things to consider when choosing the best method of insuring the safety of personnel and equipment. All possible conditions cannot be visualized in advance, and so no set rule can be given. If the pilot is sure that he can make a safe landing and is very doubtful about some of the other factors, he may be better off if he lands. On the other hand, there is no advantage gained in attempting a landing in an unknown field if a flight can easily be made to an established airport.

(*f*) When flying along the regular airways, using the radio ranges, there is no danger of the pilot becoming lost. On flights off the airways, reception of the nearest radio ranges can usually be obtained. Every attempt should be made to utilize the radio for maintaining proper orientation as outlined in section VIII. The method used for quadrant identification (fig. 44) is often valuable for use even when the pilot is not following the airways.

d. Forced landing.—(1) In the event that the pilot makes a forced landing due to impending darkness, lack of fuel, bad weather, or for any other unforeseen reason, he will send the appropriate messages to his station of departure and the station departed for. Information concerning these messages is included in the material in the flight envelope.

(2) After a forced landing has been made, no attempt will be made to fly the airplane from the field landed in until after a thorough examination of the proposed take-off strip is made, assuming the airplane to have been undamaged in the landing. This will determine that the space for take-off is suitable from the standpoint of—

(*a*) *Length of run.*—Consider airplane load, altitude, hardness of surface, etc.

(*b*) *Condition of field.*—Consider presence of ditches, holes, soft spots, crops or growth, etc.

(*c*) *Obstructions.*—Consider how high and how near obstructions are in relation to known performance of airplane.

(*d*) *Fuel obtained.*—If fuel has been added, consider whether it has an octane rating sufficiently high to enable full power to be used for the take-off.

(3) If a doubt arises as to the advisability of attempting to take off again after a forced landing, send in a request asking that a more experienced pilot be sent out to take charge of the situation.

103. Cloud shadows and smoke columns.—Any aid for the pilot which helps him judge the wind velocity is helpful. At times the surface wind may be judged from the appearance of smoke columns, or from windmills, or other objects on the ground. However, the wind velocity at the surface may be quite different from that at the altitude of the airplane. During flights when there are broken clouds at an altitude near that of the airplane, it is sometimes possible to see the shadows of the clouds on the ground and to judge the direction and speed of the wind in this manner. Such estimates of the wind indicate more accurately the actual wind affecting the airplane than do observations of the effect of surface winds.

104. **Return trip.**—After a successful flight to his destination, the inexperienced pilot may have trouble following the opposite course on the return trip.

a. The flight back should be considered a separate problem, and the procedure should be the same as when he left the home airdrome. The magnetic course back will be 180° different from that flown out since no allowance is made in the course angle for the wind. The drift angle will be the same number of degrees but of opposite sign as the drift angle out unless the wind has changed. The drift angle is always applied into the wind and can be allowed for at the start unless it is obvious that the wind has changed. Since the drift is laid off into the wind in each case, it is obvious that the heading out and the heading back will not differ by 180°, when an allowance must be made for the wind.

b. A factor which often causes trouble on the return trip is the appearance of check points. The flight back is usually made with the sun in a different position than during the flight out. This changes the aspect of the check points as seen from a distance because the shadows are different. This should cause no difficulty if the pilot waits until the check points are directly to one side or underneath before he checks on them. It sometimes makes the country appear to be different as he approaches it, so that he may think that he is off his track when in reality he is not. Always depend upon points in the immediate vicinity for accurate checks.

SECTION XI

RADIUS OF ACTION PROBLEM

	Paragraph
Radius of action (R/A) for pilot-navigator	105
R/A, returning to same base	106
R/A, returning to different base	107
Effect of data change	108

105. **Radius of action (R/A) for pilot-navigator.**—*a. Definition.*—The radius of action of an airplane is the distance it may be flown out along a certain course and still have sufficient fuel for the flight back to the starting point.

b. Solution of problem.—The solution of this problem usually includes finding the heading out, heading back, and time of turn. The distance out depends on fuel capacity of airplane, most efficient air speed, fuel and oil consumption of power plants, altitude used, and effect of wind. There are three main types of performance problems (involving distance) encountered in the Air Corps. These are—

(1) Range of action, or total distance the aircraft can fly, with certain conditions of fuel load, air speed, altitude, etc.

(2) Radius of action, returning to same base.

(3) Radius of action, returning to different base.

106. R/A, returning to same base.—*a. General.*—This problem is important to the pilot who may have to know how far out along a course he can fly and still return before dark, or how far he can go toward his destination and still return to the starting point if the need should arise, due to weather or anything else. It should be noted that favorable winds reduce flying time for a one-way trip, but if the same wind continues for the return flight the round trip always requires more flying time than it would if there were no wind. In other words, for a two-way trip the wind is always a hindrance, never a help, unless it changes during flight so as to be favorable in both directions.

b. Solution.—(1) The formula for computing R/A returning to the same base is

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

where GS_1=Ground speed out.

GS_2=Ground speed back.

T=Available fuel hours. (A reserve of 25 percent of the total fuel is usually held in reserve for unforeseen emergencies. T then is equal to total fuel hours minus 25 percent.)

(2) GS_1 and GS_2 are obtained by drawing vector diagrams in one of the following ways:

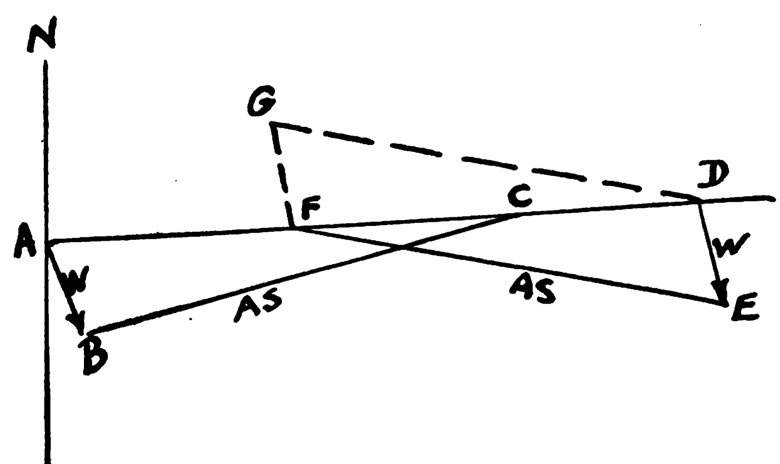

FIGURE 55.—R/A, diagram 1.

(*a*) In figure 55 the triangle *ABC* represents the wind diagram used to determine the heading out by the direction of the line *BC*, and the ground speed out by the length of the line *AC*. Similarly, *EF* indicates the heading back and *DF* the ground speed back.

(*b*) In figure 56 a saving is made in construction work. Triangle *ABC* is the same, and triangle *ABD* gives the same results as triangle *DEF* in figure 55.

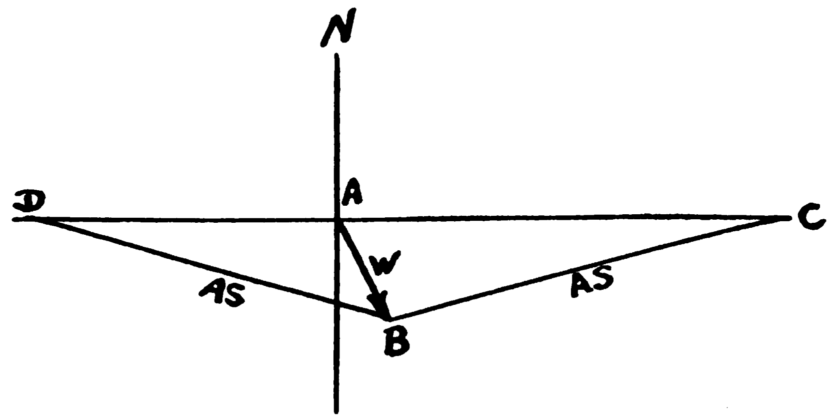

FIGURE 56.—R/A, diagram 2.

(*c*) In figure 57 a larger scale may be used when working on an ordinary sheet of paper, and better accuracy is obtained. Triangle *ABC* is the same as in the first two cases. Triangle *DAE* is the same as the upper triangle *GFD* in figure 55. *BC*=*H* out, *AC*=*GS* out, *ED*=*H* back, and *EA*=*GS* back.

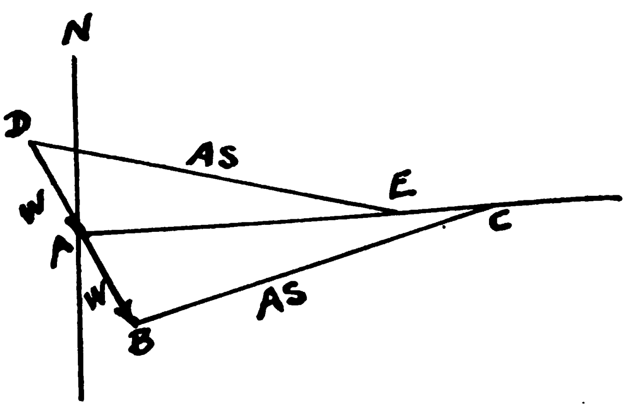

FIGURE 57.—R/A, diagram 3.

(3) By substituting values for *T* and GS_1 and GS_2 in the formula, the R/A may be determined. The diagram will show the *H* out and *H* back. The time of the turn may be found by dividing the distance out by the *GS* out, and converting this value to hours and minutes, then adding it to the starting time.

(4) The formula is only applicable for solving R/A when return is to be made to the same base from which the airplane departed.

107. R/A, returning to different base.—*a*. When an airplane is required to take off from one base, scout on a given course as far as possible, and return to a second base within the limits of available fuel and oil, the solution is more complicated than when returning to the same base. A pilot who starts for a certain destination and wants to know how far along the course he may proceed before having to turn in order to make an alternate airport uses the principles involved in R/A returning to a second base. A Navy pilot who takes off from a moving carrier with instructions to scout on a specified course and return to the carrier at the expiration of a specified number of hours also uses this method.

b. The various quantities needed to make the solution of this problem are derived from a construction diagram. The following example serves to show the method:

(1) *Problem.*—(*a*) Refer to figure 58. Base *B* bears 120° and is 90 miles from base *A*. An airplane is required to leave base *A* at 0900 hour, scout as far as possible on a course of 20°, and return to base *B* at the expiration of 4 hours. The air speed to be maintained during flight is 100 m. p. h. The meteorological wind is 25 m. p. h. from 90°.

NOTE.—The fuel reserve has already been set aside; the entire 4 hours' fuel may be used.

(*b*) Required: Heading out.
Heading back.
Hour to turn for base *B*.
Distance from *A* to the turning point.

(2) *Solution.*—(*a*) On an *N–S* line draw AX=course out, 20°; AB=120° and 90 miles; AE=25 miles from 90° (the wind).

(*b*) On the line AB select the point M so that AM is 22½ miles. AM is the distance AB (90 miles) divided by 4 hours, the time the airplane will be in the air. If the time was 4 hours and 30 minutes, instead of 4 hours, the distance AM would be 20 miles.

(*c*) From *E*, swing an arc passing through *C* so that EC=100 m. p. h., the air speed. Also swing the arc (equal to airspeed) passing through the space at *D*.

(*d*) Draw the straight line CMD, locating point *D*. Draw ED and AD.

(*e*) The figure now represents several quantities and directions, all in 1-hour units. For example, in the triangle ACE, AC is the course and ground distance traveled in 1 hour (*GS*); EC is the head-

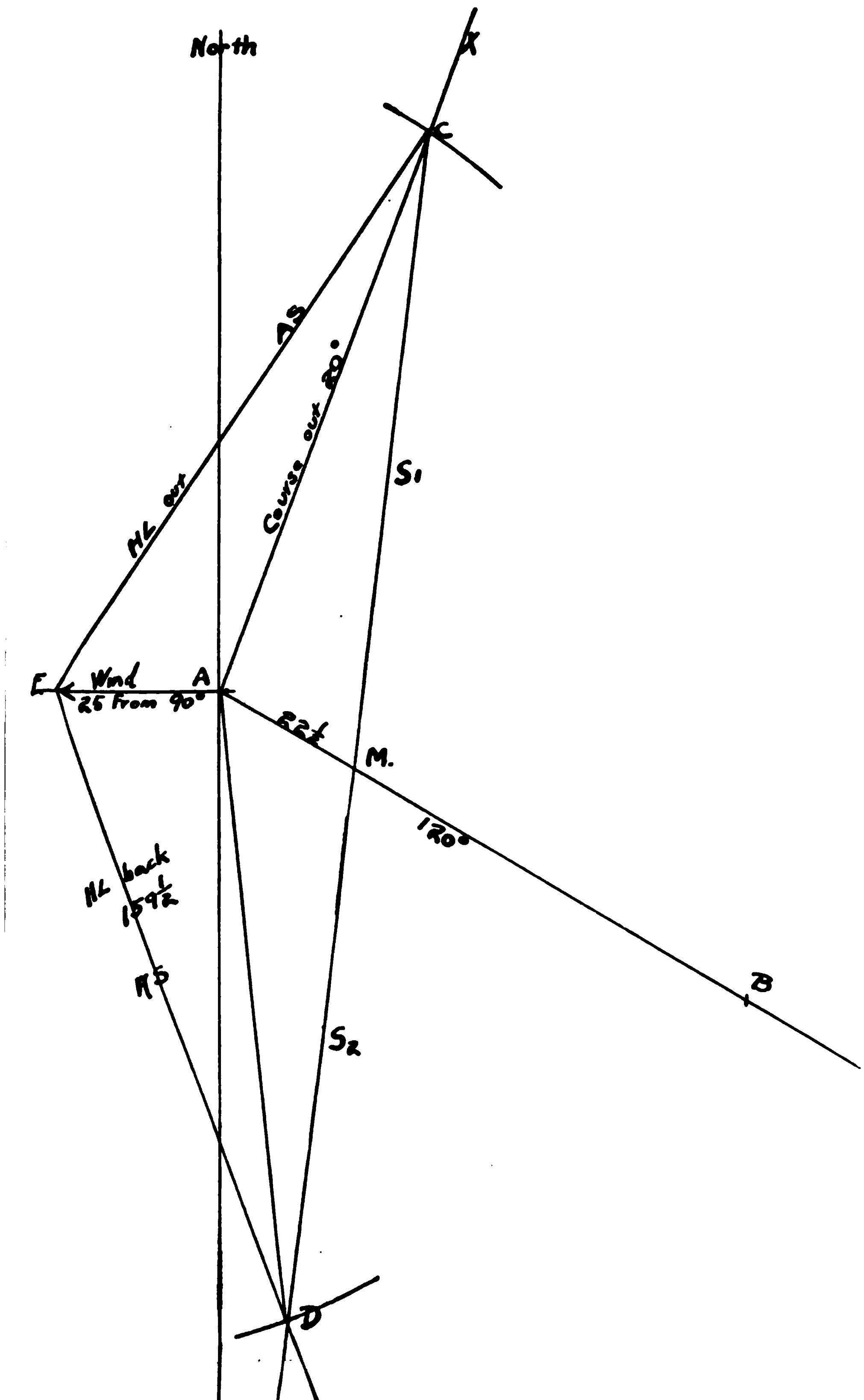

Figure 58.—R/A. returning to different or moving base.

ing and air distance traveled in 1 hour (AS); AE is the direction and distance traveled by the wind in 1 hour. The distance AB represents the total distance from the point A to the new landing position, the landing to be made 4 hours after take-off. In this problem it does not matter whether point B is a permanent landing base or a carrier which will arrive at B at the correct time. Assuming, for a moment, the latter case, the carrier departs from A at 0900 hour and reaches B at 1300 hour, the landing time of the airplane. In order to use a 1-hour unit for the 4-hour distance AB, the point M is selected to represent the position of the carrier at 1000 hour, or 1 hour after the start of the problem. Thus AM then represents a 1-hour unit, the distance the carrier makes good in 1 hour.

(*f*) The line ED now represents the heading angle of the return trip, and the line AD represents the direction of the course back. If the time out was 1 hour, the airplane would then be at point C. In order to intercept the carrier from this point, the pilot would take the heading represented by the direction ED. He would make good a course (from C) represented by the direction AD, and intercept the carrier at a point between M and B. The return trip would take more than 1 hour as shown in (*g*) below. As long as the wind velocity and all speeds and directions, as given in the original data, remained constant, the airplane could be turned *at any time* from its outward course, and would intercept the carrier by following the heading angle back. (In order to intercept the carrier at B, at 1300 hour, there is but one time and place to start back as shown below.)

(*g*) In figure 58 the length of the line CM represents the rate of departure (per hour) from the carrier. (When the airplane is at C, 1 hour after take-off, the carrier is at M.) Also, the length of MD represents the rate of return to the carrier. These lines are not of equal length, and in this example the rate of departure (S_1) is greater than the rate of return (S_2). So, if the airplane returned after 1 hour on the course out, the time back would be longer than 1 hour.

(*h*) In order to find the time to turn and the distance out when the turn is made, the following formulas may be used:

1. To find the time to turn:

$$t=\frac{T\times S_2}{S_1+S_2}$$

NOTE.—Having found t in hours and decimals thereof, change it to hours and minutes and add to the time of take-off. The result is the hour to turn.

2. To find the distance out to the turn:

$D = t \times GS$ out (t is used in the form of hours and fractions of hours).

The above letters represent:

T = available fuel hours (total capacity in hours minus reserve).
t = time out to the turn.
S_1 = rate of departure.
S_2 = rate of return.
D = distance from point of take-off at time of turn.
GS out = ground speed on flight out.

108. Effect of data change.—The radius of action problem may be solved graphically if the following facts are known: course out, air speed, wind velocity, total time for flight, and location of place to land (or speed and course if a moving base). If there is a change of data while the problem is being flown, it may be reworked as a new problem by using the new position of the plane, at the time of the change, as the new starting point. Then the balance of the original time available is used, unless otherwise specified, together with the changed data which made it necessary to rework the problem.

SECTION XII

INTERCEPTION PROBLEM

	Paragraph
Interception for pilot-navigator	109
Interception by visual method	110
Computed interception	111
Interception before 1 hour	112
Interception of aircraft when wind acting on both is the same	113
Effect of data change	114

109. Interception for pilot-navigator.—*a. Use.*—The interception problem can be used for various purposes. As the name implies, it may be the interception of two aircraft or of an aircraft and a surface vessel, etc. This problem is extensively used in the Navy for the interception of the airplane carriers by its airplanes returning to the home carrier. In time of war, bombers intercept the enemy fleet, or pursuit intercept the enemy airplanes.

b. Two kinds.—There are two general classifications of interception problems:

(1) When the aircraft or surface vessel to be intercepted is visible.

(2) When the aircraft or surface vessel is not visible but its position and course and speed are known.

c. Constant bearing.—Interception of visible or invisible craft is possible in the shortest time *only when the relative bearing between the* *approaching craft remains constant.* Plotting the relative bearings will immediately indicate whether or not interception is possible.

110. Interception by visual method.—When the craft to be intercepted is visible, it is possible to use a visual check to maintain the direction which will give interception in the shortest possible time, assuming that there is no change in the speed or direction of the craft to be intercepted.

a. In figure 59, assume that *A* and *B* are located on the lines *CE* and *DE* as shown and that *B* is directly north of *A*. Assume that the speed of *B* is such that he will reach *E* in exactly 20 minutes, and that *A* has a speed which will bring him to *E* at the same time. In this case, if the two airplanes continue, the interception will occur at *E*, and it will be in the shortest possible time at the speeds being used.

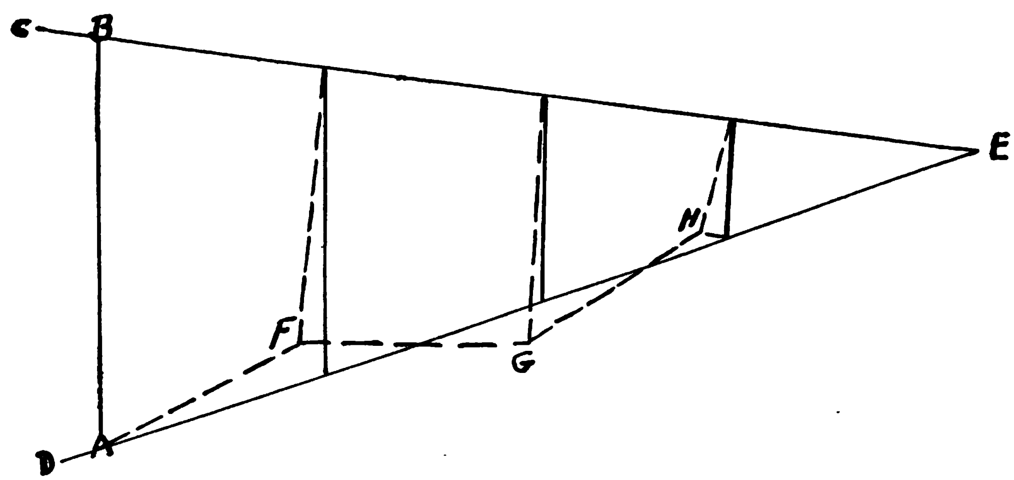

FIGURE 59.—Interception, visual method.

b. Assume that *B* continues his course and speed and that *A* is the one to find and hold the course to intercept. The pilot at *A* knows that if he heads so as to cut in toward the flight path of *B* too quickly he will finally end up behind *B*, in a stern chase, and will lose time by doing so. He also knows that if he heads in a direction too nearly parallel to *A*'s course, he will finally have to turn in to keep from getting too far ahead. So he attempts to find the mean of these two headings.

(1) Not knowing that the heading *AE* will be the correct one, *A* heads from *A* toward *F*. He notes that the original relative bearing of *B* is such that he can sight *B* over a portion of the left wing. He holds a steady heading, using the directional gyro, until he notices at point *F* that it appears as though *B* is pulling out ahead of him. This shows *A* that he is turning in too quickly and will have a stern chase if he continues.

(2) At *F* he swings several degrees to the right, straightens out on a heading with the gyro, and notes the relative position of *B*. He holds the heading for several minutes and then, at about *G*, he notices that the position of *B* seems to be moving rearward as he continues. This shows *A* that his path is too nearly parallel that of *B*, and so he turns toward the left again.

(3) When *A* finally narrows the change in headings down to a heading on which the relative bearing of *B* remains constant, he will then be on the heading which will give interception in the shortest possible time.

c. In this example, *A* required a greater air speed than *B*. Whether or not more speed is required in a given situation is determined by the courses followed, the starting positions of the aircraft, and the wind.

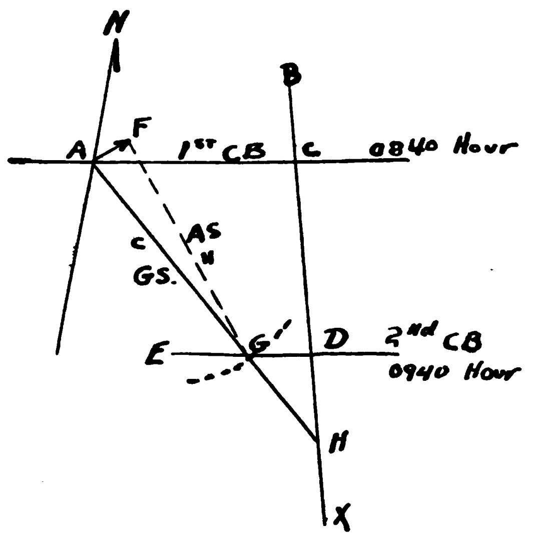

FIGURE 60.—Interception, example 1.

111. Computed interception.—*a. General.*—A diagrammatic solution of an interception problem made before the target is in sight is frequently of value. Such a problem may be solved when the location, direction of travel, and speed of the target are known, together with the interceptor's air speed and the wind velocity.

b. Example.—(1) In figure 60, assume that the objective is reported over *B* at 0830 hour and is making good the course *BX* at a known ground speed. The interceptor is situated at *A* and desires to intercept the target. Draw the interceptor's position *A* on the *N–S* line of the diagram, then draw the target's course line *BX*.

(2) Determine the time the interceptor will be ready to take off (0840 hour) and plot *C*, the location of the target *at the time the interceptor takes off.*

(3) Draw a line through *A* and *C* and label it as the first *CB* line (first constant bearing line).

(4) The position of point *D* is determined, so that *CD* equals 1 hour of the target's travel along his own course. Draw *ED* through point *D* and parallel to *AC*, and label it the second *CB* line (second constant bearing line).

(5) From A draw AF equal to 1 hour's wind, downwind. From F locate the point G on the second CB line so that FG equals 1 hour of our air speed.

(6) Draw a line from A through G and on until it intercepts the line $BCDX$ at point H.

(7) Point H will be the point of interception; AGH will be the interceptor's course out; and the direction of FG will be the heading out.

(8) There are three methods which may be used to find the time of the interception:

(*a*) Target speed may be used as follows: $CH:CD::t:60$, or the distance CH is to the distance CD as the unknown time is to 60 minutes.

(*b*) The interceptor's speed may similarly be used, as $AH:AG::t:60$.

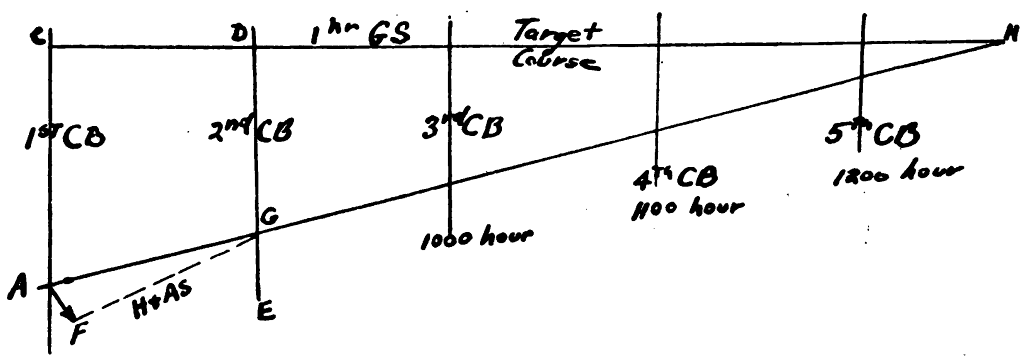

FIGURE 61.—Interception after several hours.

(*c*) The rate of closure method uses the closing in rate per hour, and it has some advantages over the other two methods. In the above example the distance AC minus the distance GD gives the rate of closure (R/C); or $R/C=AC-GD$. After finding the rate of closure, the distance AC is divided by the rate of closure to give the time required to intercept. In figure 60 the time will be $\frac{AC}{AC-GD}$, and the result will be in hours and fractions of hours. The advantage of using the rate of closure method is shown in figure 61.

1. In this example several additional lines of constant bearing show that the interception would occur at about 1230 hour, if the interceptor takes off at 0800 hour. In order to draw a diagram such as the one shown, on an ordinary sheet of paper, it would be necessary to use a small scale and this would tend to create inaccuracies in the solution.

2. Use of the rate of closure method will require only the first and second lines of constant bearing to be in the diagram and so a much larger scale can be used in the construction. To find the distance to the point of interception in such a solution the ground speed out is multiplied by the time.

112. Interception before 1 hour.—*a. General.*—Positions of the interceptor and the target and the speeds used may allow interception to be made before 1 hour has elapsed.

b. Example.—In figure 62 assume that conditions are the same as in figure 60, except that the interceptor's air speed is much faster. Interception will occur at point *H*, where the interceptor course line crosses the course of the target. (Note that the rate of closure in this case is $AC+DG$.)

113. Interception of aircraft when wind acting on both is the same.—*a. General.*—When the reported data on a target give

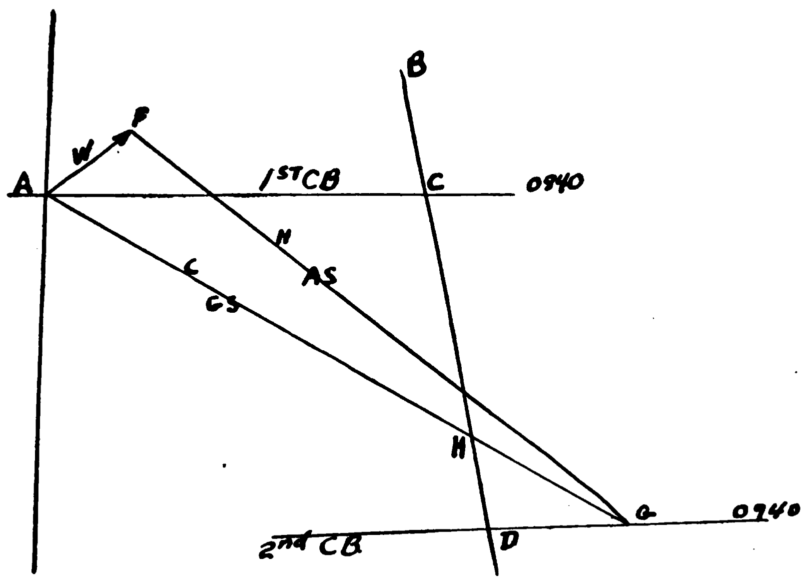

FIGURE 62.—Interception before 1 hour.

the objective's heading and air speed, instead of course and ground speed, the diagrammatic solution may be made as follows: (The wind acting on the interceptor and the objective must be the same to use this method.)

b. Example (fig. 63).—(1) Mark the position *C* of the objective at the instant of the interceptor's proposed departure from base *A*.

(2) Draw the target's heading and air speed as the line *BX*, with *CD* equal to his air distance traveled in 1 hour (air speed). Draw the first and second constant bearing lines as usual.

(3) From *A* strike an arc with radius equal to air speed of the interceptor. This arc cuts the second bearing line at *G*.

(4) Draw a line from *A* through *G* to *H*. *H* is the point of interception in relation to the air; it is the no-wind position of the intercept.

(5) The wind affects both airplanes by the amount of time involved multiplied by the wind velocity. If the wind had blown in the direction from *H* to *O*, and the distance *HO* represents the wind speed times the time interval of the flight, then the actual interception in relation to the ground would be at *O*. A straight line from *A* to *O* would represent the actual course out.

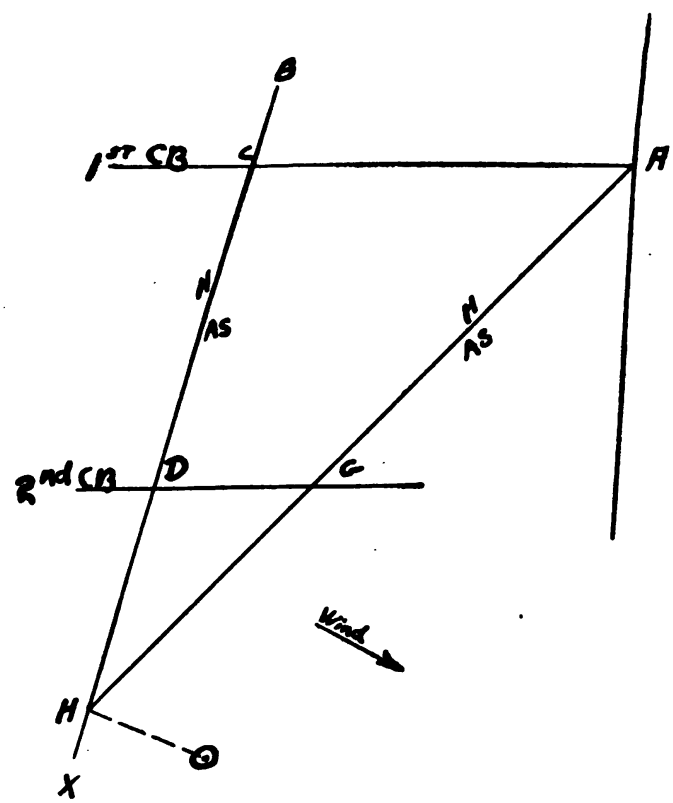

FIGURE 63.—Interception using heading and air speed.

114. Effect of data change.—If a change of data (target course or speed, wind velocity, or air speed of interceptor) occurs after takeoff, the problem must be reworked as a new problem. Use the time, the position of the interceptor when he can change his course, and the position of the target at this same time for the first new constant bearing line. Then the second new constant bearing line will be parallel to the first new constant bearing line and will be 1 hour of the target's travel down his (new) course line. The balance of the problem will then be worked as already described.

Chapter 2

PRECISION DEAD RECKONING AND RADIO NAVIGATION

Section I

GENERAL

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Accuracy	117

115. Scope.—*a.* This chapter describes the methods and technique of dead reckoning and radio navigation as employed in aircraft which carry a crew member specifically designated as navigator.

b. A knowledge of the contents of chapter 1 is essential to a complete understanding of this chapter. The principles of navigation as described in chapter 1 remain the same regardless of whether they are applied by the pilot-navigator or by a crew member who acts solely as navigator. Many of the methods and much of the procedure used by each are identical. The chief difference lies in the fact that, whereas pilot-navigation is largely a matter of approximation between check points, navigation by the navigator is accomplished by precision methods. This precision is made possible by the fact that the navigator has the time, the space, and the equipment not ordinarily available to the man who is acting in a dual capacity. Because his capabilities are great, the navigator is frequently required to perform missions, the navigational aspects of which demand performance beyond the capacity of the pilot-navigator. It is apparent, therefore, that the precision navigator requires a broader and more detailed knowledge of the subject of aerial navigation than the pilot-navigator. This chapter supplies this additional information. It does not repeat, except where necessary for clearness, the contents of chapter 1, however applicable they may be.

c. This chapter does not describe the theory or application of the principles of celestial navigation. (See TM 1-206.)

116. Arrangement.—This chapter is arranged on the premise that it will find its greatest use in the training of navigators. Experience has proved that during such training a certain advantage is to be gained by dispatching the students on practical flight missions as soon as the preliminary ground work has been laid. The arrangement is unique in that primary consideration has been given to presenting the material in a sequence which will lend itself readily to the scheduling of practical flight missions in the early stages of training. Secondary consideration has been given to grouping the material by subject matter.

117. **Accuracy.**—*a.* The accuracy of dead reckoning depends upon the skill of the navigator, the equipment, and the weather conditions existing during flight. Under normal conditions with current equipment and adequate training, the off-course error in the navigation should not exceed $\pm 1°$, and the estimated time of arrival should not vary from the actual time of arrival more than 1 minute for every hour of elapsed time from the last definitely known position.

b. The errors of both dead reckoning and radio navigation increase with distance from the point of departure. On any given flight, the error in the dead reckoning is decidedly accumulative, compensating errors being of the second order of magnitude. It is apparent, therefore, that on long flights the error may reach undesirable proportions. Under these circumstances, the interests of accuracy are best served by obtaining a new starting point or point of departure. This new point of departure may be obtained by fixing the position of the aircraft by reference to landmarks, radio stations, or celestial bodies.

Section II

MAPS AND CHARTS

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Desirable features of a map projection	119
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Hydrographic Office (H. O.) publications	128
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118. **Necessity of familiarity with chart projections.**—*a.* The operations of navigator-directed aircraft are characterized by the relatively great range of the missions, the execution of which must be accomplished in spite of the absence of frequent landmarks and radio position finding aids. The necessity for holding navigational

errors to a minimum demands that the navigator on such flights use the type of chart best suited to the methods of precision navigation. The Mercator chart fulfills these requirements, at least in the lower latitudes, principally because a rhumb line, the path made good by an airplane maintaining a constant course, appears as a straight line upon the chart.

b. The navigator frequently has occasion to refer to and to use maps and charts based on projections other than the Mercator. In the first place, many parts of the world remain unmapped on the Mercator projection. For example, no Mercator aeronautical chart of the United States has been published. Furthermore, Mercator charts are ill-suited for general navigation purposes in high latitudes, and the possibility that the navigator may be required to operate in high latitudes is an ever present one. In addition, maps based on projections other than the Mercator may prove of considerable value in making special studies of the mission.

c. It is apparent, therefore, that the navigator must have a more extensive knowledge of charts and chart projections than is to be gained from contact with the Lambert conformal aeronautical charts used so extensively by pilots in flying over the continental United States.

d. The science of cartography is a broad one, and there is no necessity for the aerial navigator to be familiar with all its ramifications. The navigator should be, however, sufficiently well versed in the characteristics of the more common types of chart projections to plot positions, draw course and azimuth lines, and use the distance scale correctly. Familiarity with the characteristics of chart projections is particularly imporant due to the fact that many a chart in current use fails to include, as part of the legend, the type of projection used in its construction. A brief study of map projections will reveal that many maps which at first glance look alike possess entirely different characteristics. The navigator who does not approach a chart of unknown projection with caution may eventually find himself in difficulty.

119. Desirable features of a map projection.—*a.* From a precision navigator's point of view, a chart projection possessing the following properties would be ideal:

(1) A rhumb line (loxodromic curve) would appear as a straight line on the chart.

(2) A great circle would plot as a straight line.

(3) There would be a constant scale, accurate in every section of the chart.

(4) Positions would be easily plotted.

b. In addition to the foregoing, the following properties of secondary importance would be desirable:

(1) Areas on the earth's surface would be represented in correct proportion on the chart.

(2) True shapes of areas on the earth's surface would be retained in projection.

(3) An angle on the earth's surface would be represented by the same angle in projection.

c. Unfortunately, it is impossible to project a globe or a portion thereof in such manner as to attain all of the foregoing characteristics. Distortion is certain to occur in one way or another as can be seen by attempting to flatten out a cap of orange peel. However, by the use of various types of projection surfaces and with the use of mathematical analysis, it is possible to design a map which possesses many of the foregoing features.

120. Map projections classified.—*a*. Map projections are classified as—

(1) *True perspective or geometric*.—In this type the eye is considered fixed at some point, and the meridians and parallels of the sphere are projected perspectively on a plane or developable surface.

(2) *Conformal*.—The shape of any small section of the surface mapped is preserved on the chart.

(3) *Equal area*.—Any given part of the map bears the same relationship to the area that it represents that the whole map bears to the whole area represented.

(4) *Azimuthal or zenithal*.—The directions of all points on the map as seen from some central point are the same as the corresponding azimuths or directions on the earth. This relationship is true only for the central point.

(5) *Arbitrary or conventional*.—In this type the projections are merely arranged arbitrarily. A map in which the meridians and parallels were drawn on rectangular coordinates to an arbitrary scale would be one type of conventional projection.

b. The foregoing classes are not mutually exclusive, i. e., a projection may fall into two or more classes.

121. Projection surfaces.—Many projections are made directly upon a plane. In some cases, however, use is made of a right circular cone or a circular cylinder as an intermediate aid. The projection is made upon one or the other of these two surfaces, and then this surface is spread out or developed into a plane by cutting an element. Actually, the projection is not constructed upon the cylinder or cone, but the principles are derived from a consideration of these surfaces, and then the projection is drawn upon the plane just as it would appear after development. A projection is referred to as conical or cylindrical, according to which of the two developable surfaces is used in the determination of its elements.

122. Mercator projection (fig. 64).—*a. Description.*—(1) The Mercator is a conformal projection upon a cylinder tangent to the earth at the Equator. There is no fixed point from which the projecting lines are drawn, although the projection point is sometimes regarded as moving along the axis of the sphere, and the pictures used to illustrate the projection show this as taking place. Actually, the only lines of a Mercator which may be constructed perspectively are the meridians. The location of the parallels is determined by mathematics.

(2) The meridians are parallel, equidistant, straight lines.

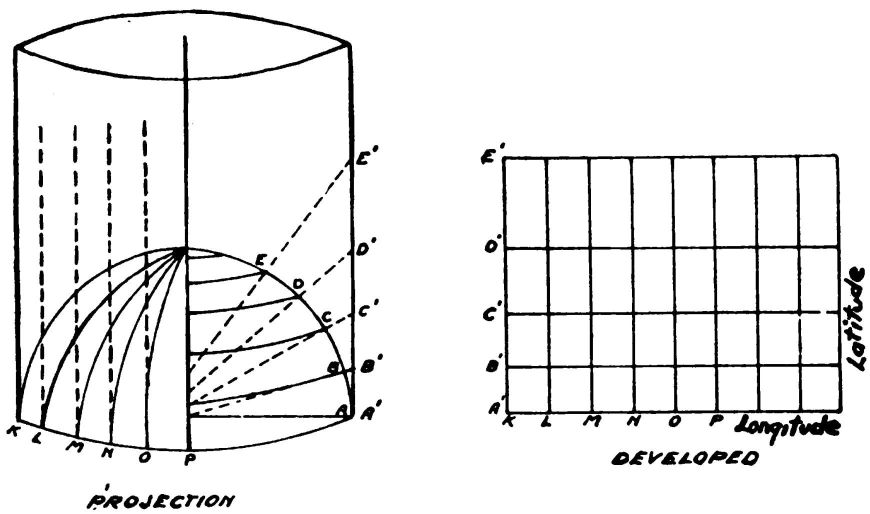


FIGURE 64.—Mercator projection.

(3) The parallels are nonequidistant, parallel straight lines at right angles to the meridians. It will be observed that the spacing between the parallels becomes greater as the latitude increases.

(4) A line on the earth's surface which intersects all meridians at the same angle (rhumb line) is represented as a straight line.

(5) The Equator and the meridians are the only great circles which are represented by straight lines.

b. Construction.—The construction of Mercator charts and the principles of Mercator flying are mutually dependent. The construction of a Mercator chart by both graphical and mathematical methods is described in paragraph 196.

c. Advantages.—(1) The characteristic that a rhumb line is represented by a straight line on the chart constitutes the primary advantage of the projection. An airplane maintaining a constant course will trace the path of a rhumb line on the earth's surface. Hence, the track or course to be made good will show as a straight line on the chart. It follows that an aircraft flying a constant course plotted on a Mercator chart will pass exactly over the points through whose charted positions the line passes. This important feature is true in no other projection.

(2) A distinct advantage of the Mercator projection is that the meridians are always straight up and down, parallel with the east and west borders of the map, just where one expects them to be. Positions are readily plotted because the grids are rectangular. By merely following the respective parallel and meridian to the nearest scales, the latitude and longitude of any point can be quickly determined.

(3) The course line may be directly plotted by protractor at the meridian through the point of departure, or may be carried by parallel motion from a compass rose to any part of the chart without error.

(4) All charts are similar and when brought to the same scale on a common latitude will fit exactly. Similarly, the meridians of charts of the same longitude scale will join exactly.

(5) Areas within any narrow latitude belt are represented by their true shapes.

(6) The projection is readily constructed.

d. Disadvantages.—The disadvantages of the Mercator projection are—

(1) *Distortion.*—The distortion of the meridians and parallels involves, of course, the distortion of the physical features which appear on the earth's surface, i. e., the relative size of areas widely separated in latitude is distorted. However, it must be borne in mind that the Mercator projection is not intended for geographic studies but as a convenient working base for the navigator to determine his course. Thus distortion, especially in normal latitudes, is of no great consequence to the aerial navigator. Due to distortion, the projection is ill-suited for navigating in latitudes higher than 60°.

(2) *Scale.*—The scale used for measuring distance is not a constant one but varies with the latitude.

(*a*) On the earth, a minute of latitude equals a nautical mile. On the chart, a minute of latitude represents a nautical mile. However, the latitude scale is a varying one on the chart. *Hence, in measuring distance the latitude scale at the midlatitude of the distance to be measured is the only scale that may be used.* (See fig. 65.)

(*b*) On the earth, a minute of longitude is equal to a minute of latitude only at the Equator. At other latitudes the length of a minute of longitude varies. On the chart, a minute of longitude is the same

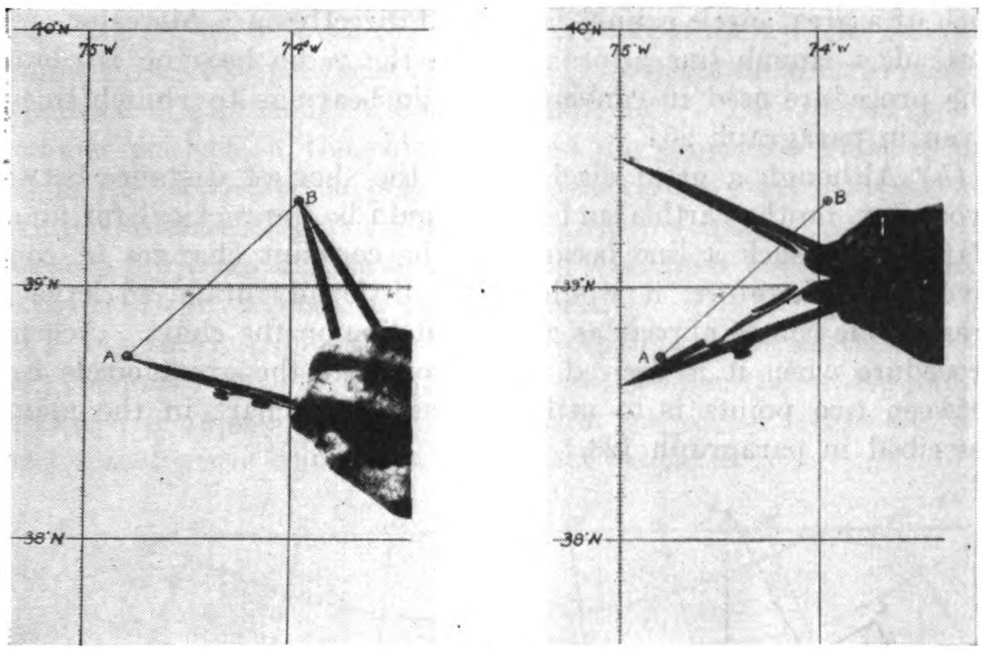


FIGURE 65.—Measuring distance on Mercator chart.

length at all latitudes of the chart. Hence the longitude scale is never used to measure distance—only to measure difference of longitude.

(3) *Great circles not straight lines* (fig. 66).—(*a*) Another disadvantage of the Mercator projection is its inability to portray great circles as straight lines. On a Mercator chart they appear as curves and hence are difficult to plot. The great circle arc being the shortest distance between two points, it would be advantageous to be able to plot it as a straight line. Thus, a radio bearing which follows the

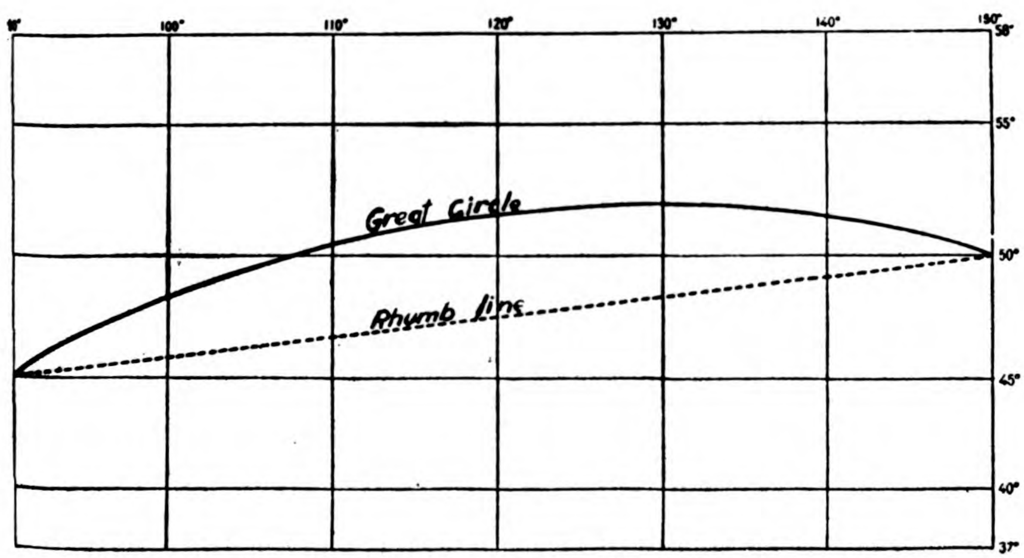
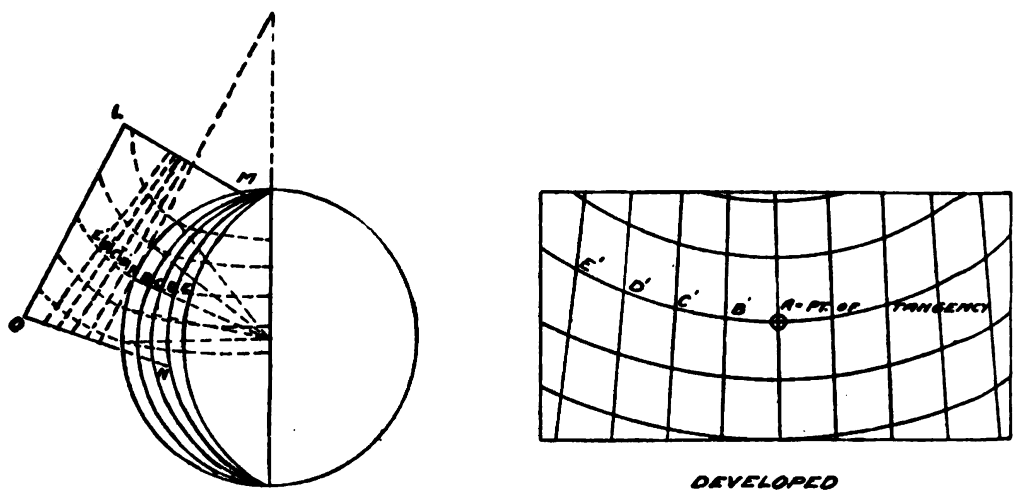


FIGURE 66.—Part of Mercator chart showing rhumb line and great circle.

path of a great circle cannot be plotted directly on a Mercator chart. Instead, a rhumb line approximating the radio bearing is plotted. The procedure used in converting radio bearings to rhumb lines is given in paragraph 204.

(*b*) Although a great circle arc is the shortest distance between two points on the earth's surface, it would be impractical for an airplane to fly such a line because of the constant changes in course involved. Therefore, it would be of little advantage to have the great circle course appear as a straight line on the chart. Accepted procedure when it is desired to approximate the great circle route between two points is to utilize a gnomonic chart in the manner described in paragraph 123.



DEVELOPED

PROJECTION
LMNO PLANE TANGENT AT PT.-A.

FIGURE 67.—Gnomonic projection.

123. Gnomonic projection (fig. 67).—*a. Description.*—(1) A gnomonic projection of a sphere is a true perspective projection upon a tangent plane. The projecting lines are drawn from the center of the sphere, i. e., the eye of the spectator may be considered as being located at the center of the terrestrial sphere, whence, being at once in the plane of every great circle, it will see these circles projected as straight lines.

(2) The meridians, being great circles, are projected as straight lines which converge to a point somewhere on the earth's axis, except when the projection plane is tangent at the Equator, in which case the meridians appear as parallel, nonequidistant straight lines.

(3) Since the planes of the parallels do not pass through the center of the earth they will be projected as curved lines. The same statement is true of any other small circle of the sphere.

(4) The angles between the meridians and parallels do not intersect at right angles except where the parallels intersect the central meridian (the meridian through the point of tangency). One special type of gnomonic projection, the polar, wherein the projection plane is tangent to the earth at the pole does, however, have all parallels and meridians intersecting at right angles. In this special case, the parallels are projected as concentric circles with their common center at the point of convergency of the meridians.

(5) The shortest distance between two points on the earth's surface being the great circle arc between the two, a line on the sphere joining the two will appear as a straight line in projection. (See fig. 68.) This characteristic is inherent in no other projection.

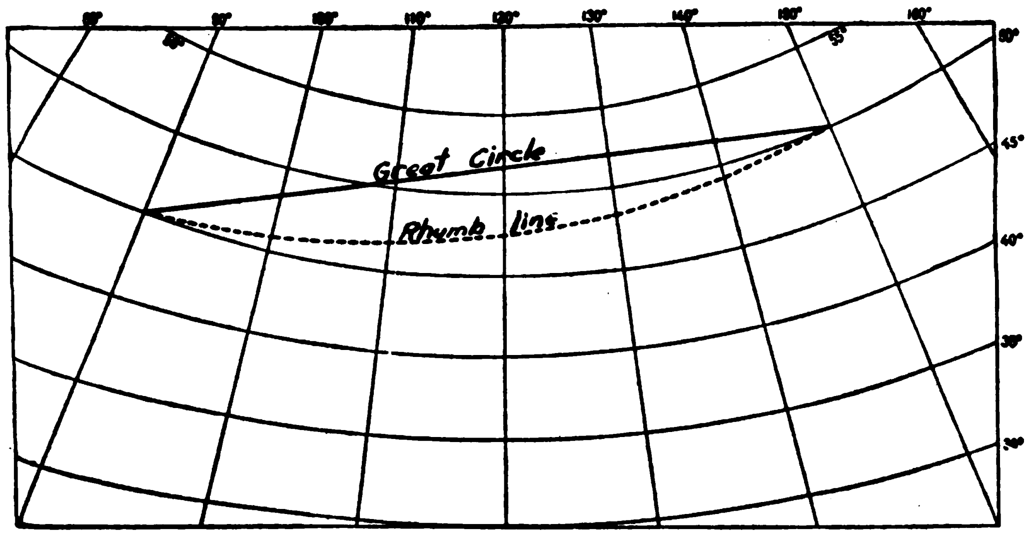


FIGURE 68.—Part of gnomonic chart showing great circle and rhumb line.

b. Employment.—(1) Charts on the gnomonic projection are not used for general navigation purposes with the possible exception of navigation in polar areas where the distortion of the Mercator projection renders it objectionable.

(2) The gnomonic projection finds its greatest application in planning air routes. In the higher latitudes considerable distance may be saved by flying a series of rhumb line chords approximating the great circle arc between two distant points, especially when their difference of latitude is small. In planning such a flight it is customary to draw the straight line representing the great circle route on the gnomonic chart. The latitude and longitude of the intersection of this line with every fifth meridian of longitude is picked from the map. The selection of every fifth meridian has been determined in practice as giving a satisfactory approximation of the great circle course, although more

frequent intersections may be selected if closer approximation is desired. These positions are then plotted on a Mercator chart and the rhumb line chords drawn. Courses and distances are then measured or computed and properly entered in the log.

(3) Visual and radio bearings, since they follow the path of great circles, will appear as straight lines. At first glance this appears to be a greater advantage than it actually turns out to be. On account of the angular distortion in a gnomonic projection, a specially computed compass rose at any given station (except at the point of tangency) is necessary in order to plot a bearing from the station.

c. Disadvantages.—(1) Areas, shapes, and distances become greatly distorted near the boundary of the map. In other words, distortion increases with departure from the point of tangency.

(2) Scale of distance is complicated and difficult to use.

(3) Courses are difficult to measure.

(4) It is not suitable for use as a general navigation work chart because the flight path of an aircraft on a constant course would appear as a curve thereon.

(5) The projection is difficult to construct.

124. Lambert conformal conic projection (fig. 69).—*a. Reference.*—Aeronautical charts constructed on this projection are described in section II, chapter 1. This paragraph supplements the information contained in that section.

b. Description.—(1) The Lambert conformal conic projection is a conformal projection of the sphere upon a right circular cone which cuts the sphere at two parallels called the standard parallels. The apex of the cone lies on the extended axis of the sphere. The cone is developed along an element. In this projection, as in the Mercator, the eye of the spectator cannot be considered as remaining at a fixed point. The construction is made by mathematical formulas.

(2) The meridians are converging straight lines which meet at the apex of the developed cone. This apex usually lies outside the boundaries of the chart. The angles between the converging meridians are directly proportional to the corresponding angles on the sphere.

(3) The parallels are equidistant, concentric circles whose common center is the point of intersection of the meridians.

(4) The angles between the parallels and the meridians are, therefore, right angles just as they are on the earth.

c. Scale and standard parallels.—The Lambert conformal conic projection employs a constant distance scale. Since the standard parallels are common to the sphere and to the cone, the scale is exact along these two parallels. Between these two parallels the scale will be too small; beyond them, too large. In general, for equal distribution of scale error the standard parallels are chosen so that one-sixth of

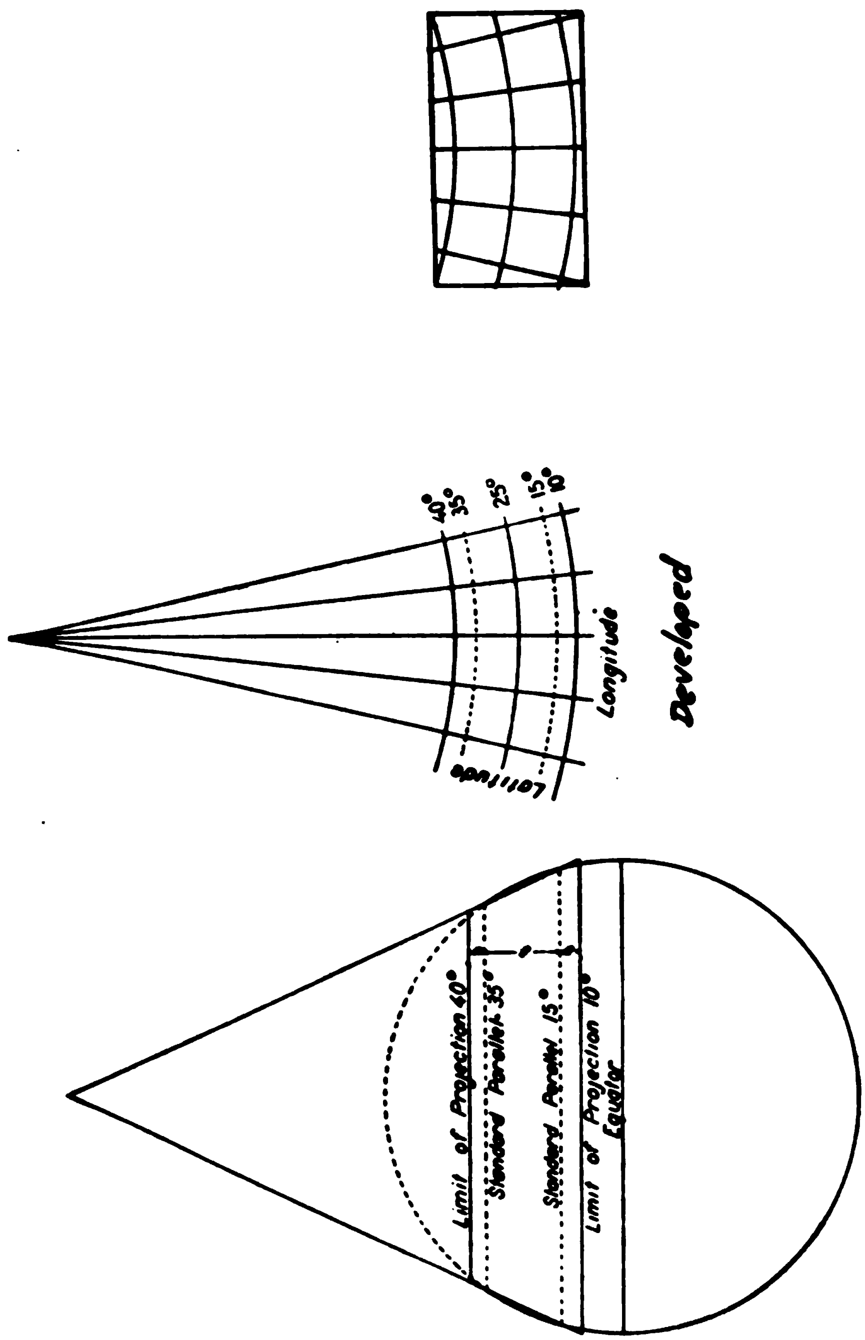


FIGURE 69.—Lambert conformal projection.

that portion of the central meridian to be represented is above and one-sixth below these parallels. It may be advisable for special reasons to bring them closer together in order to have greater accuracy at the center of the map. Because the scale is exact along the standard parallels, the projection is especially suited for maps having a predominating east and west dimension.

d. Advantages.—(1) One scale suffices for the entire map. No large errors result from assuming a constant scale.

(2) Distortion of the projection is slight.

(3) A straight line approximates a great circle. A line drawn between the point of departure and destination will approximate the great circle course between the two. Radio beams and bearings may be plotted as straight lines without appreciable error. However, when radio bearings are taken by the aircraft, a correction must be applied before plotting to allow for the convergence of the meridians. (See par. 204.)

(4) The projection is relatively easy to construct although not so simple as the Mercator.

e. Disadvantages.—(1) An airplane flying a rhumb line course will not fly over the points through which the straight line drawn from point of departure to destination passes on the map. For short distances, however, this departure is slight.

(2) A course line drawn on the chart makes a different angle with every meridian. Courses must therefore be measured at the midmeridian.

(3) Due to the curvature of the parallels and the convergence of the meridians, positions are plotted by latitude and longitude less easily than on the Mercator. Conversely, it is relatively difficult to find the exact coordinates of a physical feature printed on the map.

f. Employment.—(1) The constant scale feature and the conformality of the Lambert-conformal projection make it an excellent projection upon which to base the maps and charts used by pilots; hence, the sectional and regional charts of the United States are constructed on this projection. The pilot's primary duty is to "fly the airplane" and the other duties he performs must be subordinated to it. It is obvious that a map of constant scale causes less diversion from piloting duties than if the pilot is required to use a map with varying distance scale. Furthermore, the pilot keeps track of his position principally by means of landmarks and the advantage of using a map upon which the earth's features retain their shape almost exactly, regardless of latitude, is apparent.

(2) When a person is acting as navigator only, the constant scale and conformality advantages of the Lambert are somewhat outweighed by the disadvantages already mentioned. Because of this, the precision navigator prefers to use a chart based on the Mercator projection, at least in the lower latitudes (approximately 60° N. to 60° S.). In

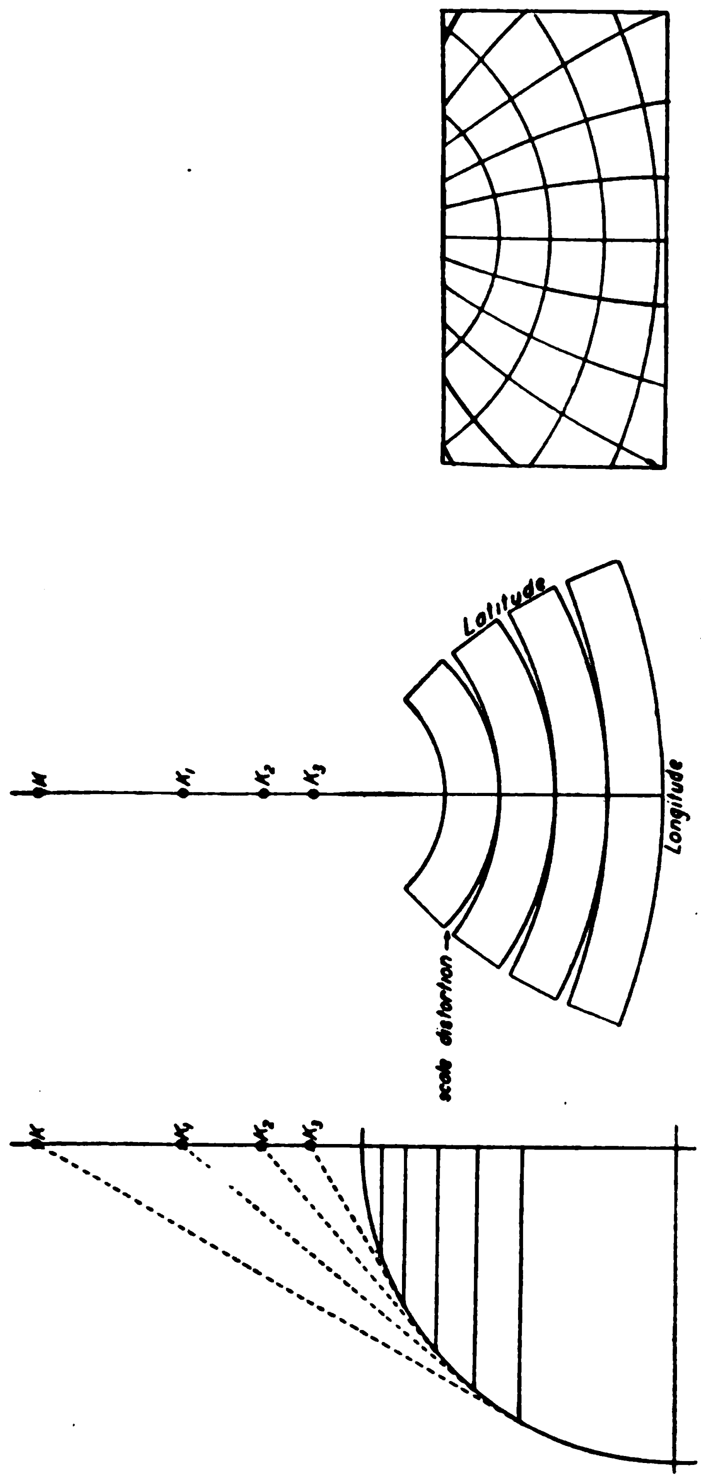


FIGURE 70.—Polyconic projection.

270209°—40——10

high latitudes, the Lambert projection is used as a general work chart by navigators as well as pilots.

125. Polyconic projection (fig. 70).—*a. Description.*—(1) The polyconic projection is a mathematical, conformal projection upon a series of cones tangent to the sphere at selected parallels of latitude. A central meridian is assumed upon which the intersections of the parallels are truly spaced. Each parallel is then separately developed upon a cone tangent to the earth at that parallel.

(2) On the developed chart the central meridian will appear as a straight line, but all other meridians will appear as curves, the curvature increasing with the longitudinal distance from the central meridian.

(3) The parallels appear as arcs of nonconcentric circles. Their centers lie in extension of the central meridian.

(4) The intersections between the meridians and parallels are not right angles except at the central meridian.

(5) A straight line on the chart approximates a great circle.

b. Construction.—The projection may be readily constructed from specially prepared tables.

c. Advantages.—(1) Distortion is slight in the vicinity of the central meridian.

(2) A constant scale is used although this scale is not exact for all sections of the chart.

d. Disadvantages.—This projection is a compromise one and may be looked upon as a link between those projections which have some definite scientific value and those generally called conventional but possess properties of convenience and use. The polyconic has many disadvantages incident to compromise.

(1) An airplane flying a rhumb line course will not pass over the points through which the course line passes on the map.

(2) A course line on the chart makes a different angle with every meridian. Courses must therefore be measured at the midmeridian. This is difficult because the meridians are curved and, furthermore, the parallels do not cut them at right angles.

(3) For the same reason, positions may not be readily plotted on the chart, nor may the coordinates of a physical feature on the map be easily determined.

(4) Due to distortion, the projection is restricted in its use to maps of wide latitude and narrow longitude.

e. Employment.—(1) Charts on this projection are seldom used by the precision navigator except when navigating over terrain not mapped on the Mercator projection. Even then he uses a Mercator plotting chart, employing the polyconic map as a reference.

(2) U. S. Army Engineer, fire control, and tactical maps are made on the polyconic projection. The ease of construction, the constant scale, and the fact that distortion is negligible for small areas make the projection satisfactory for these maps.

126. Stereographic projection.—*a.* A stereographic projection is a perspective, conformal projection with the point of projection on the surface of the earth. The projection surface is a plane perpendicular to the diameter of the sphere passing through the projection point. The projection plane usually passes through the center of the sphere, although for special reasons it may be placed tangent to the sphere at the extremity of the diameter or in any other position so long as it remains perpendicular to the diameter through the projecting point.

b. The only stereographic of interest to the navigator is the polar projection. When the north polar regions are to be shown, the projecting point is the South Pole and the projection is made on the plane of the Equator. (See fig. 71.) A plane tangent at the North Pole could be used equally well, the only difference being in the scale of the projection. On the polar stereographic: The meridians are converging straight lines intersecting at the North Pole. The parallels are nonequidistant, concentric circles with their common center at the North Pole. The parallels and meridians intersect at right angles. The polar stereographic is similar in appearance to the polar gnomonic projection and has many of the advantages and disadvantages of that projection. With the exception of the meridians, a great circle of the sphere does not appear as a straight line on the polar stereographic. However, near the pole a straight line approximates a great circle.

c. All stereographics have two outstanding features:

(1) Angles on the earth are represented by the same angle in projection, i. e., there is no angular distortion. However, due to curvature of the meridians and parallels, these angles are difficult to measure.

(2) Every circle on the earth, small or great, is projected as a circle. The only exceptions are the circles through the point of projection. They will appear as straight lines in projection.

d. Some polar navigation charts are made on the stereographic projection. On these, the course angle may be measured at the midmeridian and distance with the midlatitude scale.

127. Procurement and issue of navigation charts and allied publications.—*a.* The Office of the Chief of the Air Corps is the sole procuring agency of navigation charts and allied publications for the Air Corps. The Matériel Division is the distributing agency of charts to Air Corps stations. Requisitions for charts are made on W. D., A. G. O. Form No. 17, addressed to the Chief, Matériel Division, Wright Field, Dayton, Ohio. Requisitions except in case of emer-

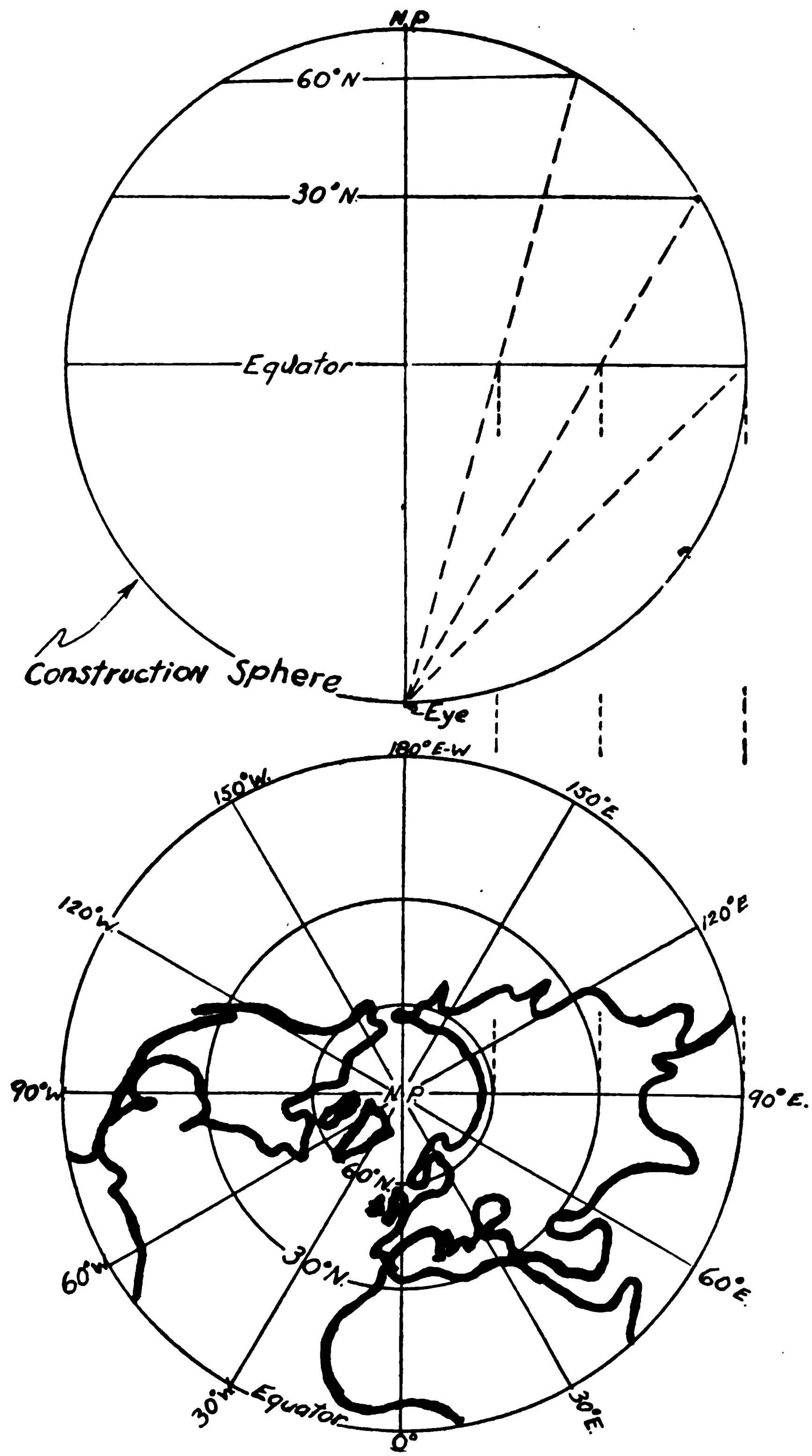


FIGURE 71.—Stereographic projection on plane of Equator.

gency are submitted quarterly. Each Air Corps station maintains one central agency, usually the base operations office, which is responsible for the consolidation of requisitions for and the issue of air navigation maps.

b. Publications pertaining to navigation other than charts may be classified as periodicals compiled by the Air Corps and those compiled by other agencies but procured and issued by the Air Corps. The supply of these publications is in some cases automatic, and in other cases they must be requisitioned (usually through base operations). The information section, Office of the Chief of the Air Corps, and the Matériel Division are the two principal sources of these publications.

c. Since the precision navigator is frequently called upon to operate over sea and land areas outside the continental United States, it is essential in making up requisitions that he be able to select charts of these areas by name and number. Such charts are published and catalogued by the following agencies:

(1) Hydrographic Office, U. S. Navy.

(2) U. S. Department of Commerce, including two of its bureaus, the Civil Aeronautics Board and the Coast and Geodetic Survey.

(3) The International Map Company, New York City, the National Geographic Society, and the American Geographical Society.

128. Hydrographic Office (H. O.) publications.—This branch of the Bureau of Navigation, U. S. Navy Department, is charged with the responsibility of issuing all charts and books pertaining to U. S. Navy navigational matters. The Hydrographic Office prints, buys, and corrects charts of the world. These charts are listed and indexed in the H. O. General Catalog of Mariner's and Aviator's Charts and Books. Although many of the charts contain marine data of little or no use to the air navigator and lack many of the features which are found on aeronautical charts, they are used with great frequency when navigating over areas for which no aeronautical charts have been published.

a. Aircraft plotting sheets.—These are Mercator plotting charts specially designed for the air navigator engaged in overwater operations. Supplemented by maps showing physical features, they are also used as work charts over land areas. These charts are on a scale of 1° Lat. = 3 inches at the middle latitude. The series is published in latitude bands as follows: VP-1, 0°-11°; VP-2, 9°-20°; VP-3, 18°-29°; VP-4, 27°-38°; VP-5, 36°-47°; VP-6, 45°-56°. The meridians of adjoining latitude bands do not match because the scale of each latitude belt is determined by the midlatitude thereof. The meridians are left unnumbered so that they they can be used for any longitude. Each degree of latitude and longitude is divided into 10-minute rectangles to facilitate plotting. Overprints of these plotting sheets for certain coastal areas of the United States and its possessions are available Since these overprints contain physical features, the designation of each meridian is fixed and is printed directly on the chart.

b. Strip aviation charts.—These are Navy strip maps on the Mercator projection. They cover areas of Central America, the West Indies Alaska, and Hawaii, for which no Department of Commerce sectionals are available.

c. Pilot charts of the upper air.—These charts are published monthly They show average conditions of wind, fog, temperature, and barometric pressures for the North Atlantic and North Pacific Oceans This information is particularly valuable for predicting conditions to be encountered in any locality at any time of the year.

d. Other publications.—The following Hydrographic Office publications contain information of value to the air navigator. Much of the material contained therein duplicates that contained in publications more familiar to the Air Corps navigator. An Air Corps navigator finds their greatest application in securing information of localities outside the continental United States.

(1) Naval Air Pilots.

(2) Notice to Aviators.

(3) Memoranda for Aviators.

(4) H. O. 205—Radio Aids to Navigation.

(5) Navigational tables of various types.

129. Department of Commerce publications.—The Department of Commerce publishes and issues navigational charts and allied publications through two of its bureaus.

a. Civil Aeronautics Administration (CAA).—The publications issued by this agency are described in chapter 1.

b. U. S. Coast and Geodetic Survey (U. S. C. and G. S.).—Navigational maps and charts issued by the Department of Commerce are compiled and printed by the U. S. Coast and Geodetic Survey. Besides publishing the aeronautical charts of the United States, the U. S Coast and Geodetic Survey publishes many nautical charts useful to the air navigator. These charts are map-indexed and listed in its catalog. In contrast to the Hydrographic Office which publishes world charts, the U. S. Coast and Geodetic Survey concerns itself with the coastal waters of the United States and its possessions.

130. Maps of land areas outside United States.—*a.* The International Map of the World sponsored by the International Committee for Air Navigation consists of a series of maps to a scale of 1:1,000,000. The entire world series has not yet been published. An index map is available through the International Map Company, New

York City. The projection adopted for these maps is a modified polyconic. The meridians are straight lines; the parallels are circles. The map has been designed to lessen and distribute the scale errors inherent in an unmodified polyconic. Each map has two standard meridians 2° on each side of the center instead of the one central meridian of the ordinary polyconic. Any sheet fits its four neighboring sheets exactly along its margins.

b. The National Geographic Society and the American Geographical Society publish and distribute maps of all sections of the world. These maps are not designed specifically for navigation but are adaptable for use.

131. Finding coordinates.—The coordinates of points of departure, destination, turning points, and other physical features of interest to the navigator are usually picked directly from the latitude and longitude scales of available charts. Often, however, these points are not printed on the chart, or if printed thereon the chart may not be of sufficiently large and convenient scale to give the coordinates of the features to the degree of accuracy required. Under these conditions, the exact coordinates may be extracted from available publications. The exact coordinates by latitude and longitude of various points of the world are listed in many of the publications already referred to in this section.

Section III

INSTRUMENTS AND EQUIPMENT

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132. Definitions.—*a. Instruments.*—Instruments are those devices which may be considered as being permanently installed in the airplane. Although the navigator has occasion to refer to all of the flight instruments installed in the airplane, his primary concern is with the following flight and navigation instruments:

Aperiodic compass.
Altimeter.
Air speed meter.
Thermometer.
Drift meter.
Pelorus.

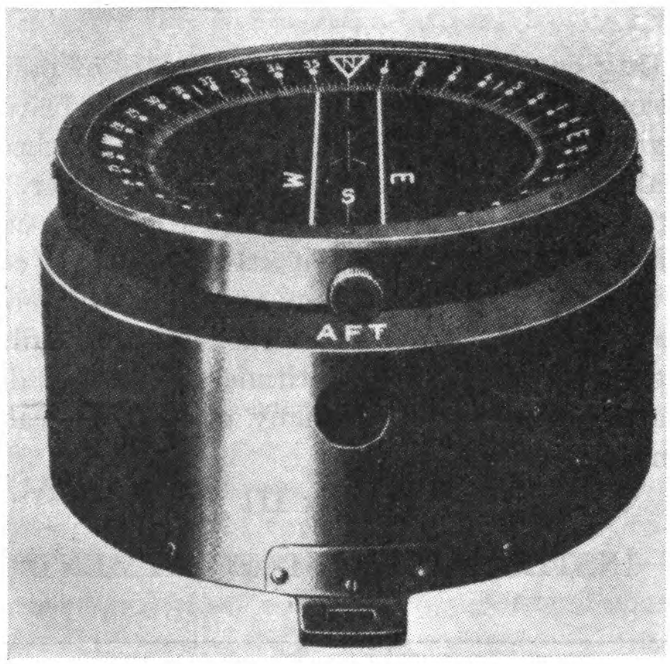

FIGURE 72.—Aperiodic compass.

b. Equipment.—The portable tools, such as drafting implements, computation tables, and charts, are considered equipment.

133. Instrument responsibility.—The navigator is responsible for knowing—

a. How to use indications of various instruments.
b. That instruments are functioning properly.
c. That instruments are properly alined and calibrated.

134. Aperiodic compass (fig. 72).—*a. Types.*—The precision navigator requires a compass that is steady but not sluggish. These requirements are fulfilled by the aperiodic type compass. Aperiodic means "without a period." When the needle is deflected from its position of equilibrium it returns to rest without appreciable overswing.

This is accomplished by the construction of radial arms or vanes attached to the card. They serve to break down skin friction between the liquid and the bowl and tend to prevent swirling of the liquid. The oscillation of the needle is thus dampened. Several variations of this type compass are in existence; some are vertically mounted and read horizontally, others are horizontally mounted and read vertically. All Air Corps models in current use are of the latter type. They are the D series compasses designed especially for the precision navigator, designated: D-4, D-7, D-12, D-13. Both the D-4 and the D-12 have 1° graduations on the azimuth ring. The D-7 and D-13 have 2° graduations on the ring and are smaller in size than the D-4 and D-12.

b. Setting and reading.—(1) *When to read.*—The compass should be read only when the airplane is in level flight and when the needle is at rest.

(2) *Position of eye.*—In order to avoid parallax when reading or setting the compass, the eye must be directly above the face of the compass. When observing the lubber lines, the eye must be in such a position that the lower lubber line coincides with the upper lubber line.

(3) *How to put airplane on course.*—First, set compass by rotating azimuth ring until desired heading is set directly on lubber line. Clamp locking screws. Recheck azimuth ring to be certain that no movement of ring occurred in clamping. Put airplane on the on-course heading by turning airplane with compass bowl about needle until north (arrowhead) end of needle points to N on azimuth ring. Continue to adjust heading of airplane until two parallel sighting wires are exactly parallel to needle. The airplane is now on course.

(4) *How to determine compass heading of airplane.*—The needle must be at rest. Rotate azimuth ring until N on azimuth ring is in juxtaposition to north end of needle. The parallel sighting wires must be made to parallel the needle. Clamp locking screws and recheck parallelity. Read compass heading from azimuth ring at lubber line.

(5) *Rotary bowl.*—Some aperiodic compasses have the bowl shock mounted on the base to reduce vibration of the mechanism. In this type, the bowl is not rigidly mounted to the base but can be moved within limits, in a rotary manner. Each side of the bowl has an arrow-like pointer attached which projects laterally out over the base. The base has a lateral mark under each pointer. The pointer must be kept in coincidence with the mark whenever the compass is being read.

135. Relationship between temperature, pressure, and den sity.—Both the sensitive altimeter and the air speed indicator ar pressure recording instruments. In order to understand how thes instruments are used and the meaning of their indications, it is firs necessary to be familiar with certain features of the atmosphere.

a. Atmosphere is the gaseous layer that envelops the earth. Thi layer of air is prevented from expanding infinitely into space by th force of gravity which tends to accumulate all of it at the surface of th earth. Equilibrium is established in accordance with the followin law: for each increase in height of 18,000 feet above sea level, th density of the atmosphere decreases by about one-half. This equilil rium is disturbed by movement of pressure areas, unequal heating o the atmosphere, and circulation of the atmosphere about the eartl so that the density at any given place is a constantly changin quantity.

b. The weight of the atmosphere exerts a force on the earth's surfac which is called atmospheric pressure. It can be shown that this pres sure on any given surface is equal to the weight of the column of ai above that surface. Therefore, atmospheric pressure varies with th density and the height of the column of air above the point at which i is measured. It is obvious that this pressure must decrease as th point at which it is measured increases in height above the earth' surface, since density decreases with height, and also the weight o the column of air above the point where it is measured is diminished b the weight of the column of air below this point. Atmospheric pres sure is measured by a barometer and usually is expressed in inches o millimeters of mercury.

c. The temperature is also a constantly changing quantity due t unequal heating and circulation of the atmosphere. Changes in tem perature affect the density and pressure according to the laws of gases The rate of change of temperature with height is defined as the laps rate. Ordinarily, there is an irregular variation in the first few thou sand feet, above which the temperature decreases with height at th rate of approximately 2° C. per 1,000 feet.

d. Thus it is seen that the three quantities, density, pressure, an temperature, are all constantly changing values, none of which i entirely dependent on the others, yet each of them is affected by vari ations in the values of the others. Therefore the atmospheric condi tions at a given place at a given time as recorded by measuring thes values would have little meaning unless there were available some standard basis for comparison. Furthermore, these values could not be compared relatively with readings made at a place of different elevation unless both sets of values could be compared to a standard. Such a standard has been arbitrarily selected and is known as the standard atmosphere. The standard atmosphere is that atmospheric condition in which a pressure of 29.92 inches and a temperature of +15° C. exists at sea level, and the temperature lapse rate is 2° C/1,000 feet.

e. In the standard atmosphere there is a definite relation between pressure and elevation, and from this relation pressure at any height may be converted into elevation above sea level. Unfortunately, however, the conditions of the standard atmosphere seldom exist. The relation between pressure and elevation under existing conditions changes from the value of this relation in the standard atmosphere as the values of the existing pressure, temperature, and lapse rate depart from their values in the standard atmosphere. Under existing conditions, to convert pressure into elevation above sea level a correction must be applied to the value of the elevation found from the standard pressure height relation. This correction depends on the variation of the existing values of pressure, temperature, and lapse rate from their values in the standard atmosphere. It is usually determined by a computer which uses as arguments the mean pressure and temperature of the air column below the point of observation.

136. Sensitive altimeter.—*a. General.*—(1) This instrument is an aneroid cell connected by linkage to pointers on a scale. Atmospheric pressure acting upon the cell causes the pointers to move on the face of the scale. The linkage is so set that pressure is converted into feet of altitude on the scale, in conformity with the conversion scale of pressure and elevation in the standard atmosphere. The linkage makes the proper conversion only when the temperature lapse rate is normal. For any other condition, indications of the instrument must be corrected for the departure of the lapse rate from normal.

(2) In flight it is seldom possible for the navigator to measure the mean temperature and the mean pressure. He can record the temperature and the pressure at the elevation of his instruments and assume these quantities to be proportionately representative of the mean value. This is sufficiently accurate for practical navigation.

b. To read pressure from altimeter.—Set the indices to zero or the barometric scale to 29.92 inches. The instrument is now a conversion medium equivalent to the pressure altitude conversion table and indicates the pressure of the atmosphere in feet of altitude at the elevation of the instrument. This figure is called pressure altitude.

For precision navigation purposes it is used with temperature in air speed calculations. When set in this manner the altimeter does not indicate elevation except in a standard atmosphere.

c. To read altitude (elevation) from altimeter.—A clock that is wound but not set will indicate the lapse of time but it will not tell time. So an altimeter will indicate change in altitude but before it can indicate elevation it must be set so that existing pressure conditions are referred to the datum of the standard atmosphere. The datum is sea level, and the pressure conditions must necessarily be those that exist at sea level. For places of an elevation not sea level, sea level pressure is calculated as a theoretical pressure. The actual pressure for any elevation, reduced to what it would theoretically be at sea level under normal temperature conditions, is called altimeter setting. Altimeter setting is expressed as pressure in inches of mercury. When the barometric scale on the altimeter is set to the altimeter setting, then actual pressure conditions are referred to the datum. Now the pointers of the altimeter indicate altitude (elevation) above sea level, provided temperature conditions are normal. This reading is known as indicated altitude. Mechanical errors in the instrument itself sometimes make it necessary to calibrate the instrument. These errors are usually small. After they have been applied to indicated altitude, the result is called calibrated altitude. Calibrated altitude must be combined with the air temperature at which the indicated altitude was recorded to determine true altitude above sea level (see par. 145*c*). In precision navigation true altitude is needed to find absolute altitude. Absolute altitude is the true height above the earth's surface and is found by properly combining the true altitude of the airplane with the altitude of the surface over which the plane is flying. Absolute altitude is used when determining ground speed by timing.

137. Air speed meter.—*a. Indicated air speed.*—This instrument also contains an aneroid cell connected by linkage to a pointer on a scale. Atmospheric pressure is conducted by a static tube to the space in the instrument case around the cell. Dynamic pressure resulting from the forward speed of the airplane is conducted by the pitot tube to the interior of the cell. This pressure overcomes the static pressure, actuates the linkage, and causes the pointer to indicate the pressure differential in units of miles per hour. The linkage is designed so that indications are true only when the density of the air is equal to the sea level density of air in the standard atmosphere. Conditions at flight level are frequently other than these. Therefore, the indicator will seldom indicate true air speed. The figure it does indicate is called indicated air speed.

b. Calibrated air speed.—Unfortunately, errors in the scale and linkage, leaks in the tubes, and burbling of air around the external opening of the pitot and static tubes do not permit actual existing pressures to be registered on the air speed meter. The instrument must therefore be calibrated. This process is called calibrating the air speed meter installation. By applying the calibration corrections to the indicated air speed, calibrated air speed is determined. Stated in simple words, calibrated air speed is what an air speed meter would read if it were a perfect meter. The procedure to calibrate the air speed meter will be described in due course.

c. True air speed.—A perfect meter will not indicate true air speed except when the existing air density is the same as the density at sea level in the standard atmosphere. Under other conditions true air speed must be determined by applying a correction to the calibrated air speed. This correction is usually applied by means of a computer which uses flight level pressure altitude and air temperature. (See par. 145*d*.)

d. True air speed meters.—True air speed meters, as the name implies, indicate the true air speed of the airplane provided no installation or instrumental errors exist. No air density correction is necessary. These meters will undoubtedly replace current types in future airplanes.

138. Air temperature thermometer.—This meter indicates the free air temperature at the elevation of the airplane. The scale of the instrument is graduated in degrees centigrade.

139. Suction gage.—The suction gage is an instrument which indicates the amount of suction in the vacuum system actuating air driven gyroscopic instruments. The gyro instruments used by the navigator are the gyrostabilized drift meter, type B-3, which requires a suction of 3½ to 5 inches of mercury; and some experimental types of aircraft octants. The suction gage is similarly used for flight instruments of the gyro type.

140. Drift meter.—There are several types of drift meters currently installed in Army aircraft. Most installations are the types B-2 and B-3. The B-3 is the more common of the two. The main point of difference between the B-2 and B-3 is that the latter is gyro stabilized whereas the former is not; otherwise, the operation, use, and alinement are identical. The B-3 drift meter is referred to throughout this paragraph.

a. Description (fig. 73).—The type B-3 drift meter is a device for measuring drift and taking visual bearings. It provides the navigator with the drift correction necessary to keep the aircraft on course and with values necessary in computing ground speed. The drift may be measured either by sighting vertically down or by sighting back, or by using these motions to follow signal devices dropped from the aircraft. The drift meter is capable of measuring drift up to and including 20° right and left and azimuth through 360°. Drift greater

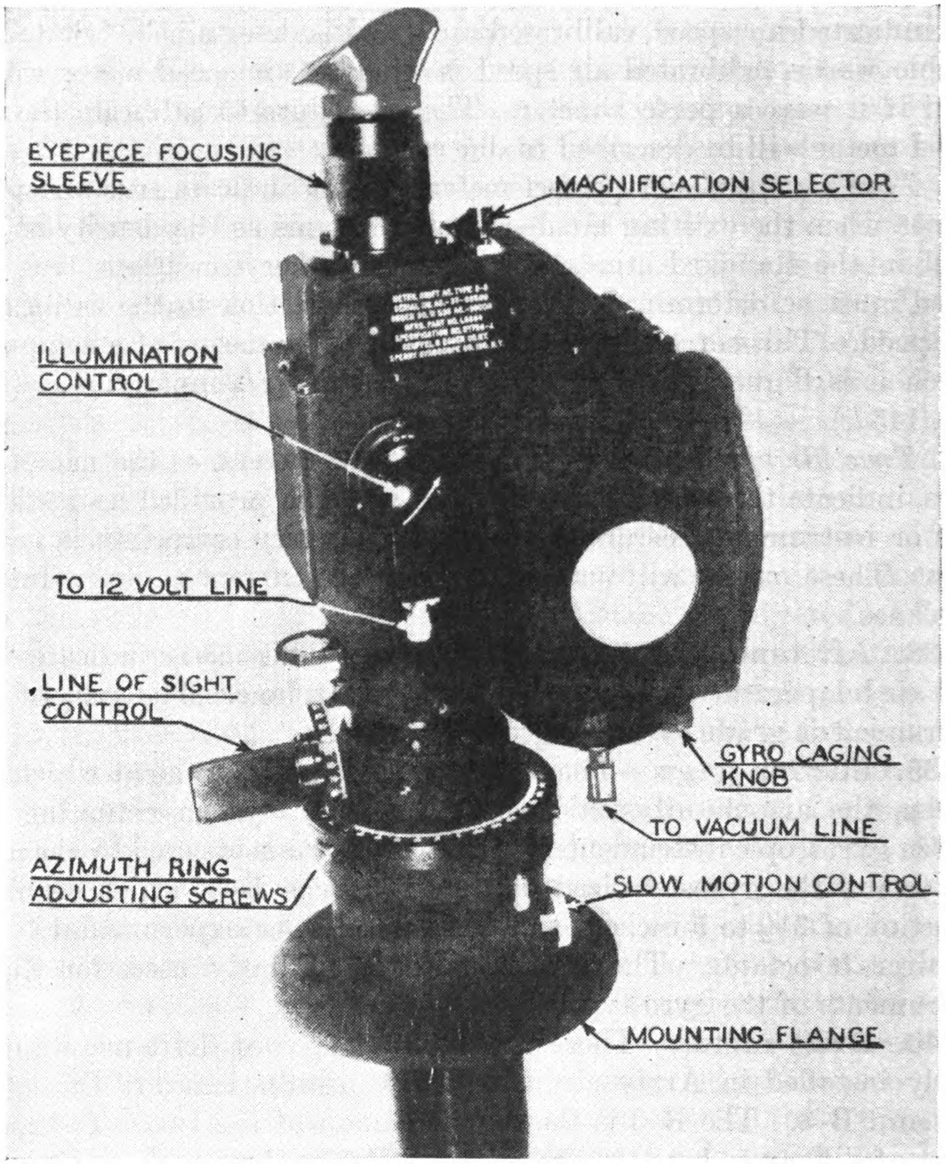

FIGURE 73.—Drift meter, type B-3.

than 20° is read on the azimuth scale. The line of sight is movable from 15° forward to 85° to the rear of the vertical with a full field of 25°. An air driven self-erecting gyroscope supports the reticle so that when the instrument is tilted the reticle and the image of the ground will be in sight and move in the same direction and the same amount as when the instrument is vertical. An optical system is mounted in the drift meter, the image being erect, and having a magnification of 1X and 3X. The drift meter has a minimum length of 3 feet 9 inches over-all, and is so constructed that sections of any desired length up to 5 feet may be readily inserted.

b. Operation.—(1) The vacuum supply is turned on before take-off to start the gyro. The gyro caging knob is located under the gyro housing. The gyro should be caged when not in use, during turns, and particularly on the take-off and landing. Allow 3 to 5 minutes for the gyro to come up to speed and then uncage it when the airplane is in level flight. After uncaging, allow 5 minutes for the gyro to erect itself before making ground speed measurements.

(2) After an appreciable change of course, the gyro is apt to be slightly displaced from the vertical, and a few minutes should be allowed for it to erect itself before taking observations. If the drift meter is tilted more than 20° from the vertical in any direction, the gyro will strike its limit stops, causing precessional forces to be generated which will render its indications erroneous for several minutes until the gyro has had time to erect itself. For this reason the instrument should always be caged preparatory to engaging in maneuvers which might exceed these limits, and uncaged when the airplane is in normal flight.

(3) The meter rotates on bearings in the mounting flange assembly, the angle of rotation being read on either the drift or azimuth scales. Slow motion and locking are provided by the worm and gear operated by the slow motion control. For rapid rotation, the worm gear knob may be pulled back, thus unmeshing the worm.

(4) The line of sight is shifted from 15° forward to 85° back of the vertical by means of the line of sight control, the angle of the center of the field being read on the attached scale. Detents are provided at the vertical position (0°), at 50°, and at 70.9°.

(5) Change in magnification from unit power to three power is accomplished by loosening the locking pin of the magnification selector and positioning the arm to the power required.

(6) The reticle is illuminated for night use by a lamp (readily replaceable) located on the forward side of the gyro housing. The socket for connection to the 12–14 volt line and the rheostat for varying the brightness are located on the rear of the meter. Although an off switch is incorporated in the rheostat, an external switch is desirable.

c. To determine drift.—(1) Set the line of sight control to zero. Rotate the meter until the drift lines are parallel to the apparent mo-

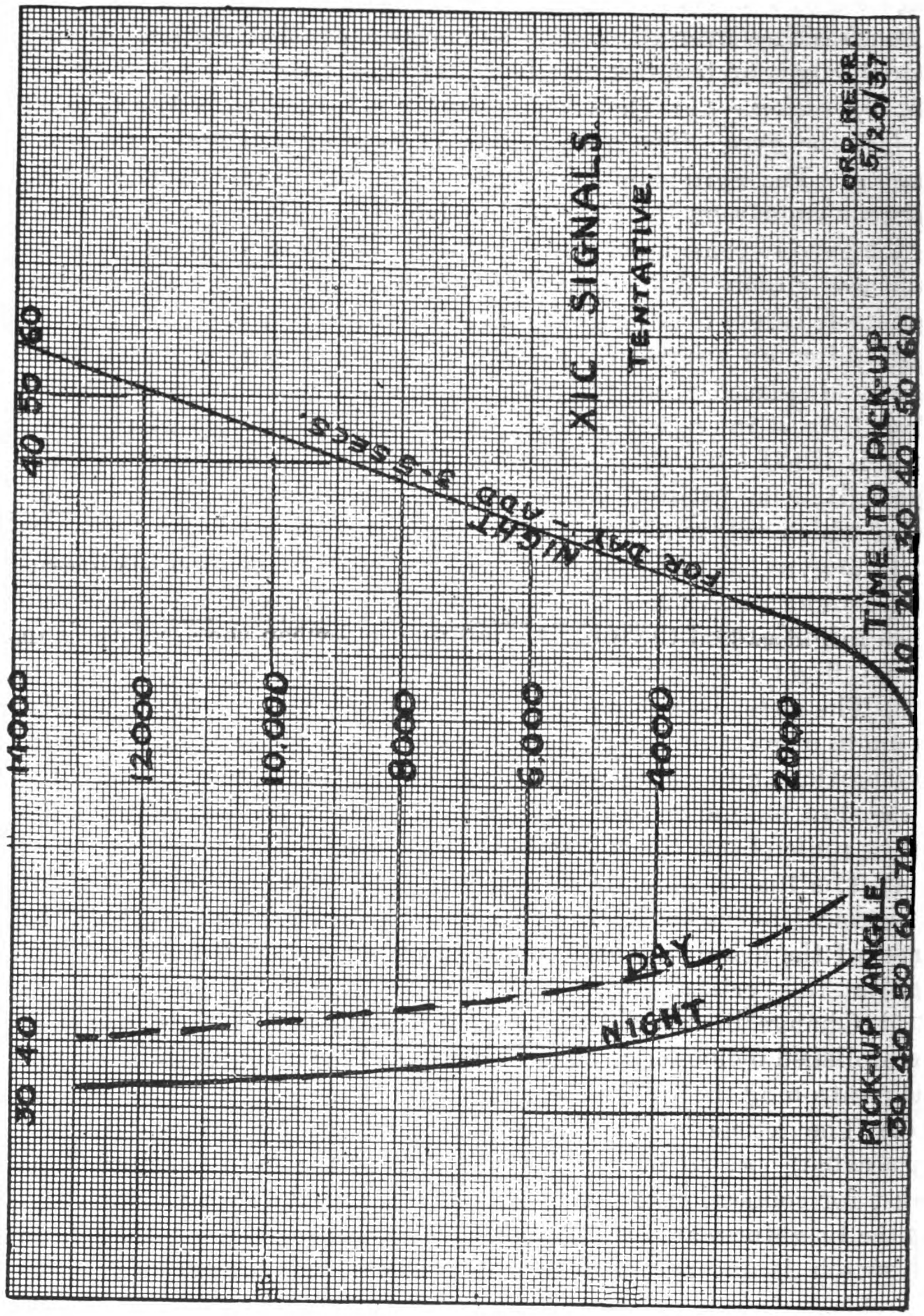

FIGURE 74.—Time and pick-up angles, XIC signals.

tion of ground objects and read drift on the drift scale. Either the central or any of the side drift lines may be used. Over water or over land on which there are few prominent or readily identifiable objects to follow along the drift lines, the eye should be held stationary, i.e., fixed on the reticle, and the general movement of the background observed without attempting to follow any one ground object.

(2) A method frequently usable, which requires somewhat more time for measurement, is to pick up, with the line of sight at zero, some object which appears in the center of the reticle system and follow it back some 50° or 60°, keeping the center of the reticle on the object. This amounts to taking a bearing on an object which has passed vertically below the airplane. In using this method, only the center of the reticle system must be used.

(3) To determine drift over smooth water or at night, a drift signal is dropped from the aircraft and the smoke or light picked up in the meter. To facilitate the pick-up, the line of sight is set at the approximate angle given in the curves on figure 74. When the signal is seen in the meter, the instrument is turned until the signal is in the center of the reticle system. In day use, the smoke is seen as a sharp pointed cone. The point of the cone, which is the location of the source of smoke, is the part to be centered in the reticle system.

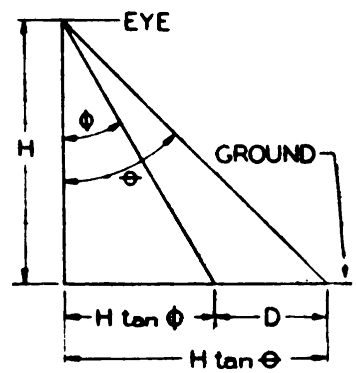

FIGURE 75.—Ground speed by timing, trail angle method.

d. Relative bearings.—Relative bearings of terrestrial objects are determined by rotating the meter and operating the line of sight control handle to put the object on the center of the reticle or on the central vertical line. Bearings are read on the azimuth scale against the inner index line.

e. Ground speed, trail angle method.—(1) By measuring the time for any ground object to pass over a convenient angle, the ground speed may be determined by formula. The principle of this method is illustrated in figure 75.

$$\text{Ground speed} = \frac{H \times (\tan\theta - \tan\phi) \times k}{t}$$

H = absolute altitude (feet).
t = time in seconds.
ϕ = angle back of the vertical that timing was started.
θ = angle at which timing was stopped.
k = A constant whose value depends on whether the ground speed is desired in knots or statute miles.

The constant used in the above formula is not the factor appearing in figure 76 ① and ② as will be shown.

The values of k and the tangent differences may be combined. The formula then becomes

$$G.\ S. = \frac{H \times \text{factor}}{t}$$

All values on this formula are the same as those in the one given above except that the factor equals $(\tan \theta - \tan \phi) \times k$. The values of this

FACTORS FOR GROUND SPEED BY TIMING $\frac{\text{NAUTICAL MILES}}{\text{HOUR}} = \frac{\text{ALTITUDE (FEET)}}{\text{TIME (SECONDS)}} \times \text{FACTOR}$						
START / FINISH	* 0°	10°	20°	30°	40°	50°
5°	.052					
10°	.104					
15°	.159	.054				
20°	.216	.111				
25°	.276	.172	.061			
30°	.342	.238	.126			
35°	.415	.310	.199	.073		
40°	.497	.392	.281	.155		
45°	.592	.488	.377	.250	.095	
* 50°	.706	.601	.490	.364	.209	
55°	.846	.741	.630	.504	.349	.140
60°	1.026	.922	.810	.684	.529	.320
65°	1.270	1.165	1.054	.928	.773	.564
* 70.9°	1.706	1.602	1.490	1.364	1.209	1.000
* B-3 DRIFTMETER HAS DETENTS AT THESE ANGLES						

① Ground speed in knots.

FIGURE 76.—Tables of factors for ground speed by timing.

factor are contained in the tables shown in figure 76. A practical example of the use of this formula is given in paragraph 145*g*.

(2) Thus, if timing is started at 0° and ended at 50° (these two angles are marked by detents in the line of sight control), the ground speed in knots is equal to the absolute altitude in feet divided by the

time in seconds and multiplied by .706 (from fig. 76). If θ is 70.9° and ϕ is 50° (both marked by detents), the factor for knots is one, and ground speed in knots is equal to the absolute altitude in feet divided by the time in seconds.

(3) Two of the three detent positions are normally used as the starting and stopping angles during the timing operation because these angles may be "felt." The table in figure 76 contains the values of (tan θ − tan ϕ) × k for the detent positions and also for several

FACTORS FOR GROUND SPEED BY TIMING

$$\frac{\text{STATUTE MILES}}{\text{HOUR}} = \frac{\text{ALTITUDE (FEET)}}{\text{TIME (SECONDS)}} \times \text{FACTOR}$$

FINISH \ START	* 0°	10°	20°	30°	40°	50°
5°	.0596					
10°	.1202					
15°	.1827	.0625				
20°	.2482	.1280				
25°	.3179	.1977	.0697			
30°	.3937	.2735	.1455			
35°	.4774	.3572	.2292	.0837		
40°	.5721	.4519	.3239	.1784		
45°	.6818	.5616	.4336	.2881	.1097	
*50°	.8126	.6924	.5644	.4189	.2405	
55°	.9737	.8535	.7255	.5800	.4016	.161
60°	1.181	1.062	.9328	.7873	.6088	.369
65°	1.462	1.342	1.214	1.068	.8900	.650
*70.9°	1.9	1.846	1.716	1.571	1.393	1.152

* B-3 DRIFTMETER HAS DETENTS AT THESE ANGLES

(2) Ground speed in miles per hour.

FIGURE 76.—Tables of factors for ground speed by timing—Continued.

other starting and stopping angles. There is rarely any occasion for using starting and stopping angles other than those contained in figure 76. However, the value of the factor for any angles of starting and stopping may be readily found by substituting the proper angular values in the formula (tan θ − tan ϕ) × k, where θ is the stopping angle, ϕ the starting angle, and k is .592 if the G. S. in knots is desired, and .681 if the G. S. in m. p. h. is desired.

(4) It is sometimes easier to pick up a ground object for the purpose of timing if the drift meter is rotated 180° so that the line of sight is projected forward. Then objects seen at the forward angles of 70.9° and 50° (the detent angles) can usually be followed backward until they are directly under the airplane at the zero angle. The factors are the same whether the sight is forward or backward.

(5) It will be noted that at the usual navigation altitudes the drift signals are picked up at between 35° and 48° so that the second pair of detents may be used conveniently to determine ground speeds.

f. Ground speed, zero angle method.—(1) On many B–3 drift meters, the reticle is marked with three transverse wires. The center one has already been described and is common to all B–3 meters. The other two wires are parallel to the center transverse wire, equidistant from it, and lie one on each side toward the front and rear of the field. Any two of the three transverse wires may be used to determine ground speed. It is customary to use the front and rear wires although the center wire and one of the others may be used equally as well, as will be explained. This method is particularly adapted for determining ground speed over water when a wave or sparkle of sunlight can be timed for a relatively short period only, and when the light and visibility conditions prevent the use of the trail angle method.

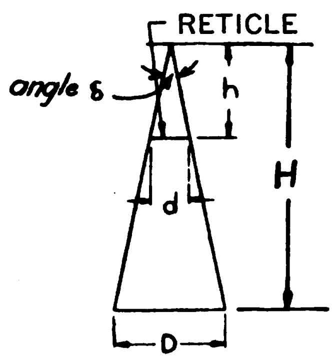

FIGURE 77.—Ground speed by timing, zero angle method.

(2) With the drift set off on the azimuth scale and the trail angle set at zero, time the passage of an object from the first ground speed wire to the third (and last) wire. The G. S. in knots is then solved by the formula:

$$G.S. = \frac{H \times K'}{t}$$

where H = absolute altitude in feet.
t = time of passage in seconds.
K' = a constant explained below.

(3) From inspection of figure 77,

$$\frac{D}{H} = \frac{d}{h} \text{ or } D = H \times \frac{d}{h}$$

where D = ground distance subtended by angle.
H = absolute altitude.
d = distance between front and rear transverse wires.
h = distance between eye and the reticle.

(4) The quantity $\frac{d}{h}$ is a constant. If not known it may be determined as described in paragraph 151*d*. Then substituting the value *D* from the above formula in the time-speed-distance formula:

$$\text{velocity}=\frac{\text{distance}}{\text{time}}$$

$$G.\ S.\ \text{in ft./sec.}=\frac{H}{t}\times\frac{d}{h}$$

$$G.\ S.\ \text{in knots}=\frac{H}{t}\times\frac{d}{h}\times.592$$ where .592 is the conversion factor of ft./sec. to knots.

$$\text{Let } K'=\frac{d}{h}\times.592$$

$$\text{Then } G.\ S.\ \text{in knots}=\frac{H}{t}\times K'$$

(5) The value of $\frac{d}{h}$ for most B-3 drift meters is .299.

$$\text{Then } K'=.299\times.592=.177$$

(6) Then the *G. S.* formula for a B-3 drift meter whose value of $\frac{d}{h}=.299$ becomes

$$G.\ S.\ \text{in knots}=\frac{H}{t}\times.177$$

(7) Due to coarse tolerances in the specifications for the etching of the ground speed wires on the reticle, the ground speed wires are not the same distance apart on all B-3 drift meters and the constant is not identical for each meter. See paragraph 151 *d* for determination of the constant *K′* for each instrument.

(8) This method can also be used by timing an object from the front wire to the center or from the center to the rear. In either case multiply the time by two and use as in formula given in (6) above.

141. Aircraft pelorus, type A-2 (fig. 78).—*a. Description.*—(1) The type A-2 pelorus is an instrument designed to measure bearings of celestial and terrestrial objects. It consists of a simple type of collimator rotatable in a housing mounted in gimbals for leveling. The assembly is mounted in the airplane on a mounting plate securely bolted to the airplane structure. This plate is mounted with the slot or keyway parallel to the center line of the airplane, thus putting the fixed lubber lines of the pelorus on this line. Means are provided for leveling the instrument, for rotating and elevating the collimator, and for measuring the angle of rotation.

(2) For terrestrial and low altitude celestial objects, the object is viewed through the glass plate (A) and the shade glasses, if necessary, and the plate rotated until the reflected image of the reticle is seen on the object. For high altitude objects, the observer looks straight down through the plate (A) seeing the reticle direct and a reflected image of the object.

(3) The clamp (B) locks the scale (movable by means of four short pins) and clamp (C) locks the collimator assembly. Illumination of the reticle is provided (12–14 volts) through the socket (D) and brightness by the rheostat (E). The screw (H) (two) serves to fasten the instrument to the mounting plate.

(4) To replace the light bulb, unscrew the collar (I) and pull the lamp support assembly straight out. It is not necessary to unsolder any wiring.

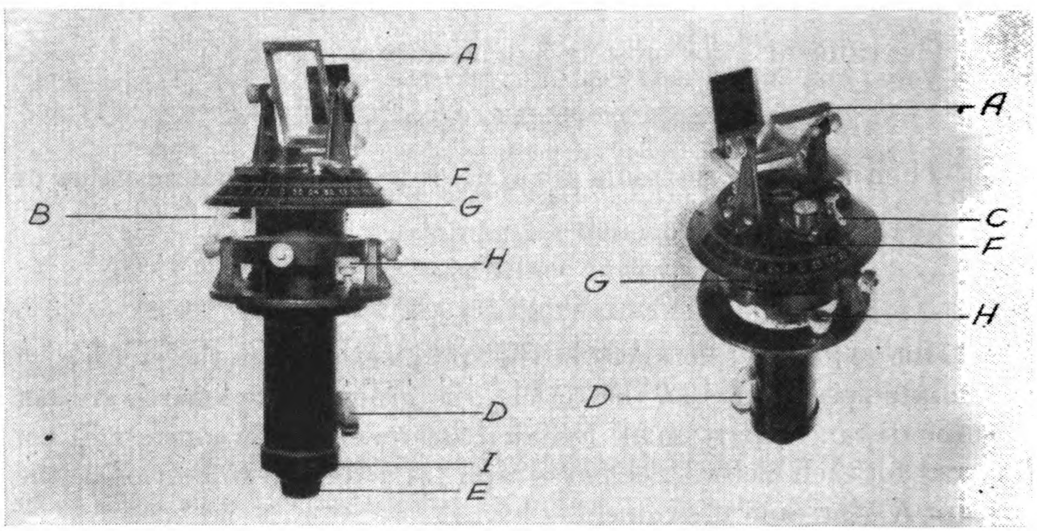

FIGURE 78.—Pelorus, type A–2.

b. Operation.—(1) To use the instrument, plug into the 12-volt circuit and adjust rheostat to full brightness.

(2) Loosen clamp (B), set zero of scale on rear index (G), and tighten (B).

(3) Level instrument, loosen clamp (C), and rotate upper assembly until object is seen through plate (A) in line with the bubble and the center of the filter plates (bubble toward the observer). Tilt plate (A) slowly until cross wires are seen, adjust brightness of reticle, and set vertical line on object.

(4) To read azimuth, set scale to true heading on fixed index (G) and azimuth will be shown against index (F).

(5) To measure relative bearings, set zero of scale on (G) and read on (F), or set 180° of scale on (G) and read on index under filters.

(6) To measure reverse bearings, set zero of scale on (G) and read on index under filters, or set 180° of scale on (G) and read on (F).

142. Flight instruments.—The navigator frequently makes use of the flight instruments and controls. In general, their indications are checked to determine that the airplane is in level flight before reading the navigation instruments. Some of the uses to which the turn indicator and automatic flight control equipment are put are as follows:

a. Turn indicator.—The pilot uses this instrument to—

(1) Make accurate turns, the amount of which has been predetermined by the navigator (as in a double drift maneuver).

(2) Maintain a steady heading, while the navigator reads the compass heading or records a relative bearing.

b. Automatic flight control equipment.—(1) Some installations of this equipment have a control, remoted to the navigator's position, by means of which he can—

(*a*) Control the heading of the airplane with reference to his compass.

(*b*) Make changes in heading that may be necessary for a navigational problem.

(2) If no remote control is available, the pilot performs these operations on instructions from the navigator.

143. Equipment.—The following equipment is required by the precision navigator. The list will require revision from time to time to keep pace with the change in methods and instruments. This equipment has been approved for issue as a kit, navigation, dead reckoning, on a basis of three per light bombardment squadron, one per medium and heavy bombardment and reconnaissance airplane. Note that the pelorus, aircraft, type A-2, is issued in this kit; it has previously been described in paragraph 141 as it may be considered as being permanently installed in the airplane.

a. Air Corps property.

(1) *Classification 05-A.*

		Quantity
Computer (assembly), aerial dead reckoning, type E-6 B, spec. 27892	each	1
Pelorus, #36D3430, type A-2	do	1
Watch, type A-7, spec. 27748, time and stop, wrist, 15 jewel	do	1
Watch type A-8 spec. 27749, stop, pocket, 10 second revolution dial 5 minute register, 7 jewel	do	1

(2) *Classification 25.*

		Quantity
Case, carrying, for holding the items in the navigator's dead-reckoning kit	each	1
Compass, fixed needle, pen and pencil point, drafting, 6-inch, type B-2, spec. GG-I-531	each	1
Divider, drawing, steel, hairspring, 6-inch, type B-3, spec. GG-I-531	do	1
Protractor, circular, transparent, 360°, graduated to ½°	do	1

		Quantity
Pencils, lead, drafting, black, hexagonal, grade 3H	each	2
Rule, parallel, ebonized boxwood, 15-inch, #1193 or equal	do	1
Scale, flat, draftsman, 14-inch, boxwood, both sides beveled, one bevel graduated to ⅛-inch graduations, other bevel plain white	each	1
Spline, transparent, drafting, 24-inch	do	1
Triangle, transparent, 45°, 6-inch, spec. GG-T-671	do	1
Triangle, transparent, 30° by 60°, 8-inch, spec. GG-T-671	do	1

(3) *Classification 29.*

Sheet, paper, garnet, class A, No. 2/0, spec. P-P-121 (sandpaper for sharpening pencils)	each	1

(4) *Classification 30.*

Blank forms.

Great Circle.
H. O. 211 (Ageton)
Navigator's Log, A. C. Form #26A.
Mercator.
Radio message.

Books.

C. A. Bulletin #11—Directory of Airports and Seaplane Bases.
TM 1-205, Air Navigation.
H. O. 205, Radio Aids to Navigation.
H. O. 9, Part II.
H. O. 211 (Ageton).
American Air Almanac or Nautical Almanac (current year).
T. O. 08-15-1, Radio Facilities Charts.
T. O. 08-15-2, Radio Data and Aids to Airways Flying.

Maps and charts.

Complete set of Department of Commerce Regional Charts.
Complete set of Department of Commerce Sectional Charts.
Complete set of Radio Direction Finding Charts.
H. O. Aircraft Plotting Sheets, VP-3, 4, 5, 6, covering latitudes 18°-56°, 10 of each sheet.
H. O. chart #526, Gulf of St. Lawrence to Strait of Juan De Fuca, including Gulf of Mexico, Caribbean Sea, and Panama Canal.
H. O. chart #1400 *a*, Pilot Chart of the Upper Air, North Atlantic Ocean.
H. O. #1401 *a*, Pilot Chart of the Upper Air, North Pacific Ocean.
H. O. charts #3000 *e, f, g, h, j*, covering latitudes 24°-53°, 10 of each sheet.
U. S. C. & G. S. chart #3060 *a*, Aeronautical Planning Chart of the U. S., Lambert conformed conic projection, showing principal cities, airports, and radio-broadcasting stations.
U. S. C. & G. S. chart #3074, Great Circle Chart of the U. S., gnomonic projection showing selected airports along air routes.
U. S. C. & G. S. chart #3077, Magnetic Chart of the U. S., showing the lines of equal magnetic variation in the United States.

Tables.

Altitude-Pressure—Feet-Inches.
Wind Force & Direction by Double Drift.
Gas consumption data.

Tables—Continued.

Ground Speed Factors: by Double Drift; by Timing.
Off-course Corrections.
Radio Bearing Conversion.
Time Tick Schedule and Frequency.
Ground Speed and Drift (wind angle from true course).

b. Quartermaster Corps property.

		Quantity
Bands, rubber, #32, spec. ZZ–B–11	each	25
Clips, paper, wire, gem pattern, steel, type I, class A, spec. FF–C–436	do	100
Eraser, pencil rubber (ruby #224 or equal)	do	1
Tacks, thumb, stamped steel, ⅜ inch, type III, spec. FF–T–311	do	100

c. Signal Corps property.

Batteries, BA–30, #3A30	each	4
Flashlight, TL–122A, #6Z4002A	do	1

144. Watches.—*a. Watch, time and stop, type A–7.*—For dead reckoning purposes any fairly accurate timepiece is sufficient. The airplane clock may be used provided it can be read conveniently from the navigator's position. The inclusion of a second timepiece is a safety precaution in event of failure of one of them. The type A–7 watch or any substitute fulfills this need. The stop feature of this watch is convenient for recording elapsed time.

b. Watch, type A–8.—This stop watch is especially designed to record short lapses of time to the tenth of a second. This feature is required for ground speed determinations by timing and for air speed calibration flights.

145. Computer, type E–6B (figs. 79 and 92).—*a. Description.*—The type E–6B dead reckoning computer is a circular slide rule and a device for solving the vector problems encountered in dead reckoning.

(1) The slide rule face of the computer may be used for solving problems involving—

Time-speed distance.
Multiplication, division, and proportion.
True air speed from calibrated air speed.
True altitude from calibrated altitude.

On the E–1 series of computers the slide rule face is practically identical with that of the E–6B. Problems involving the above factors are solved in the same way on either computer.

(2) The face used in solving vector problems consists of a transparent plotting disk integral with a graduated compass rose which can be rotated by the fingers, and a slide having concentric speed circles, radiating drift lines, and a rectangular grid printed on it, which fits in the metal frame and can be adjusted so that the slide

chart is seen through the plotting disk. The use of the vector face of the computer is described in section V.

b. Speed-time-distance.—The following are examples of the various speed-time-distance conversion computations that can be solved with the type E-6B computer:

(1) *Example 1* (fig. 79).

Given: Ground speed 180 knots.
Time of flight 35 minutes.

Find: Distance traveled.

Solution: Set the speed index (heavy arrowhead-shaped mark on rotating plate) opposite 180 (18) on the outer miles scale. Opposite 35 on the minutes scale read the distance traveled on miles scale.

Answer: 105 nautical miles.

(2) *Example 2.*

Given: Ground speed 180 knots.
Distance to travel 210 nautical miles.

Find: Time required to fly distance.

Solution: Set speed index to 180 (18) on mile scale. Opposite 210 on miles scale read 70 (7) on minutes scale or 1 hour 10 minutes (1:10) on hours scale (innermost continuous scale).

Answer: 1 hour 10 minutes.

(3) *Example 3.*

Given: Distance traveled 240 nautical miles.
Elapsed time 1 hour 20 minutes.

Find: Ground speed.

Solution: Set 1 hour 20 minutes (1:20) on hours scale opposite 240 (24) miles on miles scale. Opposite speed index read ground speed on miles scale.

Answer: 180 knots.

(4) *Example 4.*

Given: Distance 220 nautical miles.

Find: Equivalent distance in statute miles and kilometers.

Solution: Set 220 (22) miles on rotating disk opposite index marked "NAUT." Opposite indices marked "STAT" and "KM" read statute miles and kilometers, respectively.

Answer: 254 statute miles, 407 kilometers.

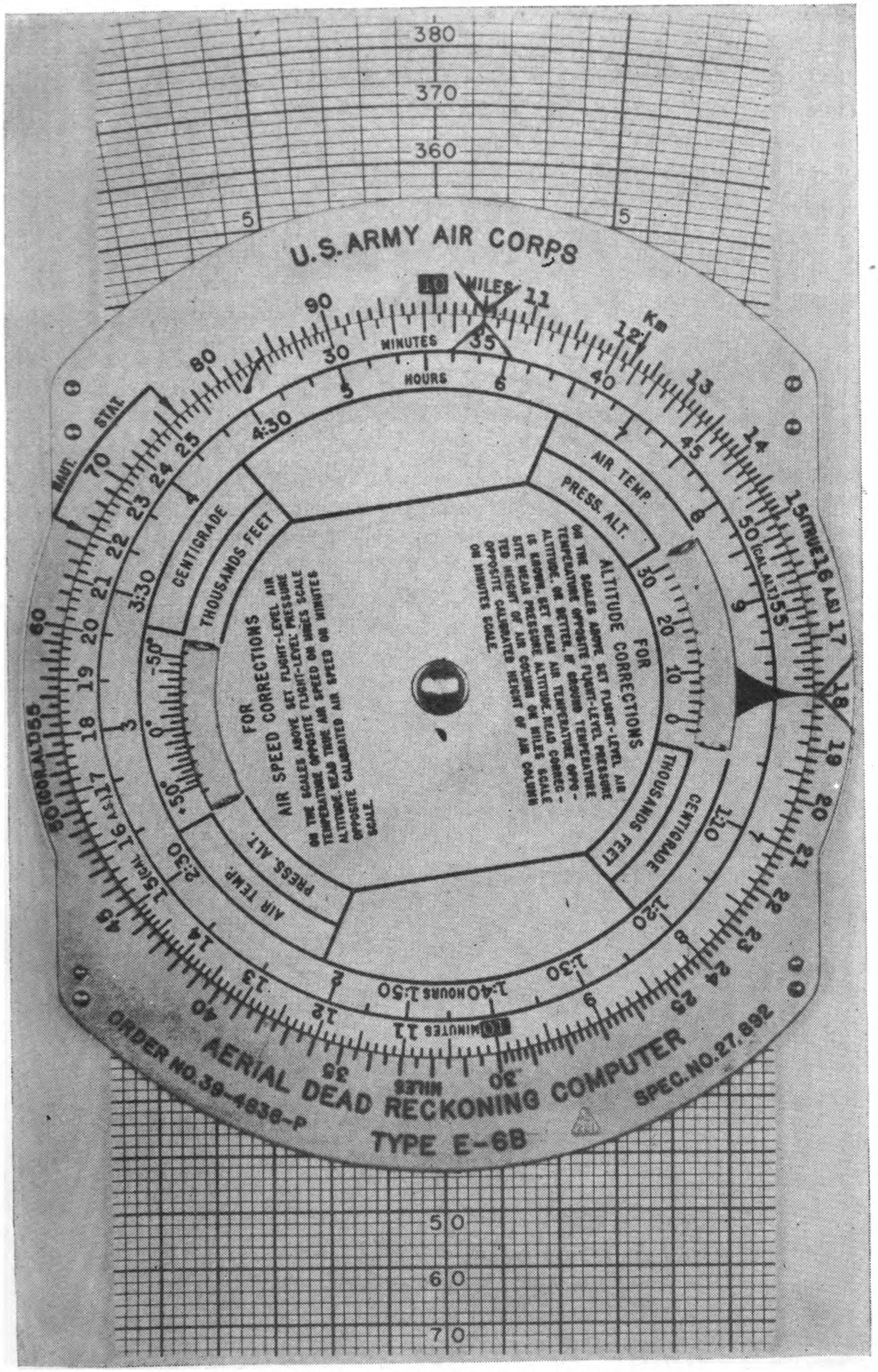

FIGURE 79.—Example 1 (par. 145b).

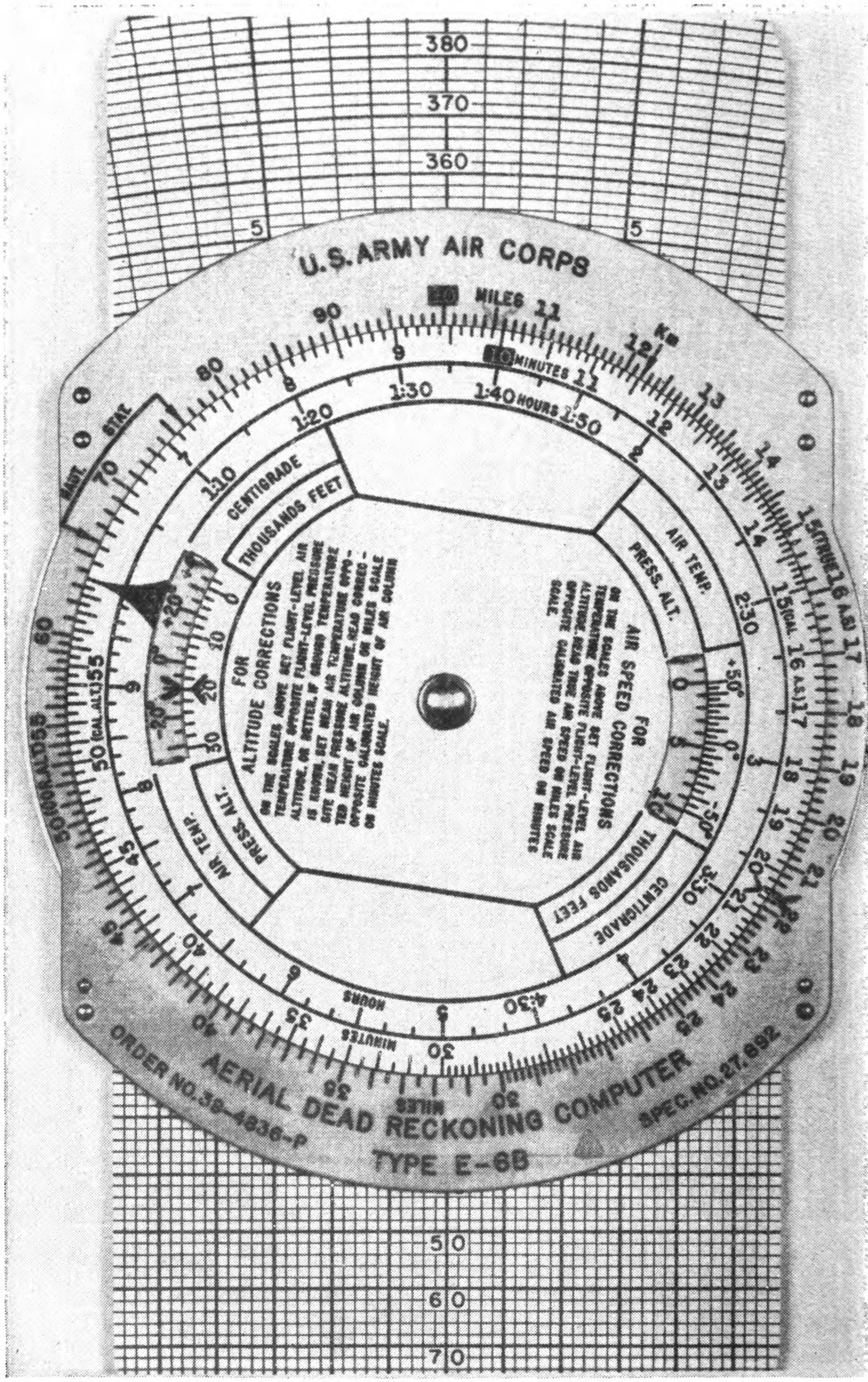

FIGURE 80.—Example (par. 145c).

c. To find true altitude.

Example (fig. 80).

Given: Indicated altitude, 20,450 feet. (Reading of instrument with atmospheric pressure scale set in accordance with altimeter setting.)

Air temperature aloft −10° C.

Pressure altitude, 20,000 feet. (Reading of instrument with atmospheric pressure scale set to 29.92 inches.)

Find: True altitude.

Solution: Set pressure altitude 20,000 feet (20) opposite temperature aloft, −10° C., which appears in air temperature cut-out. Opposite indicated altitude on minutes scale read true altitude above sea level on miles scale.

Answer: 21,650 feet.

NOTE.—Due to the small scale of the computer and the fact that the difference between pressure altitude and indicated altitude will normally be less than 1,000 feet, it is considered practical to keep the altimeter set by the broadcast altimeter setting and use the indicated altitude to set opposite the temperature aloft. Where extreme accuracy in altitude is desired, a special altitude correction computer, type C–1, is recommended.

d. To interconvert calibrated and true air speed.

(1) *Example 1* (fig. 81).

Given: Calibrated air speed, 200 knots.

Pressure altitude, 20,000 feet.

Air temperature aloft, −10° C.

Find: True air speed.

Solution: Adjust the rotating disk to bring the temperature, −10° C., opposite the figure 20 (20,000 feet) which appears in the pressure altitude cut-out. Opposite 200 (20) on the minutes scale read the true air speed on the miles scale.

Answer: 282 knots.

(2) *Example 2.*

Given: Temperature aloft, +26° C.

Pressure altitude, 125 feet.

True air speed, 162 knots.

Find: Calibrated air speed.

Solution: Set temperature +26° C. opposite pressure altitude 125 feet in cut-out. Opposite 162 knots true air speed on the miles scale read 158½ knots calibrated air speed on the minutes scale.

NOTE.—Except when calibrating the air speed meter it is practical to follow instructions in the note in paragraph 145*c*. It will be found that by using the indicated altitude instead of the pressure altitude, a difference of 1 to 2 miles in the true air speed may result. The assumption does not seriously affect the

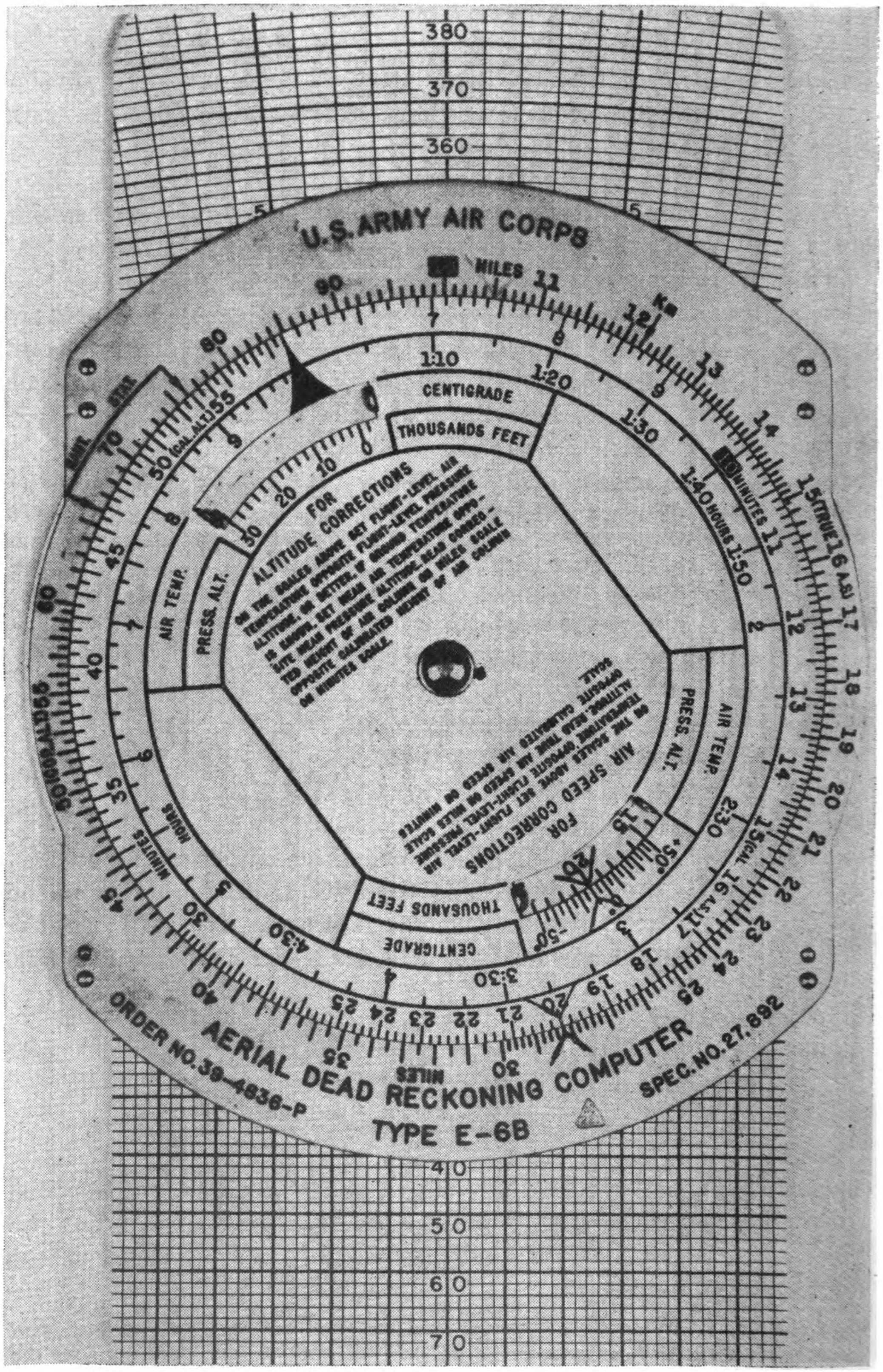

FIGURE 81.—Example 1 (par. 145*d*).

accuracy of the dead reckoning because it is doubtful that the air speed meter can be read within limits which justify taking the error into account.

e. Fuel consumption.

(1) *Example 1.*

Given: Fuel consumed, 175 gallons.
Elapsed time, 2 hours 04 minutes.

Find: Rate of consumption.

Solution: Opposite 175 on the miles scale set 2 hours 04 minutes on the hours scale. Opposite the speed index read the rate of fuel consumption on the miles scale.

Answer: 84.6 gallons per hour.

NOTE.—In the above and other cases in which the setting of time in excess of 1 hour is involved, the use of the divisions on both the hours and minutes scales facilitates the more accurate setting of the rotating disk.

(2) *Example 2.*

Given: Fuel remaining, 220 gallons.
Rate of consumption, 84.6 gallons per hour.

Find: Remaining flight time.

Solution: Set speed index to rate of consumption, 84.6 gallons per hour on miles scale. Opposite fuel remaining on miles scale read remaining time of flight on hours scale.

Answer: 2 hours 36 minutes.

f. Ground speed formula.

Example.

Given: Time, 21 seconds.
Absolute altitude, 4,500 feet.
Factor, .706.

Find: Ground speed.

Solution: Opposite 4,500 feet absolute altitude on the miles scale set 21, the time in seconds, on the minutes scale. Find the factor .706 on the minutes scale and opposite it read 151 knots ground speed on the miles scale.

146. Drafting and drawing implements.—This equipment is necessary in plotting courses, positions, scaling distances, etc. The handy use of these articles can best be acquired by practice rather than by reading any lengthy description.

147. Books.—*a. Civil Aeronautics Bulletin #11; Directory of Airports and Seaplane Bases published by the Civil Aeronautics Administration.*—This series of pamphlets, issued periodically, describes airports in the continental United States. One of the uses to which the navigator puts this publication is to find the coordinates of airports and seaplane bases listed therein.

b. TM 1-205.—This manual is an air navigation text and reference.

c. Hydrographic Office Publication #205; Radio Aids to Navigation (current year).—This publication is periodically printed, usually in two volumes, by the Hydrographic Office. It contains such useful information as the latitude and longitude, frequency, and schedule of operation of all marine radio direction finder stations and of all the marine radio beacon stations in the world; a list of many radio transmitter stations throughout the world, with their latitudes and longitudes; a schedule of operation and frequency of radio time signals throughout the world; an excellent treatise on radio bearings; etc.

d. Hydrographic Office Publication #9, Part II.—This book contains the natural and logarithmic functions of angles, logarithms of numbers, and many other tables frequently used by the navigator. H. O. 9, Part I, commonly referred to as Bowditch, contains all the tables of Part II, many additional tables, and a treatise on marine navigation. Worthy of note is the section on the principles of arithmetic, trigonometry, geometry, and logarithms.

e. Hydrographic Office Publication #211, Dead Reckoning Altitude and Azimuth Tables by Ageton.—Commonly called "Ageton," this book contains tables and formulas which solve the spherical triangle. The dead reckoning navigator may use this publication for the calculations of great circle navigation and the computation of the azimuth of celestial bodies for use in compass swinging. Explanation of the use of these tables is described in TM 1-206.

f. American Air Almanac and/or Nautical Almanac.—Tables in both of these publications permit the determination of time of sunrise, sunset, the duration of twilight; the time of moonrise and moonset. This information is frequently needed by the dead reckoning navigator in planning flights. The American Air Almanac is a recent publication compiled by the U. S. Naval Observatory. Each issue contains astronomical data for a 4-month period.

g. T. O. 08-15-1 and T. O. 08-15-2.—T. O. 08-15-1 contains the frequently used Radio Facility Charts. T. O. 08-15-2 contains Radio Data and Aids to Airways Flying. Both are published by the Matériel Division, the former monthly, and the latter periodically.

148. Tables.—*a. Altitude-pressure table—Feet-inches* (fig. 82).—This table contains the conversion of atmospheric pressure in inches of mercury to feet of altitude.

b. Ground speed factors by double drift (fig. 99).—This table contains the factor of ground speed in percent of air speed, using for arguments the drift measured on each of two headings opposed at a 90° angle. (See sec. V.)

c. Wind direction and force by double drift (fig. 100).—This table contains the factor for wind force in percent of air speed and the wind direction in terms of the wind angle clockwise from heading. The same arguments are used to enter the table. (See sec. V.)

d. Ground speed factors by timing (fig. 76 ① and ②).—These tables contain the factors which are used in the formula for ground

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ALTITUDE-PRESSURE-TABLE—FEET-INCHES

P inches	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
28.0	1824	1814	1805	1795	1785	1776	1766	1756	1746	1737
28.1	1727	1717	1707	1698	1688	1678	1668	1659	1649	1639
28.2	1630	1620	1610	1601	1591	1581	1572	1562	1552	1542
28.3	1533	1523	1513	1504	1494	1484	1475	1465	1456	1446
28.4	1436	1427	1417	1407	1398	1388	1378	1369	1359	1350
28.5	1340	1330	1321	1311	1302	1292	1282	1273	1263	1254
28.6	1244	1234	1225	1215	1206	1196	1186	1177	1167	1158
28.7	1148	1139	1129	1120	1110	1100	1091	1081	1072	1062
28.8	1053	1043	1034	1024	1015	1005	995	986	976	967
28.9	957	948	938	929	919	910	900	891	881	872
29.0	863	853	844	834	825	815	806	796	787	777
29.1	768	758	749	739	730	721	711	702	692	683
29.2	673	664	655	645	636	626	617	607	598	589
29.3	579	570	560	551	542	532	523	514	504	495
29.4	485	476	467	457	448	439	429	420	410	401
29.5	392	382	373	364	354	345	336	326	318	308
29.6	298	289	280	270	261	252	242	233	224	215
29.7	205	196	187	177	168	159	149	140	131	122
29.8	112	103	94	85	75	66	57	47	38	29
29.9	20	10	+1	—8	—17	—26	—36	—45	—54	—63
30.0	—73	—82	—91	—100	—110	—119	—128	—137	—146	—156
30.1	—165	174	183	192	202	211	220	229	238	248
30.2	—257	266	275	284	293	303	312	321	330	339
30.3	—348	358	367	376	385	394	403	412	421	431
30.4	—440	449	458	467	476	485	494	504	513	522
30.5	—531	540	549	558	567	576	585	594	604	613
30.6	—622	631	640	649	658	667	676	685	694	703
30.7	—712	721	730	740	749	758	767	776	785	794
30.8	—803	812	821	830	839	848	857	866	875	884
30.9	—893	902	911	920	929	938	947	956	965	974
31.0	—983	992	1001	1010	1019	1028	1037	1046	1055	1064

Use with caution on existing broadcasts .... February 13, 1936

FIGURE 82.

speed by the trail angle method. One table gives the factors for determining ground speed in nautical miles per hour, i. e., knots; the other in statute miles per hour.

e. Radio bearing conversion table (fig. 131).—In correcting a radio bearing (great circle) to a Mercator bearing (rhumb line) for the purpose of plotting the bearing on a Mercator chart, this table is used.

The arguments with which the table is entered are the difference in longitude between the transmitter station and the airplane's dead reckoning position, and their middle latitude. The correction must be applied to the radio bearing in accordance with the rules outlined in section X.

f. Ground speed and drift tables (*wind angle from true course*) (fig. 93).—These tables permit the predetermination of drift and ground speed when the track, wind direction and force, and true air speed are known; or knowing true air speed, drift, ground speed, and heading, the wind direction and velocity can be computed. Again, knowing only the wind angle, true air speed and drift, the ground speed and the wind force can be determined. The use of these tables is described in section V.

149. Blank forms.—*a. Great circle.*—This is a convenient form for making great circle calculations. The nature of the form depends upon the method of finding the spherical elements involved. Forms adapting the Ageton method to great circle computations are the ones most frequently used. (See TM 1-206.)

b. Ageton (*H. O. 211*).—This form refers to the Ageton solution for altitude and azimuth of celestial bodies. The azimuths are used in compass swinging. (See TM 1-206.)

c. Navigator's Log, W. D., A. C. Form No. 26A.—Form No. 26A is a paper bound book which contains log sheets (Form No. 21A), tables of ground speed by timing factors, an off-course correction table, a great circle radio bearing conversion table, and an altitude-pressure table.

d. Mercator solution (fig. 125).—This title refers to the form used for calculating the rhumb line course and distance.

e. Radio message blanks.—The form of position reports has not been standardized, hence, no universally used blank form has been published. Convenient forms are shown in paragraph 174.

Section IV

ALINEMENT, COMPENSATION, AND CALIBRATION OF INSTRUMENTS

Paragraph

General ---------- 150
Alinement of type B-3 drift meter ---------- 151
Alinement of type A-2 aircraft pelorus ---------- 152
Alinement, compensation, and swinging of compass ---------- 153
Calibration of air speed meter installation ---------- 154

150. General.—*a.* The alinement, compensation, and calibration of instruments is an arduous task devolving upon the navigator. The necessity for diligence in the performance of this duty lies in the theory that by eliminating all instrumental errors the navigational error is the navigator's personal error. With experience, the personal error becomes a known quantity, and definite allowance in the calculations can be made for it.

b. The elimination of instrumental and personal errors makes precision navigation possible. In a comparatively short time, instruments of fine accuracy have been developed. Every improvement in navigational instruments and technique enhances the tactical value of the airplane.

c. Before precision results can be obtained, the navigator must carefully aline, compensate, and calibrate his instruments. There are many ways in which the various instruments may be alined, compensated, and calibrated. This section describes a few of the methods which have proved satisfactory.

151. Alinement of type B-3 drift meter.—*a. Planes.*—The drift meter must be alined in two planes.

(1) The drift wires must be parallel to the longitudinal axis of the airplane when the pointer on the azimuth scale reads 0° or 180°. This operation is called "alining the drift wires."

(2) With the trail angle set to zero, the line of sight must be vertical when the airplane is in level flying position. This alinement is called "zeroing the trail angle," and it is accomplished by setting the trail angle at zero and adjusting the drift sight until the vertical line of sight is perpendicular to the plane containing the longitudinal and lateral axes of the plane. This alinement is necessary if the drift sight is to be used for ground speed by timing.

b. Alinement of drift wires with transit.—(1) The airplane should be placed on a level surface but need not be in flying position. With the airplane pointed toward distant objects (trees on horizon, etc.), establish the projection of the longitudinal centerline of airplane on the ground in the following manner: Drop a plumb bob from center of tail and from center of nose of aircraft; draw a line connecting plumb points and extend it forward of the nose. Set up a transit on this centerline and set cross wires of transit on tail plumb line with transit azimuth scale set to 0. Rotate transit 180° and select a distant object which appears on the vertical cross hair. This object is in the same vertical plane as the centerline of the airplane.

(2) Rotate drift meter, with gyro caged, until index is near zero of azimuth scale; turn line of sight control to 85°. Pick up distant object located by transit and by means of slow motion control rotate drift meter until object is in center of reticle system or on the central

vertical line. Loosen the four screws on edge of the azimuth drift scale (azimuth ring adjusting screws in fig. 73); rotate ring until the zero is opposite index line and tighten the four screws. The drift wires are now alined.

c. Zeroing trail angle.—(1) *General.*—Materials necessary for this operation are a 100-foot steel tape, plumb bob, chalk line, and chalk. The problem is to find a point on the ground where a line from the drift meter to the point will be perpendicular to the plane containing the longitudinal and lateral axes of the airplane. The position of the point will be approximately the same for all airplanes of the same type, but for accuracy each airplane should be considered individually. The drift wires also may be alined by this method as explained in (2) below. One advantage of this method is that it does not require use of a transit.

(2) *Procedure* (fig. 83).—(*a*) With the airplane not in flying position on a smooth, level floor or ramp, block the wheels. Have tail wheel at right angles to fuselage.

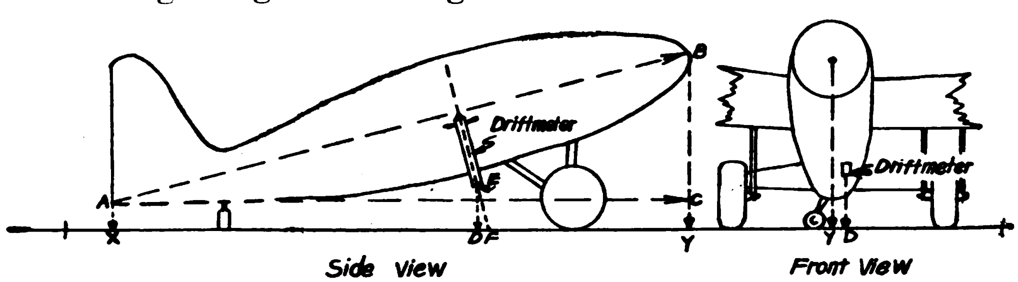

FIGURE 83.—Zeroing trail angle.

(*b*) Determine over-all length of airplane from center of nose plate to tip of tail cone. (See handbook for each type airplane.) This will be side *AB* in the triangle *ABC*.

(*c*) Drop a plumb bob from tail cone and tip of nose. Measure distance *XY*. Note that $XY = AC$.

(*d*) Connect two points *X* and *Y* with a chalk line.

(*e*) Using a plumb bob locate point on ground vertically beneath center of cover glass of drift meter trail prism. Label this point *D*. Measure length of plumb line from cover glass to point *D*. This will be side *ED* in triangle *EFD*. Note that the point *D* does not fall on the centerline *XY*. This can be seen by referring to the front view of the figure.

(*f*) Draw through point *D* a chalk line parallel to the center line *XY*.

(*g*) Triangles *ABC* and *EFD* are similar right triangles. In order to locate point *F*, solve for angle *BAC* by using the formula:

$$\cos BAC = \frac{AC}{AB}$$

But $\qquad \angle DEF = \angle BAC$

Then $\qquad DF = DE \tan DEF = DE \tan BAC.$

Locate point *F* on the parallel line through *D*, measuring from *D* toward the nose.

(*h*) Through *F* draw a line perpendicular to *DF* (not shown in figure). For lack of a better term, this line will be called the "ground speed line."

(*i*) Enter the airplane and vibrate the drift meter in its shock mounts and let it come to rest. Keep gyro caged. Rotate drift meter in azimuth so that center drift wire of meter is parallel to line *DF* on the ground. Keep trail prism at zero. Read drift scale. It should read zero. If it does not, proceed to adjust azimuth ring as in *b*(2) above until the drift scale heads zero when the drift wires are parallel to *DF*.

(*j*) With line of sight control, set center transverse cross wire on the ground speed line. The trail angle should read zero. If it does not, loosen the small screw in collar of trail angle scale segment. Holding transverse wire on ground speed line with line of sight control, move zero on scale to index. Tighten the screw. The trail angle is now zeroed.

(*k*) After these operations it may be found upon rotating the drift meter in the azimuth that the intersection of the cross wires on the reticle move off the intersection of the line *DF* and ground speed line on the ground. This indicates that the vertical axis of the drift meter does not remain in a fixed position as it should. If the movement is appreciable, either the drift meter or its installation is faulty and an instrument expert should be consulted.

d. To find the constant K′ used in ground speed determination by zero angle method, B-3 drift meter (par. 140f and fig. 77).—(1) *Procedure.*—With the airplane not in flying position, parked on a level surface, block the wheels. Select some object on the horizon at least a mile away. Rotate meter in azimuth so the line of sight is projected forward and the center drift wire is on the object. Do not allow drift meter to rotate in azimuth during the following operations: With line of sight control, set first ground speed wire on the object. Read trail angle scale. Set third (last) ground speed wire on same portion of object. Read the scale. The difference between the two scale readings is the value of angle δ.

(2) *Example.*—(*a*) From figure 77:

$$\tan \tfrac{1}{2}\delta = \tfrac{1}{2}\frac{d}{h}$$

Transposing

$$\frac{d}{h} = 2 \tan \tfrac{1}{2}\delta$$

(*b*) From paragraph 140*f* (4):

$$K' = \frac{d}{h} \times .592 = 2 \tan \tfrac{1}{2}\delta \times .592$$

$$K' = 1.184 \tan \tfrac{1}{2}\delta$$

(*c*) If

$$\delta = 17°$$

then $\tfrac{1}{2}\delta = 8\tfrac{1}{2}°$

and $K' = 1.184 \tan 8\tfrac{1}{2}° = 1.184 \times .1494$

$$K' = .177$$

152. Alinement of type A-2 aircraft pelorus (fig. 78).—The pelorus is issued with two or more mounting plates each of which must be mounted on a bracket. The brackets are mounted at convenient positions in the airplane so that the pelorus, when installed, will have the widest horizontal angle of view. The design of these brackets has not been standardized to date, principally because a bracket designed for one type of airplane may not be suitable for other types. The brackets are usually fabricated locally. It has been found that a bracket with slotted bolt holes to permit a slight rotation of the mounting plate in a horizontal plane during the alinement operation facilitates the alinement.

a. Alinement with drift meter.—This method can only be used if the drift meter has been accurately alined. With the airplane, not in flying position, parked on level ground with the nose in general direction of distant objects, proceed as follows:

(1) Attach the pelorus to mounting plate and set on bracket. Tighten bolts holding plate to bracket only enough to permit easy rotation of plate on bracket. By means of clamp (B) (fig. 78), clamp azimuth scale so that zero is coincident with lubber line (G). Do not unclamp until alinement procedure is completed.

(2) Using drift meter find clockwise relative bearing of a distant point.

(3) Set relative bearing, just determined, on pelorus. This is done by unclamping (C), setting index (F) opposite relative bearing on azimuth scale and then tightening (C).

(4) Rotate mounting plate, with pelorus attached, until lighted cross hairs of the pelorus coincide with the object.

(5) Tighten bolts holding plate to bracket. The pelorus is now alined.

(6) Scratch marks on edge of plate and on face of bracket so that coincidence of these marks shows position of the plate when alined. These marks provide a quick means of realinement in event the plate becomes offset from the position in which it has just been tightened.

(7) Repeat procedure to aline plate for each bracket installation.

b. Alinement with transit or pelorus itself.—Drop plumb bobs from center of nose and tail of airplane. Set up a transit near nose of airplane and on extension of line joining the two plumb bobs.

Measure relative bearing of a distant object. Having determined the relative bearing of the object, the procedure is the same as outlined in *a* above. If a transit is not available, the pelorus mounted on a tripod may be used to measure the relative bearing of the object.

153. Alinement, compensation, and swinging of compass.—*a. Process.*—There are three steps necessary before a compass is ready to be used on a navigation flight.

(1) *Alinement.*—The compass should be installed so that the lubber line is parallel to the fore-aft axis of the aircraft.

(2) *Compensation.*—The needle should be made to lie in the plane of the magnetic meridian as nearly as it is humanly possible to do so by placing magnets or other correctors in a chamber incorporated in the base of the compass. Due to local magnetism, a compass needle which has been made to coincide with the magnetic meridian when the airplane is headed in one direction may not remain coincident with the magnetic meridian when the airplane is headed in another direction. Since it is obviously impractical to compensate a needle so that the needle will always remain parallel to the magnetic meridian regardless of the aircraft heading, a method which produces approximate parallelity is used. Any left-over deviations of the needle from the direction of the magnetic meridian are recorded when the compass is swung and taken into account during subsequent flights.

(3) *Swinging.*—Swinging is the process of determining the angular deviations between the direction of the magnetic needle and the plane of the magnetic meridian. The process consists of finding the deviations between the direction of the needle and the magnetic meridian on known magnetic headings differing in azimuth by 10° or 15°, and recording the deviation between each compass heading and the corresponding magnetic heading. The deviation corrections are later tabulated or plotted graphically, and a smooth curve is drawn (fig. 84). Thereafter, the deviation correction for any de-

sired magnetic heading may be conveniently selected and applied when setting the azimuth ring of the compass so that the aircraft's head may be placed in a desired magnetic direction.

b. Purpose.—A compass need not be alined or compensated before swinging provided the compass is not disturbed after it has been swung.

(1) The reason for removing the lubber line error is mainly one of convenience. If the compass is not alined, the deviations on all magnetic headings may turn out to be all easterly or all westerly. The effect of lubber line error will be made apparent if the reader imagines the curve shown in figure 84 as being moved parallel to itself 15° to the right. If this should be done, all the deviation corrections would be positive although the shape of the curve will remain the same. Hence, even though the deviations are known on every heading, they may be of such one-sided magnitude as to prove extremely disconcerting. For example, a large lubber line error might require that a navigator desiring to fly a magnetic heading of 90° set his compass at 20°.

(2) The purpose of compensating the compass is to reduce the magnitude of the deviations. If the compass whose deviation curve is shown in figure 84 had not been compensated, the shape of curve would be entirely different. The curve would in all probability be much wider and more irregular than that shown in the illustration, even though the scale remained constant. In other words, the deviations would be greater. Compensation tends to flatten out the curve. The flatter the curve, the easier it is for the navigator accurately to interpolate by eye when selecting the deviation correction for any desired heading. If the deviation corrections of an uncompensated compass are carried in tabulated form, rather than as a curve, the navigator may have some difficulty interpolating between tabulated values. Hence, compensation serves to fulfill the requirements of accuracy and convenience.

c. Problems of swinging and their influence on methods.—(1) The difficulties of compensating and swinging the compass have increased with the development of modern aircraft. The ground methods of compensating and swinging were entirely adequate for the old nonmetallic types of planes which were light enough and small enough to be conveniently handled on a compass rose. Furthermore, these airplanes did not contain a profusion of electrical circuits likely to influence the compass, nor did they fly under conditions of loading likely to change the compass deviation appreciably. Consequently, the deviations determined on the ground were adequate to enable the

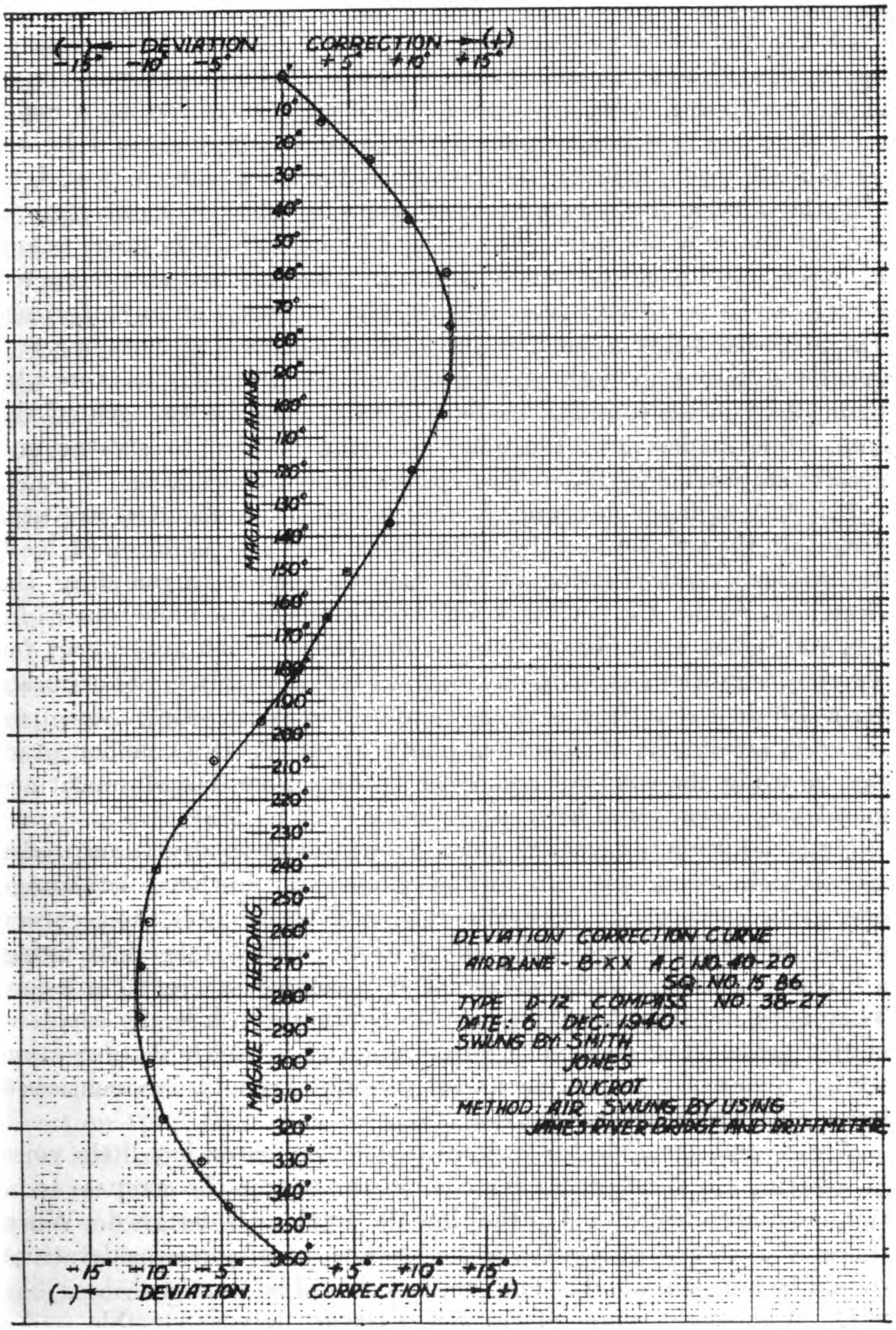

FIGURE 84.—Compass deviation curve.

pilot to perform successfully the short range navigation missions assigned him.

(2) Ground swinging methods are no longer adequate for determining the deviations of the magnetic compasses installed in the long-range military airplane. The airplane is so heavy and unwieldy as to make ground swinging difficult; and even if ground swinging could be accomplished with facility, the deviations thus determined would be of little value in flight because the deviations existing on the ground are not the same as those prevailing during flight. A great many factors cause this variation in deviation. The extended and retracted positions of the landing gear influence the deviation on any heading. The magnetic fields created by the various electrical circuits are frequently different in flight from those on the ground; consequently, their effect on the compass needle will vary with the strength of the field. The inadequacy of ground swinging has led to greater and greater emphasis and reliance being placed on air swinging.

(3) Although air swinging is resorted to, the difficulties are still great. In the air, compass deviation varies with the condition of load, the strength and polarity of the magnetic fields surrounding the electrical circuits, the "on" and "off" conditions of the numerous radio sets and lights, etc. Hence, compass deviations which are correct for one set of conditions existing during flight will probably not be accurate for a different set. It is obviously impossible to air swing a compass for every possible set of conditions likely to prevail. It is common practice to swing the compass under the two or three sets of conditions most likely to exist and let it go at that.

(4) In addition to permitting the determination of deviations under actual flight conditions, air swinging has an additional advantage over ground swinging. It permits the navigator to check the accuracy of the deviation correction on any heading while engaged in flying a mission not specifically scheduled as a compass-swinging mission. That is to say, the deviation can be determined while the airplane is on course. The method usually employed to check the deviation while on course involves the use of celestial azimuths as mentioned later in this paragraph.

d. Selecting location for compass.—The navigator has little voice in selecting the location for the compass mount, as the compass location is usually determined at the time the airplane is designed. When there is a choice of locations, the following major considerations should be borne in mind. The compass should be located—

(1) As near the center of gravity of the airplane as possible.

(2) Convenient to the navigator.

(3) As far away as possible from the magnetic fields created within the airplane. This applies particularly to those fields which fluctuate in strength.

e. Preparing airplane and compass before compensating and swinging.—The precautions contained in paragraph 36 are taken before any attempt is made to compensate or swing the compass. When the process of removing the lubber line error is combined with the process of compensation (par. 36), it is necessary to observe the above-mentioned precautions before alining.

f. Removing lubber line error.—The lubber line error may be totally eliminated or it may be partially but satisfactorily removed as described in paragraph 36. To aline the lubber line exactly, the center line of the airplane must be established and the compass rotated on its mount until the lubber line is parallel to the center line. Because of the difficulties incident to establishing the center line inside most aircraft, and in making offsets from it, this method is little used. The existence of a small lubber line error is not objectionable and, therefore, no great amount of time and effort need be spent eliminating it.

g. Compensating the compass.—(1) *Ground method.*—See paragraph 36.

(2) *Air method.*—The compass may be compensated in the air. The method used is similar to that on the ground except the N, S, E, and W magnetic directions when in flight must be established by methods described in *h* below.

h. Swinging the compass.—(1) *General.*—After the lubber line error has been removed and the compensation completed, the compass is ready to be swung. As has been already implied, there are two general classifications of swinging—ground and air. In turn there are several procedures available for use on the ground or in the air. The main point of difference between all these procedures lies in the way the magnetic heading of the airplane is determined at the time the compass heading is recorded. Ground swinging methods present little difficulty in determining the magnetic heading, either a compass rose, a master compass, or a transit serving to establish the direction (par. 36). Air swinging procedures to establish the magnetic heading present more of a problem, as will be readily apparent when a little thought is given to the influence of the airplane's speed and instability on the problem. Air procedures vary according to the instruments used to assist in determining the magnetic heading and according to whether a celestial or terrestrial bearing point, or a line upon the earth's surface (such as a straight length of railroad track), is used in the orientation. In all air procedure, smooth air conditions must exist if reliable results are to be obtained.

(2) *Air swinging by terrestrial bearings on straight stretch of railroad or highway with B-3 drift meter.*—From an aerial reconnaissance or from an accurate large scale map, select a straight section of railroad or highway and determine its magnetic direction. For convenience the length of the section should be at least a mile, preferably longer.

(*a*) The procedure for the pilot on each run is as follows: He selects any convenient compass heading to start with, for example,

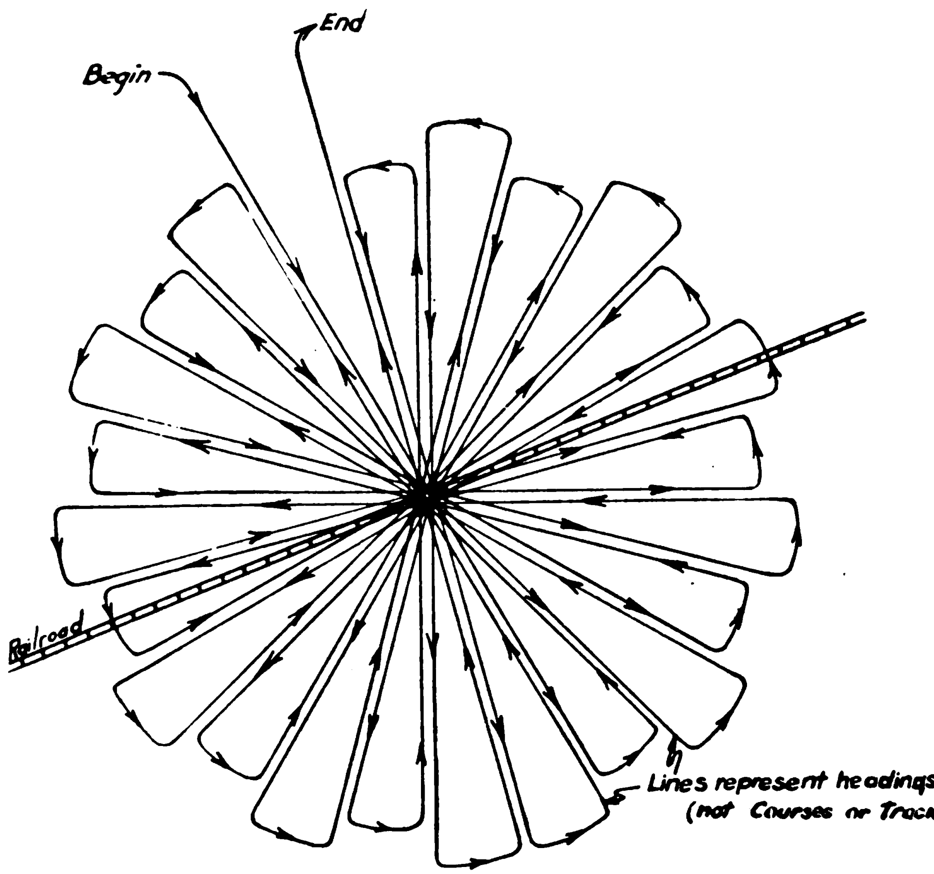

FIGURE 85.—Pattern for air swinging on railroad.

southeast. He plans to fly a long, steady course, passing over the railroad. He turns the airplane to this course by his compass, reading it after it has come to rest. Then by uncaging his gyro turn indicator to any graduation, usually zero, he maintains a constant heading for the entire run. If the compass does not read 135°, it is immaterial as long as it does read the same heading for the entire run. The gyro turn indicator must have negligible precession during the run which usually extends over a 5- to 10-minute period.

(*b*) The procedure for the navigator is as follows:

1. As soon as the airplane becomes steady on the run, the navigator rotates the drift meter so that the line of sight projects forward. The railroad is picked up in the field while it is some distance from the airplane. The center transverse cross wire is held on the railroad with the line of sight control and made to parallel it by rotating the drift sight in azimuth.

2. When the transverse wire is parallel to the railroad, the compass heading is recorded.

3. The drift meter is read.

4. Steps *2* and *3* above are repeated two or three times before crossing the railroad.

5. As the airplane crosses the railroad, the drift meter is rotated 180° and the line of sight moved in the opposite direction to keep the transverse wire on the railroad.

6. Again the compass heading is recorded and the drift meter read.

7. The data recorded from the drift meter *before* crossing the railroad are now combined with magnetic bearing of the railroad to determine the magnetic heading of the aircraft. Similarly, the data recorded from the drift meter *after* crossing the railroad are combined with the magnetic bearing of the railroad to find the magnetic heading of the aircraft. Great care is required in making the foregoing computations due to the fact that the azimuth scale of the drift meter does not indicate relative bearing measured from the head of the plane when the transverse wire is used. A detailed discussion of the problem follows in (5) below.

8. The two magnetic headings obtained in *7* above are averaged.

9. The compass headings of the run are averaged.

10. The average magnetic heading is compared with the average compass heading to determine the deviation. In determining the sign of the deviation correction, it should be remembered that to make good the magnetic heading the airplane must fly the compass heading. If the compass heading is less than the magnetic heading, the deviation correction is minus; if greater, the correction is plus. The deviation correction is now recorded.

(*c*) The procedure contained in (*a*) and (*b*) above is repeated for every 10° or 15° of compass heading. (See fig. 85.)

(*d*) After flight, the deviation corrections are tabulated on a compass card or are charted on graph paper and a smooth curve is drawn through them. The chart of the deviation corrections (fig. 84) is kept in the airplane.

(*e*) On subsequent flights the navigator can check the accuracy of the deviation correction for the particular heading he is flying whenever he passes over a line of known bearing. If the deviation correction is found to differ from that obtained from the deviation curve. the curve is adjusted to conform to the later information.

(3) *Air swinging by celestial azimuths.*—(*a*) In this method, the airplane is flown on a succession of headings just as is done when swinging on a railroad. On each run the compass heading and the relative bearing of the celestial body are read, and the correct time of the bearing recorded. The relative bearing is later combined with the calculated magnetic bearing of the body to find the magnetic heading of the airplane. Computations for magnetic bearing of celestial bodies are described in TM 1–206. Having determined the magnetic heading on each run and having read the compass on each run, the deviation corrections are found and tabulated or graphed as described above.

(*b*) If swinging is done on the sun and the airplane is flown low enough for its shadow to be observed through the drift meter, the drift meter may be used instead of the pelorus. It must be remembered when making subsequent computations that the bearing of the shadow differs from the bearing of the body by 180°.

(*c*) The method of air swinging by celestial azimuths provides an excellent means of checking deviation while the airplane is on course during a flight mission. The procedure is described in TM 1–206.

(4) *Ground swinging of compass.*—This method is described in detail in section IV, chapter 1.

(5) *Finding magnetic heading of airplane from bearing taken with drift meter on straight stretch of railroad or similar straight terrestrial bearing line.*—This discussion applies particularly when performing the computations described in (2) (*b*) 7 above.

(*a*) The B–3 drift meter is installed in the airplane so that when the family of longitudinal cross hairs on its reticle is parallel to the longitudinal axis of the airplane the index on the azimuth scale reads 0° or 180°. Likewise, when any one of the transverse cross hairs is parallel to the longitudinal axis of the airplane, the index will read 90° or 270°. It has been found advantageous to use one of the transverse cross hairs when air swinging the compass, because the drift meter can be rotated so that the trail angle feature of the field of view may be turned forward. This allows the railroad to be picked up in the field well before arriving directly over it, and also followed after passing over it.

(*b*) It will be noted that the reading of the azimuth scale when the transverse cross hair is parallel to the railroad may be one of two angles, differing by 180°, depending on which way the drift meter happened to be turned when the cross hair was alined on the railroad. It will be shown below that it is immaterial which of these two angles was read.

(*c*) In figure 86 let AB represent a railroad whose magnetic bearing is θ. Also let OH be any heading of the airplane as it crosses the railroad over point O; and let the circle and grids represent the reticle of the B–3 drift meter at the instant the airplane is directly over point O,

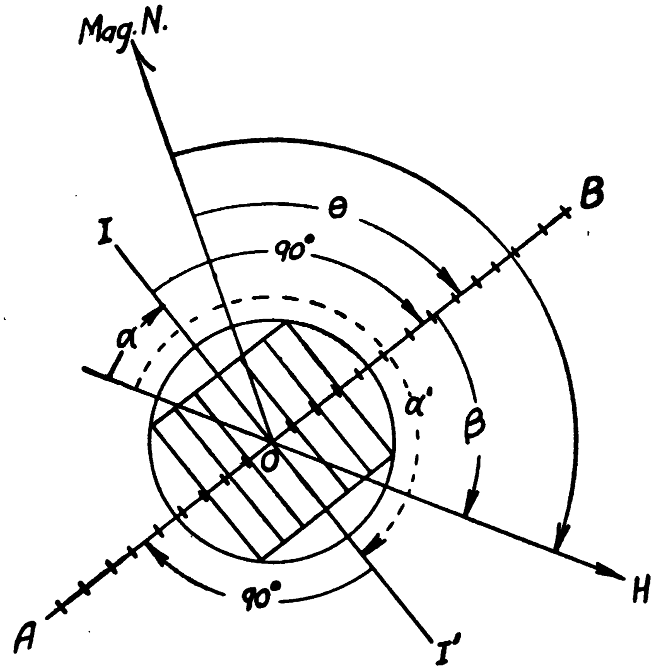

FIGURE 86.

with the transverse cross hair alined on the railroad. I or I' will be the index depending on which way the drift meter is turned. Then α or α' will be the reading of the drift meter, angle NOH will be the magnetic heading of the airplane, and angle β will be the angle between the longitudinal axis of the airplane and the railroad.

(*d*) Now $\angle NOH = \theta + \beta$

But $\beta + \alpha + 90° = 180°$ or

$$\beta = 90° - \alpha$$

Also $\beta + \alpha' + 90° = 360°$ or

$$\beta = 270° - \alpha'$$

Then $$\angle NOH = \theta + 90° - \alpha \quad (1)$$

and $$\angle NOH = \theta + 270° - \alpha' \quad (2)$$

(*e*) The magnetic direction of the railroad from B to A is $\theta+180°$.

Then $\angle NOH=\theta+180°+90°-\alpha=\theta+270°-\alpha$ (3)

and $\angle NOH=\theta+180°+270°-\alpha'=\theta+450°-\alpha'$ (4)

It will be seen that the four values of NOH in equations (1), (2), (3), and (4) differ by increments of exactly 180°.

(*f*) Now let it be assumed that the true direction of AB is 60° and that the variation at point O is 10° W.; then the magnetic bearing of AB will be 70°. Substituting in (1), (2), (3), and (4), the values of $\angle NOH$ will be

$$\angle NOH=160°-\alpha$$
$$\angle NOH=340°-\alpha'$$
$$\angle NOH=340°-\alpha$$
$$\angle NOH=520°-\alpha'.$$

(*g*) In other words by merely substituting for θ the magnetic bearing of the line on the ground in the above equations, we have four equations from which the magnetic heading of the airplane can be found by substituting in them the drift meter reading for α or α'. Ordinarily it will not be known whether the drift meter reading obtained is α or α' but this will cause no confusion as will now be shown.

(*h*) In the above example assume that the drift meter reading on a certain run is 210° and that the compass reading is 135°.

$$\angle NOH=340°-\alpha$$
$$\angle NOH=340°-210°=130°$$

The deviation would be +5°.

Suppose the formula $NOH=520°-\alpha'$ had been used, then $\angle NOH=520°-210°=310°$.

But the compass reading was 135°, and a deviation of 175° is hardly to be expected. Upon inspection it is seen that the magnetic heading of 310° found is exactly 180° from a value near the compass reading. Thus no matter which equation is used, the magnetic heading found will be either the correct one or 180° in error. In practice, the equation is selected by inspection which will give a magnetic heading near the compass reading.

(*i*) A form as shown below will be found useful for tabulating the readings and results:

Formula	Drift meter reading	Magnetic heading	Compass reading	Compass deviation
$340°-\alpha$	210°	130°	135°	+5°

(*j*) From the above discussion and example the following rules for finding the magnetic heading of the airplane from the drift meter reading and the magnetic bearing of the terrestrial bearing line may be deduced. These rules are primarily of use in air swinging the aircraft compass by this method.

1. Solve the equation $<NOH=\theta+90°-\alpha$, where θ=magnetic bearing of railroad, and α=azimuth reading of drift meter.

2. If α is greater than $(\theta+90°)$, add increments of 180° to the value of $(\theta+90°)$ to make the subtraction possible.

3. The value of angle *NOH* found from this equation will be either the correct magnetic heading of the airplane or exactly 180° in error. Eliminate this 180° ambiguity by comparing the value of angle *NOH* with the compass reading.

4. Tabulate the results on the form shown above.

154. Calibration of air speed meter installation.—*a. General.*—Calibration of the air speed meter is the process of determining the corrections which must be applied to the indicated air speed to make allowance for the effect of disturbed air flow around the Pitot static head, for characteristics of the air speed tube, and for mechanical errors of the air speed meter. The calibrated air speed thus found is plotted against corresponding values of indicated air speed in order to draw the air speed calibration curve. The two methods of calibration in general use are by timing over a measured course and by use of the trailing static bomb.

b. Timing over measured course.—This method consists of making a series of timed runs over a measured course. A pair of runs is made for each indicated air speed, one run with the wind and one run against the wind. From the formula, speed$=\frac{\text{distance}}{\text{time}}$, the speed for each run is computed, and for each pair of runs the average true air speed is found. Since the air density during calibration is not necessarily standard, the true air speed is converted to calibrated air speed by a factor which depends on the existing pressure and temperature. The best results will be obtained under smooth air conditions.

(1) *General.*—Refer to figure 87. The measured course should be from 5 to 10 miles in length with open approaches at least 2 miles long at each end. Each end of the measured course should be marked with two markers set on poles. The line between each pair of markers must be perpendicular to the axis of the course and the poles

should be at least 400 yards apart. The length of the measured course between markers must be accurately known.

(2) *Procedure.*—(*a*) An observer is required for each air speed meter installed in the airplane and all meters are calibrated simultaneously.

(*b*) Remove from the pitot static head the correction sleeve (part No. 33A4259), if one has been installed, and do not replace.

(*c*) Make sure the pilot's altimeter indicates the correct pressure altitude when the reference marks are both set to read zero.

(*d*) Throughout the procedure, pitot heat must be on if there is danger of ice forming in the pitot head.

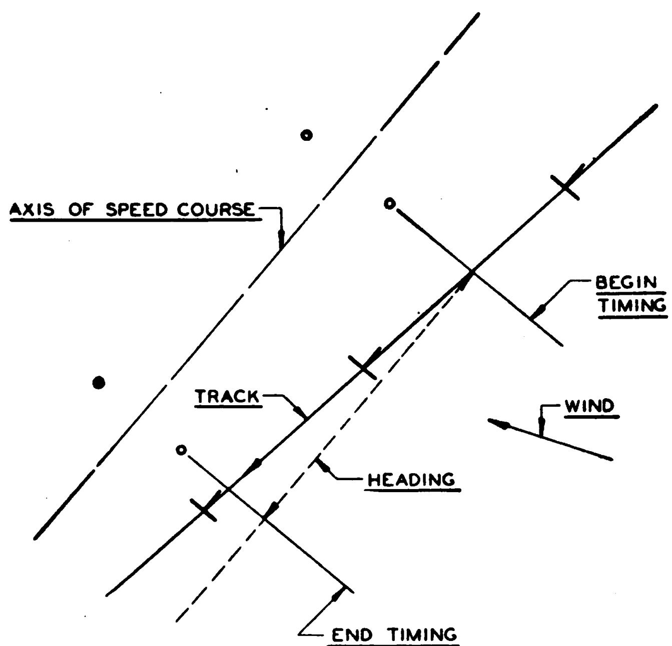

FIGURE 87.—Air speed calibration speed course.

(*e*) A constant altitude must be maintained on each run. It is common practice to make the runs along the speed course very close to the ground to insure maintaining a constant altitude on all runs.

(*f*) Observers must record air speed readings, free air temperatures, pressure altitudes, and the times for each run.

(*g*) The first pair of runs is made at maximum allowable r. p. m. (or manifold pressure), using the open approach area to ensure that a constant speed has been attained before entering the measured course.

(*h*) The runs are not to be made in the lane bounded by the posts, but to one side so that the posts may be lined up by observers to indicate the beginning and end of the measured course.

(*i*) During the run the pilot must maintain a heading parallel to the axis of the speed course as laid out on the ground. This heading is maintained regardless of drift.

(*j*) At least two observers measure the time interval between the lining up of the poles which mark the beginning of the course and the

CALIBRATION OF AIRSPEED INDICATOR

PLACE New Point Comfort Light to York Spit Light AIRPLANE B-18, A.C. # 36-315
DATE 20 Jan 39 ALTIMETER Kollsman (Pilots)
PILOT Ruetre AIRSPEED (Pilots)
OBSERVER Rogers, Ragsdale, Winstead THERMOMETER Air Temp.
LENGTH OF COURSE 5.622 Nautical Miles PITOT-STATIC TUBE (Pilots)

1	2	3	4	5	6	7	8	9	10	11	12
Run	Press. Alt.	Aver. A. S. R'D'G.	Time over course: Against wind	Time over course: With wind	Speed over course: Against wind	Speed over course: With wind	Aver. speed	Air temp.	$\sqrt{\frac{\rho_0}{\rho}}$	Cal. speed V_e Knots.	Remarks
1	446	126		161.5"		125.3	113	+2°C		114.8	
2			202.55"		100.7						
3	417	139.3		148.5"		136.3	126.1	+2°C		128.1	
4			174.5"		116.						
5	440	150.3		138.4		146.2	135.8	+3°C		137.6	
6			161.3"		125.5						
7	430	158.5		132.8"		152.4	142.7	+3°C		144.5	
8			152.2"		133						
9	200	104.8		184.1		110	44.1	+3°C		100.8	
10			224.2"		88.3						

$$V_e \text{ (Col. 11)} = \frac{\text{Aver. Speed (Col. 8)}}{\sqrt{\frac{\rho_0}{\rho}} \text{ (Col. 10)}}$$

FIGURE 88.—Air speed calibration data.

lining up of the poles which mark the end of the measured course. If only one pole or object marks each end of the course, set the pelorus to a relative bearing 90° (or 270°) from the head of the airplane, and take the time when each object is on the vertical cross hair of the pelorus. The drift meter may be used with equal facility.

(*k*) For the second pair of runs the throttle setting is reduced to give an indicated air speed 15 to 20 m. p. h. less than the speed of the first pair of runs. To insure constant speed on both runs at this throttle setting, the throttles should not be moved from the time the first run of this pair is begun.

(*l*) A pair of runs is made for additional throttle settings until the safe minimum speed is reached. The air speed should be reduced 15 to 20 m. p. h. for each new throttle setting. No special effort should be made to calibrate exactly on speeds divisible by five. A uniform indication over the entire length of the speed course is imperative if reasonable accuracy is to be obtained.

(*m*) Data required on the flight (fig. 88) are: pressure altitude for each run (column 2 of form); average indicated air speed (column 3); time up wind (column 4); time down wind (column 5); and air temperature (column 9).

(3) *Ground work.*—(*a*) Determine the speed up wind (column 6) and down wind (column 7) from the formula: speed in knots= $\frac{\text{distance in nautical miles} \times 3600}{\text{time in seconds}}$. This can be solved on the E–6B computer. Place length of the speed courses in miles on the miles scale opposite time in minutes and decimals of minutes on the minutes scale, then opposite the speed index (the arrowhead shaped mark) on the minutes scale read the speed on the miles scale. If length of speed course is in nautical miles, speed will be in knots.

(*b*) Average results of columns 6 and 7 for each pair of runs and record in column 8. This figure is the true air speed.

(*c*) Determine calibrated speed for each average in column 8 for the existing conditions of temperature and pressure. Using E–6B computer, set the temperature (column 9) opposite the pressure altitude (column 2) in the pressure altitude cut-out. Opposite the average true air speed (column 8) on the miles scale, read calibrated air speed (column 11) on the minutes scale. If true air speed is in knots, calibrated air speed will be in knots.

(*d*) On graph paper plot calibrated speed (column 11) against its indicated air speed (column 3) averaged from both runs of the pair. Draw in the best representative line. (See fig. 89.) This line should be straight. Rough air conditions, erratic timing, and faulty pilotage may result in the series of points not plotting as an approximate straight line. If the plotted points deviate considerably from a straight line, the air calibration procedure should be repeated.

(*e*) From the data of the curve construct a card as shown in figure 89. For even increments of indicated speed, read from the curve the corresponding calibrated speed. On the calibration card, draw in a line representing the even increments of indicated speed opposite the figure corresponding to the calibrated speeed. If the curve is indicated miles per hour against calibrated knots, the line on the card representing indicated speed in m. p. h. must be drawn opposite the corresponding calibrated knots.

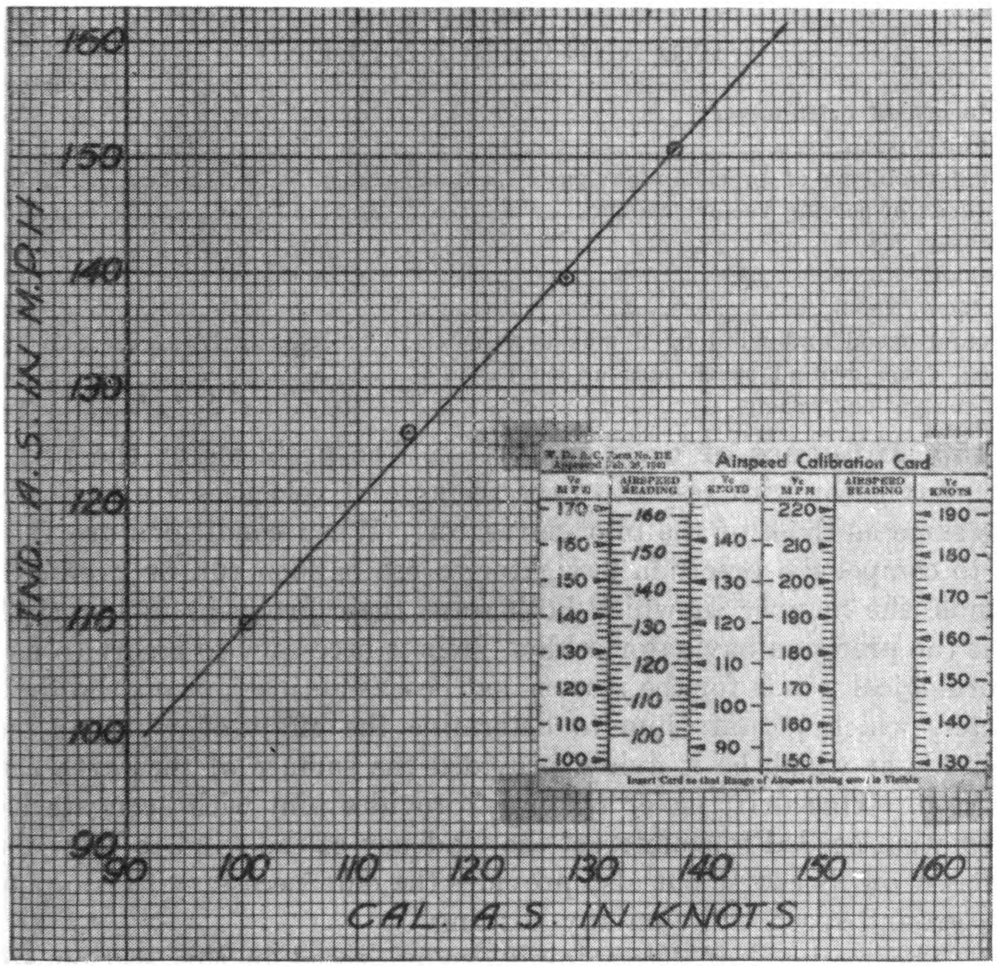

FIGURE 89.—Air speed calibration curve and card.

c. Trailing static bomb (*N. A. C. A. trailing log*).—This assembly consists of a master air speed indicator connected by tubing to a static head mounted in a small bomb suspended below the airplane in flight, and a total head meter which is mounted on a rod extended from the fuselage into undisturbed air. The whole assembly is previously calibrated in a wind tunnel. The airplane is flown at any altitude in level flight and at constant speeds. The readings of the air speed meters installed in the airplane are plotted against the readings of the master indicator to draw the air speed calibration curve.

d. Calibration by formation flying.—The air speed meter installation may be calibrated by flying the airplane in formation with another airplane whose air speed meter has been carefully calibrated. Readings of the two air speed meters must be recorded only when there is no relative motion between the two airplanes.

Section V

WIND AND GROUND SPEED

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155. Influence of drift meter.—*a.* The problems of the precision navigator with respect to the triangle of velocities are basically the same as those of the pilot-navigator. When conditions are such as to compel the precision navigator to use balloon run or predicted winds, the manner in which both solve their problems is identical. But the precision navigator seldom finds it necessary to resort to meteorological winds for the reason that he has an instrument, the drift meter, which permits him to determine the effect of wind at the altitude at which he is flying, provided the surface of the earth can be seen. This drift meter not only provides him with accurate information needed to counteract the tendency of the wind to blow the aircraft off its course but also provides the data necessary to compute the ground speed while on any heading.

b. The methods of determining ground speed in this section are confined to those involving the solution of the triangle of velocities. The method of employing the drift sight to determine ground speed by timing does not directly entail the solution of the triangle of velocities. No further explanation of ground speed by timing is given in this section as it has already been described in detail in section III.

156. Definitions.—*a.* In addition to the definitions given in section VI, chapter 1, there are two definitions of wind angle which the navigator must understand:

(1) Whenever figure 93 is being used, wind angle is the angle between the true course of the aircraft and the wind direction, measured to the right or left of the aircraft's course to the direction from which the wind blows. This angle never exceeds 180°. (See fig. 90.)

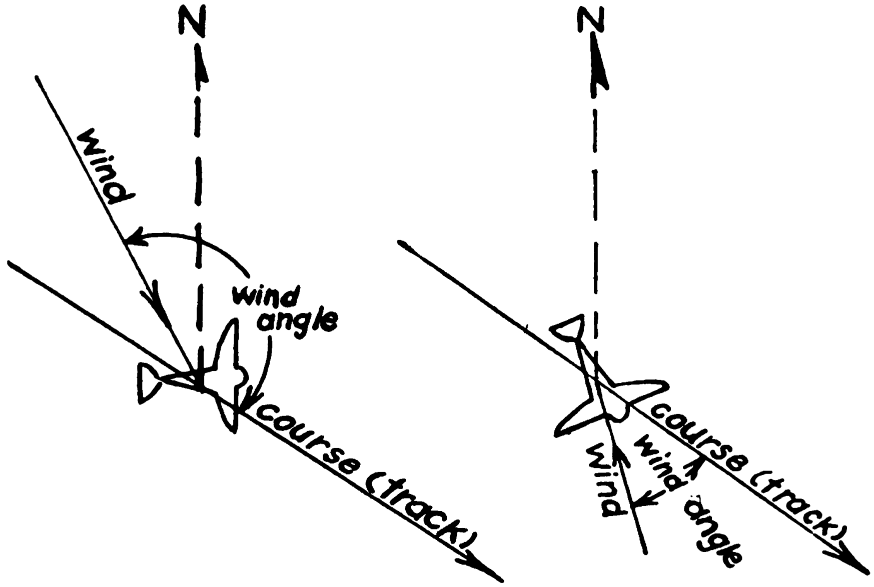


FIGURE 90.—Wind angle when using ground speed and drift table (fig. 93).

(2) Whenever figure 100 is being used, wind angle is the angle between the true heading of the aircraft and the wind direction, measured clockwise from the heading to the direction from which the

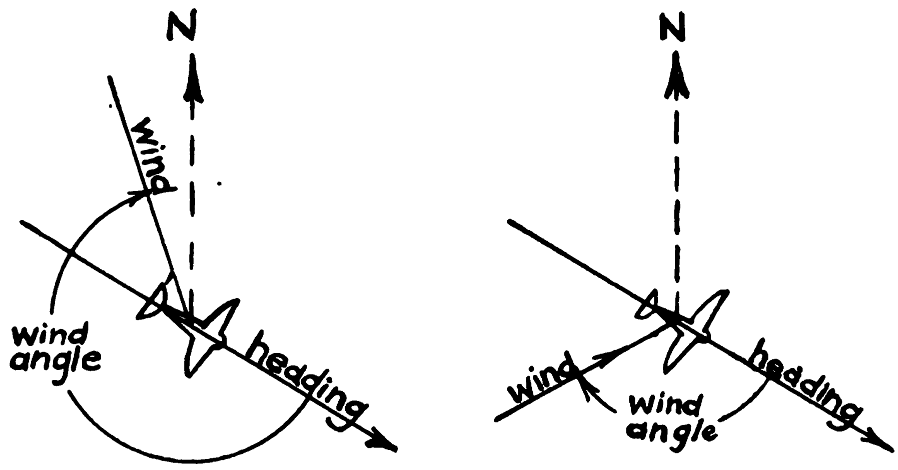


FIGURE 91.—Wind angle when determining wind from double drift measurements (fig. 100).

wind blows. Thus, this wind angle is measured from 0° to 360°, always clockwise from heading. (See fig. 91.)

b. The precision navigator almost invariably uses distances in nautical miles, true speeds in knots, and true directions when solving the triangle of velocities. The reason for using nautical-mile units is the fact that 1 minute of latitude equals 1 nautical mile, and the latitude scale is the one used in measuring distances on the chart. The reason for using true directions is to avoid the confusion which often results from solving the triangle with one vector expressed as a true direction (usually the wind) and the others as magnetic or compass directions. No inconvenience or loss of time ensues from using vectors expressed in nautical-mile units and with respect to true north. To aid him in distinguishing between the various directions and speeds, the navigator has his log sheet, adequately columned, always available.

157. Usual problems of precision navigator.—*a*. A review of the triangle of velocities described in section VI, chapter 1, will show that the triangle is composed of the following three vectors:

Wind direction and force.
Heading and air speed.
Track (or course to be made good) and ground speed.

b. Comprising the three vectors listed above are three directions and three speeds. If any two directions and any two speeds are known, the two remaining quantities may be determined by solving the triangle of velocities. The navigator is not normally concerned with solutions involving all possible combinations of two known directions and two known speeds. However, he is concerned with the solution of the triangle when certain of these combinations are known.

c. (1) The three most common problems with which the precision navigator must cope are—

(*a*) Given: Course to be made good and true air speed.
Find: Ground speed and true heading.

(*b*) Given: Course to be made good and scheduled ground speed which must be maintained.
Find: True air speed and true heading.

(*c*) Given: Heading and true air speed.
Find: Track and ground speed.

(2) The solutions of the three preceding problems require a knowledge of the wind direction and force as an intermediate step before the required quantities may be found. Although this wind information may be secured from available meteorological data, that is not the usual source. Rather, the wind is determined by the navigator in flight by a method known as the double drift or drift on multiple-headings method. This method requires an understanding of the proper way to combine the headings, air speeds, and drift angles of two triangles of velocities for the purpose of determining

wind and ground speed. Obviously, it is essential that the navigator understand the solution of a single triangle before he attempts to combine two or more. Therefore, the method of determining wind in flight will not be described until the student has complete grasp of the solution of the single triangle.

(3) The navigator occasionally finds it necessary to solve the triangle when the given and required quantities are different from those listed in (1) above. Included among the examples which follow in this section are a few of the uncommon problems.

(4) Referring to the three problems in (1) above, the precision navigator has no difficulty in finding the true heading necessary to make good a required course; nor is he troubled in finding the course being made good while the aircraft is flying a constant heading. He simply reads the drift as indicated by the drift meter and applies this angle (drift or drift correction) with proper sign to the known direction in order to find the unknown. Finding the ground speed when the air speed is given and finding the air speed which must be maintained to make good a scheduled ground speed are not so simple.

158. Methods of solving vector triangle.—The triangle of velocities may be solved—

a. By construction.—This is principally a classroom method and provides an excellent means of illustrating the principles involved. It is a laborious method and therefore is seldom used in the air or at any other time when quick results are desired.

b. By computer.—This is essentially the same as solving by construction. However, it is distinguished by the fact that few if any construction lines need be drawn as they are already incorporated on the computer. The standard Air Corps computer is the type E-6B. This computer provides a rapid solution and is most frequently used for preflight planning and during flight.

c. By tables.—Tables provide an alternate means when computers are not available. Tables are distinguished by their cheapness and the ease with which they may be reproduced. They are faster than solving by construction but slower than the computer.

159. Problem No. 1.

Given: Wind force and direction 30 knots from 315°.
Heading (true) 165°.
Air speed (true) 180 knots.
Find: Track.
Ground speed.

a. Solution by construction.—The procedure in solving by construction is similar to that used in paragraph 48*b*.

b. Solution by E-6B computer.—(1) When using the E-6B computer to solve problems in which heading is given, the center line of the chart is used to represent the heading line. Hence, air speeds

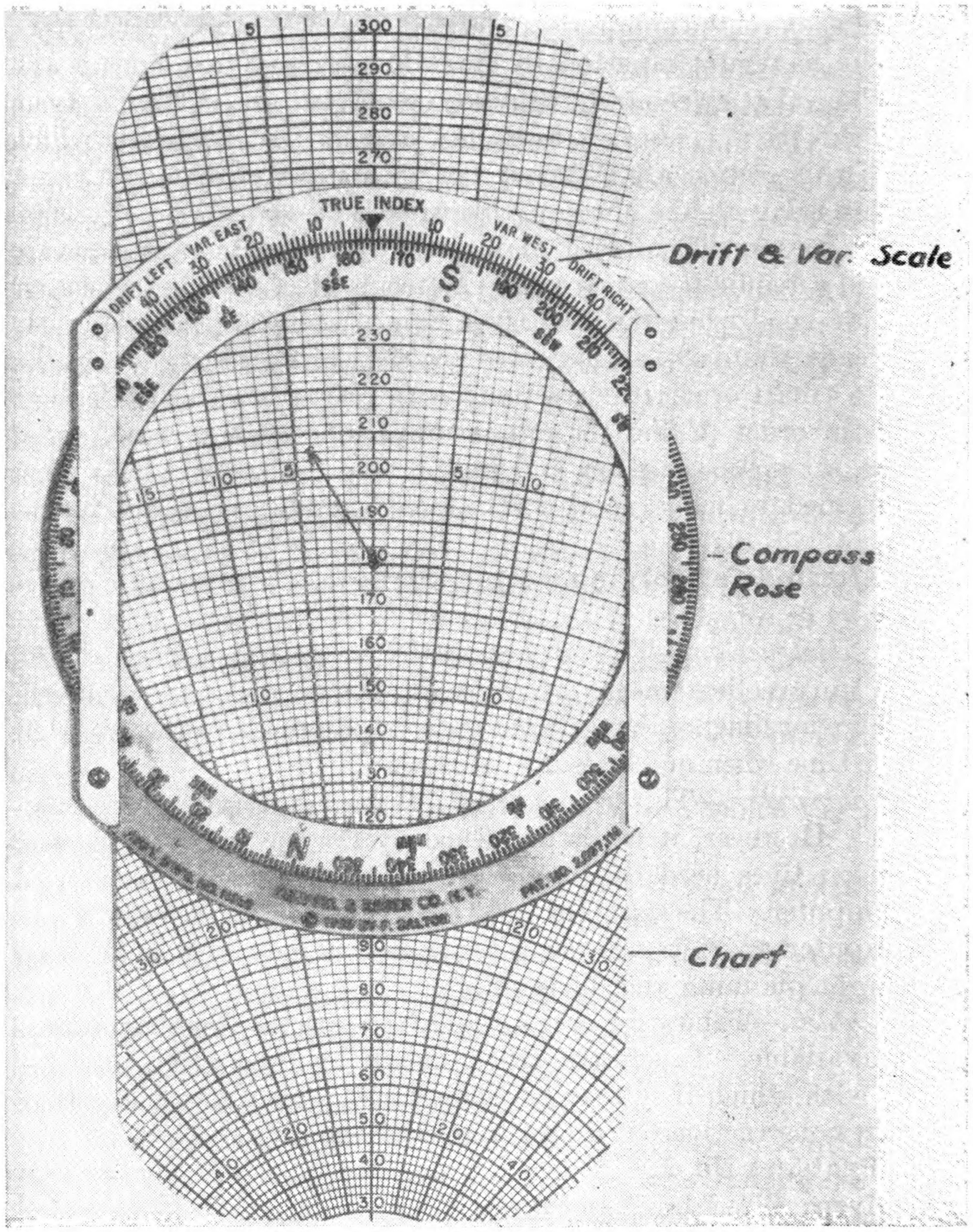


FIGURE 92.—Problem No. 1 (par. 159).

will be measured along this center line. The track (course) line will be one of the radiating lines to the right or left of the center line, and ground speed will be indicated along this radiating line. The drift, being measured from heading to track (course), will be read from the center line to the right or left to the track (course) line. In this type of problem the wind must be plotted from the center of the plotting disk straight down the center line of the chart. The tail of the wind arrow is at the center of the disk.

(2) Refer to figure 92. Turn compass rose to read 315°, the direction from which the wind is blowing, at "true index." Plot wind arrow from center of plotting disk straight down center line of chart 30 units according to scale of center line. Set heading (165°) at true index and slide chart to read air speed (180 knots) at center mark of transparent disk. At end of wind arrow read from radiating track (course) lines and speed circles of chart the drift (4° L.) and ground speed (206 knots). Opposite 4° left on drift and variation scale read track (161° true).

(3) In solving vector triangles on the E-6B, it infrequently occurs that the end of one of the vectors falls off the transparent disk, thus preventing solution unless half-hour vector lengths are used instead of hourly lengths. When this occurs, the proper procedure is to divide the lengths of all known vectors by two before setting up on the computer. All vectors resulting from the solution will be read at one-half their true values. Throughout this procedure, angles must not be reduced to one-half value. If any vector falls off the plotting disk when reduced to half-hour lengths, the problem may be worked by reducing all vectors to quarter-hour lengths.

c. Solution by tables in figure 93.—(1) One of the entering arguments when using this table is wind angle measured to the right or left from course as described in paragraph 126*a*(1). As the course is not given, the navigator in flight must first determine the course being made good by applying the drift as read from the drift sight to the given heading. If the problem is not solved in flight, no great error will result when computing wind angle by assuming that the heading and the course are the same. This assumption is acceptable except under conditions of extreme divergence of course and heading lines.

(2) Assume drift is measured as 4° L. Then the course being made good is 161°. The wind angle is $315° - 161° = 154°$, which for convenience in entering the table will be considered 155°. Select that section of the table which is headed "air speed 180 knots." In the wind column marked 30 knots and along the line marked wind angle 155° (interpolating between 150° and 160°), read wind correction (4°) and ground speed (206 knots). To determine whether the drift correction should be added to or subtracted from the course, the recommended procedure is to draw a free-hand sketch of the

AIR SPEED 100 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	90	0	85	0	80	0	75	0	70	0	60
10	1	90	1	85	2	80	2	75	3	70	4	60
20	2	90	3	86	4	81	5	76	6	71	8	62
30	3	91	4	87	6	82	7	78	9	73	12	64
40	4	92	6	88	7	84	9	80	11	75	15	66
50	4	93	7	90	9	86	11	82	13	78	18	70
60	5	94	7	92	10	89	13	85	15	82	20	74
70	5	96	8	94	11	92	14	89	16	86	22	79
80	6	98	8	96	11	95	14	93	17	90	23	85
90	6	100	9	99	12	98	14	97	17	95	24	92
100	6	101	8	102	11	102	14	101	17	101	23	99
110	5	103	8	104	11	105	14	106	16	106	22	106
120	5	105	7	107	10	108	13	110	15	112	20	114
130	4	106	7	109	9	112	11	114	13	116	18	121
140	4	107	6	111	7	114	9	118	11	121	15	127
150	3	108	4	113	6	117	7	121	9	126	12	133
160	2	109	3	114	4	119	5	123	6	128	8	137
170	1	110	1	115	2	120	2	124	3	129	4	139
180	0	110	0	115	0	120	0	125	0	130	0	140

AIR SPEED 105 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	95	0	90	0	85	0	80	0	75	0	65
10	1	95	1	90	2	85	2	80	3	75	4	66
20	2	95	3	91	4	86	5	81	6	76	8	67
30	3	96	4	92	6	87	7	83	9	78	11	69
40	4	97	6	93	7	89	9	85	11	80	13	71
50	4	98	7	95	9	91	11	87	13	83	17	75
60	5	100	7	97	10	94	12	90	15	87	19	79
70	5	101	8	99	11	97	13	94	16	91	21	85
80	6	103	8	101	11	100	14	98	17	96	22	91
90	6	105	9	104	11	103	14	102	17	101	23	97
100	6	107	8	107	11	107	14	107	17	106	22	105
110	5	108	8	109	11	111	13	111	16	111	21	112
120	5	110	7	112	10	114	12	115	15	117	19	119
130	4	111	7	114	9	117	11	119	13	122	17	126
140	4	112	6	116	7	119	9	123	11	126	15	132
150	3	113	4	118	6	122	7	126	9	130	11	136
160	2	114	3	119	4	124	5	128	6	132	8	142
170	1	115	1	120	2	125	2	129	3	134	4	144
180	0	115	0	120	0	125	0	130	0	135	0	145

AIR SPEED 110 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	100	0	95	0	90	0	85	0	80	0	70
10	1	100	1	95	2	90	2	85	3	80	4	71
20	2	100	3	96	4	91	4	86	5	81	7	72
30	3	101	4	97	5	93	6	88	8	83	10	74
40	3	102	5	98	7	94	8	90	10	85	14	76
50	4	103	6	100	8	96	10	92	12	88	16	80
60	5	105	7	102	9	99	11	95	14	92	18	84
70	5	106	7	104	10	102	12	99	15	96	20	90
80	5	108	8	106	10	105	13	103	16	100	21	96
90	5	110	8	109	10	108	13	107	16	106	21	102
100	5	112	8	112	10	112	13	112	16	111	21	110
110	5	113	7	114	10	116	12	116	15	116	20	117
120	5	115	7	117	9	119	11	120	14	122	18	124
130	4	116	6	119	8	122	10	124	12	127	16	131
140	3	117	5	121	7	125	8	128	10	131	14	137
150	3	118	4	123	5	127	6	131	8	135	10	143
160	2	119	3	124	4	129	4	133	5	138	7	147
170	1	120	1	125	2	130	2	134	3	139	4	149
180	0	120	0	125	0	130	0	135	0	140	0	150

AIR SPEED 115 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	105	0	100	0	95	0	90	0	85	0	75
10	1	105	1	100	2	95	2	90	3	85	4	76
20	2	105	3	101	4	96	4	91	5	87	7	77
30	3	106	4	102	5	97	6	93	8	88	10	79
40	3	107	5	103	7	99	8	95	10	91	13	82
50	4	108	6	105	8	101	10	97	12	94	15	86
60	5	110	7	107	9	104	11	101	13	97	17	90
70	5	111	7	109	10	107	12	104	15	101	19	95
80	5	113	8	111	10	110	13	108	15	106	20	101
90	5	115	8	114	10	113	13	113	15	111	20	108
100	5	117	8	117	10	117	13	117	15	117	20	115
110	5	118	7	119	10	121	12	122	15	122	19	123
120	5	120	7	122	9	124	11	126	13	127	17	130
130	4	121	6	124	8	127	10	130	12	132	15	136
140	3	122	5	126	7	130	8	133	10	137	13	143
150	3	123	4	128	5	132	6	136	8	140	10	148
160	2	124	3	129	4	134	4	138	5	142	7	152
170	1	125	1	130	2	135	2	140	3	144	4	154
180	0	125	0	130	0	135	0	140	0	145	0	155

AIR SPEED 120 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	110	0	105	0	100	0	95	0	90	0	80
10	1	110	1	105	2	100	2	95	3	90	3	81
20	2	110	2	106	3	101	4	96	5	92	6	82
30	2	111	4	107	5	103	6	98	7	93	9	84
40	3	112	5	108	6	104	8	100	9	96	12	87
50	4	113	6	110	7	106	9	102	11	99	14	91
60	4	115	6	112	8	109	10	106	12	102	16	95
70	5	116	7	114	9	112	11	109	14	106	17	100
80	5	118	7	116	9	115	12	113	14	111	18	106
90	5	120	7	119	10	118	12	118	14	116	18	113
100	5	122	7	122	9	122	12	122	14	122	18	120
110	5	123	7	124	9	126	11	127	14	127	17	128
120	4	125	6	127	8	129	10	131	12	132	16	135
130	4	126	6	129	7	132	9	135	11	137	14	142
140	3	128	5	131	6	135	8	138	9	142	12	148
150	2	129	4	133	5	137	6	141	7	145	9	153
160	2	129	2	134	3	139	4	143	5	148	6	157
170	1	130	1	135	2	140	2	145	3	149	3	159
180	0	130	0	135	0	140	0	145	0	150	0	160

AIR SPEED 125 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	115	0	110	0	105	0	100	0	95	0	85
10	1	115	1	110	2	105	2	100	3	95	3	86
20	2	115	2	111	3	106	4	101	5	97	6	87
30	2	116	4	112	5	107	6	103	7	98	9	89
40	3	117	5	113	6	109	8	105	9	101	12	92
50	4	118	6	115	7	111	9	108	11	104	14	96
60	4	120	6	117	8	114	10	111	12	107	16	100
70	5	121	7	119	9	117	11	114	14	112	17	106
80	5	123	7	122	9	120	12	118	14	116	18	112
90	5	125	7	124	10	124	12	123	14	122	18	119
100	5	127	7	127	9	127	12	127	14	127	18	126
110	5	128	7	130	9	131	11	132	14	132	17	133
120	4	130	6	132	8	134	10	136	12	138	16	141
130	4	131	6	134	7	137	9	140	11	143	14	147
140	3	133	5	136	6	140	8	143	9	147	12	153
150	2	134	4	138	5	142	6	146	7	150	9	158
160	2	134	2	139	3	144	4	148	5	152	6	162
170	1	135	1	140	2	145	2	150	3	154	3	164
180	0	135	0	140	0	145	0	150	0	155	0	165

① Air speed 100 to 125 knots or m. p. h.

FIGURE 93.—Tables for ground speed and drift (wind angle from course to right or left).

AIR SPEED 130 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G.S.	15 m. p. h. Drift Corr.	15 m. p. h. G.S.	20 m. p. h. Drift Corr.	20 m. p. h. G.S.	25 m. p. h. Drift Corr.	25 m. p. h. G.S.	30 m. p. h. Drift Corr.	30 m. p. h. G.S.	40 m. p. h. Drift Corr.	40 m. p. h. G.S.
0	0	120	0	115	0	110	0	105	0	100	0	90
10	1	120	1	115	2	110	2	105	2	100	3	91
20	1	120	2	116	3	111	4	106	4	101	6	92
30	2	121	3	117	4	112	6	108	7	103	9	94
40	3	122	4	118	6	114	7	110	9	106	11	97
50	3	123	5	120	7	116	8	113	10	109	14	101
60	4	125	6	122	8	119	10	116	12	112	15	106
70	4	126	6	124	8	122	10	119	13	117	17	111
80	4	128	6	127	9	125	11	123	13	121	18	117
90	4	130	7	129	9	129	11	128	13	127	18	124
100	4	132	6	132	9	132	11	132	13	133	18	131
110	4	133	6	134	8	136	10	136	13	137	17	138
120	4	135	6	137	8	139	10	141	12	143	15	146
130	3	136	5	139	7	142	8	145	10	148	14	152
140	3	137	4	141	6	145	7	148	9	152	11	158
150	2	138	3	143	4	147	6	151	7	155	9	163
160	1	139	2	144	3	149	4	153	4	158	6	167
170	1	140	1	145	2	150	2	155	2	159	3	169
180	0	140	0	145	0	150	0	155	0	160	0	170

AIR SPEED 135 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G.S.	15 m. p. h. Drift Corr.	15 m. p. h. G.S.	20 m. p. h. Drift Corr.	20 m. p. h. G.S.	25 m. p. h. Drift Corr.	25 m. p. h. G.S.	30 m. p. h. Drift Corr.	30 m. p. h. G.S.	40 m. p. h. Drift Corr.	40 m. p. h. G.S.
0	0	125	0	120	0	115	0	110	0	105	0	95
10	1	125	1	120	2	115	2	110	2	105	3	96
20	1	125	2	121	3	116	4	111	4	106	6	97
30	2	126	3	122	4	118	6	113	7	108	9	99
40	3	127	4	123	6	119	7	115	9	112	11	102
50	3	128	5	125	7	121	8	118	10	114	14	106
60	4	130	6	127	8	124	10	121	12	117	15	111
70	4	131	6	129	9	127	10	125	13	122	17	116
80	4	133	6	132	9	130	11	129	13	127	18	122
90	4	135	7	134	9	134	11	133	13	132	18	129
100	4	137	6	137	9	137	11	137	13	137	18	137
110	4	138	6	140	9	141	10	142	13	143	17	144
120	4	140	6	142	8	144	10	146	12	148	15	151
130	3	141	5	144	7	147	8	150	10	153	14	157
140	3	143	4	146	6	150	7	153	9	157	11	163
150	2	144	3	148	4	152	6	156	7	160	9	168
160	1	145	2	149	3	154	4	158	4	162	6	172
170	1	145	1	150	2	155	2	160	2	164	3	174
180	0	145	0	150	0	155	0	160	0	165	0	175

AIR SPEED 140 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G.S.	15 m. p. h. Drift Corr.	15 m. p. h. G.S.	20 m. p. h. Drift Corr.	20 m. p. h. G.S.	25 m. p. h. Drift Corr.	25 m. p. h. G.S.	30 m. p. h. Drift Corr.	30 m. p. h. G.S.	40 m. p. h. Drift Corr.	40 m. p. h. G.S.
0	0	130	0	125	0	120	0	115	0	110	0	100
10	1	130	1	125	1	120	2	115	2	110	3	100
20	1	130	2	126	3	121	3	116	4	111	6	102
30	2	131	3	127	4	123	5	118	6	113	8	104
40	3	132	4	128	5	124	7	120	8	117	11	107
50	3	133	5	130	6	126	8	123	9	119	13	111
60	3	135	5	132	7	129	9	126	11	122	14	116
70	4	136	6	134	8	132	10	130	12	127	16	121
80	4	138	6	136	8	135	10	134	12	132	16	127
90	4	140	6	139	8	139	10	138	12	137	17	134
100	4	142	6	142	8	143	10	142	12	142	16	142
110	4	143	6	145	8	146	10	147	12	148	16	149
120	3	145	5	147	7	149	9	151	11	153	14	156
130	3	146	5	149	6	152	8	155	9	158	13	162
140	3	148	4	151	5	155	7	158	8	162	11	168
150	2	149	3	153	4	157	5	161	6	165	8	173
160	1	150	2	154	3	159	3	163	4	168	6	177
170	1	150	1	155	1	160	2	164	2	169	3	179
180	0	150	0	155	0	160	0	165	0	170	0	180

AIR SPEED 145 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G.S.	15 m. p. h. Drift Corr.	15 m. p. h. G.S.	20 m. p. h. Drift Corr.	20 m. p. h. G.S.	25 m. p. h. Drift Corr.	25 m. p. h. G.S.	30 m. p. h. Drift Corr.	30 m. p. h. G.S.	40 m. p. h. Drift Corr.	40 m. p. h. G.S.
0	0	135	0	130	0	125	0	120	0	115	0	105
10	1	135	1	130	1	125	2	120	2	115	3	105
20	1	135	2	131	3	126	3	121	4	116	6	107
30	2	136	3	132	4	128	5	123	6	118	8	109
40	3	137	4	133	5	129	7	125	8	122	11	112
50	3	138	5	135	6	132	8	128	9	124	13	116
60	4	140	5	137	7	134	9	131	11	128	14	121
70	4	141	6	139	8	137	10	135	12	132	15	127
80	4	143	6	142	8	141	10	138	12	137	16	133
90	4	145	6	144	8	144	10	143	12	142	16	139
100	4	147	6	147	8	147	10	147	12	148	16	147
110	4	149	6	150	8	151	10	152	12	153	15	154
120	4	150	5	152	7	154	9	156	11	158	14	161
130	3	151	5	154	6	157	8	160	9	163	13	168
140	3	153	4	156	5	160	7	163	8	167	11	173
150	2	154	3	158	4	162	5	166	6	170	8	178
160	1	155	2	159	3	164	3	168	4	172	6	182
170	1	155	1	160	1	165	2	170	2	174	3	184
180	0	155	0	160	0	165	0	170	0	175	0	185

AIR SPEED 150 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G.S.	15 m. p. h. Drift Corr.	15 m. p. h. G.S.	20 m. p. h. Drift Corr.	20 m. p. h. G.S.	25 m. p. h. Drift Corr.	25 m. p. h. G.S.	30 m. p. h. Drift Corr.	30 m. p. h. G.S.	40 m. p. h. Drift Corr.	40 m. p. h. G.S.
0	0	140	0	135	0	130	0	125	0	120	0	110
10	1	140	1	135	1	130	2	125	2	120	3	110
20	1	140	2	136	3	131	3	126	4	121	5	112
30	2	141	3	136	4	132	5	128	6	123	8	114
40	2	142	4	138	5	134	6	130	7	126	10	117
50	3	143	4	140	6	137	7	133	9	129	12	121
60	3	145	5	142	7	139	8	136	10	133	13	126
70	4	146	5	144	7	142	9	140	11	137	14	132
80	4	148	6	147	8	146	9	142	11	142	15	138
90	4	150	6	149	8	149	10	148	12	147	15	145
100	4	152	6	152	8	152	9	152	11	153	15	152
110	4	154	5	155	7	156	9	157	11	158	14	159
120	3	155	5	157	7	159	8	161	10	163	13	166
130	3	156	4	159	6	162	7	165	9	168	12	173
140	2	157	4	161	5	165	6	168	7	172	10	178
150	2	158	3	163	4	167	5	171	6	175	8	183
160	1	159	2	164	3	169	3	173	4	178	5	187
170	1	160	1	165	1	170	2	175	2	179	3	189
180	0	160	0	165	0	170	0	175	0	180	0	190

AIR SPEED 155 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G.S.	15 m. p. h. Drift Corr.	15 m. p. h. G.S.	20 m. p. h. Drift Corr.	20 m. p. h. G.S.	25 m. p. h. Drift Corr.	25 m. p. h. G.S.	30 m. p. h. Drift Corr.	30 m. p. h. G.S.	40 m. p. h. Drift Corr.	40 m. p. h. G.S.
0	0	145	0	140	0	135	0	130	0	125	0	115
10	1	145	1	140	1	135	2	130	2	125	3	115
20	1	145	2	141	3	136	3	131	4	126	5	117
30	2	146	3	142	4	137	5	133	6	128	8	119
40	2	147	4	143	5	139	6	135	7	131	10	122
50	3	148	4	145	6	142	7	138	9	134	12	126
60	3	150	5	147	7	144	8	141	10	138	13	131
70	4	151	5	149	7	147	9	145	11	143	14	137
80	4	153	6	152	8	151	9	148	11	147	15	143
90	4	155	6	154	8	154	10	153	12	152	15	150
100	4	157	6	157	8	157	9	158	11	158	15	157
110	4	159	5	160	7	161	9	163	11	163	14	165
120	3	160	5	162	7	164	8	166	10	168	13	171
130	3	161	4	164	6	167	7	170	9	173	12	178
140	2	163	4	166	5	170	6	174	7	177	10	184
150	2	164	3	168	4	172	5	176	6	181	8	189
160	1	164	2	169	3	174	3	178	4	182	5	192
170	1	165	1	170	1	175	2	180	2	184	3	194
180	0	165	0	170	0	175	0	180	0	185	0	195

② Air speed 130 to 155 knots or m. p. h.

FIGURE 93.—Tables for ground speed and drift (wind angle from course to right or left)—Continued.

AIR SPEED 160 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	150	0	145	0	140	0	135	0	130	0	120
10	1	150	1	145	1	140	2	135	2	130	2	120
20	1	150	2	146	2	141	3	136	4	131	5	122
30	2	151	3	147	4	142	4	138	5	133	7	124
40	2	152	3	148	5	144	6	140	7	136	9	127
50	3	153	4	150	5	147	7	143	8	139	11	131
60	3	154	5	152	6	149	8	146	9	143	13	136
70	3	156	5	154	7	152	8	150	10	148	14	142
80	4	158	5	157	7	156	9	154	11	152	14	148
90	4	159	5	159	7	159	9	158	11	157	15	155
100	4	162	5	162	7	162	9	163	11	163	14	162
110	3	164	5	165	7	166	8	167	10	168	14	170
120	3	165	5	167	6	169	8	171	9	173	13	176
130	3	166	4	169	5	172	7	175	8	178	11	183
140	2	168	3	171	5	175	6	179	7	182	9	189
150	2	169	3	173	4	177	4	181	5	186	7	194
160	1	169	2	174	2	179	3	183	4	188	5	197
170	1	170	1	175	1	180	2	185	2	189	2	199
180	0	170	0	175	0	180	0	185	0	190	0	200

AIR SPEED 165 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	155	0	150	0	145	0	140	0	135	0	125
10	1	155	1	150	1	145	2	140	2	135	2	125
20	1	155	2	151	2	146	3	141	4	136	5	127
30	2	156	3	152	4	148	4	143	5	139	7	129
40	2	157	3	153	5	150	6	145	7	141	9	132
50	3	158	4	155	5	152	7	148	8	144	11	136
60	3	160	5	157	6	155	8	151	9	148	13	141
70	3	161	5	159	7	158	8	155	10	153	14	147
80	4	163	5	162	7	161	9	159	11	157	14	153
90	4	165	5	164	7	164	9	163	11	163	14	160
100	4	167	5	167	7	168	9	168	11	168	14	167
110	3	169	5	170	7	171	8	172	10	173	14	175
120	3	170	5	172	6	174	8	176	9	178	13	181
130	3	171	4	175	5	177	7	180	8	183	11	188
140	2	173	3	177	5	180	6	184	7	187	9	194
150	2	174	3	178	4	182	4	186	5	191	7	198
160	1	174	2	179	2	184	3	188	4	192	5	202
170	1	175	1	180	1	185	2	190	2	194	2	204
180	0	175	0	180	0	185	0	190	0	195	0	205

AIR SPEED 170 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	160	0	155	0	150	0	145	0	140	0	130
10	1	160	1	155	1	150	1	145	2	140	2	130
20	1	160	2	155	2	151	3	146	3	141	5	132
30	2	161	3	156	3	153	4	148	5	144	7	134
40	2	162	3	158	4	155	5	150	7	146	9	137
50	3	163	4	160	5	157	6	153	8	149	10	141
60	3	165	4	162	6	160	7	156	9	153	12	146
70	3	166	5	164	6	163	8	160	9	157	13	152
80	3	168	5	167	7	166	8	164	10	162	13	158
90	3	170	5	169	7	169	8	168	10	168	13	165
100	3	172	5	172	6	173	8	173	10	173	13	172
110	3	174	5	175	6	176	8	177	9	178	13	180
120	3	175	4	177	6	179	7	181	9	183	12	186
130	3	176	4	180	5	182	6	185	7	188	10	193
140	2	178	3	182	4	185	5	188	6	192	9	198
150	2	179	2	183	3	187	4	191	5	196	7	202
160	1	180	2	184	2	189	3	193	3	198	5	207
170	1	180	1	185	1	190	2	195	2	199	2	209
180	0	180	0	185	0	190	0	195	0	200	0	210

AIR SPEED 175 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	165	0	160	0	155	0	150	0	145	0	135
10	1	165	1	160	1	155	1	150	2	145	2	135
20	1	165	2	161	2	156	3	151	3	146	5	137
30	2	166	3	162	3	158	4	153	5	149	7	139
40	2	167	3	163	4	160	5	155	7	151	9	142
50	3	168	4	165	5	162	6	158	8	154	10	147
60	3	170	4	167	6	165	7	161	9	158	12	151
70	3	171	5	169	6	168	8	165	9	162	13	157
80	3	173	5	172	7	171	8	169	10	167	13	163
90	3	175	5	175	7	174	8	173	10	173	13	170
100	3	177	5	177	6	178	8	178	10	178	13	177
110	3	179	5	180	6	181	8	181	9	183	13	186
120	3	180	4	182	6	182	7	186	9	188	12	192
130	3	181	4	185	5	185	6	190	7	193	10	198
140	2	183	3	187	4	190	5	193	6	197	9	204
150	2	184	2	188	3	192	4	196	5	201	7	208
160	1	185	2	189	2	194	3	198	3	202	5	212
170	1	185	1	190	1	195	2	200	2	204	2	214
180	0	185	0	190	0	195	0	200	0	205	0	215

AIR SPEED 180 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	170	0	165	0	160	0	155	0	150	0	140
10	1	170	1	165	1	160	1	155	2	150	2	140
20	1	170	2	166	2	161	3	156	3	151	4	142
30	2	171	2	167	3	163	4	158	5	153	6	144
40	2	172	3	168	4	164	5	160	6	156	8	147
50	2	173	4	170	5	167	6	163	7	159	10	152
60	3	175	4	172	6	169	7	166	8	163	11	156
70	3	176	5	174	6	172	8	170	9	167	12	162
80	3	178	5	177	6	176	8	174	9	172	13	168
90	3	180	5	180	6	179	8	178	9	177	13	175
100	3	182	5	182	6	183	8	183	9	182	13	182
110	3	184	5	185	6	186	8	185	9	188	12	190
120	3	185	4	187	6	189	7	191	8	193	11	197
130	2	186	4	189	5	192	6	195	7	198	10	203
140	2	188	3	191	4	195	5	198	6	202	8	209
150	2	189	2	193	3	197	4	201	5	205	6	214
160	1	190	2	194	2	198	3	203	3	206	4	217
170	1	190	1	195	1	200	1	205	2	209	2	219
180	0	190	0	195	0	200	0	205	0	210	0	220

AIR SPEED 185 KNOTS OR MILES PER HOUR

Wind angle	10 m. p. h. Drift Corr.	10 m. p. h. G./S.	15 m. p. h. Drift Corr.	15 m. p. h. G./S.	20 m. p. h. Drift Corr.	20 m. p. h. G./S.	25 m. p. h. Drift Corr.	25 m. p. h. G./S.	30 m. p. h. Drift Corr.	30 m. p. h. G./S.	40 m. p. h. Drift Corr.	40 m. p. h. G./S.
0	0	175	0	170	0	165	0	160	0	155	0	145
10	1	175	1	170	1	165	1	160	2	155	2	145
20	1	175	2	171	2	166	3	161	3	157	4	147
30	2	176	2	172	3	168	4	163	5	159	6	150
40	2	177	3	173	4	170	5	165	6	161	8	153
50	2	178	4	175	5	172	6	168	7	165	10	157
60	3	180	4	177	6	175	7	171	8	168	11	162
70	3	181	5	179	6	178	8	175	9	173	12	168
80	3	183	5	182	6	181	8	179	9	177	13	174
90	3	185	5	185	6	185	8	183	9	183	13	181
100	3	187	5	187	6	188	8	188	9	188	13	188
110	3	189	5	190	6	191	8	191	9	193	12	196
120	3	191	4	192	6	195	7	197	8	199	11	202
130	2	192	4	194	5	197	6	201	7	203	10	208
140	2	193	3	196	4	200	5	204	6	207	8	214
150	2	194	2	198	3	202	4	207	5	211	6	220
160	1	195	2	199	2	204	3	209	3	212	4	223
170	1	195	1	200	1	205	1	210	2	215	2	224
180	0	195	0	200	0	205	0	210	0	215	0	225

③ Air speed 160 to 185 knots or m. p. h.

FIGURE 93.—Tables for ground speed and drift (wind angle from course to right or left)—Continued.

course and wind direction. The sign of the correction will thus be made readily apparent. A sketch shows the drift correction in the example to be positive (plus), making the heading 165°, which checks with that given in the problem.

(3) In using this table, interpolations by eye may be made, depending on the degree of accuracy desired.

(4) From the foregoing discussion, it will be seen that the ground speed and drift tables are ill-suited for solving problems in which the heading but not course is known. For this reason, the table finds its greatest application as a means of precomputing ground speed and heading for a desired course and air speed. Tables similar in arrangement to those shown in figure 93, but so constructed as to tabulate wind angle measured from heading instead of from course, have been published. This problem (No. 1) can be solved readily by such tables because it is not necessary to estimate or measure the drift first as was necessary when using the tables shown in figure 93. These "wind angles from heading" tables have been omitted from this manual for two reasons: first, the problem can be solved accurately and easily on the E-6B computer; and, second, the tables in figure 93 will solve the problem accurately when the course (or the heading and drift) is known beforehand, and approximately when the heading is known but the exact drift is unknown.

160. Problem No. 2.

Given: Wind force and direction, 40 knots from 90°.
Course to be made good, 215°.
Air speed (true), 160 knots.

Find: Heading (true).
Ground speed.

a. Solution by construction.—The procedure in solving by construction is similar to that used in paragraph 45*b*.

b. Solution by E-6B computer.—(1) When using the E-6B computer to solve problems in which course to be made good or track is given, the simplest procedure is to use the center line as the course (track) line. Ground speed will then be measured along the center line. The heading line will be one of the radiating lines to the right or left of the center line, and air speed will be indicated along the radiating line. The drift, being measured from heading to track, will be read from the radiating heading line to the right or left to the course (track) line which will be the center line of the chart. In solving problems in which the center line represents course (track), the wind must be plotted to the disk center from a point on the chart center line vertically above it. The head of the arrow is at the center of the disk.

(2) Refer to figure 94. Set compass rose to direction from which wind is blowing (90° true) and plot wind to center from a point 40 units above it. Set course (215° true) opposite true index. Move

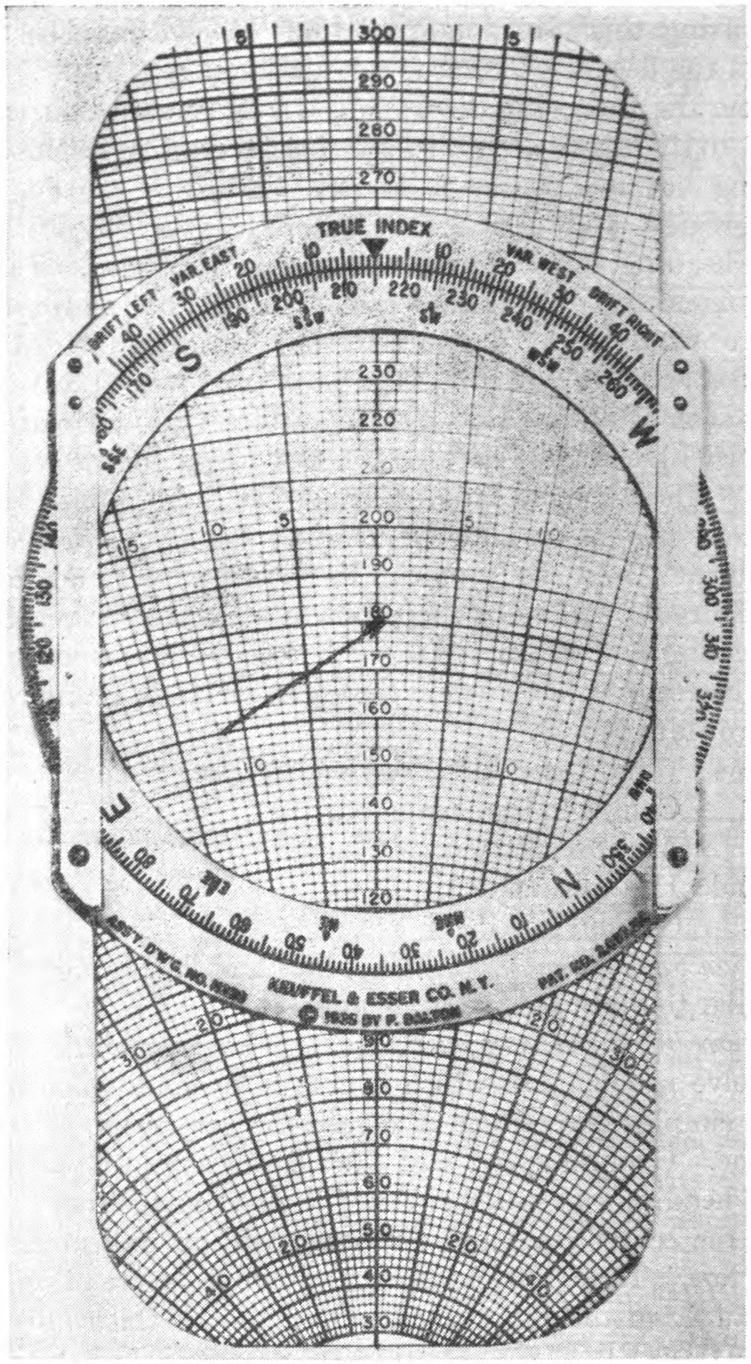


FIGURE 94.—Problem No. 2 (par. 160).

chart until tail of wind arrow falls on true air speed (160 knots) as indicated on concentric circles. Read ground speed (180 knots) at center of disk. Read drift (12° R.) at tail of wind arrow. Since the drift is 12° R., a true heading of 215°−12°=203° must be flown to make good the given course.

c. Solution by tables in figure 93.—The wind angle measured from course is 125°. Select that section of the table which is titled air speed 160 knots. Enter this table with wind (40 knots) and wind

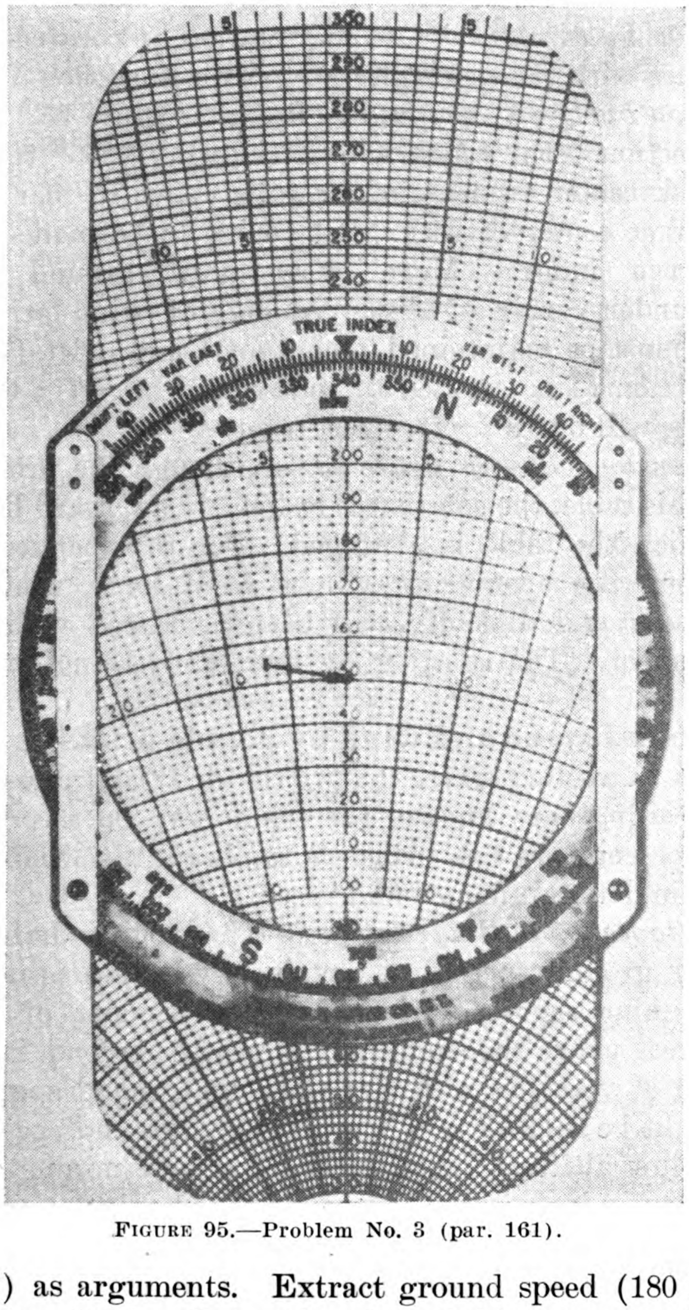


FIGURE 95.—Problem No. 3 (par. 161).

angle (125°) as arguments. Extract ground speed (180 knots) and drift correction (12°). Determine sign of this correction by drawing a free-hand sketch. The drift correction to be applied to course will be negative (minus); therefore, the true heading is 215°−12°=203°.

161. Problem No. 3.

Given: Wind force and direction, 20 knots from 260°.
Course to be made good, 340° true.
Scheduled ground speed, 150 knots.

Find: Heading.
Air speed (true) to make good scheduled ground speed.

a. Solution by construction.—The solution by construction is made in accordance with the principles laid down in section VI, chapter I.

b. Solution by E-6B computer.—Refer to figure 95. Set compass rose to direction from which wind is blowing (260° true) and plot wind to disk center from point 20 units above it, marking head of wind arrow at center of disk. Set course to be made good (340°) opposite true index. Move chart until ground speed (150 knots) is under center of disk. At tail of wind arrow read air speed that must be maintained (154 knots) and drift (7° R.). The drift correction to be applied to course will be −7°; therefore, the true heading will be 340° − 7° = 333° true.

c. Solution by tables in figure 93.—Although the problem may be solved by this table, the solution is extremely awkward because of the way in which the table is arranged. For this particular problem the three entering arguments will be wind force, wind angle, and ground speed; and difficulty will be experienced with the ground speed argument. The solution by this table, being impractical, is omitted.

162. Ground speed and wind by double drift.—*a. Principle.*—A principle of vectors states that if the drift and air speed on two or more headings are known, the wind may be ascertained. The air navigator employs this principle to obtain the wind information so essential in determining ground speed.

b. Advantages and disadvantages.—The double drift method of determining ground speed has certain advantages over the ground speed by timing method: first, it is independent of the altitude of the aircraft above the surface of the earth; second, it can be used when flying at very low altitudes when the ground speed by timing method might be difficult. When using the ground speed by timing method at low altitudes, a small error in determining the absolute altitude causes a large error in ground speed calculations. The disadvantages of the double drift method are: first, it depends on knowing the true air speed; and, second, it requires that the aircraft be turned from the on-course heading for short intervals.

c. Procedure (fig. 96).—(1) The procedure for taking a double drift is as follows:

(*a*) Record true air speed while flying the on-course heading.

(*b*) Take up a heading 45° to right of on-course heading and read drift.

(*c*) Make a 90° left turn so that heading of airplane is 45° to left of on-course heading and read drift.

(*d*) Resume on-course heading.

(*e*) *Precaution:* Care should be taken to maintain straight and level flight at a constant air speed while on the aforementioned headings. The length of time the airplane should be held on the second leg should be so estimated that when the on-course heading is resumed, the airplane will be making good the desired course. It is common practice to remain on the left leg the same length of time as was spent

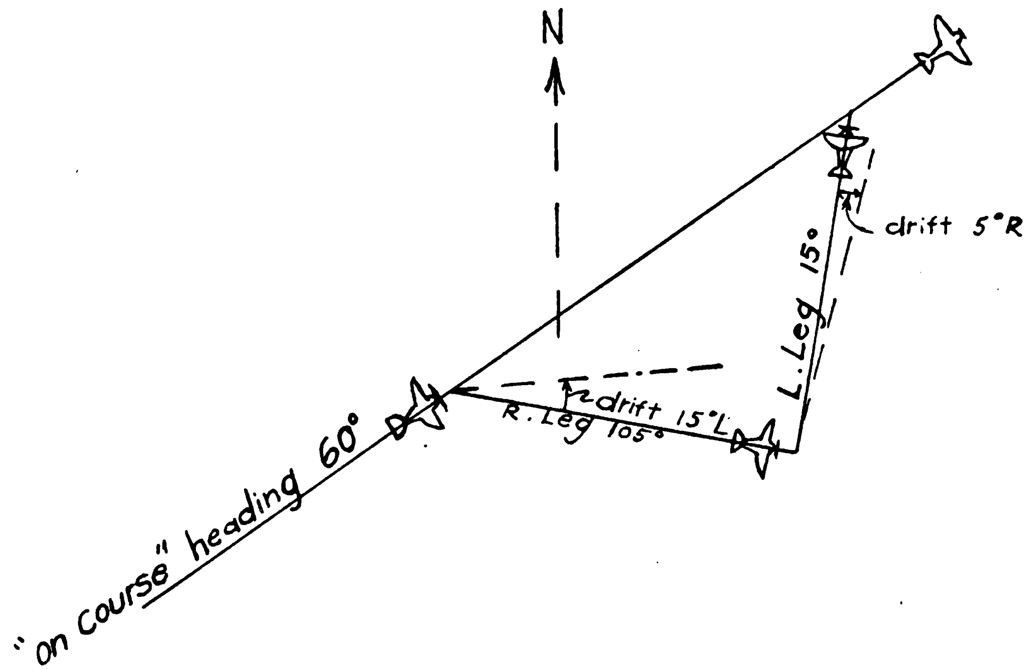


FIGURE 96.—Taking a double drift.

on the right leg. This procedure is mathematically incorrect, but the error is slight if the airplane has been turned off the on-course heading not more than 2 or 3 minutes on each leg.

(2) It is advisable although not essential to fly alternate headings of 45° on either side of the on-course heading. 45° legs are necessary, however, if the tables in figures 99 and 100 are to be used in reducing these data. By obtaining drift on two headings separated by 90° a good vector intersection is assured as will be seen.

d. Example.—Assume the navigator of an aircraft to have taken a double drift under the following conditions:

Given: On-course heading, 60° true.
Air speed (true), 120 knots.

On 45° right leg, drift was 15° L.
On 45° left leg, drift was 5° R.
Find: Ground speed on course being made good while flying the on-course heading.
Wind force and direction.

(1) *Solution by construction* (fig. 97).—(*a*) The solution by construction is sometimes referred to as the wind star method. Draw a circle with radius equal to air speed (120 knots). Draw *AO* representing original heading (60°). Draw *BO* representing heading while on right leg (105°). Draw *CO* representing heading on left leg (15°). From *B* draw an indefinite line *BX* so that angle *OBX* is equal to drift on right leg (15° L.). From *C* draw *CY* so that angle *OCY* is equal to drift on left leg (5° R.). *BX* and *BY* intersect at *W*. Draw *OW*. The length of *OW* represents the wind force (38 knots). The wind direction is *OW* (from 215°) with the head of the wind arrow at *W*. *AW* is the ground speed (156 knots) while flying the on-course heading. Angle *OAW* is the drift (6° L.) while holding the on-course heading.

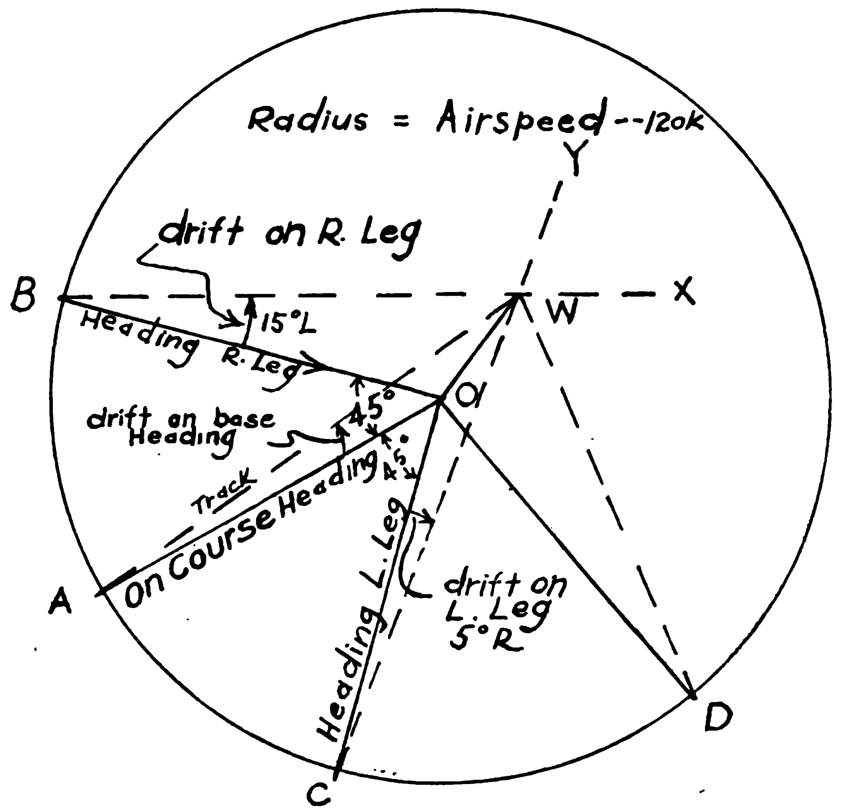


FIGURE 97.—Double drift solution by construction.

(*b*) The drift and ground speed while on any other heading such as *DO* will be the angle *ODW* and the length *DW*, respectively.

(c) It is apparent that if a construction diagram is drawn, the double drift legs need not be flown 45° to the right and left of the on-course heading so long as the actual headings are recorded and

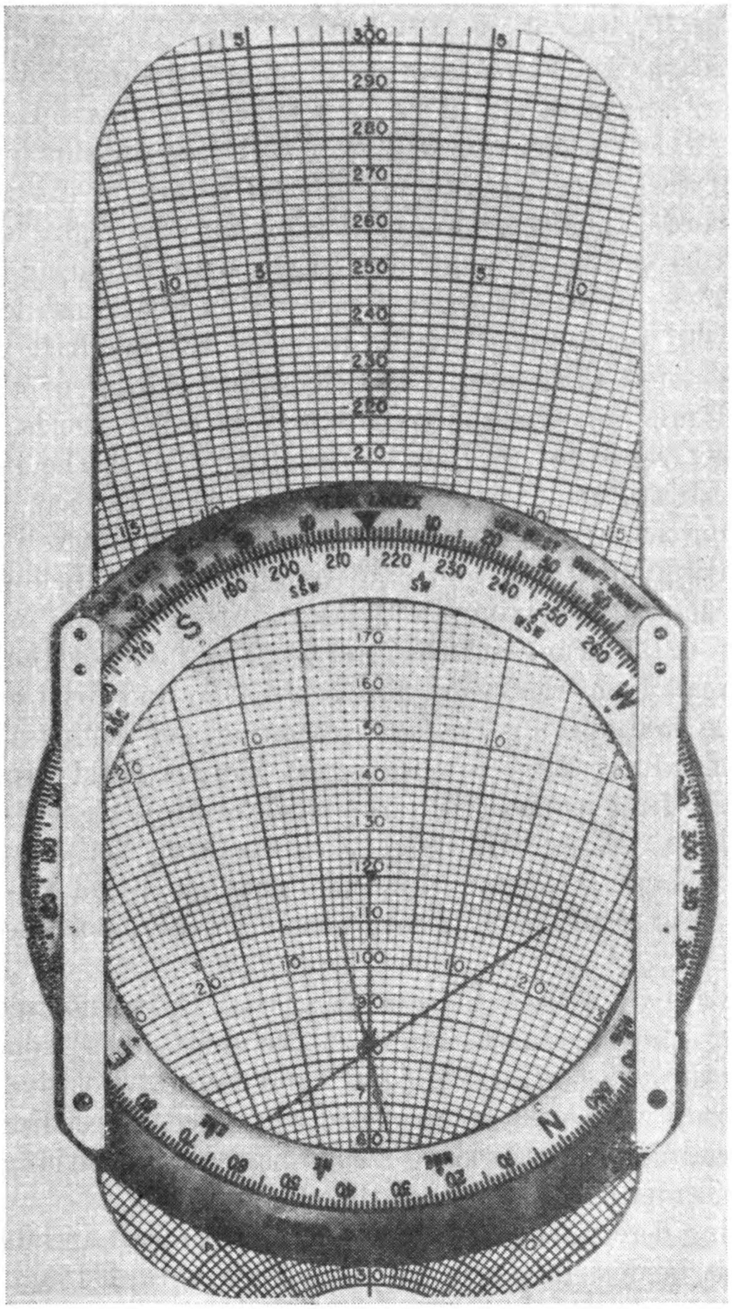


FIGURE 98.—Double drift on E–6 B computer.

correctly plotted. Also the radius of the air speed circle may be the air speed for only a portion of an hour, in which case the wind force and ground speeds measured from the diagram will be for the same part of an hour.

(*d*) In analyzing figure 97 it will be found of assistance to imagine 3 airplanes leaving *A*, *B*, and *C* simultaneously and heading for *O* at the same air speed. Under no-wind conditions they would meet at *O* at the end of 1 hour. Under the prevailing wind conditions they will meet at *W*.

(2) *Solution by E-6B computer* (fig. 98).—(*a*) Set air speed (120 knots) at center of disk. Set 60° on compass rose opposite 45° on drift left scale. It will be noted that in this position the heading of the right leg (105°) will fall opposite the true index; in other words, the center line will represent the right leg heading. Trace on disk a line of indefinite length over radiating line representing 15° L. drift, the drift measured on the right leg. Rotate disk until 60° on compass rose is opposite 45° on drift right scale. It will be noted that in this position the heading of the left leg (15°) will fall opposite the true index; in other words, the center line will not represent the left leg heading. Mark the point where the 5° R. drift line of the left leg heading intersects the 15° L. drift line on the right leg. This is the wind point. As in figure 98, rotate plotting disk to bring wind point vertically below center of disk (on chart center line) and read direction from which wind is blowing (215° true) at true index. The force of the wind (38 knots) is read from the center line scale. To find drift and ground speed while maintaining on-course heading, set compass rose with on-course heading (60°) opposite true index. Read ground speed (156 knots) from concentric circle scale and drift (6° L.) from radiating lines. This drift should correspond to that actually measured with the drift meter while the airplane is on the on-course heading. This third drift measurement serves as a check on accuracy.

(*b*) It is apparent from the foregoing that 45° turns need not have been made, since the intersection of the drift lines from any two headings will suffice to indicate the wind point. Positive assurance of an accurate wind measurement can be gained by reading the drift on three headings, thus forming a reasonably small "triangle of closing" whose center may be taken as the wind point.

(*c*) Having determined the wind, the ground speed and drift on any heading may be determined as described in paragraph 159.

(3) *Solution by tables in figures 99 and 100*.—(*a*) *General*.—The table in figure 99 is used to determine the ground speed factor. The table in figure 100 is used to determine the wind. Legs 45° to the right and left of the on-course heading must be flown. If the drift on either leg is greater than 20° the tables cannot be used. In both tables, the abscissa applies to drift measurements on the right leg, the ordinate to

drift measurements on the left leg. The columns to the right of the vertical center line of each table contain left drifts (+drift corrections) on the right leg. The columns to the left of the vertical center

RIGHT LEG

LEFT LEG DRIFT \ RIGHT LEG DRIFT	RIGHT (−) 20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	LEFT (+) 20
LEFT (+) 20	.62	.63	.64	.65	.65	.66	.67	.68	.69	.70	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.79	.80	.81	.82	.83	.83	.84	.85	.86	.87	.87	.88	.89	.90	.91	.92	.92	.93	.94	.95
19	.63	.64	.65	.65	.66	.67	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.80	.81	.82	.83	.84	.84	.85	.86	.87	.88	.89	.90	.90	.91	.92	.93	.94	.95	.95	.96
18	.64	.65	.65	.66	.67	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.80	.81	.82	.83	.84	.85	.85	.86	.87	.88	.89	.90	.91	.92	.92	.93	.94	.95	.96	.97	.98
17	.65	.65	.66	.67	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.80	.81	.82	.83	.84	.85	.86	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.95	.96	.97	.98	.99
16	.65	.66	.67	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.81	.82	.83	.84	.85	.86	.87	.88	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.00	1.01
15	.66	.67	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.81	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.92	.93	.94	.95	.96	.97	.98	1.00	1.00	1.01	1.02
14	.67	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	.99	1.01	1.02	1.02	1.03
13	.68	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.00	1.01	1.02	1.03	1.04	1.05
12	.69	.69	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.00	1.01	1.02	1.03	1.04	1.06	1.07
11	.70	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.00	1.02	1.03	1.04	1.05	1.06	1.07	1.08
10	.70	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.85	.87	.88	.89	.90	.91	.92	.93	.94	.96	.96	.98	.99	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.08	1.09	1.10
9	.71	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.83	.84	.85	.86	.86	.87	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.00	1.01	1.02	1.03	1.05	1.06	1.07	1.08	1.09	1.10	1.12
8	.72	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.83	.83	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08	1.10	1.11	1.12	1.13
7	.73	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	.99	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.13	1.14	1.15
6	.74	.74	.75	.76	.77	.78	.79	.80	.81	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	1.00	1.01	1.02	1.03	1.04	1.05	1.07	1.08	1.09	1.10	1.12	1.13	1.14	1.15	1.17
5	.75	.75	.76	.77	.78	.79	.80	.81	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.98	1.00	1.01	1.02	1.03	1.04	1.06	1.07	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.17	1.19
4	.75	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.99	1.00	1.01	1.02	1.03	1.05	1.06	1.07	1.08	1.10	1.11	1.12	1.14	1.15	1.16	1.18	1.19	1.20
3	.76	.77	.78	.79	.80	.81	.82	.82	.83	.84	.85	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.97	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.13	1.14	1.15	1.17	1.18	1.20	1.21	1.22
2	.77	.78	.79	.80	.81	.81	.82	.83	.84	.85	.87	.88	.89	.90	.91	.92	.93	.94	.95	.96	.98	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.13	1.14	1.15	1.17	1.18	1.20	1.21	1.23	1.24
1	.78	.79	.80	.81	.81	.82	.83	.84	.85	.86	.88	.89	.90	.91	.92	.93	.94	.95	.96	.98	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.10	1.12	1.13	1.14	1.16	1.17	1.19	1.20	1.22	1.23	1.25	1.26
0	.79	.80	.80	.81	.82	.83	.84	.85	.86	.87	.89	.90	.91	.92	.93	.94	.95	.96	.98	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.10	1.12	1.13	1.14	1.16	1.17	1.19	1.20	1.22	1.23	1.25	1.27	1.28
1	.80	.80	.81	.82	.83	.84	.85	.86	.87	.88	.90	.91	.92	.93	.94	.95	.96	.98	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.19	1.21	1.22	1.24	1.25	1.27	1.29	1.30
2	.80	.81	.82	.83	.84	.85	.86	.87	.88	.89	.91	.92	.93	.94	.95	.96	.98	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.18	1.19	1.21	1.22	1.24	1.26	1.27	1.29	1.31	1.32
3	.81	.82	.83	.84	.85	.86	.87	.88	.89	.90	.92	.93	.94	.95	.96	.97	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.12	1.14	1.15	1.16	1.18	1.19	1.21	1.22	1.24	1.26	1.27	1.29	1.31	1.33	1.35
4	.82	.83	.84	.85	.86	.87	.88	.89	.90	.91	.93	.94	.95	.96	.97	.99	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.24	1.26	1.28	1.29	1.31	1.33	1.35	1.37
5	.83	.84	.85	.86	.87	.88	.89	.90	.91	.92	.94	.95	.96	.97	.98	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.12	1.14	1.15	1.17	1.18	1.20	1.21	1.23	1.24	1.26	1.28	1.30	1.31	1.33	1.35	1.37	1.39
6	.84	.84	.85	.87	.88	.89	.90	.91	.92	.93	.95	.96	.97	.98	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.33	1.35	1.37	1.39	1.41
7	.84	.85	.86	.87	.89	.90	.91	.92	.93	.94	.96	.97	.98	.99	1.01	1.02	1.03	1.05	1.06	1.08	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.37	1.39	1.41	1.44
8	.85	.86	.87	.88	.89	.91	.92	.93	.94	.95	.97	.98	.99	1.01	1.02	1.03	1.05	1.06	1.07	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46
9	.86	.87	.88	.89	.90	.92	.93	.94	.95	.96	.98	.99	1.00	1.02	1.03	1.04	1.06	1.07	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.48
10	.87	.88	.89	.90	.91	.93	.94	.95	.96	.97	.99	1.00	1.02	1.03	1.04	1.06	1.07	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.19	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.51
11	.88	.89	.90	.91	.92	.93	.95	.96	.97	.99	1.00	1.01	1.03	1.04	1.05	1.07	1.08	1.10	1.12	1.13	1.15	1.16	1.18	1.19	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.51	1.54
12	.89	.90	.91	.92	.93	.94	.96	.97	.98	1.00	1.01	1.02	1.04	1.05	1.07	1.08	1.10	1.11	1.13	1.15	1.16	1.18	1.19	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.51	1.54	1.56
13	.90	.91	.92	.93	.94	.95	.97	.98	.99	1.01	1.02	1.04	1.05	1.06	1.08	1.10	1.11	1.13	1.14	1.16	1.18	1.19	1.21	1.23	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.45	1.47	1.49	1.52	1.54	1.56	1.59
14	.90	.91	.93	.94	.95	.96	.98	.99	1.00	1.02	1.03	1.05	1.06	1.08	1.09	1.11	1.12	1.14	1.16	1.17	1.19	1.21	1.22	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.52	1.54	1.57	1.59	1.62
15	.91	.92	.93	.95	.96	.97	.99	1.00	1.01	1.03	1.04	1.06	1.07	1.09	1.10	1.12	1.14	1.15	1.17	1.19	1.20	1.22	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.52	1.54	1.57	1.59	1.62	1.65
16	.92	.93	.94	.96	.97	.98	1.00	1.01	1.02	1.04	1.05	1.07	1.09	1.10	1.12	1.13	1.15	1.17	1.18	1.20	1.22	1.24	1.26	1.27	1.29	1.31	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.52	1.54	1.57	1.60	1.62	1.65	1.68
17	.93	.94	.95	.96	.98	.99	1.01	1.02	1.04	1.05	1.06	1.08	1.10	1.11	1.13	1.15	1.16	1.18	1.20	1.22	1.24	1.25	1.27	1.29	1.31	1.33	1.35	1.38	1.40	1.42	1.44	1.47	1.49	1.51	1.54	1.57	1.59	1.62	1.65	1.68	1.71
18	.93	.95	.96	.97	.99	1.00	1.02	1.03	1.05	1.06	1.08	1.09	1.11	1.12	1.14	1.16	1.18	1.20	1.21	1.23	1.25	1.27	1.29	1.31	1.33	1.35	1.37	1.39	1.42	1.44	1.46	1.49	1.51	1.54	1.57	1.59	1.62	1.65	1.68	1.71	1.74
19	.94	.96	.97	.98	1.00	1.01	1.03	1.04	1.06	1.07	1.09	1.10	1.12	1.14	1.16	1.17	1.19	1.21	1.23	1.25	1.27	1.28	1.31	1.33	1.35	1.37	1.39	1.41	1.44	1.46	1.49	1.51	1.54	1.56	1.59	1.62	1.65	1.68	1.71	1.74	1.77
RIGHT (−) 20	.95	.96	.98	.99	1.01	1.02	1.03	1.05	1.07	1.08	1.10	1.12	1.13	1.15	1.17	1.18	1.20	1.22	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.39	1.41	1.43	1.46	1.48	1.51	1.53	1.56	1.58	1.61	1.64	1.67	1.70	1.73	1.77	1.80

LEFT LEG

FIGURE 99.—Ground speed factors by double drift (turns 45° from heading).

line contain right drifts (−drift corrections) on the right leg. Similarly, the right (−drift corrections) and left (+drift corrections) drifts for the left leg lie below and above the horizontal center line, respectively. It must constantly be borne in mind that the signs refer to drift corrections and the names to drift.

(*b*) *Ground speed.*—Entering table in figure 99 find the column marked "left (+) 15° for the right leg." Locate the intersection of this column with the line marked "right (−) 5° for the left leg." The factor at this intersection is 1.30. Multiply this factor (1.30) by the true air speed (120 knots) to obtain ground speed (156 knots) while on the on-course heading. The factor is always applied to the true air speed. The foregoing example serves to show that the ground speed was obtained without actually determining the wind. (Fig. 100.)

(*c*) *Wind.*—Entering table in figure 100 find the box corresponding to the two drifts, left (+) 15° and right (−) 5°, as above. The boxed figures are [16/.32]. Following the rules printed at the bottom of the table, the wind direction is 60°+160°=220°. The wind angle is always added to the true heading. The wind force is the factor (.32) multiplied by the true air speed (120 knots). The wind force is 37.5 knots.

(*d*) *Accuracy.*—Assuming errorless drift and air-speed recordings, the accuracy of the results obtained by the tables in figures 99 and 100 is as follows:

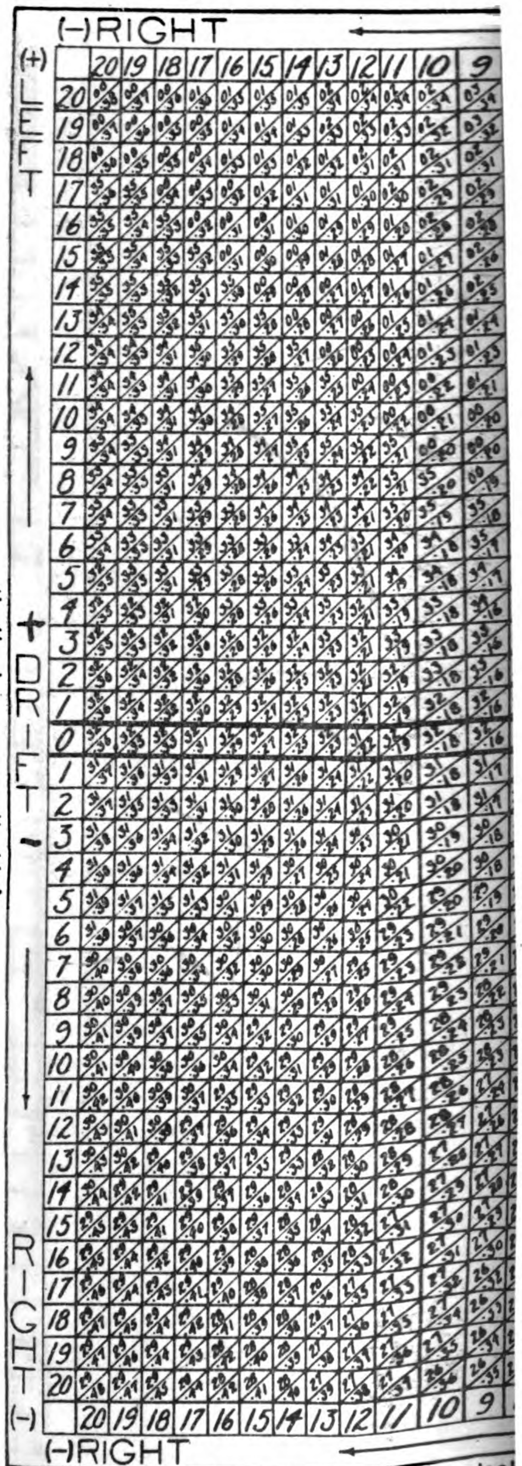
Ground speed, within ½ percent.
Wind direction, within 5°.
Wind force, within ½ percent.

163. Wind from ground speed measurements.—*a. Application.*—Usually, if the ground speed can be determined so can the heading and the track, which would be sufficient to determine the wind at once by constructing a simple vector diagram or by using the tables or the computer. However, there are occasions, such as at night or when flying a radio range, when only an approximate heading is maintained, while fairly accurate ground speed measurements are obtainable by timing between lighted cities, marker beacons, intersections of radio ranges, etc. In such cases the method to be illustrated may give a useful plot of the wind point. The air speed must be kept constant to obtain accurate wind.

b. Example.

Given: Air speed (true), 120 knots.
Ground speed, 134 knots on true heading of 171°.
Ground speed, 98 knots on true heading of 95°.
Find: Wind force and direction.

(1) *Solution by construction* (fig. 101).—The wind-star diagram is employed in this construction as in the double-drift solution.



Add zero to obtain wind direction clock

FIGURE 100.—

From
gs, 171°
adius is
eading.
d speed
rsect at
head of
knots)

ead air
each of
disk an
he two
center
Read

be con-
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of so-
ication

Draw a circle with radius equal to the air speed (120 knots). From the center O draw AO and BO representing the two headings, 171° and 95°, respectively. From A swing an arc MM' whose radius is equal to the ground speed (134 knots) while flying the 171° heading. From B swing an arc NN' whose radius is equal to the ground speed (98 knots) while flying the 95° heading. These two arcs intersect at W, the wind point. OW is the wind direction (58°) with the head of the arrow at W. The length of OW represents the force (30 knots) of the wind to scale.

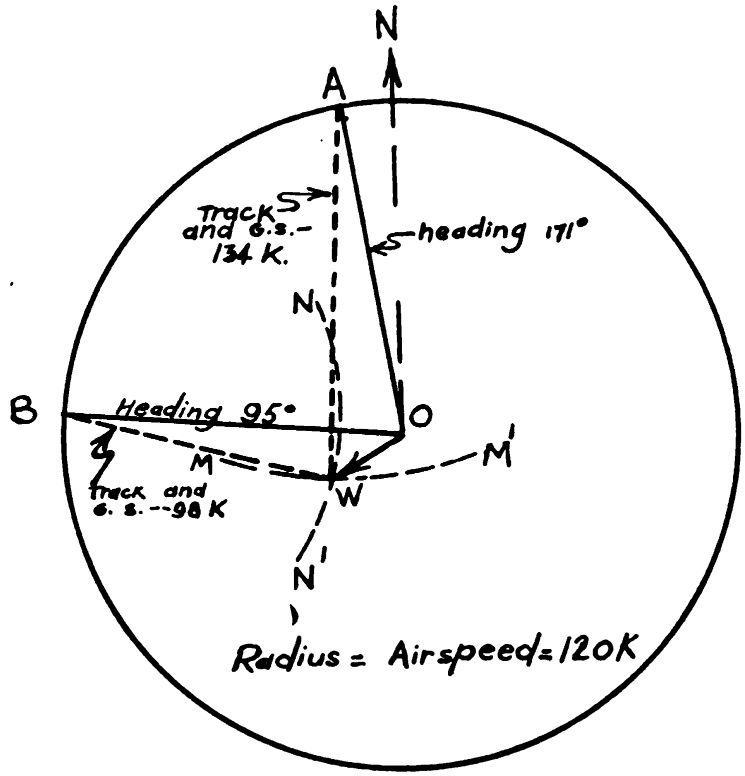

FIGURE 101.—Wind from ground speed measurements.

(2) *Solution by E-6B computer* (fig. 102).—Set chart to read air speed (120 knots) under center of disk. Set compass rose at each of headings, 171° and 95°, in turn, and at each setting trace on disk an arc of appropriate ground speed circle; the intersection of the two arcs in the wind point. Orientate wind point vertically below center of disk to read wind direction (from 58° true) at true index. Read wind force (30 knots) from center line scale.

(3) *Solution by tables in figure 93.*—This problem cannot be conveniently solved by these tables because the wind angle is unknown.

164. Off-course corrections.—*a. Application.*—The use of so-called off-course correction tables or diagrams has little application to precision dead reckoning. A navigator who discovers himself to be so many miles to the right or left of his course has simply to plot the fix on his chart, draw a new course line from the fix to his desti-

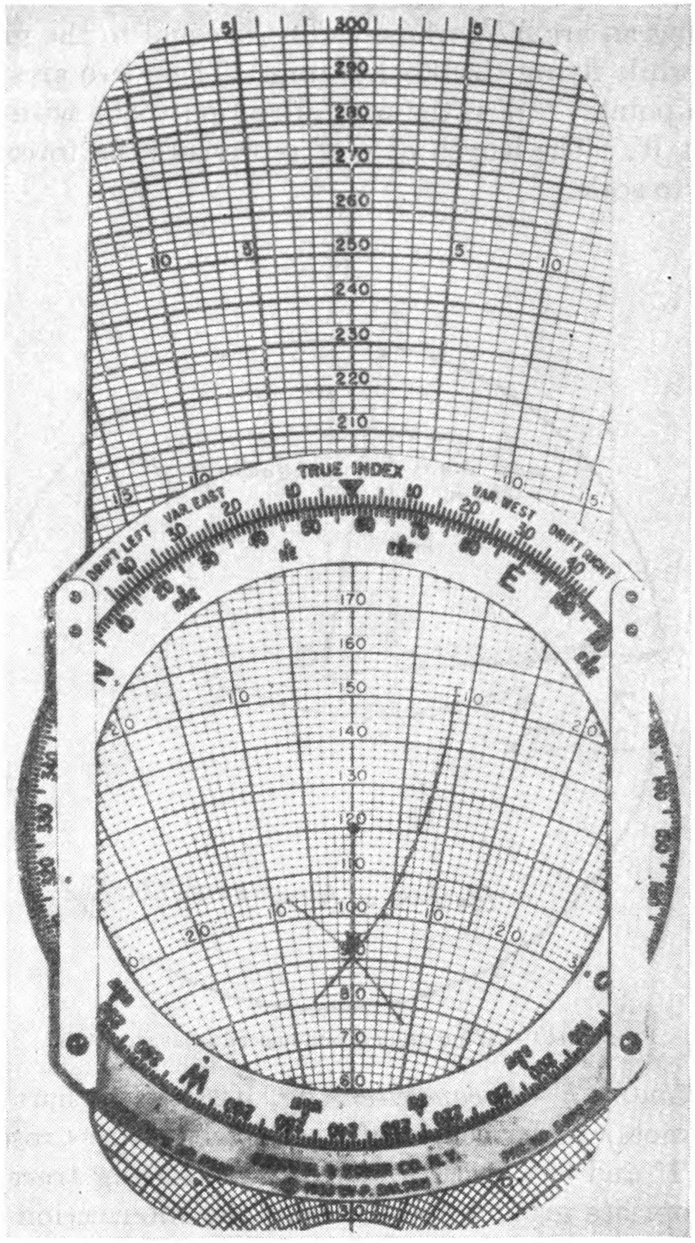

FIGURE 102.—Wind from ground speed on E-6B computer.

nation, and fly a heading which will make good the new course. It may so happen, however, that the fix and the destination lie on different charts, in which case it may be convenient to use the off-course correction method.

b. Basis of tables.—Off-course correction table (fig. 103) and diagrams are based on the assumption that a change in heading produces the same change in track. This assumption is mathematically incorrect because any change in heading results in a change in the drift effect of the wind. However, when only small corrections to heading are made, the assumption may be considered as being substantially correct.

c. Example.—The navigator of an airplane flying a true heading of 90° obtains a fix. The fix is 80 nautical miles from the point of departure and 6 miles to the right of the desired course. What is the correction to parallel the course? What is the total correction necessary to converge on his destination which lies 100 nautical miles ahead?

MILES FLOWN	MILES OFF COURSE															
	1	2	3	4	5	6	7	8	9	10	15	20	25	30	40	50
	COMPASS CORRECTION TO PARALLEL TRACK COURSE															
10	6°	12°	17°	24°	30°	37°	44°	53°	64°	90°	°	°	°	°	°	°
20	3	6	9	12	14	17	20	24	27	30	49	90				
30	2	4	6	8	10	12	14	15	17	19	30	42	56	90		
40	1	3	4	6	7	9	10	12	13	14	22	30	39	49	90	
50	1	2	3	5	6	7	8	9	10	12	17	24	30	37	53	90
60	1	2	3	4	5	6	7	8	9	10	14	19	25	30	42	56
70	1	2	3	3	4	5	6	7	7	8	12	17	21	25	35	46
80	1	1	2	3	4	(4)	5	6	6	7	11	14	18	22	30	39
90	1	1	2	3	3	4	4	5	6	6	10	13	16	19	26	34
100	1	1	2	2	3	(3)	4	5	5	6	9	12	14	17	24	30
110	1	1	2	2	3	3	4	4	5	5	8	10	13	16	21	27
120	0	1	1	2	2	3	3	4	4	5	7	10	12	14	19	25
130	0	1	1	2	2	3	3	4	4	4	7	9	11	13	18	23
140	0	1	1	2	2	2	3	3	4	4	6	8	10	12	17	21
150	0	1	1	2	2	2	3	3	3	4	6	8	10	12	15	19
160	0	1	1	1	2	2	3	3	3	4	5	7	9	11	14	18
170	0	1	1	1	2	2	2	3	3	3	5	7	8	10	14	17
180	0	1	1	1	2	2	2	3	3	3	5	6	8	10	13	16
190	0	1	1	1	2	2	2	2	3	3	5	6	8	9	12	15
200	0	1	1	1	1	2	2	2	3	3	4	6	7	9	12	14

FIGURE 103.—Correction for distance off-course table.

(1) *Solution by table in figure 103.*—Find intersection of 6 miles off-course column with 80 miles-flown line. The correction to parallel the course is 4°. Since the airplane is to the right of the desired course the correction is negative. Now, find intersection of same column with the 100 mile line. The additional correction to converge

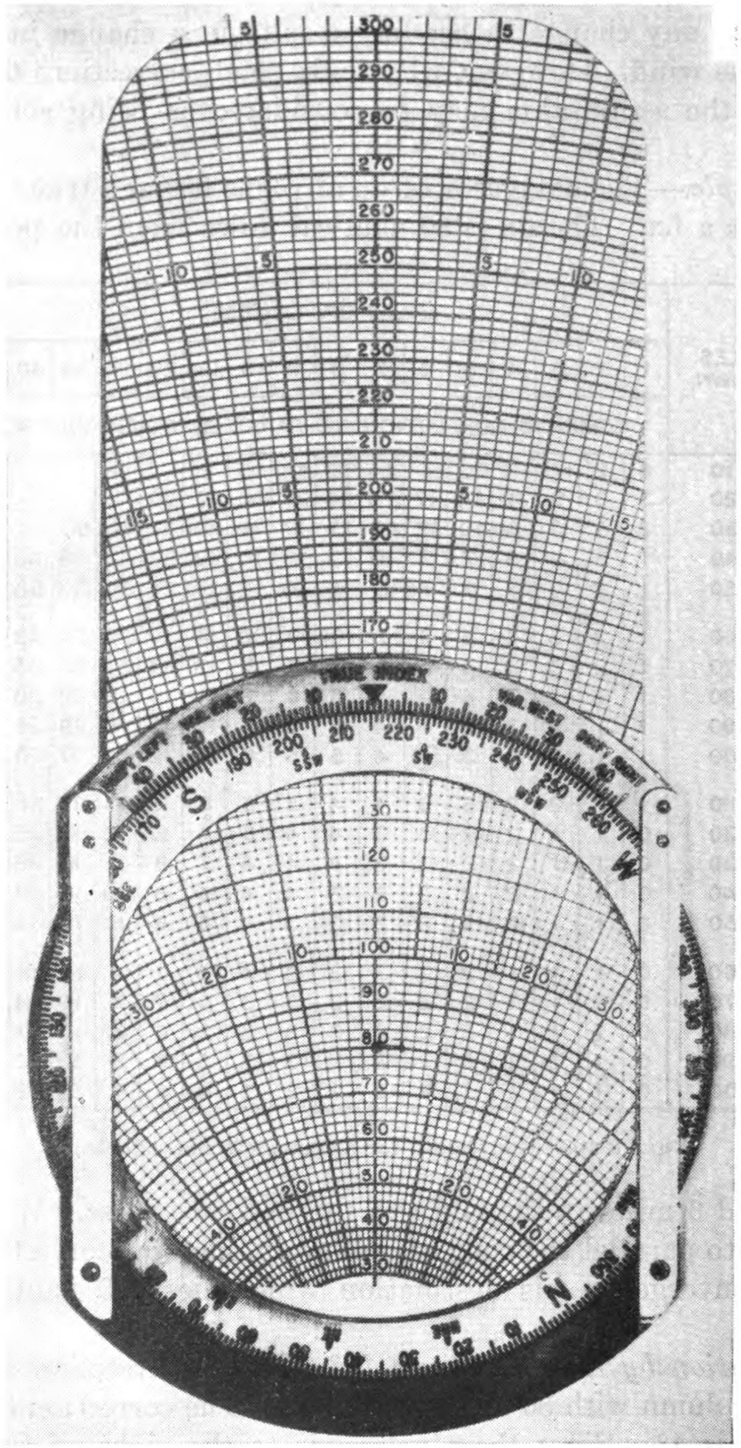

FIGURE 104.—Off-course correction on E-6B computer.

on the destination is 3°, also negative. The total correction is therefore −7°.

(2) *Solution by E–6B computer* (fig. 104).—The compass rose may be in any position during the following procedure but must remain unmoved throughout. Place rectangular grid under plotting disk and pencil mark a line from center 6 miles to right (perpendicular to center line of chart). Reverse chart and set distance flown (80 miles) under center of plotting disk. Read drift (4° R.). Since the drift is 4° R., the heading must be altered 4° to the left to parallel the desired course. To converge on the destination set the distance to go (100 miles) under the center. Read additional correction needed to converge (3½°). The total correction necessary to converge is −6½°.

Section VI

BEARINGS AND FIXES

	Paragraph
Influence of instruments	165
Definitions	166
Line of bearing a great circle arc	167
Taking and plotting a bearing	168
Fixes from bearings	169
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165. Influence of instruments.—The precision navigator possesses the freedom of action and the instruments whereby he is able to determine his position by bearings with far greater frequency and accuracy than the pilot-navigator. These instruments are the pelorus, the drift meter (type B–3 or similar), and the rotatable loop radio compass.

166. Definitions (fig. 105).—*a. Bearing.*—(1) Bearing is the direction of one object from another expressed as an angle measured clockwise from the north. Bearings are true bearings unless otherwise specified.

(2) Magnetic bearing is true bearing with variation applied, i. e., the bearing measured from magnetic north.

(3) Compass bearing is magnetic bearing with deviation applied, i. e., the bearing measured from the compass north.

(4) Relative bearing is the direction of an object expressed as an angle measured clockwise from the true heading of an aircraft.

(5) Reciprocal bearing is the bearing ± 180°. It is sometimes called reverse bearing.

b. Line.—If the bearing of a landmark or a radio station from an airplane is measured at any instant, and this bearing line is correctly drawn upon the navigator's chart, this line will be the locus of the possible positions of the airplane at that instant. This line is called a line of position (LoP). The time of the bearing is always written along the plotted line.

c. Fix.—A fix is the intersection of two or more lines of position or bearings taken at or reduced to the same instant of time. A fix is indicated on a map or chart: ⊙ 0900 GCT or 0900 GCT. A fix may be obtained from two or more intersecting terrestrial, celestial, or radio bearings, or any combination thereof. Fixes involving celestial lines of position are beyond the scope of this manual.

167. Line of bearing a great circle arc.—*a.* The line of bearing between an observer and a terrestrial (or celestial) object is an arc of a

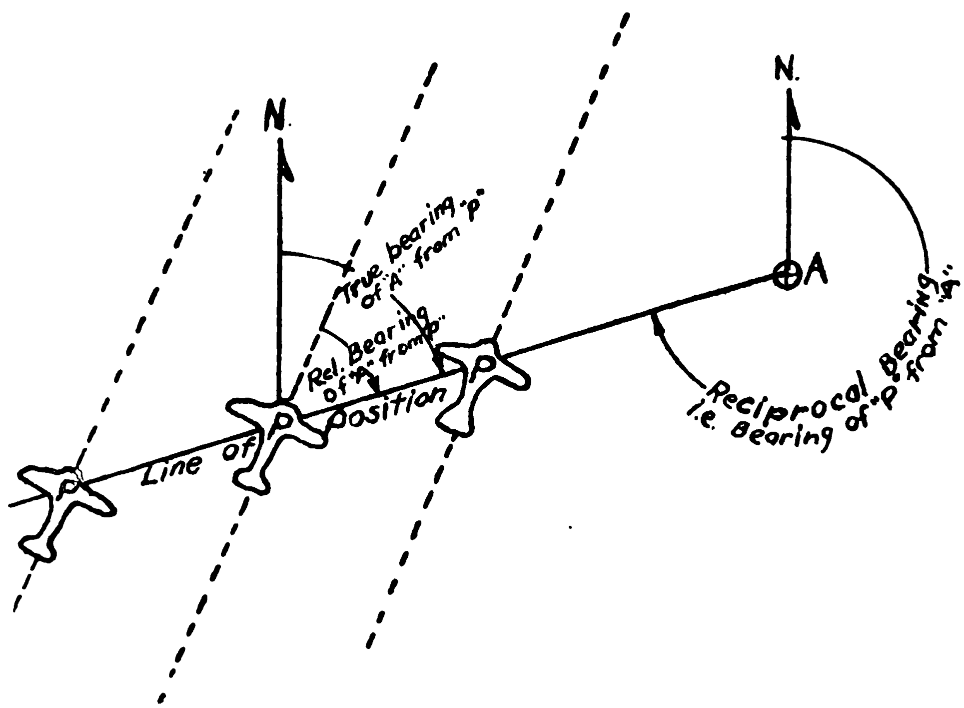

FIGURE 105.—Bearing and line of position.

great circle because the line of sight follows the path of the shortest distance between the two. Radio bearings also follow the great circle path. A problem arises, then, of how to plot these great circle paths on the Mercator chart, the universal work sheet of the precision navigator. In the case of a terrestrial bearing, the range of the eye is comparatively short (seldom greater than 100 miles, usually much less, depending on visibility), and the deviation between the great circle arc and the rhumb line joining the observer and the bearing point may be considered negligible. A visual bearing may therefore be plotted as a straight line on the Mercator chart without rectification.

b. A radio bearing, on the other hand, may be taken when the distance between the observer and the station is several hundred miles, in which case considerable deviation may exist between the great circle path and the rhumb line joining the two. In this event, a correction must be made to convert the great circle bearing to a rhumb line before it can be plotted. Of course, an expedient would be to use a gnomonic chart whereon the bearing line would be a straight line; but, nevertheless, a problem would still exist because a special protractor would have to be carried for each bearing point. Also, a bearing taken with the radio compass is subject to radio compass deviations just as the magnetic compass suffers deviational errors due to the aircraft's magnetism. Both of these differences between radio and visual bearings are described in detail in section X. The point to remember is: after a radio bearing has been corrected for radio compass deviation and rectified from a great circle arc to a rhumb line, it is treated exactly as a terrestrial bearing.

168. Taking and plotting a bearing.—*a. Known point.*—One of the most difficult facts for the beginner to grasp is that a bearing line must be plotted from a known point. Therefore, prior to taking a bearing the navigator must assure himself that the bearing point appears on the chart or, at least, that its coordinates are to be found in one of the publications carried in his kit. A bearing taken upon a point whose position is unknown is worthless.

b. Taking the bearing.—The azimuth scales of current type peloruses, drift meters, and radio compasses are arranged in such a manner as to render it far less confusing if the navigator measures relative bearing. Relative bearing is later changed to true bearing as will be shown. When taking a bearing the azimuth plate should be leveled, otherwise erroneous angular measurement will result. Having taken the bearing, the time thereof should be noted immediately.

c. Plotting.—(1) Since the bearing line must be plotted from the bearing point, a work form similar to that which follows will be of considerable value, especially when more than one bearing is taken before any is plotted.

BEARING WORK FORM

1	Bearing point (name or location)			
2	Time of bearing			
3	Relative bearing (by pelorus or drift meter)			
4	True heading of airplane (from log)			
5	True bearings of bearing point from plane. To obtain: always add (3) and (4)			
6	Add or subtract 180° to obtain (7)	180°	180°	180°
7	True bearing of plane from bearing point			

(2) Having computed the bearing of the plane from the bearing point, the navigator places his protractor at the location of the bearing point on the chart, draws in the bearing line or line of position of the airplane, and on it records the time. This line is the line of position of the airplane for the given instant. Some navigators omit steps (6) and (7) and plot the bearing line by zeroing the 360° protractor on south and plotting the direction recorded in (5). This method is just as correct as the one given above.

d. Range bearing.—The expression "range bearing" is often misunderstood. If the navigator at any time finds the airplane to be in line with two terrestrial points which appear on his chart, obviously, he need not measure an angle and go through the process described in *c* above in order to lay down a line of bearing. He

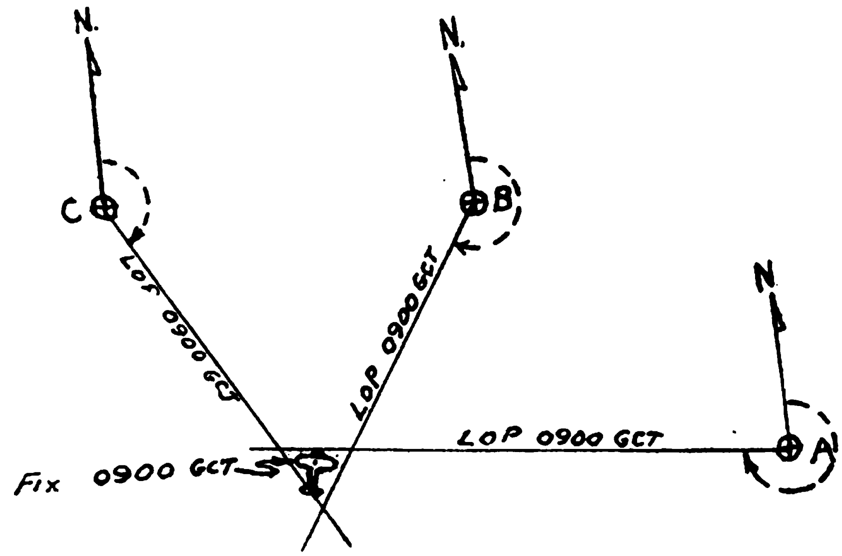

FIGURE 106.—Fix by three simultaneous bearings.

simply draws a line of indefinite length through the two points on his chart. This is his line of position. Similarly, the on-course signal of a radio range system is a range bearing because it establishes the airplane as being somewhere on a line which is already plotted on the map. Hence, a range bearing simplifies the procedure of laying down a line of position.

169. Fixes from bearings.—*a. Number used.*—(1) When two or more bearings are used to determine a fix, the bearings should differ by at least 30° to assure positive intersection.

(2) A fix resulting from three bearings is more reliable than that obtained from only two bearings. The three bearing lines will form a triangle of closing, and the airplane is considered as being at the center of the triangle. (See fig. 106.)

b. Simultaneous and nonsimultaneous bearings.—It is physically impossible to take two bearings simultaneously with a single instrument. However, with practice, some navigators become so adept in manipulating the instrument that the elapsed time between bearings on two different points may be neglected. In this case, the fix is plotted as illustrated in figure 106. Usually, however, an appreciable length of time intervenes between bearings and, if so, the run of the airplane must be considered before the fix can be determined. Under these circumstances the navigator makes what is known as a running fix.

c. Running fix.—(1) The running fix is the resulting intersection after all bearing lines of a group have been resolved to a common instant of time. The instant of time chosen is customarily that of the last bearing of a group. To make the running fix, each earlier bearing line must be moved forward parallel to itself a distance equal to the ground distance traveled during the interval which has elapsed between the time of the bearing and the time of the fix. This distance is always measured along the track or a line parallel to it. Hence, the accuracy of a running fix depends on the navigator's knowledge of his ground speed and track. (The navigator assumes that his track is parallel to the intended course. He is not certain he is making good this course, for if he were, there would be no need for making the fix.) By avoiding long runs between bearings the navigator can minimize the effect of errors resulting from incorrect measurements of ground speed.

(2) Running fixes may be secured from bearings on two or more different bearing points or from two bearings on the same point. The following examples serve to illustrate the method:

(*a*) *Example No. 1* (fig. 107).—Point *B* is 15 nautical miles and bears 170° from point *A*. An airplane is on a true course of 230°. The drift correction is +10°, making the true heading 240°. The ground speed being made good is 120 knots. At 0900 GCT the navigator takes a sight on *A* and finds it to have a relative bearing of 50° from the plane. At 0903 GCT he sights on *B* and finds it to have a relative bearing of 323° from the plane. Required: Distance and bearing of plane from *B* at 0903 GCT. The construction is shown in figure 107. At 0903 the plane is 6 nautical miles and bears 23° from point *B*.

(*b*) *Example No. 2* (fig. 108).—An airplane is on a true course of 345°. +25° drift correction is being carried, making the true heading 10°. The G. S. being made good is 120 knots. The navigator takes sights on a distant peak. At 1000 GCT the peak has a relative bearing of 45° from the plane. At 1018 GCT the peak has a relative bearing of 90°. Required: Distance and bearing of the plane from the peak at 1018 GCT. The construction is shown in figure 108. At 1018 the airplane is 47 nautical miles and bears 280° from the peak.

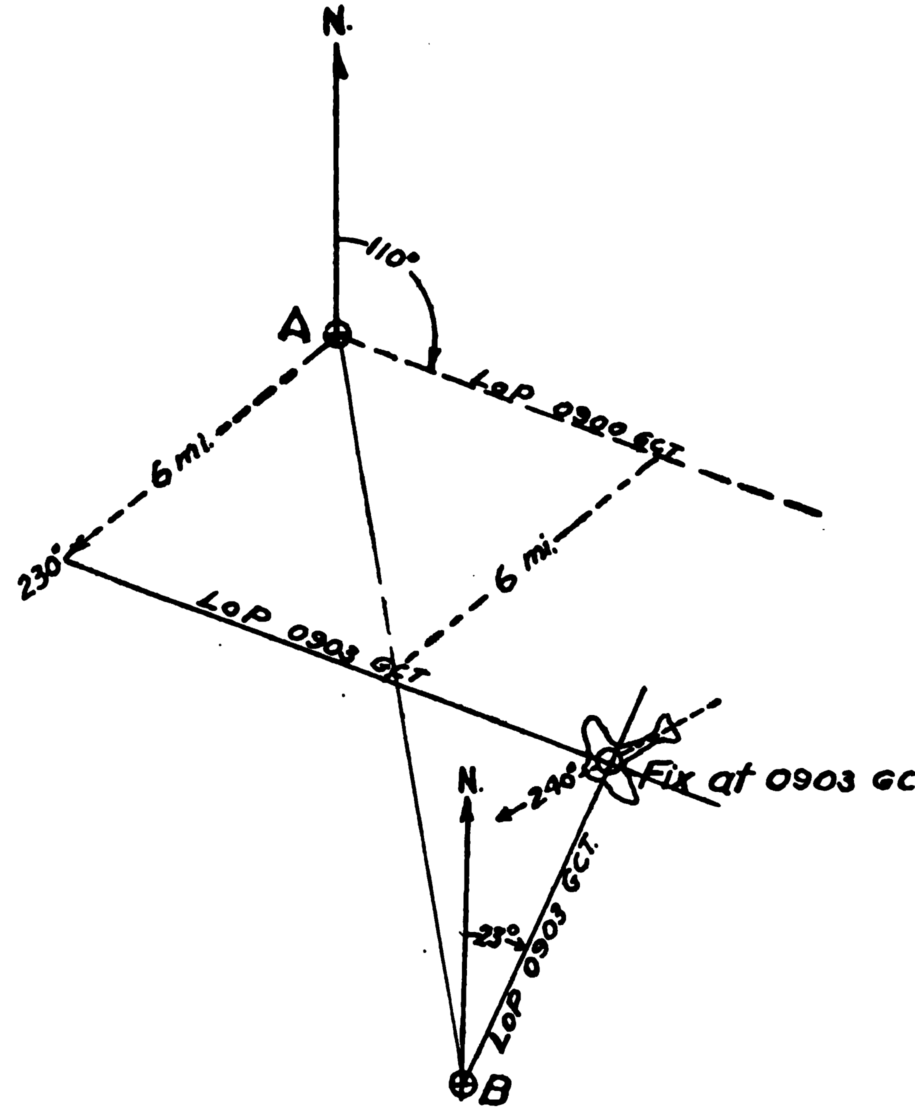

FIGURE 107.—Fix by nonsimultaneous bearings.

170. Wind direction and force from bearings.—*a. Procedure.*—In this method the airplane is flown over some definite object and the heading held constant for a definite length of time at the expiration of which a new heading, preferably 90° to the first, is assumed. The bearing of the object from the airplane is measured at any time while the airplane is on the first heading. The time of turning to the second heading is recorded. At any convenient instant after assuming the second heading, the bearing of the object is again measured and the time recorded. The following example illustrates the method of solution.

b. Example.—(1) *Factors.*—An airplane on a heading of 270° and maintaining a constant true air speed of 120 knots passes over a small patch of burning grass at 2200 GCT. At approximately 2205 GCT the navigator reads the relative bearing of the burning patch to be 175°. At 2206 GCT he takes up a heading of 0° and at 2210 GCT

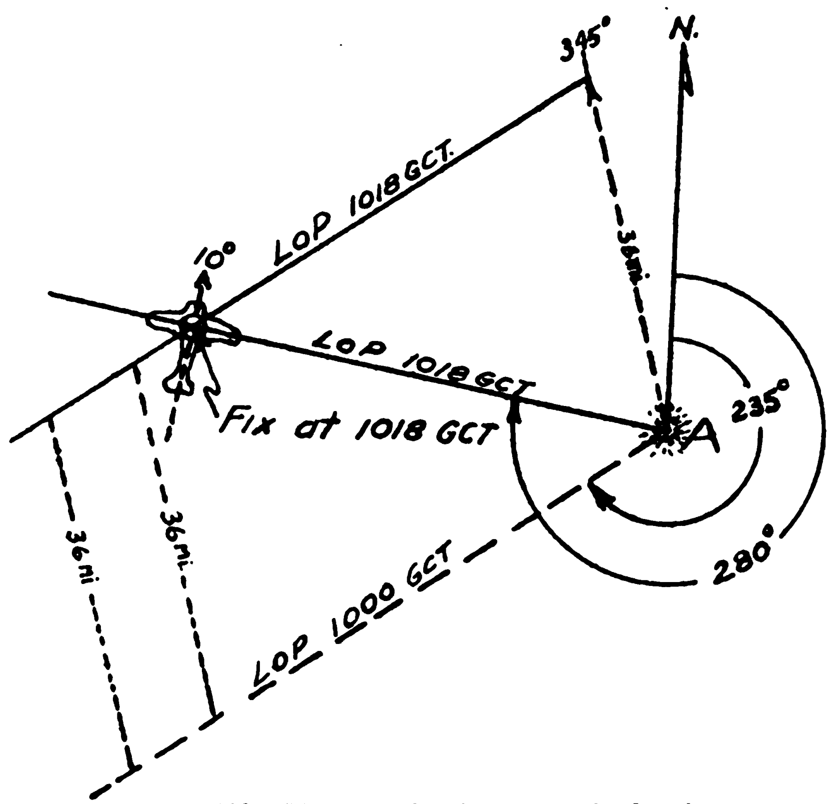

FIGURE 108.—Fix by two bearings on one landmark.

reads the relative bearing of the burning patch as 115°. Required: Wind direction and force.

(2) *Solution* (fig. 109).—Let *A* represent the bearing point. Draw *AX* (270°) representing the first heading. Find *B*, the no-wind position of the airplane at 2206 GCT. *AB*=6 minutes at 2 nautical miles per minute=12 nautical miles. Draw *BY* (0°) representing the second heading. Find *C*, the no-wind position of the airplane at 2210 GCT. *BC*=4 minutes at 2 nautical miles per minute=8 nautical miles. Find *D*, the no-wind position of the airplane at 2210 GCT had it continued to remain on the first heading. *BD*=8 nautical miles. Draw *DW* so that angle *XDW* (175°) is the relative

bearing measured on the first heading. Draw CW so that angle YCW (115°) is the relative bearing measured at 2210 GCT from the second heading. DW and CW intersect at W. WA represents, in direction and length, the direction and force of the wind for 10 minutes (2.2 nautical miles from 28°), making the hourly wind 13.2 knots from 28°. It should be carefully noted that the head of the wind arrow is always at A.

c. Conditions.—Conditions under which the foregoing method may be applied are—

(1) To find the wind by radio bearings on a station when the airplane is above an overcast.

(2) To find the wind at night when the airplane flies over a single lighted object. (Under these circumstances, if the absolute altitude

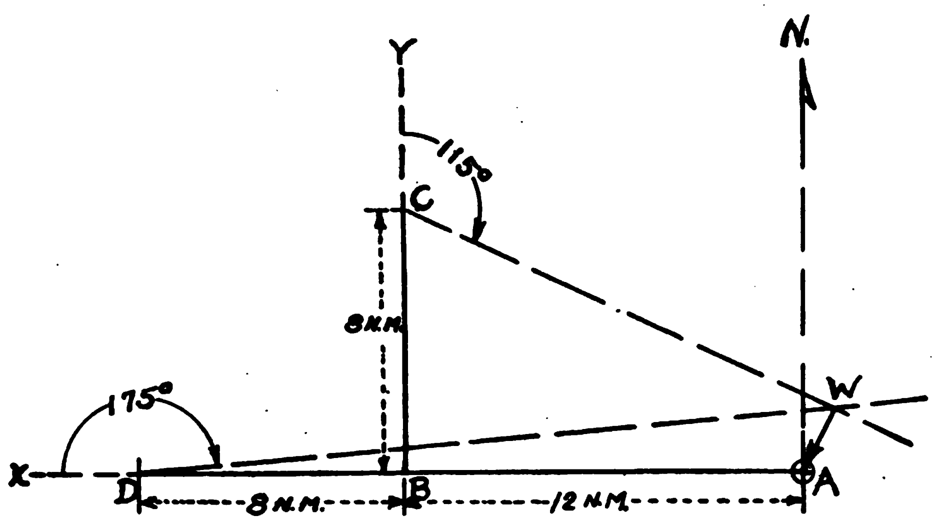

FIGURE 109.—Wind by bearings.

is known, the preferred procedure is to use the timing method to find the ground speed. Then knowing ground speed, air speed, and the direction of the track and heading lines, the wind may be found.)

(3) To find the wind when circumstances preclude using methods other than the one illustrated.

SECTION VII

DEAD RECKONING PROCEDURE

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Paragraph
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171. Factors influencing procedure.—*a.* The planning and the execution of the navigational requirements of a flight mission are influenced by a number of factors, among them being the extent and type of the mission, the instruments and equipment available, and the conditions actually encountered as the flight progresses. The exacting demands placed upon aerial navigators have led to the development of a procedure designed to minimize the chance of personal errors. It should be borne in mind, however, that no hard and fast set of rules which will meet the requirements of every situation can be prescribed. Although the general principles of procedure remain the same, their application may and should be varied to meet the needs of the particular situation.

b. The procedure described in this section is based upon the assumption that—

(1) The airplane contains the instruments described in section III. These instruments have been properly installed and calibrated.

(2) The navigator is provided with the equipment and the tools listed in section III.

172. Teamwork.—Coordination between the pilot and the navigator is of utmost importance if accurate results are to be obtained. It is especially important during flight that the pilot make no change in heading, altitude, or air speed without informing the navigator *at the time* of the change.

173. Navigator's log.—*a.* A log or history of every flight must be kept. W. D., A. C. Form No. 21A provided for the purpose of keeping the navigational record is shown in figure 110. The importance of keeping a detailed, accurate, and neat log cannot be overemphasized. The computations must be rechecked constantly. On long missions, two navigators working in shifts must use the same log. In this case it is obligatory that each of them follows a standard procedure in keeping the common log. When the flight is ended, the log must tell the *complete* story of the flight.

b. The form will require minor changes from time to time to accommodate new methods of procedure. The present form was designed at the time when the double drift method of obtaining ground speed and wind was used almost exclusively. Since the B-3 drift meter has been issued to the service, many navigators frequently use the ground speed by timing method. No provision is made on Form No. 21 A for recording the data obtained when computing ground speed by timing. By referring to the right hand side of the log sheet shown in figure 111 it will be seen how the navigator can augment the form to accommodate his desire for system and neatness.

c. The space in which to enter the various quantities pertaining to the log are, on the whole, apparent from inspection of the form. Some doubt may exist, however, as to certain types of entries.

(1) *Mission.*—On the line "mission" is placed the mission number, if it has one, and the type of mission. For example, a navigation school mission might be entered as "No. 6, intercept of surface vessel"; for a tactical mission the entry might be "Search of area so-and-so."

(2) *Time.*—(*a*) Time is reckoned on the 24-hour clock system, normally using the zone time of the base from which the airplane is operating. Because of the relatively great range of aircraft, there is much to be said for using Greenwich civil time on a 24-hour clock, and many navigators make a habit of using it. A caution to be observed is that no matter what kind of time the navigator may choose for his own convenience, when he communicates with others he must use the kind of time they will understand.

(*b*) All entries of time which have any bearing upon the dead reckoning are noted on the log sheet under the column marked "time."

(*c*) All incidental time entries, such as the time of take-off and landing, are placed in the remarks column. Position reports, weather, and items of general history are also placed chronologically in the remarks column.

(3) *E. T. A. columns.*—It will be noted that there are two E. T. A. columns. If the mission is a simple point-to-point mission, only the last of these two columns is used. If the mission is one which is composed of several legs, the first E. T. A. column is used to give the E. T. A. at the end of the particular leg being flown, the second E. T. A. column containing the E. T. A. at the destination.

d. The following abbreviations, in addition to those already listed in this manual, are used when making entries on the log sheet:

T.O.: Take-off.
E. T. A.: Estimated time of arrival.
P R: Position report.

D D: Double drift.
L H: Lighthouse.
L S: Lightship.
T P: Turning point other than a landmark.
W X: Weather.
S L: Sea level.
DEST: Destination.

174. Position reports.—*a. General.*—Radio position reports are rendered according to a prearranged schedule, or, if the net is a free one, at the convenience of the navigator. All reports are written before they are turned over to the radio operator for transmittal. When reports are transmitted according to a prearranged schedule, care must be taken to have the position report prepared sufficiently in advance to permit prompt transmittal. As a general rule, position reports should be rendered at least hourly. When pronounced changes in heading are made while operating over sea areas, position reports covering such changes should be submitted as soon as practicable after their occurrence. This is necessary in the interest of safety.

b. Form.—Position reports may take a variety of forms depending upon whether the position of the airplane itself is to be given or whether the position of an enemy objective is to be reported. The report may give location by latitude and longitude or by distance and bearing from a predesignated base point. The use of a predesignated base point changed by prearrangement as frequently as necessary has the advantage of attaining greater secrecy but requires additional work on the part of the navigator. Instructions may require that position reports be encoded before transmittal.

(1) A recommended form for reporting the position of the aircraft itself is as follows:

Time	Lat.	Long.	Course	G. S.	Operator's time	Signature
0855	3748	7420	052	204	0900	15B4

(*a*) Time—time for the position, not the time the message is composed or transmitted. It is a four-figure group without punctuation.

(*b*) Lat. and long.—four-figure groups without punctuation.

(*c*) Course—three-figure group. If the course is between 0° and 99°, incl., it is preceded by 0; for example, 000 or 099 meaning 0° or 99°.

(*d*) G. S. (in knots)—three-figure group. Speeds slower than 100 knots are preceded by a zero; for example, 090.

(*e*) Operator's time—time the message is transmitted. It is a four-figure group.

(*f*) Signature—tactical call letters of the airplane.

(2) When required to report on enemy craft a recommended form is as follows:

No.	Type	Time	Lat.	Long.	Course	Speed	Operator's time	Signature
3	BB	0920	3625	6801	010	015	0930	2B4

(*a*) No.—number of enemy craft observed.

(*b*) Type—type of craft; for example, BB (battleship), CV (carrier), etc.

(*c*) Time—time the hostile craft is (are) at the latitude and longitude designated in the report.

(*d*) Lat., Long., Course, Speed—refer to the enemy craft not to the reporting plane. If an objective capable of movement is stationary, both course and speed are designated as 000. No ambiguity will result from designating a craft which is actually making good a northerly course as 000 and one which is motionless as 000. The speed group contains the key.

175. Preflight preparation.—As soon as possible after a mission has been assigned, the navigator begins collecting data for the flight.

a. Courses and distances.—(1) If the location of the point of departure, all turning points, and the destination are not printed on the Mercator plotting charts, obtain coordinates from one of the following publications: H. O. 205; Civil Aeronautics Bulletin No. 11; Goode's School Atlas; Light Lists of the World; sectional or regional aeronautical charts or other accessible maps and charts.

(2) Plot coordinates on Mercator plotting chart. If the flight is a long one in which the legs run from one chart to another, a Mercator planning chart should be used to supplement the plotting charts. This planning chart should be of sufficiently small scale to contain the entire

operating area but of large enough scale that the desired accuracy is not sacrificed.

(3) Calculate or measure Mercator course and distance of each leg and draw course lines on chart. The course and distance of long legs should be computed, especially when the courses run from one sheet to another. For extreme accuracy, the coordinates of the points at which the rhumb line cuts the border meridians and/or parallels of each chart may be calculated.

(4) A decision should be made whether any advantage will be gained by planning to fly rhumb line chords approximating the great circle route on any leg. A great circle distance calculation (par. 197) will give sufficient information upon which to base the decision. If the great circle path is to be approximated, the route under consideration should be planned as described in paragraph 197.

(5) Record courses and distances in log book. Figure 110 illustrates how these entries should be made. When a flight consists of several legs, each leg is treated as a separate flight with zero (0) being entered in the "distance run" column and the length of the leg entered in the "distance to run" column.

b. Variation.—Obtain average variation on each leg from an up-to-date chart and record with proper sign on log form. In certain localities where rapid changes in variation occur it may be necessary to divide a long leg into sections and use the average variation of each section. In this case, the points where variation is to be changed should be marked on the chart so that the changes in heading may be applied when the airplane reaches the indicated position. Unless variation is taken into account frequently, the airplane will not make good the path of the rhumb line plotted on the chart.

c. Weather data.—Obtain weather data, especially winds aloft, over the route to be flown. This weather information, even though "stale," may have to be used in the event all other methods of determining wind in flight fail. This information will normally be supplemented by weather broadcasts as the flight progresses.

d. Time.—Set watch to the correct time, preferably by radio time signal.

e. Amount of fuel.—From available information calculate amount of fuel necessary to perform mission, allowing adequate reserve for unforeseen emergencies. Notify airplane commander of fuel requirements.

176. Upon crew taking positions in airplane.—*a.* Arrange equipment in an orderly manner so that it is readily accessible. During flight each tool should be returned to its compartment after use.

WAR DEPARTMENT
Air Corps
Form No. 21 A
Revised March 9, 1939

LOG SHEET—NAVIGATOR

DEPARTURE *Chesapeake L.S.*　　DESTINATION *Boston via Nantucket Shoals. L.S. and T.P. {42°40'N 69°40'W*
DATE *6 Dec. 1940*　　PILOT *Capt. B.S. Smith*
AIRPLANE TYPE AND No. *B-XX A.C. #40-17 Sq. No. 15B4*　　NAVIGATOR *Lt. J.B. Ducrot*
MISSION *No. 6*

POSITION	TIME	TRUE COURSE	DRIFT CORR.	TRUE HEAD.	VAR.	MAG. HEAD.	DEV.	COMP. HEAD.	RUN DIST.	RUN TIME	G. S.	TO RUN DIST.	TO RUN TIME	E. T. A.	E. T. A. DEST.	ALTITUDE
Chesapeake L.S.		52½°			+11°				0			358				
Nantucket Sh. L.S.		359°			+16°				0			123				
T.P. {42°40' N. 69°40' W.		254°			+16°				0			64				

REMARKS
Total Dist. 595 N.M.
Est. flight Time with no wind—3h 15m

DOUBLE DRIFT

TIME	TRUE AIR SPEED	DRIFT RIGHT LEG	DRIFT LEFT LEG	G. S. FACTOR	G. S.	WIND DIRECTION	WIND VELOCITY

FIGURE 110.—Preflight preparation of log.

b. Make check to see that magnetic compass deviation card, A. S. calibration card, and radio compass deviation chart are posted.

c. Inspect compass installation.

d. Test drift meter suction and drift meter for proper functioning insofar as rapid ground check will permit. At night check reticle light.

e. Check presence of drift flares.

f. Synchronize pilot's and radio operator's watches or clocks.

g. Check interphone communication with pilot.

h. Set altimeters. For safety reasons, altimeters are usually set to indicate altitude above sea level. Pressure altitude, which the navigator uses in computing true air speed, may henceforth be obtained by a simple mental calculation in which the difference between the actual position of the reference indices and the zero (standard atmosphere) position is applied with proper sign to the indicated altitude.

i. Record deviation correction for the initial leg on the log form and complete the first line of the log as far as "compass heading." Initial drift correction may be estimated or drift correction may be carried as zero (0) for the purpose of obtaining compass heading at this time.

j. Instruct pilot as to—

(1) Time to take-off.

(2) Altitude desired.

(3) Air speed desired.

(4) Point of departure and time to leave it.

(5) Initial magnetic heading. Caution must be exercised not to give the aperiodic compass heading to the pilot as he steers by the pilot's compass which may have an entirely different deviation.

177. Take-off.—*a*. Signal pilot to take-off.

b. Record the time and place of take-off in remarks column of the log form.

178. Approach to point of departure.—*a*. The pilot maneuvers the airplane to a position back of the point of departure and in extension of the initial leg. He approaches the point of departure on a heading which will approximately make good the track desired on the first leg. He maintains constant altitude and air speed. The automatic flight control may be engaged at this time.

b. The navigator now places the airplane *exactly* on course in the following manner:

(1) Reads drift correction and enters it in log.

(2) Computes compass heading and resets aperiodic compass.

(3) If the sighting wires are not parallel to the compass needle, the heading of the airplane is changed the necessary number of degrees to effect parallelity. (See par. 134 *b* (3).) If the navigator's position is equipped with a remote automatic flight control, the navigator himself may make the heading adjustment; otherwise the pilot is instructed to turn so many degrees right (or left).

(4) Recheck drift if the heading has been changed and make necessary entries.

(5) Recheck compass deviation correction especially if a large drift correction has been applied. Remember that a change in drift correction results in a change in magnetic heading. The deviation correction must be selected for the latest magnetic heading. This comparison of magnetic heading with the deviation card must be carried on throughout the mission.

179. Over point of departure.—Record time of departure to nearest quarter minute.

180. After leaving point of departure and while flying first course.—*a.* Complete any of the tasks described in paragraph 178*b* which lack of time may have prevented.

b. From the instant of leaving the point of departure to the completion of the mission, the checking of drift by drift meter and the checking of the aircraft's heading against the aperiodic compass are a continuous process. Frequent verification of the heading is especially important because of the constant precession of the directional gyro by means of which a steady heading is maintained.

c. The navigator determines ground speed and records the time and speed in the log.

(1) If the ground speed by timing method is used, the average of several time readings should be obtained, absolute altitude recorded, and the G. S. determined by the formula

$$\text{G. S.} = \frac{\text{absolute altitude}}{\text{time in seconds}} \times \textbf{factor.}$$

(2) If ground speed is determined by the double drift method, prior to making the 45° turns off heading, record the time, pressure altitude, free air temperature, and calibrated air speed. Using the last three quantities compute true air speed and record it. Then the 45° right and left headings are taken up, the drift on each read and recorded, and the G. S. determined in accordance with instructions contained in paragraph 162. If the automatic flight control is on remote, the navigator may control the turns. If not on automatic, the navigator directs the pilot to "take a double drift," whereupon the pilot assumes the right leg heading by making a 45° gyro turn to

WAR DEPARTM
Air Corps
Form No. 21 A
Revised March 9, 1

UBLE DRIFT

DEPARTURE

DATE 6

AIRPLANE TY

MISSION

FT LEFT LEG	G. S. FACTOR	G. S.	WIND DIRECTION	WIND VELOCITY
R.7(-7)	Used E-6B	204	250°	25 K.
R5(-5)	"	202	240°	20 K.
R.7½(-7½)	"	211	245°	30 K.
		190	223°	15 K.
		168	205°	24 K.

Chesapea

DR { 37° / 74°

PRESS. ALT.
2200'
2000'
2000'

DR { 38° / 72°

G. S. -By- Timing				
TIME E.S.T.	STOP WATCH TIME	ABS. ALT.	FACTOR	G. S.
1035	34.2 s	6500'	1.000	190
1107	38.7 s	6500'	1.000	168

...ce of navigator, not part of form 21A

DR { 39° / 70°5

NanTucke

Nantucket

DR { 42°15 / 69°39

TP { 42°40 / 69°40

Boston Ai

the right. After reading the drift, the navigator directs "O.K. Take up left leg," whereupon the pilot assumes the left leg heading by making a 90° gyro turn to the left. After reading the drift on the left leg, the navigator directs "OK. Return to course," whereupon the pilot makes a 45° gyro turn to the right, thereby assuming the on-course heading. The navigator checks the compass to verify the heading.

d. Compute the wind direction and velocity and enter these values on the log form.

e. Computations for E. T.A. and PRs.—Ground speed is normally computed at least once each half-hour of flight.

(1) If the estimated time to fly the first leg will be approximately a half hour, the G. S. just computed may be used for the entire leg, in which case the E.T.A. at the end of the leg is immediately computed, adding 1 minute to the E.T.A. of the leg for the distance lost while taking the double drift, *if* that method has been used. The time which must be added to the E.T.A. for the double drift depends on many factors, and each navigator must determine the increment from practice.

(2) Suppose, on the other hand, that the leg is a long one so that it is apparent that ground speed will be measured several times and also several position reports will be rendered while flying the initial leg. The following example will illustrate the treatment. Refer to figure 111. Suppose an airplane left the point of departure at 0830 on a 358-mile leg. Assume the first position report is due for transmittal at 0855, and subsequently at 25 and 55 minutes past each hour. Assume a double drift was taken at 0845 and ground speed of 204 knots was determined. Immediately, the navigator decides to find his position as of 0855 in order that the position which he sends to the plotting room at 0855 will be an up-to-the-minute one. He enters the time, 0855, in the time column. On the same line but in the time column under "dist. run" he enters 24 minutes. Although the actual elapsed time from the point of departure will be 25 minutes, at 0855 only 24 minutes of that time will have been used in making forward progress, 1 minute's worth having been consumed taking the double drift. Calculate the distance run in 24 minutes at 204 knots $=81\frac{1}{2}$ nautical miles. Record this in distance run column. Subtract $81\frac{1}{2}$ from 358 and enter the distance to run, $276\frac{1}{2}$ miles, in the "to run" column. Compute the time necessary to travel $276\frac{1}{2}$ miles at 204 knots=1 hour 21 minutes, and enter it in the time to run column. Add 1 hour 21 minutes to the 0855 figure appearing in the time column to obtain the E.T.A. at the end of the first leg. Enter this figure, 1016, in the E.T.A. column.

(3) If the ground speed by timing method has been used, the full 25 minutes will have been used in making forward progress. Then at 0855 the airplane will have progressed 85 miles and have 273 miles to go. The time to run will be 1 hour 20¼ minutes and the E.T.A will be 1015¼. Additional examples are shown on sheet #2 of figure 111.

f. Prepare a position report. In the example illustrated in figure 111, plot the 0855 position on the chart by measuring 81½ miles along the course line from the point of departure. Pick off the coordinates of the point (fig. 112) and record them in the position column of the leg form and also complete the position report form (see par. 174*b*(1)).

g. If the mission consists of several legs, compute the E.T.A. at the destination and record it.

h. From now on the procedure on the leg is a repetition of the preceding steps. The checking of drift by drift meter and heading against the compass is continuous. Ground speed is determined at approximate half-hour intervals. Position reports and E.T.A.'s for the leg and for the destination are computed after each ground speed determination. It is advantageous to precompute and plot on the chart a position at which the airplane will be in 15 minutes or a half hour. The position corresponding to the time at which the next position report is due is often convenient. When no position reports are being transmitted, a precomputed position should nevertheless be maintained.

181. Upon arrival at end of first leg.—*a. If terminus is a visible landmark.*—(1) If the aircraft passes directly over the landmark, record the actual time of arrival in the time column and the expression "dead on" in the remarks column.

(2) If the landmark is to one side of the airplane, the time when the landmark bears relatively 90° or 270° from the track is recorded. The distance between the airplane and the landmark at that instant is noted. The time is entered in the time column; the distance in the remarks column. The sign R. (right) or L. (left) is affixed to the distance to signify that the track made good was to the right or left of the intended course.

b. If terminus is a landmark which is not visible.—In the absence of any ground reference points which will indicate the location of the objective, continue flying the original course beyond the E.T.A. 1½ minutes for every hour of elapsed time since the point of departure. This is to insure against "undershooting." If the objective is still not visible, conduct a systematic search. The search should be planned well in advance.

c. If terminus is an indistinguishable point (as when turning "on a wave").—Inform the pilot of the magnetic heading for the second leg and give him the signal of execution a few seconds before the termination of the E.T.A. of the first leg. The purpose of making the turn a few seconds early is to distribute the arc of the turn on both legs. The amount of time to be allowed for this turn depends, of course, upon the amount of the turn and the rate at which the turn is made.

182. Succeeding legs.—*a.* When the terminus of any leg is a landmark, it is customary to reorientate the airplane and fly each succeeding leg as a separate flight until the destination is reached. Note in figure 111 the manner in which the distances and times are recorded in the run and to run columns. The compass should be set for new courses a few minutes before each course is taken up.

b. When the terminus of any leg is not a landmark, the procedure is similar to that described in paragraph 181*c*. The time of arrival and the time of departure are assumed to be the same.

c. Upon landing at the destination the time and place of landing are recorded.

183. Reorienting on fixes.—If at any time during the flight a fix is obtained from landmarks, radio stations, or celestial bodies, the position of the airplane at that instant may be used as a new point of departure. During training flights certain restrictions are usually placed on intermediate reorientation, depending upon the purpose of the mission.

184. Follow the pilot procedure.—Frequently, for tactical reasons or on account of weather, the pilot may be forced to fly headings and assume altitudes and air speeds not directed by the navigator. Nevertheless, the navigator must keep account of the path of the aircraft. Whenever new headings, speeds, or altitudes are assumed, the navigator must record the time and nature of the change.

a. Changes in heading.—The navigator reads the compass, takes a drift reading, and records both values. Now, working from right to left on his log sheet he determines the course being made good and plots it on the chart. He determines the ground speed by timing if time permits; otherwise, he finds the ground speed by using the drift on the previous heading in conjunction with that obtained on the new heading; or as a last resort, he finds it by using the most recently determined wind.

b. Changes in air speed.—Any change in air speed results in a change in drift correction and ground speed. Therefore, these two quantities should be checked as soon as possible after a new air speed has been assumed. When air speed is changed so frequently as to make it difficult for the navigator to keep up with the individual changes, the average of the several air speeds may be used.

c. Changes in altitude.—These changes require that the changes in ground speed and drift correction during the climb or dive be taken into account. When level flight is resumed a new drift correction must be applied and the ground speed computed.

185. When ground is not visible.—*a.* When in or above the clouds, the drift meter cannot be used. In the absence of radio or celestial information, the navigator continues to carry the same drift correction as before entering the clouds and assumes the same ground speed. After emerging from the clouds, he takes a new drift reading and assumes that the drift while in the clouds was the average of the two. He computes a new ground speed and averages it with the old in a similar manner. Using these averages, he reckons the track and speed of the aircraft while in the clouds.

b. Above all, the navigator must not allow the sequence of the dead reckoning to be lost. Regardless of the adversities which he may face, the least the navigator can do is to record the compass heading and the air speed. By applying variation and deviation to the compass heading he can find the true heading. In the absence of any drift indications, he assumes the true heading to be his true course and plots his DR position along this line by assuming ground speed and true air speed to be the same. By thus maintaining the continuity of the dead reckoning, approximate though it may be, the navigator never becomes hopelessly lost.

c. It is apparent that dead reckoning may lose accuracy rapidly when the ground cannot be seen. Under these conditions dead reckoning alone should not be relied on for extended periods.

186. After flight.—Upon completion of the mission, careful analysis of the navigational aspects of the flight are made. This analysis is usually written upon a conveniently arranged form which is retained in the files for comparison with the analyses of future flights. The errors in course and ground speed are investigated to determine whether they have been caused by instrumental or personal factors. Whenever the cause of an error has been ascertained, all possible corrective measures are taken before the next mission is flown.

a. In analyzing course error it is customary to convert the distance off course as recorded on the log to angular error. The angular error is determined by the formula:

$$\text{degree of error on any leg} = \frac{\text{nautical miles off course at end of leg} \times 60}{\text{length of the leg.}}$$

For example, suppose the length of a leg to have been 210 nautical miles and the off-course distance 9 nautical miles left at the end of the leg. Then the

$$\text{degree of error} = \frac{9 \times 60}{210} = 2.6° \text{ L.}$$

b. The ground-speed error on any leg is determined in the following manner:

(1) Find the actual ground speed made good by dividing the length of the leg by the actual elapsed time on the leg.

(2) Find the average estimated ground speed by dividing the length of the leg by the elapsed time between the time of departure and the last estimated time of arrival.

(3) Express the estimated ground speed as being "so many miles fast (or slow) of the actual ground speed."

SECTION VIII

PRECISION DEAD RECKONING APPLIED TO RADIUS OF ACTION, INTERCEPT, SEARCH, AND PATROL

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187. Radius of action.—*a*. The methods of solving radius of action problems by construction and computation are described in section XI, chapter 1. The vector triangles involved in radius of action may be solved on the E-6B computer. However, when the radius of action involves returning to a second base, the E-6B solution for the values of S_1 and S_2 (the rates of departure and return) is relatively complicated. Unless the navigator uses the E-6B constantly for R/A solutions he will find difficulty in remembering the rules for finding S_1 and S_2. There is less chance of personal error if he constructs the R/A diagram on his chart.

b. The chief point of difference between the manner in which the pilot-navigator and the navigator perform radius of action problems lies in the fact that the navigator has the time and the facilities to take into account data changes during flight. Because he has precise means of handling changes as they occur, the navigator is not required to hold as large a percentage of fuel in reserve as the pilot navigator who must rely principally on his "weather eye" and rule of thumb estimations to guide him throughout the mission.

188. Intercept.—*a*. The methods of solving intercept problems are described in section XII, chapter 1. The vector triangles involved in intercept may be solved on the E–6B computer. If the interceptor and the objective are on the same or reciprocal courses, the solution is simple. However, when the interceptor and the objective are not on the same or reciprocal courses the E–6B solution is relatively complicated and the solution by construction will be found more facile and less subject to personal error.

b. In intercept, as in radius of action, the chief distinguishing feature between the pilot-navigator and the navigator is that the navigator can account for data changes as they occur. This is a distinct advantage, especially in view of the fact that information of changes in the objective's course, speed, and position are often received after take-off.

c. (1) There are a great many factors which must be considered when performing an interception flight, among them being—

(*a*) Weather conditions.

(*b*) Size of (area covered by) objective.

(*c*) Likelihood of errors in the reported position, course, and speed of objective.

(*d*) Capabilities and probable intentions of objective.

(*e*) Personal error of interceptor's navigator.

(2) Information is frequently too meager to assign definite values to many of the variables listed above. In the absence of information indicating a different procedure, it is customary to assume that a hostile vessel (or vessels) will maintain course but that its speed will be 5 to 10 knots faster than reported. No set rules can be prescribed whereby the speed allowance may be exactly determined. Experience is the best guide. Having determined the allowance, the intercept diagram is constructed by using the arbitrarily assigned speed, not the reported speed, of the objective. The interceptor then flies the mission to the point where the intercept track intersects the objective's course. If, upon reaching this point, the objective is not sighted, the aircraft changes course so as to fly in the reverse direction the objective is steaming. This course is maintained for a distance equal to the product of the excess speed allowance and the elapsed time between the reported position of the objective and the predicted point of interception. At this point, if the vessel is not sighted, a search is instituted. The search should be planned in accordance with the principles set forth in paragraph 189.

(3) When the objective's course is such that the passage of time serves to increase the distance between the interceptor's base and the objective, it is preferable to assign a slower speed to the objective than that reported. Then the objective's course line will be intersected at a point behind the objective's most probable position, and the enemy

may be approached from the rear, thus enhancing the chances of surprise.

(4) Another method of allowing for the variables consists of arbitrarily assigning a "lead" distance to the objective and thereafter using the reported speed of the vessel in constructing the interception diagram. This in effect accomplishes the same end as the method described in (2) above. If the lead is laid off in the reverse direction to the objective's course, the effect will be similar to that described in (3) above.

d. When several aircraft are flying in formation, the chances of failure to intercept may be minimized by having the airplanes of the unit assume a scouting formation prior to arriving at the point of interception. This formation should be maintained until the objective is sighted.

e. The probability of intercepting hostile aircraft without the assistance of an aircraft warning net, or a tracking plane upon which to take bearings, is remote. The wide freedom of movement open to the enemy with regard to choice of course, speed, and altitude makes the problem of aircraft interception a most difficult one.

189. Search and patrol.—*a*. (1) A *search* mission is a reconnaissance flight executed for the purpose of locating enemy forces known or thought to be at sea.

(2) A *patrol* mission is a flight executed for the purpose of maintaining continuous observation of a line to detect the approach or passage of enemy sea forces.

b. *Navigator's task*.—(1) The planning of searches and patrols, other than those ensuing from failure to intercept, is normally of little concern to the navigator. The responsibility for search and patrol planning rests with the tactical commander, and the task of the navigator is simply to apply his navigational doctrine to carrying out the instructions issued by the commander. In order to have a complete understanding of the contents of search and patrol orders it is necessary that the navigator be familiar with the—

(*a*) Many terms frequently appearing in search and patrol orders but seldom encountered elsewhere.

(*b*) Factors affecting search.

(*c*) Methods of search.

(*d*) Common search patterns.

(2) *Terminology of search and patrol* (fig. 113).—(*a*) *Scout*.—A scout is an airplane engaged in a search.

(*b*) (*AB*) *Scouting line*.—Straight, broken, or curved line on which scouts are located in a formation suitable to conduct a scouting operation in accordance with a definite plan.

(*c*) (*FN*) *Scouting distance.*—Distance in miles between adjacent aircraft on a scouting line.

(*d*) (*OP*) *Scouting front.*—Distance in miles measured along the scouting line from the extremity of visibility on one end of the scouting line to the extremity of visibility at the opposite end of that line.

(*e*) (*RS*, *ST*, *or TU*, *etc.*) *Scouting interval.*—Distance in miles measured between two scouts which are patroling the same line, measured along this line. (This definition is used only in certain methods of search.)

(*f*) (*IJK*) *Position circle.*—Locus of position points of a force which has proceeded a known or assumed distance from a known or assumed point of departure. The circle is drawn with the point of

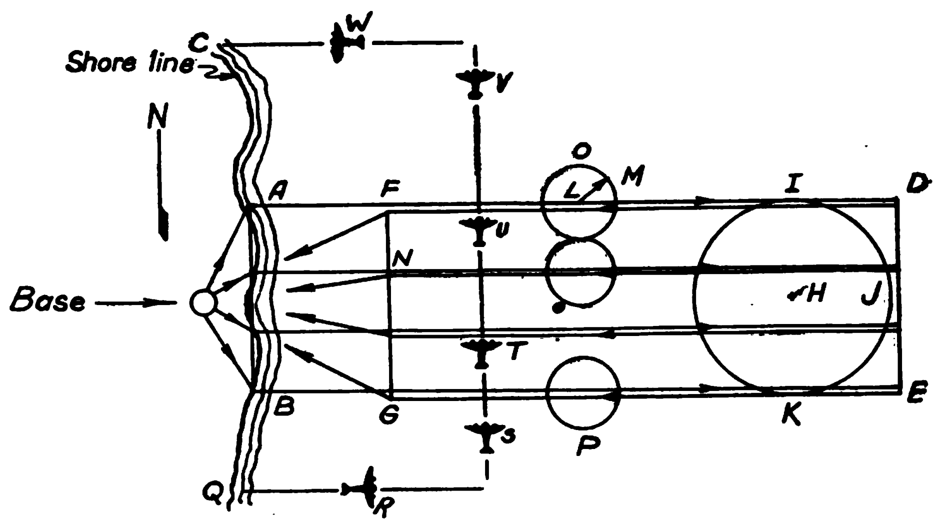

FIGURE 113.—Terminology chart.

departure as a center and radius equal to the distance covered by the force. Point *H* in figure 113 represents the last reported position of enemy surface craft.

(*g*) (*AD*) *Scouting course.*—True course steered by scouts when searching toward the enemy or across his probable routes. The scouting course shown in figure 113, line *AD*, is 90°.

(*h*) (*AB*) *Line of departure.*—Initial position of a scouting line, from which scouts proceed on their prescribed courses for search.

(*i*) (*DE*) *Line of retirement.*—Position of the scouting line at which a search to the rear is initiated.

(*j*) (*FG*) *Line of return.*—Position of the scouting line where scouts leave their stations on the scouting line and return to their bases.

(*k*) (*OP*) *Maintenance of scouting line.*—Scouting line is said to be maintained when scouting distance and scouting front are kept constant.

(*l*) (*AB*) *Line of bearing.*—Direction of a straight scouting line from a reference point, expressed as a true bearing from that point. In figure 113, *A* is the reference point; the line of bearing of the scouting line is thus 180°.

(*m*) (*A or B*) *Point of origin.*—Geographical position of one end of the initial position of the scouting line.

(*n*) (*L–M*) *Radius of visibility.*—Radius of a circle from the center of which the object to be observed can be seen in any direction.

(3) *Factors affecting search.*—The methods to be used in search operations can be determined only after careful consideration of the factors which may influence the search. Some of the important factors are—

(*a*) *Characteristics of searching aircraft as to range and speed.*—These characteristics affect the size of the area that can be searched, time required for search, and frequency with which search can be repeated.

(*b*) *Number of aircraft available for search.*—This factor primarily affects the size of the area that can be searched.

(*c*) *Availability of convenient base or bases from which search operations may be conducted.*—This becomes a major factor if the operating base or bases are located in areas considerably removed from the coastal frontier, as such location necessitates the operations of aircraft over unprofitable land areas prior to taking up the search.

(*d*) *Size and shape of area to be searched.*—These factors have a direct bearing on the number of airplanes required, hours of daylight essential for the operation, and method of search employed. The search of a long, narrow area extending seaward to the limit of the radius of action of the scouts presents problems materially different from those that arise in the search of a long coastal area of limited depth seaward.

(*e*) *Time available for search.*—Sea search at night is relatively unprofitable; hence, the amount of daylight available for the conduct of the search will influence the selection of the search method.

(*f*) *Weather conditions.*—Weather is a factor primarily because of its effect on visibility and the safety of flight. Weather conditions, if sufficiently unfavorable, may preclude flight operations entirely.

(*g*) *Flight navigational errors.*—The scouting distance normally is based upon the estimated radius of visibility in the search area for the type of objective sought, less the allowance for air navigational errors;

hence these errors influence the number of scouts required for the search of a given area. To allow for flight navigational errors, the scouting distance should be less than twice the visibility.

(*h*) *Location, direction, and rate of movement of objectives.*—The location, direction, and rate of movement of the objective directly influence the extent of the area that must be covered. The rate of movement and the time elapsed since the objective was last sighted will determine the size of the position circle.

(4) *Methods of search.*—(*a*) Search operations may be conducted in a wide variety of methods. No one plan is suitable for or adaptable to all situations. The methods selected for employment in any particular situation should be well suited to the conditions existing at the initiation of the search and those likely to be encountered during the operation.

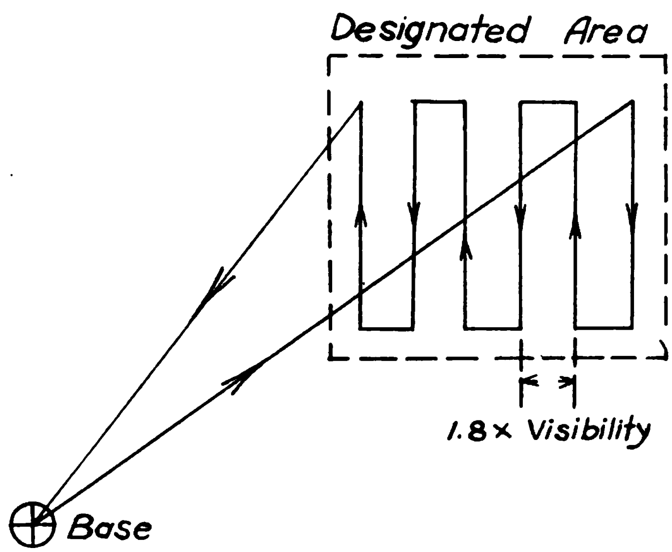

FIGURE 114.—Simple search by one scout.

(*b*) Search plans should be as simple as possible. The problems of navigation, particularly when operating over sea areas out of sight of land, are tremendously increased if the plan requires that a multiplicity of courses be flown during the mission.

(*c*) Aircraft engaged upon search missions usually operate singly within assigned subareas or along designated courses, the whole operation being so coordinated as to insure complete coverage of the entire area to be searched. When the number of aircraft available is insufficient to examine effectively all of an area desired to be searched, it is far better to search completely the most critical portion of the area than to search the entire area in an ineffective manner. Search operations may be performed by aircraft in tactical formation whenever

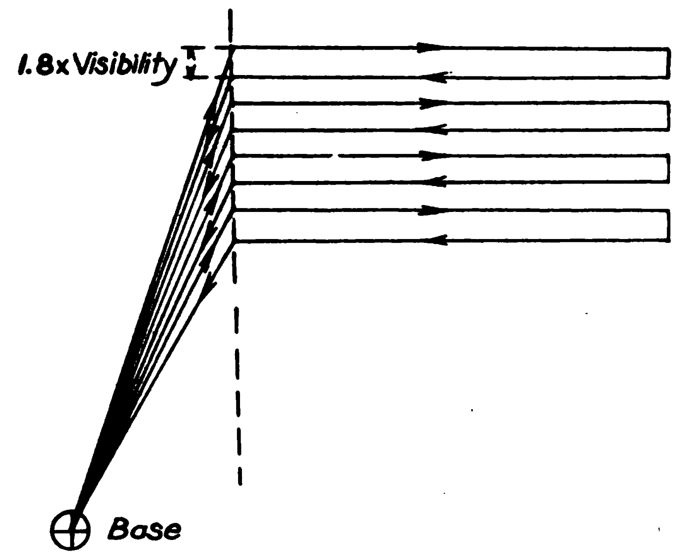

FIGURE 115.—Parallel search with return to same base.

the situation is such as to require either offensive or defensive action beyond the capabilities of individual aircraft.

(5) *Search patterns.*—(*a*) *Simple parallel search by one scout* (fig. 114).—The original course is drawn to one extremity of the area and parallel courses drawn, separated by a distance equal to 1.8 times the effective range of visibility, to provide some overlap. This method requires a number of relatively short courses, which are a source of error.

(*b*) *Parallel search by several scouts* (figs. 115 and 116).—Parallel search is a form of search in which the scouts take positions on a

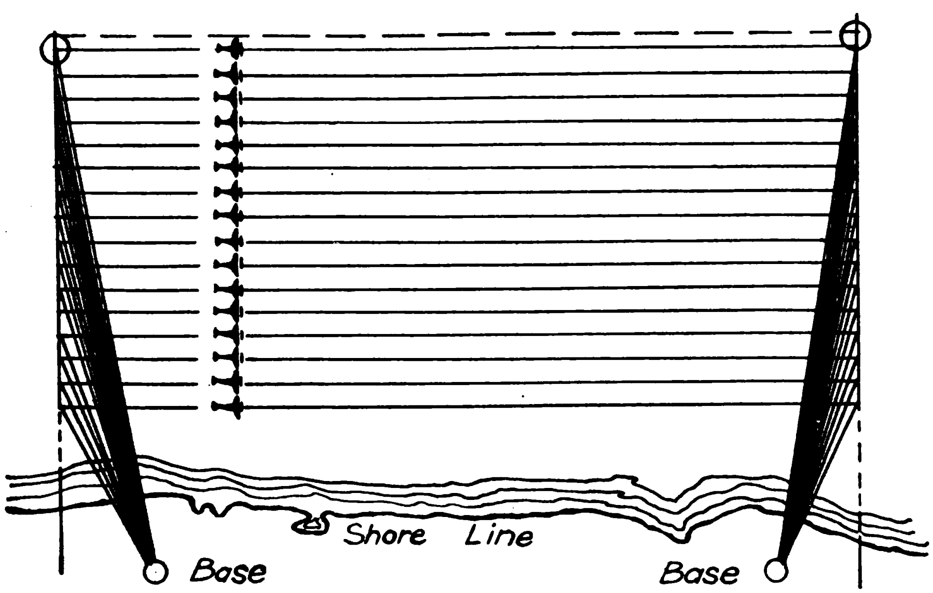

FIGURE 116.—Parallel search with return to second base.

scouting line which is advanced by the movement of all scouts along parallel courses.

(*c*) *Radial search by several scouts* (fig. 117).—Radial search, as its name implies, is a method of search wherein the scouts leave a common point and fan out radially. Even when some other form of

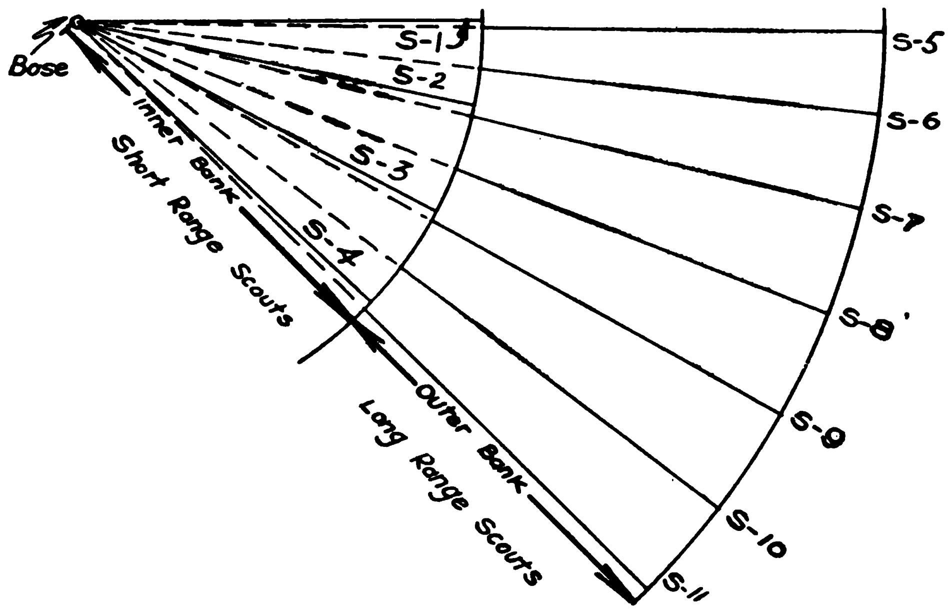

FIGURE 117.—Radial search, double bank method.

search is employed, the beginning and end of the search may take the form of a radial search, since oftentimes the scouts are based at one airdrome. In this method the distance between aircraft increases with the radial distance from the base. The scouting distance at the

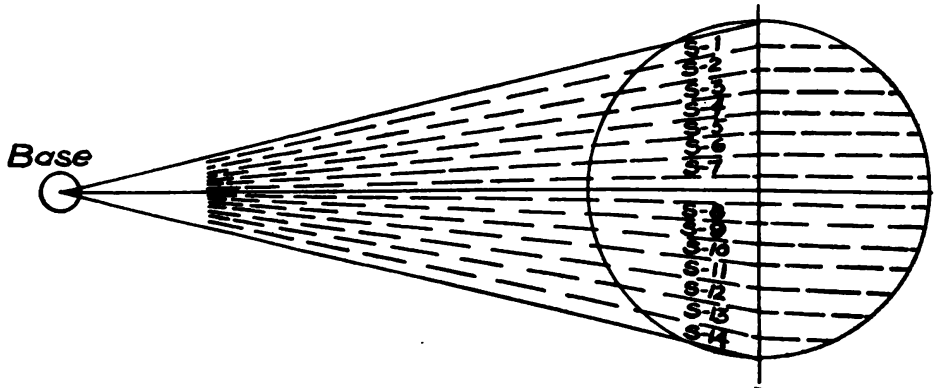

FIGURE 118.—Radial parallel search.

extremity of the radii should not exceed twice the visibility minus the allowance for navigational errors of the scouts. When the distance to the line of retirement is great, the number of aircraft required may sometimes be reduced by using the double bank method.

(*d*) *Radial parallel search* (fig. 118).—A combination of radial and parallel search methods may be employed in searching for an objective reported to have been in a specific position at a previous time, with location, time, and space factors such as to preclude the possibility of the objective being elsewhere at the time the search is started.

SECTION IX

FLYINGS

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190. Calculated flying.—*a.* By utilizing the principles of trigonometry the changes in latitude and longitude, departure, course, and distance occasioned by flying over the earth's surface may be computed. The solutions of the various problems that arise from the relations between these quantities have been called sailings in marine navigation and when borrowed for use in air navigation are called flyings. The most frequent use that the aerial navigator has for calculated flying is the computation of the rhumb line course and distance between his point of departure and destination, when the distance is so great that the desired accuracy cannot be obtained by scaling on the chart or when the rhumb line extends over more than one chart. The converse of this case, i. e., to find the latitude and longitude of his position when he knows the course and distance made good, is a problem seldom encountered in air navigation.

b. Each problem of calculated flying involves the solution of one or more plane right triangles. These triangles may be solved by—

(1) *Construction.*—The construction method is laborious and inaccurate unless a very large scale is used and is seldom employed except as a classroom exercise.

(2) *Traverse tables* (*table 2, H. O. 9, Bowditch*).—The traverse tables are a tabulation of solutions of plane right triangles for every course angle in whole degrees and values of difference of latitude and departure for every distance in whole miles up to 600. By the use of these tables any right triangle may be rapidly solved with little calculation except that incident to interpolation. Because of their arrangement, the traverse tables are awkward to use except when

course is one of the entering arguments. When the course angle is not one of the entering arguments or when the distance involved exceeds the limits of the tables, solution by trigonometry is recommended.

(3) *Trigonometry.*—The solution by trigonometry may be made by using either natural or logarithmic functions. The trigonometric solution by logarithms is the method most generally used.

191. Definitions.—The following quantities are involved in the solution of problems of the flyings:

a. The *difference of latitude* (DL) between two places on the earth's surface is the arc of a meridian intercepted between their parallels of latitude. Since 1 minute of latitude equals 1 nautical mile, the measurement of the difference of latitude is identical in both minutes of arc and in nautical miles. The difference of latitude of two places is the algebraic difference of their latitudes and is named N. or S. according to the direction in which it is made good.

b. The *difference of longitude* (DLo) between two places on the earth's surface is the arc of the Equator intercepted between their meridians. Since 1 minute of longitude equals 1 nautical mile only at the Equator, the difference of longitude is expressed only in minutes of arc. The difference of longitude of two places is the algebraic difference of their longitudes except when this difference is greater than 180° in which case it must be subtracted from 360°. The truth of the foregoing statement will be made clear upon inspection of a world globe. Difference of longitude is named E. or W. according to the direction in which it is made good.

c. Departure (Dep) is the linear measure in nautical miles of an arc of a parallel of latitude between two meridians. The departure between two meridians varies with the latitude of the parallel upon which it is measured according to the formula: $\text{Dep} = \text{DLo} \cos \text{L}$. When the spherical surface of the earth is taken into account, the departure made good by an airplane flying from A to B, two points of different latitude on the earth's surface, is not the departure between their respective meridians as measured on the parallel through A nor the departure as measured on the parallel through B. It is approximately equal to the departure between A and B as measured on the parallel of their middle latitude. Departure is named E. or W. according to the direction it is made good.

d. Distance (Dist) as used in the flyings is the rhumb line distance measured in nautical miles.

e. Course (C) is the angle between a meridian and the rhumb line joining two points on the earth's surface. It is measured from north in a clockwise direction from 0° to 360°. Sometimes, such as to facilitate solutions of problems in calculated flying, course is measured in quadrants from 0° at north or south toward the east or west, in which case the angle must always be named. Thus, a course of 120° is the same as S. 60° E.

f. Meridional parts (see par. 196*a*).

g. Difference of meridional parts (see par. 196*d*).

192. Plane flying.—This method assumes the earth's surface to be flat, hence the name "plane flying." When the area involved is small, and in the lower latitudes, the spherical form of the earth may be disregarded and the earth's surface assumed to be a plane without material error. The error decreases as the course angle and the distance become smaller.

a. Plane flying triangle.—The plane right triangle formed by the meridian of the point of departure, the parallel of the point arrived at, and the rhumb line joining the two places are shown in figure 119. *A* is the point of departure, B is the destination, AX is the meridian of point *A*, *BX* is the parallel of point *B*, and *AB* is the rhumb line joining *A* and *B*. Then *AX* will represent the difference of latitude, *BX* the departure, *AB* the distance, and *C* the course angle.

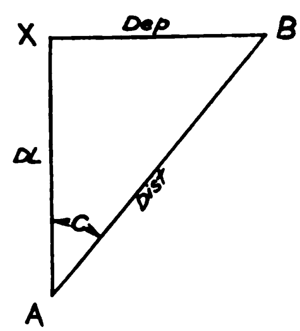

FIGURE 119.—Plane flying.

(1) From this triangle the following formulas may be deduced:

$$\sin C=\frac{\text{Dep}}{\text{Dist}} \text{ or Dep}=\text{Dist} \sin C$$

$$\cos C=\frac{\text{DL}}{\text{Dist}} \text{ or DL} =\text{Dist} \cos C$$

$$\tan C=\frac{\text{Dep}}{\text{DL}}$$

(2) When any two of the above quantities are known the triangle may be solved for the unknowns by selecting the appropriate formulas.

(3) It should be noted that none of the formulas of plane flying contain the quantity DLo. This quantity can neither be used in nor found from the solution of the plane flying triangle alone.

(4) The course angle must be expressed in quadrants from 0° at north or south toward the east or west. In naming this course, place N. or S. in front of the number of degrees and E. or W. after, according to the directions in which the DL and Dep are made good.

b. Example No. 1.—An aircraft flies on a course of 275° (N. 85° W.) for a distance of 115 miles. Required: DL and Dep.

(1) *Solution by trigonometry.*

Formulas: DL = Dist cos C
Dep. = Dist sin C

Dist	115	log	2.06070	
C	N. 85° W.	log cos	8.94030−10	Add
DL	10.02′ N.	log	11.00100−10	
Dist	115	log	2.06070	
C	N. 85° W.	log sin	9.99834−10	Add
Dep	114.56 miles W.	log	12.05904−10	

DL = 10.02′ N.
Dep = 114.56 miles W.

(2) *Solution by traverse tables.*—Enter the table with the course N. 85° W. at the bottom of the page, and the distance 115 miles in the Dist column, and pick out opposite the distance the DL, 10.0, in the column headed Lat at the bottom of the page, and the Dep, 114.6 miles, in the column headed Dep at the bottom of the page. Name the DL N. or S. and the Dep E. or W. according to the direction of the course.

DL = 10.0′ N.
Dep = 114.6 miles W.

c. Example No. 2.—In flying from *A* to *B*, the difference of latitude made good is 244′ N. and the departure made good is 171 miles E. Required: Course and distance from *A* to *B*.

(1) *Solution by trigonometry.*

$$\text{Formulas: } \tan C = \frac{\text{Dep}}{\text{DL}}$$

$$\text{Dist} = \frac{\text{Dep}}{\sin C}$$

Dep 171 E.	log	2.23300	
DL 244′ N.	log	2.38739	Subtract
C = N. 35° 02′ E.	log tan	9.84561−10	
Dep 171	log	2.23300	
C N. 35° 02′ E.	log sin	9.75895−10	Subtract
Dist = 297.9 miles	log	2.47405	

Course = 35°02′—Converted to course measured clockwise from north. (In this case there is no numerical change in the number of degrees since the angle is in the N. E. quadrant.)

(2) *Solution by traverse tables.*—Enter the traverse tables, and the nearest agreement of the values of DL and Dep in their proper columns will be found for course N. 35° E. The nearest corresponding distance is 298 miles.

d. Rules.—From the above examples it can be seen that the following rules apply for solutions by use of the traverse tables:

(1) When the course and distance are given, to find the DL and Dep—

(*a*) Find the page where the course is given either at top or bottom of page.

(*b*) Find the given distance in the column headed Dist.

(*c*) Opposite the distance read the DL in the column headed Lat and the departure in the column headed Dep.

(*d*) If the given course is found at the top of the page use headings for Lat and Dep columns at top of page, and if course is at bottom of page use headings for these columns at bottom of page.

(2) When the DL and Dep are given and the course and distance are required, the problem is to find the page on which the given values most nearly appear together in their proper columns. For greatest accuracy a three-way interpolation between these values on two pages is necessary. This problem is easier solved by trigonometry.

193. Traverse flying.—*a. General.*—A traverse is the irregular track of an aircraft when it has flown several different rhumb line courses in succession. The method of traverse flying assumes the earth's surface to be a plane and consists of tabulating the DL made good to the N. or S. and the departure made good to the E. or W. for each of the several courses. The algebraic sums of these differences of latitude and departures are obviously the net DL and Dep made good, from which the resultant course and distance may be found. The work can be readily accomplished by use of the traverse tables.

b. Example.—An aircraft leaves a point and flies a true course of 35° for 105 miles, then a course of 95° for 50 miles, then a course of 275° for 15 miles. Required: Course and distance from point of departure.

Course	Dist	DL		Dep	
		N.	S.	E.	W.
N. 35° E.	105	86		60. 2	
S. 85° E.	50		4. 4	49. 8	
N. 85° W.	15	1. 3			14. 9
Totals		87. 3′	4. 4′	110. 0	14. 9
Algebraic totals		82. 9′		95. 1	

Resultant course = N. 49° E.
Dist = 126 nautical miles.

194. Parallel flying.—If an aircraft flies due east or west along a parallel of latitude, there is no change in latitude, and the departure is equal to the distance. This is the simplest form of spherical flying, and by its method, departure, and difference of longitude may be interconverted, which is impossible in plane flying.

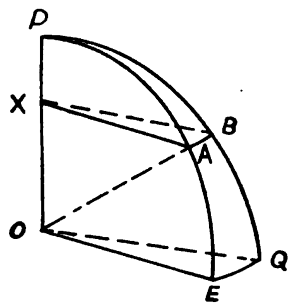

FIGURE 120.—Parallel flying.

a. Formulas.—In figure 120, let A and B represent any two places on the same parallel of latitude, P the pole, and O the center of the earth. AB is the arc of the parallel of latitude between A and B, whose radius is AX and whose latitude is angle AOE. EQ is the arc of the Equator intercepted between the meridians of A and B. Then the linear measure of arc AB is the departure, and the angular measure of arcs AB and EQ is the difference of longitude. AB and EQ are similar arcs of two circles because—

$$\angle AXB = \angle EOQ$$
$$AO = EO$$

then

$$\frac{AB}{EQ} = \frac{AX}{EO} = \frac{AX}{AO}$$

From triangle AOX,

$$\frac{AX}{AO} = \cos XAO = \cos AOE$$
$$\frac{AB}{EQ} = \cos AOE$$
$$\frac{\text{Dep}}{\text{DLo}} = \cos \text{Lat}$$
$$\text{Dep} = \text{DLo} \cos \text{Lat, and}$$
$$\text{DLo} = \text{Dep} \sec \text{Lat}$$

b. Example.—An aircraft in latitude 38° flies a true course of 270° for a distance of 215.5 miles. Required: Difference of longitude.

(1) *By trigonometry.*

Formula: DLo=Dep sec Lat

Lat	38°	log sec	. 10347
Dep	215. 5′	log	2. 33345
DLo	= 273. 5′	log	2. 43692
	= 4° 33. 5′		

(2) *By traverse tables* (*tables 2, H. O. 9*).—(*a*) Since the traverse tables are based on the formula: Dist=DL sec C, the substitution of DLo for Dist, Dep for Lat, and Lat for C adapts the tables to solution of parallel flying problems. These rules are given at the bottom of each page of table 2 (Bowditch).

(*b*) Enter the tables with the latitude 38° as a course, and opposite 215.5 in the Lat column is found the number 273.5 in the Dist column. Then 273.5 is the difference of longitude in minutes, or DLo=4°33.5′.

(3) *By table 4, H. O. 9, Bowditch.*—Entering table 4 with Lat 38°, the length of 1° of longitude at Lat 38° is found to be 47.395 nautical miles. Then $DLo=\frac{215.5}{47.395}=4°33.5'$.

195. Middle latitude flying.—*a.* The departure made good by an aircraft flying between two places in different latitudes is not equal to the departure as measured on the parallel of either of the places, but is nearly equal to the departure as measured on the parallel in their middle latitude. This fact is the basis of middle latitude flying and permits the solution of problems involving difference of longitude and departure when there is a difference of latitude involved.

b. Since the departure made good is not exactly equal to that measured on the parallel of the middle latitude of two places, the middle latitude solution is only approximate, and appreciable errors may result when the distance exceeds 200 miles, especially in the higher latitudes. A correction may be applied to the midlatitude to make the basic assumption true. The correction table appears in H. O. 9. An additional disadvantage is that the middle latitude solution cannot be used when the course line crosses the Equator without dividing the problem into two triangles, one on each side of the Equator.

c. Because of the disadvantages of the middle latitude solution, the aerial navigator seldom uses it, employing instead the Mercator solution.

196. Mercator flying.—Mercator flying is the method by which values of the various elements are determined from considering them in the relation in which they are plotted upon a Mercator chart. Mercator flying is the most generally used method of calculated flying because its accuracy is not limited by the magnitude of the different quantities involved in the problem.

a. Meridional parts.—(1) It has been stated that the Mercator projection is a mathematical projection on which all meridians appear as equidistant vertical parallel lines, and all parallels of latitude appear as horizontal parallel lines intersecting the meridians at right angles. It follows that any rhumb line must appear as a straight line. The Mercator is a conformal projection, i. e., it preserves the shape of areas projected. The meridians on the earth's surface converge as the poles are approached so that, although 1° of longitude equals 60 nautical miles at the Equator, at latitude 60° this same degree of longitude subtends an arc of the parallel only 30 nautical miles in length. But on the Mercator projection the meridians, being parallel, are the same distance apart at all latitudes. Therefore, a distance on the chart equal to 1° of longitude must represent on the chart at the Equator a distance of 60 nautical miles and at latitude 60° a distance of 30 nautical miles. In other words, the scale of the chart has increased as the distance from the Equator became greater so that at latitude 60° the scale is twice that at the Equator. Now, since 1 minute of latitude always equals 1 nautical mile on the earth's surface, in order to keep the projection conformal it is necessary to expand the latitude scale on the chart in the same proportion as the longitude scale has been expanded by drawing the meridians as parallel lines. The problem then resolves itself into determining the distance from the Equator of each parallel of latitude in units of minutes of longitude at the Equator.

(2) The meridional parts (Mer. Pts.) of any parallel of latitude may be defined as the length of an arc of a meridian between the Equator and the parallel, as drawn on a Mercator chart, expressed in units of 1 minute of longitude at the Equator. Tables have been computed giving the distance from the Equator of each minute of latitude in units of 1 minute of longitude at the Equator. These are known as "Tables of Meridional Parts" and are given to one place of decimals in table 3, H. O. 9 (Bowditch). The computation of meridional parts takes into account the ellipsoid shape of the earth and involves mathematics beyond the scope of this manual.

b. Construction of a Mercator chart from tables of meridional parts.—(1) *Procedure.*—If the chart for which the projection is to be made includes the Equator, the values to be measured off are given directly by the tables of meridional parts. If the Equator is not to be shown upon the chart, then the parallels of latitude to be laid down should be referred to a principal parallel, preferably the lowest parallel to be drawn on the chart. The distance of any other parallel of latitude from the principal parallel is then the difference of the meridional parts for the two taken from the tables and reduced to the scale of the chart.

(*a*) For example, if it be required to construct a chart on a scale of 2 inches to 1° of arc on the Equator, the minute or unit of measurement (one meridional part) will be $1/60 \times 2$ inches $= 1/30$ inch. Then 1° of latitude north or south of the Equator will be represented by: $1/30 \times 59.6 = 1.987$ inches. The value 59.6 is the difference between the meridional parts given opposite latitudes 0°00′ and 1°00′.

(*b*) If the chart does not include the Equator and if the principal parallel is, for example, latitude 40°00′, and the longitude scale is the same as above, then the measurement of the interval between 40°00′ and 41°00′ will be: 1/30×78.6=2.62 inches. The value 78.6 is the difference of the meridional parts given opposite latitudes 40°00′ and 41°00′.

(2) *Example No. 1.*—Let it be required to construct a Mercator chart between the parallels of latitude 32°00′ N. and 35°00′ N. and between longitudes 116° W. and 120° W., on a scale of 1° longitude equals 2 inches. Integral degrees of latitude and longitude are to be shown. (See fig. 121.)

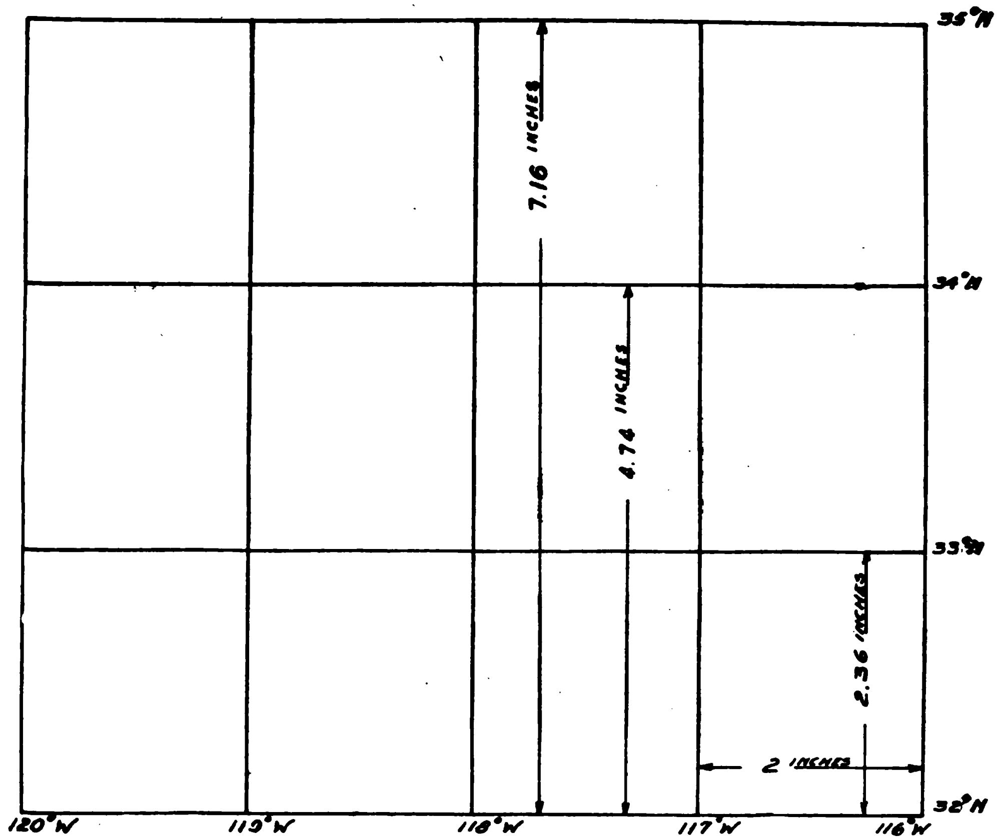

FIGURE 121.—Construction of small area Mercator map by meridional parts.

(*a*) Draw a straight line 8 inches in length parallel to the lower edge of the sheet. This line will be the principal parallel of latitude 32°00′ N.

(*b*) At intervals of 2 inches along the principal parallel erect perpendiculars. These lines from right to left will be the meridians 116° W., 117° W., 118° W., 119° W., and 120° W.

(*c*) Since the scale of the chart is 1° of longitude equals 2 inches, the unit of measurement (one meridional part) will be: $\frac{1}{60}\times 2=\frac{1}{30}$ inch.

(*d*) Enter the tables of meridional parts and find for latitude 32° the value 2,016.0 and for latitude 33° the value 2,086.8. The difference: 2,086.8−2,016.0=70.8, is the number of meridional parts between the parallels 32° and 33°. Then the distance on the chart between these parallels will be $\frac{1}{30} \times 70.8 = 2.36$ inches.

(*e*) On two of the meridians already constructed lay off the distance 2.36 inches, and through the points thus obtained draw a straight line which will be the parallel 33°00′.

(*f*) Proceed in the same manner to lay down all of the parallels; the distances of parallels 34° and 35° from the principal parallel 32° will be, respectively:

$$\frac{1}{30} \times (2158.4 - 2016.0) = 4.74 \text{ inches.}$$

$$\frac{1}{30} \times (2230.9 - 2016.0) = 7.16 \text{ inches.}$$

(*g*) The whole degrees of latitude and longitude may be subdivided as minutely as required. The subdivisions of the degrees of longitude are found by dividing the degrees into equal parts, and the subdivisions of the degrees of latitude are found accurately by using the tables of meridional parts as described above, though it will generally be found sufficiently exact to make equal subdivisions of each degree of latitude, as was done when dividing the degrees of longitude.

(3) *Example No. 2.*—A Mercator chart is to be constructed to a scale of 3 inches equals 1° of latitude at latitude 40°. What is the length of 1° of longitude on the chart?

(*a*)

Mer. Pts.	40°30′	=2646.8
Mer. Pts.	39°30′	=2568.8
Mer. DL		= 74.0

(*b*) Then 3 inches on the chart are equal to 74.0 meridional parts, and the unit of measurement (one meridional part) is equal to 3/74.0 inches.

(*c*) The length of 1° of longitude on the chart, then, is $60 \times 3/74.0 =$ 2.43 inches.

c. Graphical construction of a Mercator chart.—(1) *General.*—The graphical construction of a Mercator chart is based on the assumption that the earth is a true sphere, in which case the meridians are true circles. While this assumption is not exactly true, for a small area the resulting error may be disregarded. Cross-section paper will facilitate the construction.

(2) *Example.*—Required a small area Mercator chart from latitude 40° N. to 43° N., and from longitude 75° W. to 78° W., on a scale of 3 inches to 1° of longitude. Each integral degree of latitude and longitude is to be subdivided into 10′ intervals. (See fig. 122.)

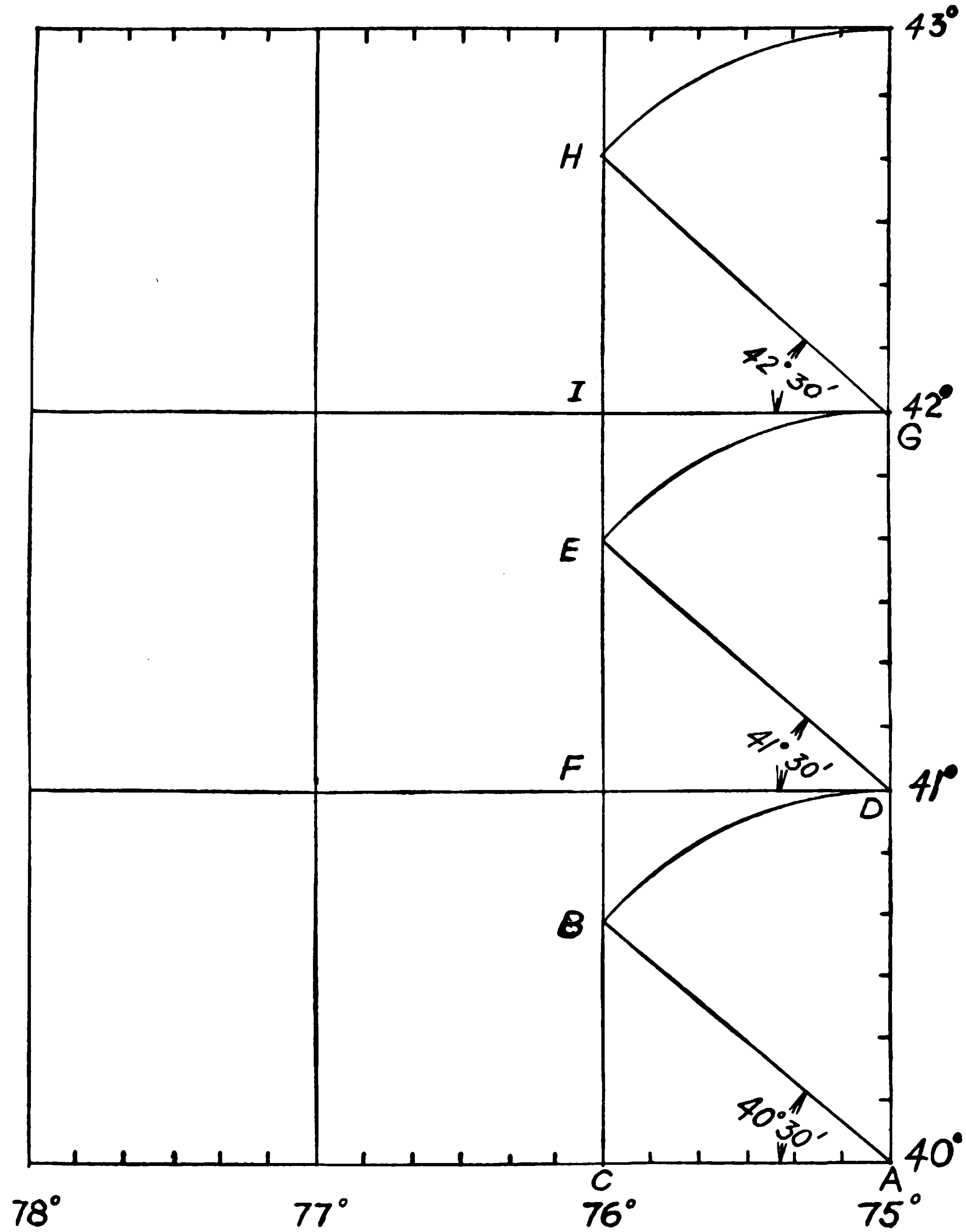

FIGURE 122.—Graphical construction of Mercator chart.

(*a*) Draw a straight line 9 inches in length parallel to the lower edge of the sheet. This will represent the base parallel of latitude 40°00′ N. From the ends of this line and at 3-inch intervals along it carefully erect perpendicular lines, which from right to left will be the meridians 75° W., 76° W., 77° W., 78° W.

(*b*) Lay off a line *AB* so that angle *BAC* equals the mean latitude between the parallels 40° and 41°, or 40°30′. Then from triangle *ABC*, *AB*=*AC* sec *BAC*, or the length *AB* is the longitude scale expanded in the ratio of the secant of the latitude. This, it will be remembered from parallel flying, is the same ratio that was found to exist between DLo and Dep or, in other words, the amount by which the scale of a Mercator chart has been expanded at any given latitude by drawing the meridians as equidistant parallel lines.

(*c*) Measuring upward along the meridians from the base parallel 40° lay off the distance *AD* equal to *AB*, and through these points draw the parallel of latitude 41°.

(*d*) In the same manner, determine the parallel 42° by laying off the line *DE* so that angle *EDF* equals 41°30′, and the parallel 43° by laying off the line *GH* so that angle *HGI* equals 42°30′.

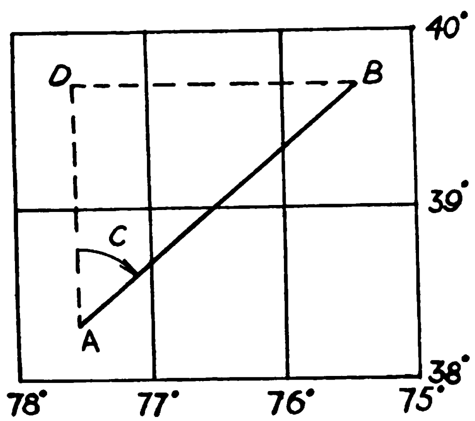

FIGURE 123.—Mercator flying.

(*e*) On the border, parallels and meridians subdivide the degrees into 10′ intervals of longitude and latitude, by dividing each degree into six equal parts. Each degree of latitude must be separately subdivided.

d. Mercator solution.—The principle of construction of the Mercator chart affords a method of computing the course angle when the DL and DLo are known without using the departure. Having found the course, the distance may be found from the plane flying formula: Dist = DL sec C. The formulas of the Mercator solution are mathematically correct for any course and distance. From the construction of the Mercator chart by the use of meridional parts it has been seen that there are two different scales of vertical coordinates available: First, the constant scale of meridional parts by which the location of the different parallels of latitude is determined and which is the same scale as the minutes of longitude or horizontal scale on the chart; and second, the minutes of latitude-and-nautical-miles scale which, though it represents a constant scale on the earth's surface is a constantly varying scale on the chart. Therefore, if any triangle drawn on the Mercator chart is referred to the first system of coordinates, all of its sides will be measured in the same unit of length and it may be readily solved by trigonometry.

(1) In figure 123, let A and B be two points on a Mercator chart and AB the rhumb line joining them. Then C will be the course angle, BD will be the difference of longitude, and AD will be the difference of latitude.

(2) The length of AD in meridional parts will be the difference of the meridional parts found in the tables opposite the latitudes of A and B. This difference will be abbreviated "mer DL."

(3) Then, $\tan C = \frac{DLo}{mer\ DL}$

(4) Having found the course angle C, the distance may be found from the plane flying formula: Dist = DL sec C.

(5) The right triangles of the plane and Mercator solutions are similar for a given course angle and may be drawn together in such a manner that the relations between the various quantities can easily be deduced. In figure 124, let A and B represent two places, joined by a rhumb line AB, whose course angle is C. Then, triangle ABD is the triangle of plane flying, and AB is the distance, AD the difference of latitude, BD the departure. Now if the side AD is extended so that AE is laid off equal to the difference of meridional parts corresponding to the latitudes of A and B, and the right triangle AEF is completed, then EF will represent the difference of longitude. Triangle AEF is the triangle of Mercator flying and is the way the plane triangle ABD would appear when plotted on a Mercator chart.

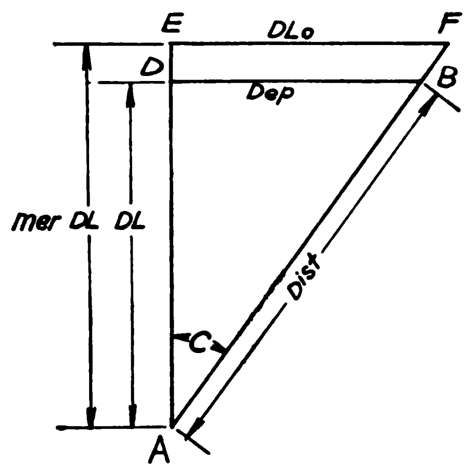

FIGURE 124.—Mercator triangle.

(6) (*a*) *Methods.*—Problems in Mercator flying may be solved by construction, by trigonometry, or by the traverse tables. When using the traverse tables for solving triangle AEF of figure 124, DLo must be substituted for Dep and mer DL for Lat in the column headings of the tables. Instructions as to column headings are given at the bottom of each page. Triangle ABD (fig. 124) is solved as in plane flying. Trigonometric solution by the use of logarithms is greatly facilitated by use of the form shown in figure 125.

(*b*) *Example of trigonometric solution.*—Required the course and distance by rhumb line from a point in Lat. 42°03′ N., Long. 70°04′ W., to another in Lat. 36°59′ N., Long. 25°10′ W. The solution is shown in figure 125.

(7) When the course given is exactly 90° or 270° the Mercator solution becomes indeterminate, since tan 90° is infinite and cos 90° is zero. In this case the method of parallel flying must be used.

197. Great circle flying.—The shortest distance between any two points on the earth's surface is the arc of the great circle joining them. Where distances are great the saving in distance over the rhumb line course often makes it advantageous to fly the great circle arc as a track. All great circles with the exception of the Equator and the meridians themselves intersect every meridian at a different angle, and in order to fly the great circle course a constantly changing compass course would be necessary. To obviate this difficulty rhumb line chords to the great circle are flown.

a. Great circle track.—(1) The great circle track always lies nearer the pole than the rhumb line between any two points in latitudes of

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Air Corps
Form No. 21 G
Approved Feb. 6, 1937

SOLUTION—MERCATOR FLYING

Lat.	42° 03′ N	Mer. Pts.	2770.1	Long.	70° 04′ W
Lat.	36° 59′ N	Mer. Pts.	2377.3	Long.	25° 10′ W
DL	5° 04′ } S 304′	Mer. DL	392.8	DLo	44° 54′ } E 2694′
DLo	2694	Log	3.43040		
Mer. DL	392.8	Log	2.59417	(Sub)	
Course	S 81° 42′ E	Log Tan	83623	Log Sec.	.84056
DL	304			Log	2.48287 (Add)
Dist.	2106 miles			Log	3.32343
Course	98° 18′ (measured clockwise from north)				

FIGURE 125.

the same name, and if the points are in opposite latitudes the great circle intersects the rhumb line at the Equator. That portion of the great circle in the Northern Hemisphere will then lie north of the rhumb line and the other part of it south of the rhumb line.

(2) When the great circle course is plotted on a Mercator chart it appears as a curve lying on the polar side of the rhumb line and is apparently a longer distance than the rhumb line. This appearance is caused by the distortion of the Mercator chart, and it should be understood that the rhumb line is actually the indirect route.

b. Finding great circle course and distance.—(1) *From chart.*—The most convenient method of determining the great circle course between two points is to draw a straight line between those points on a great circle or gnomonic chart. The approximate course and distance may be found by a method explained on the chart. The great circle course is transferred to a Mercator chart by taking the latitudes and longitudes of points at about 5° intervals of longitude along the great circle and plotting these points on the Mercator chart. By joining the points thus plotted with rhumb lines the navigator has an approximate great circle route which is practicable to fly.

(2) *By computation.*—The great circle route may be accurately found by computing the coordinates of a series of points along the great circle and the courses at these points. These points are then plotted on a Mercator chart in the same manner as above. There are several methods of performing this computation, all of which involve spherical trigonometry beyond the scope of this manual. Great circle computations are described in TM 1-206. A quick method of determining the great circle distance between two points is shown below.

(*a*) Required the great circle distance from Sandy Hook Lightship, N. Y., Lat. 40°28′ N., Long. 73°50′ W., to Pt. Loma Lighthouse, Calif., Lat. 32°40′ N., Long. 117°15′ W.

From Lat.	40°	28′ N.		Long.	73°	50′ W.	
To Lat.	32°	40′ N.		Long.	117°	15′ W.	
DL	7°	48′		DLo	43°	25′	
DLo	43°	25′		log Hav		9.13613−10	
From Lat.	40°	28′		log cos		9.88126−10	
To Lat.	32°	40′		log cos		9.92522−10	
							add
			K	log Hav		8.94261−10	
			K	nat Hav		0.08763	
DL	7°	48′		nat Hav		0.00463	
							add
Dist=	35°	22′		nat Hav		0.09226	
=	2,122 nautical miles.						

(*b*) Tables of log Haversines and natural Haversines may be found in table 45, H.O.9 (Bowditch).

(*c*) The value of the constant K in the above solution is not required. The value K nat Hav is found in the tables of Haversines opposite the value of K log Hav.

(*d*) The above solution is used for computation of great circle distance only and cannot be used to find the coordinates of points along the great circle.

(3) *Use of Lambert chart.*—A very close approximation to the great circle course may be found by drawing a straight line between the two points on a Lambert conformal chart. The use of the Lambert chart permits more convenient measurement of course, distance, and coordinates of points than on the gnomonic chart.

Section X

RADIO NAVIGATION AS APPLIED BY PRECISION NAVIGATOR

	Paragraph
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Characteristics of radio bearings	199
Principle of radio direction-finder (RDF)	200
Aircraft radio compasses	201
Marine radio beacons	202
Radio direction-finder stations	203
Converting radio bearing	204

198. General.—*a.* The chief point of difference between the pilot-navigator and the navigator, insofar as radio aids are involved, lies in the fact that the navigator makes far more frequent use of radio bearings. Whereas the pilot-navigator concerns himself principally with flying the radio beams and with "homing" by means of his radio compass, the navigator has the time and the equipment to employ radio bearings extensively. These bearings may be taken by means of the radio direction-finding equipment installed in the airplane or they may be taken by a radio direction-finder station on the ground.

b. The use of radio bearings, as is the case with all radio aids, is limited only by the quality and range of the equipment (ground and air), the skill of the operator, and the availability of an adequate number of bearing stations. Although numerous ground transmitters and direction-finding stations are continuously available as navigational aids in peacetime, their operation in wartime will in all probability be considerably curtailed. This fact merits serious consideration by the military navigator and should have a profound effect upon the amount that he "leans" on radio aids in peacetime training.

c. Due to certain inherent characteristics (see par. 199) of radio waves and to the design of present-day equipment, radio bearings over long distances have not attained the degree of accuracy regarded as compatible with the demands of precision navigation. This is true whether the bearings are taken from the aircraft or by surface direction-finder stations. But what radio bearings lack in accuracy is partially offset by the ease and rapidity with which they may be taken. The greater the number of bearings taken, the more accurate is the resulting fix.

d. The developments in radio are so rapid that no accurate prediction can be made of its future possibilities. Certainly the accuracy of bearings will improve with the development of better equipment.

Furthermore, the secrecy with which bearings may be taken will in all probability reach a high state of refinement.

199. Characteristics of radio bearings.—*a.* Radio bearings, like visual and celestial bearings, follow the track of a great circle; but the path of the radio wave may be refracted or reflected by storm areas, by mountains, by crossing alternate areas of land and water, and by what is known as night effect. The latter effect causes erratic readings of the bearing angle during the hours of twilight both at sunset and sunrise. Obviously, all of the foregoing factors influence the accuracy of a radio bearing, and the unfortunate part about it is that the amount these factors deflect the radio wave is uncertain due to the widely varying conditions which may prevail at the time the bearing is taken.

b. Even if the radio wave is not deflected from the direct great circle path between the airplane and the bearing station, the bearing indicated on the azimuth scale of direction finding equipment is not the direct great circle bearing because the radio wave is distorted by the mass of metal surrounding the radio direction finding equipment. This distortion occurs whether the bearing is taken by the airplane or by the ground station. The amount of this distortion is determinate, and the process of finding the deviations is known as "calibrating the radio compass." Calibration is described in detail in paragraph 201*c*.

c. After the deviation of the radio compass has been taken into account and an additional correction applied to permit plotting on the particular projection being used (par. 204), radio bearings are plotted in exactly the same manner as visual bearings. Like visual bearings, the accuracy of a fix can be improved by taking bearings on more than two stations. Running fixes are made in the same manner as described in section VI.

200. Principle of radio direction finder (RDF).—*a.* Radio direction finders depend on the directional characteristics of a loop antenna. When the plane of the loop is turned perpendicular to the direction of the radio transmitter, little or no signal will be heard. This "null" may be determined aurally or by a visual indicator. Therefore, if an azimuth ring is attached to the loop, the direction from which a given signal is being received can be determined by turning the loop until the point of minimum signal strength is found.

b. The loop antenna has a front and a back, and the null can be obtained with the azimuth scale in two positions 180° opposed, depending upon whether the front or the back of the loop is facing the transmitting station. In other words, a bearing is bilateral, its point of origin being somewhere on a line but possessing an ambiguity of 180°. All current Army aircraft direction finder sets permit the navigator to make a bearing unilateral, i. e., to determine whether the fore bearing or back bearing is indicated on the azimuth scale. The means of determining the fore bearing varies with the design of the equipment.

201. Aircraft radio compasses.—*a. Definition.*—The RDF sets installed in aircraft are called radio compasses, although, in the strict sense of the word, the term applies to a compass with a fixed loop which requires that the entire airplane be pointed in the direction of the station if a bearing is taken. However, throughout this section, the term "radio compass" will be used when referring to the rotatable loop type.

b. Types.—Radio compasses may be classified as automatic or manually operated.

(1) The automatic radio compass is the type in which a motor driven loop automatically turns to a position perpendicular to the station as soon as the station is tuned. The design is such that the bearing is unilateral, the fore bearing being automatically indicated on the azimuth scale by a pointer. Hence, the navigator need not concern himself with the possibility of confusing the fore and back bearings. This type of compass is further distinguished by the fact that the azimuth scale may be set so that the pointer indicates true, instead of relative bearings. Only a few automatic compasses are currently installed in Army aircraft.

(2) In the manually operated compass, the loop is set by rotating the yoke of the loop by hand or by a hand-operated crank. There are two general types of manually operated compasses.

(*a*) The type installed in most Army aircraft has a visual indicator which indicates sensings only. The indicator serves a dual purpose; first, it indicates to which side of the fore-aft axis of the airplane the station lies; second, it indicates whether the fore or back bearing has been taken (see *d*(3) below). The bearing of the station is indicated by a fixed lubber line over a rotating azimuth scale graduated from 0 to 360° which moves with the loop. The lubber line is parallel to the fore-aft axis of the airplane. Therefore, relative bearings are indicated on the scale. Since this compass is the type in current use, subsequent paragraphs pertaining to calibration and taking of bearings assume that this type compass is installed in the airplane.

(*b*) The second type of manually operated compass is very similar to the automatic type in that a pointer on the azimuth scale indicates the bearing of the station when the loop is in the null position. As in the automatic type, the azimuth scale may be set so that the pointer indicates true instead of relative bearings. Since the loop does not automatically seek the null position, a visual indicator is installed so that the navigator can see when the loop is in the null position and can obtain a sensing as to whether the front or back of the loop is facing the station.

c. Calibration.—(1) As has already been stated, the mass of metal of the aircraft distorts the radio wave in the vicinity of the aircraft

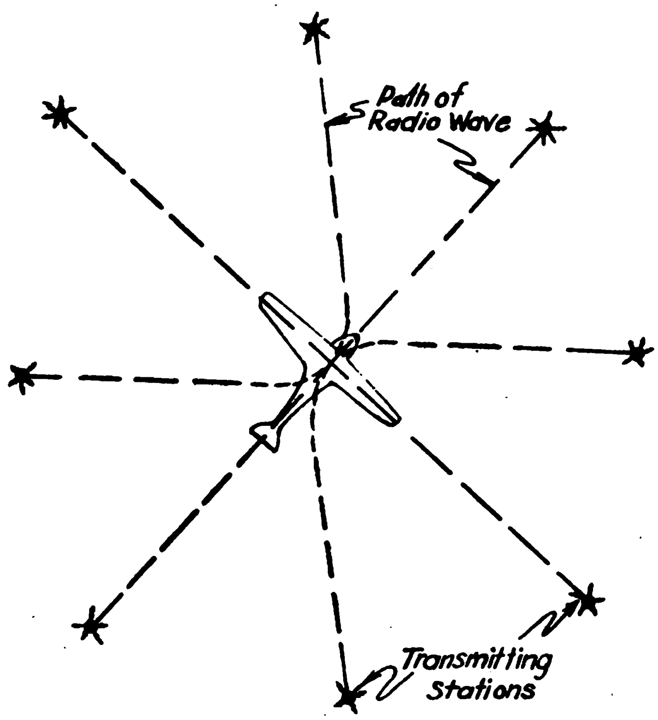

FIGURE 126.—Deviation effect of mass metal of airplane.

and, consequently, an erroneous bearing may be indicated on the azimuth scale. Deviations of bearings taken on stations bearing fore and aft and directly abeam of the aircraft are usually small, but they may be of the order of 15° on stations bearing to the quarter of the head or tail. (See fig. 126.) It is essential that the loop be carefully calibrated in order to obtain accurate bearings.

(2) Any one of several procedures may be used in calibrating. At first glance it would appear that an air procedure would be superior to a ground method because in flight the loop is in flying position, land effect is minimized, and the airplane is definitely remote from any exterior mass of metal. However, ground and air procedures have

resulted in nearly identical indications. Whether the two procedures will continue to give the same results with the equipment of the future is problematical. One type of air calibration procedure is described in (3) below.

(3) (*a*) The procedure for calibrating the loop consists of taking a series of bearings from over a given point on a radio station whose bearing from the given point is known. Each reading of the compass loop is compared with the relative bearing found from the true heading of the aircraft on that run and the true bearing of the radio station from the given point. A deviation curve is drawn from this comparison.

(*b*) Referring to figure 127, let *B* be a given radio station whose true bearing from point *A* is known, and let *AH* be any true heading of the aircraft as it passes over point *A*. Then angle *NAB* will be the true bearing of *B* from *A*, angle *HAB* (clockwise from *HA*) will be the relative bearing of *B* from the airplane. Then angle *HAB* (clockwise) = 360° − (angle *NAH* − angle *NAB*), or correct relative bearing = 360° + true bearing − true heading. If the true heading is less than the true bearing, 360° need not be added to the true bearing in order to subtract.

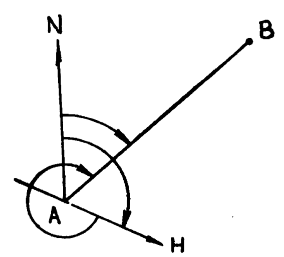

FIGURE 127.—Calibration of radio compass.

(*c*) If, at the instant of passing over point *A*, a radio bearing is taken on *B* with the loop, the deviation of the loop on that bearing is the difference between the relative bearing found above and the reading of the azimuth ring of the loop. The sign of the deviation correction is plus when the azimuth reading of the loop is less than the relative bearing, and minus when the reading is greater than the relative bearing.

(*d*) Readings should be taken in this manner at 10° or 15° intervals of azimuth around the loop, at the same time taking the magnetic compass reading on each heading in order to find the true heading of each run. These values should be tabulated; and for each run the true heading of the airplane, the relative bearing of the radio station, and the deviation of the loop computed. Then, by plotting the deviations thus found against the azimuth readings of the loop, the deviation curve can be drawn. A typical curve is shown in figure 128. Obviously, the deviations of the magnetic compass must be accurately known in order to get accurate results from the foregoing procedure. This constitutes one of the primary disadvantages of this type of air procedure.

(4) The radio compass should be calibrated on a frequency as near as possible to the frequencies which will be used in taking bear-

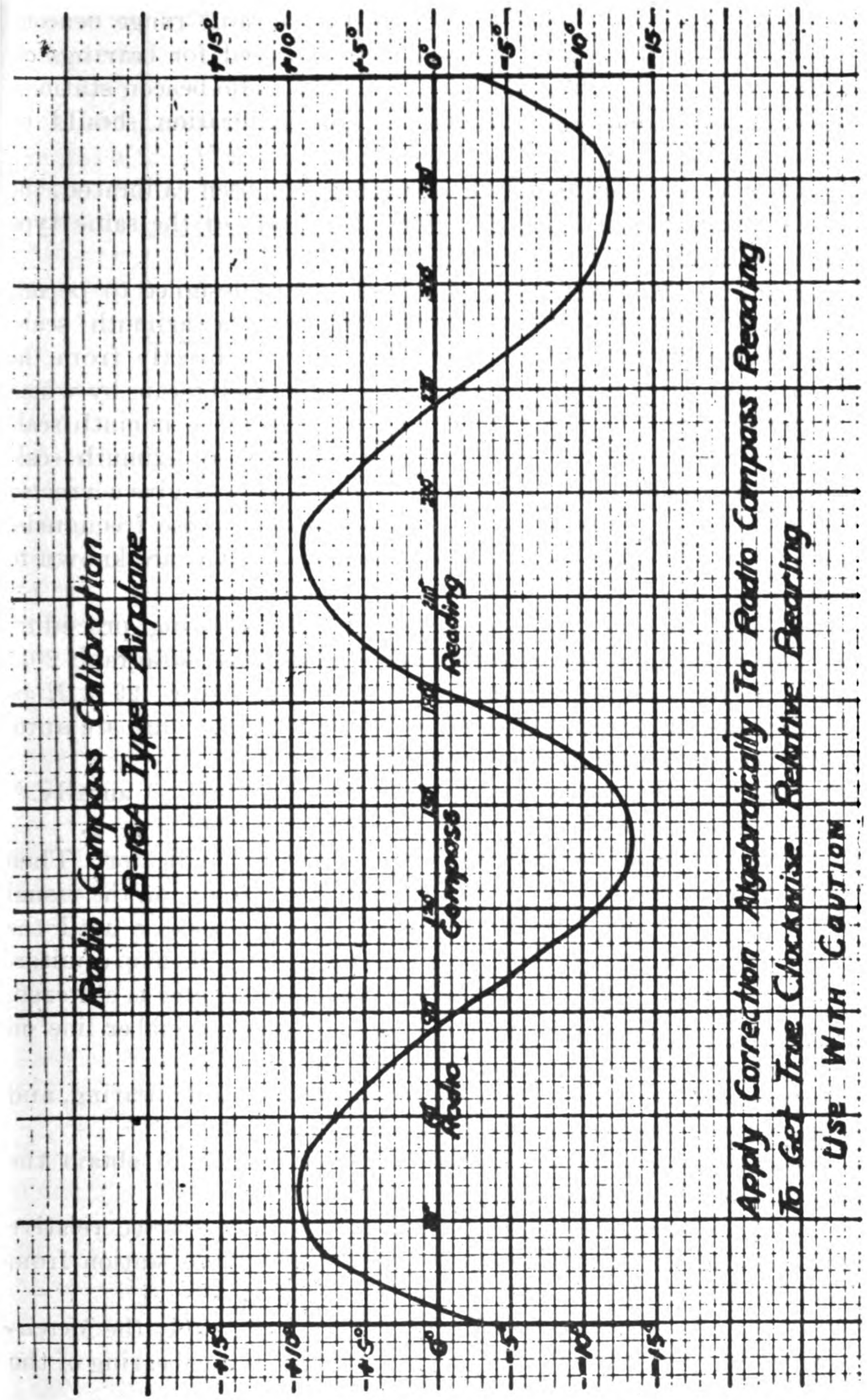

FIGURE 128.—Radio compass deviation curve.

ings. For example, a calibration made on a frequency about midway through the range of frequencies covered by the radio range beacons in the United States (about 300 kc) could be used for bearings on all radio range stations and also on the marine radio beacon stations. For commercial broadcast stations another calibration should be made.

(5) Once the radio compass of an aircraft has been calibrated, the deviation curve will usually serve for all aircraft of the same type which contain the identical compass.

(6) Many of the newer types of compasses are designed to permit incorporation of the deviation corrections into the azimuth scale. The bearing corrected for deviation may be read directly from the scale, no computation being necessary. The mechanical means by which the deviation curve is attached to or incorporated in the azimuth scale varies with the design of the compass. Obviously, an azimuth scale adjusted to apply compass deviation automatically will give corrected bearings only when bearings are taken on stations whose frequencies lie within the frequency band for which the deviations are known to be accurate.

d. To take and plot a radio bearing.—The following procedure applies when using compasses of the type referred to in paragraph 201*b* (2)(*a*). A work form similar to that shown in figure 129 will be found convenient. Certain steps of the following procedure are automatically accounted for in the latest compasses.

(1) Tune a station whose location is known. Identify it aurally.

(2) Place loop so that azimuth scale reads zero (360°).

(3) Note the direction of deflection of the visual indicator. Then rotate the loop as follows: If the deflection of the needle on the visual indicator is to the right of zero, rotate the loop clockwise until the pointer moves to the center mark; if to the left, rotate the loop counterclockwise until the pointer is centered. When the pointer is centered, the indicated relative radio bearing appears under the lubber line on the azimuth scale.

(4) Read and record the time, indicated relative radio bearing, and true heading of aircraft.

(5) Apply radio compass deviation (from curve) to obtain the corrected relative radio bearing.

(6) Add the true heading of the aircraft to the corrected relative radio bearing to obtain the true radio bearing of the station from the airplane.

(7) If plotting is to be done on a Mercator chart, apply the Mercator correction (par. 204), thus obtaining the rhumb line bearing of the station from the airplane.

1.	Station						
2.	Frequency						
3.	Time of Bearing						
4.	Indicated Relative Radio Bearing						
5.	Radio Compass Deviation						
6.	Corrected Relative Radio Bearing: 4 ~ 5						
7.	True Heading of Plane						
8.	True Radio Bearing of Station from Plane: 6 + 7						
9.	Mercator Correction from Table "C"						
10.	Mercator Bearing of Station from Plane 8 ~ 9. Apply Correction as directed on bottom of sheet.						
11.	± 180° for Reciprocal Bearing						
12.	Mercator Bearing of Plane from Station.						

FIGURE 129.—Radio bearing work sheet.

(8) Add or subtract 180° (whichever is convenient) to obtain the true bearing of the airplane from the station.

(9) Plot line of position on the chart by laying off the bearing from the transmitting towers of station. The bearing is plotted as described in section VI.

e. Accuracy of radio compass bearings.—(1) Bearings obtained by aircraft radio compasses are subject to the vagaries of radio waves described in paragraph 199. An additional source of error may be found in the radio compass deviation curve. It has been said that the compass deviation changes with the frequency of the incoming wave. It is manifestly impractical to construct deviation curves for more than a few commonly used frequencies. Furthermore, in rough air an airplane is a relatively unsteady platform. If the heading of the aircraft is different from what the navigator believes it to be, the error is carried through when making the computations for plotting the line of position. Also, interstation interference is frequently responsible for many false bearings.

(2) It has been found that bearings taken on radio range beacons are more accurate than those taken on broadcasting stations. Radio bearings on the old "loop" type radio range beacons are difficult to obtain due to the oscillations they cause in the visual indicator. Most of the loop beacons have been replaced by "simultaneous" range beacons which do not create oscillations of the needle. The power as well as the location of stations should be considered when selecting bearing stations. Other things being equal, bearings should be taken on the more powerful stations.

(3) Under the best conditions radio bearings taken with present-day compasses must be regarded as likely to have an error of ± 2° or 3°. Under adverse conditions the error may be greater.

202. Marine radio beacons.—*a.* Marine radio beacons have been established along coast lines to serve as bearing stations for the direction finders installed in surface craft. They may be used by aircraft equally as well. These beacons should not be confused with the radio range beacons located along the airways. Marine beacons are not directional. They simply transmit a definite signal upon which an airplane's radio compass may be tuned.

b. The United States and Canada have a coordinated system of radio beacon operation in which all radio beacons are assigned group frequencies and definite operating periods. In fog all station groups transmit continuously, each station in rotation and on its assigned minute. In clear weather, station groups operate for one or two 10-minute periods per hour.

c. Complete information on radio beacons may be found in H. O. 205.

203. Radio direction-finder stations.—*a. General.*—At the present time there are few ground DF stations except those established primarily to take and report bearings to surface craft, although they may be used by aircraft with equal facility. These stations are located along shore lines and on islands over most of the world. In addition to taking bearings, the RDF stations of the United States will transmit their call signals upon the request of ships and aircraft desiring to use them as radio beacons. Detailed procedure for obtaining bearings from shore stations is given in H. O. 205 together with a list of direction finding stations with their frequencies, call letters, hours of operation, and geographical positions. Since the DF stations are not used with great frequency by Army aircraft, the radio operator may not be any too familiar with the correct procedure in requesting a bearing. It behooves the navigator to assure himself that the operator knows the procedure in advance of any contemplated use.

b. Secrecy.—Since there is no necessity for DF stations to transmit except to report bearings, greater secrecy may be attained by using DF stations than by using radio beacons which must operate continuously to be of much service. The airplane need only send out the request to the surface DF stations and hold down the key long enough for the DF station to get the bearing. In view of the short period of transmission required to report the bearing to the airplane, it is extremely unlikely that any hostile goniometer station will pick up the signals.

c. Accuracy of bearings.—(1) The bearings taken by surface direction finders are generally more accurate than those taken by aircraft, first, because the bearings are taken from a rigid platform, and, second, because the deviations of the compass are generally more accurately determined. The bearings taken by radio direction-finder stations and reported by them to aircraft are corrected for all determinable errors except the difference between a great circle track and a rhumb line (par. 204), and are normally accurate within 2° for distances under 150 miles.

(2) Each direction-finder station has a sector about its receiving loop, usually seaward from the station, in which the deviation of radio bearings has been determined by calibration. Bearings which do not fall within the calibrated sector should be regarded as unreliable.

(3) The best bearings can be taken on aircraft whose signals are steady, clear, strong, and accurately tuned to the proper frequency.

(4) When the bearing lies obliquely along a shore line or crosses intervening areas of high ground it may be in error by 5° or more. Direction-finder stations know in which sectors such errors are found,

and these sectors are not included in the calibrated sector or are called sectors of uncertain calibration.

(5) When radio bearings are reported by direction-finder stations as doubtful, approximate, second class, or the equivalent, they should be considered unreliable and used with caution.

d. Correction of bearings.—Although most surface DF sets are equipped with sensing indicators which eliminate the hazards of transmitting the back bearing by mistake, some of the older apparatuses do not enable the operator to make the bearing unilateral. If it becomes apparent to the navigator that the DF station has reported the back bearing, he must call for the correct bearing instead of applying 180° to the bearing given because the deviations on reciprocal bearings may differ widely.

e. Plotting of bearings.—Bearings taken by RDF stations must be plotted from the position of the receiving loop of the RDF station.

204. Converting radio bearing.—*a. Gnomonic chart.*—The track of a radio bearing is a great circle and will appear as a straight line on a gnomonic chart. The great disadvantage to plotting the bearing on a gnomonic chart is that a specially graduated protractor is necessary for each bearing station. (See par. 123.)

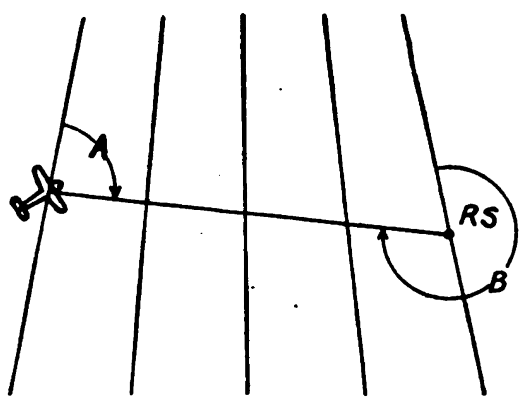

FIGURE 130.—Radio bearing line on Lambert chart.

b. Lambert chart.—The characteristics of the Lambert conformal projection are such that the bearing may be plotted as a straight line without appreciable error. One precaution must be taken. The meridians on the Lambert conformal conic projection converge. Because of this, an error will be introduced if the reciprocal of a bearing taken by an aircraft is laid off with a protractor orientated on the meridian through the bearing station. This error is illustrated in figure 130 where obviously angle B does not equal angle $A+180°$. The error may be eliminated by measuring the convergence of the meridian through the aircraft's DR position and that through the station and applying the necessary angular correction. However, the bearing angle at the station may be plotted with sufficient accuracy by alining the protractor "by eye" so that its zero line is parallel to the meridian through the DR position of the aircraft. This error *does not* occur when a bearing taken by a ground DF station is plotted on the Lambert chart.

c. Mercator bearings.—(1) *Rules.*—When plotting radio bearings on a Mercator chart they must first be converted to rhumb line bearings. No serious error will result if short bearings lines are plotted as straight without converting. However, it should be remembered that

CORRECTION REQUIRED to CONVERT a RADIO GREAT CIRCLE BEARING to MERCATORIAL BEARING.

Middle Latitude.	Difference of Longitude of Ship and Radio Station.														
	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
66	0·9	1·8	2·8	3·7	4·6	5·5	6·4	7·3	8·2	9·1	10·0	11·0	11·9	12·8	13·7
63	0·9	1·8	2·7	3·6	4·5	5·4	6·3	7·1	8·0	8·9	9·8	10·7	11·6	12·5	13·3
60	0·9	1·7	2·6	3·5	4·3	5·2	6·1	6·9	7·8	8·6	9·5	10·4	11·2	12·1	12·9
57	0·8	1·7	2·5	3·4	4·2	5·0	5·9	6·7	7·5	8·4	9·2	10·0	10·9	11·7	12·5
54	0·8	1·6	2·4	3·3	4·1	4·9	5·7	6·5	7·3	8·1	8·9	9·7	10·5	11·3	12·1
51	0·8	1·6	2·3	3·1	3·9	4·7	5·5	6·2	7·0	7·8	8·5	9·3	10·1	10·8	11·6
48	0·8	1·5	2·2	3·0	3·7	4·5	5·2	5·9	6·7	7·4	8·2	8·9	9·6	10·4	11·1
45	0·7	1·4	2·1	2·8	3·5	4·2	4·9	5·6	6·3	7·1	7·8	8·5	9·2	9·9	10·6
42	0·7	1·4	2·0	2·7	3·4	4·0	4·7	5·4	6·0	6·7	7·4	8·0	8·7	9·4	10·0
39	0·6	1·3	1·9	2·5	3·2	3·8	4·4	5·0	5·7	6·3	6·9	7·5	8·1	8·8	9·4
36	0·6	1·2	1·8	2·4	3·0	3·5	4·1	4·7	5·3	5·9	6·4	7·0	7·6	8·2	8·7
33	0·5	1·1	1·6	2·2	2·7	3·3	3·8	4·4	4·9	5·4	6·0	6·5	7·1	7·6	8·1
30	0·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·4
27	0·5	0·9	1·4	1·8	2·3	2·7	3·2	3·6	4·1	4·5	5·0	5·4	5·9	6·3	6·8
24	0·4	0·8	1·2	1·6	2·1	2·4	2·9	3·3	3·6	4·0	4·4	4·8	5·2	5·6	6·0
21	0·3	0·7	1·1	1·4	1·8	2·2	2·5	2·9	3·2	3·6	3·9	4·3	4·6	5·0	5·3
18	0·3	0·6	0·9	1·2	1·6	1·9	2·2	2·5	2·8	3·1	3·4	3·7	4·0	4·3	4·6
15	0·3	0·5	0·8	1·0	1·3	1·6	1·8	2·1	2·3	2·6	2·8	3·1	3·3	3·6	3·8
12	0·2	0·4	0·6	0·8	1·0	1·3	1·5	1·7	1·9	2·1	2·3	2·5	2·7	2·9	3·1
9	0·2	0·3	0·5	0·6	0·8	1·0	1·1	1·2	1·4	1·6	1·7	1·9	2·0	2·2	2·3
6	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·5	1·6
3	0·1	0·1	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·5	0·6	0·6	0·7	0·7	0·8

CORRECTION TO BE APPLIED TO RADIO BEARINGS TAKEN BY AN AIRCRAFT

In North Latitude;

Plane East of Station Subtract Correction

Plane West of Station Add Correction

In South Latitude;

Plane East of Station Add Correction

Plane West of Station Subtract Correction

FIGURE 131.—Radio bearing conversion table.

the divergence between the rhumb line and the great circle arc between two points varies with the midlatitude and the difference in longitude. The great circle bearing is converted to a rhumb line by means of the radio bearing conversion table shown in figure 131. The table is entered with difference of longitude and middle latitude as arguments, and the correction is applied to the radio bearing to obtain the Mercator bearing.

(*a*) When the bearings are taken by a shore station and reported to the aircraft the following rules apply:

1. In north latitude when the aircraft is $\frac{\text{east}}{\text{west}}$ of the station the correction is $\frac{\text{added}}{\text{subtracted}}$.

2. In south latitude when the aircraft is $\frac{\text{east}}{\text{west}}$ of the station the correction is $\frac{\text{subtracted}}{\text{added}}$.

(*b*) When the bearings are taken by the aircraft the following rules apply:

1. In north latitude when the aircraft is $\frac{\text{east}}{\text{west}}$ of the station the correction is $\frac{\text{subtracted}}{\text{added}}$.

2. In south latitude when the aircraft is $\frac{\text{east}}{\text{west}}$ of the station the correction is $\frac{\text{added}}{\text{subtracted}}$.

(*c*) The above rules can be deduced by remembering that the great circle always lies on the polar side of the rhumb line. Figure 132 shows a great circle and a rhumb line bearing in north latitude on a Mercator chart. The aircraft *A* is east of the station *S*. Then angle *b* will be the true bearing of *A* from *S*, and angle *b′* will be the Mercator bearing of *A* from *S*; angle *a* will be the true bearing of *S* from *A*, and angle *a′* will be the Mercator bearing of *S* from *A*. It can be seen that the correction must be added to the great circle bearing taken by the RDF station to obtain the Mercator bearing of *A* from *S*; and that the correction must be subtracted from the great circle bearing taken by the aircraft to obtain the Mercator bearing of *S* from *A*. Also it is obvious that 180° must be applied to the Mercator bearing of *S* from *A* in order to plot the bearing from *S*.

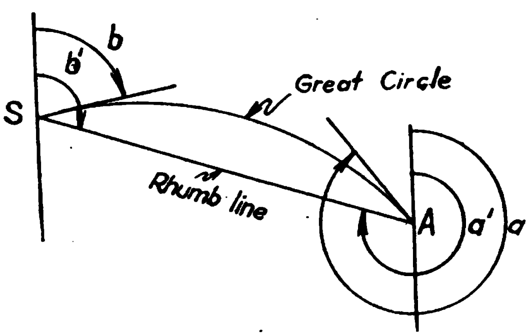

FIGURE 132.—True and Mercator bearings.

(2) *Example.*—An aircraft whose DR position is Lat. 38°03′ N., Long. 56°00′ W. and flying on a true heading of 240° takes a relative radio bearing on Bar Harbor Station, Lat. 44°19′ N., Long. 68°11′ W. The relative radio bearing measures 60°. To find the Mercator bearing of the aircraft from Bar Harbor Station:

Middle latitude=41°11′ N.; difference of longitude=12.2° W.

Enter table with middle latitude 41° and DLo 12.2°. The correction is found to be 4.1°. Since the aircraft is in north latitude and to the east of the station the correction is subtracted and in this case becomes −4.1°.

Indicated relative radio bearing	60°
Radio compass deviation (from curve)	+7°
Corrected relative radio bearing	67°
True heading of airplane	240°
True radio bearing of station from plane	307°
Mercator correction	−4. 1°
Mercator bearing of station from plane	302. 9°
−180° for reciprocal bearing	−180.
Mercator bearing of plane from station	122. 9°

Appendix I

NOMENCLATURE OF AIR NAVIGATION

Air navigation.—The art of determining the geographical position, and maintaining desired direction, of an aircraft relative to the earth's surface by means of pilotage, dead reckoning, celestial observations, or radio aids.

NOTE.—The term "avigation" has been suggested but is considered unnecessary and undesirable.

Air speed.—The true speed of an aircraft relative to the air. It is the true air speed unless otherwise stated. Air speed is obtained by correcting the calibrated air speed for density, using temperature and pressure altitude corrections.

Indicated air speed.—The reading of the air speed indicator.

Calibrated air speed.—The reading of the air speed indicator, corrected for instrumental and installation errors.

Aircraft navigational computer (celestial).—A device for solving the astronomical triangle which may or may not contain means for observing the altitude of celestial bodies.

Aircraft navigational computer (D. R.).—A device for computing speed, time, distance, true air speed, wind correction, ground speed, altimeter correction, etc.

Aircraft plotter.—A device for plotting tracks, headings, position lines, or bearings on a chart.

Altimeter.—An instrument that measures the height of an aircraft above a given datum plane. Unless otherwise designated, it is taken to be barometric.

Sonic altimeter.—An altimeter utilizing sound waves.

Radio altimeter.—An altimeter utilizing radio waves.

Altimeter setting.—The existing station pressure reduced to sea level in accordance with the U. S. standard atmosphere. Altimeter setting is also the standard atmosphere pressure corresponding to pressure altitude variation.

Altitude.—The true height above sea level. The calibrated altitude corrected for air temperature and for barometric pressure. It is always true unless otherwise designated.

Indicated altitude.—The height above sea level as read on the altimeter.

Calibrated altitude.—The indicated altitude corrected for instrumental and installation errors.

Indicated absolute altitude.—The height above the earth's surface read on the altimeter when set to read altitude above the earth's surface.

Calibrated absolute altitude.—The indicated absolute altitude corrected for instrumental and installation errors.

Absolute altitude.—The true height above the earth's surface. It is the calibrated absolute altitude corrected for air temperature and barometric pressure.

Indicated pressure altitude.—The reading of the altimeter when the correction table is set to read zero feet or 29.92 inches of mercury.

Pressure altitude.—The indicated pressure altitude corrected for instrumental and installation errors.

Azimuth (Z.)—The bearing of a celestial body measured as an arc on the horizon from the true meridian north or south to the east or west. Abbreviation Zn is used where the azimuth has been changed to read from the north through east to 360°.

Bearing (B.)—The direction of one object from another, expressed as an angle measured clockwise from true north. Bearing is true unless otherwise designated.

Magnetic bearing.—Bearing (true) with variation applied.

Compass bearing.—The magnetic bearing with deviation applied.

Relative bearing.—The direction of an object expressed as an angle measured clockwise from the heading of an aircraft.

Celestial navigation.—The method of determining the geographical position of an aircraft by observation of celestial objects.

Compass.—An instrument indicating the angle of the longitudinal axis of the aircraft with respect to the axis of the compass needle. Taken to be a magnetic compass unless otherwise designated.

Aperiodic compass.—A cardless magnetic compass in which the needle when deflected from its point of rest returns to that point with small overswing.

Radio direction finder (R. D. F.).—A device for indicating the direction of a transmitting station. The term "radio compass" has been incorrectly used for this device.

Compass error (C. E.).—The algebraic sum of the variation and deviation.

Compass compensation.—A practical method of applying magnets or other correctors to neutralize the magnetic forces exerted on the compass by the aircraft structure and equipment.

Compass rose.—A small circle, graduated in degrees (0 to 360), placed on maps or charts as a reference to directions true or magnetic. Also used to designate the graduated circle used as a base for ground compass swinging.

Compass swinging.—The process of determining the deviation of the magnetic compass.

Course (C.).—The direction over the surface of the earth, expressed as an angle, with respect to true north, that an aircraft is intended to be flown. It is the course laid out on the chart or map and is always the true course unless otherwise designated. All courses are measured from north through east to 360°.

Magnetic course (M. C.).—The course true, with variation applied.

Compass course (C. C.).—The magnetic course with deviation applied.

Course made good.—The resultant true direction the aircraft bears from the point of departure.

Dead reckoning (D. R.).—The method of determining the geographical position of an aircraft by applying the track and ground speed as estimated or calculated over a certain period of time from the point of departure or from the last known position. D. R. position is indicated by an *X*.

Departure (Dep.).—The linear measure in nautical miles of an arc of a parallel. Departure is also the distance to the eastward or westward made good by an airplane flying from one point to another.

Departure, point of.—A specified position from which the course or track of the airplane is commenced.

Deviation.—The angular error between the axis of the compass needle and the magnetic meridian caused by magnetic influences in the aircraft. It is named east or west according to the direction in which the needle is deflected.

Distance.—The number of miles between any two points. Distance may be expressed as statute or nautical miles. A statute mile is an arbitrary measurement and is equal to 5,280 feet. A nautical mile is the length of 1 minute of latitude and for practical purposes is taken as 6,080 feet.

Great circle distance.—The length of the great circle arc joining two points.

Rhumb line or Mercator distance.—The length of the rhumb line course between two points.

Airway distance.—The length of the rhumb line course between two points, which is flown with due regard to airway aids and regulations, existing equipment, and known hazards.

Double drift.—A method of determining the force and direction of the wind by observing the drift angle on each of two or more headings at a known air speed; sometimes referred to as the multiple heading drift method.

Drift.—The angle between the heading and the track. Named right or left according to the way the aircraft is drifted.

Drift correction.—The angle added to or subtracted from an aircraft's course (true) to obtain heading. In case of a right drift the angle is subtracted from the course to obtain the heading, and in case of a left drift it is added.

Drift float.—An article or substance dropped from an aircraft over water, forming a point of reference for observing the drift angle or the surface wind direction.

Estimated time of arrival (E. T. A.).—The computed time that an aircraft will reach its destination or turning point.

Fix.—The intersection of two or more lines of position or bearings. A fix is indicated on a map or chart by a dot or cross centered in a circle.

Great circle.—A circle on the earth's surface whose plane passes through the center of the earth.

Great circle course.—The route between any two places along the circumference of the great circle which joins them. It is the shortest distance between two points over the surface of the earth.

Ground speed.—Actual speed relative to the earth's surface.

Ground speed meter.—An instrument for determining ground speed.

Heading.—The angular direction of the longitudinal axis of the aircraft with respect to true north. In other words it is the course with the drift correction applied. It is true heading unless otherwise designated.

Magnetic heading.—Heading with variation applied.

Compass heading.—Magnetic heading with deviation applied.

Intercept bearing.—The bearing that must be maintained in order to intercept another moving object.

Intercept heading.—The direction of the longitudinal axis of an aircraft to make good a given intercept course.

Intercept track.—The track flown by an aircraft over the earth's surface from a known position to a moving object.

Intercept speed.—The rate at which the distance between two moving objects is being reduced.

Knot.—The unit of speed used in navigation, and equal to a speed of 1 nautical mile per hour. (It is equivalent to 1.15 statute miles per hour.)

Latitude (Lat.).—The angular distance north or south of the Equator as subtended at the center of the earth measured from the Equator as a plane of origin.

Line of position.—A line on which the aircraft is observed to be. The intersection of two lines of position determines a fix.

Log.—A written record of computed or observed navigational record.

Longitude (Long.).—The angular distance at the axis of the earth between the plane of a meridian and the plane of the prime meridian of Greenwich, England, measured to the eastward or westward to 180°

Lubber line.—A prominent fixed line on the aircraft compass, drift sight, directional gyro, pelorus, and radio direction finder loop, oriented parallel with the aircraft's longitudinal axis to furnish a reference point to indicate a heading or bearing.

Mercator course (rhumb line).—A line on the earth's surface which intercepts all meridians at the same angle.

Navigational plot.—A diagram such as is used in navigation chart work in which lines indicate, by their direction and length, courses and distances made good over the ground.

No-drift position.—The position in which the aircraft would be at a given time, if there were no wind.

Off-course correction.—An angular correction applied to the course to parallel or to return to the original course in a given distance.

Pelorus.—A circular bearing plate graduated in degrees, mounted so that it lies horizontally, and provided with sighting means, which when oriented may be used to determine true or relative directions of objects.

Pilotage.—The method of conducting an aircraft from one point to another by observation of landmarks either previously known or recognized from a map.

Point of interception.—The place where two moving objects make contact, having flown intercept tracks.

Pressure:

Field elevation pressure.—The existing atmospheric pressure at a point 10 feet above the mean elevation of the runway. It is obtained by applying a suitable correction to the station pressure. It is assumed that the altimeter in an airplane is 10 feet higher than the landing surface.

Station pressure.—The existing atmospheric pressure at the elevation of the mercurial barometer located in the weather station.

Radio navigation.—The method of conducting an aircraft from one point to another by radio aids, such as the radio beacon, radio-direction finder, or radioed bearings.

Radius of action.—The distance an aircraft can fly before returning to a base, with a designated margin of fuel and oil.

Relative wind.—The force and direction of the wind with respect to any moving object.

Sextant:

Bubble sextant.—Any instrument used to measure the vertical angle of celestial bodies from a bubble horizon.

Marine sextant.—An instrument used to measure the vertical angle of celestial bodies from the natural horizon, or to measure the horizontal angles between terrestrial objects.

Temperature:

Air temperature.—Temperature of the air at the altitude being maintained by an aircraft.

Ground temperature.—The temperature of the air at a ground station.

Mean temperature.—The mean between the ground and air temperatures, used in correcting altimeter readings.

Track.—Actual path of an aircraft over the surface of the earth. Track is the path that has been flown. Course (true) is the path intended to be flown.

Variation (Var.).—The angle between the plane of the true meridian and a line passing through a freely suspended compass needle influenced solely by the earth's magnetism. It is named east or west according to the direction of the compass needle from true north. Variation changes with time and place.

Wind angle (from course).—The angular difference between the course (true) of an aircraft and the wind direction, measured to the right or left of the aircraft's course to the direction from which the wind blows. The wind angle never exceeds 180°.

Wind angle (from heading).—The angular difference between the true heading of an aircraft and the wind direction, measured clockwise from the heading to the direction from which the wind blows. This wind angle may be any number of degrees from 0 to 360. This definition applies when making double drift turns from heading.

Wind direction and force.—The wind is designated by the direction from which it blows. The force of the wind is expressed as the speed in miles per hour or knots.

Wind star.—A solution for the force and direction of the wind by the double drift method.

Appendix II

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BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

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