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to U.S. Dept of Army

FM 1-30

WAR DEPARTMENT

AIR CORPS FIELD MANUAL

AIR NAVIGATION

FM 1-30

AIR CORPS
FIELD MANUAL

AIR NAVIGATION

Prepared under direction of the
Chief of the Air Corps

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FM 1–30, Air Corps Field Manual, Air Navigation, is published for the information and guidance of all concerned.

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BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

E. S. ADAMS,
Major General,
The Adjutant General.

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AIR CORPS FIELD MANUAL

AIR NAVIGATION

CHAPTER 1

GENERAL

■ 1. SCOPE.—This manual is a general treatise on all methods and technique of air navigation and a brief summary of instruments and equipment used.

■ 2. DEFINITION.—Air navigation is the art of determining geographical position and maintaining desired direction of aircraft relative to the earth's surface by means of pilotage, dead reckoning, celestial observations, or radio aids.

■ 3. EMPLOYMENT.—The four means of air navigation are complementary and are used separately or in conjunction with each other in military operations. Radio silence, extremely low ceilings, strange or mountainous terrain, complete overcast, darkness, or necessity for overwater flying are conditions that necessitate use of one or more of the four types of navigation.

■ 4. NECESSITY OF TRAINING.—*a*. The varied characteristics of military operations tax to the extreme the ingenuity and ability of those responsible for navigation and require that personnel concerned be highly trained. It is imperative that those charged with the responsibility of navigation be well versed in, and fully competent to use, any and all of the four navigation methods.

b. Precise flying, both instrument and noninstrument, is an indispensable requirement of accurate air navigation. The automatic pilot is capable of more accurate flying than can be secured by manual piloting and its use improves the accuracy of air navigation.

■ 5. INSTRUMENT RESPONSIBILITY.—The success of a navigation mission depends to a great extent upon satisfactory functioning of the instruments involved, and presupposes their correct installation, calibration, and operation. The navigator is responsible for their satisfactory functioning. He must be familiar with their calibration and operation, and must be able to use properly their indications in the practice of air navigation.

■ 6. REFERENCES.—*a. Technical publications.*—For a complete list of War Department technical publications, see FM 21–6.

(1) *Technical Manuals.*—TM 1–205 and TM 1–206 are complementary manuals explaining in detail the methods and technique of air navigation.

(2) *Technical orders.*—For a complete list of Air Corps Technical Orders, see Air Corps Technical Order 00–1. Technical orders set forth information and instructions relative to specific items of equipment. They are guides for training personnel in installation, calibration, and operation of particular items of equipment. In general those covering navigation instruments and equipment fall within the Air Corps Technical Order 05-series. Radio equipment and facilities used as aids to navigation are described in Air Corps Technical Order 08–15–1 and Air Corps Technical Order 08–15–2.

b. Miscellaneous.—(1) *Air Corps circulars.*—Air Corps Circular 15–21 contains a list of forms and tables for air navigation. Air Corps Circular 50–3 contains instructions for altimeter setting. Air Corps Circular 65–101 lists the equipment contained in the dead reckoning navigation case. Air Corps Circular 100–20 contains a description of the Army Airways Communication System facilities used by the navigator. Air Corps Circular 90-series contains other aids to navigation.

(2) *Hydrographic Office, U. S. Navy.*—Navigation tables and equipment used by the navigator are listed in the General Catalog of Mariners' and Aviators' Charts and Books. The following publications are of especial interest to the air navigator:

(*a*) Useful tables from the American Practical Navigator, Hydrographic Office 9, Part II.

(*b*) Radio Aids to Navigation, Hydrographic Office 205.

(*c*) Dead Reckoning Altitude and Azimuth Tables, Hydrographic Office 211.

(*d*) Computed Altitude and Azimuth Curves, Hydrographic Office 214.

(*e*) Rude Star Finder and Identifier, Hydrographic Office 2102a.

CHAPTER 2

PILOTAGE AND DEAD RECKONING

SECTION I

GENERAL

■ 7. PILOTAGE.—Pilotage is the method of conducting aircraft from one point to another by observation of landmarks either previously known or recognized from a map.

■ 8. DEAD RECKONING.—Dead reckoning is the method of determining geographical position of aircraft by applying track and ground speed as estimated or calculated over a certain period of time from point of departure or from last-known position.

■ 9. METHOD OF TREATMENT.—Methods of pilotage and dead reckoning have been treated as a combined method of air navigation in this manual. However, the combined method has been separated into two divisions, methods and technique of the pilot-navigator limited in equipment and facilities, and the more precise methods and technique of the navigator.

SECTION II

PILOT-NAVIGATOR

■ 10. GENERAL.—*a*. Navigation duties fall upon the pilot in single place or multiplace aircraft where space or equipment does not permit or where nature of mission does not require a navigator. A pilot-navigator seldom employs celestial navigation. Radio navigation will be discussed separately as applicable only when radio facilities exist.

b. Instruments and equipment available to the pilot-navigator include compass, gyro-turn indicator, thermometer, altimeter, air-speed indicator, watch, computers, prepared forms, tables, and charts (maps). Invariable existence of a wind at some time during flight necessitates determination of wind effect upon movements of aircraft over the ground which will not be precisely as indicated by basic instruments, compass, and air-speed indicator.

■ 11. INSTRUMENTS.—*a.* The compass is the directional instrument and as such is one of the most important. Its errors should be known and their method of application thoroughly understood.

b. The gyro-turn indicator is used in conjunction with the aircraft compass both as a reference instrument for precision steering and as an amount indicator in making precision turns. When used as a steering reference the gyro-turn indicator is usually set at zero.

c. The thermometer is used to provide information for correcting altimeter and air-speed readings for temperature changes. These corrections are determined by computer.

d. The altimeter is used to determine height of the airplane relative to terrestrial objects as a means of determining air density for correction of air-speed indicator readings, and in conjunction with some types of drift meters for determining ground speed.

e. The air-speed indicator is the basic speed instrument. Its indications, when corrected, give true speed of aircraft through the air mass. Correction includes calibration for installation errors and those for variation of air density from standard. Corrections for air density (temperature and altitude) may be determined by computer.

f. The watch is used as a navigational instrument to indicate times of observations.

■ 12. EQUIPMENT.—*a.* Several types of air navigation computers are employed. They are basically circular slide rules permitting calculations of speed-time-distance and fuel-consumption problems. Scales on the computers permit correction of air-speed meter readings for air density, and of altimeters for temperature changes. Instructions furnished with particular computers explain their detailed use.

b. Charts available for use include a variety of projections and forms. The pilot-navigator should be familiar with comparative advantages and disadvantages of Mercator, Lambert conformal, polyconic, and gnomonic projections and be able to select and use the type of chart most suitable to his needs.

(1) The following aeronautical charts are now being published by the U. S. Coast and Geodetic Survey:

(*a*) *Sectional charts* of the entire United States, in 87 sheets, at a scale of 1:500,000.

(*b*) *Regional charts* of the entire United States, in 17 sheets, at a scale of 1:1,000,000.

(*c*) *Radio direction finding charts* of the entire United States, in 6 sheets, at a scale of 1:2,000,000.

(*d*) *Aeronautical planning chart* of the United States (No. 3060a), at a scale of 1:5,000,000.

(*e*) *Great Circle chart* of the United States (No. 3074) at a scale of approximately 1:5,000,000.

(*f*) *Magnetic chart* of the United States (No. 3077) showing lines of equal magnetic variation, at a scale of approximately 1:7,500,000.

(2) The U. S. Coast and Geodetic Survey also publishes Mercator charts of territorial waters of the United States and insular possessions, while the Hydrographic Office, U. S. Navy, publishes charts of all oceans, seas, and bays of the world on Mercator or gnomonic projections. These charts include coastlines and show all marine navigation data available. Catalogs are available listing all charts published by both agencies.

■ 13. PREFLIGHT PREPARATION.—*a*. Prior to take-off, the pilot-navigator procures all necessary data and equipment and arranges it for convenient use in flight. The use of a log sheet on any type of air navigation mission is essential as a means of insuring proper preparation and facilitates a constant flight check. Proper charts should be selected and prepared. From available wind data, drift corrections and ground speeds are computed. These data are entered in the log prior to take-off, together with estimated flight time to reference landmarks.

b. A knowledge of existing and anticipated weather along a contemplated flight course is necessary for intelligent preparation and execution of a mission as pertaining both to safety and air navigation of the flight.

■ 14. MISSION.—*a*. A check of navigation instruments is made while climbing in the general direction of the course, or to some initial point previously selected. Upon arrival at selected altitude or initial point, the proper compass heading is assumed and time noted.

b. In flight necessary changes in direction are determined by locating position with reference to landmarks. Amount of change may be determined from prepared tables. From the determined time of flight for a known distance, speed and estimated time of arrival (ETA) at other landmarks or destination may be computed.

c. During flight position is continuously checked and recorded in a log. These entries are supplemented by data on course being flown and ground speed to permit computation of dead reckoning position of the aircraft. The pilot-navigator is more concerned with a knowledge of his position and his subsequent ability to reach his destination than with the execution of a precise navigation flight.

SECTION III

NAVIGATOR

■ 15. GENERAL.—*a.* Whenever precision navigation is required, navigation duties are assigned to a competent member of the crew whose sole duty is that of navigator. Such assignment is especially desirable in aircraft of long flight range. All methods of air navigation are normally available to the navigator.

b. All instruments and equipment available to the pilot-navigator are normally employed by the navigator. However, space and the opportunity to use other instruments and equipment enlarge his capabilities for extensive and precise navigation.

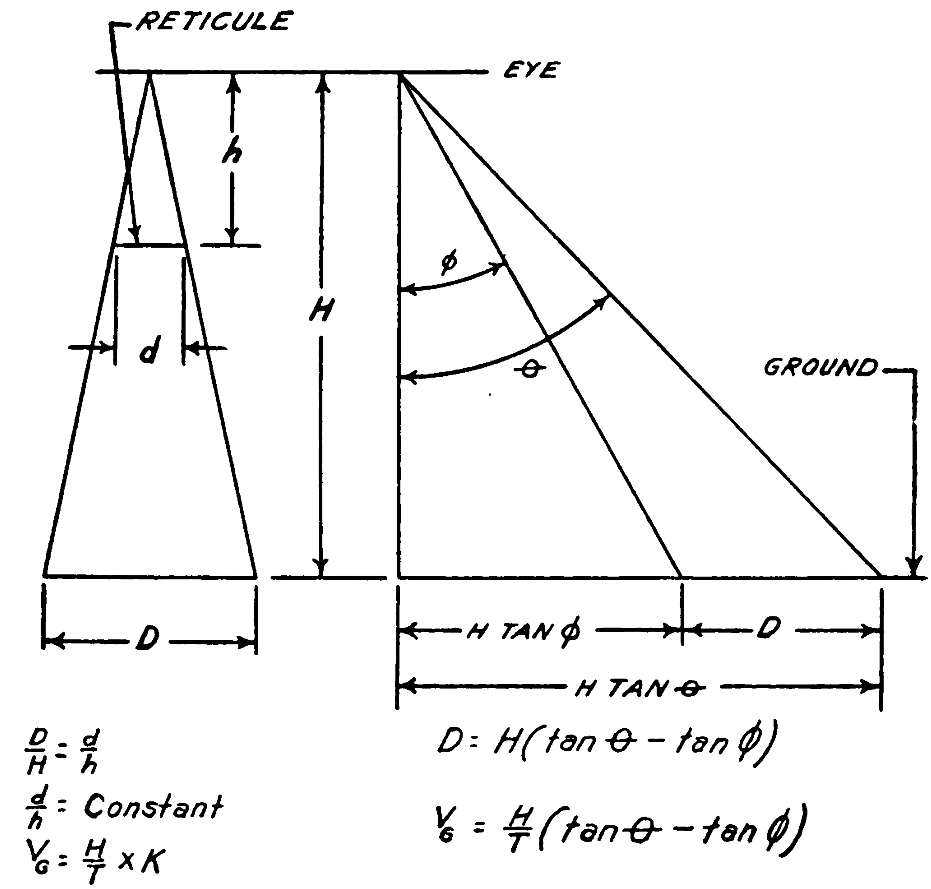
c. Celestial navigation methods and equipment are discussed in chapter 4.

■ 16. INSTRUMENTS.—*a.* The aperiodic type compass is normally employed for precise navigation. The damping characteristic of this compass makes it superior to other types for precise reading.

b. A movable reference, or lubber line, that can be remotely controlled by the navigator is a necessary adjunct to the gyro-turn indicator for precision navigation.

c. The drift meter is essentially a device used to measure the angle between longitudinal axis of the airplane and direction of motion of the airplane relative to the earth. Amount of drift can be read directly from the instrument and is designated as a drift angle right or left according to the side toward which the wind is carrying the airplane, or as a drift correction minus or plus, respectively, indicating amount of angular correction to be applied to the *course* to counteract effect of wind, and to obtain the *heading*. Use of *drift floats* requires a back sighting or trail type drift meter. Most drift meters serve also as ground speed meters. The two general methods of determining ground speed by measurement are—

(1) *Timing*.—Timing instruments use the geometrical relation of similar triangles to determine ground speed and



① Vertical type sight. ② Trail type sight.

FIGURE 1.—Ground speed determination.

require a knowledge of the actual height or altitude above the ground. Figure 1 ① illustrates use of the vertical type sight and figure 1 ② the trail type sight. Ground speeds may be obtained from tables provided for the particular instrument using the factors of time and absolute altitude of flight.

(2) *Multiple drift measurements.*—To determine ground speed from drift readings on two headings, two velocity triangles are solved, the wind line closing the two triangles and completing their solutions. The solution of a typical problem of this sort is illustrated in figure 2.

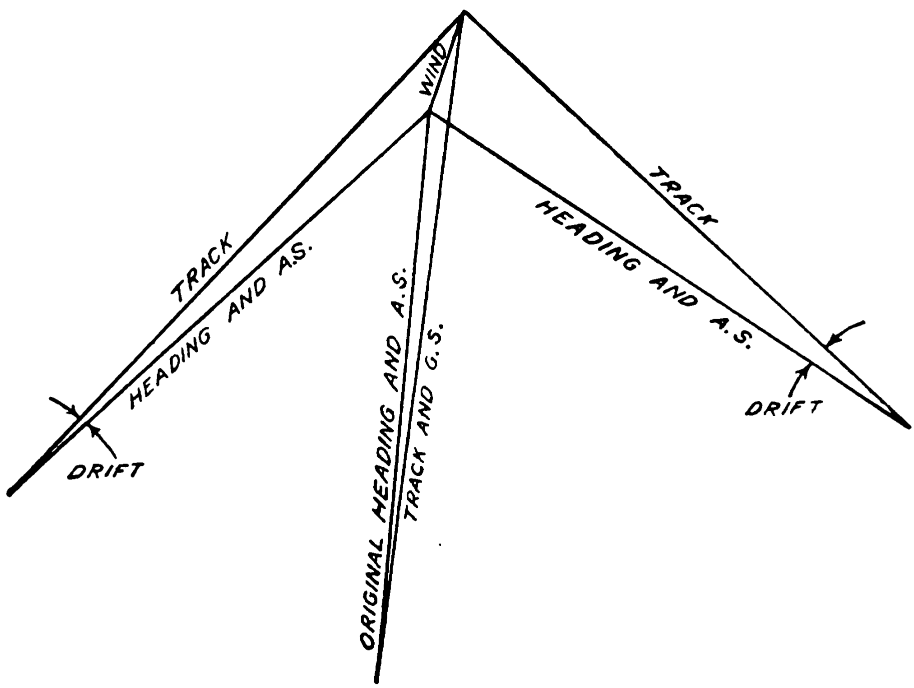


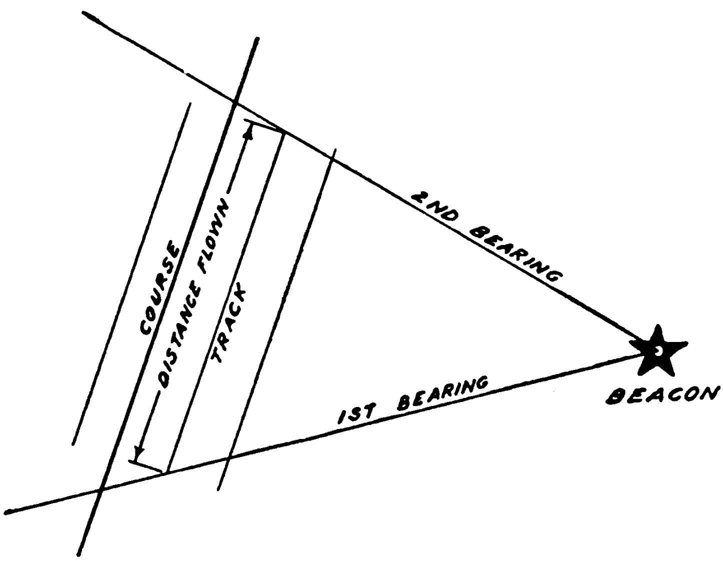
FIGURE 2.—Graphical solution of ground speed by multiple drift measurements.

■ 17. EQUIPMENT.—*a.* Two types of aircraft chart boards are available for use by navigators. One consists of a grid board covered by a circular transparent plate pivoted at the center. The other consists of a mounting board for charts which is equipped with small arm protractors and scales. These boards permit rapid solution of dead reckoning problems and assist in plotting celestial observations.

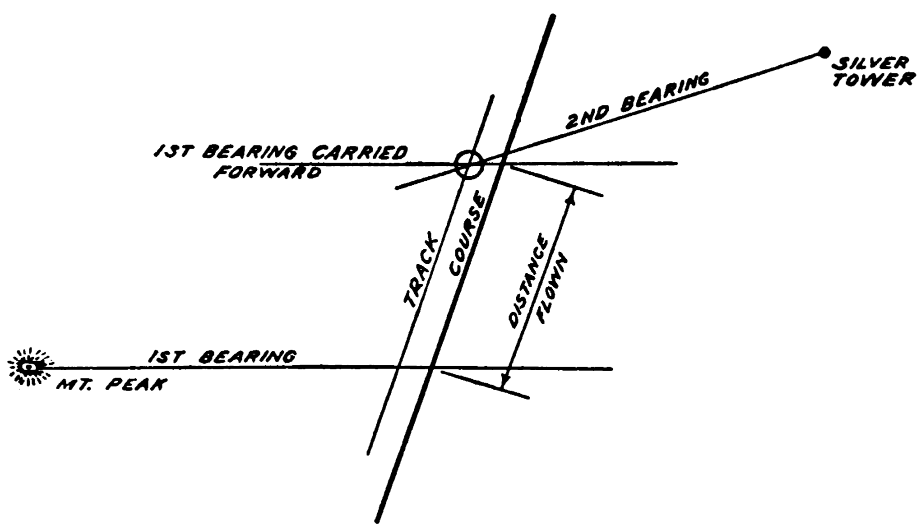
b. The pelorus is an instrument used to obtain bearings on terrestrial or celestial objects. This instrument may be a mechanical sighting device or it may be the optical type employing prisms and reflected images.

Each bearing gives a line of position, that is, a line on which the aircraft is observed to be. The intersection of two or more lines of position determines a *fix* or known position.

(1) Two bearings may be taken of the same object, in which case the estimated distance flown is fitted in between the two bearings so as to parallel the known course. This use of bearings is illustrated in figure 3 ①.



① Two bearings of one object.



② Two bearings of different objects.

FIGURE 3.—Bearings.

(2) Two bearings may be taken of different objects, the first bearing being carried forward by parallel motion the estimated distance flown during the time interval between taking the two bearings. This use of bearings is illustrated in figure 3 ②.

c. Computers and calculators are used extensively in air navigation. Computers used by the navigator are normally the same as those used by the pilot-navigator but may be larger and contain more data.

d. The navigator should be familiar with all types of chart projections to enable him to select the proper chart for his needs. He should also be familiar with calculation of course and distance as applicable to the Mercator projection as that projection is extensively used over water areas.

e. A navigation case provided with drafting equipment for plotting purposes is available.

■ 18. PREFLIGHT PREPARATION.—Preparation for a mission by the navigator is similar to that of the pilot-navigator but is more detailed. Probable length and nature of the flight require that greater significance be placed upon the factors of weather, terrain, and light, and the advantage of additional instruments and equipment requires greater preparation to assure their proper functioning in flight. A conference between the navigator, pilot, and airplane commander to determine courses to be flown, initial point, and altitude is an important element of preflight preparation.

■ 19. MISSION.—*a.* Use of a definite procedure in making corrections for drift, in determining ground speed, and in their recording in the log is most important. Because it is impossible to remember the great number of readings, corrections, and calculations of speed, time, and distance, the navigator should make it an inflexible rule to record all data. Numerous forms are made available for this purpose.

b. Drift is read and heading changed at such intervals as are necessary to maintain the desired course. Changes in course are determined, based on location of position by pilotage, dead reckoning, radio aids, or celestial observations.

c. Ground speed is obtained and continually checked. The distance made good is determined by pilotage, bearings on terrestrial objects, radio bearings, or celestial lines of position.

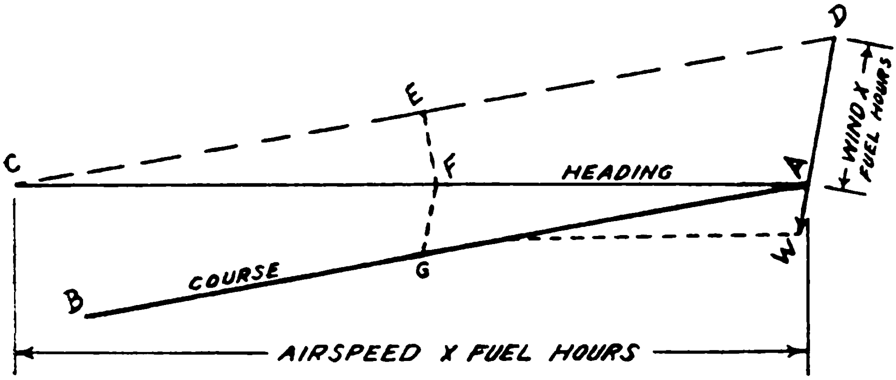
d. When for safety of aircraft detours must be made on account of weather, the pilot is in the most advantageous position to determine change or changes of heading necessary. If heading is constantly changed to avoid some obstacle, sequence of dead reckoning may be lost. When confronted by need for a change in heading, the pilot should decide definitely upon a safe heading, announce his intention to turn to it, change to the new heading, and maintain it carefully until a second change is necessary, or until a new course can be established for completion of the mission under direction of the navigator. In this manner continuity is not broken and track of the airplane may be determined more readily.

e. Special problems of radius of action, intercept, and search confront the navigator.

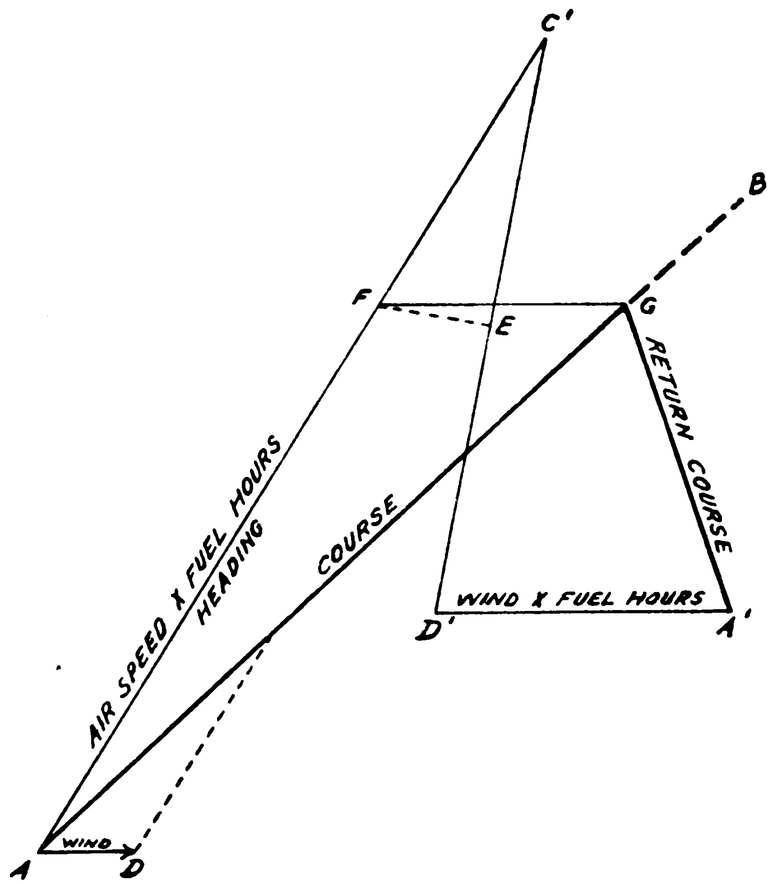
(1) Radius of action is determined by computing ground speeds with reported winds on a given course and their application to the *distance=time×speed* formula. The problem of returning to a base other than the point of departure must be solved graphically. Graphical solutions for radius of action problems are shown in figure 4 ① and ②.

(*a*) In figure 4 ① an aircraft departs from point A on course AB with given wind AW and 3 fuel-hours (excluding reserve). AC represents heading required to maintain the designated course and is equal in length to *air speed×fuel hours.* AD *into* the wind is equal in length to *wind velocity×fuel hours.* The line EF is the perpendicular bisector of the line DC. The line GF is drawn parallel to the wind to intersect the course at G. AG represents the radius of action of the aircraft to return to point A.

(*b*) In figure 4 ② an aircraft departs from point A on course AB with given wind AD and 3 fuel-hours (excluding reserve) and returns to point A′. AC represents the heading required to maintain the designated course AB, and is equal in length to *air speed × fuel hours.* A′ D′ *into* the wind is equal in length to *wind velocity × fuel hours.* The line EF is the perpendicular bisector of the line C′ D′. The line GF is drawn parallel to the wind to intersect the course at G. The length of AG represents the radius of action of the aircraft to return to point A′. The line GA′ represents the course to point A′.



① Returning to same base.



② Returning to different base.

FIGURE 4.—Radius of action.

(2) The problem of interception is merely one of maintaining a greater speed than the target and keeping it on a constant bearing on converging lines. In figure 5, A is the target maintaining a course AC at a known speed and B is the intercepting craft. The line AB is drawn, joining the respective positions of A and B *at the same instant.* If the

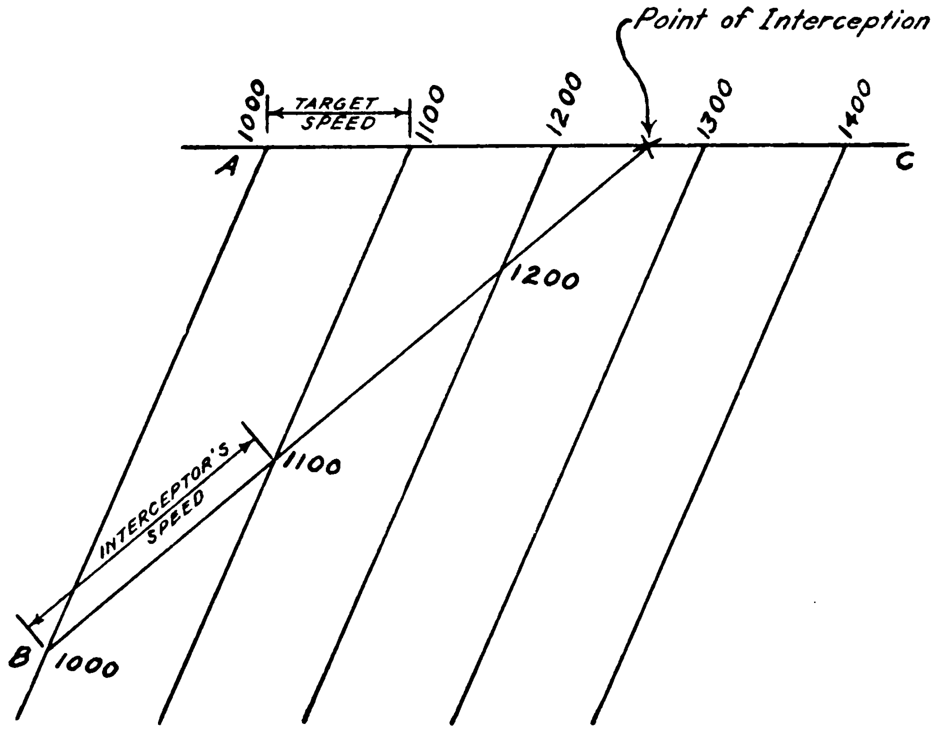


FIGURE 5.—Interception plot.

target alters its track, the problem must be reworked, starting with the respective positions of the two craft at the same instant.

(3) Search of a sea area is a specific navigation problem and normally involves only point-to-point navigation. The search pattern depends upon tactical considerations which include aircraft available, size of area, visibility, and aircraft range.

CHAPTER 3

RADIO NAVIGATION

SECTION I

FACILITIES AND EQUIPMENT

■ 20. GENERAL.—One of the features of radio which is applied to air navigation is that direction from which radio waves are received may be determined fairly accurately by means of directional characteristics of loop antenna. This same directional characteristic of a loop is also applicable to a limited extent to transmission.

■ 21. RADIO RANGES.—*a*. The equi-signal radio range is designed to provide directional guidance for aircraft in flight. The width of on-course signals of a radio range increases at the approximate rate of 1 mile in 10 from the transmitting station. As generally used, the range station employs two loop antennas, the loops being energized respectively with Morse signals, N (— .) and A (. —). The resultant aural effect is N and A signals in alternate quadrants separated by predetermined range courses where the two signals interlock to give a continuous monotone sound. An N quadrant always contains the direction of true north unless a course range is on true north in which case the N quadrant is to the west. The range courses need not be at right angles but may be arranged within limits to suit directions of an air route. As shown on airways charts and in radio range data all courses are magnetic.

b. Radio ranges are subject to errors which must be determined to permit intelligent use of these facilities.

(1) Some ranges are subject to an error known as multiple courses. This phenomenon results in additional on-course signals bounded by distinct N and A zones, and roughly parallel to the intended on-course range. Probability of this condition occurring on a particular range has been deter-

mined by experience and this information is available. The only definite means of avoiding errors caused by multiple courses is to maintain an additional check by pilotage or dead reckoning.

(2) Terrain features also cause a bending of radio range courses from their intended direction. Probability of this error has likewise been determined by experience and that information recorded and published. Pilotage and dead reckoning again must be relied upon to avoid errors from this cause.

(3) Particularly at sunset and sunrise but also at night a swinging of some radio ranges occurs. However, this swinging has a fairly definite period and is not particularly wide. Its probability of existence has been determined and recorded. Errors again must be avoided by pilotage and dead reckoning check.

c. Radio ranges have a peculiarity which serves as a position marker. This is the cone of silence which exists over the transmitting antenna of the range. The cone of silence may be recognized aurally by a complete fade-out of the signals followed by a surge in strength greater than that existing prior to reaching the cone of silence. This phenomenon does not always occur directly over the station but may tilt from the vertical to some extent. In some instances a false cone of silence exists which is generally known and recorded. Check of relative location of respective N and A zones near the station, together with pilotage and dead reckoning checks, will avoid errors due to a false cone of silence.

d. Almost all radio range stations are equipped for voice transmission. Of the stations transmitting voice, some use simultaneous range transmission while others interrupt the range to transmit by voice on the same frequency. Weather broadcasts are made from designated stations at times listed for the particular station. In the simultaneous transmission of range signals and weather, the voice frequency is one kilocycle lower, permitting the operator by careful tuning to receive the weather information stronger than the range. Airways control is exercised in accordance with Civil Aeronautics Authority Regulations by voice transmission from certain designated points. The Army Airways Communication System also maintains receiving and transmitting stations at designated fields.

■ 22. MARKER BEACONS.—Marker beacons are used along the airways to mark intersections of some ranges and other geographic points. Marker beacons are of two types.

a. Low power nondirectional beacons with a distance range of less than 5 miles. These beacons are usually set on the same frequency as the range on which they are located, or on the same two frequencies as the two intersecting ranges they locate.

b. (1) Low power fan beacons whose directional effect is vertical (like an open fan). These beacons are generally placed on ranges near airports and serve as distance markers on approaches. Marker fan beacons require a separate receiver set hooked up to a visual indicator, and all operate on the same frequency (75 megacycles). Those installed by the Civil Aeronautics Authority have identifying code indications whereas those used by the Army Air Corps do not.

(2) Some of the later type radio ranges are equipped with vertical cone-shaped marker beacons known as the "Z" type which supplement position-marking effect of cones of silence. These beacons operate on the same frequency as fan marker beacons (75 megacycles) and actuate a visual indicator hooked up to a special receiver.

■ 23. LOOP ANTENNAS.—The loop antenna is so constructed that when coupled with a suitable receiver bearings may be taken on distant radio stations by rotating the loop until the signal is of minimum strength, at which time the plane of loop is perpendicular to the great circle course to the transmitting station. In practice, a visual indicator is used in connection with the loop to indicate signal strength. The loop as applied to aircraft may be fixed or free to rotate. Loop receivers on metal aircraft are subject to electrical effects very similar to compass deviation which change direction of incoming signals. Consequently, the aircraft on which a rotatable loop is installed should be swung and a tabulation similar to a compass deviation card made of the errors. This table of errors differs from a compass deviation card in that errors are dependent upon direction of the loop relative to the airplane's heading, and not on actual direction of the loop relative to north. The fixed loop which is used normally only as a homing device does not require swinging.

■ 24. DIRECTION FINDER STATIONS.—Direction finder stations are located generally on the coasts and serve to best advantage on overwater flights. These stations plot the position of aircraft by means of radio bearings taken on the airplane. They are organized in groups, usually of three stations, and carefully located to avoid as much as possible interference and errors caused by terrain or atmospheric conditions. Direction finder stations require two-way transmission and are not capable of handling any material volume of traffic. They have a useful role as aids to air navigation but their results should always be checked by other available means.

■ 25. NAVIGATION INFORMATION.—Civil Aeronautics Authority publications include charts of all installations and booklets listing facilities, monthly Airways Bulletin, and when necessary weekly Notices to Airmen show all changes. The Air Corps publishes information on radio installations, facilities, and weather broadcasts. Sectional and regional aeronautical charts also give radio range and weather broadcast information.

■ 26. AIRCRAFT RADIO EQUIPMENT.—Practically all Air Corps aircraft carry receivers that may be set to operate in the frequency band used by the Civil Aeronautics Authority Airways Network, permitting reception of weather information and use of the radio range system. Radio compasses (aircraft radio direction finders) are installed in many Air Corps aircraft. The loop is generally rotatable in installations in larger aircraft and fixed in the smaller. Receivers to which the loops are coupled are normally set to operate in the commercial broadcast band, although most receivers are equipped with two or more coils and a frequency switch permitting selection of frequency band desired. Those aircraft equipped with a radio compass usually have the receiver and cockpit indicator used with the fan-type, Z-type, and Air Corps marker beacons which are all on the same frequency. Visual indicators used with present Air Corps radio compass installations indicate direction of turn required to obtain a *zero* *reading* (minimum signal strength). When the transmitting station is passed over, the sense of the visual indicator is reversed and turns which previously brought the indicator to zero will increase the off-course indication. However, a zero reading may still be obtained when flying away from a station indicating that the longitudinal axis of the airplane, extended, passes through the station departed from.

SECTION II

PRACTICE

■ 27. GENERAL.—*a*. Army aircraft when using Civil Aeronautics Authority airways facilities comply with all Civil Aeronautics Authority Regulations.

b. Pilot-navigators and navigators should be sufficiently familiar with radio facilities available and with operation and use of equipment provided to secure the benefits of radio aids to navigation.

■ 28. USE OF RADIO RANGES.—*a*. Radio range on-course or equi-signal zones serve as known courses which the pilot can follow by maintaining a reasonably steady heading approximating the magnetic course of the range. Occasional changes may be necessary to maintain position on the range and are indicated by change in signals received. Normally, flight is conducted on the right hand side of a range where the on-course signal has the faint letter signal of the zone on that side impressed upon it. This is known as the *twilight zone*. For greater accuracy, particularly when approaching a range station and seeking the cone of silence, aircraft should attempt to remain in the center of the equi-signal zone.

b. Drift corrections to remain on the range may be determined by pilotage, dead reckoning, or by trial and error. The latter method is the only recourse when instrument conditions prevail and when no previous drift corrections have been applied. To determine drift by this method, the magnetic course of the range is compared with the compass course required to maintain the same position relative to the on-course signal. To arrive at this position it is best to overcorrect both in changes necessary to regain lost position and in the trial drift correction applied, then reduce these corrections gradually until the proper drift correction is obtained. In other words, bracket the correction.

c. Ground speed may be obtained on radio ranges by several methods. Marker beacons of all types and cones of silence serve to indicate a position on a range course. From successive known positions, distance and time are measured

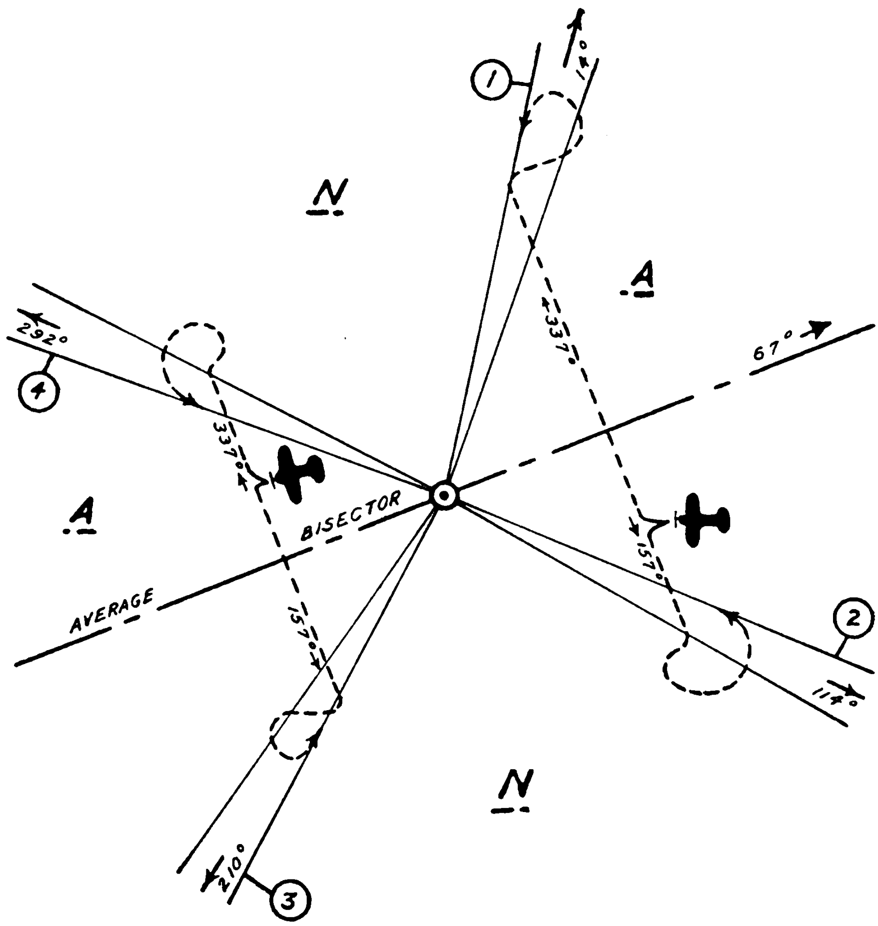


FIGURE 6.—Identification of the quadrant and range courses, 90° method.

and ground speed computed. Intersections of two ranges may also be used as a fix to determine ground speed. This is accomplished when flying a range by tuning to an intersecting range and timing the point of intersection. An area position may be determined in a similar manner by tuning to several nearby ranges, noting their quadrant identification, and by elimination determining the area of position from appropriate charts.

d. The problem of quadrant orientation may present itself to the pilot-navigator when but one radio range is available. Several systems in use involve the assumption of certain definite flight courses until a range is intercepted and identified, using increase or decrease in signal strength as an indication of approach to or departure from the transmitting station. Most systems require courses that are either parallel or perpendicular to the bisecting azimuth of the respective N and

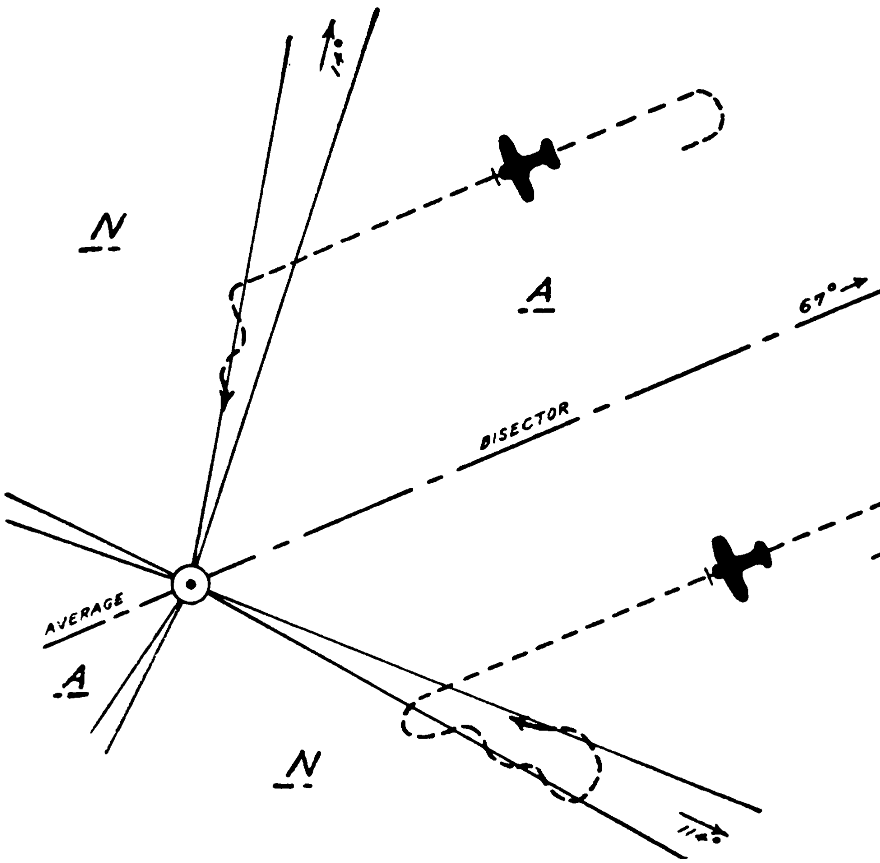


FIGURE 7.—Identification of the quadrant and range courses, fade-out method.

A quadrants. The best systems are generally a combination of definite intercept courses with the aural feature of change in signal strength. Two of the systems used are illustrated in figures 6 and 7. The particular method selected will depend upon training and familiarity of the pilot with that method, and by terrain characteristics in the vicinity of a particular range and angular acuity of the courses of the particular range.

■ 29. USE OF RADIO COMPASS.—*a*. (1) Use of the fixed loop permits aircraft to be navigated to a transmitting station by keeping the pointer of the radio compass indicator centered. Simplicity of this procedure and availability of many commercial broadcast stations make this method of air navigation of great value. When using a fixed loop in this manner, the aircraft is always kept headed toward the transmitting station with the result that a cross wind causes a curved track to be flown. This fact is of no great concern if the loop is used as a homing device on relatively short flights. On long flights, however, the loop should be used only as a means of taking bearings in conjunction with use of other forms of air navigation.

(2) The fixed type loop permits bearings to be taken on two or more transmitting stations but involves maneuver of the airplane. Head or tail bearings may be taken, the sense of the visual indicator as compared to direction of turn being used to determine whether direct or reciprocal bearings are obtained.

b. The rotatable type loop is of great advantage, as it permits taking bearings without changing heading of the airplane. Moreover, corrections may be made more readily for drift when the radio compass is used as a homing device by rotating the loop. Corrections for radio compass errors must always be applied. When Mercator charts are used, bearings are converted from great circle to Mercator by use of radio bearing correction tables. Radio bearings are generally converted to reciprocal true bearings and used in the same manner as bearings taken by a pelorus.

■ 30. DIRECTION FINDER STATIONS.—When a position is to be obtained from radio direction finder stations, the aircraft radio operator calls the controlling station of the group and transmits his call sign or M-signals for a short interval while the three stations take simultaneous bearings. The control station receives all these bearings, plots them on a special chart, and the position represented by the intersection of the bearings or the course necessary to arrive at one of the stations is transmitted to the aircraft. The procedure for requesting these bearings is contained in U. S. Hydrographic Office Publication No. 205.

CHAPTER 4

CELESTIAL NAVIGATION

SECTION I

GENERAL

■ 31. DEFINITION.—Celestial navigation is the method of determining geographical position of aircraft by observation of celestial objects.

■ 32. EMPLOYMENT.—*a*. Range capabilities of modern aircraft make necessary a form of navigation by which position information can be obtained without recourse to terrestrial or radio aids. Celestial navigation makes use of the sun, stars, planets, and moon to obtain such information and thus provides a self-contained method of determining positive position within limits of equipment used and weather conditions prevailing.

b. Celestial navigation is not an independent form of air navigation but is employed to verify or correct the other forms. The study or practice of celestial air navigation thus requires a thorough knowledge of the other methods.

■ 33. TERMINOLOGY.—Definition and application of terms employed in this form of air navigation must also be thoroughly understood. The glossary contained in the appendix gives brief definitions of navigation terms not defined elsewhere in this manual.

SECTION II

INSTRUMENTS AND EQUIPMENT

■ 34. OCTANT.—The octant is an optical device for measuring the angular height of a body above a horizontal plane. This measurement in celestial navigation is called *altitude*. A bubble is incorporated in the aircraft octant instrument to indicate horizontal plane. The octant is a precision instrument and must be carefully handled.

■ 35. TIMEPIECE.—An accurate timepiece is required to obtain correct results from celestial observations. In the larger type aircraft a master watch or clock is provided in a shockproof case. In addition to the master watch or as a substitute therefor, a second-setting wrist or pocket watch is generally employed in making observations.

■ 36. FORMS.—The chance of error in making calculations necessary to obtain data desired from celestial observations may be reduced considerably by employing tabular forms specially prepared for the method being used. These forms are arranged so as to permit speed with accuracy.

■ 37. TABLES.—First in importance among the tables used is the American Nautical Almanac, a yearly publication of the Hydrographic Office, U. S. Navy. The Almanac lists the positions of celestial bodies used for navigation purposes so that their precise locations at any instant during the year may be determined. In addition to the Almanac other tables are required if no computer is used. Other tables include Dead Reckoning Altitude and Azimuth Table (Ageton) (H. O. 211) and the Tables of Computed Altitude and Azimuth (H. O. 214).

■ 38. COMPUTERS.—The astronomical triangle (see par. 41) may be solved by a computer designed for the purpose instead of by tables. Selection of computer or tabular method of solution depends on availability of equipment, space, and reliability of computers available.

■ 39. STAR FINDER.—A star finder is desirable for proper planning and execution of a celestial navigation flight. Under adverse weather conditions star identification is facilitated by use of such a device. The Rude Star Finder (H. O. 2102a) produced by the Hydrographic Office has been developed for use indicated. Star identification tables and charts are also found in other publications on celestial navigation.

SECTION III

CELESTIAL LINE OF POSITION

■ 40. BASIC PRINCIPLE.—The observed altitude of a heavenly body at any instant locates the observer on a circle circumscribed about the geographical position of that body at the instant of observation (see fig. 8). This is a position circle whose radius is determined by the altitude measured. If two bodies may be observed simultaneously and the position circles of the observer determined, their points of intersection become positive positions. Computations aided by dead reckoning

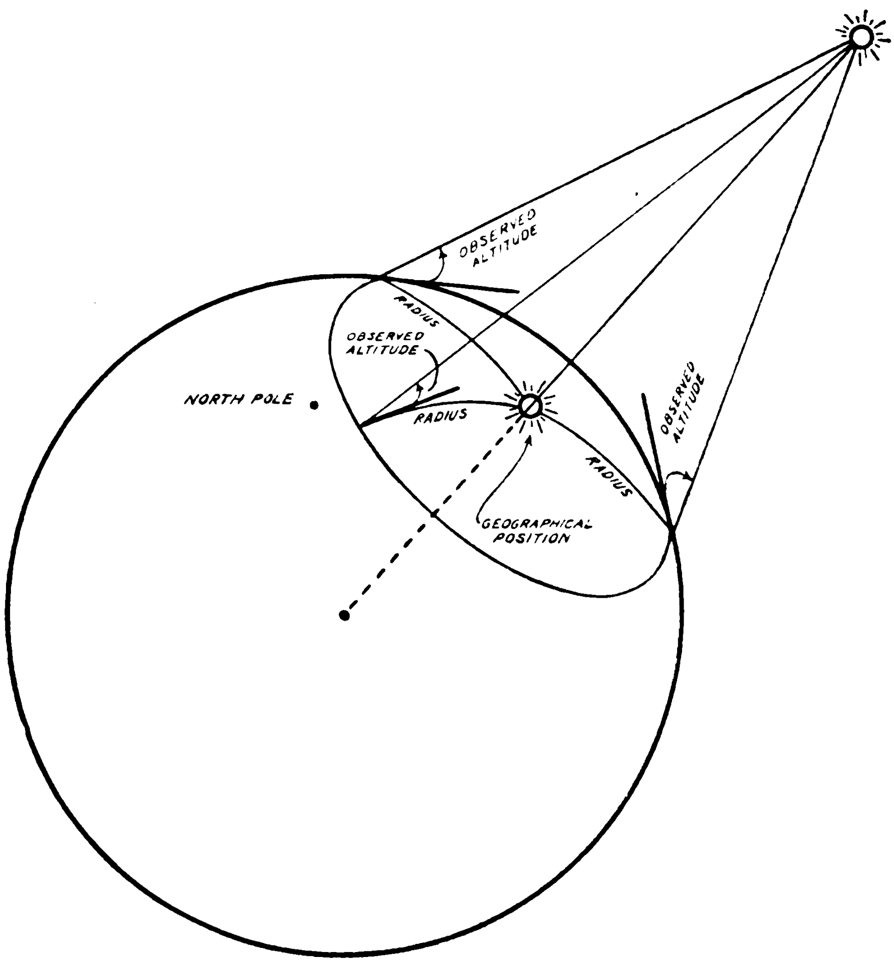


FIGURE 8.—Position circle.

provide the means of determining that portion of the position circle or the point of intersection of two position circles applicable to the flight path, and also data for plotting applicable portion of position circle(s) on a chart. These computations are performed in solution of the *astronomical triangle.*

■ 41. ASTRONOMICAL TRIANGLE.—This triangle is formed by the great circle arcs joining assumed position of the observer, geographical position of the celestial body at the instant of observation, and nearest pole (see fig. 9).

■ 42. ASSUMED POSITION OF OBSERVER.—Assumed position of the observer may be the dead reckoning position at time of observation but more generally is one selected arbitrarily in the vicinity of the dead reckoning position. Selection of an

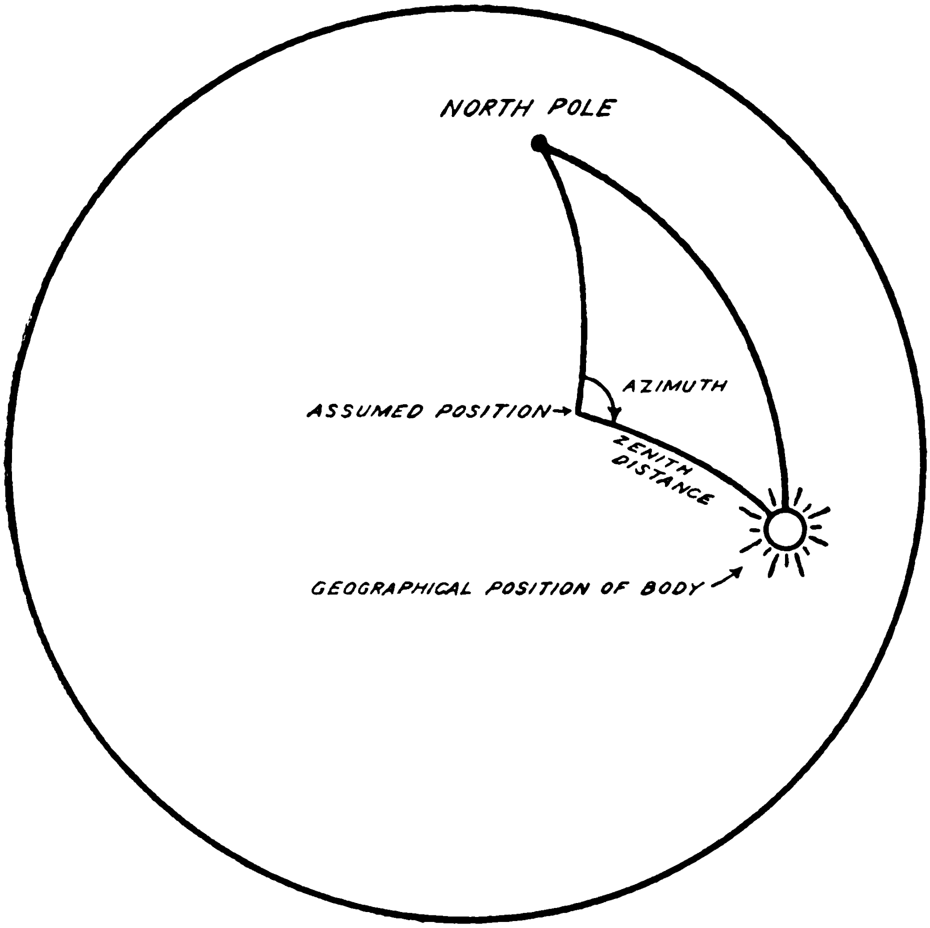


FIGURE 9.—Astronomical triangle.

assumed position depends upon method of solution and is so made as to facilitate process of solution. This arbitrary assumption of position introduces no appreciable error in resulting position circle.

■ 43. GEOGRAPHICAL POSITION OF A CELESTIAL BODY.—The geographical position of a celestial body is that point on the earth's surface which is exactly under a given heavenly body at any one instant. An observer at the geographical position would find the corresponding body exactly at his zenith. The geographical position of a heavenly body is generally designated by declination and Greenwich hour angle, which are in reality latitude and longitude. The correct Greenwich Civil Time and the Nautical Almanac provide the means of obtaining these coordinates, declination, and Greenwich hour angle having been tabulated for a specific body at a specific instant. In most solutions of the astronomical triangle the local hour angle is used. This is the angular difference between the Greenwich hour angle of the body and the longitude of the observer's assumed position as measured from the assumed meridian of the observer. The use of a diagram as shown in figure 10 is desirable in finding the local hour angle.

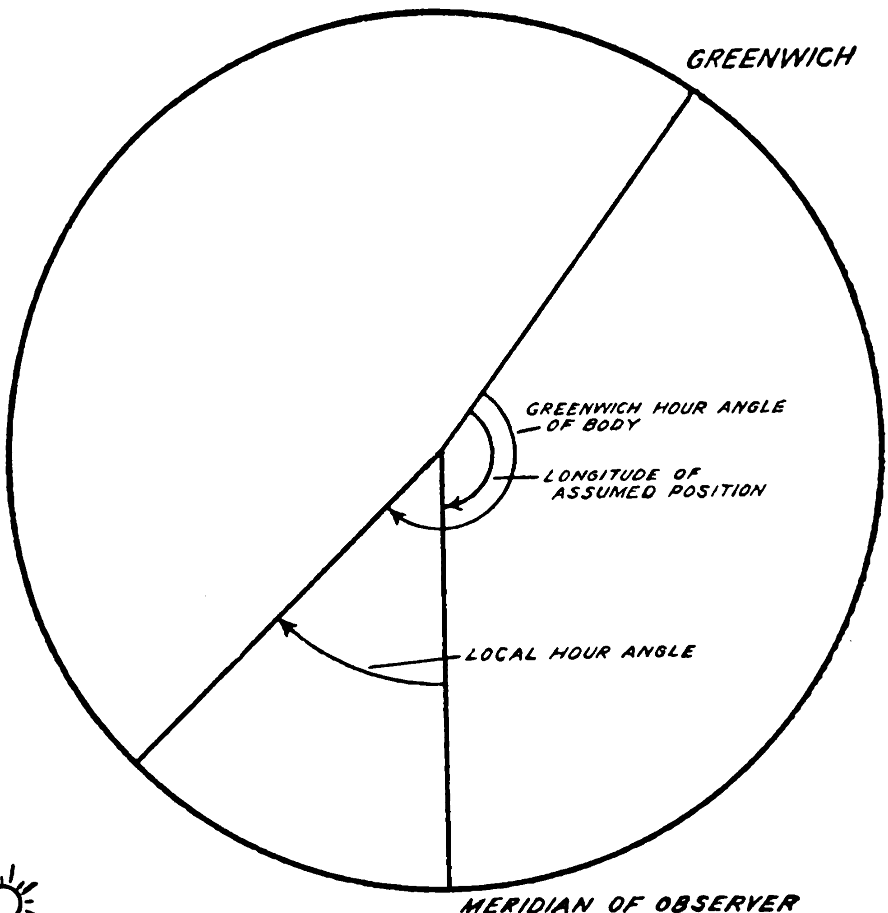


FIGURE 10.—Hour angle diagram.

■ 44. Observed Altitude.—The octant altitude (Hs) of a body is determined by measurement with an octant. Time of observation determines geographical position of the heavenly body at the instant its altitude was measured. Corrections may be necessary to the octant altitude to obtain observed altitude (Ho). Values of corrections and various combinations of corrections are tabulated in celestial navigation publications. These corrections are as follows:

a. Correction must be made for dip when using natural horizon; amount of correction depends upon height of eye of the observer above the earth's surface. No such correction is required with an artificial horizon.

b. Correction must also be made for refraction errors due to bending of light rays by the atmosphere.

c. In observations of the sun or moon correction must be made to allow for diameters of these bodies. This is known as correcting for *upper or lower limb* of the body, depending upon whether measurement was made to upper or lower edge of the periphery.

d. In observations of the moon correction also must be made for parallax due to its relative proximity to the earth.

e. Index errors in the scale of the particular octant are determined by precision measurements and are recorded on an index error card. The zero index error may be satisfactorily determined by the navigator as prescribed in manuals pertaining to the particular instrument.

■ 45. Computed Altitude.—Computed altitude (Hc) of a body is the altitude computed for assumed position at instant of observation. It is found by subtracting computed *zenith distance* of the body observed from 90° (see fig. 11). Zenith distances obtained from observed and computed altitudes are the radii of the position circles passing through the observer and the assumed position respectively. The angular distance from position circle of an observer to an assumed position can therefore be determined by arithmetical difference between computed and observed altitudes of a celestial body at the instant of observation.

■ 46. Azimuth.—Azimuth from assumed position to geographical position of a heavenly body is determined by solution of the astronomical triangle. This azimuth serves to identify segments of the position circle applicable to the particular problem.

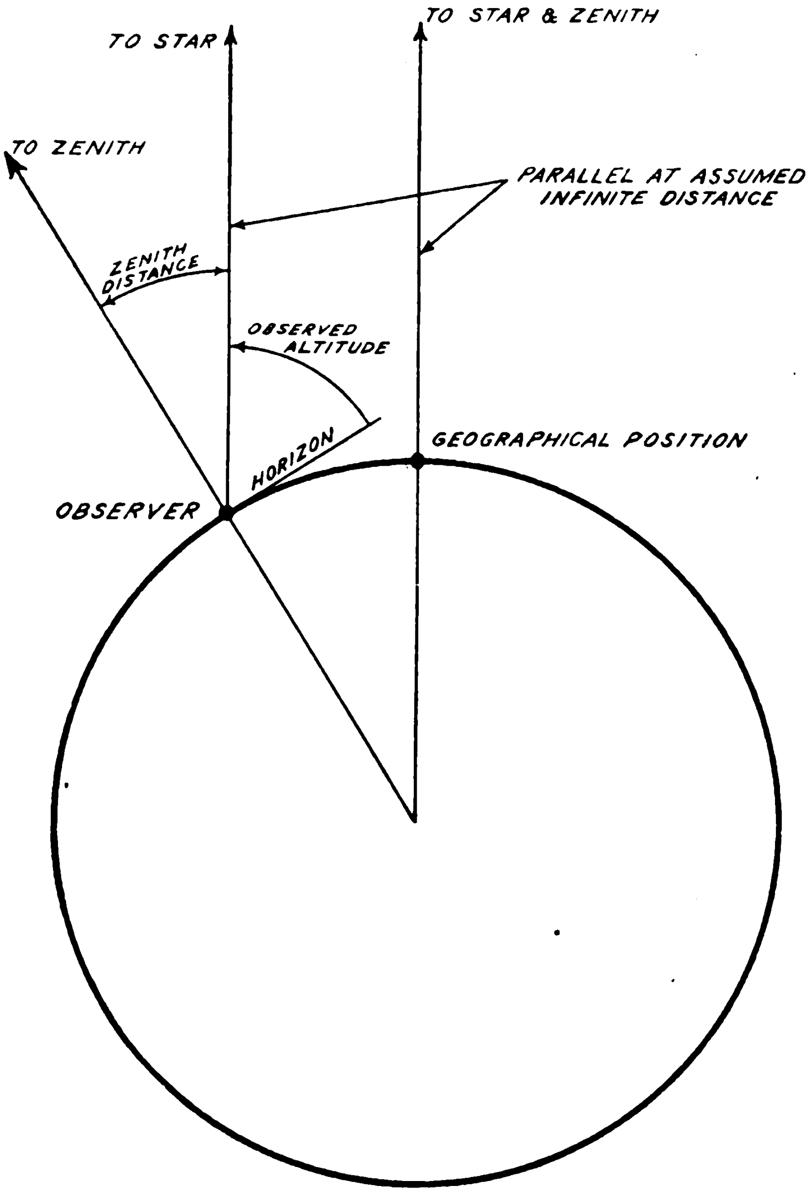
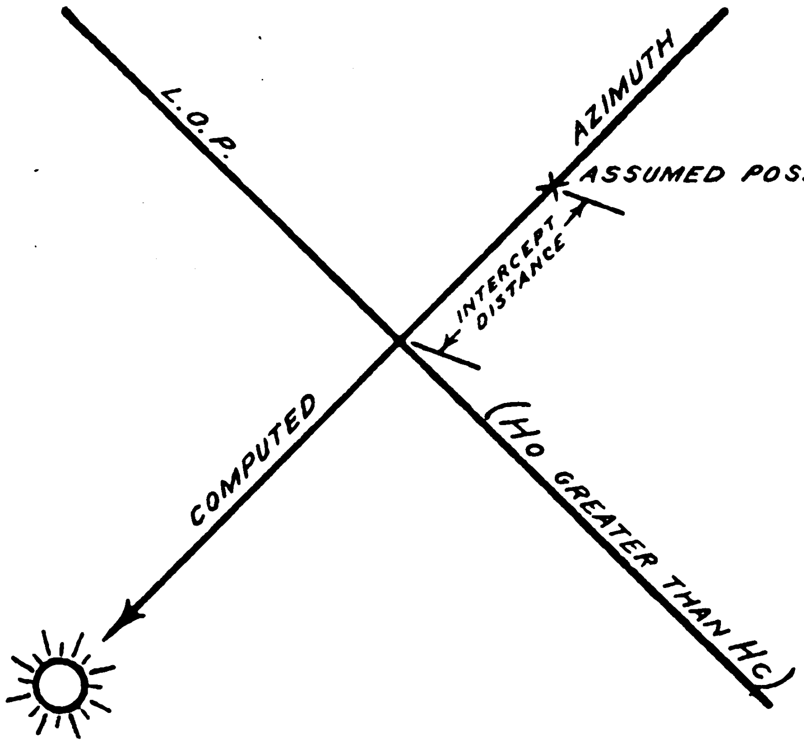
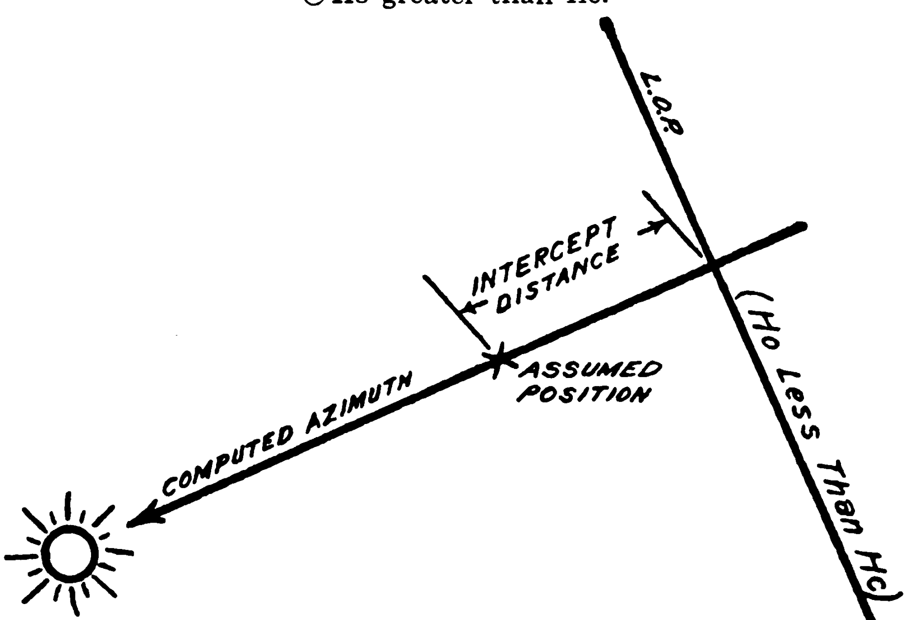


FIGURE 11.—Zenith distance and observed altitude complementary.

■ 47. PLOTTING.—In plotting a segment of a position circle a straight line is used. This line is known as a *line of position* (LOP) and is drawn perpendicular to the computed azimuth. In actual plotting the following procedure is followed (see fig. 12):



① Ho greater than Hc.



② Ho less than Hc.

FIGURE 12.—Plot of celestial line of position.

a. Plot assumed position and through it draw computed azimuth line.

b. Find *altitude difference* between observed (Ho) and computed altitudes (Hc) in minutes of arc.

c. From assumed position lay off as a distance altitude difference (1 minute of arc equals 1 nautical mile) along azimuth line, either toward or away from the celestial body as observed altitude is respectively greater or less than computed altitude.

d. Through this point draw a line perpendicular to azimuth line. This is the *line of position* of the observer.

SECTION IV

PREFLIGHT PREPARATION

■ 48. GENERAL.—Prior to flight the navigator makes such preliminary computations as are possible and assures himself that he is provided with all necessary instruments and equipment.

■ 49. CHECK OF WATCH.—The master watch is an instrument of extreme importance in celestial navigation. Checking this instrument for determining its rate is a continuous, periodic duty. Actual reading of a watch is unimportant so long as the watch error can be determined. Watches are checked by reference to radio time signals which are broadcast by both commercial and governmental agencies daily. (See Radio Aids to Navigation, H. O. No. 205.)

■ 50. CHECK OF OCTANT.—The index error of the octant used by the navigator should be known. Personal error should be determined by a series of observations taken from a rigid support and compared with computed data.

SECTION V

PRACTICE

■ 51. GENERAL.—Applied celestial navigation embraces use of lines of position by the navigator in a manner that enables him to determine drift, ground speed, or position in order that serious errors do not enter into dead reckoning. To obtain basic data for these determinations the navigator must first make his celestial observations.

■ 52. Celestial Observations.—Celestial observations from aircraft are normally made in groups of ten or more averaging altitudes read and times of observations. Corrected observed altitude (Ho) and time are then reduced by precomputed data or by tables and forms available, and plotted as a line of position. Observations are taken in groups and averaged in an effort to reduce the resultant value of error due to acceleration, manipulation, and other causes inherent in the bubble type octant. Observations made in fore and aft direction of aircraft are generally less subject to acceleration error than lateral observations.

■ 53. Time Factor.—Successful air navigation demands rapidity and accuracy in reduction of celestial observations to usable data. Development of averaging devices, tables, forms, and computers has decreased time required. Proper technique and skill in use of instruments are necessary to obtain satisfactory results.

■ 54. Weather Conditions.—Weather conditions may be such as to make identification of heavenly bodies difficult. In such case it is advisable to make observations whenever possible, and then with an estimated bearing determined from the heading and the time, a star finder may be utilized to identify the body observed.

■ 55. Interpretation of Data.—Proper interpretation by the navigator of the data derived from a plotted line of position is important. A single position line or successive position lines, if approximately parallel to the course, will give accurate information as to directional or on-course position. Position lines cutting the course at near right angles will give accurate distance information from which ground speed may be derived. Intersection of two or more lines of position will establish a fix and give both directional and distance information.

■ 56. Obtaining Fix.—Celestial lines of position may be treated in the same manner as bearing lines. In this manner, a fix may be obtained by the intersection with other lines of position. In obtaining a fix the celestial radio or terrestrial lines of position used should be so selected that they intersect as nearly at right angles to each other as practicable. This insures a sharp intersection and consequently greater accuracy.

■ 57. CELESTIAL BODIES AVAILABLE.—Information as to celestial bodies that will be available during a proposed flight can be secured by the navigator by use of a star finder and the Nautical Almanac. Type of information desired (whether directional or distance) and possibility of a fix are considered in selection of bodies for precomputation of data.

■ 58. PRECOMPUTATION OF DATA.—Precomputation of data saves time and increases accuracy of information derived from celestial observations. Precomputation involves thorough study of the flight plan, considering factors of celestial bodies available, possibility of day or night observations, and time of flight. This information permits the navigator actually to make certain calculations prior to take-off. Small corrections may be necessary to compensate for the difference between time and azimuth of precomputed data and data derived from actual observation. No serious error in data obtained is thus introduced.

a. Course curves of precomputed altitudes and azimuths for a body may be drawn, using as assumed positions dead reckoning positions at equal time intervals.

b. Computed altitudes and azimuths may be determined, the altitudes being recorded and azimuths actually plotted through dead reckoning positions used as assumed positions on proposed flight course.

c. Prepared *simultaneous star altitude curves* may be used to obviate necessity of precomputing star data.

■ 59. LANDFALL METHOD OF REACHING DESTINATION.—The landfall method is valuable for reaching a destination under conditions where only one heavenly body may be observed. This method enables the navigator to gain a position on a bearing line from the destination with a degree of accuracy limited only by results of celestial navigation performed. Procedure followed is basically the same whether one or more observations are made. Precomputed data is generally employed based on estimated time of arrival at a point some distance from the destination with destination as assumed position. The airplane is headed well to one side of the objective. At the preselected time for which computations were made, one or more observations are taken. Then according to whether observed altitude is less or greater than computed altitude, the navigator takes up a course of the computed azimuth or its reciprocal, respectively, flying for a distance equal to the altitude difference (distance between observed line of position and line of position through destination). This places him on the position line passing through the destination. Once on this line the course to the destination is the azimuth plus or minus 90°. The initial course is laid to one side of the destination to eliminate possibility of error in selection of direction of turn.

a. When but one observation is to be made, time used in precomputation of data is estimated time of arrival at a point whose estimated distance from the destination renders the dead reckoning dependable.

b. When more than one observation is to be made, a stationary curve for the assumed position (the destination) is prepared covering the period of time during which contemplated observations are to be made. This method enables the navigator to make continued checks on his dead reckoning after landfall procedure is initiated.

APPENDIX

GLOSSARY OF TERMS

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 calibrated air speed for density, using temperature and pressure altitude corrections.

Indicated.—Reading of air-speed indicator.

Calibrated.—Reading of air-speed indicator corrected for instrumental and installation errors.

Altitude.—True height above sea level. The calibrated altitude corrected for air temperature and for barometric pressure. It is always true unless otherwise designated.

Indicated.—Height above sea level as read on altimeter.

Calibrated.—Indicated altitude corrected for instrumental and installation errors.

Absolute.—True height above the earth's surface. It is calibrated absolute altitude corrected for air temperature and barometric pressure.

Azimuth.—Bearing of a celestial body measured as an arc on the horizon from the true meridian north or south to east or west. Abbreviation: Z. Abbreviation Zn is used where the azimuth has been changed to read from north through east to 360°.

Bearing.—Direction of one object from another expressed as an angle measured clockwise from true north. Bearing is true unless otherwise designated. Abbreviation: B.

Compass.—An instrument indicating angle of longitudinal axis of aircraft with respect to axis of compass needle. Taken to be a magnetic compass unless otherwise designated.

Aperiodic.—A cardless magnetic compass in which the needle when deflected from its point of rest returns to that point with small overswing.

Error.—Algebraic sum of variation and deviation. Abbreviation: C. E.

Course.—Direction over 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. Abbreviation: C. All courses are measured from north through east to 360°.

Curves.—Stationary.—Plotted graph of computed altitude or azimuth of a celestial body for a fixed position with time as the abscissa.

Course.—Plotted graph of altitude or azimuth of a celestial body computed for dead reckoning positions on a flight course at equal time intervals.

Simultaneous Star Altitude.—Plotted position circles of selected stars on a small Mercator chart covering 10° or 11° of latitude and 360° of longitude. These curves are generally prepared in booklet form.

Declination.—Angular distance of any point on celestial sphere from celestial equator measured along the great circle through the celestial pole. It is designated north or south according to direction of the point from celestial equator. Declination upon the celestial sphere corresponds to latitude on the earth.

Deviation.—Angular error between axis of the compass needle and magnetic meridian caused by magnetic influences in the aircraft and is named east or west according to direction in which needle is deflected.

Dip.—Amount of angular depression from the horizontal line through the eye of an observer to a line to visible horizon.

Distance.—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.

Drift Float.—An article or substance dropped from an aircraft over water, forming a point of reference for observing drift angle or surface wind direction.

Great Circle.—A circle on the earth's surface whose plane passes through the center of the earth.

Greenwich Hour Angle.—Angle at the pole between meridian of Greenwich and meridian through a celestial body measured from meridian of Greenwich to the west 0° to 360°.

Heading.—Angular direction of longitudinal axis of the aircraft with respect to true north. In other words it is the course with drift correction applied. It is true heading unless otherwise designated.

Knot.—Unit of speed used in navigation, and equal to a speed of 1 nautical mile per hour. (Equivalent to 1.15 statute miles per hour.)

Latitude.—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. Abbreviation: Lat.

Longitude.—Angular distance at axis of the earth between plane of meridian and plane of the prime meridian of Greenwich, England, measured to eastward or westward to 180°. Abbreviation: Long.

Lubber Line.—A fixed line inside a compass bowl so placed that a plane through it and center of the compass pivot is parallel to a plane through longitudinal and vertical axes of the aircraft. The lubber line represents direction of the longitudinal axis of the aircraft.

Mercator Course (Rhumb line).—A line on the earth's surface which intersects all meridians at the same angle.

Off-course Correction.—An angular correction applied to the course to parallel or to return to original course in a given distance.

Parallax.—The angle contained between the two straight lines joining a heavenly body and two different points on the earth.

Radio Direction Finder.—A radio receiving unit incorporating use of loop antenna for obtaining direction of transmitted signals. The aircraft installation is known as a radio compass.

Temperature.—Air.—Temperature of the air at altitude being maintained by aircraft.

Variation.—Angle between plane of 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 direction of the compass needle from true north. Variation changes with time and place. Abbreviation: Var.

Wind Direction and Force.—Wind is designated by direction from which it blows. Force of wind is expressed as speed in miles per hour or knots.

Zenith.—Zenith is the point of the celestial sphere vertically over a terrestrial position.

Zenith Distance.—Angular distance of a celestial body from observer's zenith.

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