Chapter 5

LINES OF POSITION, BEARINGS, AND FIXES

BEARINGS AND LINES OF POSITION

Good dead reckoning techniques can result in fairly accurate positions. But, even when employing the very best techniques, the DR position will become less accurate as time increases since the last known position. Individual small errors tend to accumulate until the total error is unacceptable. To minimize this error, the navigator must be able to establish an accurate position from which to restart dead reckoning. This accurate position is free of any errors due to dead reckoning and is called a *fix*. A fix is simply a point from which the navigator can restart dead reckoning just as if it were the takeoff point.

Lines of Position

It is possible to solve part of the fix problem without knowing your exact location. For example, assume you are in a strange town and you call a friend to meet you downtown. If you tell this person that you are somewhere on Park Street, your friend can limit any search for you to that particular street. In this case, Park Street is a line of position (LOP). A line of position is a series of possible positions or fixes. It can be a straight line (such as a city street) or a curved line (such as a river), but it gives a definite clue to your position.

If you tell your friend that you are at Park Street where it crosses the Karuzas River, it would then establish your exact location. You have used two LOPs to determine your exact position. Thus, two intersecting LOPs identify a point which establishes a fix.

You can use the same procedure as a navigator. You may be flying along a railroad that you identify as the Jedicke Railroad on your chart. As you continue on this course, you notice the railroad crosses a river that is labeled the King River on your chart. When you fly over the point where these two visual LOPs cross, you know your exact location over the ground and on your chart. You now have a fix from which you can continue dead reckoning.

Types of LOPs

A fix gives definite information as to both track and groundspeed of an aircraft since the last fix, but a single LOP can only define either the track or the groundspeed—not both. And it may not clearly define either. The evidence obtained from an LOP depends upon the angle at which it intersects track. LOPs are sometimes classified according to this angle.

Course Line. An LOP which is parallel or nearly parallel to the course is called a course line (figure 5-1). It gives informa-

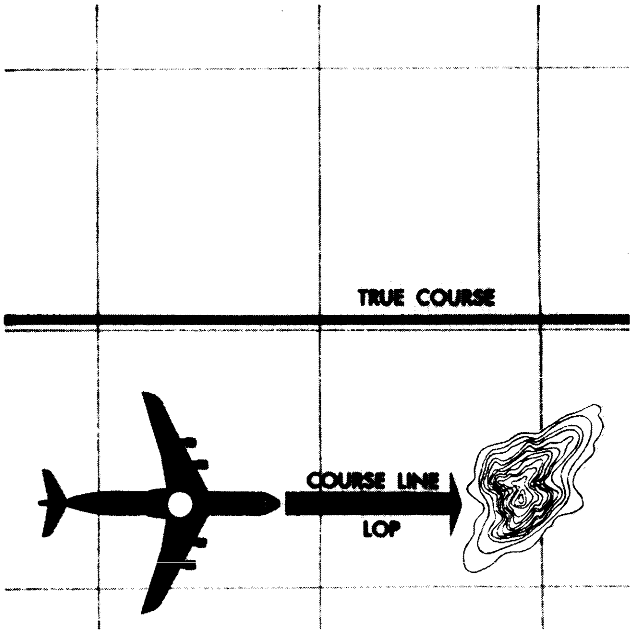


Figure 5-1. LOP Parallel to Track is Course Line.

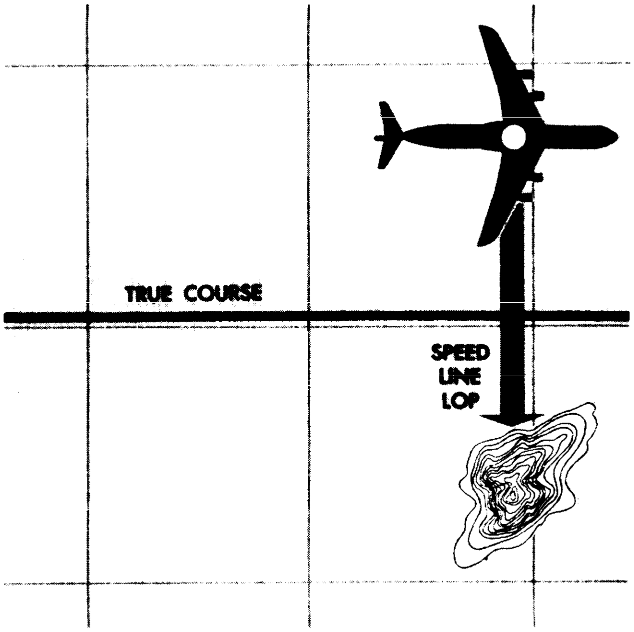


Figure 5-2. LOP Perpendicular to Track is Speed Line.

tion as to possible locations of the aircraft laterally in relation to the course; that is, whether it is to the right or left of course. Since it does not indicate how far the aircraft is along the track, no speed information is provided.

Speed Line. An LOP which is perpendicular (or nearly so) to the track is called a speed line (figure 5-2), since it indicates how far the aircraft has traveled along the track, and thus is a measure of groundspeed. It does not indicate whether the aircraft is to the right or left of the course.

Lines of Position by Bearings. One method of determining a line of position is to establish the direction of the line of sight to a known, fixed object. Some navigators use a periscopic sextant (normally used for celestial navigation) to get a fairly accurate sighting on a prominent landmark or object. The illustration in figure 5-3 shows a line of sight from the aircraft to a fixed object on the ground. The direction of the line of sight is the bearing of the object from the aircraft. A line plotted in the direction of the bearing is a line of position. At the time of the observation, the aircraft was on the line of position.

Relative Bearings. A relative bearing is the angle between the fore-and-aft axis of the aircraft and the line of sight to the object, always measured clockwise from 000° at the nose of the aircraft through 360°. In figure 5-4, the relative bearing of the object is shown as 070°. You must convert this to a true bearing before you can plot it. To do this, you simply add the relative bearing to the true heading the aircraft was flying when you obtained the bearing. (Subtract 360° if the total exceeds this amount.) Thus:

$$TB = RB + TH$$

where:

TB is the true bearing,

RB is the relative bearing, and

TH is the true heading.

Assuming the aircraft was on a true heading of 210° when the bearing was taken, the corresponding true bearing of the object is 280°

Figure 5-4. True Bearing Equals Relative Bearing Plus True Heading.

Plotting the LOP

As previously stated, two intersecting LOPs determine the position of the aircraft. The only other possible point from which to begin plotting the LOP is the object on which you took the bearing. The procedure is to use the reciprocal of the true bearing of the object, thus drawing an LOP toward the aircraft. In actual practice, it is not necessary to compute the reciprocal of the bearing; the true bearing is measured with the plotter, and the LOP is drawn towards the opposite end of the plotter.

To establish an LOP by relative bearing, the navigator must know:

- The position of the source (object) of the bearing.
- The true heading of the aircraft.
- The relative bearing of the object.
- The exact time at which the true heading and relative bearings were taken. Figure 5-5 shows the procedure to follow.

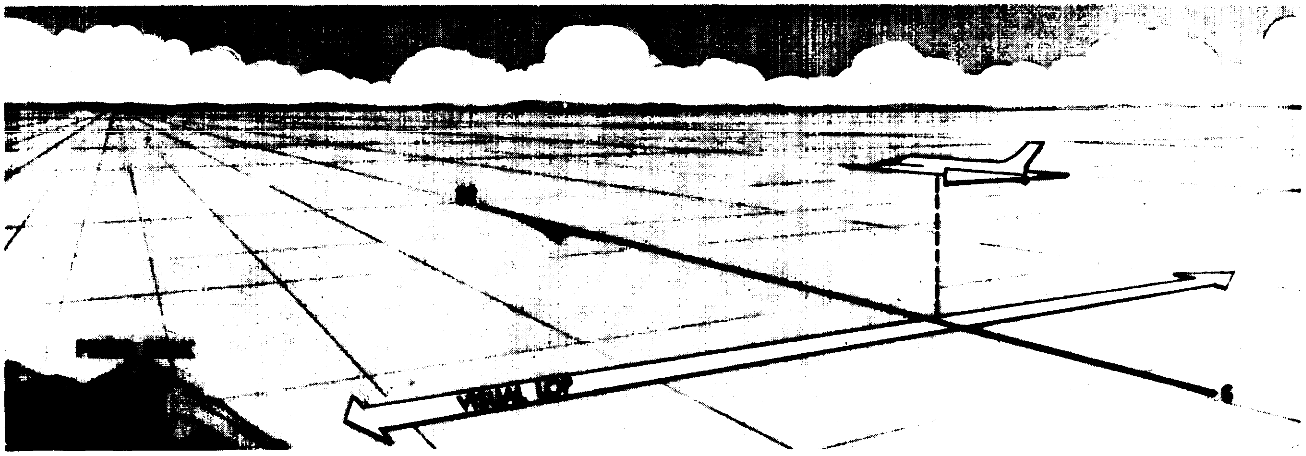


Figure 5-3. Establish a Visual LOP.

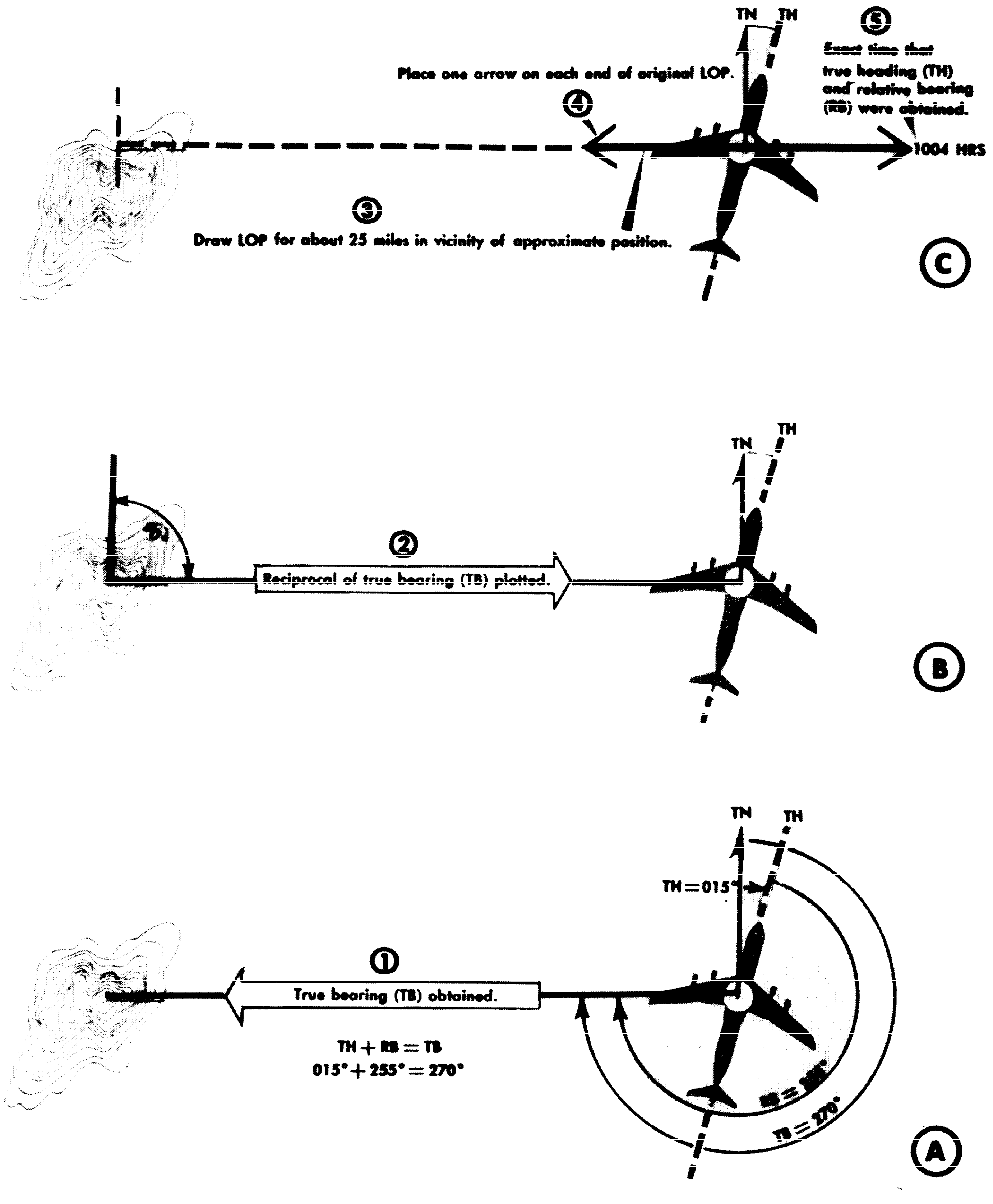


Figure 5-5. Procedures for Plotting LOP.

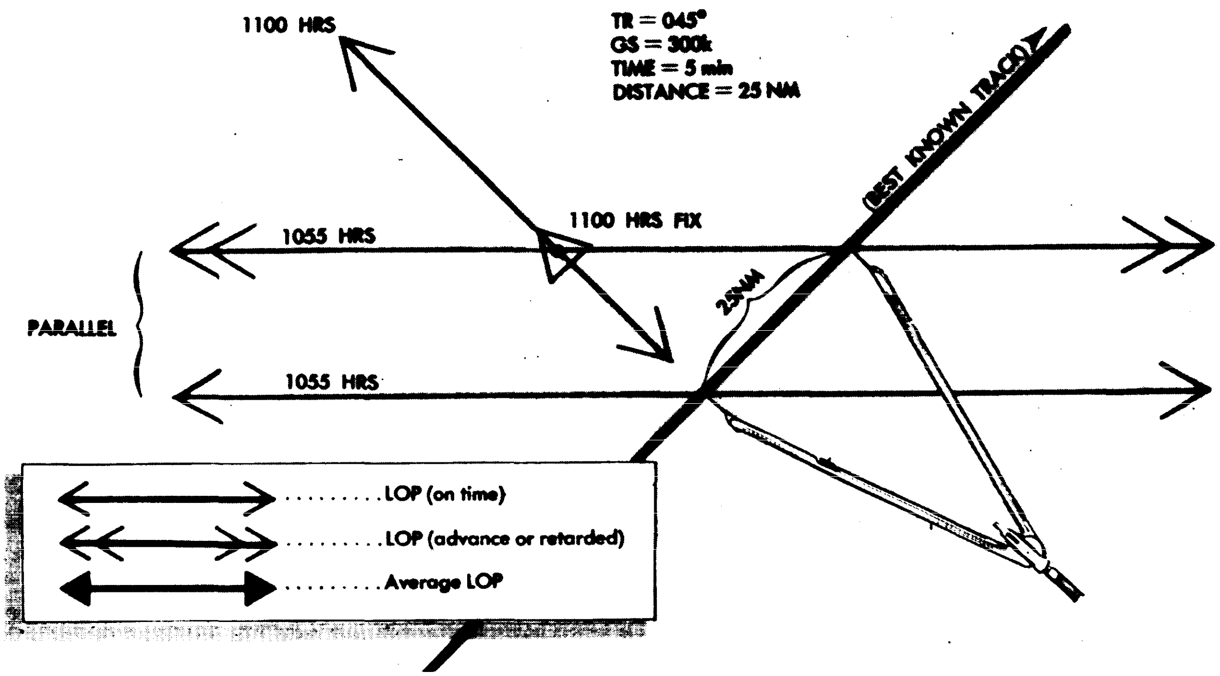


Figure 5-6. Adjusting LOPs for Fix.

FIXES

Adjusting LOPs for a Fix

Sometimes, it is impossible for an air navigator to obtain more than one LOP at a given time. If two LOPs are for two different times, their intersection does not constitute a fix because the aircraft moved between the time it was on the first LOP and the second LOP.

The illustration in figure 5-6 shows a bearing taken at 1055 and another at 1100. At 1055, when the navigator took the first bearing, the aircraft was somewhere along the 1055 line of position (single-barbed LOP) and, at 1100, it was somewhere along the 1100 LOP. The intersection of these two lines, as plotted, does not constitute a fix. For an intersection to become a fix, the navigator must either obtain the LOPs at the same time or adjust them to a common time by using the motion of the aircraft between the observations. The usual method of adjusting an LOP for the motion of the aircraft is to advance one line to the time of the other. The illustration in figure 5-6 shows how this is done. The desired time of the fix is 1100.

1. Determine the time interval to advance the 1055 LOP (5 minutes) and multiply this time by the groundspeed of the aircraft (300 knots).

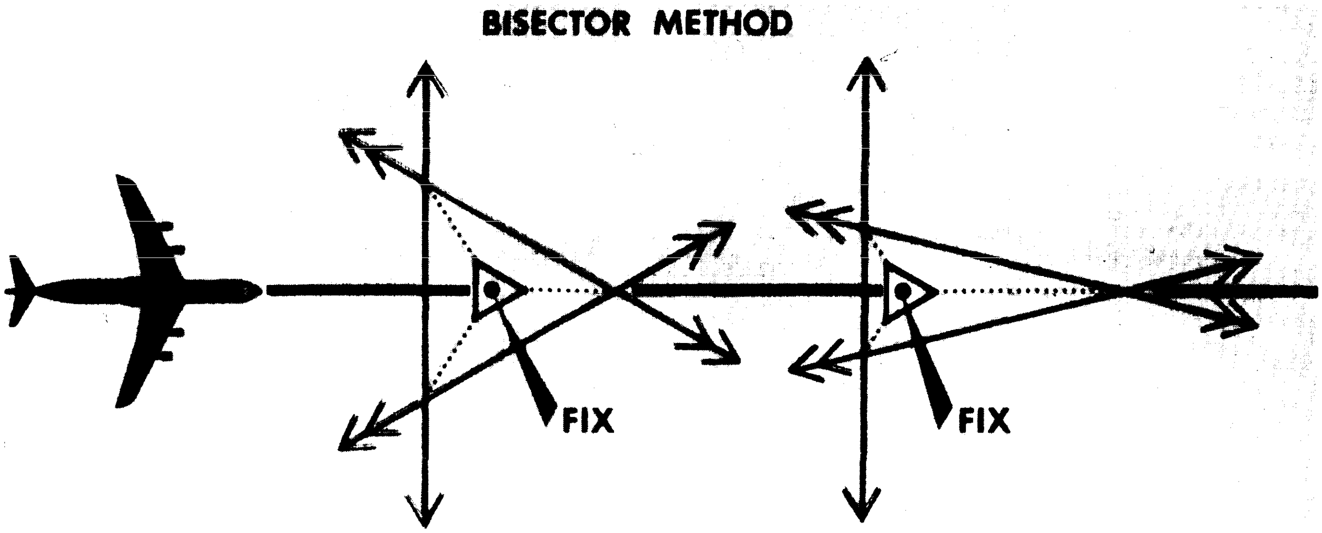


Figure 5-7. Use Center of Triangle for Fix.

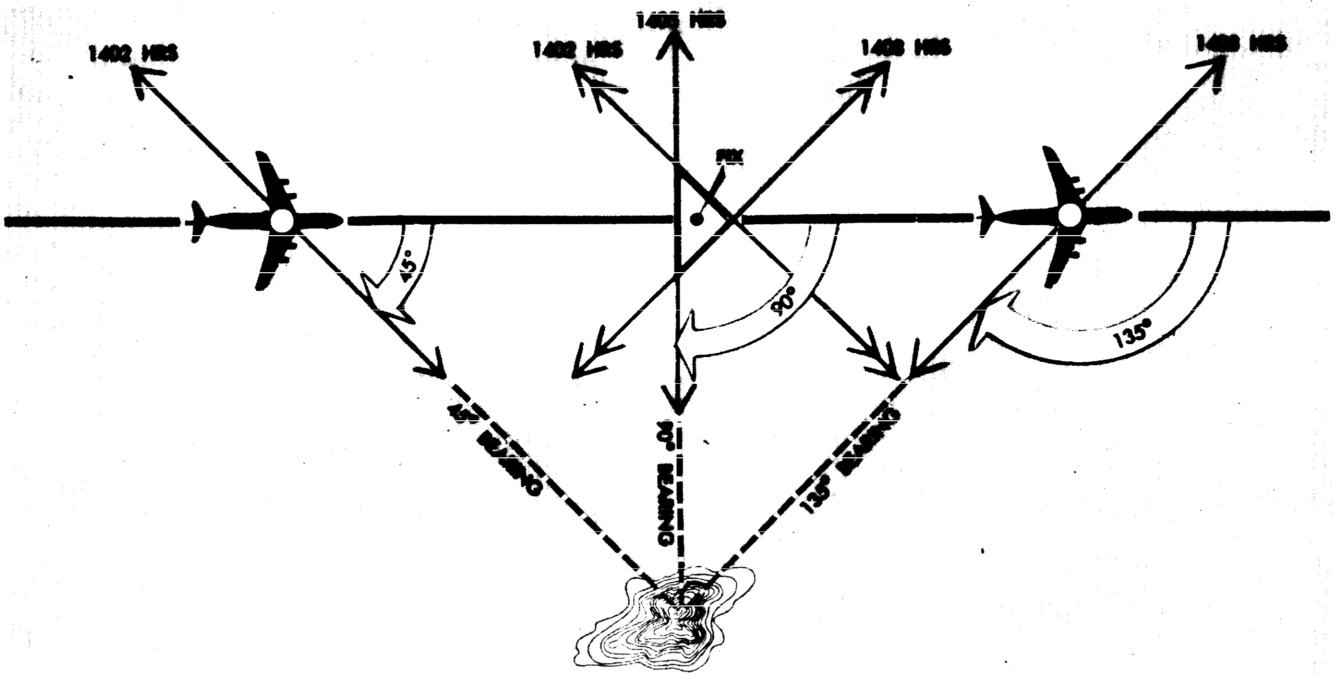


Figure 5-8. The Running Fix.

2. Take the distance computed in the first step and measure it in the direction of the track of the aircraft (045°).

3. Draw a line through this point parallel to the 1055 LOP (double-barbed LOP). This represents the advanced LOP. The intersection of the advanced LOP and the 1100 LOP is the fix.

The advanced LOP is usually plotted on the chart with two arrowheads, while the unadvanced LOP is marked with a single arrowhead.

When three LOPs are involved, the procedure is exactly the same as for only two. The resolution of three LOPs, however, may result in a triangle instead of a point, and the triangle may be large enough to vary the position of the fix. The technique most Air Force navigators use is to place the fix at the center of the triangle. The illustration in figure 5-7 shows a technique for finding the center of the triangle by bisecting the angles of the triangle. The point of intersection of the bisectors is equal distance from all three LOPs and is the fix position.

The Running Fix

It is possible to establish an aircraft position by a series of bearings on the same object. For best accuracy, these relative bearings are taken when the object is approximately 45°, 90°, and 135° from the aircraft. The navigator then advances or retards the LOPs to a common time. The result is a *running fix*. The accuracy is based on the aircraft's distance from object and the amount of time it takes to go from the first bearing to the last bearing, since you must move two of the LOPs for the aircraft's track and groundspeed. The running fix is illustrated in figure 5-8.

Accuracy of a Fix

The accuracy of a fix can sometimes be improved by the use of a little foresight. If the track of the aircraft is known more accurately than the groundspeed, the course line should be adjusted since any error in the groundspeed will have little effect on it. If, however, you desire to adjust a speed line under these conditions, the accuracy of the fix is in doubt. Similarly, if the groundspeed is known more accurately than the track, the speed line should be adjusted to the time of the course line. The line which will be affected least by the information in doubt is the line which should be adjusted.

Chapter 6

MAP READING

Map reading is the determination of aircraft position by matching natural or built-up features with their corresponding symbols on a chart. It is one of the more basic aids to DR and certainly the earliest used form of aerospace navigation. The degree of success in map reading depends upon a navigator's proficiency in chart interpretation, ability to estimate distance, and the availability of landmarks.

CHECKPOINTS

Checkpoints are landmarks used to fix the position of the aircraft. Basically, a checkpoint is a fix that has been anticipated, and the position of the fix, relative to its anticipated position, is the main information derived. Arrival over checkpoints at anticipated times is a confirmation of the accuracy of the wind prediction and indicates reliability of the predicted track and groundspeed. If the aircraft passes near but not over a checkpoint, the anticipated track was not made good. If checkpoints are crossed but not at the predicted time, the anticipated groundspeed was in error.

Prudent navigators are quick to observe and evaluate the difference between an anticipated position and an actual position. They must make corrections to maintain their intended course as soon as possible because small errors can be cumulative and may eventually result in the aircraft becoming lost. It might also be important to closely monitor time control. On many map reading missions, the aircraft is required to pass over certain checkpoints at exact times. On these missions, navigators must adjust the aircraft's airspeed to make good their anticipated groundspeeds.

Before fixing each position, navigators should look for several related details around each checkpoint to make sure it has been positively identified. For example, if the checkpoint is a small town, there may be a lake to the north, a road intersection to the south, and a bridge to the east. Generally, it is better to select a feature on the chart and then seek it on the ground, rather than to work from the ground to the chart. The chart does not show all the detail which is on the ground, and one could easily become confused.

Checkpoints should be features or groups of features which stand out from the background and are easily identifiable. In open areas, any town or road intersection can be used; however, these same features in densely populated areas are difficult to distinguish. Figures 6-1, 6-2, 6-3, and 6-4 compare various chart and corresponding photo areas and list the features to look for when identifying landmarks as checkpoints.

CHART SELECTION

A chart should be used for map reading that will provide sufficient natural and built-up features to accurately position the aircraft. The Operational Navigation Chart (ONC), with a scale of 1:1,000,000, has excellent cultural and relief portrayal. For increased detail, a Tactical Pilotage Chart (TPC), with a scale of 1:500,000, or a Joint Operations Graphics Chart (JOG), with a scale of 1:250,000, may be used.

MAP READING PROCEDURES

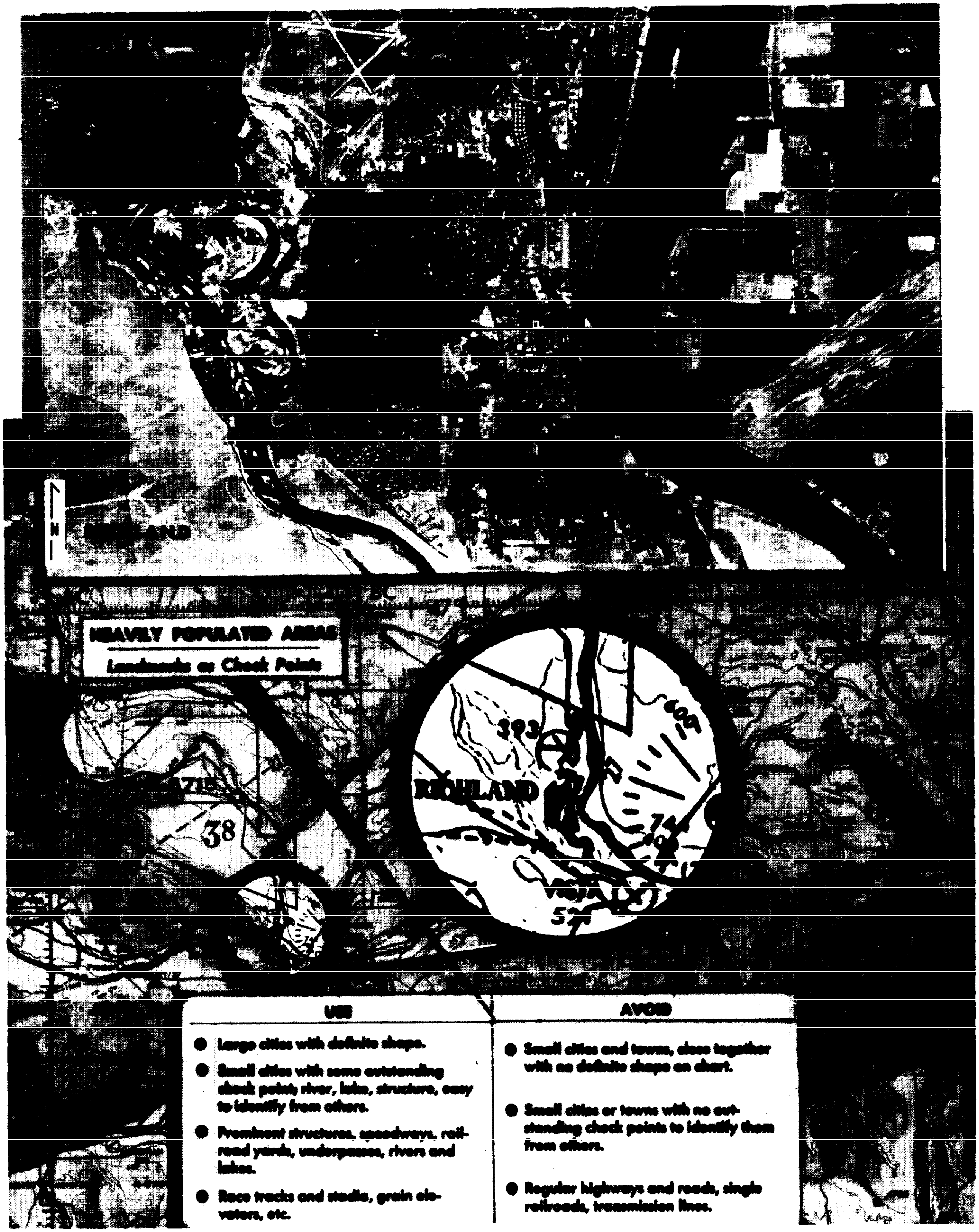
When in flight, orient the chart so that north on the chart is toward true north. The course line on the chart will then be aligned with the intended course of the aircraft so that landmarks on the ground appear in the same relative position as the features on the chart. Obtain the approximate position of the aircraft by DR. Select an identifiable landmark on the chart at or near the DR position. It is important to work from the chart to the ground since the chart may not portray all of the features visible on the ground. Identify the landmark selected and fix the position of the aircraft. The importance of a good DR cannot be over emphasized.

When there is any uncertainty of position, every possible detail should be checked before identifying a checkpoint. The relative positions of roads, railroads, airfields, and bridges make good checkpoints. Intersections and bends in roads, railroads, and rivers are equally good. When a landmark is a large feature such as a major metropolitan area, select a small prominent checkpoint within the large landmark to fix the position of the aircraft.

When a landmark is not available as a reference at a scheduled turning point, make the turn on the ETA. Extend the DR position to the next landmark and fix the position of the aircraft to make sure the desired course and groundspeed are being maintained. Remember that the desired magnetic course on any given leg corrected for drift is the magnetic heading which will parallel course. This will help to keep from getting any farther off course.

Low Level Map Reading

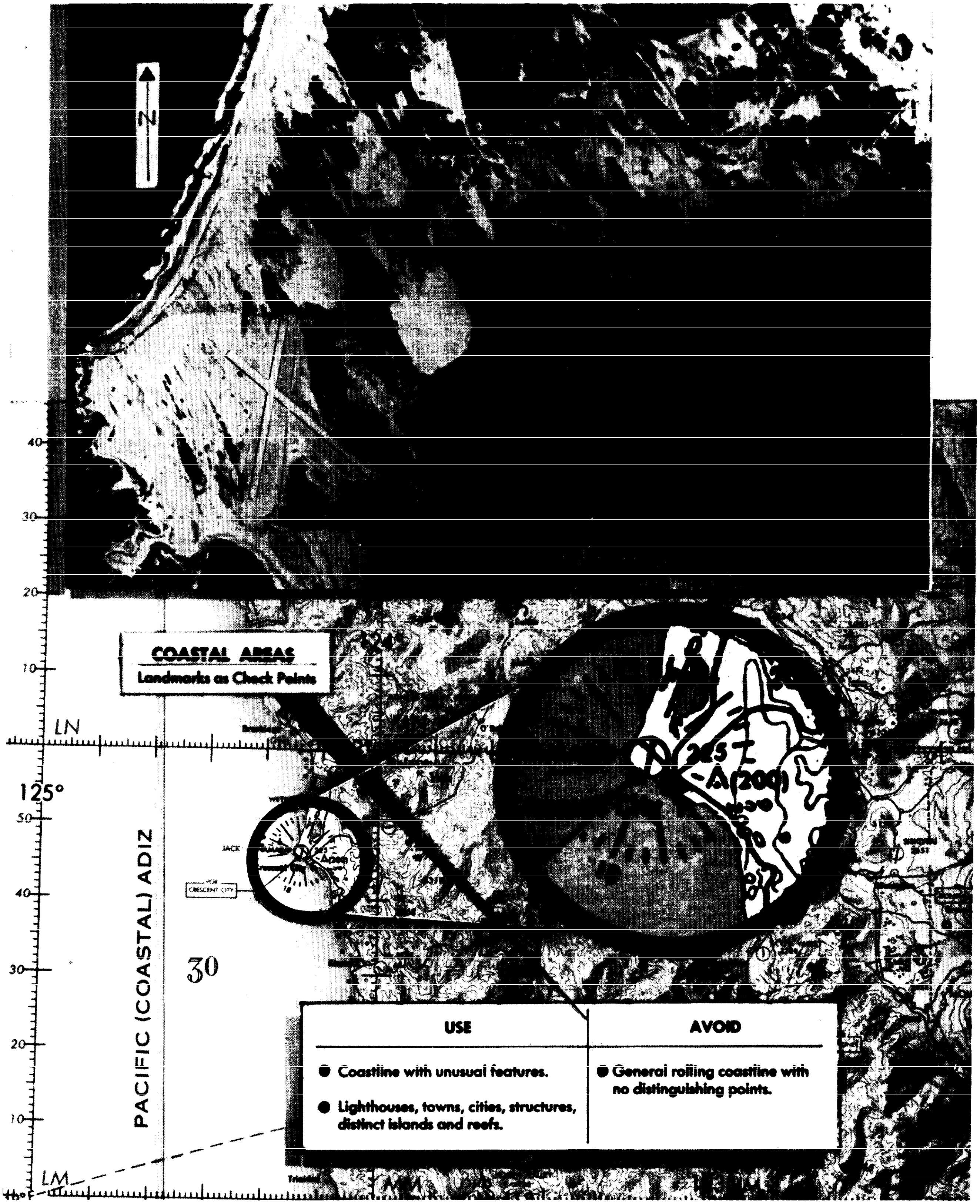
On low level flights, navigators may encounter additional difficulties. Most modern aircraft have a drift angle and groundspeed readout available. It can be derived from a Doppler radar set or from an INS. But, should one of the devices fail, accurate



USE	AVOID
● Large cities with definite shape. ● Small cities with some outstanding check point; river, lake, structure, easy to identify from others. ● Prominent structures, speedways, railroad yards, underpasses, rivers and lakes. ● Race tracks and stadia, grain elevators, etc.	● Small cities and towns, close together with no definite shape on chart. ● Small cities or towns with no outstanding check points to identify them from others. ● Regular highways and roads, single railroads, transmission lines.

Figure 6-1. Landmarks as Checkpoints, Heavily Populated Areas.

drift observations are hampered by the speed with which the ground seems to rush by. Air turbulance increases the difficulty of instrument observations. Depending on the aircraft's altitude above-ground-level (AGL), the circle of visibility can be greatly reduced, and those objects that are visible pass by so rapidly that only the boldest landmarks can be easily recognized.



USE	AVOID
● Coastline with unusual features. ● Lighthouses, towns, cities, structures, distinct islands and reefs.	● General rolling coastline with no distinguishing points.

Figure 6-2. Landmarks as Checkpoints, Coastal Areas.

In low level navigation, preflight planning is especially important as there is little time for in-flight computations. The courses should be laid out to take full advantage of prominent checkpoints. An important part of good mission planning is proper chart preparation. The most commonly used chart for low level work is the Tactical Pilotage Chart (TPC) with a scale

MOUNTAINOUS AREAS

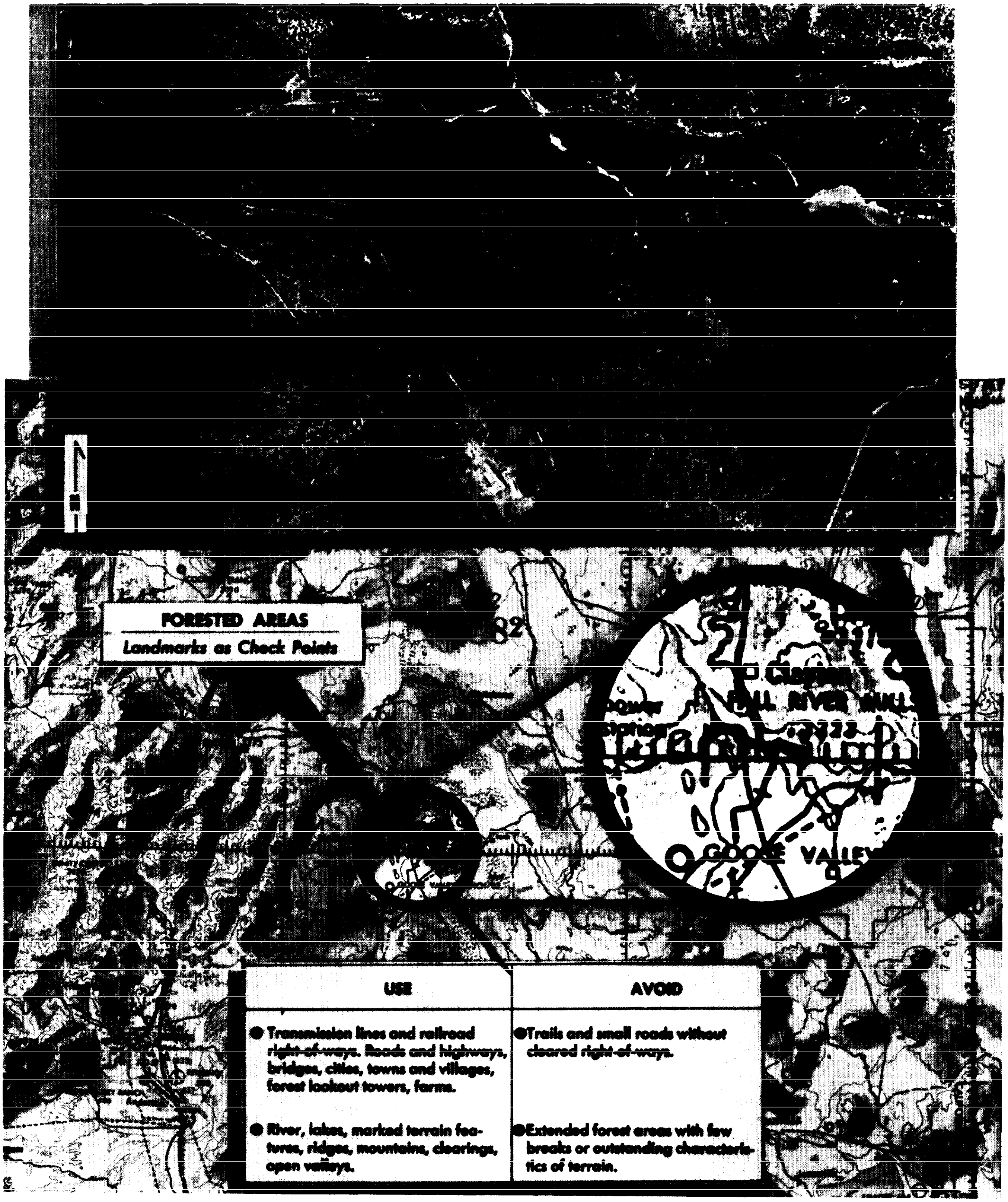
Landmarks as Check Points

USE	AVOID
● Prominent peaks, cuts and passes, gorges. ● General profile of ranges, transmission lines, railroads, large bridges over gorges, highways, lookout stations, dams, and lakes. ● Tunnel openings and mines. Clearings and grass valleys.	● Smaller peaks and ridges, similar in size and shape.

Figure 6-3. Landmarks as Checkpoints, Mountainous Areas.

of 1:500,000. Courses should be laid out on the chart into each checkpoint with radius of turn taken into account after each turn. Time elapsed marks and distance remaining marks along the course line of each leg will give navigators a running DR with the aid of a stopwatch.

In low level flight, one should be particularly alert to possible



USE	AVOID
● Transmission lines and railroad right-of-ways. Roads and highways, bridges, cities, towns and villages, forest lookout towers, farms.	● Trails and small roads without cleared right-of-ways.
● River, lakes, marked terrain features, ridges, mountains, clearings, open valleys.	● Extended forest areas with few breaks or outstanding characteristics of terrain.

Figure 6-4. Landmarks as Checkpoints, Forested Areas.

danger from obstructions. Hills and mountains are easily avoided if the visibility is good. Radio and television masts, which may extend as much as 1,000 feet or more into the air, often from elevated ground, are less conspicuous. All such obstructions may or may not be shown on the aeronautical charts being used. This points out the importance of keeping all charts

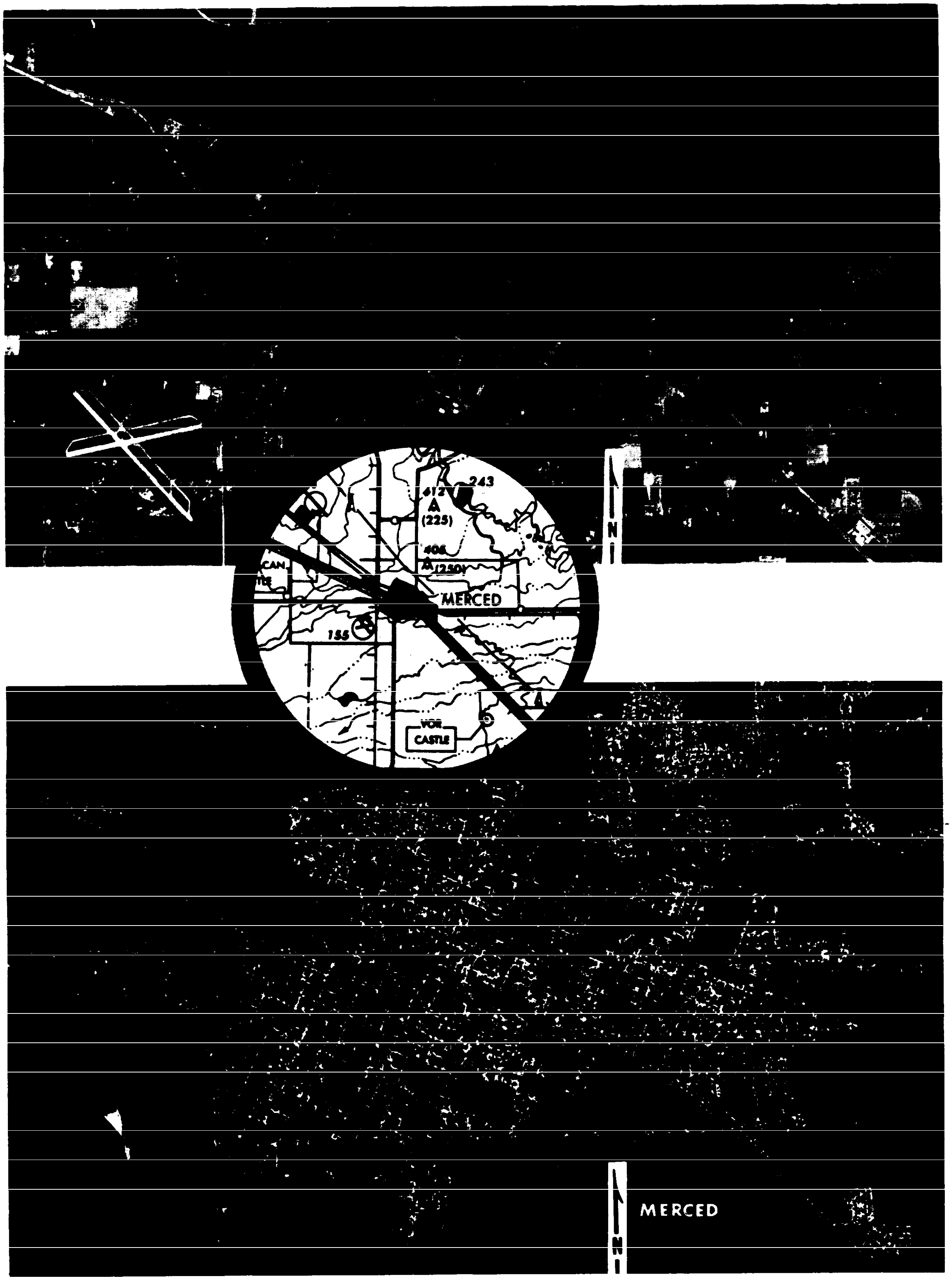


Figure 6-5. Landmarks at Night.

updated as to the location of towers that have been constructed since the chart was published. This is done with the Chart Update Manual (CHUM). The CHUM lists all current navigational charts and any important changes to them. The practice of updating charts in this manner is usually called "CHUMing charts."

Map Reading at Night

During hours of darkness, an unlighted landmark may be difficult or impossible to see. Lights can be confusing because they appear closer than they really are. Fixing on points other than those directly beneath the aircraft is very difficult. Objects are more easily seen by scanning or looking at them indirectly; this eliminates the eye's visual blind spot commonly encountered at night. Navigators should preserve their night vision by working with red light.

In moonlight, some of the prominent, unlighted landmarks are visible from the air. Coastlines, lakes, and rivers are usually seen without difficulty. Reflected moonlight often causes a river or lake to stand out brightly for a moment, but this condition is usually too brief for accurate fixing. By close observation, roads and railroads may be seen after the eyes are accustomed to the darkness.

Lighted landmarks such as cities and towns stand out more clearly at night than in daytime. Figure 6-5 illustrates a typical night view of the Merced, California, area. Large cities can often be recognized by their distinctive shapes. Many small towns are darkened at night and are not visible. Airfields with distinctive light patterns may be used as checkpoints. Military fields use a double white and single green rotating beacon, while civilian fields use a single white and single green rotating beacon. Early in the evening, busy highways are discernible because of automobile headlights.

Estimating Distance

A landmark often falls right or left of course and the navigator must estimate the distance to it. While the ability to estimate distance from a landmark rests largely in skill and experience, the following methods may be of assistance. One method is to compare the distance to a landmark with the distance between two other points as measured on the chart. Another method, shown in figure 6-6, is to estimate the angle between the aircraft subpoint and the line of sight. The distance in nautical miles from the landmark to the subpoint of the aircraft depends on the sighting angle:

(60°) horizontal distance = absolute altitude × 1.7
(45°) horizontal distance = absolute altitude
(30°) horizontal distance = absolute altitude × .6

Cross-check the validity of the estimate by sighting landmarks on each side of the aircraft and comparing the results.

Seasonal Changes

Seasonal changes can conceal landmarks or change their appearance. Small lakes and rivers may dry up during the summer. Their outlines may change considerably during the wet season. Snow can cover up almost all of the normally used landmarks. When flying in the winter, it is often necessary to rely on more prominent checkpoints such as river bends, hills, or larger towns. However, due to the size of these checkpoints, course control can be somewhat downgraded.

Map Reading in High Latitudes

Map reading in high latitudes is considerably more difficult than map reading in the lower latitudes. The nature of the terrain is drastically different, charts are less detailed and less precise, seasonal changes may alter the terrain appearance or hide it completely from view, and there are fewer cultural features.

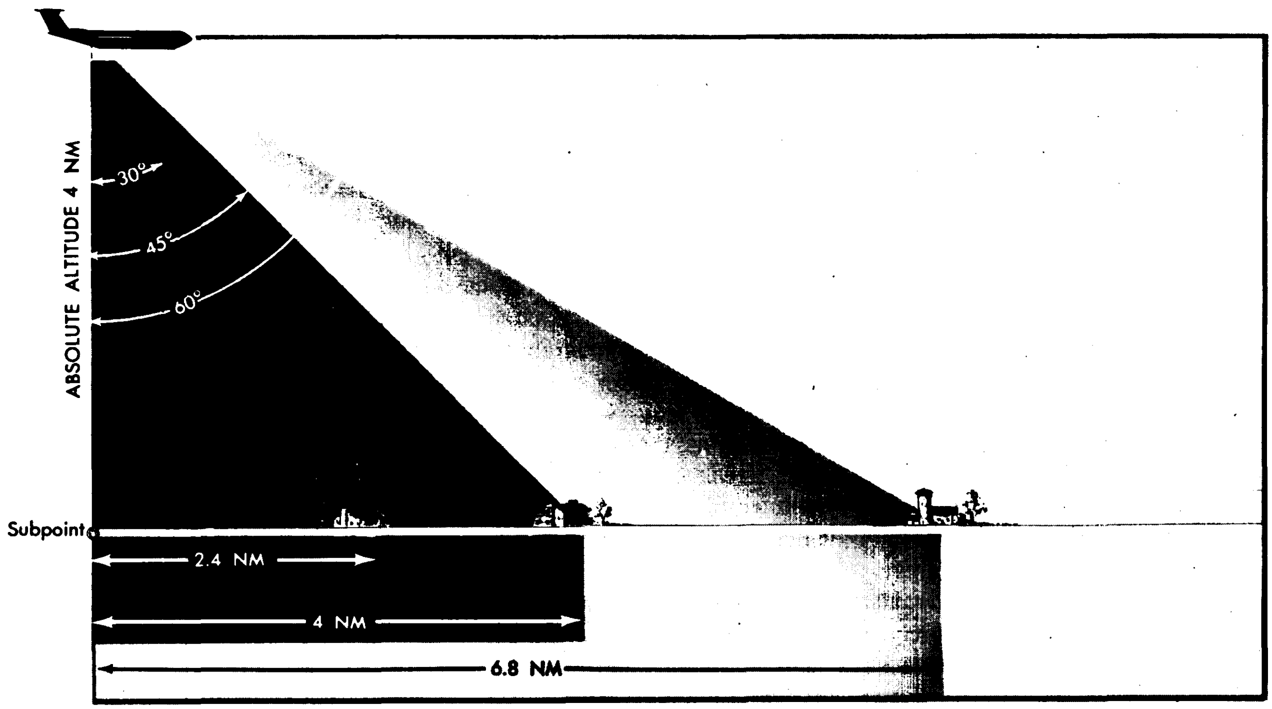


Figure 6-6. Estimating Distances.

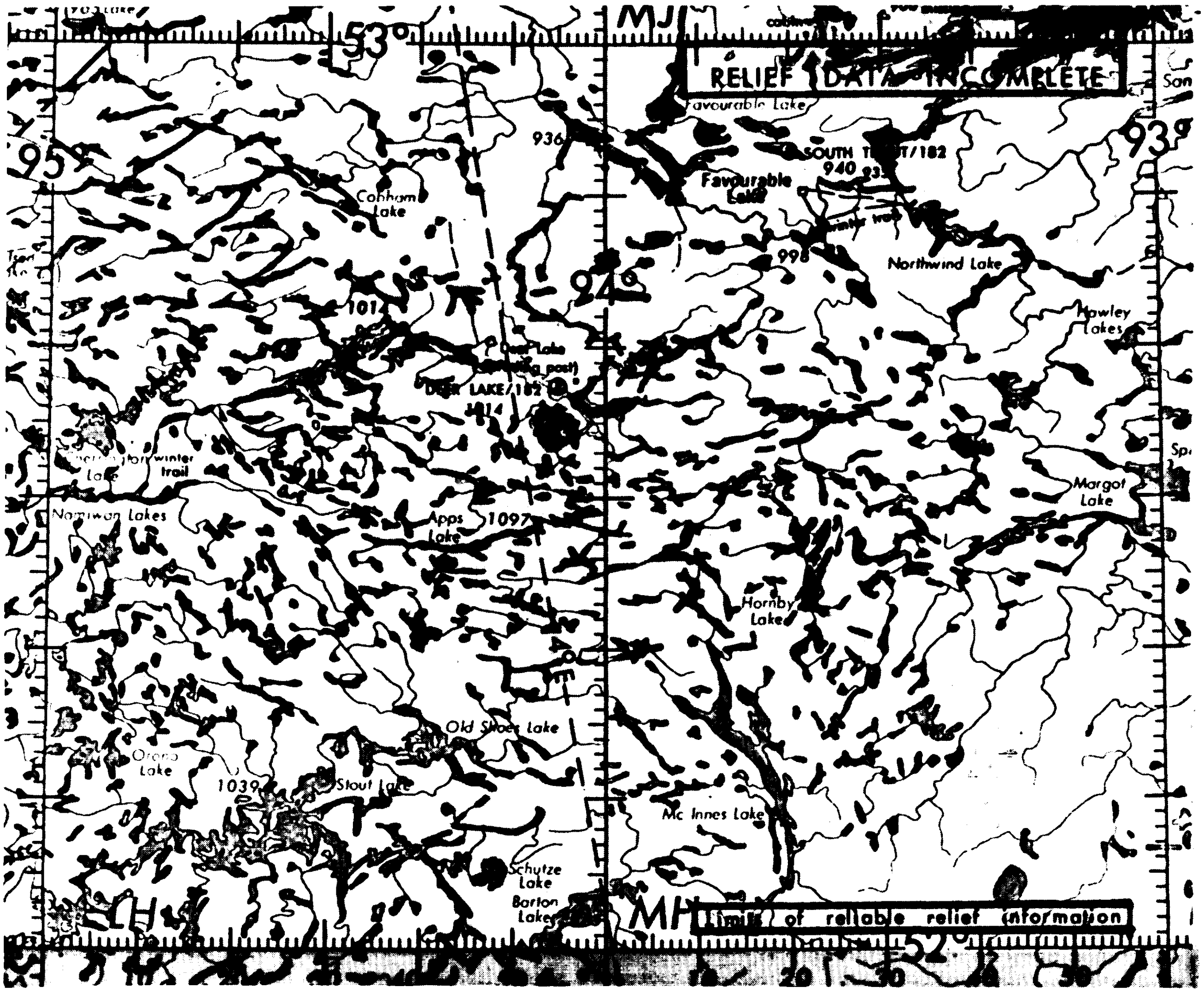


Figure 6-7. Natural and Cultural Features in High Latitudes.

In high latitudes, navigators find few distinguishable features from which to determine a position. Built-up features are practically nonexistent. The few which do exist are closely grouped, offering little help to the navigator flying long navigation legs. Natural features which do exist are in limited variety and are difficult to distinguish from each other. As illustrated by figure 6-7, lakes seem endless in number and identical in appearance. The countless inlets are extremely difficult to identify, particularly in winter. What appears to be land may in reality be floating ice, the shape of which can change from day to day. Recognizable, reliable checkpoints are few and far between.

Map reading in high latitudes is further complicated by inadequate charting. Some polar areas, as shown in figure 6-7, are yet to be thoroughly surveyed. The charts portray the appearance of general locales, but many individual terrain features are merely approximated or omitted entirely. In place of detailed outlines of lakes, for example, charts often carry the brief annotation—"many lakes." A fix is possible, but requires extended effort and keen judgment on the part of the navigator.

When snow blankets the terrain from horizon to horizon navigation by map reading becomes acutely difficult. Coastal ice becomes indistinguishable from the land, coastal contours appear radically changed, and many inlets, streams, and lakes disappear.

Blowing snow may extend to heights of 200 to 300 feet and may continue for several days, but visibility is usually excellent in the absence of interfering clouds or ice crystal haze. However, when snow obliterates surface features and the sky is covered with a uniform layer of clouds so that no shadows are cast, the horizon disappears, causing Earth and sky to blend together. This forms an unbroken expanse of white called "whiteout." In this complete lack of contrast, distance and height above ground are virtually impossible to estimate. Whiteout is particularly prevalent in northern Alaska during late winter and spring. The continuous darkness of night presents another hazard; nevertheless, surface features are often visible because the snow is an excellent reflector of light from the Moon, the stars, and the aurora.

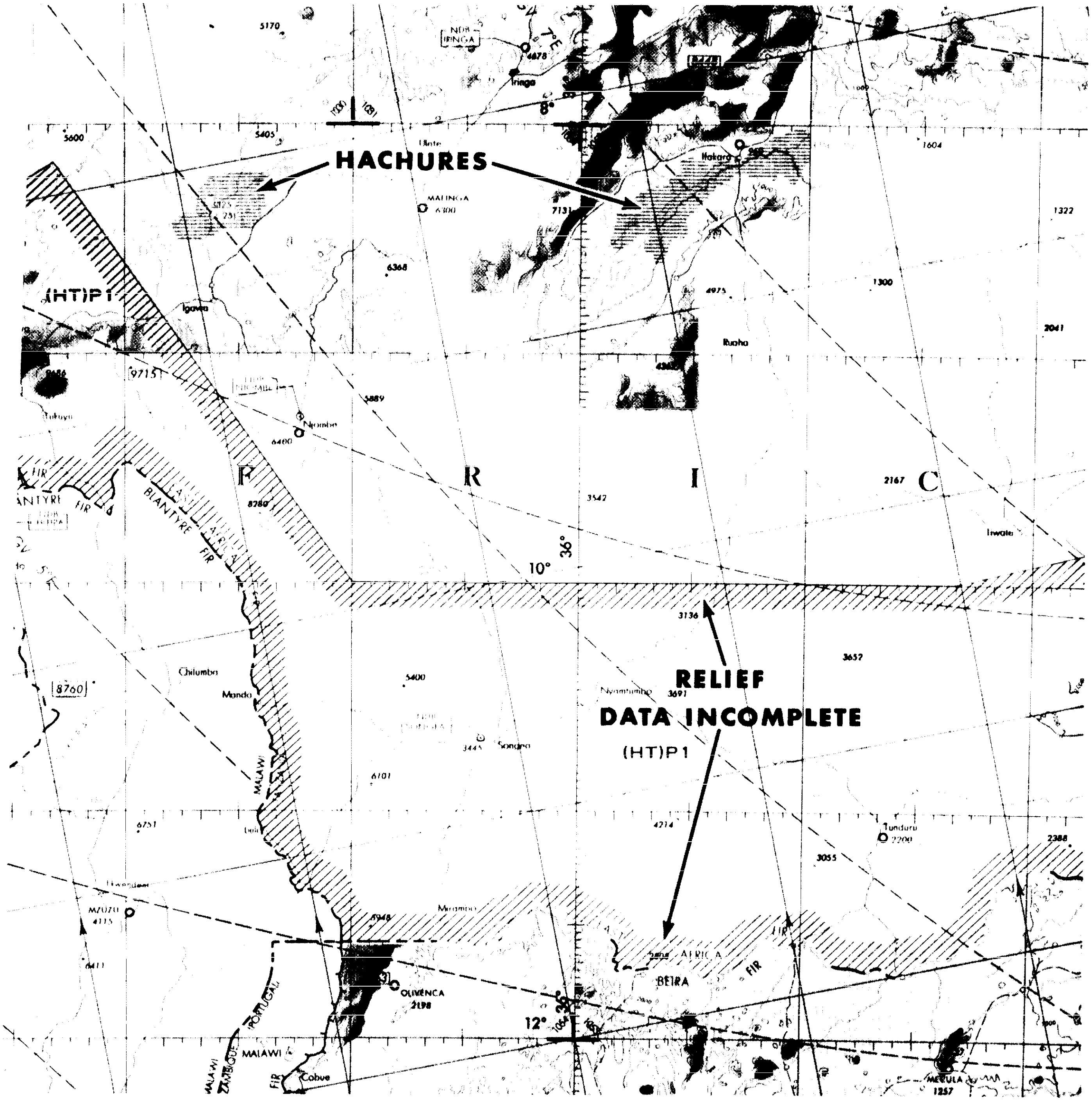


Figure 6-8. Use of Hachures on Contour Map.

Contour Map Reading

Use of contours is the most common method of showing relief features on a chart. Contours are lines that, at certain intervals, connect points of equal elevation. To understand contours better, think of the zero contour line to be sea level. If the sea were to rise 10 feet, the new shore line would be the 10-foot contour line. Similarly, successive 10-foot contour lines could be easily determined. Contour lines are closer together where the slope is steep and farther apart where the slope is gentle. Within the limits of the contour intervals, the height of points can be determined from the chart and the angle of slope can also be determined. Refer to figure 2-35 for an illustration of the use of contour lines.

Contour intervals are determined by the scale of the chart, the amount of relief, and the accuracy of the survey. These intervals may range from 1 foot on a large scale chart through 2,000 feet or greater on a smaller scale chart. Contours may be shown on charts in varying colors and are frequently labeled with "figures of elevation." To further accentuate the terrain, a gradient system of coloring is also employed. The lighter colors are used to show lower areas while a gradual increase in density (darkness) is used to portray the higher terrain.

Military operations require the analysis of contour-labeled charts to visualize the land. In operational planning, this is of the utmost importance, whether it is planning a route for a safe flight or in determining the best escape from enemy territory.

On charts of poorly known areas, mountains may be indicated by hachures or shading lines, with the elevations of peaks given as accurately as they are known. Hachures may be used on charts to show prominent hills or buttes too small to show up otherwise because of the large contour interval (figure 6-8).

Chapter 7

RADIO AND RADIO AIDS TO NAVIGATION

The first airborne radio was used to enable the pilot to keep informed of weather along flightpath. The gradual development of directional radio equipment made possible a system of radio routes (beams) which eventually formed aerial highways. World War II fostered the development of several new radio aids, the most important of which were LORAN and radar.

The rapid growth of our air traffic following World War II necessitated improved radio aids for instrument navigation and traffic control. Some of the aids developed were the VOR system, TACAN, IFF/SIF, and improved communication equipment. These terms are explained and discussed in this chapter.

FUNDAMENTALS

Frequency Classification

Energy in the frequency of 20 to 20,000 hertz (Hz) is capable of carrying audible communications. This frequency range is called the audio-frequency (AF) band.

NOTE: The National Bureau of Standards has adopted the hertz (Hz) as the Standard Unit Notation for measures of frequency. Thus, 60 cycles per second has become 60 Hz units, 400 CPS has become 400 Hz units, and so on. The name is in honor of

BAND	ABBRE-VIATION	Frequency range	WAVE LENGTH	
			Longest	Shortest
AUDIO	AF	0.02 to 20KHz	∞	20,000 m
RADIO				
Very low frequency	VLF	Below 30 KHz	30,000 m	10,000 m
Low frequency	LF	30 to 300KHz	10,000 m	1,000 m
Medium frequency	MF	300 to 3,000KHz	1,000 m	100 m
High frequency	HF	3,000 to 30,000KHz	100 m	10 m
Very high frequency	VHF	30 to 300MHz	10 m	1 m
Ultra high frequency	UHF	300 to 3,000MHz	100 cm	10 cm
Super high frequency	SHF	3,000 to 30,000MHz	10 cm	1 cm
Extremely high frequency	EHF	30,000 to 300,000MHz	1 cm	0.1 cm
HEAT AND INFRARED		3×10^{11} to 3.6×10^{14} Hz	10^{-1} cm	8.3×10^{-5} cm
VISIBLE SPECTRUM		3.6×10^{14} to 7.8×10^{14} Hz	8.3×10^{-5} cm	3.8×10^{-5} cm
ULTRAVIOLET		7.8×10^{14} to 2.4×10^{16} Hz	3.8×10^{-5} cm	1.2×10^{-6} cm
X-RAYS		6×10^{15} to 5×10^{19} Hz	5×10^{-6} cm	6×10^{-10} cm
GAMMA RAYS		6×10^{18} to 6×10^{20} Hz	5×10^{-9} cm	5×10^{-11} cm
COSMIC RAYS		3×10^{20} to 10^{23} Hz (+)	10^{-10} cm	shorter than 3×10^{-13} cm

Figure 7-1. Electromagnetic Spectrum.

REFLECTION **REFRACTION** **DIFFRACTION** **ABSORPTION**

Figure 7-2. Properties of Radio Waves.

Heinrich Rudolph Hertz, discoverer of electromagnetic waves.

The range of frequencies used in radio communications is called the *radio spectrum*. Radio frequencies extend from approximately 10 kHz to 300,000 MHz and have been arbitrarily divided into bands (figure 7-1).

Radio waves, like light waves, undergo reflection, refraction, diffraction, and absorption, and become attenuated (reduced in amplitude) as they travel from the source (figure 7-2).

Reflection. Reflection is the sharp change in the direction of travel of an incident wave which occurs at the surface of a medium. The waves "bounce" from the reflecting surface. A common example of this is the reflection of a beam of light from a mirror. All types of waves can be reflected under certain conditions. Radio waves are no exception. When reflection occurs, the angle of incidence is exactly equal to the angle of reflection.

Refraction. Electromagnetic energy emitted from a hypothetical "point" source (such as an antenna) travels in all directions in a series of ever-expanding, concentric spheres. A small portion of one of these spheres is termed the *wave front*. At a considerable distance from the antenna, the spherical nature of the wave front is less evident and it appears as a plane at right angles to the direction of energy propagation. Refraction is the bending of wave fronts as they pass obliquely from one medium to another or through a medium of varying density. The refraction, or bending, is caused by a difference in the speed of the waves through two mediums. The mediums through which radio waves travel are the various strata or layers of ionized gases which surround the Earth called the ionosphere.

Diffraction. Diffraction of electromagnetic enery occurs when energy travels near the edge of solid objects through which it cannot pass. Again, the concept of the wave front may be used to explain the process.

Absorption. Absorption is the loss of radio energy within a medium resulting from its conversion into heat. Radiated energy is absorbed by objects on the surface of the Earth, such as trees and buildings, and by the Earth itself. The radiated energy is said to be *attenuated* as it passes through a medium.

Electromagnetic Propagation

Behavior of Radio Waves. Radio waves are generally classified as ground waves, sky waves, or direct waves according to the path along which they travel to the receiver (figure 7-3). The properties of each are as follows:

1. Ground Waves. Radiated energy which follows the surface of the Earth is called the ground wave. Transmission frequency and transmitter power determine the distance a ground wave can be used for reliable reception. Ground wave signals in the low and medium frequency bands can be received reliably at distances of several hundred miles. As transmission frequency increases, ground wave coverage decreases rapidly. At VHF

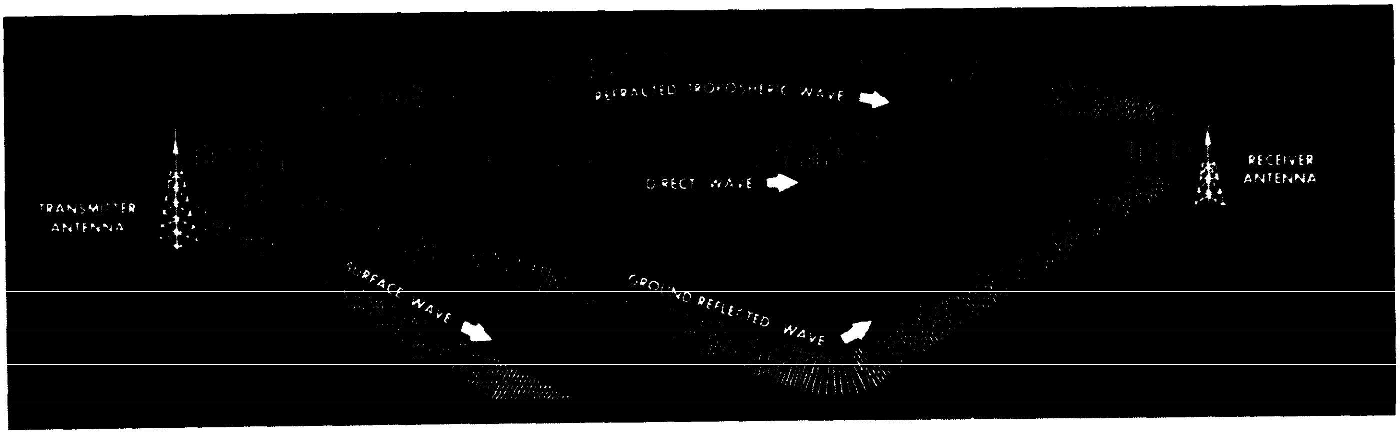


Figure 7-3. Ground Waves, Sky Waves, and Direct Waves.

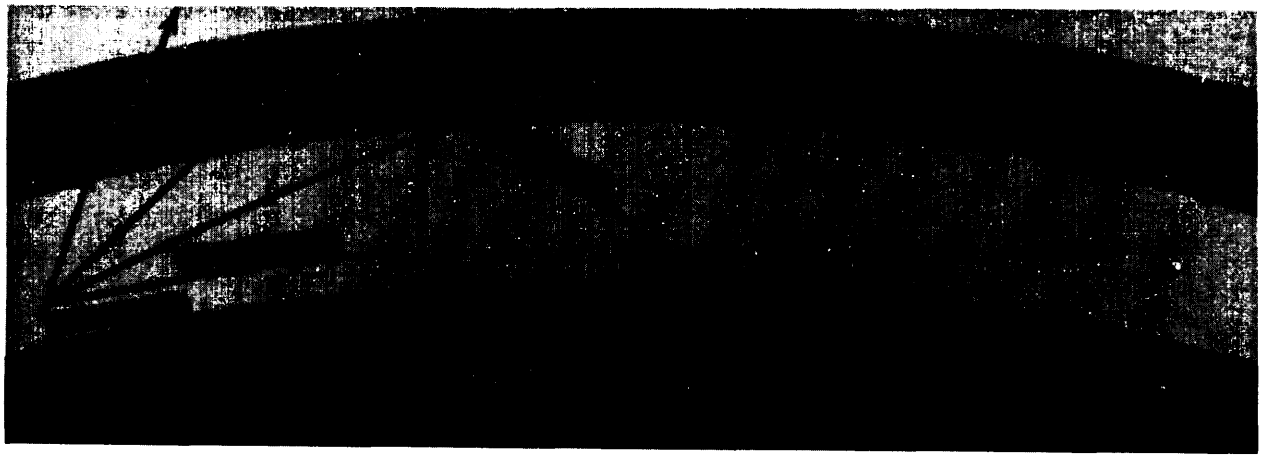


Figure 7-4. Skip Distance and Skip Zone.

and higher frequencies, ground wave coverage is limited to only a few miles.

2. Sky Waves. Sky waves are radio waves which are refracted by the Earth's atmosphere. Radio communications between distant points on the Earth depends principally upon sky waves.

As frequency is increased from the LF band through the HF band, skip distance becomes greater and greater until the VHF band is reached. Although VHF skip signals are not uncommon, in most instances, ionospheric refraction is not sufficient to return these signals to Earth. UHF and higher frequencies are refracted to an even lesser degree than VHF.

Whether or not a given wave returns to the Earth depends on the degree of ionization, wave radiation angle, and the transmission frequency of the signal.

3. Direct Waves. Radio energy which follows a line-of-sight path between a transmitter and a receiver is called a direct wave. Normal air-to-ground communications in the VHF, UHF, and higher bands rely on the use of direct waves.

Skip Distance. For a given frequency, there is a minimum distance from the transmitting antenna within which sky waves are not received. This minimum distance is called skip distance. When the distance covered by ground waves is less than the skip distance, a *skip zone* occurs between the outer limit of the ground waves and the first sky wave. Skip distance and skip zone are illustrated in figure 7-4.

Other Considerations. Since radio waves are influenced by many variables, it is essential to understand several other factors which affect a transmitted signal.

Night Effect. There is a period of time during sunrise and sunset when ground waves and sky waves overlap because of rapid changes occuring in the ionosphere. This is known as polarization error or night effect, and causes difficulty in matching the correct signals.

Fading. Fading occurs when a single transmission of radio energy arrives at a receiver as both a ground wave and a sky wave, or two different sky waves. If the two waves arrive in phase, they reinforce each other, resulting in a stronger signal. If they arrive in opposite phase, however, they tend to cancel each other. The changing phase relationship of two such signals causes intermittent fading.

Shore Line Effect. When ground waves pass over a coast line at an oblique angle, they tend to be refracted because of the difference in conductivity between the land and the water. The resultant change in direction is known as shore line effect. This factor causes some inaccuracy of radio bearings whenever a coast line is situated between the receiver and the transmitter.

Another factor which produces erroneous bearing indications is bending and splitting of ground waves in mountainous areas, or over areas of natural magnetic disturbance.

Interference. Unwanted signals in a receiver are called interference. The intentional production of such interference to obstruct communications is called *jamming*.

Weather Disturbances. Electrical discharges produced by thunderstorms generate signals in the low and medium frequency bands which can masquerade as a desired signal. Because of this, a radio compass is usually erratic in thunderstorm areas and may even point to an area of electircal disturbance rather than to the desired station. In thunderstorm areas, LF and MF communications may become garbled or saturated by static.

Antennas

Antennas may be classifed as either directional or nondirectional.

Nondirectional Antennas. A nondirectional antenna is one which radiates or receives radio energy equally in all directions. The most common nondirectional antenna is a vertical metal mast mounted on an insulated base. This antenna has almost no top surface and radiates comparatively little energy directly above the mast.

Vertical nondirectional antennas are commonly used in LF and MF bands for marine and aeronautical navigation beacons and for commercial broadcast stations. Figure 7-5 shows the transmission pattern of a vertical antenna.

Directional Antennas. A directional antenna is one which either transmits or receives energy more efficiently in one or more directions than others. Thus, directional information can be obtained by orienting a directional antenna for either max-

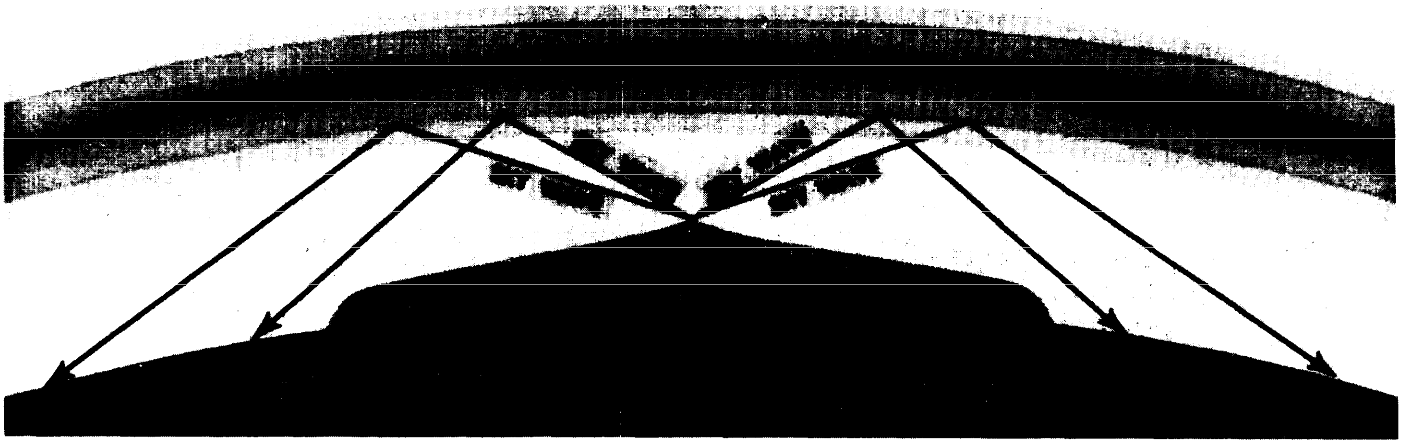


Figure 7-5. Transmission Pattern of a Vertical Antenna.

imum or minimum signal strength from a received signal. (See section on radio beacons.)

RADIO AIDS TO NAVIGATION

Radio Beacons

Radio beacons transmit a nondirectional signal which is easily identified as a specific station. If an aircraft has automatic direction finding (ADF) equipment, the direction of the beacon from the aircraft can be determined. Most low frequency direction finding equipment will receive any frequency between 100 and 1750 kHz. The IFR supplement lists the location and frequency of low frequency radio ranges and nondirectional beacons (NDB).

The operation of a radio compass depends primarily upon the characteristics of a loop antenna (figure 7-6). A loop-receiving antenna gives maximum reception when the plane of the loop is parallel to (in line with) the direction of wave travel. As the loop is rotated from this position, volume gradually decreases and reaches minimum when the plane of the loop is perpendicular to the direction of the wave travel.

These characteristics of the loop antenna result from the fact that the receiver input from a loop antenna is the resultant of the opposing voltages in the two halves of the loop. When current flows in a looped conductor, it must flow in opposite directions in each half of the loop. This occurs when the plane of the loop is in line with the station. Since one side of the loop is closer to the

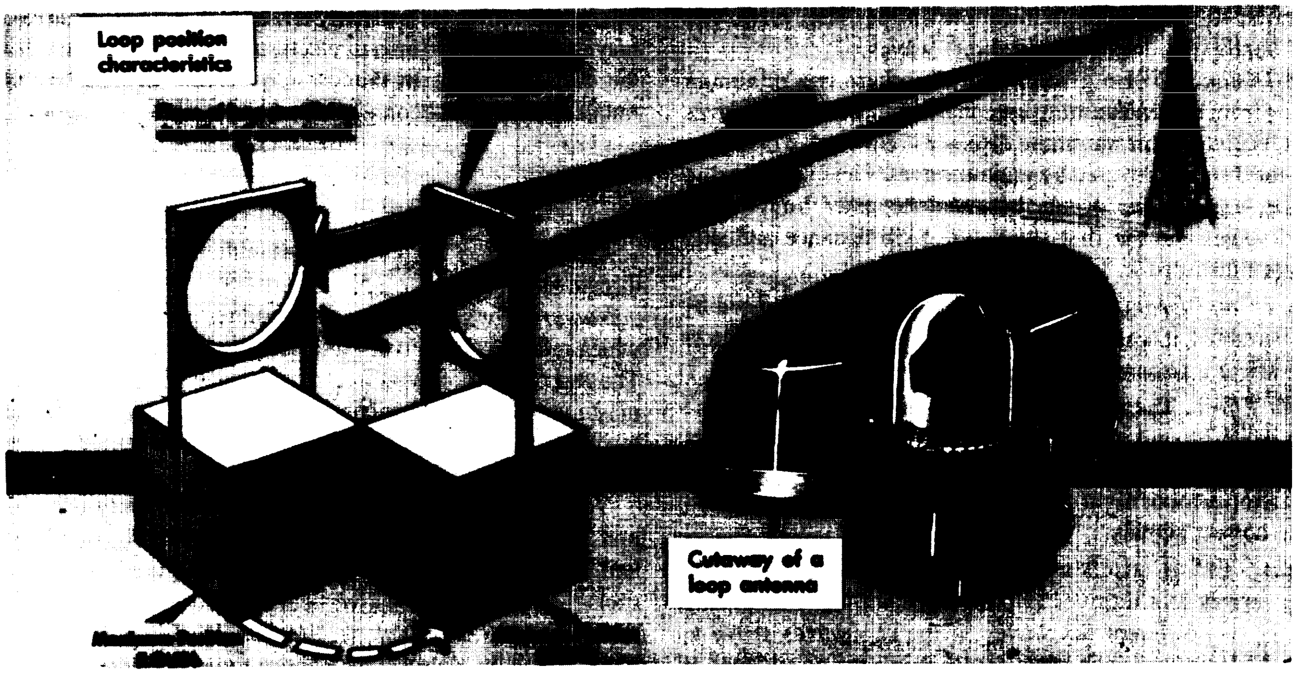


Figure 7-6. Loop Antenna.

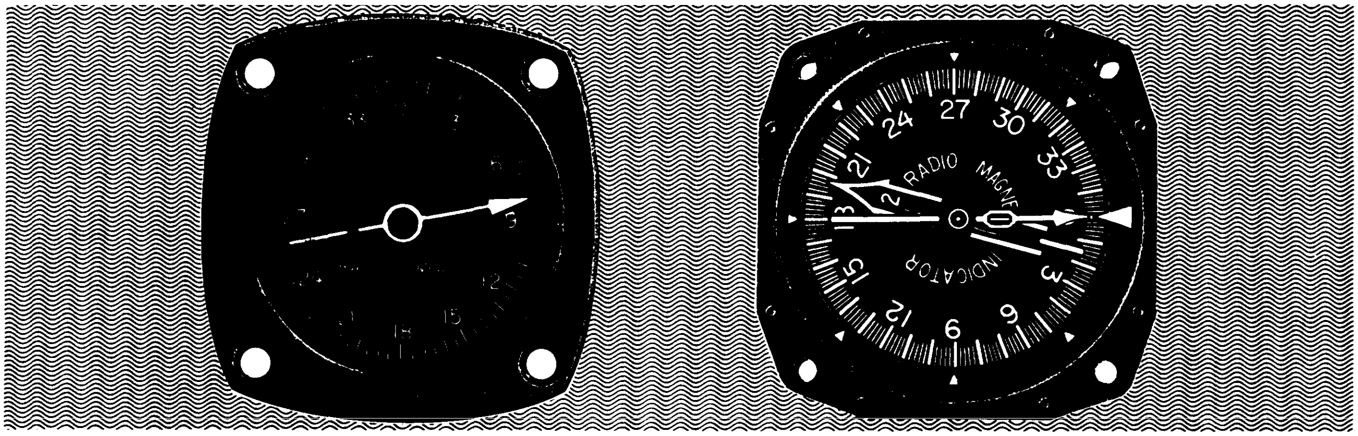


Figure 7-7. Fixed Card Indicator and Radio Magnetic Indicator.

transmitter, there is a slight delay between the time the radio wave reaches one side and the time it reaches the other. Therefore, there is a phase difference between the voltages induced in each half of the loop, which causes a resultant current flow through the transformer and creates a signal input to the receiver. When the plane of the loop is parallel to the direction of wave travel, maximum voltage is induced in the loop and the strength of the signal is maximum. Conversely, when the plane of the loop is perpendicular to the direction of wave travel, both sides are equidistant from the transmitter, the induced voltage is zero, and the strength of the signal is minimum. This is called the *null* position of the loop.

This null position is used for direction finding (obtaining a bearing to a station). This position of the loop is used because it can be determined more accurately than the maximum position.

One additional problem exists. The loop antenna is unable to determine either of two possible directions to the station. This 180° ambiguity is eliminated by a nondirectional or sensing antenna. The loop antenna of the radio compass is automatically rotated to the null position when signals are received by both the loop and sensing antennas. The combination of signals energizes a phasing system which operates a motor on the loop drive. The bearing pointer is electrically synchronized and turns with the loop, thus indicating bearing to the station when the loop is in the null position.

Two types of indicators are used with the radio compass (ADF). On the fixed card type (figure 7-7), zero degrees represents the nose of the aircraft and the ADF bearing pointer yields relative bearing to the station. The type of indicator with a rotating compass card shows magnetic heading of the aircraft under the top index. The ADF pointer points to the station and indicates magnetic bearing.

Plotting on a Chart

Before an ADF bearing (LOP) can be plotted on a navigational chart, two things must be done. First, the bearing obtained must be converted to a true bearing. If a nonrotatable compass card is used, the resultant relative bearing (RB) may be converted to true bearing (TB) by adding the aircraft true heading (TH) (TH + RB = TB). If a rotatable compass card is used, the true bearing can be found by applying the magnetic variation at the vicinity of the aircraft. Secondly, if a great distance exists between the aircraft and the station, a correction is required to convert the great circle of the radio bearing to a great circle course on a chart. (See figure 7-8 for table of corrections.)

UHF/DF

Some aircraft are equipped with automatic direction finders in the UHF frequency range (225.0 - 399.9 megacycles) which utilize loop and sensing (antennas) to give bearing information. Operation of the direction finder is controlled from the UHF radio panel. It is used to obtain bearing to other aircraft and to emergency locator beacons (ELT).

Omnirange

The VHF omnidirectional range (VOR) is a radio aid which has eliminated interference due to atmospheric conditions. VOR stations operate between 108.00 and 117.95 MHz. VHF communications operate between 118.00 and 135.90 MHz. Station identifiers for VOR navaids are given in code or voice, or by alternating code and voice transmissions.

As with TACAN, VOR provides an infinite number of courses or radials emanating from the station. The transmission principle of the VOR is based on creating a phase difference between two signals. One of these signals, the reference phase, is omnidirectional and radiates from the station in a circular pattern. The second signal is a variable phase which rotates uniformly at 1,800 RPM and its phase changes 1 degree for each degree change in azimuth around the VOR (figure 7-9).

Magnetic north is used as the base line for electronically measuring the phase relationship between the reference and the variable phase signals. At magnetic north, the signals are exactly in phase; however, the phase difference increases as we proceed clockwise around the station (000°-359°). This phase

MIDDLE LATITUDE	CORRECTION REQUIRED TO CONVERT A RADIO GREAT CIRCLE BEARING TO MERCATORIAL BEARING														
	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

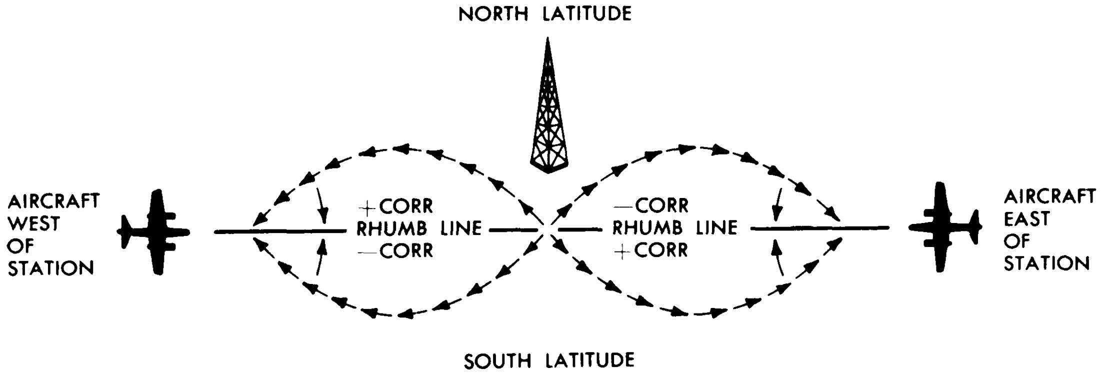


Figure 7-8. Rhumb Line Correction Table and Diagram.

difference is measured electronically by the aircraft receiver and is displayed as a radial or magnetic bearing to the station on a radio magnetic indicator (RMI) or bearing direction heading indicator (BDHI).

VOR transmissions are limited by line of sight, and a combination of aircraft altitude and distance to the station. Accurate information may be obtained from 40 to 100 NM around the facility although the usable range may be much greater (300 NM).

VOR may be used by flying courses from one station to

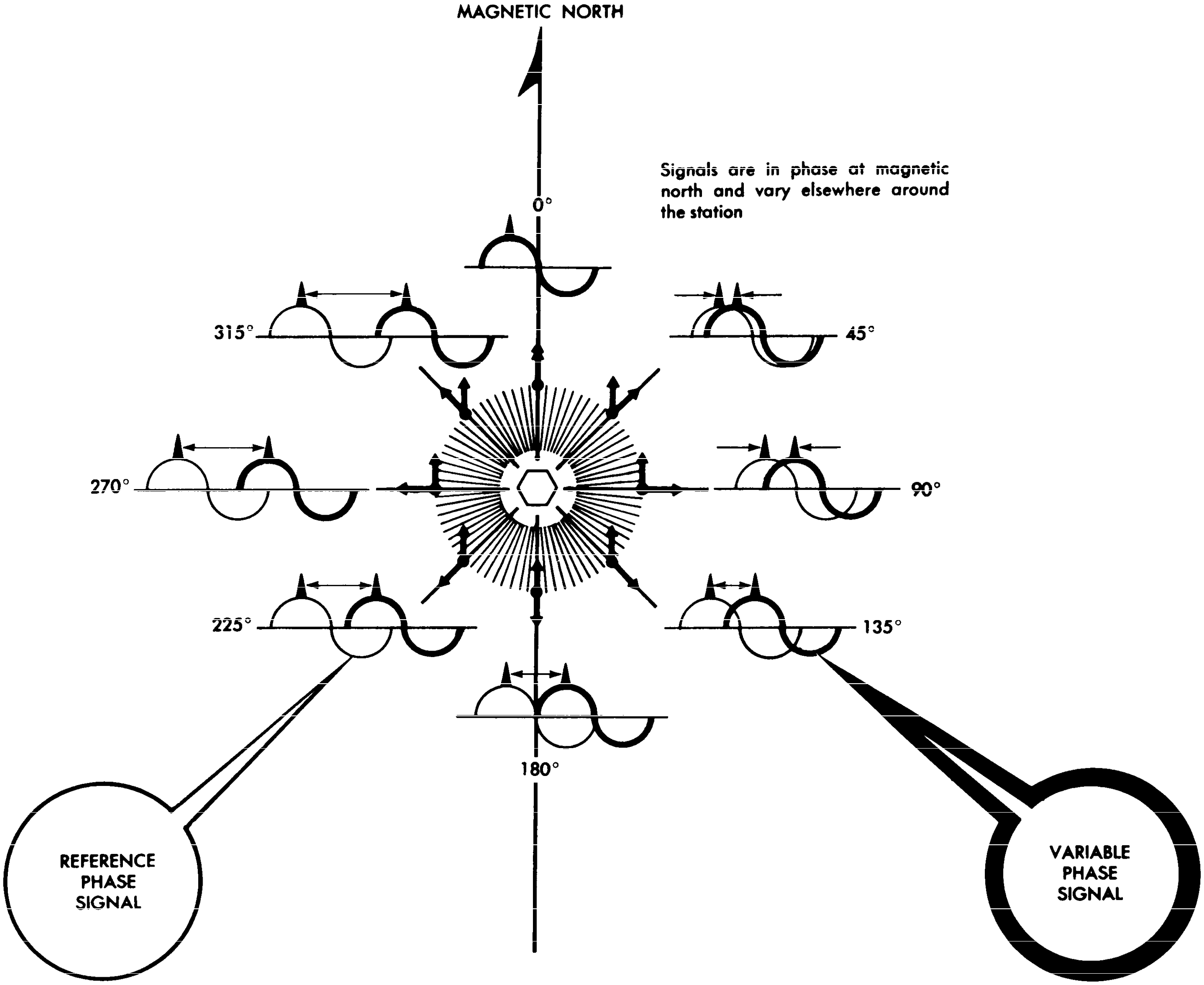


Figure 7-9. Signal Phase Relationship for VOR.

another as part of the high or low jet navigation airways system. It may be used as a fixing aid by taking a bearing and applying magnetic variation at the station (converting magnetic bearing to true bearing) and plotting a line of position. In aircraft equipped with two VORs, the bearings to two different stations may be taken simultaneously, plotted, and a fix position obtained. The aircraft is directly overflying a VOR when the bearing pointer drops rapidly below the 3 or 9 o'clock positions.

Control Panel. A VOR control panel contains (1) a power switch, (2) frequency window, (3) volume control, (4) equipment self-test capability, and (5) frequency selector controls all shown in figure 7-10. To tune a VOR, turn power switch to PWR, select desired frequency, and identify the station. For positive test indications, consult aircraft tech order.

Indicator Panel. Several types of indicators exist which display VOR information. Examples shown here are the course

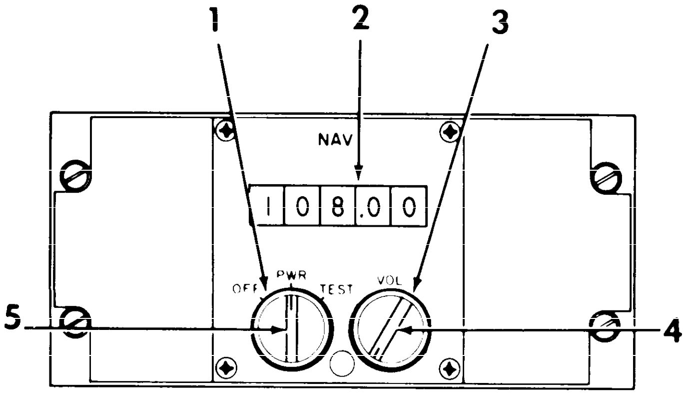


Figure 7-10. VOR Nav Control Panel.

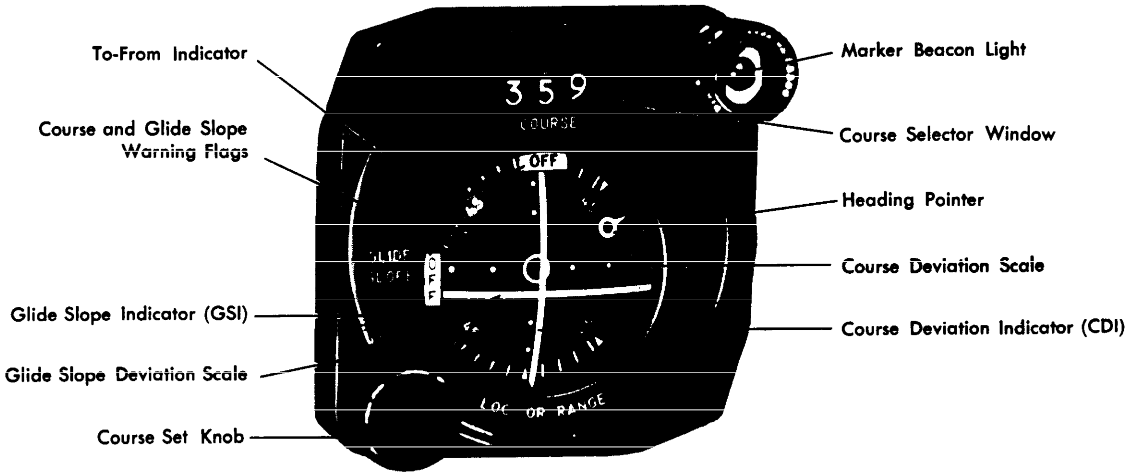


Figure 7-11. Course Indicator.

indicator (figure 7-11), the radio magnetic indicator (RMI) (figure 7-12), and the bearing direction heading indicator (BDHI) (figure 7-13).

The course indicator has eight significant features:

TO-FROM indicator
Glide slope and course warning flags
Course selector window
Marker beacon light
Glide slope indicator
Heading pointer
Course deviation indicator (CDI)
Course set knob

The TO-FROM indicator shows whether the radial set in the course selector window is to or from the station, and the CDI represents this radial. If the aircraft is to the right of the radial, the CDI is displaced to the left of center on the course indicator. The glide slope indicator is similar to the CDI but represents the glide slope transmitted by an instrument landing system (ILS). If the glide slope indicator is below the center of the course indicator, the aircraft is above the glide slope. The glide slope and course warning flags inform the user that either the glide slope indicator or CDI is inoperative, or that signals received are too weak to be used. The heading pointer indicates the difference, left or right, between the aircraft magnetic heading and the radial set in the course selection window. The marker beacon light flashes when passing over a marker beacon (such as, outer marker of the ILS).

The RMI is a bearing indicator, usually with two pointers and a movable compass rose. The compass rose rotates as the aircraft turns, indicating the compass heading of the aircraft under the top of the index at all times. Therefore, all bearings taken from an RMI are magnetic. Consult the specific tech order as to which pointer is the VOR.

The BDHI is similar to the RMI in that a pointer provides magnetic bearing information. Additional information concerning the BDHI is contained in the TACAN section.

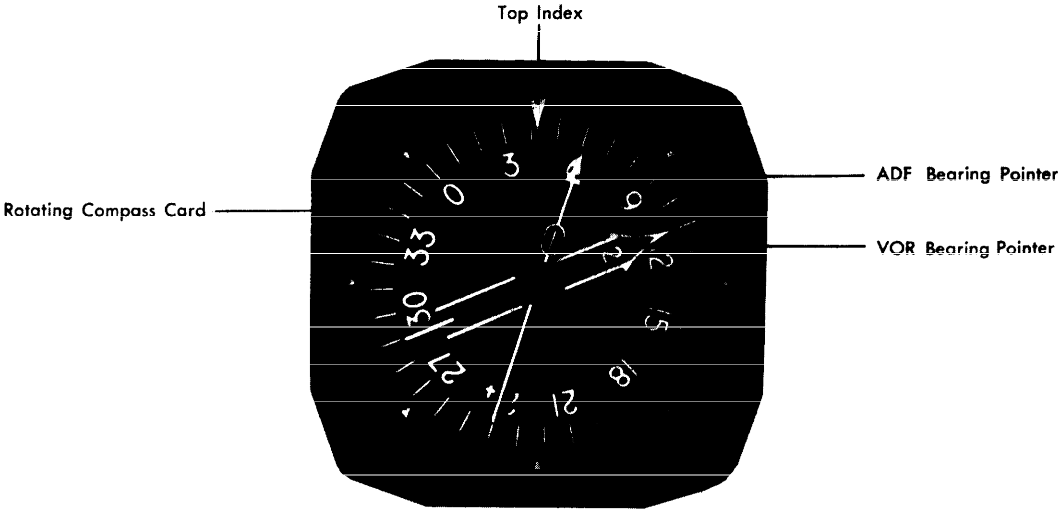


Figure 7-12. Radio Magnetic Indicator (RMI).

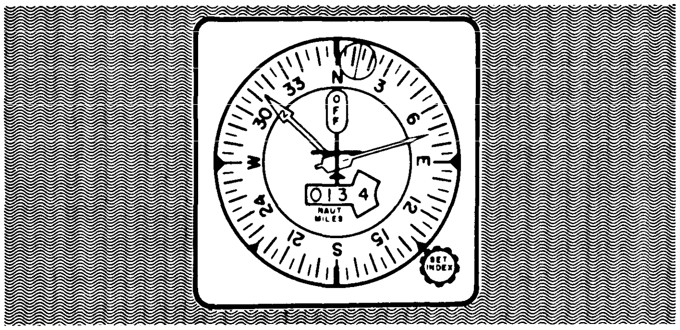


Figure 7-13. Bearing Distance Heading Indicator (BDHI).

TACAN

The Tactical Air Navigation (TACAN) system was developed to provide the crewmember with information needed for precise positioning within 200 nautical miles. As with VOR, TACAN provides an infinite number of radials radiating outwardly from the station. In addition, distance measuring equipment (DME), an integral part of TACAN, provides continuous slant-range distance information.

TACAN operates in the UHF band and has 126 channels available in the X-band pulse code. Development of pulse coding has given ground equipment the capability of an additional 126 channels in the Y-band. The station identifier is transmitted at 35-second intervals in international Morse code. Airborne DME transmits on 1025 - 1150 MHz; associated ground-to-air frequencies are in the 962 - 1024 MHz and 1151 - 1213 MHz ranges. Channels are separated at 1 MHz intervals in these bands.

The ground equipment consists of a rotating-type antenna for transmitting bearing information and a receiver-transmitter (transponder) for transmitting distance information. Permanent, fully monitored ground stations are dual transmitter-equipped (one operating and one in standby) installations which automatically switch to the standby transmitter when a malfunction occurs. Each station has a ground monitor which is set to alarm at a radial shfit of ± 1° from the alignment to magnetic north. This alarm is usually located in the base control tower or approach control, and sets off a light and buzzer to warn the ground crew when an out-of-tolerance condition exists. It is possible to select a TACAN station and get erroneous DME and azimuth lock-on when the station is undergoing maintenance. This can be detected by an absence of signal identifier. Checks of en route or radio navigational aids may be made by consulting NOTAMs prior to flight or by contacting air traffic control for advisories when airborne.

Airborne equipment also contains a multi-channel transmitter-receiver (transceiver). Bearing information is automatically obtained with the correct channel selected. Distance is determined by measuring the elapsed time between transmission of interrogating pulses of the airborne set and reception of corresponding reply pulses from the ground stations. This sequence is initiated by the aircraft transmitter and requires about 12 microseconds per nautical mile round trip. Since the DME gives a readout of slant range rather than ground range, a correction has to be applied to the reading when within approximately 25 NM at normal aircraft altitudes. (See slant range table for correction.)

TACAN DME is designed to provide range information to maximum distance of from 200 to 300 NM, dependent on aircraft equipment. Accuracy is on the order of ± 600 feet plus two-tenths of one percent of the distance being measured.

Since a large number of aircraft could be interrogating the same station, the aircraft TACAN must sort out the pulses which are replies to its own signal. Interrogation pulses are transmitted on an irregular, random basis by the airborne set which then searches for replies synchronized to its own interrogations. If the signals are interrupted, a memory circuit maintains the last distance indications on the range indicator for approximately 10 seconds to prevent the search operation from recurring. This process starts automatically whenever a new station is tuned or when there is a major interruption of signals. Depending upon the actual distance from the station, the searching process may require up to 22 seconds. The maximum number of aircraft which can be accommodated by one station at any one time is 100. With the development of the X and Y bands, this number can be doubled.

TACAN Characteristics

Bearing/Distance "Unlock." Since TACAN bearing/DME are subject to line-of-sight restrictions, this information could be lost any time signals are blocked. Temporary obstructions can occur in flight any time any part of the aircraft gets between the ground and aircraft antenna. Other aircraft, terrain, and buildings are external causes for unlock. Any time the signal is obstructed for more than 10 seconds for DME and 2 seconds for azimuth, the unlock conditions will be indicated by a rotating bearing needle and a tumbling DME readout.

Azimuth Cone of Confusion. TACAN antennas transmit radio energy in circular patterns out from the transmitter. However, waves are not transmitted directly above the station. Therefore, as the aircraft approaches a TACAN station, signals are lost. This is indicated by a rotating TACAN bearing needle in the RMI.

The azimuth cone can be up to 100° or more in width or approximately 15 NM wide at 40,000 feet. Thus, one may enter the cone of confusion at approximately 7.5 DME at this altitude. Approaching the station, usable TACAN information is lost before the cone is reached as aircraft memory circuits maintain last information.

Range Indicator Fluctuations. Slight oscillations up to approximately 1/4 NM are normal for range indicator operation due to the pulses generated by the transmit or receive function. When a usable signal is lost, the memory circuit maintains the indicated range for about 10 seconds, after which unlock will occur unless usable signals are regained.

Forty Degree Azimuth Error Lock-on. The construction of the TACAN ground antenna is such that it transmits a series of 9 signal lobes (8 auxiliary and one main reference pulse) 40°

apart. With the airborne receiver working correctly, these pulses lock on the airborne equipment with the main reference at 090°. With a weak signal, the main reference pulse may "slide over" or miss the 090° slot and lock on at one of the auxiliary positions. When this occurs, azimuth indications will be 40° or a multiple of 40° in error. Forty degrees azimuth lock-on error will not cause a course warning flag to appear on the indicator. Rechanneling the airborne receiver may give the set another chance to lock on properly.

Co-Channel Interference. Co-channel interference occurs when an aircraft is in a position to receive TACAN signals from more than one ground station on the same frequency. This normally occurs only at high altitudes when distance separation between like-frequencies is inadequate. DME, azimuth, or identification from either station may be received. This is not a malfunction of either airborne or ground equipment, but a result of position.

Air-to-Air TACAN. This function is provided to give distance information between two aircraft, working in the same manner as a regular ground-based TACAN station. Some sets provide only DME information. Other newer sets provide both distance and bearing information to other aircraft. In order to obtain useful information, the air-to-air (A/A) function should be selected by both aircraft with a 63-channel frequency separation. In addition, each aircraft must have the same frequency band (X or Y) selected. Therefore, one aircraft sets A/A channel 4 and the other sets A/A channel 67 in the X band and useful information should be obtained.

Air-to-air TACAN is primarily used during the rendezvous portions of air refueling operations or formation flights. A prescribed turn range (DME) and offset (bearing, if available) between the two aircraft are used to effect the rendezvous. Proper air-to-air channels for each air refueling route are found in the FLIP Planning Document.

Tuning and Controls. The basic controls of most TACAN systems is shown in figure 7-14: The proper channel is tuned by rotating channel selector knobs (1) to any of 126 channels. (2) Internal test mode—validates working condition of TACAN. The channel mode selector (4) allows X or Y band to be selected. These controls are presented in the channel indicator (3). A volume control (5) adjusts the audio level of the station identifier signal. The TACAN test button permits the user to perform a system self-test. The function selector (6) has four settings:

OFF—Removes power to the set
REC—Energizes the receiver to obtain bearing information
T/R—Energizes both receiver and transmitter to obtain both bearing and distance information
A/A—System transmits and receives interrogations and replies to measure range to another A/A TACAN-equipped aircraft. Bearing information is not provided on this set.

TACAN bearing is presented on an RMI (bearing) and a BDHI (bearing and DME) as shown in figures 7-12 and 7-13.

VORTAC. In order to provide both military and civilian pilots the capability of positioning from the same radio navaids, a combination of VOR and TACAN station was developed. Each facility offers three services. VOR azimuth signals are transmitted on the published VOR frequency. TACAN azimuth and DME signals are broadcast on the published UHF channel.

Point-to-Point Navigation (Using RMI/BDHI)

Flying from one radial and DME to another may be required during departures and approaches. A heading to the desired point may be derived quickly through the use of an RMI provid-

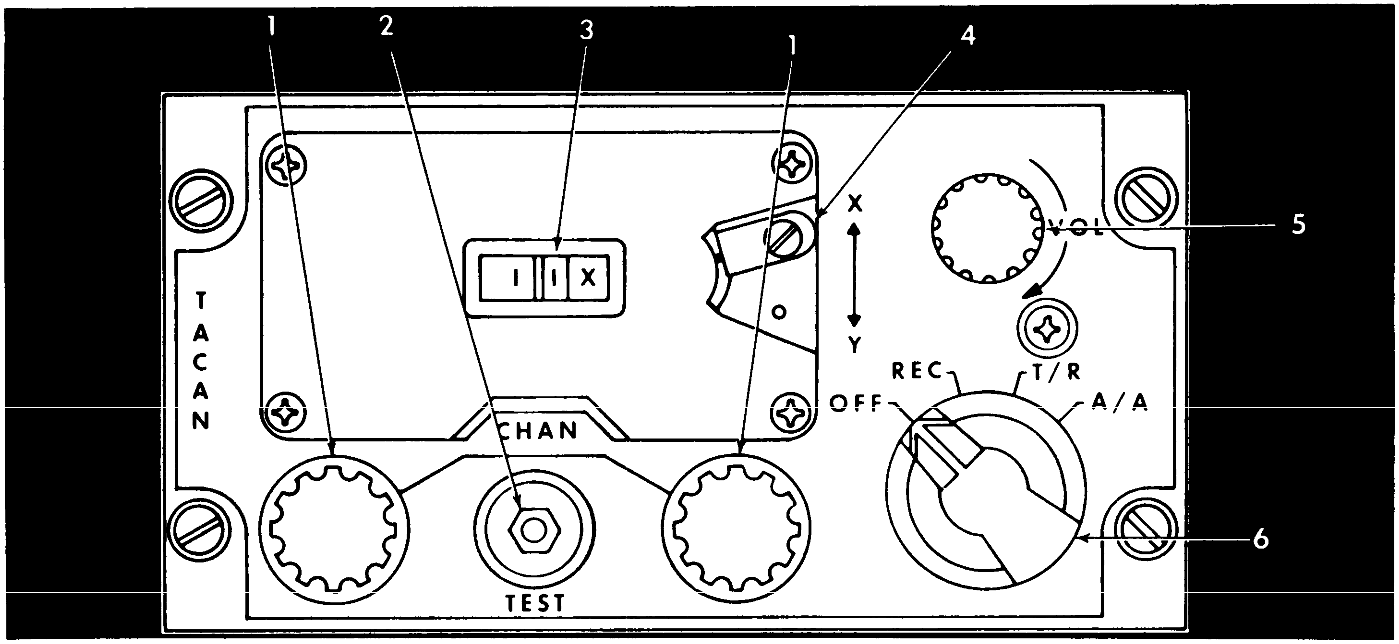


Figure 7-14. TACAN Control Panel.

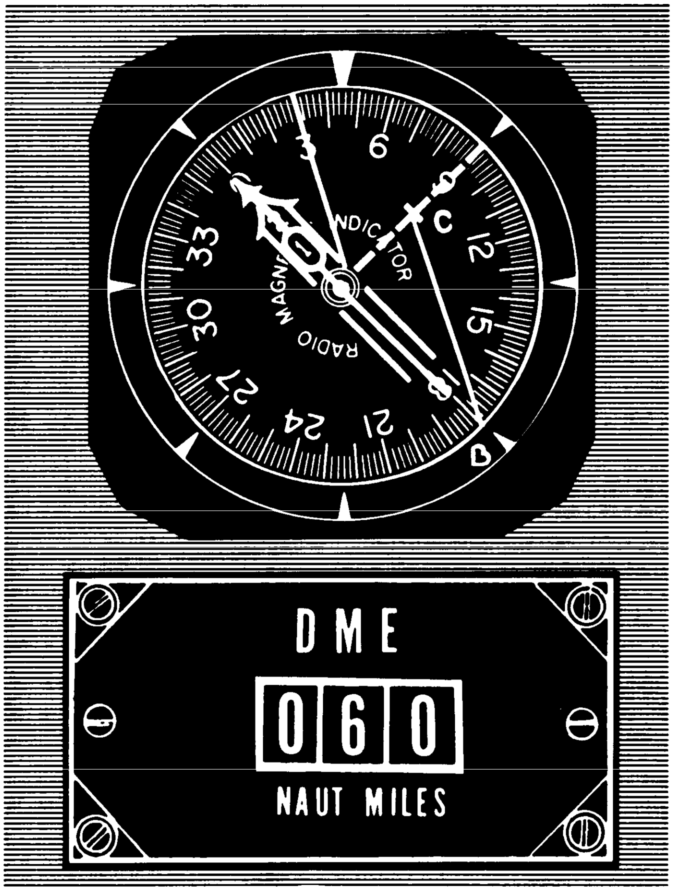


Figure 7-15. Fix-To-Fix Solution.

ing a radial and a separate readout of DME. The following technique and example are provided in order to demonstrate how to compute a heading. Refer to figure 7-15.

Example: Present Position = 180/60
Desired Position = 090/30
Present Heading = 000°

1. Tune, identify, and monitor correct VOR/TACAN.

2. Turn the aircraft in the general direction of the desired fix by turning to a heading approximately halfway between the head of the bearing pointer (000°) and the radial on which the desired fix is located (090°). In this case, turn to 045°.

3. Visualize your aircraft position and the desired fix on the RMI as follows:

    a. Consider the center of the RMI to be the VOR/TACAN, and that the compass rose simulates the radials around the station.

    b. The fix with the greater range (180/60) is established at the outer edge of the compass card.

    c. The fix with the lesser range (090/30) is established at a point which is proportional to the distance represented by the outer edge of the compass card.

4. Next, determine the heading to the desired fix by connecting your present position to your desired fix with an imaginary line on the RMI (B to C). Establish another imaginary line parallel to the line labeled B to C through the center of the RMI. This line will indicate your no-wind heading to your desired fix (030°).

5. Turn to 030° and apply any drift correction. With 5° right drift, we would turn to 025°.

6. Continually cross-check your position and correct as necessary.

COMMUNICATION

Air-to-ground communications can be achieved through the use of many types of radio equipment. High frequency bands (HF, VHF, UHF) are relatively static-free and are less susceptible to outside interference than lower frequencies. It must be remembered, however, that the higher the frequency, the more nearly the transmission will follow a line-of-sight path. As frequency increases, therefore, communication range decreases.

AN/APX-64 Transponder

The AN/APX-64 (figure 7-16) provides for Mark X IFF with selective identification feature (SIF) in normal operating modes. Two additional modes allow more specific identification by controlling agencies. Mode C works in conjunction with the aircraft altitude computer and gives automatic altitude reporting to ground radar. Mode 4 provides a secure IFF capability for military aircraft.

IFF Master Control Knob. This is a five-position detented rotary switch.

- OFF
- STBY—No transmission capability. Warmup period.
- LOW—Receiver sensitivity is reduced and only local interrogations are answered.
- NORM—Full range operation.
- EMER—Causes automatic transmission of emergency reply signals when interrogated by Mode 1, Mode 2, or Mode 3/A.

IFF Mode Switches. Four three-position toggle switches are used to select the desired operating modes. Mode 1 is the aircraft security identity mode. Mode 2 is for personal unit identity. Mode 3/A is for normal air traffic control identity. Mode C is the altitude reporting mode. The three positions are identical for all four toggle switches.

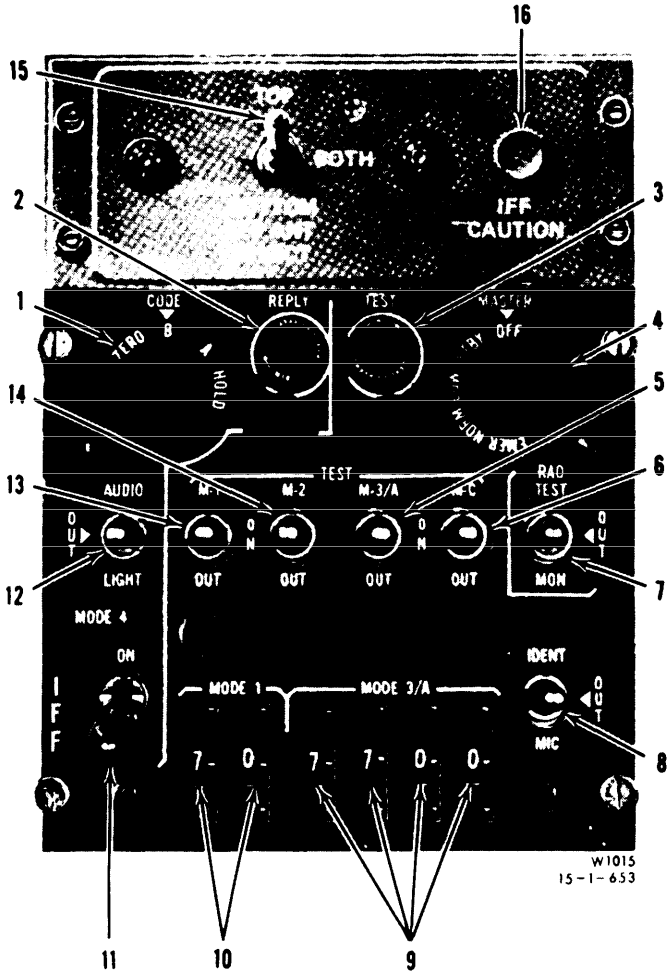
- OUT—Mode disabled.
- ON—Allows normal response to mode interrogations.
- TEST—Spring-loaded for in-flight test of selected mode. Test interrogations are generated, the transponder response is analyzed, and a positive indication illuminates the test light.

Code Selector Wheels.

- MODE 1—Sets any one of 32 possible codes.
- MODE 2—Sets any one of 4,096 possible codes. Not located on this control unit.
- MODE 3/A—Sets any one of 4,096 possible codes.

Identification of Position Switch. A three-position toggle switch that enables IDENT replies (illuminates return on controller's scope more brightly).

IDENT—Spring-loaded switch which initiates a 30-second reply.



1. MODE 4 CODE SWITCH
2. MODE 4 REPLY LIGHT
3. TEST LIGHT
4. MASTER SWITCH
5. MODE 3/A ENABLING SWITCH
6. MODE C ENABLING SWITCH
7. RAD TEST/MON SWITCH
8. IDENT/MIC SWITCH
9. MODE 3/A CODE SELECTORS
10. MODE 1 CODE SELECTORS
11. MODE 4 ON/OUT SWITCH
12. MODE 4 AUDIO/LIGHT SWITCH
13. MODE 1 ENABLING SWITCH
14. MODE 2 ENABLING SWITCH
15. IFF ANTENNA SWITCH
16. IFF MODE 4 CAUTION LIGHT

Figure 7-16. IFF/SIF Transponder.

OFF

MIC—Initates a reply for 30 seconds whenever the MIC button is depressed and the interphone transmitter selector knob is set to UHF.

Radar Test/Monitor Switch. Used by ground maintenance and in conjunction with the test lamp to monitor all responses in any SIF mode.

Test Lamp. Lights in conjunction with proper mode/test conditions and RAD TEST/MON SW interrogations.

Mode 4. Mode 4 is a classified transponder system which provides secure IFF capability to military aircraft. This capability is provided by an airborne cryptographic computer which generates coded replies in response to valid interrogations generated by an interrogator cryptographic computer. Codes are set by a keying device prior to flight by the aircrew or maintenance personnel.

Mode 4, Enable Switch. Controls operation of Mode 4. Has three positions which permits aural and reply lamp monitoring of valid Mode 4 interrogations and replies in AUDIO.

- OUT—No monitoring capability.
- LIGHT—Reply lamp monitoring only.
- REPLY LAMP—Used with Mode 4 only.

Long Range

Systems used for long-range radio communications between aircraft and ground stations may be either amplitude modulation (AM) or single sideband (SSB) transmissions. Single sideband transmitters concentrate all available power into one sideband; therefore, SSB is much more efficient and has greater range than an AM transmitter of the same power.

Although HF ground waves attenuate rapidly, sky waves at these frequencies are capable of transmitting at distances up to 12,000 miles or more, depending on ionospheric conditions. HF equipment is used mostly in remote areas where VHF or UHF communication is not possible because of the great distance which must be spanned.

Short Range Air-to-Air and Air-to-Ground

Short range air-to-air and air-to-ground communications are confined to VHF and UHF bands. VHF channels are spaced 25 kHz intervals from 116 to 151.975 MHz and UHF channels are spaced 50 kHz apart from 225.0 to 399.9 MHz. Most UHF transceivers have a manual frequency selection capability in addition to a number of preset channels. Transmission and reception are accomplished with a single antenna.

IFF/SIF

Identification friend or foe (IFF) is an airborne transponder which transmits coded signals when interrogated by ground-based search radar which was first used during World War II. Pulses received from the airborne equipment produce "blips" on the ground-based radarscope and are used to positively identify and locate aircraft.

The addition of a selective identification feature (SIF) allows faster isolation and identification of any aircraft under surveillance. Positive identification can be established and maintained by the ground controller when a designated SIF "mode" and "code" is set into the airborne transponder. Initial identification is usually established by using the "IP" or "ident" function of the airborne set. Tracking is maintained by setting the requested mode and code into the aircraft equipment.

Chapter 8

RADAR

BASIC PRINCIPLES

Radar, in the hands of the skilled operator, provides precise updates to DR for navigation and airborne delivery operators. At cruising altitudes, it provides information of land and water characteristics as well as hazardous weather conditions over hundreds of miles around the aircraft. At low level, it provides detailed terrain information used to navigate at high speed over changing courses. It is adapted to terrain-avoidance and terrain-following equipment. Radar is a source of track and drift angle information for wind computations and can be used with beacons for intercept and rendezvous operations.

The basis of the system has been known theoretically since the time of Hertz who, in 1888, successfully demonstrated the transfer of electromagnetic energy in space and showed that such energy is capable of reflection. The transmission of electromagnetic energy between two points was developled as "radio", but it was not until 1922 that practical use of the reflection properties of such energy was conceived. The idea of measuring the elapsed time between the transmission of a radio signal and receipt of its reflected echo from a surface originated nearly simultaneously in the United States and England. In the United States, two scientists working with air-to-ground signals noticed that ships moving in the nearby Potomac River distorted the pattern of these signals. In 1925, the same scientists were able to measure the time required for a short burst, or pulse, of radio energy to travel to the ionosphere and return. Following this success, it was realized that the radar principle could be applied to the detection of other objects, including ships and aircraft.

By the beginning of World War II, the Army and Navy had developed equipment appropriate to their respective fields. During and following the war, the rapid advance in theory and technological skill brought improvements and additional applications of the early equipment. By suitable instrumentation, it is now possible to measure accurately the distance and direction of a reflecting surface in space—whether it is an aircraft, a ship, a hurricane, or a prominent feature of the terrain—even under conditions of darkness or restricted visibility. For these reasons, radar has become a valuable navigational tool.

The following material is limited to the general procedures for using radar as an aid to navigation. For detailed information concerning a specific set, consult the appropriate manual or technical order.

As noted previously, the fundamental principle of radar may be likened to that of relating sound to its echo. Thus, a ship sometimes determines its distance from a cliff at the water's edge by blowing its whistle and timing the interval until the echo is received.

The same principle applies to radar, which uses the reflected echo of electromagnetic radiation traveling at the speed of light. This speed is approximately 162,000 nautical miles per second; it may also be expressed as 985 feet per microsecond. If the interval between the transmission of the signal and return of the echo is 200 microseconds, the distance to the target is:

$$\frac{985 \times 200}{2} = 98{,}500 \text{ ft} = 16.2 \text{ NM}$$

TYPICAL RADAR SET

RAdio **D**etection **A**nd **R**anging is accomplished by developing a pulse of microwave energy that is transmitted from the aircraft and is reflected by objects in its path. The reflected pulse is amplified and converted by the receiver for display on the cathode-ray tube (CRT). All the actions in the set are synchronized by the timing unit, or synchronizer. To this basic unit, improvements are added for special purposes such as weather avoidance, filtering, and terrain following.

COMPONENTS

The *transmitter* and *receiver* are usually one unit (the R/T) with separate functions that, for this description, are dealt with separately. (See figure 8-1.)

The *transmitter* produces the RF energy using magnetrons. A magnetron generates radar pulses by bunching electrons using alternately charged grids that the electrons travel past. The spurts of energy are of high power and short duration. The energy is released at intervals (the *pulse recurrence rate*) determined by the selected operating range.

The generated pulse travels through either coaxial cable or, more frequently, a hollow tube called the *waveguide*. The waveguide requires pressurization to insure the maintenance of conditions for proper microwave conduction. The energy passes an electronic switching device that directs outgoing pulses to the antenna and incoming pulses from the antenna to the receiver.

The *antenna* is a parabolic "dish" with a protruding waveguide. It is gimbal-mounted to allow rotation of the dish and, in most cases, to allow stabilization of the dish relative to the Earth's surface when the aircraft turns. Rotation of the antenna could be through 360° or in a sector (either variable or preset). The 360° rotation or scan is usually for mapping whereas a sector is used in aircraft with limited space for the antenna or where the intent is to concentrate energy in a small area.

The antenna assembly will be either permanently locked to the longitudinal axis of the aircraft (boresighted) or only so aligned when stabilization units are inactive. When not "caged" the antenna stabilization is accomplished using gyro-

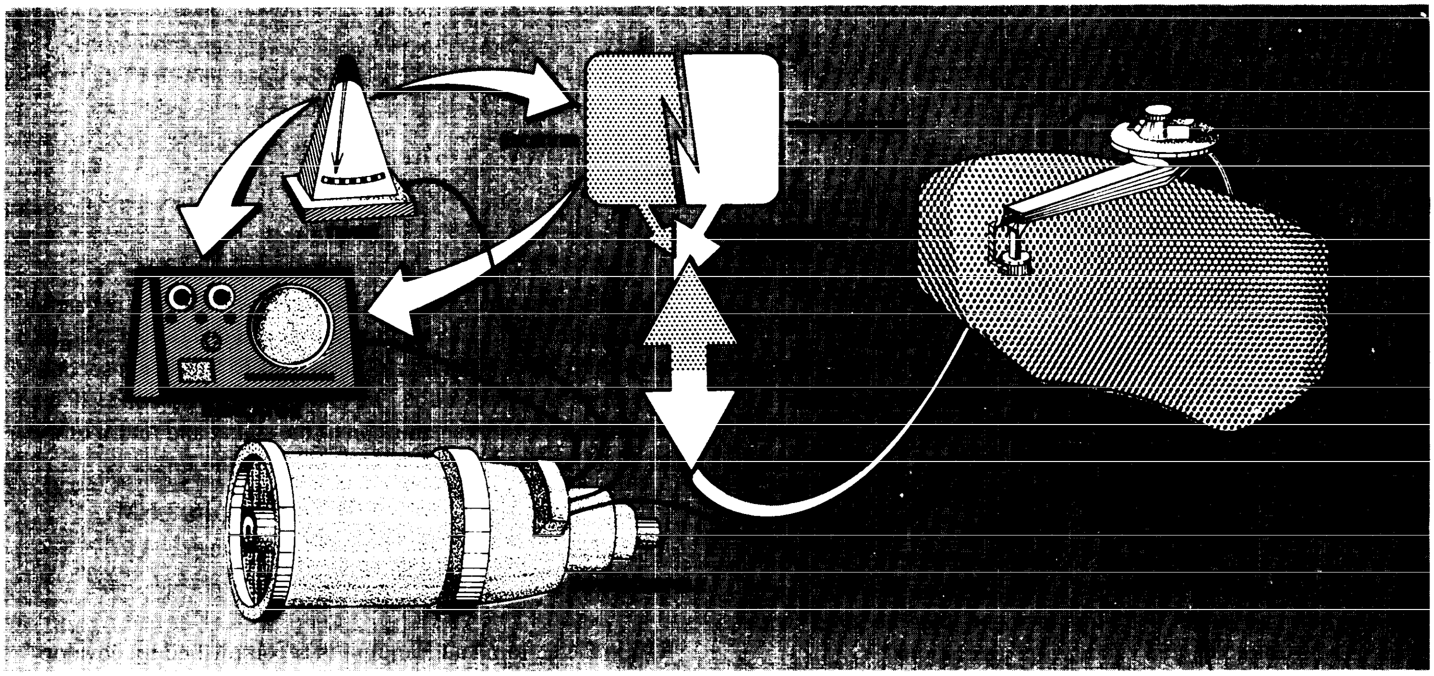


Figure 8-1. Major Components of Radar Sets.

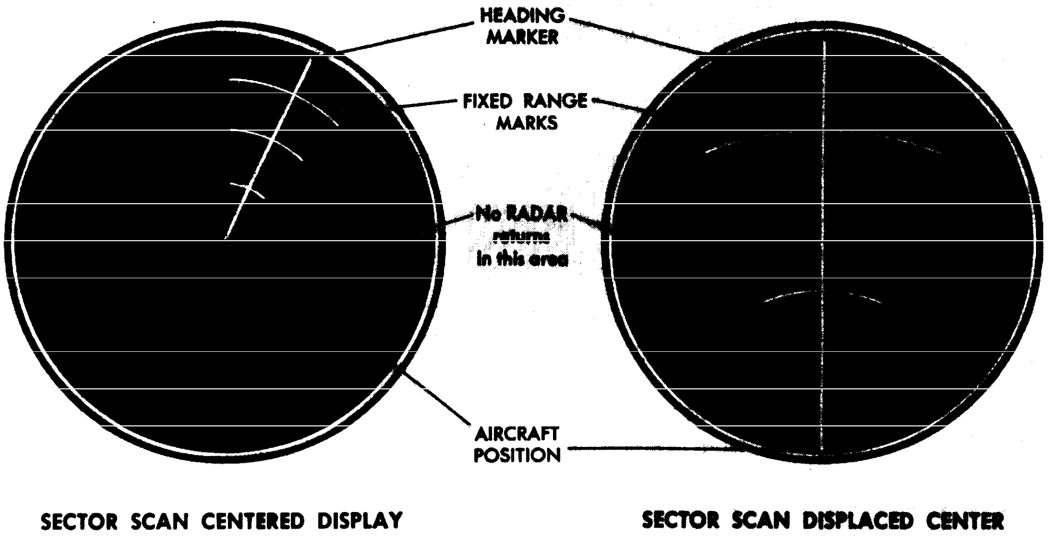
servo mechanisms. A sensor system that provides information to a computer keeps the antenna radiation plane parallel to the Earth even when the aircraft is in a climb or a bank.

There are two radiation patterns popular in airborne radar design—fan and pencil beams. The fan beam, best for general mapping, is a wide, "cosecant squared" pattern that distributes the RF energy across the beam, in proportion to the distance it must travel (figure 8-2). To concentrate the energy emitted, the pencil beam antenna is used. The pencil beam dish allows scanning for weather or aircraft in a small plane while eliminating ground clutter. It can be used to put more energy on a section of ground to increase returns.

The antenna can be manipulated to aim the emissions through a control that tilts the dish from the horizontal plane. At cruising altitudes, in the mapping mode, it is sufficient to slightly tilt the dish down but tilt should be constantly adjusted for optimum returns.

After transmission, the reflected energy is directed back to the wave-guide where it travels past the switching device which directs the returns to the *receiver*. The receiver converts the microwave returns to electrical signals that are amplified and sent to the planned position indicator—a CRT. The amplification of the returns is controllable through a gain circuit. Depending on the type of return desired on the PPI, the operator adjusts the receiver gain. Other booster circuits, such as sweep intensity or video gain, are available but operation of the receiver gain is

Figure 8-2. Radiation Pattern of Antenna.



SECTOR SCAN CENTERED DISPLAY

SECTOR SCAN DISPLACED CENTER

Figure 8-3. Sector Scan Displays.

most important. If adequate receiver amplification of weak returns is not applied, no amount of later stage adjustments will put the target on the scope.

The planned position indicator, or scope, offers both range and azimuth information about targets to the operator. This information is relative to the aircraft's position which can be referenced at either the center of the scope or offset to the side of the screen (figure 8-3). The PPI is a CRT with focusing coils and a deflection coil. The deflection coil is an electro-magnet whose variable field manipulates the electron beam so that returns can be presented on the scope in their correct position relative to the observer (figure 8-4).

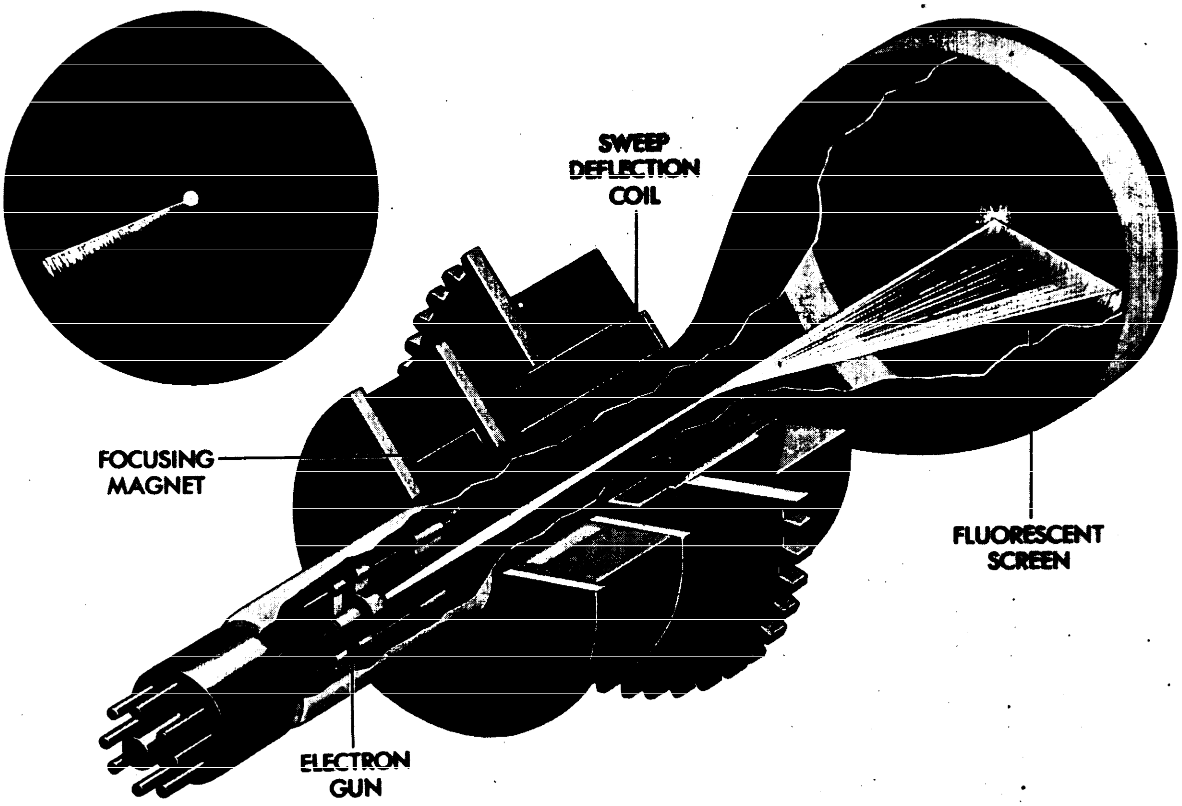


Figure 8-4. Electromagnetic Cathode Ray Tube (CRT).

The actual presentation of the return is produced by applying a polarization to the signals going to the CRT. The null return has a predominantly positive charge; therefore, the trace is suppressed. A polarization shift is produced in the current to produce a "blooming" of the trace corresponding to the strength and position of the received signal.

Range is determined by the travel time of a pulse from, and back to, the R/T unit. Knowing that RF energy travels at the constant speed of light, range determination is simple. Its display on the PPI is coordinated by the timer.

At the same instant that the timer triggers the transmitter, it also sends a trigger signal to the indicator. Here, a circuit is actuated which causes the current in the deflection coils to rise at a linear (uniform) rate. The rising current, in turn, causes the spot to be deflected radially outward from the center of the scope. The spot thus traces a faint line on the scope; this line is called the sweep. If no echo is received, the intensity of the sweep remains uniform throughout its entire length. However, if an echo is returned, it is so applied to the CRT that it intensifies the spot and momentarily brightens a segment of the sweep relative to the size of the target. Since the sweep is linear and begins with the emission of the transmitted pulse, the point at which the echo brightens the sweep will be an indication of the range to the object causing the echo.

The progressive positions of the pulse in space also indicate the corresponding positions of the electron beam as it sweeps across the face of the CRT. If the radius of the scope represents 40 miles and the "return" appears at three-quarters of the distance from the center of the scope to its periphery, the target is represented as being about 30 miles away.

Of interest here is the extremely short time scale which is used. In the preceding example, the radar is set for 40-mile range operation. The sweep circuits will thus operate only for an equivalent time interval, so that targets beyond 40 miles will not appear on the scope. The time equivalent to 40 miles of radar range is only 496 microseconds (496×10^{-6} seconds). Thus, 496 microseconds after a pulse is transmitted (plus an additional period of perhaps 100 microseconds to allow the sweep circuits to recover), the radar is ready to transmit the next pulse. The actual pulse repetition rate in this example is about 800 pulses per second. The return will therefore appear in virtually the same position along the sweep as each successive pulse is transmitted, even though the aircraft and the target are moving at appreciable speeds.

At times, the PPI will not display targets across the entire range selected on the scope. In these cases, the effective range of the set has been affected by atmospheric refraction and the line-of-sight characteristics of radar energy. The following formula can determine the radar's range in these situations:

$$D = \sqrt{2h} \times .87 = 1.23 \sqrt{h}$$

when D is distance and h is the aircraft altitude.

Azimuth measurement is achieved by synchronizing the deflection coil with the antenna. In the basic radar unit, when the antenna is pointed directly off the nose of the aircraft, the deflection coils are aligned to fire the trace at the 12 o'clock position on the scope. As the antenna rotates, the deflection coil moves at the same rate. Relative target presentations are displayed as the sweep rotation is combined with the range display.

SCOPE INTERPRETATION

The plan position indicator presents a map-like picture of the terrain below and around the aircraft. Just as map reading skill is largely dependent upon the ability to correlate what is seen on the ground with the symbols on the chart, so the art of scope presentation analysis is largely dependent upon the ability to correlate what is seen on the scope with the chart symbols. Application of the concept of radar reflection and an understanding of how received signals are displayed on the PPI are prerequisites to scope interpretation. Furthermore, a knowledge of these factors, applied in reverse, enables the navigator to *predict* the probable radarscope appearance of any area.

Factors Affecting Reflection

A target's ability to reflect energy is based on the target's composition, size, and the radar beam's angle of reflection. The range of the target from the aircraft is definitive in the quantity of returned energy. The range of a target produces an inverse effect on the target's radar cross-section. And there will be some atmospheric attenuation of the pulse proportional to the distance that the energy must travel. (See figure 8-5.)

Generally, all four factors contribute to the displayed return. A single factor can, in some cases, either prevent a target from reflecting sufficient energy for detection, or cause a disproportionate excess of reflected energy to be received and displayed. The following are general rules of radarscope interpretation:

1. The greatest return potential exists when the radar beam forms a horizontal right angle with the frontal portion of the reflector.
2. Radar return potential is roughly proportional to the target size and the reflective properties (density) of the target.
3. Radar return potential is greatest within the zone of the greatest radiation pattern of the antenna.
4. Radar return potential decreases as altitude increases because the vertical reflection angle becomes more and more removed from the optimum. (There are many exceptions to this general rule since there are many structures which may present better reflection from roof surfaces than from frontal surfaces or in the case of weather.)
5. Radar return potential decreases as range increases because of the greater beam width at long ranges and because of atmospheric attenuation.
6. All of the factors affecting reflection must be considered to determine the radar return potential.

Typical Radar Returns

The principal problem in radarscope interpretation is finding the meaning of contrast in brightness. This comes ahead of the purely navigational problem because a particular feature must be identified before it becomes useful.

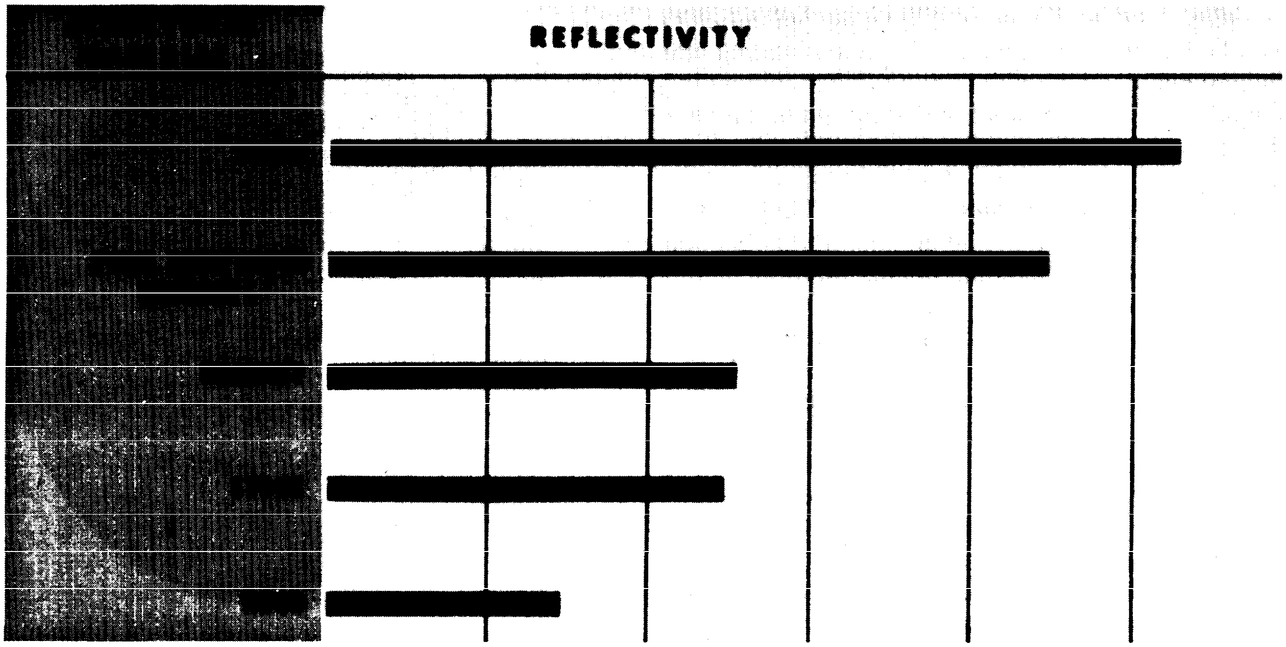


Figure 8-5. Relative Reflectivity of Structural Materials.

Returns From Land. All land surfaces present minute irregular parts of the total surface for reflection of the radar beam; thus, there is usually a certain amount of radar return from all land areas. The amount of return varies considerably according to the nature of the land surface scanned. This variance is caused by (1) the difference in reflecting materials of which the land area is composed, and (2) the texture of the land surface. These are the primary factors governing the total radar return from specific land areas.

Flat land. A certain amount of any surface, however flat in the overall view, is irregular enough to reflect the radar beam. Surfaces which are apparently flat are actually textured and may cause returns on the scope. Ordinary soil absorbs some of the radar energy and thus the return that emanates from this type of surface is not strong. Irregularly textured land areas present more surface to the radar beam than flat land and thus causes more return. The returns from irregularly textured land areas are most intense when the radar beam scans the ridges or similar features at a right angle. This effect is particularly helpful in detecting riverbeds, gulleys, or other sharp breaks in the surface height. At times, in desolate areas that are "flat," these occasional surface changes are apparent where it would not have appeared in more irregular topography. Such returns provide recognizable targets in otherwise sparse circumstances. In other cases, especially at low level over broken terrain this affect could complicate scope interpretation.

Hills and Mountains. Hills and mountains will normally give more radar returns than flat land because the radar beam is more nearly perpendicular to the sides of these features. the typical return is a bright return from the near side of the feature and an area of no return on the far side. The area of no return, called a mountain shadow, exists because the radar beam cannot penetrate the mountain, and its line-of-sight transmission does not allow it to intercept targets behind the mountain (figure 8-6). The shadow area will vary in size, depending upon the height of the aircraft with respect to the mountain. As an aircraft approaches a mountain, the shadow area becomes smaller and smaller. Furthermore, the shape of the shadow area and the brightness of the return from the peak will vary as the aircraft's position changes. As the aircraft closes on the mountainous area, shadows may disappear completely as the beam covers the

Figure 8-6. "No-Show" Returns.

entire surface area. At this point, a great deal of energy is reflected back at the antenna and recognizable features in that area will be rare.

Recognition of mountain shadow is important because any target in the area behind the mountain cannot be seen on the scope.

In areas with isolated high peaks or mountain ridges, contour navigation may be possible because the returns from such features assume an almost three-dimensional appearance. This allows specific peaks to be identified.

In more rugged mountainous areas, however, there may be so many mountains with resulting return and shadow areas that contour navigation is almost impossible. But these mountainous areas are composed of patches of mountains or hills, each having different relative sizes and shapes and relative positions from other patches. By observing these relationships on a chart, general aircraft positioning is feasible. Additionally, flying over the line of demarcation between a mountainous and a level area or a ridgeline might serve as a line of position even though the complexity of the scope picture makes positive position-finding impossible (figure 8-7).

Coastlines and Riverbanks. The contrast between water and land is very sharp, so that the configuration of coasts and lakes are seen with map-like clarity in most cases (figure 8-8). When the radar beam scans the banks of a river, lake, or larger body of water, there is little or no return from the water surface itself, but there is usually a return from the adjoining land. The more rugged the bank or coastline, the more returns will be experienced. In cases where there are wide, smooth mud flats or sandy beaches, the exact definition of the coastline will require careful tuning.

Since both mountains and lakes present a "dark" area on the scope, it is sometimes fairly easy to mistake a mountain shadow for a lake. This is particularly true when navigating in mountainous areas which also contain lakes. One difference between returns from mountain areas and lakes is that returns from mountains are bright on the near side and dark on the far side while returns from lakes are of more uniform brightness all around the edges. Another characteristic of mountain returns is that the no-show area changes its shape and position quite rapidly as the aircraft moves; returns from lakes change inconsequentially.

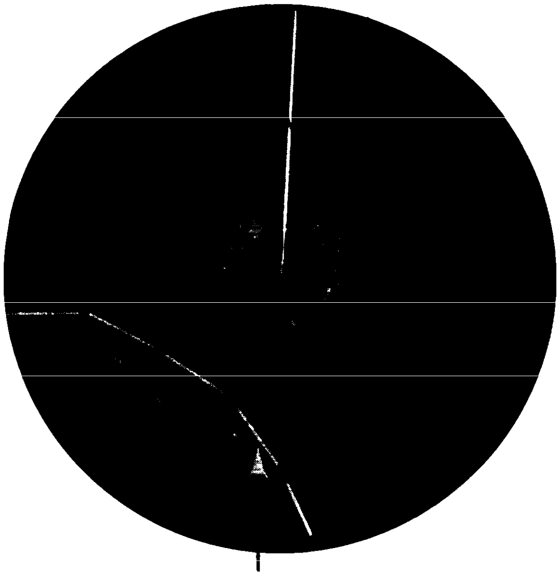


Figure 8-7. Line of Demarcation.

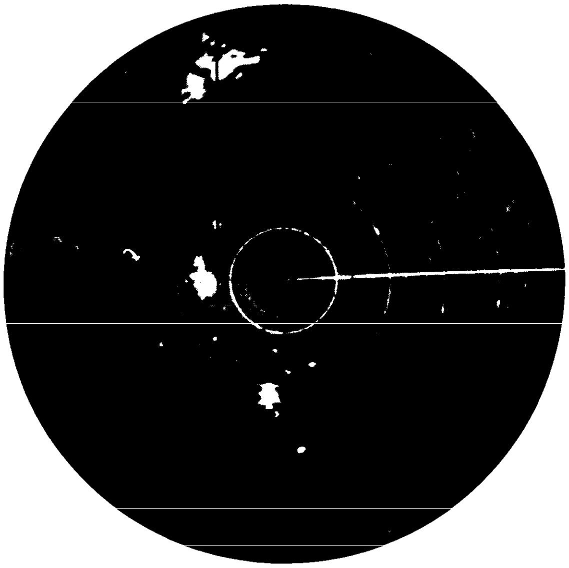


Figure 8-8. Radar Returns.

Cultural Returns. The overall size and shape of the radar return from any given city can usually be determined with a fair degree of accuracy by referring to a current map of the area (figure 8-8). However, the brightness of one cultural area as compared to another may vary greatly, and this variance can hardly be forecasted by reference to the navigation chart. In general, due to the collection of dense materials therein, urban and suburban areas generate strong returns, although the industrial and commercial centers of the cities produce a much greater brightness than the outlying residential areas. Many isolated or small groups of structures create radar returns. The size and brightness of the radar returns these features produce are dependent on their construction. If these structures are not plotted on the navigation charts, they are of no navigational value. However, some of them give very strong returns—such as large concrete dams, steel bridges, etc—and, if any are plotted on the chart and can be properly identified, they can provide valuable navigational assistance.

Weather Returns. Cloud returns which appear on the scope are of interest for two reasons. First, since the brightness of a given cloud return is an indication of the intensity of the weather within the cloud, intense weather areas can be avoided by directing the pilot through the areas of least intensity or by circumnavigating the entire cloud return. Second, cloud returns obscure useful natural and cultural features on the ground. They may also be falsely identified as a ground feature, which can lead to gross errors in radar fixing.

Clouds must be reasonably large to create a return on the scope. However, size alone is not the sole determining factor. The one really important characteristic that causes clouds to create radar returns is the size of the water droplets forming them. Radar waves are reflected from large rain droplets and hail which fall through the atmosphere or are suspended in the clouds by strong vertical air currents. Thunderstorms are characterized by strong vertical air currents; therefore, they give very strong radar returns.

Cloud returns may be identified by the following characteristics:

Brightness varies considerably, but the average brightness is greater than a normal ground return.

Returns generally present a hazy, fuzzy appearance around their edges.

Returns often produce shadow areas similar to mountain shadows because the radar beam does not penetrate clouds completely.

Returns do not fade away as the antenna tilt is raised, but ground returns do tend to decrease in intensity with an increase in antenna tilt.

Returns can appear in the altitude hole when altitude delay is not used and the distance to the cloud is less than the altitude.

★ *Effects of Snow and Ice.* The effects of snow and ice are similar to the effect of water. If a land area is covered to any great depth with snow, (1) some of the radar beam will reflect from the snow and, (2) some of the energy will be absorbed by the snow. The overall effect is to reduce the return which would normally come from the snow-blanketed area.

Ice will react in a slightly different manner, depending upon its roughness. If an ice coating on a body of water remains smooth, the return will appear approximately the same as a water return. However, if the ice is formed in irregular patterns, the returns created will be comparable to terrain features of commensurate size. For example, ice ridges or ice mountains would create returns comparable to ground embankments or mountains, respectively. Also, offshore ice floes tend to disguise the true shape of a coastline so that the coastline may appear vastly different in winter as compared to summer. This phenomenon is termed "arctic reversal" because the resultant PPI display will often be the opposite of the anticipated display (see figure 8-8.1).

Inherent Scope Errors

Another factor which must be considered in radarscope interpretation is the inherent distortion of the radar display. This distortion is present to a greater or lesser degree in every radar set, depending upon its design. Inherent scope errors may be attributed to three causes—width of beam, the length (time duration) of the transmitted pulse, and the diameter of the electron spot.

Beam Width Error. Beam width error is not overly significant in radar navigation (although it must be taken into account in radar bombing). Since the distortion is essentially symmetrical, it may be nullified by bisecting the return with the bearing cursor when a bearing is measured. Beam width distortion is also lessened by reducing the receiver gain control.

Pulse Length Error. Pulse length error is caused by the fact that the radar transmission is not instantaneous but lasts for a brief period of time. There is a distortion in the range depiction on the far side of the reflector, and this pulse length error is equal to the range equivalent of one-half of the pulse time.

Since pulse length error occurs on the far side of the return, it may be nullified by reading the range to (and plotting from) the near side of a reflecting target when taking radar ranges.

Spot Size Error. Spot size error is caused by the fact that the electron beam which displays the returns on the scope has a definite physical diameter. No return which appears on the scope can be smaller than the diameter of the beam. Furthermore, a part of the glow produced when the electron beam strikes the phosphorescent coating of the CRT radiates laterally across the scope. As a result of these two factors, all returns displayed on the scope will appear to be slightly larger in size than they actually are.

Spot size distortion may be reduced by using the lowest practicable receiver gain, video gain, and bias settings, and by keeping the operating range at a minimum so that the area represented by each spot is kept at a minimum. Further, the operator should check the focus control for optimum setting.

Total Distortion. For navigational purposes, these errors are often negligible. However, the radar navigator should realize that they do exist and that optimum radar accuracy demands that they be taken into account.

They are usually most significant when the target is a thin, "no-show" (river), when it is very reflective but small, or when it is in close proximity to another "show" target. Thin "no-shows" are erased except for their wider points. With tiny but very reflective targets, the cross-section of the return would normally be negligible on the PPI. Their extremely strong reflectability though, coupled with the inherent errors, causes them to appear larger and of seemingly more significance on the indicator. When "show" targets are close to each other, these errors will cause them to blend together, thus diminishing the scope resolution.

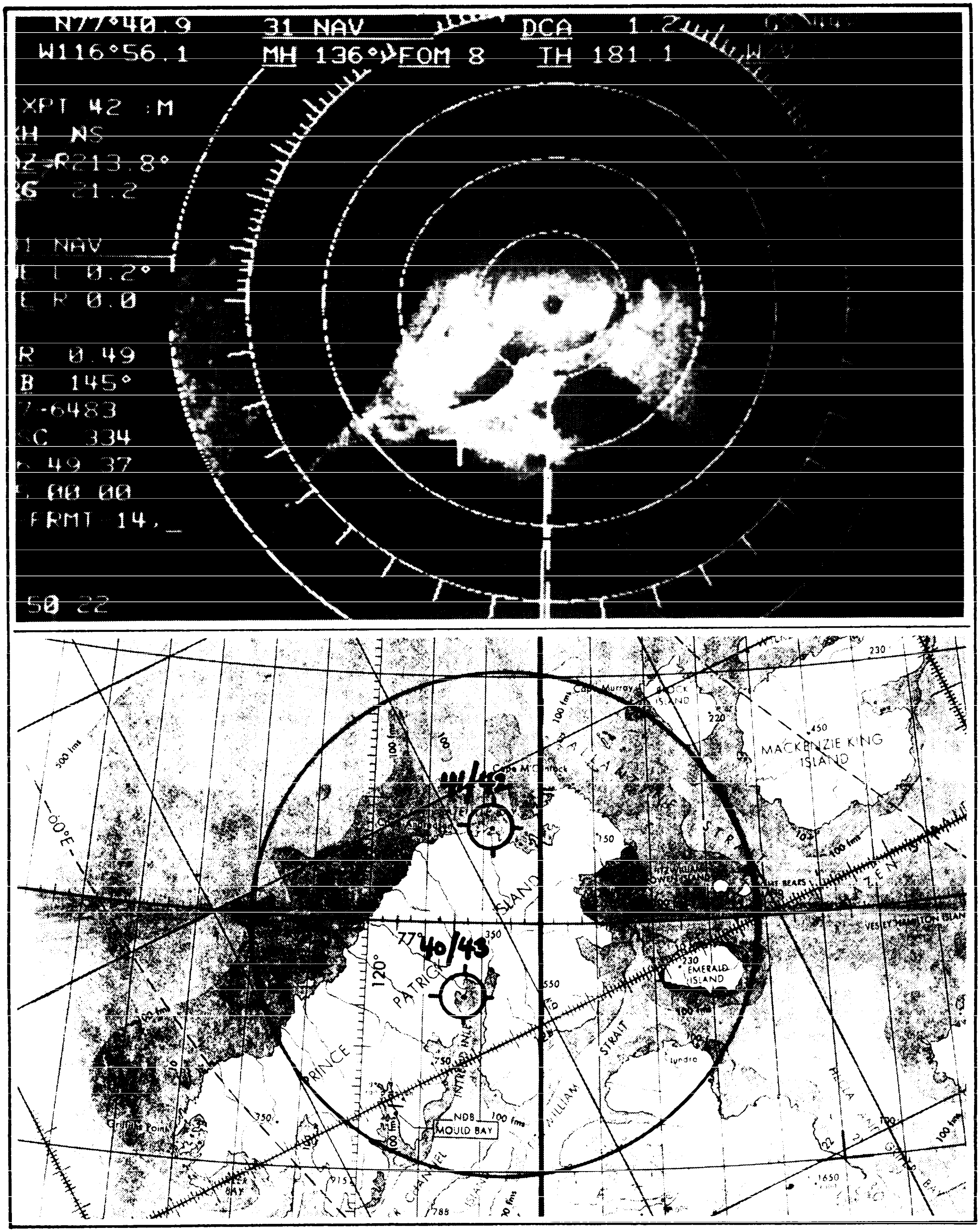
Generally, the combined effects of the inherent errors cause reflecting targets to appear larger and nonreflecting targets to dwindle (figure 8-9).

IMPROVEMENTS TO RADAR

The airborne radar sets used throughout the Air Force vary slightly in the navigational refinements offered. The following is a description of refinements designed to overcome some of the common problems encountered in radar navigation.

Variable Range Marker and Crosshairs

Most radar sets also provide a range marker which may be moved within certain limits by the radar operator. This variable range marker permits more accurate measurement of range because the marker can be positioned more accurately on the scope. Furthermore, visual interpolation is not necessary when using the variable range marker because it can be placed at the particular return being considered.



★ Figure 8-8.1. Arctic Reversal.

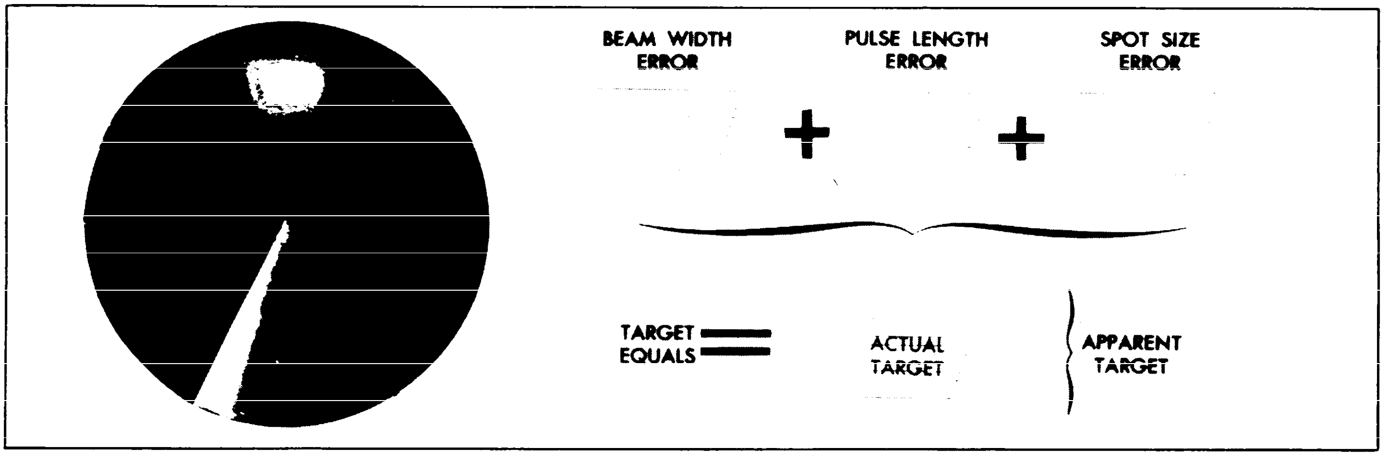


Figure 8-9. Combined Effects of Inherent Errors.

On many radar sets, an electronic azimuth marker has been added to the variable range marker because it can be placed at the particular return being considered.

On many radar sets, an electronic azimuth marker has been added to the variable range marker to facilitate fixing. The intersection of the azimuth marker and the variable range marker is defined as radar crosshairs.

Altitude Delay

It is obvious that the ground directly beneath the aircraft is the closest reflecting object. Therefore, the first return which can appear on the scope will be from this ground point. Since it takes some finite period of time for the radar pulses to travel to the ground and back, it follows that the sweep must travel some finite distance radially from the center of the scope before it displays the first return. Consequently, a hole will appear in the center of the scope within which no ground returns can appear. Since the size of this hole is proportional to altitude, its radius can be used to measure altitude. Thus, if the radius of the altitude hole is 12,000 feet, the absolute altitude of the aircraft is 12,000 feet.

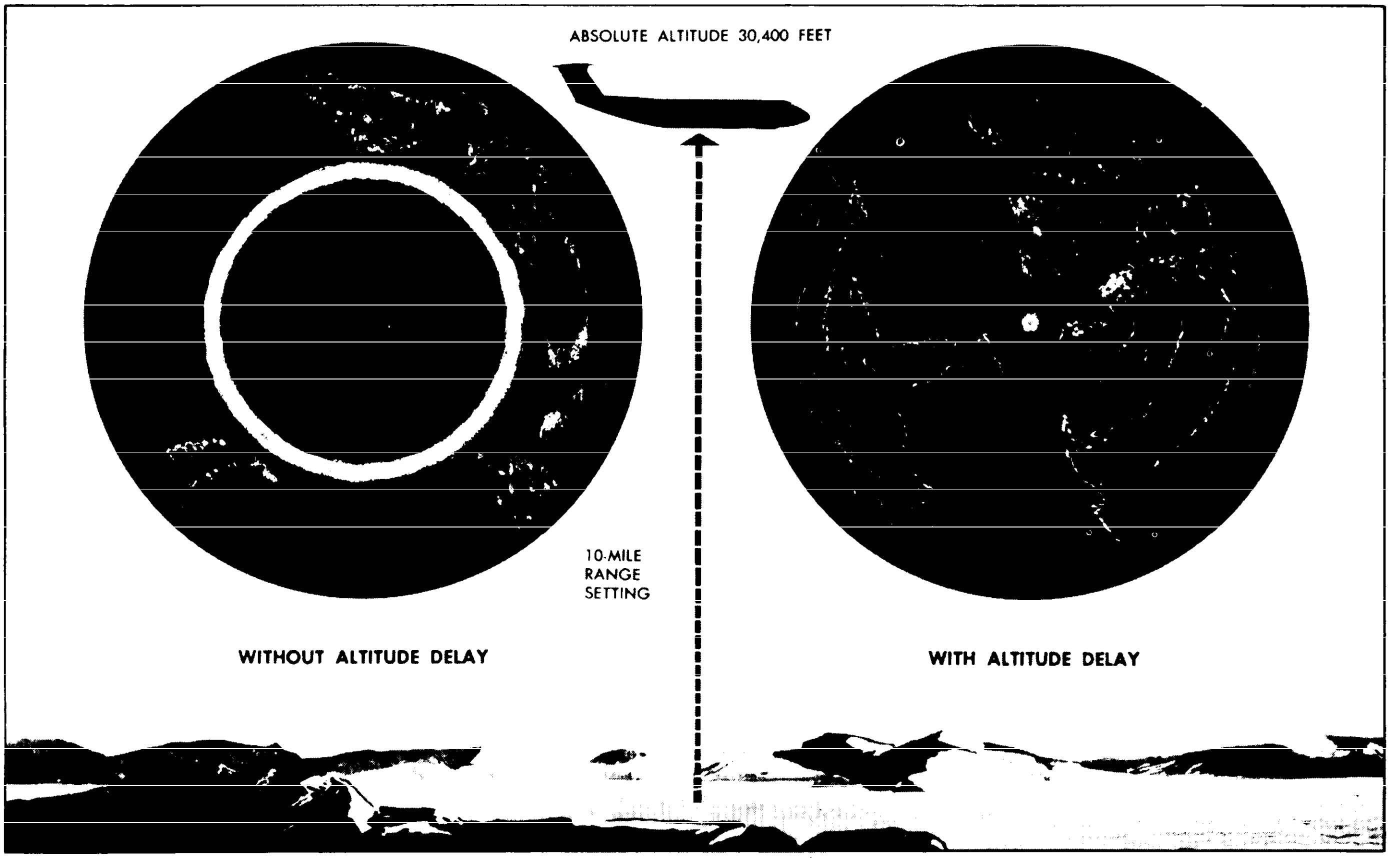


Figure 8-10. Altitude Delay Eliminates the Hole.

Although the altitude hole may be conviently used to measure altitude, it occupies a large portion of the scope face, especially when the aircraft is flying at a high altitude and using a short range. This may be seen in figure 8-10. In this particular case, the range selector switch is set for a 10-mile range presentation. Without altitude delay, the return shown on the first 5 miles of the scope consists of the altitude hole, and the return shown on the remaining 5 miles is a badly distorted presentation of all of the terrain within 10 miles of the point below the aircraft. To obviate such a condition, many radar sets incorporate an altitude delay circuit which permits the removal of the altitude hole. This is accomplished by delaying the start of the sweep until the radar pulse has had time to travel to the ground point directly below the aircraft and back. Hence, the name altitude delay circuit. The altitude delay circuit also minimizes distortion and makes it possible for the radarscope to present a ground picture which preserves the actual relationships between the various ground objects.

Sweep Delay

Sweep delay is a feature which delays the start of the sweep until after the radar pulse has had time to travel some distance into space. In this respect, it is very similar to altitude delay. The use of sweep delay enables the radar operator to obtain an enlarged view of areas at extended ranges.

For example, two targets which are 45 miles from the aircraft can only be displayed on the scope if a range scale greater than 45 miles is being used. On the 50-mile range scale, the two targets might appear very small and close together. By introducing 40 miles of sweep delay, the display of the two targets will be enlarged as long as the range displayed on the scope is less than that displayed before sweep delay was introduced. For instance, if the scope is on a 50-mile range scale, as in the preceding example, introducing 40 miles of sweep delay would have no enlarging effect unless the range being displayed is reduced to some value below 50 miles (figure 8-11). The more this range is reduced, the greater will be the enlarging effect. On some sets, the range displayed during sweep delay operation is fixed by the design of the set and cannot be adjusted by the operator.

Iso-Contour

Detection of hazardous weather's presence with most radar units is not difficult in the normal *mapping* mode. The *weather* mode of equipped aircraft offers an increased sensitivity to weather phenomenon. But to discriminate between areas of varying hazards presents a dilemma. Reflected energy from weather is dependent on the density of the rain and hail it contains. The limitations of PPI capabilities to display these dynamic characteristics make detection of the more intense

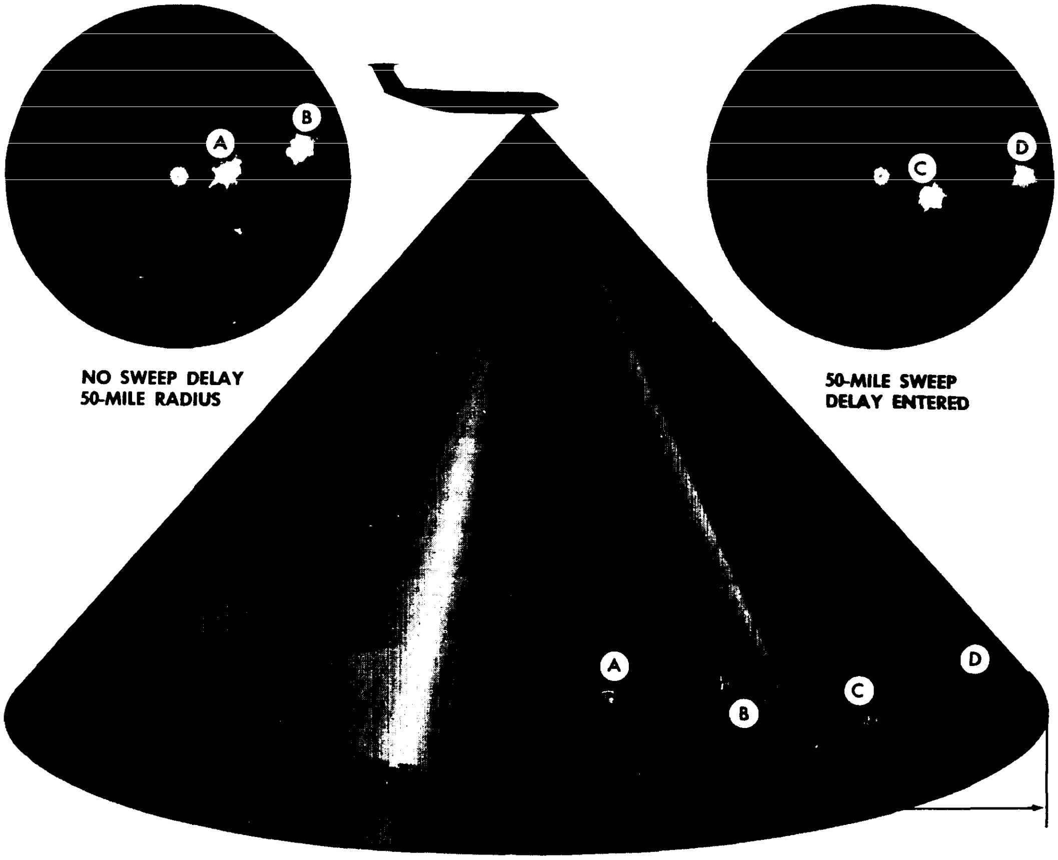


Figure 8-11. Sweep Delay Provides Telescopic View.

areas difficult. Furthermore, the human eye is ineffective in detecting the slight variations in shading.

The *iso-echo* or *iso-contour* control compensates for this deficiency by presenting a void area on the PPI corresponding to a hazardous area in the weather environment. This void area, the "black hole," is dependent on a control that the operator sets to define the intensity of the area that is to be avoided. For instance, say only the largest cells of weather are desired to be displayed. The operator would set the appropriate control and, on the PPI, the weather depiction would be present. The areas within the weather where the most hazardous cells were located would be no-show areas or "black holes." The iso-contour circuits are capable of sensing the variation in the received signals and act like a radio "squelch" control to block presentation of selected intensitities. A word of caution! Iso-contour is not selective in the targets it will block. If ground returns are received by the radar and a portion of their intensity falls into the range selected to be blocked, they too will be blocked from the scope (figure 8-20).

Radar Beacon

Radar beacons (racon) have been used for many years in air-to-ground operations. In the past, airfields had beacons visible on radar much like a nondirectional beacon but most are now decommissioned. Aircraft IFF-SIF transponders are the outgrowth of this earlier equipment. Radar beacons are still used in air-to-air operations by SAC and TAC for types of rendezvous.

Racons consist of interrogator and responder units operating from different locations. In most cases, an interrogator pulse is transmitted which triggers the responder. The responder generates a coded pulse which is then transmitted. The coded return is received by the interrogator and the usual time lapse and azimuth or sweep relationships are used to display the coded returns on the PPI. The time needed for generation of the return pulse causes a range error amounting to 1/2 mile, generally.

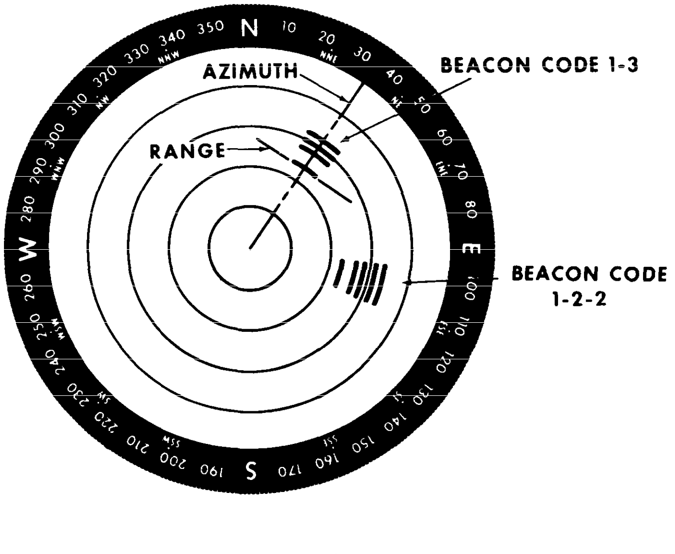


Figure 8-12. Radar Beacon Returns.

Radar beacons are sometimes coded with a mixture of aircraft identification and flight parameters for ARTCC. Aircraft equipped with beacons like the APN-69 can both interrogate or respond to like-equipped aircraft. Beacons like the APN-69 use a pulsed code of up to six pulses. The pulse codes are set by the responder aircraft and will appear on the interrogator's PPI. The first pulse will be in the relative position of the responder with successive pulses trailing. The range between aircraft is equal to the range of the first pulse (minus 1/2 NM) and the azimuth is measured through the middle of the pulse's length.

Two blocking circuits are included in the units to prevent interference from radar on other frequencies or a return of the interrogating pulse. This sometimes prevents a "ring around" where false azimuth inputs are presented on the PPI. In such cases, excessive gain causes returns to be picked up by side lobes of the antenna. Figure 8-12 is an example of a racon return on the scope.

Sensitivity Time Constant (STC)

Most radar sets produce a "hot spot" in the center of the radar-scope because the high gain setting required to amplify the weak echos of distant targets overamplifies the strong echos of nearby targets. If the receiver gain setting is reduced sufficiently to eliminate the "hot spot," distant returns are weakened or eliminated entirely. The difficulty is most pronounced when radar is used during low-level navigation; to make best use of the radar, the navigator is forced to adjust the receiver gain setting constantly.

STC solves the problem by increasing the gain as the electron beam is deflected from the center to the edge of the radarscope, automatically providing an optimum gain setting for each range displayed. In this manner, the "hot spot" is removed while distant targets are amplified sufficiently.

STC controls vary from one model radar set to another. Refer to the appropriate technical order for operating instructions.

Terrain Avoidance Radar

With the increased emphasis on low-level flights, better equipment was needed for flying safety. Terrain avoidance radar (TAR) gives the aircrew all-weather, low-level capability. As mentioned earlier, interpreting mountain shadows on a normal radarscope can be confusing. There is no time for indecision at low levels and at high speeds. TAR increases safety and eliminates confusion by displaying only those vertical obstructions which project above a selected clearance plane.

The two basic types of presentation used with terrain avoidance radar are illustrated in figure 8-13.

Plan Display. The plan display is a sector scan presentation that indicates the range and direction of obstructions projecting above a selected clearance plane. The clearance plane can be manually set at any level from 3,000 feet below the aircraft up to the level of the aircraft. In figure 8-15, assume that the clearance plane, represented by the shaded area, is set 1,000 feet below the aircraft. Only those peaks projecting above the clearance plane are displayed; all other returns are inconsequential and are

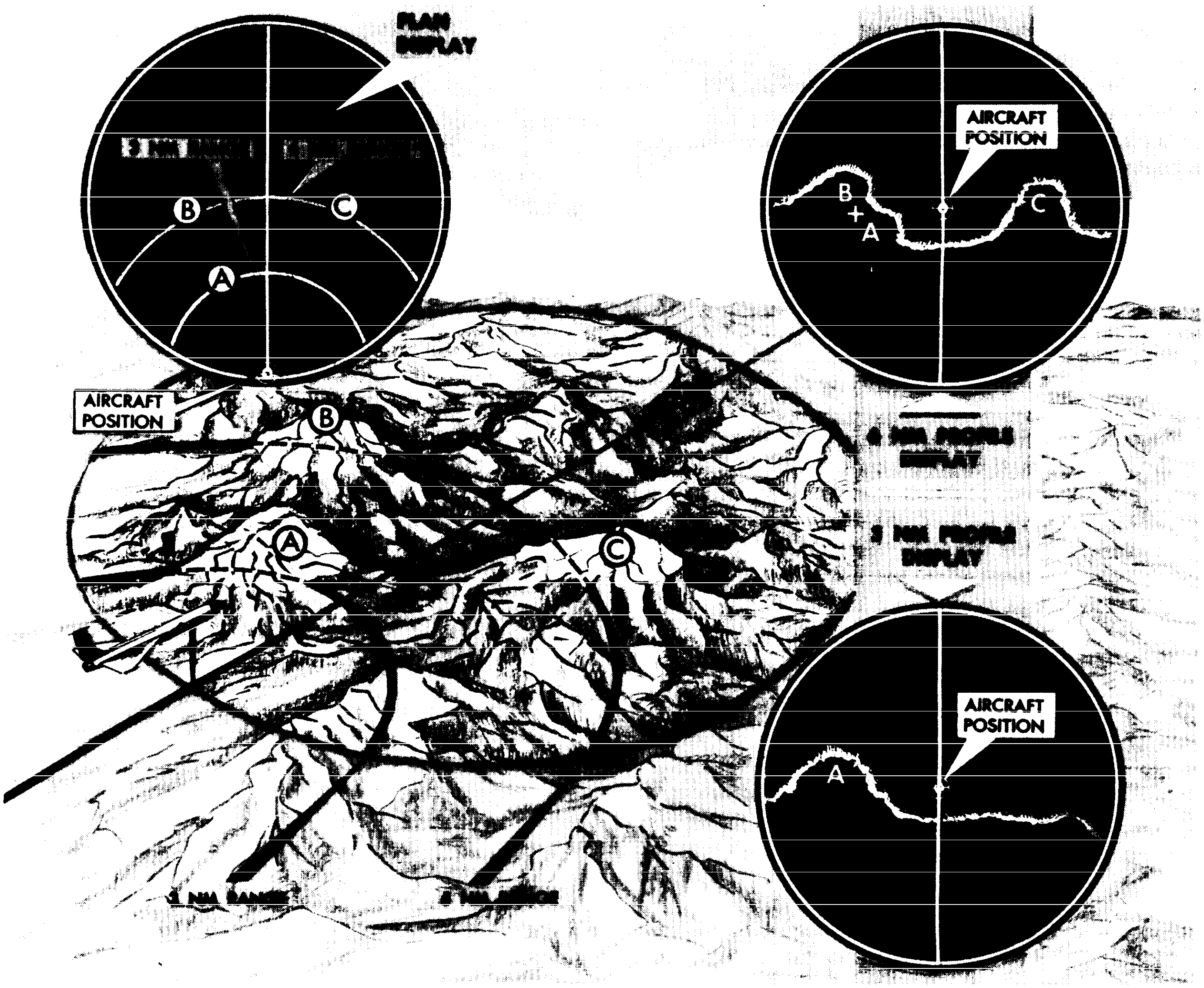


Figure 8-13. Terrain Avoidance Radar Presentations.

eliminated. The sector scan presentation limits the returns to those ahead of the aircraft. The ground track of the aircraft is represented by the vertical line and ranges are determined by range marks.

Profile Display. The profile display, normally received only by the pilot, provides an outline of the terrain 1,500 feet above and below the clearance plane. Elevations of returns are represented vertically; azimuth is represented horizontally. This display gives the operator a look "up the valley." The returns seen represent the highest terrain within the selected range. The position of the aircraft is represented by an engraved aircraft symbol on the indicator overlay. Figure 8-13 shows both a 3-mile and a 6-mile presentation.

Techniques on Radar Usage

Radar sets in current usage offer variations of special equipment and capabilities. The following are techniques to use with radar in common situations and with special equipment designed to enhance radar usage. These are basic suggestions that can and should be adapted to specific aircraft and mission requirements.

Radar Fixing

Techniques in radar fixing change from operator to operator and most provide accurate results. The following are reminders that will affect the fix accuracy if not considered.

Radar is an aid to DR. Before any radar return can be accurately identified, the operator should be familiar with a chart of the target area. This chart study relies on knowing the approximate location of the aircraft, and therefore, it is essential to radar fixing that the best possible dead reckoning position be ascertained.

In examining the area surrounding the DR on the chart, attention should be given to details like roadways and water-ways as well as the more prominent urban returns. Cultural returns build up along such byways therefore discrepancies between the chart (which could be years old) and the PPI display can be more successfully analyzed.

Prior to fixing, take care to adjust gain, antenna tilt, and check for heading marker error. If a mechanical cursor is used, insure its center is aligned with the origin of the sweep or a parallax error could ensue.

Do not accept a return on the scope as the chosen target unless it has been verified using surrounding returns. Blind acceptance of even "obvious" returns has led to errors. Work from chart to scope. If a desired target does not show but there is a return on the PPI that (it is believed) is recognized, go back to the chart and find something with which to verify the return before fixing from it.

When obtaining fix readings, remember to compensate for inherent scope errors. If the fix is a multirange or multi-bearing type, the targets should be chosen to provide the optimum cut. When multiple targets are used, the returns that are changing their values the fastest should be "fixed" closest to fix time (with multirange, a target off the nose changes range faster than the one off the wing).

Slant Range

Once a return has been identified, it may be used to fix the position of the aircraft by measuring its bearing and distance from the known geographical point. Of particular significance in any discussion of radar ranging is the subject of slant range versus ground range (figure 8-14). Slant range is the straight-line distance between the aircraft and the target, while ground range is the range between the point on the Earth's surface directly below the aircraft and the target.

To fix the position of the aircraft, the navigator is interested in the ground range from the fixing point. Yet the fixed range markers give slant range. The problem, then, is to determine the critical range below which the navigator must convert slant range to ground range in order not to introduce significant errors in the fixes. This critical range may be determined by a simple formula:

$$\frac{\text{Absolute Altitude} - 5{,}000}{1{,}000} = \text{Critical slant range (in NM)}$$

Example: $$\frac{30{,}000 \text{ (Absolute Altitude in feet)} - 5{,}000}{1{,}000} = 25 \text{ NM}$$

In this example, if the slant range is less than 25 miles, it should be converted to ground range before the fix is plotted. At ranges in excess of 25 miles, slant range would so closely approximate ground range that conversion would be unnecessary.

Slant range can be converted to ground range using the latitude and longitude lines of a chart if the slant range table is not available. Set dividers at the slant range distance to the target. Place point #1 of the dividers at the equivalent (in nautical miles) of the aircraft's altitude on the longitude line. Set point #2 where it meets a nearby latitude line. Without moving point #2, reset point #1 along the latitude line at the intersection of the latitude and longitude lines. The distance, in nautical miles, between points 1 and 2 is the ground range (figure 8-15). Slant range correction charts are provided in figures 8-16 and 8-17.

Side Lobe Cancellation

Side lobes are phenomena created due to antenna design and strong gain requirements. In the quest to pulse large amounts of RF energy but focus it in small cross-sections, antenna design has a recognized, but accepted flaw. Small subsidiary fields of microwave energy called *side lobes* are generated. These rarely are strong enough or big enough to generate a return and, therefore, are ignored. In the case where a very reflective target is close enough to come into this field or when the transmitter power increases the size of the lobes, they will generate multiple "shadow" returns on the PPI. Like the "ring around" in racon systems, the shadow returns are offset from the true return (generated by the main pulse) by the same relationship that the side lobes have to the main pulse.

The problem being an excessive amount of gain, the best solution is reduction of the gain where and when the phe-

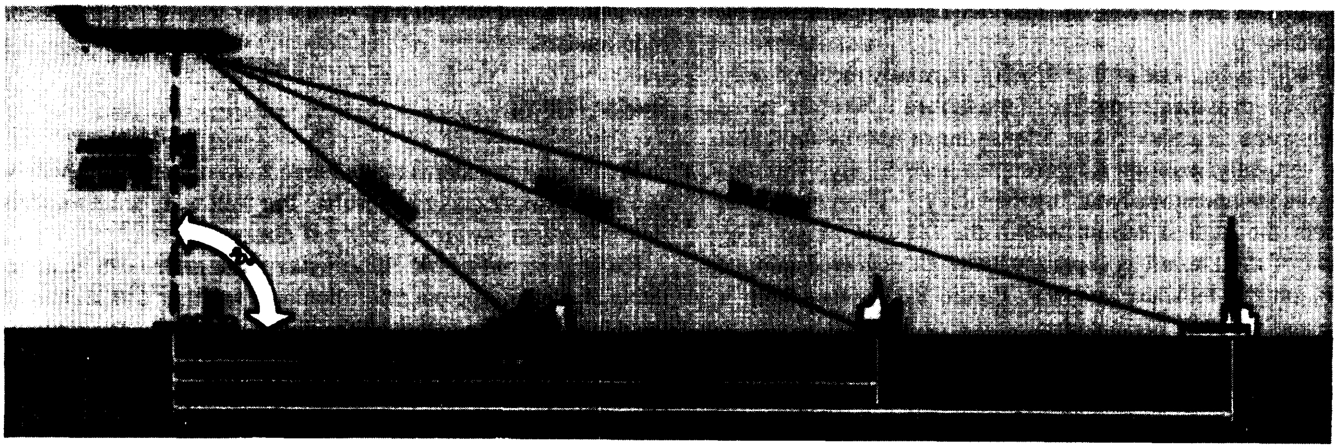


Figure 8-14. Slant Range Compared to Ground Range.

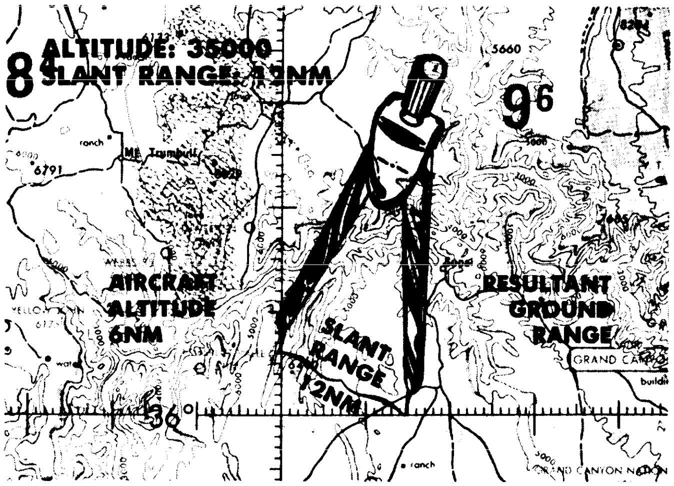


Figure 8-15. Slant Range Solution from Chart.

nomenon is observed.

Radar Computers

Because of the increasing complexities of navigation and bombing problems in modern high-speed aircraft, various computer systems have been devised to assist navigators in the completion of their missions.

Radar computer systems provide such capabilities as precision position determination, wind runs, and bomb runs. These computers range from the relatively simple to the enormously complex.

Regardless of the type, all computers require certain information that must be fed into the system either manually or electronically. In turn, the computer will furnish the navigator with the position of the aircraft at any time. If a wind has been computed, this position will be an accurate DR position; if no wind is set into the system, the position will be an air position.

The computer system accomplishes this in the following manner. First, the navigator sets in a departure point by taking a fix on a known object. Next, one of two actions will occur. Either the latitude and longitude of the fix is manually fed to the computer, or the computer, through a tie-in to the PPI, determines the fix coordinates (based on its range and bearing from the coordinates of a preentered target). From this point on, the system computes the departure from that point. Normally, the navigator will compute a wind at the same time that the fix is being taken. This wind is set into the system and the computer will continue to use this wind until another is set in. Since the navigator manually sets in the departure point and the wind, some system must be incorporated to provide TH and TAS. This

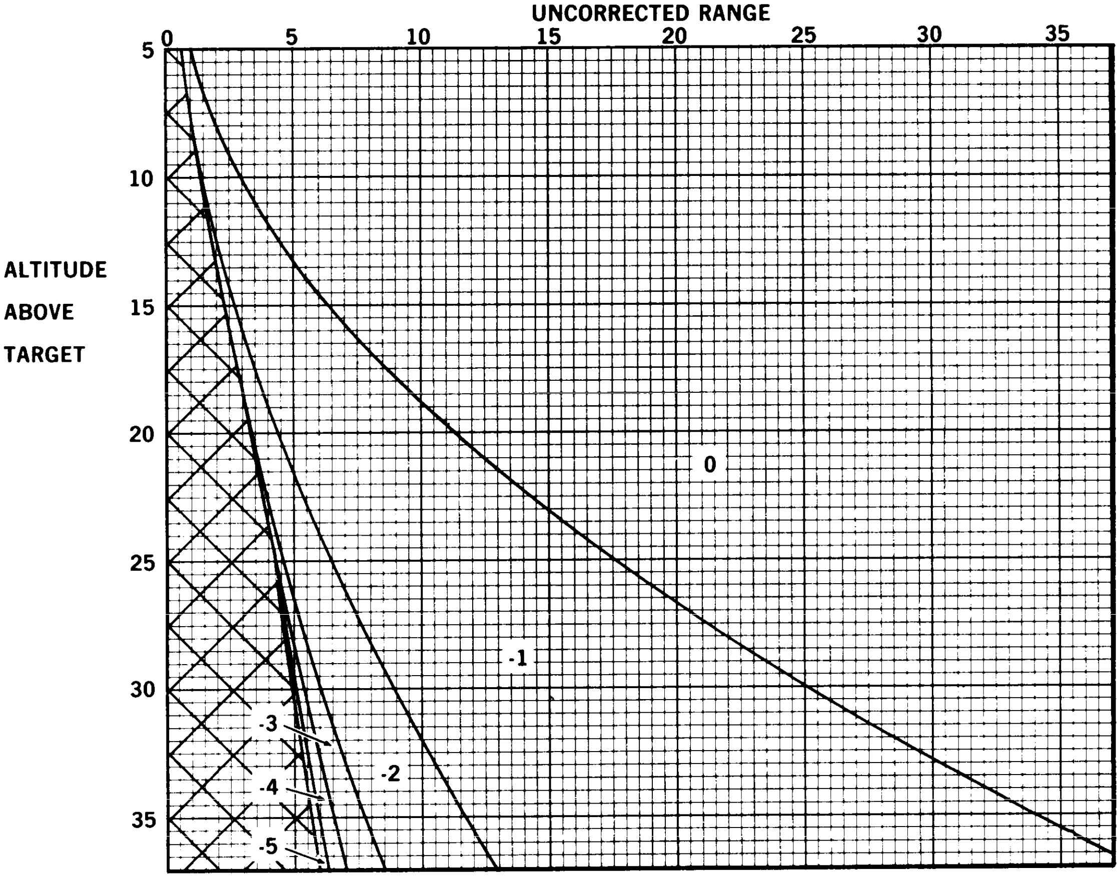


Figure 8-16. Slant Range Correction Chart.

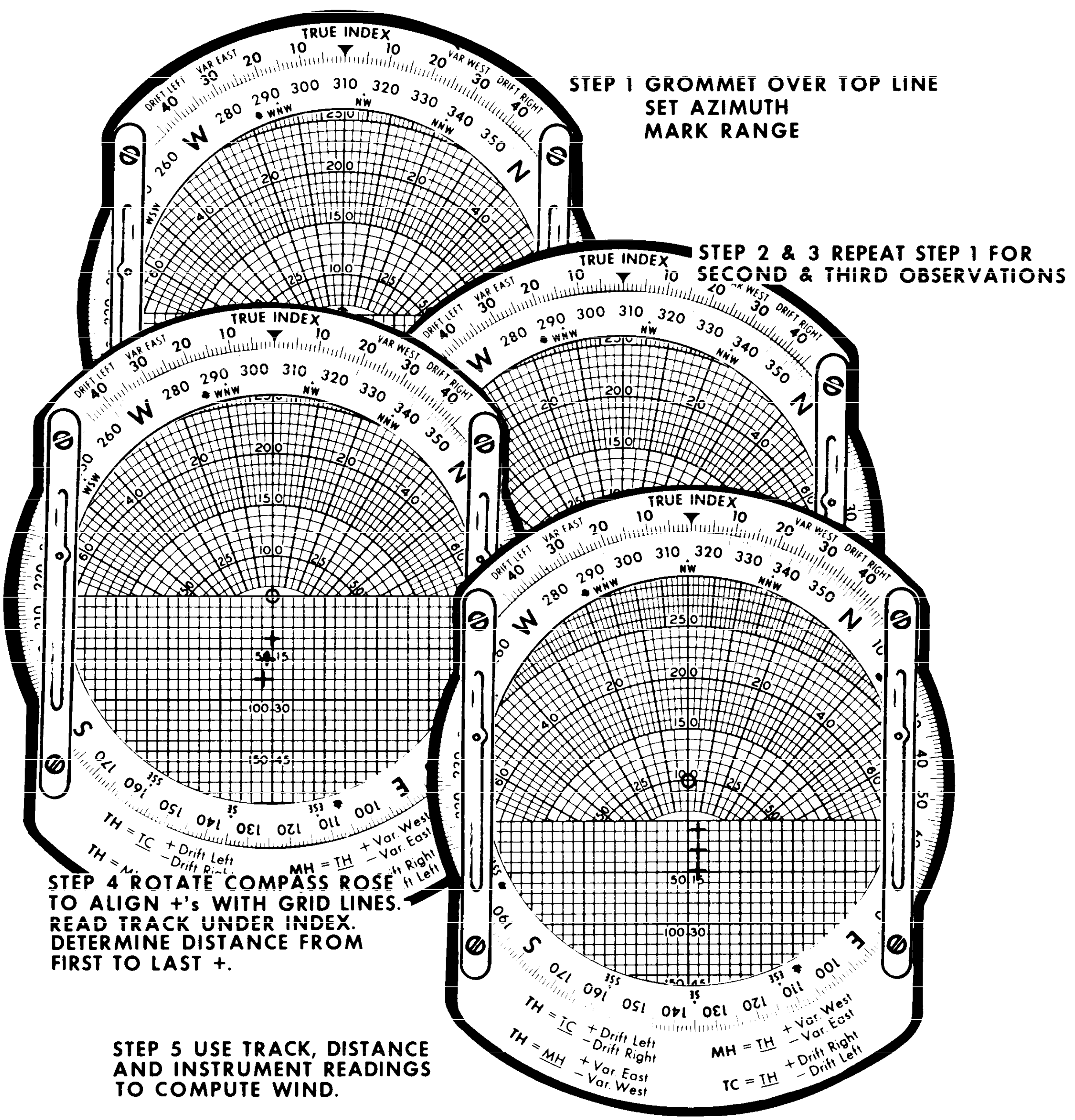
Absolute Altitude (Thousands of feet)	SLANT RANGE							
	5NM	10NM	15NM	20NM	25NM	30NM	35NM	40NM
	CORRESPONDING GROUND RANGE (NM)							
13	4.5	9.8	14.9	19.9	24.9	29.9	34.9	40.0
14	4.5	9.8	14.8	19.9	24.9	29.9	34.9	39.9
15	4.4	9.7	14.8	19.9	24.9	29.9	34.9	39.9
16	4.2	9.6	14.8	19.8	24.9	29.9	34.9	39.9
17	4.1	9.6	14.7	19.8	24.8	29.9	34.9	39.9
18	4.0	9.5	14.7	19.8	24.8	29.9	34.9	39.9
19	3.9	9.5	14.7	19.8	24.8	29.8	34.9	39.9
20	3.7	9.4	14.6	19.7	24.8	29.8	34.8	39.9
21	3.6	9.4	14.6	19.7	24.8	29.8	34.8	39.9
22	3.5	9.3	14.6	19.7	24.7	29.8	34.8	39.8
23	3.3	9.3	14.5	19.7	24.7	29.8	34.8	39.8
24	3.0	9.2	14.5	19.6	24.7	29.7	34.8	39.8
25	2.8	9.1	14.4	19.6	24.7	29.7	34.8	39.8
26	2.5	9.0	14.4	19.5	24.6	29.7	34.7	39.8
27	2.2	8.9	14.3	19.5	24.6	29.7	34.7	39.8
28	2.0	8.9	14.3	19.5	24.6	29.7	34.7	39.7
29	1.5	8.8	14.2	19.4	24.5	29.6	34.7	39.7
30	.8	8.7	14.2	19.4	24.5	29.6	34.7	39.7
31		8.6	14.1	19.3	24.5	29.6	34.6	39.7
32		8.5	14.1	19.3	24.4	29.5	34.6	39.6
33		8.4	14.0	19.2	24.4	29.5	34.6	39.6
34		8.3	13.9	19.2	24.4	29.5	34.6	39.6
35		8.2	13.9	19.1	24.3	29.4	34.5	39.6
36		8.1	13.8	19.1	24.3	29.4	34.5	39.6
37		7.9	13.7	19.0	24.2	29.4	34.5	39.5
38		7.8	13.6	19.0	24.2	29.3	34.4	39.5
39		7.7	13.6	18.9	24.2	29.3	34.4	39.5
40		7.5	13.5	18.9	24.1	29.3	34.4	39.5
41		7.4	13.4	18.8	24.1	29.2	34.4	39.4

Figure 8-17. Slant Range/Ground Range Table.

is accomplished electrically by integration with the compass and pitot-static systems. Thus, as the aircraft progresses along track, the navigator can determine the DR position at any time.

Target Timing Wind

This is a technique for obtaining a wind by using radar targets to provide track and groundspeed of an aircraft. The MB-4 computer solution for wind requires true heading (TH), true airspeed (TAS), drift angle (DA), and groundspeed (GS). The first two can be derived from basic aircraft instruments (IAS and compass). The other two require a target which can be tracked for about 4 minutes and which is preferably within 20 degrees of the radar heading marker. The identity of the target is irrelevant but it should not be so big as to make range and bearing determination vague, or so small that it will disappear. Choose a target that has just begun to appear on the scope and take its range and bearing. Also, start a stopwatch or note the minute and seconds on a clock so elapsed time can be measured. At least two range and bearings should be taken over a distance of 20 to 25 NM. One technique is to fix at the 40, 30, and 20 NM range marks to space the fixes evenly. At the last observation, stop the watch and determine the elapsed time. On the windface grid of the MB-4, place the grommet over the center mark of the top



STEP 1 GROMMET OVER TOP LINE
SET AZIMUTH
MARK RANGE

STEP 2 & 3 REPEAT STEP 1 FOR SECOND & THIRD OBSERVATIONS

STEP 4 ROTATE COMPASS ROSE TO ALIGN +'s WITH GRID LINES. READ TRACK UNDER INDEX. DETERMINE DISTANCE FROM FIRST TO LAST +.

STEP 5 USE TRACK, DISTANCE AND INSTRUMENT READINGS TO COMPUTE WIND.

Figure 8-18. Target Timing Wind Solution.

reference line. Turn the compass rose to the azimuth of the first fix. Using your own values for each of the horizontal grid lines, plot a point representing the range of the first fix (going down). Then, turn the compass rose to the azimuth of the second fix and plot a point (measuring from the top line again) representing the range of the second fix. Repeat for the successive fixes (see figure 8-18).

To solve for the wind, rotate the compass rose so that the three plotted lines are parallel to the vertical grid lines and read the track under the true index of the compass rose. Then, determine the GS by measuring the distance between the first and last plotted points using the grid lines. Using track and TH, find the DA and use the standard MB-4 wind solution.

Example:

TH = 320°	Fix 1	310°	40 NM
TAS = 400°	Fix 2	308°	30 NM
Time = 3 + 30 min	Fix 3	305°	20 NM

Solution:
TC = 316°
GS = 352k
Wind = 349°/53k

Airborne Radar Approach

The airborne radar approach (ARA) may be described as a GCA in reverse. It is used only as an emergency procedure in marginal weather conditions if air-to-ground communication is impossible and no radio navigation aids are available. However, it should be practiced often against the time when it may be the only method of effecting a safe landing. Even when the letdown and approach are directed by ground radar, such direction should be monitored by the navigator on the airborne radar.

The ARA involves the use of the airborne radar set to guide the aircraft to a point on the final approach where the pilot can either complete the landing visually or decide that the landing cannot be safely completed.

There are two main phases in the airborne radar approach—the letdown and the approach itself. The letdown is normally accomplished from a nearby VOR or TACAN station in accordance with published procedures. If these are not available, the navigator must pick a point on the extension of the runway that will provide adequate time for descent and early alignment of the aircraft with the runway.

After completion of the letdown, the approach itself is begun. Again, the procedures used vary with the capabilities of the radar used. Monitoring the runway environment, the navigator should provide headings, altitude calls, and distance-to-the-runway information for the pilots. Terminal approach plates should be used to locate possible hazards. In general, on radar sets equipped with computers, the cross-hairs are used to monitor the distance and direction to the end of the runway; on the other sets, the fixed range markers are used. When moveable etched cursors are used for runway alignment reference, the landing environment should move along the cursor (indicating the aircraft is flying straight towards the field). Any drifting from this path should prompt a heading change. Remember to monitor drift angle changes since, as the aircraft descends through different altitudes, the wind structure will shift.

Caution should be used when flying an ARA without backup navigational aids for orientation and when using an AZ STAB setting other than north orientation. Insure familiarity with runway location and direction relative to surrounding returns. It is possible to fly an apparently good approach to the field only to find that the aircraft is over the threshold but considerably off the runway heading. Again, a point on the runway extension should be used for initial alignment with the runway to avoid this problem. The specific steps for each type of radar are included in the appropriate aircraft flight handbook.

Station Keeping

Station keeping is a technique wherein radar is used to maintain a fixed position relative to one or more aircraft in flight. Today's formations may require separations on the order of a mile or more.

At distances such as this, radar provides a means of performing station keeping more accurately. In addition, it is superior to the visual method of formation flying since it is an all-weather method.

Positions within the formation are maintained with fixed or variable range markers or with the crosshairs. With radar sets having directional "pencil-type" beam, returns appear on any portion of the scope. On the other sets, the various aircraft in the formation appear in the altitude hole.

Aircraft equipped with station keeping equipment (SKE) should follow the recommendations of their associated manuals.

To use the basic radar set for station keeping, there are three considerations—altitude separation, angular offset, and airspeed adjustments. The relative importance of each of these considerations depends on the type of formation being flown.

Basic tuning for station keeping is best achieved by placing the antenna in pencil beam; adjusting the tilt to level; and setting AZ STAB in the relative position.

In all formations, altitudes are prearranged and should be monitored, although this is facilitated by autopilot altitude hold.

In trial formations, airspeed is the most important aspect in maintaining assigned separation. It is not sufficient to match the lead aircraft's airspeed. Compensation must also be made for altitude differences. As a general rule, 3 knots of IAS increase for every 500 feet above lead's altitude will usually keep groundspeeds close. By working the TAS to IAS conversion on the MB-4, an exact compensation may be achieved for each situation.

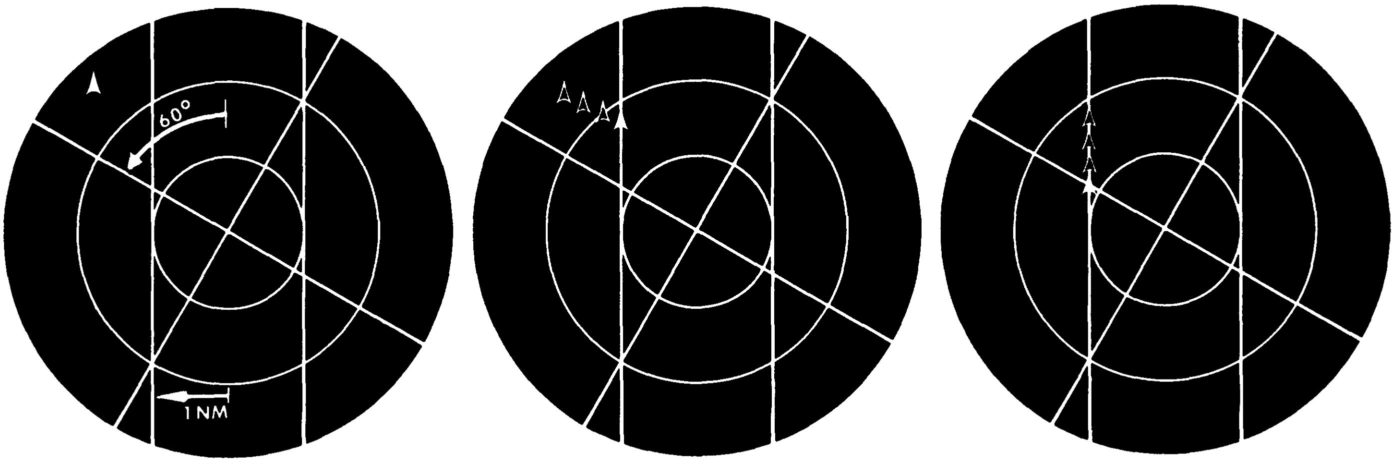
In an offset formation, the airspeed and angular adjustments must be combined which slightly complicates the technique. It is recommended that the angular offset and desired separation be marked on the scope with either a mechanical or an electronic cursor. When flying in formations, extreme corrections should be avoided. Corrections should be planned to be quick but should cause the least confusion.

For example, assume a 60° offset at 1 NM is to be maintained. To establish the position, myriad of combinations are possible but a basic approach is presented here (see figure 8-19). First, maneuver the aircraft so that the lead's radar return is at the desired distance from the heading marker (in this case—1 NM) and turn to lead's heading. Secondly, adjust airspeed so that lead's return moves parallel to the heading marker toward the angular offset (this mechanical cursor is offset 60° from the heading flash). Once in position, adjust airspeed to match lead's (compensate for altitude as above). Equipment and capabilities vary among aircraft so expand upon these basics as necessary.

Navigation Through Weather

The use of radar for weather avoidance has become increasingly important in recent years from the standpoint of both safety and operational flexibility. Severe turbulence, hail, and icing associated with thunderstorms constitute severe hazards to flight. It is mandatory that these thunderstorms be avoided whenever possible. Airborne weather radar, if operated and interpreted properly, can be an invaluable aid in avoiding thunderstorm areas.

Several factors affect the radar returns from thunderstorms, and the operator must be aware of these and the limitiations they impose on the weather radar if optimum use of this tool is to be achieved. Some of these factors are nonmeteorological and depend on the characteristics of the radar set and the way it is operated. The same weather target can vary considerably in its radarscope appearance as the operators change the operating characteristics of the set. Operators must insure that they are



TURN TOWARD LEAD.

TURN TO PARALLEL LEAD'S HEADING. ACCELERATE

REDUCE SPEED TO MATCH LEADS.

Figure 8-19. Station Keeping.

using the set as designed for weather avoidance. Primary meteorological factors which affect radar returns are the size, shape, number, and phase of the water droplets in the weather target and atmospheric absorption characteristics between the radar antenna and the target. The most important factors are the number and size of the water droplets.

The operator must realize that the predominant weather-induced returns on most radarscopes are caused by precipitation-size water droplets, not by entire clouds. Intense returns indicate the presence of very large droplets. These large droplets are generally associated with the most hazardous phenomena; those with strong vertical currents which are necessary to maintain these droplets in the cloud. It is possible, however, to encounter such strong turbulence in an echo-free area or even in an adjacent cloud-free area, so avoiding areas giving intense returns will not necessarily guarantee safe flight in the vicinity of thunderstorms. Various researchers have empirically determined what they consider to be safe distances for avoiding these intense returns. These distances vary with altitude and echo characteristics. The avoidance procedures recommended by these researchers vary and change somewhat as research continues. While similar they rarely recommend passing closer than 10 miles to intense echoes at low altitudes. Avoidance by even greater distances is recommended at higher altitudes. Navigators should make careful note of all areas forecast to have the potential for hazardous weather. Being forwarned is the best motivation for monitoring the area above the ground for hazards.

Generally, the map mode of the radar with a moderate amount of gain applied is adequate for obtaining a return from hazardous cells. Sometimes, detection is hampered by ground returns in the area that hide the storm. Most often, this occurs in mountainous areas where ground returns are similar and the air mass lifting action in the area breeds the cells. For these reasons, any opportunity to raise the beam above the ground (tilt) or narrow the beam (pencil beam) or both, are techniques that will speed weather detection.

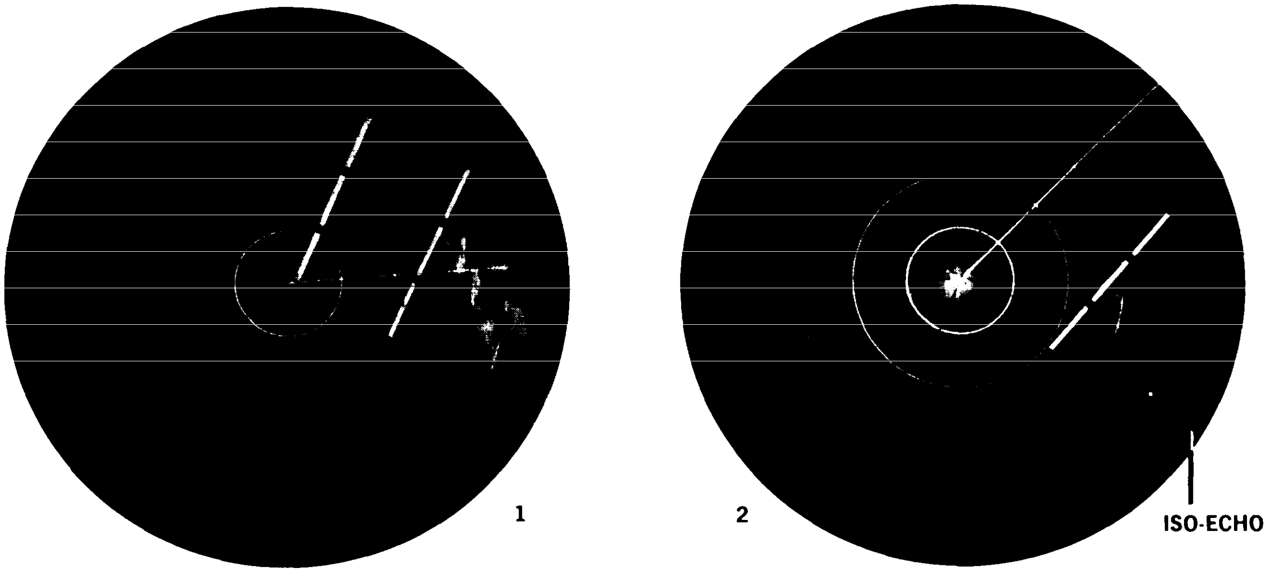
When weather is identified, its altitude should be judged. The pilots might provide a visual report or a ground station might know. In IFR conditions, raise the tilt until the weather return dissipates. The relative position of the tilt then might offer a judgment of the "tops," but calibration of the tilt is not always certain so, when there is doubt, avoid the area.

Weather avoidance with radar is mainly of two types: (1) avoidance of isolated thunderstorms, and (2) penetration of line of thunderstorms. The process of avoiding an isolated return is one of first identifying the return and then circumnavigating it at a safe distance.

When a weather system is detected, its extent should be ascertained. Analyze the weather's layout relative to planned track and decide either to deviate around it or penetrate the line. If the system is complex, attempt to determine if your deviation could lead to worsening the situation by flying into a "sucker-hole," where a solid system could surround the aircraft. Sometimes, what seems to be a good heading at low ranges will seem foolish when the long range view is analyzed. Remember, ARTCC can sometimes aid in this analysis.

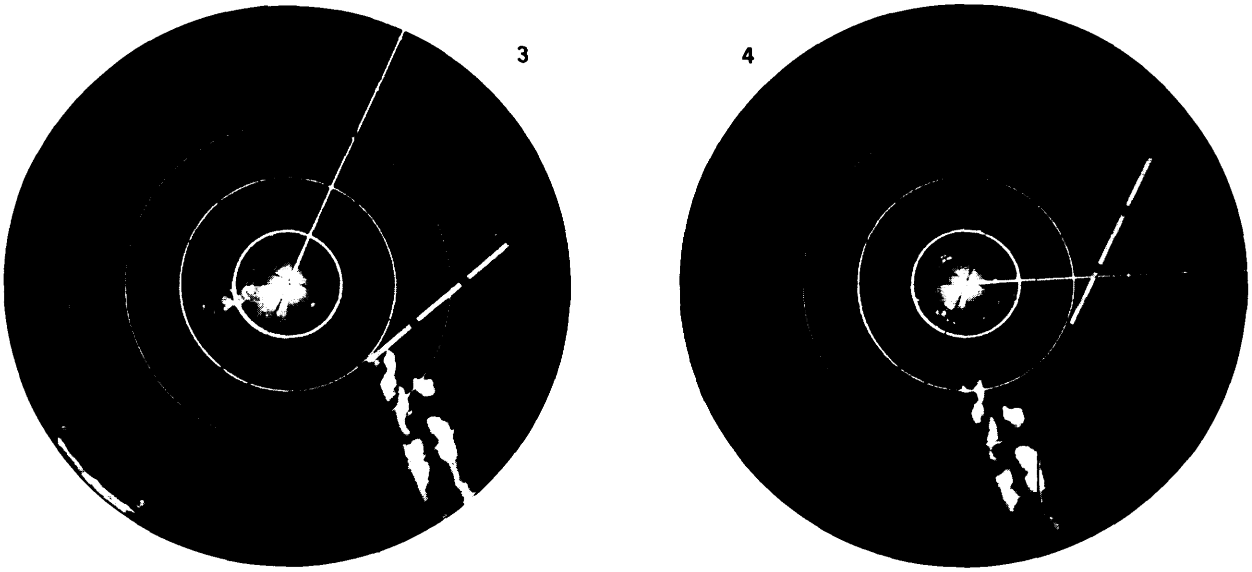
A simple technique for flying around weather at a preferred distance (say 20 NM) is the "flying disc" technique. Imagine the aircraft is a disc defined by the 20 NM range mark on the PPI. The heading marker is the "nose" of the disc. Draw an imaginary tangent from the disc to the edge of the weather (or use a pencil or plotter). Turn the aircraft the same number of degrees that it would take to get the heading marker to fire parallel to the tangent. After the turn, recheck the heading in the same manner. This technique works best with a scan of more than 180° (figure 8-20). Radars with sector scan less than 180° can adapt more readily to this technique. Penetration of a line of thunderstorms presents a somewhat different problem. Since the line may extend for hundreds of miles, circumnavigation is not often practical nor even possible. If the flight must be continued and the line penetrated, the main objective is to avoid the more dangerous areas in the line.

An example of frontal penetration using radar is shown in



Use Tangent of Desired Clearance for Heading

Further Alter Required



Watch for Tangent to Clear Weather

Return to Course

Figure 8-20. Weather Avoidance.

figure 8-21. If the aircraft is equipped with iso-contour, then it can be used to discriminate between the safe and violent areas. Without it, decreasing the gain will work to highlight the worst areas leaving the densest of the water cells, in most cases, as the last returns on the PPI. Upon approaching the line, the navigator determines an area which has weak or no returns, and which is large enough to allow avoidance of all intense returns by the recommended distances throughout penetration. The navigator selects this as the penetration point and directs the aircraft to that point, making the penetration at right angles to the line so as to remain in the bad weather areas for the shortest possible time. Great care must be taken to avoid the dangerous echoes by the safe distances. It should be emphasized that penetration of a line of severe thunderstorms is always a potentially dangerous procedure. It should be attempted only when continuation of the flight is mandatory and the line cannot be circumnavigated. In all cases, when deviating from flight-planned route, advise ARTCC of your intentions, when able.

Procedure Turns

A procedure turn is one so planned that the aircraft will roll on the proper heading to make good a predetermined track. In bombing, for example, the bomb run to the target must begin

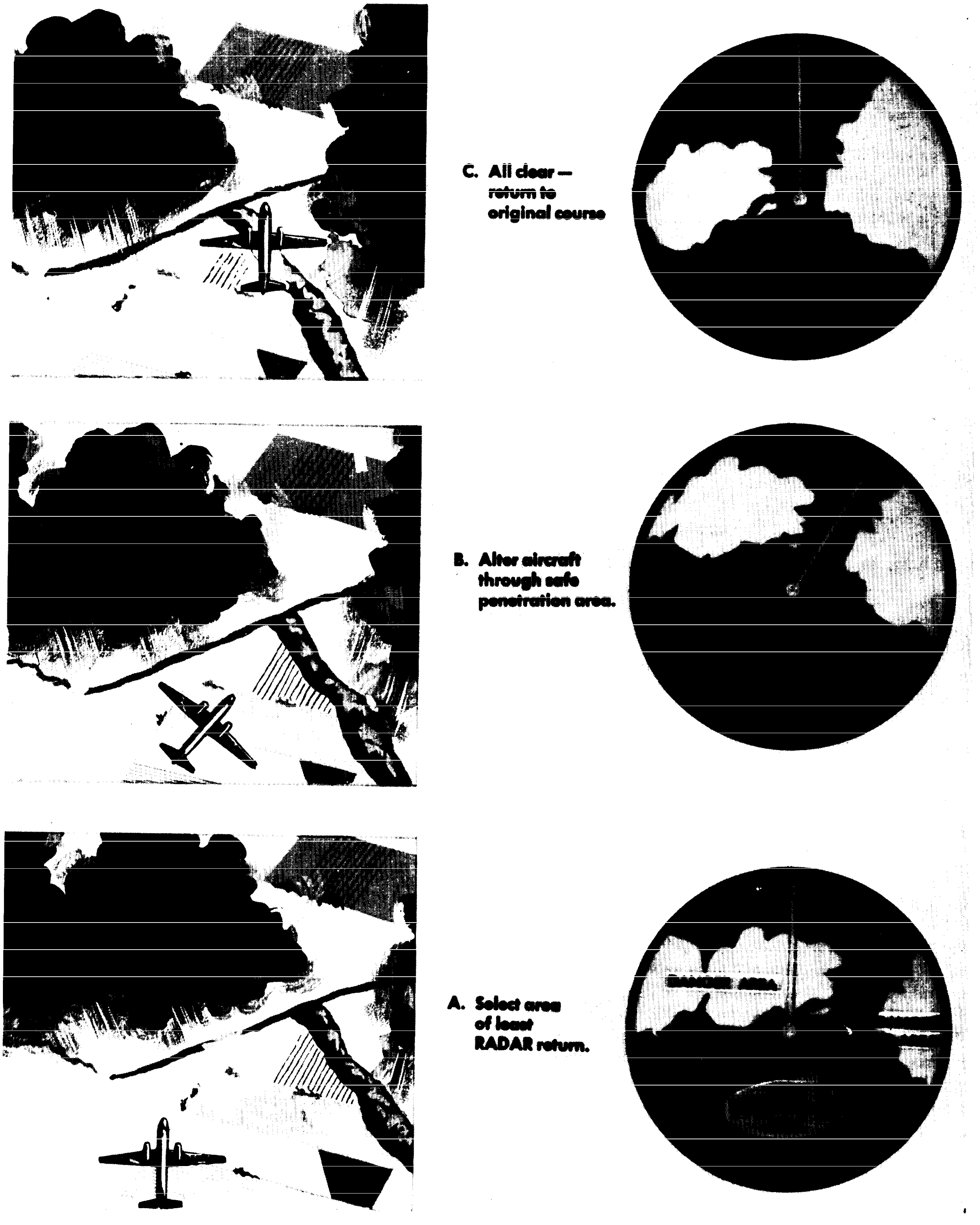


Figure 8-21. Penetration of Thunderstorm Area.

from a fixed point, called the IP (initial point). To roll out on the track from the IP to the target, the turn onto the bomb run must begin at some point prior to the IP. This situation is shown in figure 8-22. There are several methods of executing the proce-

GS (KNOTS) TO IP		DEGREE OF TURN (TH TO TH)				
	10°	50°	60°	70°	80°	90°
160	.5	1.5	2.0	2.0	2.5	3.0
180	.5	1.5	2.0	2.5	3.0	3.5
200	.5	2.0	2.5	3.0	3.5	4.0
220	.5	2.0	2.5	3.0	3.5	4.5
240	.5	2.0	3.0	3.5	4.0	5.0
260	.5	2.5	3.0	3.5	4.5	5.0

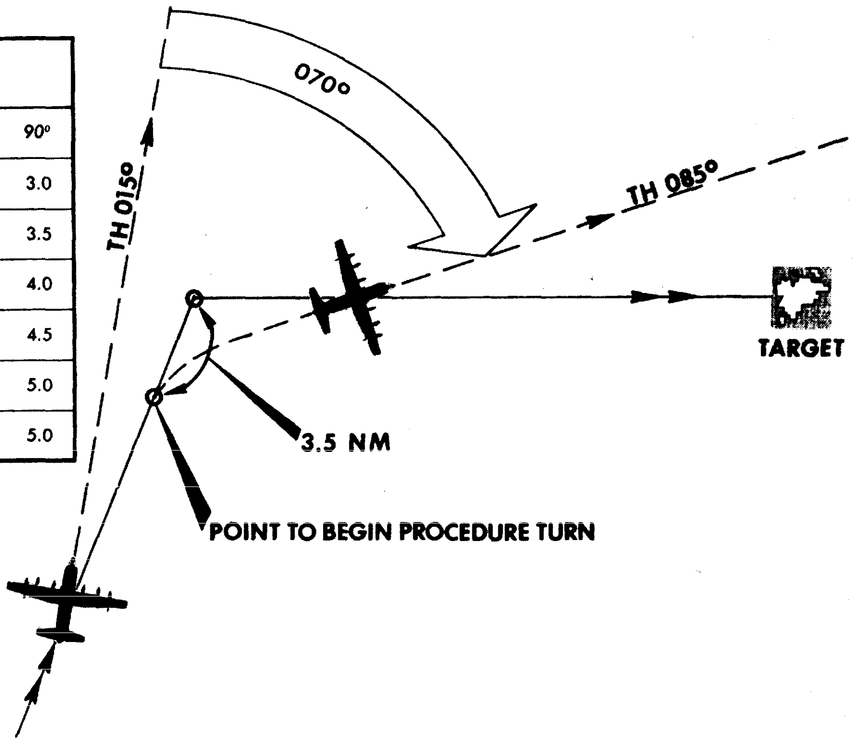


Figure 8-22. Executing a Procedure Turn.

dure turn.

Computing the Point to Start the Turn. The point at which a procedure turn should begin is computed on the basis of the amount of turn to be made, the turning rate, and the groundspeed of the aircraft. The turn angle and the groundspeed must be determined prior to the turn, through normal navigational procedures. The turn rate is governed by local directives, but it is usually a one-quarter or one-half needlewidth turn. A one-quarter needlewidth turn is an 8-minute, 360° turn, and a one-half needlewidth turn is a 4-minute, 360° turn.

To find the turn distance, enter the table in figure 8-22 for the turning rate to be used. At the intersection of the groundspeed column and the degree of turn column, read the ground distance from the IP to the actual turning point. Plot this distance on the chart. In the illustration, the aircraft is approaching the IP on a true heading of 015° at a groundspeed of 250 knots. The true heading to the target is 085°. Enter the table with 250 knots and 70° (085°—015°); the difference between the new heading and the old one. The distance from the IP to start the turn is 3.5 nautical miles. The problem now becomes one of determining when the aircraft is at the turning point. This is found in several ways.

Fixed Range Marker Method. The slant range corresponding to the ground range distance can be computed. When the IP appears at the proper slant range on the scope as indicated by the fixed range markers, execute the turn.

Variable Range Marker Method. When using a radar set on which there is a variable range marker, execute the turn when the IP intersects the VRM.

Bearing Method. If the bearing from the turning point to some easily identifiable ground point is measured, make the turn when the bearing of the aircraft to this point reaches the measured bearing. For greatest accuracy, the line of bearing from the turning point to the reference point should intersect the track at approximately a right angle.

Off-Course Method. If the aircraft is not on the desired track to the IP, each of the three methods described above will be inaccurate. For example, if the aircraft is several miles to the left of track and the radar operator waits until the IP is 3.5 nautical miles from the aircraft, the aircraft will roll out on a track above that desired. However, if a line is drawn on the scope through the IP and in the direction of the new track, make the turn when the line—not the IP—is 3.5 nautical miles from the aircraft.

Bearing Correction. For optimum accuracy, it may sometimes become necessary to correct the bearings taken on the various targets. This necessity arises whenever (1) the heading marker reading does not agree with the true heading of the aircraft when azimuth stabilization is used, or (2) the heading marker reading does not agree with 360° when azimuth stabilization is not used.

Example: If the TH is 125° and the heading marker reads 120°, all of the returns on the scope will indicate a bearing which is 5° less than it should be. Therefore, if a target indicates a bearing of 50°, 5° must be added to the bearing before it is plotted. Conversely, should the heading marker read 45° when the TH is 040°, all of the scope returns will indicate a bearing which is 5° more than it should be. Therefore, if a target indicates a bearing of 275°, 5° must be subtracted from the bearing before it is plotted. The greater the distance of the target from the aircraft, the more important this heading marker correction becomes.

Chapter 9

TIME

In celestial navigation, the position of the aircraft is determined by observing the celestial bodies. The apparent position of these bodies in respect to a point on the Earth changes with time. Therefore, the determination of the position of the aircraft relies on exact timing of the observation.

MEASURING TIME

Time is measured in terms of the rotation of the Earth and the resulting apparent motions of the celestial bodies. Several different systems of measurement, each of which has a special use, are considered in this chapter.

Before getting into the actual discussion of the various kinds of time, there is one basic term that must be understood. That term is transit. The time at which a body passes the observer's meridian is divided by the poles into halves. Notice in figure 9-1 that the upper branch is that half which contains the observer's position. The lower branch is the opposite half. Every day, because of the Earth's rotation, every celestial body transits the upper and lower branches of the observer's meridian. As mentioned before, there are several kinds of time. The first presented here is solar time.

Apparent Solar Time

The Sun as seen in the sky is called the true Sun, and is also referred to as the apparent Sun. Apparent solar time is based upon the movement of the Sun as it crosses the sky. A sundial would accurately indicate apparent solar time.

The use of apparent solar time is impractical because the apparent length of day varies throughout the year. A timepiece would have to operate at different speeds to indicate correct apparent time. However, apparent time accurately indicates upper and lower transit. Upper transit occurs at noon apparent

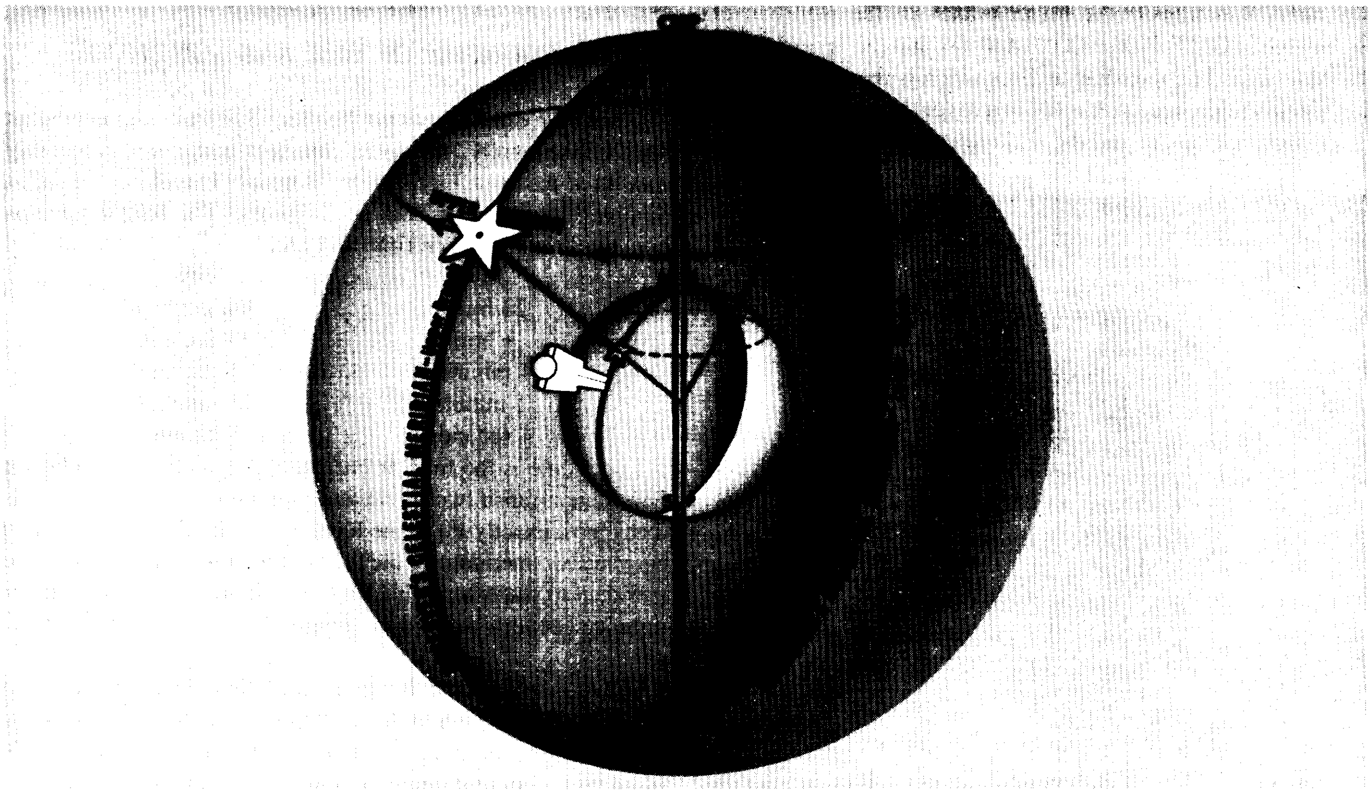


Figure 9-1. Transit is Caused by the Earth's Rotation.

time and lower transit at 2400 apparent time. The difficulties utilizing apparent time led to the introduction of "mean time."

Mean Solar Time

A mean day is an artificial unit of constant length, based on the average of all apparent solar days over a period of years. Time for a mean day is measured with reference to a fictitious body, the mean Sun, so designed that its hour circle moves westward at a constant rate along the celestial equator. Time computed using the mean Sun is called mean solar time and is nearly equal to the average apparent solar time. The coordinates of celestial bodies are tabulated in the Air Almanac with respect to mean solar time, making it the time of primary interest to the navigator.

The difference in length between the apparent day (based upon the "true" Sun) and the mean day (based upon the "mean" Sun) is never as much as a minute. The differences are cumulative, however, with the result that the imaginary mean Sun is considered to precede or follow the apparent Sun by approximately a quarter of an hour at certain times during the year.

Greenwich Mean Time (GMT)

GMT is especially important in celestial navigation since it is the time used for most celestial computation. Greenwich mean time is mean solar time measured from the lower branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle passing through the mean Sun (figure 9-2). The mean Sun transits the lower branch of the meridian of Greenwich at GMT 2400 (0000) each day and the upper branch at GMT 1200. The meridian at Greenwich is the logical selection for this reference, as it is the origin for the measurement of Greenwich hour angle and the reckoning of longitude. Consequently, celestial coordinates and other information are tabulated in almanacs with reference to GMT. GMT is sometimes referred to as Zulu time or just plain "Z" time.

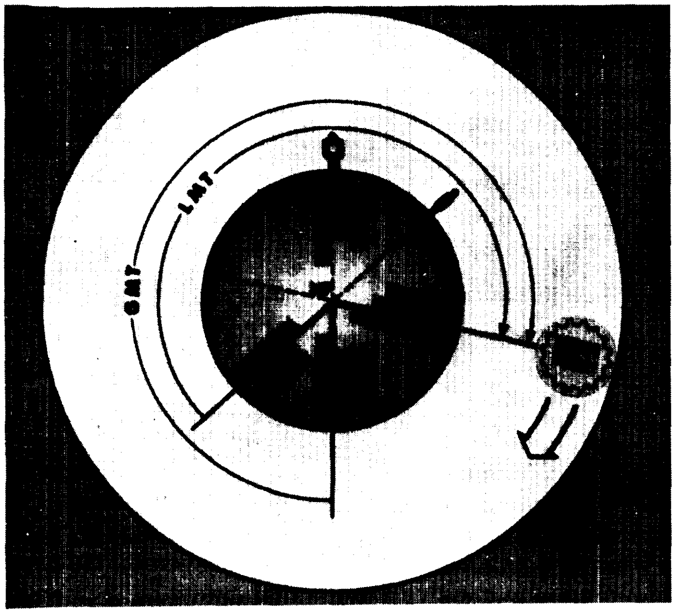


Figure 9-2. Measuring Greenwich Mean Time (GMT).

Greenwich mean time is not a convenient time for use in regulating everyday activities throughout the world. If all clocks were set to GMT, the time of occurrences at many places on the Earth of such natural phenomena as sunrise, noon, and sunset would vary greatly from the time normally associated with these events.

Local Mean Time (LMT)

Just as Greenwich mean time is mean solar time measured with reference to the meridian at Greenwich, so local mean time (LMT) is mean solar time measured with reference to the local meridian of an observer. LMT is measured from the lower branch of the observer's meridian westward through 360°, to the upper branch of the hour circle passing through the mean Sun (refer to figure 9-2). The mean Sun transits the lower branch of the meridian of an observer at LMT 0000 (2400) and the upper branch at LMT 1200. Note that, if an observer were at the Greenwich meridian, GMT would also be the LMT of the observer.

LMT is not used to regulate everyone's activities because LMT, being based on the meridian of each observer, varies continuously with longitude. This disadvantage of LMT has led to the introduction of zone time as the basis for governing routine activities. The navigator uses LMT in the computation of local sunrise, sunset, twilight, moonrise, and moonset at various latitudes along a given meridian.

RELATIONSHIP OF TIME AND LONGITUDE

It has been established that the mean Sun travels at a constant rate. Consequently, the mean Sun will make two successive transits of the same meridian in 24 hours. Therefore, the mean Sun travels an arc of 360° in 24 hours. The following relationship exists between time and arc.

Time	Arc
24 hours	360 degrees
1 hour	15 degrees
4 minutes	1 degree
1 minute	15 minutes
4 seconds	1 minute

Local time is the time at one particular meridian. Since the Sun cannot transit two meridians simultaneously, no two meridians have exactly the same local time. The difference in time between two meridians is the time of the Sun's passage from one meridian to the other. This time is proportional to the angular distance between the two meridians. One hour is equivalent to 15°.

If two meridians are 30° apart, their time differs by 2 hours. The local time is later at the easternmost of the two meridians, since the Sun has crossed its lower branch first; thus the day is older there. These statements hold true whether referring to the apparent Sun or the mean Sun. Figure 9-3 demonstrates that the Sun crossed the lower branch of the meridian of observer #1 at

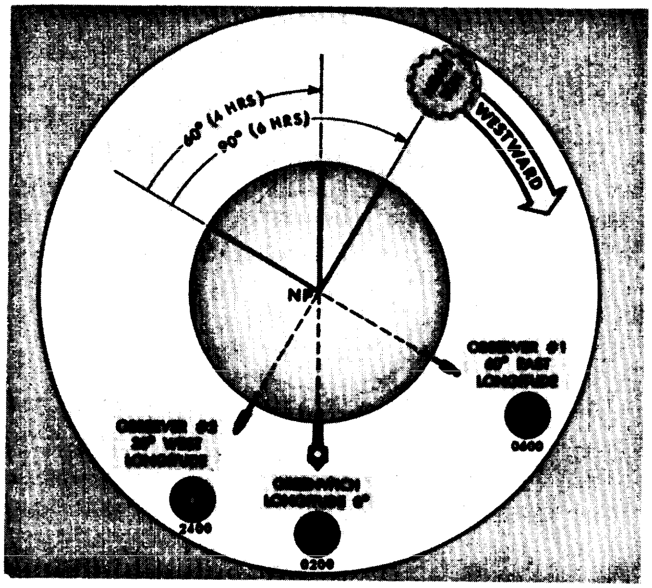


Figure 9-3. Local Time Differences at Different Longitudes.

60° east longitude 4 hours before it crossed the lower branch of the Greenwich meridian (60 divided by 15), and 6 hours before it crossed the lower branch of the meridian of observer #2 at 30° west longitude (90 divided by 15). Therefore, the local time at 60° east longitude is later by the respective amounts.

Standard Time Zone

The world has been divided into 24 zones, each zone being 15° of longitude in width. Each zone uses the LMT of its central meridian. Since the Greenwich meridian is the central meridian for one of the zones, and each zone is 15° or one hour wide, the time in each zone differs from GMT by an integral number of hours. The zones are designated by numbers from 0 to + 12 and − 12, each indicating the number of hours which must be added or subtracted to local zone time (LZT) to obtain GMT. Thus, since the time is earlier in the zones west of Greenwich, the numbers of these zones are plus, in those zones east of Greenwich, the numbers are minus (figure 9-4). Sometimes, zones are designated by letters of the alphabet for additional reference.

The zone boundaries have been considerably modified to conform with geographical boundaries for greater convenience. For example, in case a zone boundary passed through a city, it would be impractical to use the time of one zone in one part of the city and the time of the adjacent zone in the other part. In some countries, which overlap two or three zones, one time is used throughout.

Date Changes at Midnight

Typically, when traveling west from Greenwich around the world and setting one's watch back an hour for each time zone, a navigator would have set the watch back a total of 24 hours upon arriving back at Greenwich and the date would be one day behind that of Greenwich. Conversely, traveling eastward, the watch would have been advanced a total of 24 hours—gaining a day in comparison with Greenwich.

To keep the records straight, it is necessary to add a day somewhere if going around the world to the west, and to lose a day if going around to the east. The 180° meridian was selected arbitrarily as the international date line where a day is gained or lost. The date line follows the meridian except where it makes broad detours to avoid eastern Siberia, the western Aleutian Islands, and several groups of islands in the South Pacific.

The local civil date changes at 2400 or midnight. Thus, the date changes as the mean Sun transits the lower branch of the meridian.

Consider the situation in another way. The hour circle of the mean Sun is divided in half at the poles. On the half away from the Sun (the lower branch), it is always midnight local mean time. As the lower branch moves westward (figure 9-5) it pushes the old date before it and drags the new date after it. As the lower branch approaches the 180° meridian, the area of the old date decreases and the area of the new date increases. When the lower branch reaches the date line, that is, when the mean Sun transits the Greenwich meridian, the old date is crowded out and the new date for that instant prevails in the world. Then, as the lower branch passes the date line, a newer date begins east of the lower branch, and the process starts all over again. (Because of the irregularities of the date line, the lower branch of the hour circle of the mean Sun cannot coincide with the date line at any time. Therefore, strictly speaking, it is never the same date all over the world).

The zone date changes at midnight zone time, or when the lower branch of the mean Sun transits the central meridian of the zone.

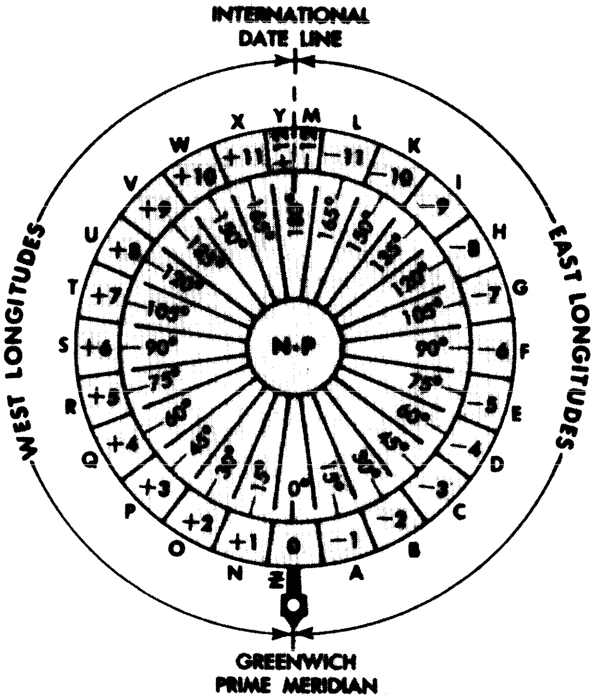


Figure 9-4. Standard Time Zones.

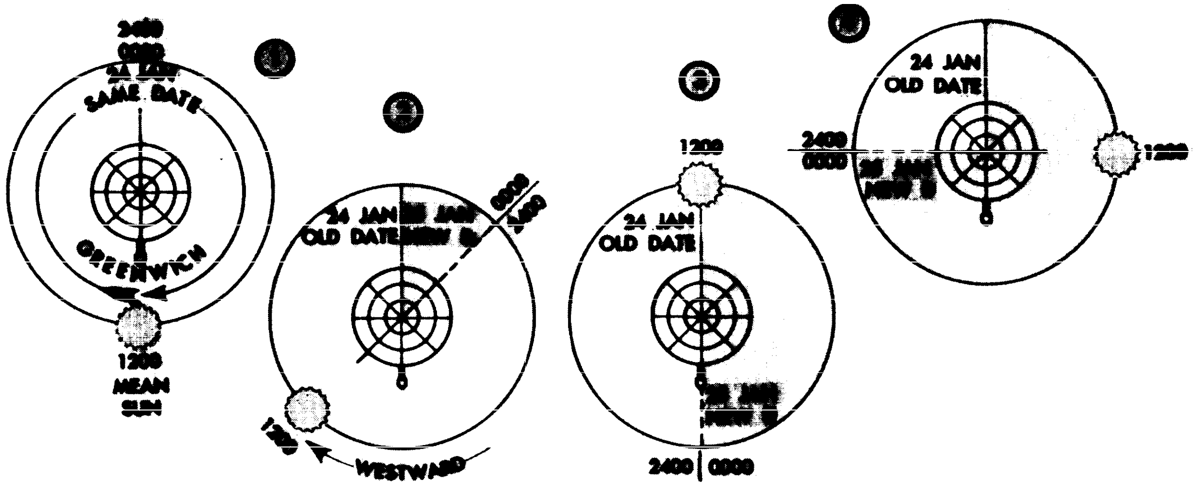


Figure 9-5. Zone Date Changes.

Time Conversion

There are times when it is necessary to convert from local time to GMT, or from GMT to local (figure 9-6). To aid in this process, the Air Almanac contains a table for conversion of arc to time (figure 9-7). The table is based upon the Sun covering 15° of arc in 1 hour of time.

This conversion is only good for LMT to GMT, not zone time to GMT. Zone time is influenced by daylight savings time and geographical boundaries. For example, if a navigator wanted to convert GMT to LMT at 126° 36′W, table 12-1 of the Air Almanac would be utilized. The conversion factors would be:

126° = 8 hr 24 min
36′ = 2 min 24 sec
126° – 36′ = 8 hr 26 min 24 sec

To derive LMT for GMT, the time is subtracted in the Western

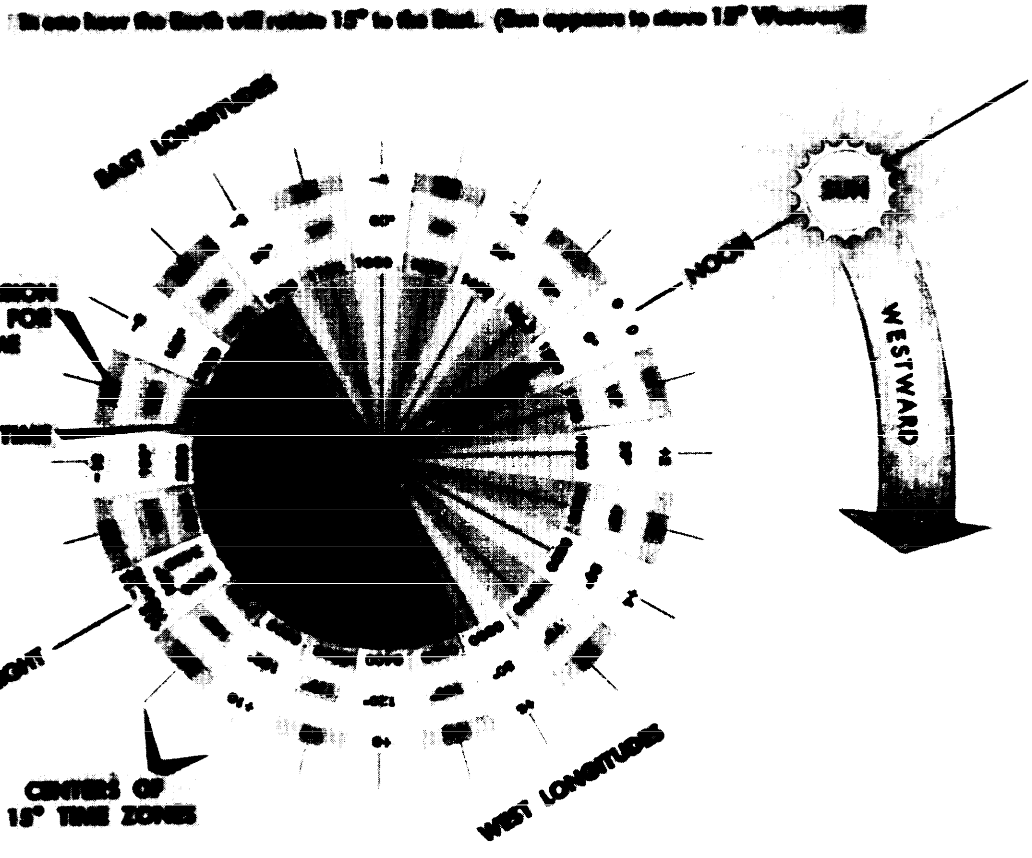


Figure 9-6. Time Conversion.

°	h m	°	h m	°	h m	°	h m	°	h m	°	h m	′	m s
0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40	10	0 40
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56
15	1 00	75	5 00	135	9 00	195	13 00	255	17 00	315	21 00	15	1 00
16	1 04	76	5 04	136	9 04	196	13 04	256	17 04	316	21 04	16	1 04
17	1 08	77	5 08	137	9 08	197	13 08	257	17 08	317	21 08	17	1 08
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20	20	1 20
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40	25	1 40
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56
30	2 00	90	6 00	150	10 00	210	14 00	270	18 00	330	22 00	30	2 00
31	2 04	91	6 04	151	10 04	211	14 04	271	18 04	331	22 04	31	2 04
32	2 08	92	6 08	152	10 08	212	14 08	272	18 08	332	22 08	32	2 08
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56
45	3 00	105	7 00	165	11 00	225	15 00	285	19 00	345	23 00	45	3 00
46	3 04	106	7 04	166	11 04	226	15 04	286	19 04	346	23 04	46	3 04
47	3 08	107	7 08	167	11 08	227	15 08	287	19 08	347	23 08	47	3 08
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to L.M.T. (*added* if *west*, *subtracted* if *east*) to give G.M.T., or vice versa, particularly in the case of sunrise, sunset, etc.

Figure 9-7. Air Almanac Conversion of ARC to Time.

Hemisphere and added in the Eastern Hemisphere. The opposite is true converting from LMT to GMT, as indicated at the bottom of figure 9-5.

SIDEREAL TIME

Solar time is measured with reference to the true Sun or the mean Sun. Time may also be measured by the Earth's rotation relative to some fixed point in space. Time so measured is sidereal or star time. The reference point used is the first point of Aries, which is considered as stationary in space, although it does have slight movement.

The sidereal day begins when the first point of Aries transits the upper branch of the observer's meridian. Local sidereal time (LST) is the number of hours that the first point of Aries has moved westward from the observer's meridian. Expressed in degrees, it is equal to the LHA of Aries. This is shown in figure 9-8. Local sidereal time at Greenwich is Greenwich sidereal time (GST), which is equivalent to the GHA of Aries.

Greenwich sideral time, or GHA of Aries, specifies the position of the stars with relation to the Earth. Thus, a given star is in the same position relative to the Earth at the same sidereal time each day.

NUMBER OF DAYS IN A YEAR

A year is the period of the Earth's revolution about the Sun. The number of days in the year is determined by the number of rotations of the Earth during one revolution.

Actually, the Earth rotates eastward about 366.24 times in the course of its 1 yearly eastward revolution. The total effect of one revolution and 366.24 rotations is that the Sun appears to revolve around the Earth 365.24 times per year. Therefore, there are 365.24 solar days per year.

Since the sidereal day is measured with reference to a relatively fixed point, the length of the sidereal day is essentially the period of the Earth's rotation. Therefore, the number of sidereal days in the year is equal to the number of rotations per year, which is 366.24.

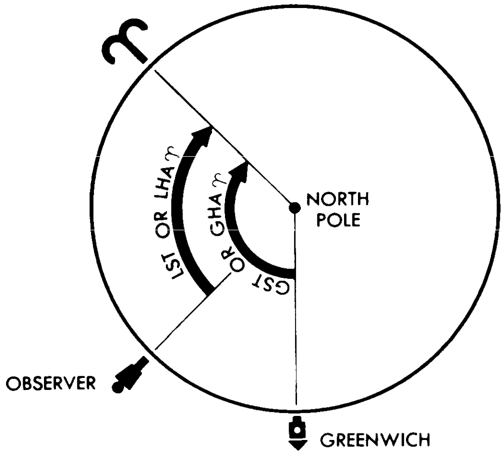


Figure 9-8. Greenwich Sidereal Time.

Time, regardless of which type is considered, is measured with respect to either a celestial body or fictitious point in space. Time has a definite relationship to longitude, namely, that 15° equals 1 hour. Since this relationship exists, celestial bodies can be positioned with reference to time.

NAVIGATOR'S USE OF TIME

The navigator makes direct use of three different kinds of time. These are Greenwich mean time (GMT), local mean time (LMT), and zone time (ZT). All three are based upon the motions of the fictitious "mean Sun". The mean Sun is considered to revolve about the Earth at the average rate of the "apparent Sun," making one complete revolution in 24 hours.

The reckoning of time is based upon the motion of the Sun relative to a given meridian, the time being 2400-0000 at lower transit and 1200 at upper transit. In Greenwich mean time, the reference meridian is that of Greenwich; in local mean time, the reference meridian is that of a given place; in zone time, the reference meridian is the standard meridian of a given zone.

The difference between two times is equal to the difference of longitude of their reference meridians, expressed in units of time. GMT differs from LMT by the longitude of the place; GMT differs from ZT by the longitude of the standard meridian of the zone; LMT differs from ZT by the difference of longitude between the standard meridian of the zone and the meridian of the place. In applying a time difference, a place which is east of another place has a later time than that place, and a place which is west of another place has an earlier time than that place. In interconverting ZT and GMT, the navigator makes use of zone description in applying these rules. The zone difference (ZD) of a zone is the time difference between its standard meridian and GMT, and it is given a sign to indicate the correction to ZT to obtain GMT. The sign is plus (+) for places in west longitude and minus (–) for places in east longitude.

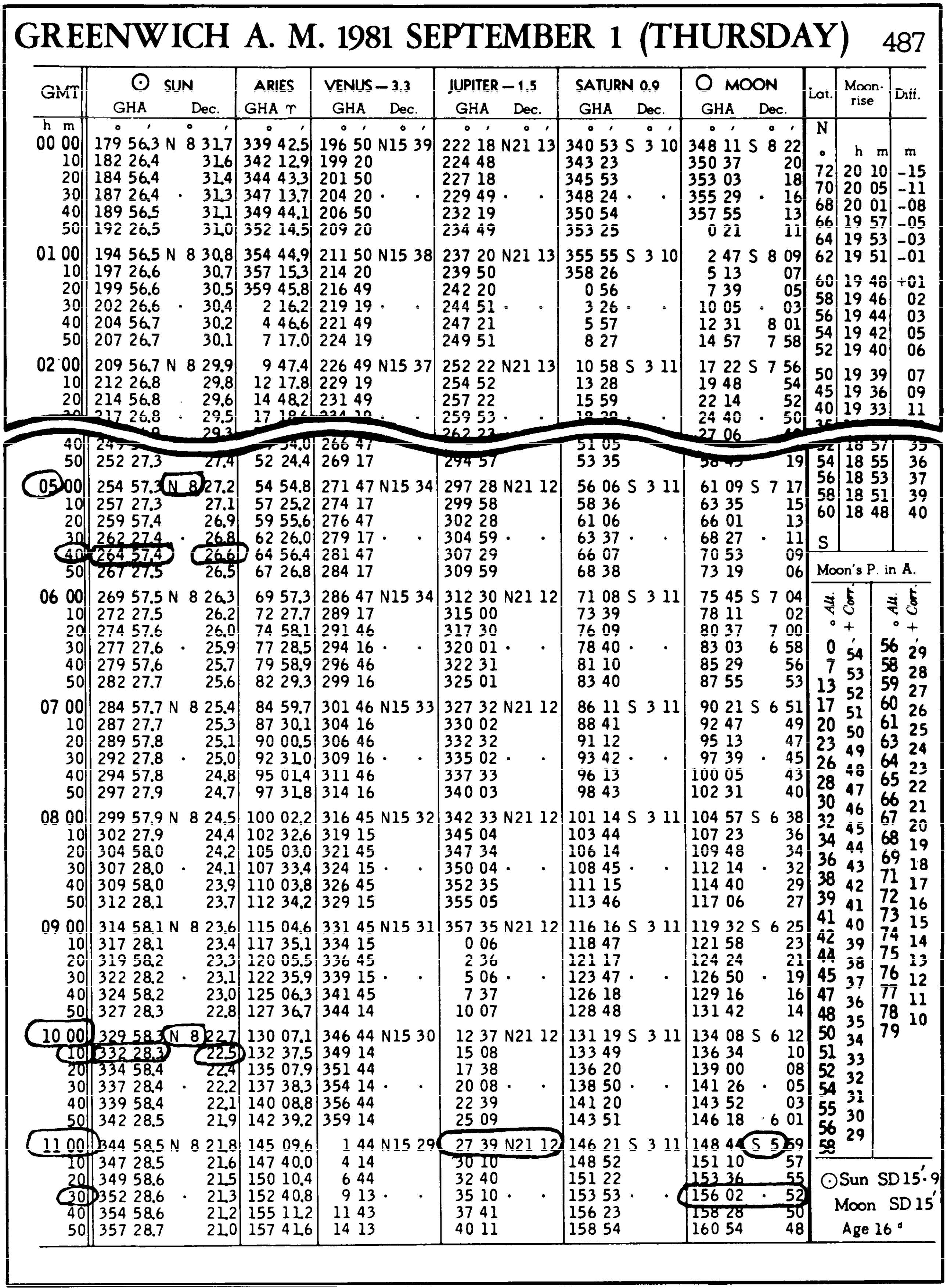
AIR ALMANAC

Although the Air Almanac contains a variety of astronomical data needed in navigation, most of it is devoted to the tabulation of the GHA of Aries, and the GHA and Declination of the Sun, the three navigational planets most favorably located for observation, and the Moon. Enter the daily pages, which are arranged in calendar form, with Greenwich date and GMT to extract the GHA and Declination (Dec) of a celestial body.

Finding GHA and Dec of the Sun

The GHA of the Sun is listed for 10-minute intervals on each daily sheet. If the time of the observation is listed, read the GHA and Dec directly under the proper column opposite the time.

For example, find the GHA and Dec of the Sun at GMT 0540 on 1 Sep 81. Refer to figure 9-9. The GHA is 264° – 57′.4 and Dec is N 8° – 26′.6. NOTE: For use with the astrotracker, the GHA and Dec are given to 0′.1′ with the decimal in smaller type. For general use, it suffices to ignore this decimal instead of rounding off in the normal way. A small additional error, never



GREENWICH A. M. 1981 SEPTEMBER 1 (THURSDAY) 487

GMT	☉ SUN GHA	☉ SUN Dec.	ARIES GHA ♈	VENUS — 3.3 GHA	VENUS — 3.3 Dec.	JUPITER — 1.5 GHA	JUPITER — 1.5 Dec.	SATURN 0.9 GHA	SATURN 0.9 Dec.	○ MOON GHA	○ MOON Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
00 00	179 56.3	N 8 31.7	339 42.5	196 50	N15 39	222 18	N21 13	340 53	S 3 10	348 11	S 8 22
10	182 26.4	31.6	342 12.9	199 20		224 48		343 23		350 37	20
20	184 56.4	31.4	344 43.3	201 50		227 18		345 53		353 03	18
30	187 26.4	· 31.3	347 13.7	204 20	· ·	229 49	· ·	348 24	· ·	355 29	· 16
40	189 56.5	31.1	349 44.1	206 50		232 19		350 54		357 55	13
50	192 26.5	31.0	352 14.5	209 20		234 49		353 25		0 21	11
01 00	194 56.5	N 8 30.8	354 44.9	211 50	N15 38	237 20	N21 13	355 55	S 3 10	2 47	S 8 09
10	197 26.6	30.7	357 15.3	214 20		239 50		358 26		5 13	07
20	199 56.6	30.5	359 45.8	216 49		242 20		0 56		7 39	05
30	202 26.6	· 30.4	2 16.2	219 19	· ·	244 51	· ·	3 26	· ·	10 05	· 03
40	204 56.7	30.2	4 46.6	221 49		247 21		5 57		12 31	8 01
50	207 26.7	30.1	7 17.0	224 19		249 51		8 27		14 57	7 58
02 00	209 56.7	N 8 29.9	9 47.4	226 49	N15 37	252 22	N21 13	10 58	S 3 11	17 22	S 7 56
10	212 26.8	29.8	12 17.8	229 19		254 52		13 28		19 48	54
20	214 56.8	29.6	14 48.2	231 49		257 22		15 59		22 14	52
	217 26.8	· 29.5	17 18	234 19	· ·	259 53	· ·	18 29	· ·	24 40	· 50
		29.3				262 23				27 06	
40	[illegible]		[illegible]	266 47				51 05			
50	252 27.3	27.4	52 24.4	269 17		294 57		53 35		[illegible]	19
05 00	254 57.3	N 8 27.2	54 54.8	271 47	N15 34	297 28	N21 12	56 06	S 3 11	61 09	S 7 17
10	257 27.3	27.1	57 25.2	274 17		299 58		58 36		63 35	15
20	259 57.4	26.9	59 55.6	276 47		302 28		61 06		66 01	13
30	262 27.4	· 26.8	62 26.0	279 17	· ·	304 59	· ·	63 37	· ·	68 27	· 11
40	264 57.4	26.6	64 56.4	281 47		307 29		66 07		70 53	09
50	267 27.5	26.5	67 26.8	284 17		309 59		68 38		73 19	06
06 00	269 57.5	N 8 26.3	69 57.3	286 47	N15 34	312 30	N21 12	71 08	S 3 11	75 45	S 7 04
10	272 27.5	26.2	72 27.7	289 17		315 00		73 39		78 11	02
20	274 57.6	26.0	74 58.1	291 46		317 30		76 09		80 37	7 00
30	277 27.6	· 25.9	77 28.5	294 16	· ·	320 01	· ·	78 40	· ·	83 03	6 58
40	279 57.6	25.7	79 58.9	296 46		322 31		81 10		85 29	56
50	282 27.7	25.6	82 29.3	299 16		325 01		83 40		87 55	53
07 00	284 57.7	N 8 25.4	84 59.7	301 46	N15 33	327 32	N21 12	86 11	S 3 11	90 21	S 6 51
10	287 27.7	25.3	87 30.1	304 16		330 02		88 41		92 47	49
20	289 57.8	25.1	90 00.5	306 46		332 32		91 12		95 13	47
30	292 27.8	· 25.0	92 31.0	309 16	· ·	335 02	· ·	93 42	· ·	97 39	· 45
40	294 57.8	24.8	95 01.4	311 46		337 33		96 13		100 05	43
50	297 27.9	24.7	97 31.8	314 16		340 03		98 43		102 31	40
08 00	299 57.9	N 8 24.5	100 02.2	316 45	N15 32	342 33	N21 12	101 14	S 3 11	104 57	S 6 38
10	302 27.9	24.4	102 32.6	319 15		345 04		103 44		107 23	36
20	304 58.0	24.2	105 03.0	321 45		347 34		106 14		109 48	34
30	307 28.0	· 24.1	107 33.4	324 15	· ·	350 04	· ·	108 45	· ·	112 14	· 32
40	309 58.0	23.9	110 03.8	326 45		352 35		111 15		114 40	29
50	312 28.1	23.7	112 34.2	329 15		355 05		113 46		117 06	27
09 00	314 58.1	N 8 23.6	115 04.6	331 45	N15 31	357 35	N21 12	116 16	S 3 11	119 32	S 6 25
10	317 28.1	23.4	117 35.1	334 15		0 06		118 47		121 58	23
20	319 58.2	23.3	120 05.5	336 45		2 36		121 17		124 24	21
30	322 28.2	· 23.1	122 35.9	339 15	· ·	5 06	· ·	123 47	· ·	126 50	· 19
40	324 58.2	23.0	125 06.3	341 45		7 37		126 18		129 16	16
50	327 28.3	22.8	127 36.7	344 14		10 07		128 48		131 42	14
10 00	329 58.3	N 8 22.7	130 07.1	346 44	N15 30	12 37	N21 12	131 19	S 3 11	134 08	S 6 12
10	332 28.3	22.5	132 37.5	349 14		15 08		133 49		136 34	10
20	334 58.4	22.4	135 07.9	351 44		17 38		136 20		139 00	08
30	337 28.4	· 22.2	137 38.3	354 14	· ·	20 08	· ·	138 50	· ·	141 26	· 05
40	339 58.4	22.1	140 08.8	356 44		22 39		141 20		143 52	03
50	342 28.5	21.9	142 39.2	359 14		25 09		143 51		146 18	6 01
11 00	344 58.5	N 8 21.8	145 09.6	1 44	N15 29	27 39	N21 12	146 21	S 3 11	148 44	S 5 59
10	347 28.5	21.6	147 40.0	4 14		30 10		148 52		151 10	57
20	349 58.6	21.5	150 10.4	6 44		32 40		151 22		153 36	55
30	352 28.6	· 21.3	152 40.8	9 13	· ·	35 10	· ·	153 53	· ·	156 02	· 52
40	354 58.6	21.2	155 11.2	11 43		37 41		156 23		158 28	50
50	357 28.7	21.0	157 41.6	14 13		40 11		158 54		160 54	48

Lat.	Moon-rise	Diff.
N		
°	h m	m
72	20 10	-15
70	20 05	-11
68	20 01	-08
66	19 57	-05
64	19 53	-03
62	19 51	-01
60	19 48	+01
58	19 46	02
56	19 44	03
54	19 42	05
52	19 40	06
50	19 39	07
45	19 36	09
40	19 33	11
52	18 57	35
54	18 55	36
56	18 53	37
58	18 51	39
60	18 48	40
S		

Moon's P. in A.

° Alt.	+ Corr. ′	° Alt.	+ Corr. ′
0		56	
	54		29
7		58	
	53		28
13		59	
	52		27
17		60	
	51		26
20		61	
	50		25
23		63	
	49		24
26		64	
	48		23
28		65	
	47		22
30		66	
	46		21
32		67	
	45		20
34		68	
	44		19
36		69	
	43		18
38		71	
	42		17
39		72	
	41		16
41		73	
	40		15
42		74	
	39		14
44		75	
	38		13
45		76	
	37		12
47		77	
	36		11
48		78	
	35		10
50		79	
	34		
51			
	33		
52			
	32		
54			
	31		
55			
	30		
56			
	29		
58			

☉Sun SD 15′.9
Moon SD 15′
Age 16 ᵈ

Figure 9-9. Daily Page from Air Almanac.

INTERPOLATION OF G.H.A.

Increment to be added for intervals of G.M.T. to G.H.A. of:
Sun, Aries (♈) and planets; Moon.

SUN, etc. m s	° ′	MOON m s	SUN, etc. m s	° ′	MOON m s	SUN, etc. m s	° ′	MOON m s
00 00		00 00	03 17		03 25	06 37		06 52
01	0 00	00 02	21	0 50	03 29	41	1 40	06 56
05	0 01	00 06	25	0 51	03 33	45	1 41	07 00
09	0 02	00 10	29	0 52	03 37	49	1 42	07 04
13	0 03	00 14	33	0 53	03 41	53	1 43	07 08
17	0 04	00 18	37	0 54	03 45	06 57	1 44	07 13
21	0 05	00 22	41	0 55	03 49	07 01	1 45	07 17
25	0 06	00 26	45	0 56	03 54	05	1 46	07 21
29	0 07	00 31	49	0 57	03 58	09	1 47	07 25
33	0 08	00 35	53	0 58	04 02	13	1 48	07 29
37	0 09	00 39	03 57	0 59	04 06	17	1 49	07 33
41	0 10	00 43	04 01	1 00	04 10	21	1 50	07 37
45	0 11	00 47	05	1 01	04 14	25	1 51	07 42
49	0 12	00 51	09	1 02	04 19	29	1 52	07 46
53	0 13	00 55	13	1 03	04 23	33	1 53	07 50
00 57	0 14	01 00	17	1 04	04 27	37	1 54	07 54
01 01	0 15	01 04	21	1 05	04 31	41	1 55	07 58
05	0 16	01 08	25	1 06	04 35	45	1 56	08 02
09	0 17	01 12	29	1 07	04 39	49	1 57	08 06
13	0 18	01 16	33	1 08	04 43	53	1 58	08 11
17	0 19	01 20	37	1 09	04 48	07 57	1 59	08 15
21	0 20	01 24	41	1 10	04 52	08 01	2 00	08 19
25	0 21	01 29	45	1 11	04 56	05	2 01	08 23
29	0 22	01 33	49	1 12	05 00	09	2 02	08 27
33	0 23	01 37	53	1 13	05 04	13	2 03	08 31
37	0 24	01 41	04 57	1 14	05 08	17	2 04	08 35
41	0 25	01 45	05 01	1 15	05 12	21	2 05	08 40
45	0 26	01 49	05	1 16	05 17	25	2 06	08 44
49	0 27	01 53	09	1 17	05 21	29	2 07	08 48
53	0 28	01 58	13	1 18	05 25	33	2 08	08 52
01 57	0 29	02 02	17	1 19	05 29	37	2 09	08 56
02 01	0 30	02 06	21	1 20	05 33	41	2 10	09 00
05	0 31	02 10	25	1 21	05 37	45	2 11	09 04
09	0 32	02 14	29	1 22	05 41	49	2 12	09 09
13	0 33	02 18	33	1 23	05 46	53	2 13	09 13
17	0 34	02 22	37	1 24	05 50	08 57	2 14	09 17
21	0 35	02 27	41	1 25	05 54	09 01	2 15	09 21
25	0 36	02 31	45	1 26	05 58	05	2 16	09 25
29	0 37	02 35	49	1 27	06 02	09	2 17	09 29
33	0 38	02 39	53	1 28	06 06	13	2 18	09 33
37	0 39	02 43	05 57	1 29	06 10	17	2 19	09 38
41	0 40	02 47	06 01	1 30	06 15	21	2 20	09 42
45	0 41	02 51	05	1 31	06 19	25	2 21	09 46
49	0 42	02 56	09	1 32	06 23	29	2 22	09 50
53	0 43	03 00	13	1 33	06 27	33	2 23	09 54
02 57	0 44	03 04	17	1 34	06 31	37	2 24	09 58
03 01	0 45	03 08	21	1 35	06 35	41	2 25	10 00
05	0 46	03 12	25	1 36	06 39	45	2 26	
09	0 47	03 16	29	1 37	06 44	49	2 27	
13	0 48	03 20	33	1 38	06 48	53	2 28	
17	0 49	03 25	37	1 39	06 52	09 57	2 29	
03 21	0 50	03 29	06 41	1 40	06 56	10 00	2 30	

Figure 9-10. Interpolation of GHA, Air Almanac.

exceeding 0′.5′ arises, if, as recommended, the decimal in smaller type is ignored rather than rounded off. This error can be avoided by rounding off the tabulated values. Therefore, in this example, the GHA is 264° − 57′ and the Dec is N 8° − 27′. To convert these values to the geographical coordinates of the subpoint for the time of the observation, latitude is 8° − 27′ north. When GHA is greater than 180°, subtract it from 360° to get east longitude. Therefore, longitude in this example is (360° − 264°57′) 95°03′E.

When an observation is made at a time not listed, make the main entry for the time immediately before that of the GMT required. Then, use the table marked "Interpolation of GHA" to determine the increment to be added to GHA (see figure 9-10).

This table is conveniently located both inside the front cover of the almanac and on the back of the star chart.

On 1 September 1981, the Sun is observed at 1012 GMT. What is the GHA and Declination? Turning to the A.M. page for 1 September 1981 (figure 9-9), the GHA listed for 1010 is 332° − 28′. The observation is for a time 2 minutes after the listed time. In the "Interpolation of GHA" table (figure 9-10), the correction listed for 2 minutes of time is 30′ of arc. By adding this correction to the listed GHA, the GHA of the Sun for the exact time of the observation is 332° − 58′. The Dec for the same time is N 8° − 23′. Thus, at the time of the observation, the subpoint of the Sun is at latitude 8° − 23′ north, longitude (360° − 332° 58′) 027° − 02′ east.

Finding GHA and Declination of the Sun Without the Air Almanac

It is possible to obtain an accurate Greenwich Hour Angle and Declination of the Sun without the use of the Air Almanac. The procedure and applicable tables are included in the HO 249, vol II and III. The following is an example with the tables included:

Problem: Determine the GHA and Declination of the Sun for 18 Jan 1981 GMT = 0330:35

Step One: Determine the Orbit Time (OT)
OT = GMT (nearest integral hour)
+ Corr. (Table a)
OT = 18 Jan 0400 + 7 hr
OT = 18 Jan 1100

Step Two: Enter table 4 to determine E and declinations (figure 9-11)
E = 5 degrees + Equation of Time
Jan 18 OT E = 2 − 26 Dec = S20 − 40

Step Three: Corrections to E and Dec are found in table b. These values are found by entering vertically with the number of hours in the OT and horizontally with the difference between consecutive values of E and Dec

Jan 18th OT	E = 2 − 26	Dec = S20 − 40
Corr	− −02	− −06
	2 − 24	S20 − 34

Step four: Obtain the final value by adding the values of the diurnal arc from tables c and d to correct the GHA (figure 9-12). *Note:* This table is entered using the original GMT, not the OT determined in step one

GHA =	002 − 24
Table c	227 − 30
Table d	0 − 09
GHA =	230 − 03 Dec = S20 − 40

Finding GHA and Dec of a Planet

GHA and Dec of a planet can be obtained in almost the same way as GHA and Dec of the Sun. The declination of a planet

GHA and Declination of the Sun for the Years 1965-2000—Argument "Orbit Time"

2

O.T.	JAN			FEB			MAR			APR		
00h	E	Dec.		E	Dec.		E	Dec.		E	Dec.	
d	° ′	° ′		° ′	° ′		° ′	° ′		° ′	° ′	
1	4 11	S 23 03	5	1 37	S 17 16	17	1 52	S 7 49	23	3 58	N 4 18	24
2	4 04	22 58	5	1 35	16 59	17	1 55	7 26	23	4 02	4 42	23
3	3 57	22 53	6	1 33	16 42	18	1 58	7 03	23	4 07	5 05	23
4	3 50	22 47	6	1 31	16 24	18	2 01	6 40	23	4 11	5 28	23
5	3 43	22 41	7	1 30	16 06	18	2 04	6 17	23	4 16	5 51	22
6	3 36	S 22 34	7	1 29	S 15 48	18	2 07	S 5 54	23	4 20	N 6 13	23
7	3 30	22 27	8	1 28	15 30	19	2 11	5 31	24	4 24	6 36	23
8	3 23	22 19	8	1 27	15 11	19	2 14	5 07	23	4 28	6 59	22
9	3 17	22 11	8	1 26	14 52	19	2 18	4 44	24	4 33	7 21	22
10	3 11	22 03	9	1 26	14 33	20	2 22	4 20	23	4 37	7 43	23
11	3 05	S 21 54	10	1 26	S 14 13	20	2 26	S 3 57	24	4 41	N 8 06	22
12	2 59	21 44	9	1 26	13 53	20	2 30	3 33	23	4 45	8 28	22
13	2 53	21 35	10	1 26	13 33	20	2 34	3 10	24	4 49	8 50	21
14	2 47	21 25	11	1 26	13 13	20	2 38	2 46	24	4 53	9 11	22
15	2 42	21 14	11	1 27	12 53	21	2 42	2 22	23	4 56	9 33	21
16	2 37	S 21 03	11	1 27	S 12 32	20	2 46	S 1 59	24	5 00	N 9 54	22
17	2 31	20 52	12	1 28	12 12	21	2 50	1 35	24	5 04	10 16	21
18	2 26	20 40	12	1 29	11 51	22	2 55	1 11	23	5 07	10 37	21
19	2 22	20 28	13	1 30	11 29	21	2 59	0 48	24	5 10	10 58	21
20	2 17	20 15	13	1 32	11 08	22	3 04	S 0 24	24	5 14	11 19	20
21	2 13	S 20 02	13	1 33	S 10 46	21	3 08	0 00	24	5 17	N 11 39	21
22	2 08	19 49	14	1 35	10 25	22	3 12	N 0 24	23	5 20	12 00	20
23	2 04	19 35	14	1 37	10 03	22	3 17	0 47	24	5 23	12 20	20
24	2 00	19 21	14	1 39	9 41	22	3 22	1 11	24	5 26	12 40	20
25	1 57	19 07	15	1 41	9 19	23	3 26	1 35	23	5 29	13 00	19
26	1 53	S 18 52	15	1 44	S 8 56	22	3 31	N 1 58	24	5 31	N 13 19	19
27	1 50	18 37	16	1 46	8 34	23	3 35	2 22	23	5 34	13 38	20
28	1 47	18 21	16	1 49	8 11	22	3 40	2 45	24	5 36	13 58	19
29	1 44	18 05	16	1 52	7 49	23	3 44	3 09	23	5 38	14 17	18
30	1 41	17 49	16				3 49	3 32	23	5 40	14 35	19
31	1 39	S 17 33	17				3 53	N 3 55	23			

O.T.	MAY			JUN			JUL			AUG		
00h	E	Dec.		E	Dec.		E	Dec.		E	Dec.	
d	° ′	° ′		° ′	° ′		° ′	° ′		° ′	° ′	
1	5 42	N 14 54	18	5 36	N 21 58	8	4 06	N 23 09	4	3 25	N 18 10	15
2	5 44	15 12	18	5 33	22 06	8	4 03	23 05	4	3 26	17 55	15
3	5 46	15 30	17	5 31	22 14	8	4 00	23 01	5	3 27	17 40	16
4	5 48	15 47	18	5 28	22 22	7	3 57	22 56	5	3 28	17 24	16
5	5 49	16 05	17	5 26	22 29	6	3 55	22 51	6	3 30	17 08	16
6	5 50	N 16 22	17	5 23	N 22 35	7	3 52	N 22 45	6	3 31	N 16 52	16
7	5 51	16 39	16	5 21	22 42	5	3 49	22 39	6	3 33	16 36	17
8	5 52	16 55	17	5 18	22 47	6	3 47	22 33	7	3 35	16 19	17
9	5 53	17 12	16	5 15	22 53	5	3 45	22 26	7	3 37	16 02	17
10	5 54	17 28	15	5 12	22 58	5	3 42	22 19	8	3 39	15 45	18
11	5 55	N 17 43	16	5 09	N 23 03	4	3 40	N 22 11	8	3 41	N 15 27	18
12	5 55	17 59	15	5 06	23 07	4	3 38	22 03	8	3 43	15 09	18
13	5 56	18 14	15	5 03	23 11	3	3 36	21 55	9	3 46	14 51	18
14	5 56	18 29	14	5 00	23 14	3	3 35	21 46	9	3 48	14 33	18
15	5 56	18 43	15	4 57	23 17	3	3 33	21 37	9	3 51	14 15	19
16	5 56	N 18 58	13	4 54	N 23 20	2	3 31	N 21 28	10	3 54	N 13 56	19
17	5 55	19 11	14	4 50	23 22	2	3 30	21 18	10	3 57	13 37	19
18	5 55	19 25	13	4 47	23 24	1	3 29	21 08	10	4 00	13 18	19
19	5 54	19 38	13	4 44	23 25	1	3 28	20 58	11	4 04	12 59	20
20	5 54	19 51	13	4 41	23 26	0	3 27	20 47	11	4 07	12 39	20
21	5 53	N 20 04	12	4 37	N 23 26	1	3 26	N 20 36	12	4 11	N 12 19	20
22	5 52	20 16	12	4 34	23 27	1	3 25	20 24	12	4 14	11 59	20
23	5 51	20 28	11	4 31	23 26	1	3 24	20 12	12	4 18	11 39	20
24	5 50	20 39	11	4 28	23 25	1	3 24	20 00	13	4 22	11 19	21
25	5 48	20 50	11	4 24	23 24	1	3 24	19 47	13	4 26	10 58	20
26	5 47	N 21 01	11	4 21	N 23 23	2	3 23	N 19 34	13	4 30	N 10 38	21
27	5 45	21 12	10	4 18	23 21	2	3 23	19 21	13	4 34	10 17	21
28	5 44	21 22	9	4 15	23 19	3	3 23	19 08	14	4 38	9 56	21
29	5 42	21 31	10	4 12	23 16	3	3 24	18 54	14	4 43	9 35	22
30	5 40	21 41	9	4 09	23 13	4	3 24	18 40	15	4 47	9 13	21
31	5 38	N 21 50	8				3 25	N 18 25	15	4 52	N 8 52	22

SEP			OCT			NOV			DEC			O.T.
E	Dec.		E	Dec.		E	Dec.		E	Dec.		00h
° ′	° ′		° ′	° ′		° ′	° ′		° ′	° ′		d
4 57	N 8 30	22	7 31	S 2 57	23	9 05	S 14 14	19	7 48	S 21 42	10	1
5 01	8 08	21	7 36	3 20	24	9 06	14 33	19	7 43	21 52	9	2
5 06	7 47	22	7 41	3 44	23	9 06	14 52	19	7 37	22 01	8	3
5 11	7 25	23	7 45	4 07	23	9 06	15 11	19	7 31	22 09	8	4
5 16	7 02	22	7 50	4 30	23	9 06	15 30	18	7 25	22 17	8	5
5 21	N 6 40	22	7 55	S 4 53	23	9 05	S 15 48	18	7 19	S 22 25	7	6
5 26	6 18	23	7 59	5 16	23	9 05	16 06	18	7 12	22 32	7	7
5 31	5 55	22	8 03	5 39	23	9 04	16 24	17	7 06	22 39	7	8
5 36	5 33	23	8 07	6 02	23	9 03	16 41	17	7 00	22 46	5	9
5 41	5 10	23	8 12	6 25	22	9 02	16 58	17	6 53	22 51	6	10
5 47	N 4 47	22	8 16	S 6 47	23	9 00	S 17 15	17	6 46	S 22 57	5	11
5 52	4 25	23	8 19	7 10	23	8 59	17 32	16	6 39	23 02	4	12
5 57	4 02	23	8 23	7 33	22	8 57	17 48	16	6 32	23 06	5	13
6 02	3 39	23	8 27	7 55	22	8 55	18 04	16	6 25	23 11	3	14
6 08	3 16	23	8 30	8 17	23	8 52	18 20	15	6 18	23 14	3	15
6 13	N 2 53	23	8 34	S 8 40	22	8 50	S 18 35	15	6 11	S 23 17	3	16
6 18	2 30	24	8 37	9 02	22	8 47	18 50	15	6 03	23 20	2	17
6 24	2 06	23	8 40	9 24	22	8 44	19 05	14	5 56	23 22	2	18
6 29	1 43	23	8 43	9 46	21	8 41	19 19	14	5 49	23 24	1	19
6 34	1 20	23	8 46	10 07	22	8 38	19 33	14	5 41	23 25	1	20
6 40	N 0 57	24	8 48	S 10 29	21	8 34	S 19 47	13	5 34	S 23 26	1	21
6 45	0 33	23	8 51	10 50	21	8 30	20 00	13	5 26	23 27	1	22
6 50	N 0 10	23	8 53	11 11	22	8 26	20 13	13	5 19	23 26	0	23
6 56	S 0 13	24	8 55	11 33	20	8 22	20 26	12	5 11	23 26	1	24
7 01	0 37	23	8 57	11 53	21	8 18	20 38	11	5 04	23 25	2	25
7 06	S 1 00	24	8 59	S 12 14	21	8 14	S 20 49	12	4 57	S 23 23	2	26
7 11	1 24	23	9 00	12 35	20	8 09	21 01	11	4 49	23 21	2	27
7 16	1 47	23	9 02	12 55	20	8 04	21 12	11	4 42	23 19	3	28
7 21	2 10	24	9 03	13 15	20	7 59	21 23	10	4 34	23 16	4	29
7 26	2 34	23	9 04	13 35	20	7 54	21 33	9	4 27	23 12	4	30
			9 05	S 13 55	19				4 20	S 23 08	4	31

a. Corr. to GMT

1

Year	Corr.	Year	Corr.	Year	Corr.
	h		h		h
1965	+ 4	1977	+ 7	1989	+ 9
1966	− 1	1978	+ 1	1990	+ 3
1967	− 7	1979	− 5	1991	− 3
1968	−13	1980	−11	1992	− 9
"	+11•	"	+13•	"	+15•
1969	+ 5	1981	+ 7	1993	+10
1970	− 1	1982	+ 1	1994	+ 4
1971	− 7	1983	− 4	1995	− 2
1972	−12	1984	−10	1996	− 8
"	+12•	"	+14•	"	+16•
1973	+ 6	1985	+ 8	1997	+10
1974	0	1986	+ 2	1998	+ 4
1975	− 6	1987	− 4	1999	− 1
1976	−12	1988	− 9	2000	− 7
"	+12•	"	+15•	"	+17•

• After Feb. 29

b. Interpolation for Hours of O.T.

Diff.	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24	Diff.	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24
h	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	h	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′	′ ′ ′
0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	12	1 1 2	2 3 3	4 4 5	5 6 6	7 7 8	8 9 9	10 10 11	11 12 12
1	0 0 0	0 0 0	0 0 0	0 0 1	1 1 1	1 1 1	1 1 1	1 1 1	13	1 1 2	2 3 3	4 4 5	5 6 7	7 8 8	9 9 10	10 11 11	12 12 13
2	0 0 0	0 0 1	1 1 1	1 1 1	1 1 1	1 1 2	2 2 2	2 2 2	14	1 1 2	2 3 4	4 5 5	6 6 7	8 8 9	9 10 11	11 12 12	13 13 14
3	0 0 0	1 1 1	1 1 1	1 1 2	2 2 2	2 2 2	2 3 3	3 3 3	15	1 1 2	3 3 4	4 5 6	6 7 8	8 9 9	10 11 11	12 13 13	14 14 15
4	0 0 1	1 1 1	1 1 2	2 2 2	2 2 3	3 3 3	3 3 4	4 4 4	16	1 1 2	3 3 4	5 5 6	7 7 8	9 9 10	11 11 12	13 13 14	15 15 16
5	0 0 1	1 1 1	1 2 2	2 2 3	3 3 3	3 4 4	4 4 4	5 5 5	17	1 1 2	3 4 4	5 6 6	7 8 9	9 10 11	11 12 13	13 14 15	16 16 17
6	0 1 1	1 1 2	2 2 2	3 3 3	3 4 4	4 4 5	5 5 5	6 6 6	18	1 2 2	3 4 5	5 6 7	8 8 9	10 11 11	12 13 14	14 15 16	17 17 18
7	0 1 1	1 1 2	2 2 3	3 3 4	4 4 4	5 5 5	6 6 6	6 7 7	19	1 2 2	3 4 5	6 6 7	8 9 10	10 11 12	13 13 14	15 16 17	17 18 19
8	0 1 1	1 2 2	2 3 3	3 4 4	4 5 5	5 6 6	6 7 7	7 8 8	20	1 2 3	3 4 5	6 7 8	8 9 10	11 12 13	13 14 15	16 17 18	18 19 20
9	0 1 1	2 2 2	3 3 3	4 4 5	5 5 6	6 6 7	7 8 8	8 9 9	21	1 2 3	4 4 5	6 7 8	9 10 11	11 12 13	14 15 16	17 18 18	19 20 21
10	0 1 1	2 2 3	3 3 4	4 5 5	5 6 6	7 7 8	8 8 9	9 10 10	22	1 2 3	4 5 6	6 7 8	9 10 11	12 13 14	15 16 17	17 18 19	20 21 22
11	0 1 1	2 2 3	3 4 4	5 5 6	6 6 7	7 8 8	9 9 10	10 11 11	23	1 2 3	4 5 6	7 8 9	10 11 12	12 13 14	15 16 17	18 19 20	21 22 23

Figure 9-11. HO249 Extraction to Compute GHA and DEC.

GHA and Declination of the Sun for the Years 1965–2000—Argument "Orbit Time"—Continued

c. Hours and Tens of minutes of GMT

	00m	10m	20m	30m	40m	50m
h	° ′	° ′	° ′	° ′	° ′	° ′
00	175 00	177 30	180 00	182 30	185 00	187 30
01	190 00	192 30	195 00	197 30	200 00	202 30
02	205 00	207 30	210 00	212 30	215 00	217 30
03	220 00	222 30	225 00	227 30	230 00	232 30
04	235 00	237 30	240 00	242 30	245 00	247 30
05	250 00	252 30	255 00	257 30	260 00	262 30
06	265 00	267 30	270 00	272 30	275 00	277 30
07	280 00	282 30	285 00	287 30	290 00	292 30
08	295 00	297 30	300 00	302 30	305 00	307 30
09	310 00	312 30	315 00	317 30	320 00	322 30
10	325 00	327 30	330 00	332 30	335 00	337 30
11	340 00	342 30	345 00	347 30	350 00	352 30
12	355 00	357 30	0 00	2 30	5 00	7 30
13	10 00	12 30	15 00	17 30	20 00	22 30
14	25 00	27 30	30 00	32 30	35 00	37 30
15	40 00	42 30	45 00	47 30	50 00	52 30
16	55 00	57 30	60 00	62 30	65 00	67 30
17	70 00	72 30	75 00	77 30	80 00	82 30
18	85 00	87 30	90 00	92 30	95 00	97 30
19	100 00	102 30	105 00	107 30	110 00	112 30
20	115 00	117 30	120 00	122 30	125 00	127 30
21	130 00	132 30	135 00	137 30	140 00	142 30
22	145 00	147 30	150 00	152 30	155 00	157 30
23	160 00	162 30	165 00	167 30	170 00	172 30

d. Minutes and Seconds of GMT

m s	° ′	m s	° ′	m s	° ′	m s	° ′	m s	° ′	m s	° ′
00 00		01 37		03 17		04 57		06 37		08 17	
	0 00		0 25		0 50		1 15		1 40		2 05
01		41		21		05 01		41		21	
	0 01		0 26		0 51		1 16		1 41		2 06
05		45		25		05		45		25	
	0 02		0 27		0 52		1 17		1 42		2 07
09		49		29		09		49		29	
	0 03		0 28		0 53		1 18		1 43		2 08
13		53		33		13		53		33	
	0 04		0 29		0 54		1 19		1 44		2 09
17		01 57		37		17		06 57		37	
	0 05		0 30		0 55		1 20		1 45		2 10
21		02 01		41		21		07 01		41	
	0 06		0 31		0 56		1 21		1 46		2 11
25		05		45		25		05		45	
	0 07		0 32		0 57		1 22		1 47		2 12
29		09		49		29		09		49	
	0 08		0 33		0 58		1 23		1 48		2 13
33		13		53		33		13		53	
	0 09		0 34		0 59		1 24		1 49		2 14
37		17		03 57		37		17		08 57	
	0 10		0 35		1 00		1 25		1 50		2 15
41		21		04 01		41		21		09 01	
	0 11		0 36		1 01		1 26		1 51		2 16
45		25		05		45		25		05	
	0 12		0 37		1 02		1 27		1 52		2 17
49		29		09		49		29		09	
	0 13		0 38		1 03		1 28		1 53		2 18
53		33		13		53		33		13	
	0 14		0 39		1 04		1 29		1 54		2 19
00 57		37		17		05 57		37		17	
	0 15		0 40		1 05		1 30		1 55		2 20
01 01		41		21		06 01		41		21	
	0 16		0 41		1 06		1 31		1 56		2 21
05		45		25		05		45		25	
	0 17		0 42		1 07		1 32		1 57		2 22
09		49		29		09		49		29	
	0 18		0 43		1 08		1 33		1 58		2 23
13		53		33		13		53		33	
	0 19		0 44		1 09		1 34		1 59		2 24
17		02 57		37		17		07 57		37	
	0 20		0 45		1 10		1 35		2 00		2 25
21		03 01		41		21		08 01		41	
	0 21		0 46		1 11		1 36		2 01		2 26
25		05		45		25		05		45	
	0 22		0 47		1 12		1 37		2 02		2 27
29		09		49		29		09		49	
	0 23		0 48		1 13		1 38		2 03		2 28
33		13		53		33		13		53	
	0 24		0 49		1 14		1 39		2 04		2 29
37		17		04 57		37		17		09 57	
	0 25		0 50		1 15		1 40		2 05		2 30
01 41		03 21		05 01		06 41		08 21		10 00	

Figure 9-12. HO249 Extraction to Compute GHA and DEC.

changes slowly; therefore, it is recorded only at hourly intervals. The Dec listed for the hour is used for the entire hour.

For 1 September 1981, find the GHA and Dec of Jupiter at 1109 GMT. Enter the correct daily page (see figure 9-9) for the time of 1100 GMT. The GHA and Dec for 1100 GMT is 27° − 39′ GHA and N21° − 12′Dec. Enter the Interpolation of GHA table under Sun, etc. (figure 9-10) and obtain the adjustment to be added for 9 minutes. For a 9-minute interval of GMT, the increment to be added is 2° − 15′. Therefore, GHA is 29° − 54′. The subpoint of Jupiter at the time of the observation is at latitude 21° − 12′N, longitude 29° − 54′ W.

Finding GHA and Dec of Moon

The Moon moves across the sky at a different rate than the Sun and planets; consequently, its GHA and Dec is given at 10-minute intervals. In the interpolation tables for the GHA, separate values on the right are used for the Moon.

The tables are arranged as critical tables, and the increment is found opposite the interval (in the left-hand column for the Sun, Aries, and planets; in the right-hand column for the Moon) in which the difference of GMT occurs. If the difference (for example, $06^{m}31^{s}$ for the Moon) is an exact tabular value, the upper of the two possible increments (that is, 1°34′) should be taken. This rule applies generally to all critical tables.

On 1 September 1981, the Moon is observed at 1136 GMT. The following information is extracted from the Air Almanac (see figures 9-9 and 9-10):

GHA of Moon at 1130 GMT	156°02′
GHA Correction for 6 minutes	1°27′
GHA	157°29′
Declination	S5°52′

Thus, at the time of the observation, the subpoint of the Moon is at latitude 5° − 52′ S, longitude 157° − 29′ W.

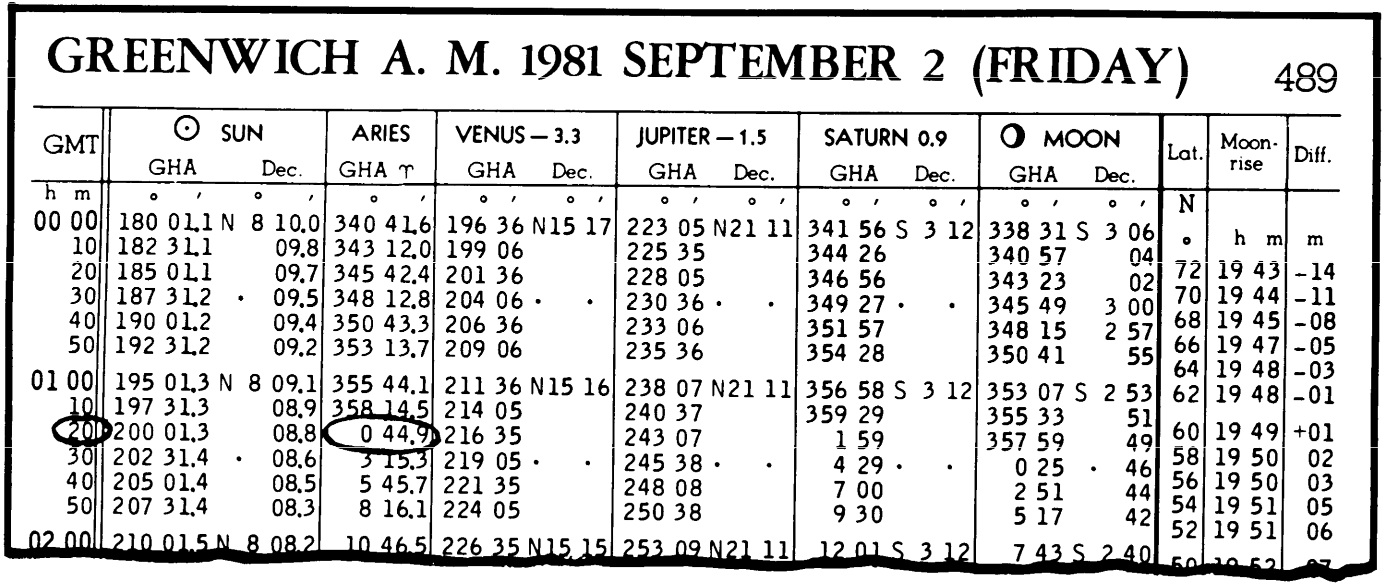
Finding GHA and Dec of a Star

Since the declination of each star is constant throughout the period of the almanac, it need be shown only once. The Sun, Moon, and planets move across the sky at varying rates and, as a result, their GHA changes irregularly. However, the stars and the first point of Aries remain fixed in their same relative positions in space, so that the GHAs of all stars and Aries change at the same rate. Consequently, it is unnecessary for the almanac to list the GHA of each navigational star throughout the day. Instead, the almanac lists the GHA of Aries at 10-minute intervals and gives the SHA of the star only once. The GHA of a star for any time can be found by adding the GHA of Aries for that time and the SHA of the star.

The table, "STARS," is found inside the front cover of the almanac and on the back of the star chart. This table lists navigational stars and the following information for each star: the number corresponding to the sky diagram in the back, the name, the magnitude or relative brightness, the SHA, the declination, whether used in HO 249, and stars that can be used with declination tables. Note: When a higher degree of accuracy is required, the SHA and declination of the stars is listed to tenths of degree in the white pages of the Air Almanac.

On 2 September 1981, Altair is observed at $01^{h}24^{m}$GMT. What is its GHA and declination? Look at the extracts from the tables in figures 9-13 and 9-14 to see where the values were obtained.

GHA γ $01^{h}20^{m}$ GMT	360° − 45′
GHA γ correction for 4^{m}	1° − 00′
GHA γ $01^{h}24^{m}$	001° − 45′
SHA Altair	62° − 43′
GHA Altair $01^{h}24^{m}$	064° − 28′
Declination Altair	8° − 47′N



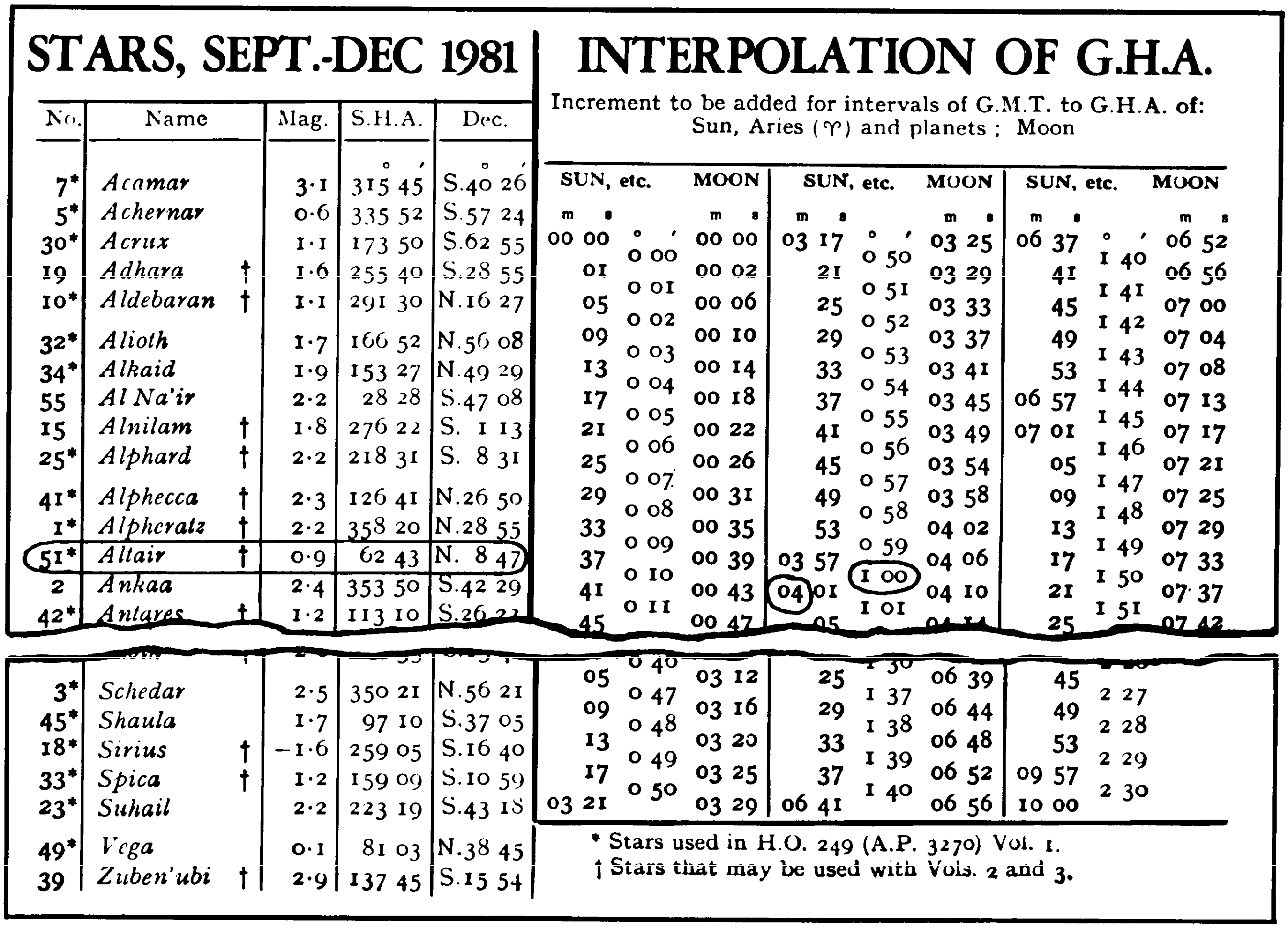
GREENWICH A. M. 1981 SEPTEMBER 2 (FRIDAY) 489

GMT	☉ SUN GHA	Dec.	ARIES GHA ♈	VENUS — 3.3 GHA	Dec.	JUPITER — 1.5 GHA	Dec.	SATURN 0.9 GHA	Dec.	☾ MOON GHA	Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
00 00	180 01.1	N 8 10.0	340 41.6	196 36	N15 17	223 05	N21 11	341 56	S 3 12	338 31	S 3 06
10	182 31.1	09.8	343 12.0	199 06		225 35		344 26		340 57	04
20	185 01.1	09.7	345 42.4	201 36		228 05		346 56		343 23	02
30	187 31.2 ·	09.5	348 12.8	204 06 ·	·	230 36 ·	·	349 27 ·	·	345 49	3 00
40	190 01.2	09.4	350 43.3	206 36		233 06		351 57		348 15	2 57
50	192 31.2	09.2	353 13.7	209 06		235 36		354 28		350 41	55
01 00	195 01.3	N 8 09.1	355 44.1	211 36	N15 16	238 07	N21 11	356 58	S 3 12	353 07	S 2 53
10	197 31.3	08.9	358 14.5	214 05		240 37		359 29		355 33	51
20	200 01.3	08.8	0 44.9	216 35		243 07		1 59		357 59	49
30	202 31.4 ·	08.6	3 15.3	219 05 ·	·	245 38 ·	·	4 29 ·	·	0 25 ·	46
40	205 01.4	08.5	5 45.7	221 35		248 08		7 00		2 51	44
50	207 31.4	08.3	8 16.1	224 05		250 38		9 30		5 17	42
02 00	210 01.5	N 8 08.2	10 46.5	226 35	N15 15	253 09	N21 11	12 01	S 3 12	7 43	S 2 40

Lat.	Moon-rise	Diff.
N °	h m	m
72	19 43	-14
70	19 44	-11
68	19 45	-08
66	19 47	-05
64	19 48	-03
62	19 48	-01
60	19 49	+01
58	19 50	02
56	19 50	03
54	19 51	05
52	19 51	06

Figure 9-13. GHA of Aries Obtained from Air Almanac.

Thus, at the time of the observation, the subpoint of Altair is at latitude 8° – 47′N, longitude 064° – 28′W.



STARS, SEPT.-DEC 1981

No.	Name		Mag.	S.H.A.	Dec.
				° ′	° ′
7*	*Acamar*		3·1	315 45	S.40 26
5*	*Achernar*		0·6	335 52	S.57 24
30*	*Acrux*		1·1	173 50	S.62 55
19	*Adhara*	†	1·6	255 40	S.28 55
10*	*Aldebaran*	†	1·1	291 30	N.16 27
32*	*Alioth*		1·7	166 52	N.56 08
34*	*Alkaid*		1·9	153 27	N.49 29
55	*Al Na'ir*		2·2	28 28	S.47 08
15	*Alnilam*	†	1·8	276 22	S. 1 13
25*	*Alphard*	†	2·2	218 31	S. 8 31
41*	*Alphecca*	†	2·3	126 41	N.26 50
1*	*Alpheratz*	†	2·2	358 20	N.28 55
51*	*Altair*	†	0·9	62 43	N. 8 47
2	*Ankaa*		2·4	353 50	S.42 29
42*	*Antares*	†	1·2	113 10	S.26
3*	*Schedar*		2·5	350 21	N.56 21
45*	*Shaula*		1·7	97 10	S.37 05
18*	*Sirius*	†	–1·6	259 05	S.16 40
33*	*Spica*	†	1·2	159 09	S.10 59
23*	*Suhail*		2·2	223 19	S.43 18
49*	*Vega*		0·1	81 03	N.38 45
39	*Zuben'ubi*	†	2·9	137 45	S.15 54

INTERPOLATION OF G.H.A.

Increment to be added for intervals of G.M.T. to G.H.A. of:
Sun, Aries (♈) and planets ; Moon

SUN, etc.		MOON	SUN, etc.		MOON	SUN, etc.		MOON
m s	° ′	m s	m s	° ′	m s	m s	° ′	m s
00 00		00 00	03 17		03 25	06 37		06 52
	0 00			0 50			1 40	
01		00 02	21		03 29	41		06 56
	0 01			0 51			1 41	
05		00 06	25		03 33	45		07 00
	0 02			0 52			1 42	
09		00 10	29		03 37	49		07 04
	0 03			0 53			1 43	
13		00 14	33		03 41	53		07 08
	0 04			0 54			1 44	
17		00 18	37		03 45	06 57		07 13
	0 05			0 55			1 45	
21		00 22	41		03 49	07 01		07 17
	0 06			0 56			1 46	
25		00 26	45		03 54	05		07 21
	0 07			0 57			1 47	
29		00 31	49		03 58	09		07 25
	0 08			0 58			1 48	
33		00 35	53		04 02	13		07 29
	0 09			0 59			1 49	
37		00 39	03 57		04 06	17		07 33
	0 10			1 00			1 50	
41		00 43	04 01		04 10	21		07 37
	0 11			1 01			1 51	
45		00 47				25		07 42
05		03 12	25		06 39	45		
	0 47			1 37			2 27	
09		03 16	29		06 44	49		
	0 48			1 38			2 28	
13		03 20	33		06 48	53		
	0 49			1 39			2 29	
17		03 25	37		06 52	09 57		
	0 50			1 40			2 30	
03 21		03 29	06 41		06 56	10 00		

* Stars used in H.O. 249 (A.P. 3270) Vol. 1.
† Stars that may be used with Vols. 2 and 3.

Figure 9-14. SHA Obtained from Table.

Determining the GHA of Aries Without an Air Almanac

Using tables in figures 9-15, it is possible to determine the GHA of Aries without having an Air Almanac available. The following is an example determining the GHA of Aries for 23 December 1980 at 0725:07

Step one: GHA for 1 Dec 80 from table a
= 070 – 00

Step two: GHA for 23 Dec 80 at 0700 from table b
= 126 – 58

Step three: GHA for 25 min and 07 sec from table c
= 006 – 18

Step four: GHA of Aries equals the sum of steps 1, 2, and 3.
= 070 – 00
126 – 58
006 – 18
303 – 16

TABLE 4—G.H.A. ♈ FOR THE YEARS 1977-1985

a. G.H.A.♈ AT 00^h ON THE FIRST DAY OF EACH MONTH

Year	Jan. 1	Feb. 1	Mar. 1	April 1	May 1	June 1	July 1	Aug. 1	Sept. 1	Oct. 1	Nov. 1	Dec. 1
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
1977	100 32	131 05	158 41	189 14	218 49	249 22	278 56	309 29	340 03	9 37	40 10	69 44
1978	100 18	130 51	158 27	189 00	218 34	249 07	278 42	309 15	339 48	9 22	39 56	69 30
1979	100 03	130 36	158 12	188 46	218 20	248 53	278 27	309 00	339 34	9 08	39 41	69 15
1980	99 49	130 22	158 57	189 30	219 04	249 38	279 12	309 45	340 19	9 53	40 26	70 00
1981	100 33	131 07	158 43	189 16	218 50	249 23	278 58	309 31	340 04	9 38	40 12	69 46
1982	100 19	130 52	158 28	189 02	218 36	249 09	278 43	309 16	339 50	9 24	39 57	69 31
1983	100 05	130 38	158 14	188 47	218 21	248 55	278 29	309 02	339 35	9 10	39 43	69 17
1984	99 50	130 24	158 59	189 32	219 06	249 40	279 14	309 47	340 20	9 54	40 28	70 02
1985	100 35	131 09	158 44	189 18	218 52	249 25	278 59	309 33	340 06	9 40	40 13	69 48

b. INCREMENT OF G.H.A.♈ FOR DAYS AND HOURS

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
h	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
00	0 00	0 59	1 58	2 57	3 57	4 56	5 55	6 54	7 53	8 52	9 51	10 51	11 50	12 49	13 48	14 47
01	15 02	16 02	17 01	18 00	18 59	19 58	20 57	21 56	22 56	23 55	24 54	25 53	26 52	27 51	28 50	29 50
23	345 57	346 56	347 55	348 54	349 53	350 52	351 52	352 51	353 50	354 49	355 48	356 47	357 46	358 45	359 45	0 44

Day	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
h	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
00	15 46	16 45	17 44	18 44	19 43	20 42	21 41	22 40	23 39	24 38	25 38	26 37	27 36	28 35	29 34	30 33
01	30 49	31 48	32 47	33 46	34 45	35 44	36 44	37 43	38 42	39 41	40 40	41 39	42 38	43 37	44 37	45 36
02	45 51	46 50	47 49	48 49	49 48	50 47	51 46	52 45	53 44	54 43	55 43	56 42	57 41	58 40	59 39	60 38
03	60 54	61 53	62 52	63 51	64 50	65 49	66 48	67 48	68 47	69 46	70 45	71 44	72 43	73 42	74 42	75 41
04	75 56	76 55	77 54	78 53	79 53	80 52	81 51	82 50	83 49	84 48	85 47	86 47	87 46	88 45	89 44	90 43
05	90 59	91 58	92 57	93 56	94 55	95 54	96 53	97 53	98 52	99 51	100 50	101 49	102 48	103 47	104 46	105 46
06	106 01	107 00	107 59	108 58	109 58	110 57	111 56	112 55	113 54	114 53	115 52	116 52	117 51	118 50	119 49	120 48
07	121 03	122 03	123 02	124 01	125 00	125 59	126 58	127 57	128 57	129 56	130 55	131 54	132 53	133 52	134 51	135 51
08	136 06	137 05	138 04	139 03	140 02	141 02	142 01	143 00	143 59	144 58	145 57	146 56	147 56	148 55	149 54	150 53
09	151 08	152 08	153 07	154 06	155 05	156 04	157 03	158 02	159 02	160 01	161 00	161 59	162 58	163 57	164 56	165 55
22	346 40	347 40	348 39	349 38	350 37	351 36	352 35	353 34	354 34	355 33	356 32	357 31	358 30	359 29	0 28	1 28
23	1 43	2 42	3 41	4 40	5 39	6 39	7 38	8 37	9 36	10 35	11 34	12 33	13 33	14 32	15 31	16 30

c. INCREMENT OF G.H.A.♈ FOR MINUTES AND SECONDS

	00^s	04^s	08^s	12^s	16^s	20^s	24^s	28^s		32^s	36^s	40^s	44^s	48^s	52^s	56^s	60^s	
m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	m
00	0 00	0 01	0 02	0 03	0 04	0 05	0 06	0 07	**00**	0 08	0 09	0 10	0 11	0 12	0 13	0 14	0 15	**00**
01	0 15	0 16	0 17	0 18	0 19	0 20	0 21	0 22	**01**	0 23	0 24	0 25	0 26	0 27	0 28	0 29	0 30	**01**
23	5 46	5 47	5 48	5 49	5 50	5 51	5 52	5 53	**23**	5 54	5 55	5 56	5 57	5 58	5 59	6 00	6 01	**23**
24	6 01	6 02	6 03	6 04	6 05	6 06	6 07	6 08	**24**	6 09	6 10	6 11	6 12	6 13	6 14	6 15	6 16	**24**
25	6 16	6 17	6 18	6 19	6 20	6 21	6 22	6 23	**25**	6 24	6 25	6 26	6 27	6 28	6 29	6 30	6 31	**25**
26	6 31	6 32	6 33	6 34	6 35	6 36	6 37	6 38	**26**	6 39	6 40	6 41	6 42	6 43	6 44	6 45	6 46	**26**
27	6 46	6 47	6 48	6 49	6 50	6 51	6 52	6 53	**27**	6 54	6 55	6 56	6 57	6 58	6 59	7 00	7 01	**27**
28	7 01	7 02	7 03	7 04	7 05	7 06	7 07	7 08	**28**	7 09	7 10	7 11	7 12	7 13	7 14	7 15	7 16	**28**
29	7 16	7 17	7 18	7 19	7 20	7 21	7 22	7 23	**29**	7 24	7 25	7 26	7 27	7 28	7 29	7 30	7 31	**29**
58	14 32	14 33	14 34	14 35	14 36	14 37	14 38	14 39	**58**	14 40	14 41	14 42	14 43	14 44	14 45	14 46	14 47	**58**
59	14 47	14 48	14 49	14 50	14 51	14 52	14 53	14 54	**59**	14 55	14 56	14 57	14 58	14 59	15 00	15 01	15 02	**59**

Figure 9-15. Extraction HO249 Vol I, Epoch 1980.

Chapter 10

CELESTIAL CONCEPTS

Celestial navigation is a universal aid to dead reckoning. Because it is available most of the time and in all areas of the globe, it often becomes the only means to position the aircraft. Independent of ground aids, celestial navigation cannot be jammed nor does it give off any signals.

Each celestial observation yields one line of position. In the daytime, when the Sun may be the only visible celestial body, it may become necessary to use single LOPs as course lines or speed lines. At night, when numerous bodies are visible, LOPs obtained from the observation of two or more bodies may be crossed to determine a fix.

It is impossible to state, in so many miles, the accuracy expected from a celestial fix. Celestial accuracy depends on the navigator's skill, the type and accuracy of the equipment, and the prevailing weather conditions. With the ever-increasing speeds and ranges of aircraft, celestial navigation has become more demanding of the navigator's ability. It is important that the fix be plotted and used as quickly as possible.

The navigator does not have to be an astronomer or mathematician to establish a celestial line of position. The ability to use a sextant is a matter of practice, and specially designed celestial tables have reduced the necessary computations to simple arithmetic.

A detailed understanding of navigational astronomy is not essential to establish an accurate celestial position because many simplifications have eliminated the need for the navigator to know the relationship of the Earth to the other heavenly bodies. However, celestial work and celestial lines of position will have more meaning if the navigator understands a few basics of celestial astronomy. Celestial astronomy includes the navigational bodies in the universe and their relative motions.

Although there are an infinite number of heavenly bodies in the universe, celestial navigation utilizes only 63 of them: 57 stars, 4 planets, the Moon, and the Sun. Venus, Jupiter, Mars, and Saturn are the four planets that are used in navigation.

CELESTIAL CONCEPTS

To facilitate the use of celestial navigation, certain assumptions have been established. These assumptions enable the navigator to obtain accurate lines of position without a detailed knowledge of celestial astronomy. A working knowledge of celestial concepts will enable the navigator to cross-check all computations. Celestial positioning will be more than a series of extractions from various books.

The initial assumption of celestial navigation is that the Earth is a perfect sphere. That is, every point on the Earth's surface is equidistant from the center, forming the *terrestrial sphere*. The terrestrial sphere is assumed to be the center of the universe. All other bodies, with the exception of the Moon, are considered to be at an infinite distance from the terrestrial sphere. They are located on the inside surface of a concentric sphere, the *celestial sphere*. Because the stars, planets, and the Sun are considered to be located at an infinite distance from the Earth's center, it is assumed that any point on the Earth's surface approximates the center of the universe.

The celestial concept of the universe is similar to the theory proposed by Ptolemy in 127 AD. That is, the Earth is the center of the universe, and all bodies rotate about the Earth from east to west. In the relatively short periods of time involved with celestial positioning, it can be assumed that all bodies located on the inside surface of the celestial sphere rotate at the same rate. In actuality, over periods of months or years, the planets move amongst the stars at varying rates.

Establishing an artificial celestial sphere with an infinite radius simplifies computations for three reasons. First, since the

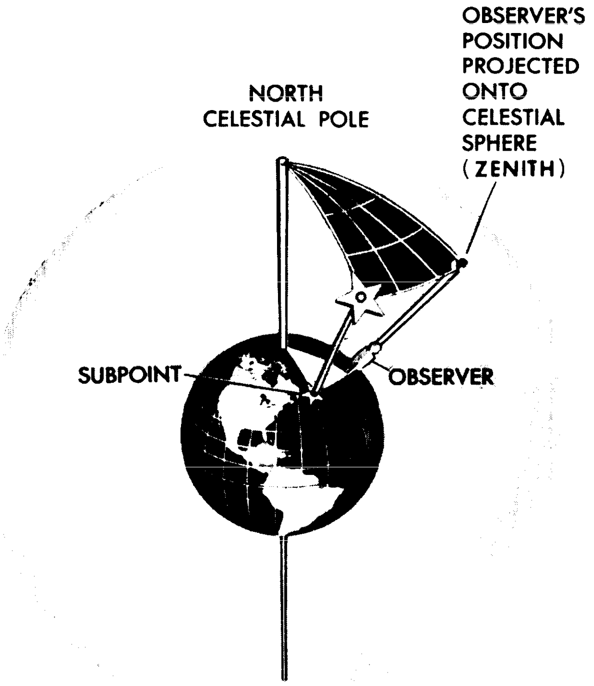


Figure 10-1. Points on Celestial Sphere Have Same Relationship as Their Subpoints on Earth.

terrestrial and celestial spheres are geometrically similar, every point on the celestial sphere has a corresponding point on the terrestrial sphere, and conversely, every point on the terrestrial sphere corresponds to a point on the celestial sphere. By establishing concentric spheres, angular relationships also remain constant.

Secondly, establishing an infinite radius leads to the assumption that a body's location on the celestial sphere will remain constant regardless of the observer's location. An infinite radius also means that all light rays from the celestial body arrive in parallel rays. This means that the angle will be the same whether viewed at the Earth's center, upon the surface, or at 35,000 feet in an aircraft.

Thirdly, all the relationships are valid for all bodies located on the celestial sphere. The Moon, with its close proximity to the Earth, must be treated as a special case; with certain corrections the moon still provides an accurate LOP. This will be addressed in chapter 12.

Because the celestial sphere and terrestrial sphere are concentric, every point on the terrestrial sphere has a corresponding point on the celestial sphere. Each sphere contains an equator, two poles, meridians, and parallels of latitude/declination. The relationships can be seen in figures 10-1 and 10-2.

Consistent with the celestial assumptions, neither the Earth nor the celestial meridians rotate. All celestial bodies located on the inside surface of the celestial sphere, with the exception of the Moon, rotate at a constant rate of 15 degrees per hour past the celestial meridians. The Moon moves at approximately 14.5 degrees per hour.

Two other relationships should be established. The observer on Earth has a point directly overhead, on the celestial sphere, called the zenith. A celestial body has a corresponding point on

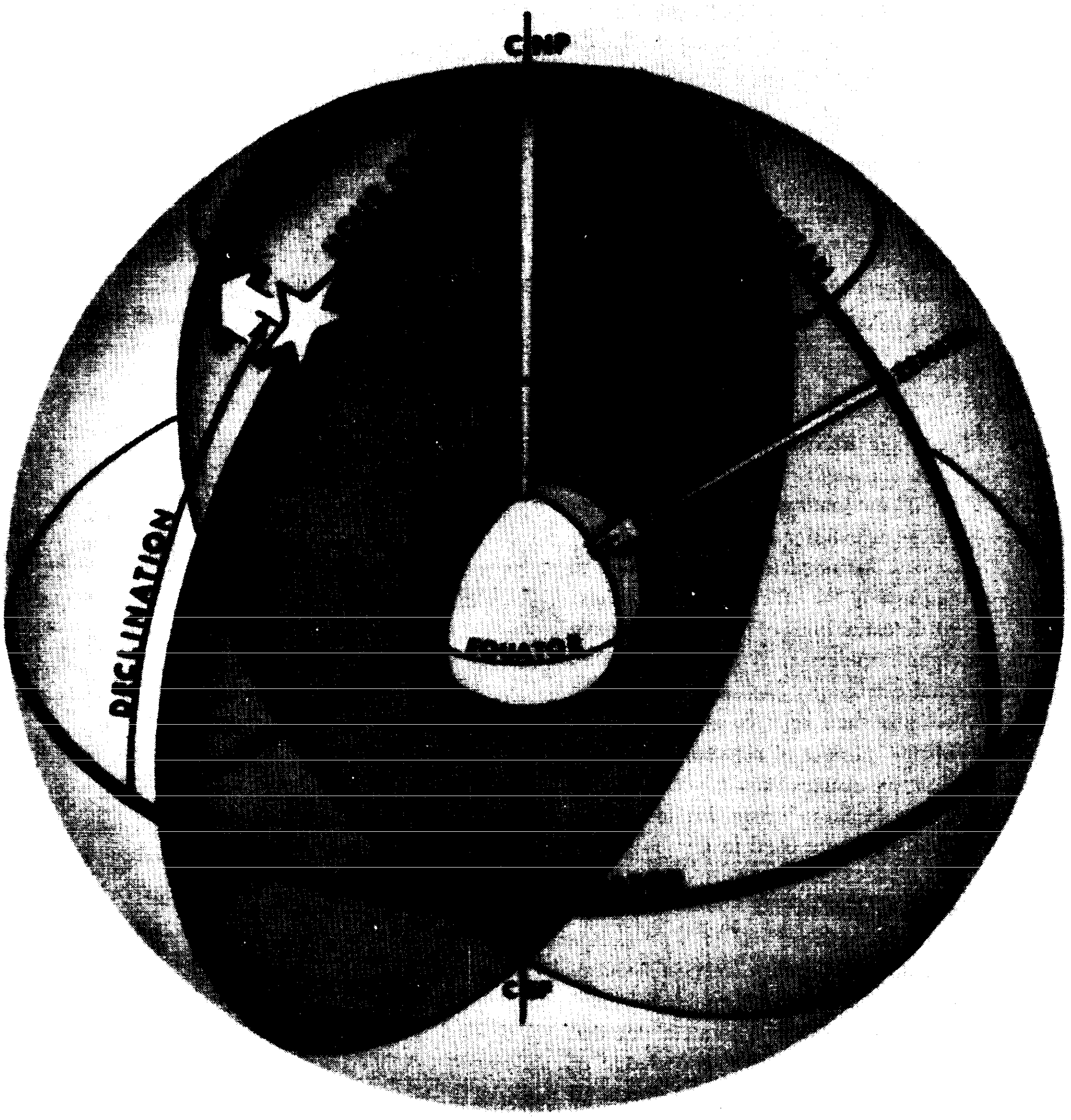


Figure 10-2. Elements of the Celestial Sphere.

the terrestrial sphere directly below it which is referred to as the *subpoint* or *geographic position*. At the subpoint, the light rays from the body are perpendicular to the Earth's surface, and the body is located directly overhead.

MOTIONS OF CELESTIAL BODIES

All of the bodies in the universe have two types of motion, absolute and apparent. *Absolute motion* is measured relative to a fixed point. Because all bodies in the universe are in motion, it has been impossible to establish a definable point from which to reference absolute motion. *Apparent motion* is of more concern to the navigator. This is the motion of one celestial body as perceived by an observer on another body, which is also in motion. Since all apparent motion is relative, it is essential to establish the reference point for that motion. For example, the apparent motion of Venus would be different if observed from the Earth, or from the Sun.

Apparent Motion

The apparent motion of the celestial bodies as observed from Earth is a result of the combination of the Earth's rotation and revolution. Rotation is the spinning of the Earth upon its axis and has the greatest effect on the apparent motion of bodies. It causes celestial bodies to appear to rise in the east, climb to a maximum height, then set in the west. All bodies appear to move along a daily circle or diurnal circle, which is approximately parallel to the plane of the equator.

The apparent effect of rotation varies with the latitude of the observer. At the equator, the bodies appear to rise and set perpendicular to the horizon. Each body is above the horizon for approximately 12 hours each day. At the North and South Poles, a different phenomenom occurs. The same group of stars is continually above the horizon; they neither rise nor set, but move on a plane parallel to the equator. This characteristic explains the periods of extended daylight, twilight, and darkness at higher latitudes. The remainder of the Earth is a combination of these two extremes; that is, some bodies will rise and set, while others will continually remain above the horizon.

The greater the northerly declination of a body, the higher it appears in the heavens to an observer at the North Pole. Polaris has a declination of almost 90 degrees and, therefore, will appear overhead. Any body with a southern declination is not visible from the North Pole.

A circumpolar body appears to revolve about the pole and never set. If the angular distance of the body from the elevated pole is less than the observer's latitude, the body is circumpolar. For example, the declination of Dubhe is 62 degrees north. Therefore, it is located at an angle of 90° – 62° from the North Pole, or 28 degrees. So, an observer located above 28 degrees north will view Dubhe as circumpolar. Although figure 10-3 uses the North Pole, the same characteristics can be observed from the South Pole.

If it were possible to stop the rotation of the Earth, the effect of the Earth's revolution on the apparent motion of celestial bodies would be more noticeable. The Sun would appear to make one complete circle around the Earth each year. It would cover a 360 degree full circle in 365 days, or move eastward at slightly less than 1 degree per day. The stars move at the same rate, and this accounts for why different constellations are visible at different times of the year. Each evening the same star appears to rise four minutes earlier.

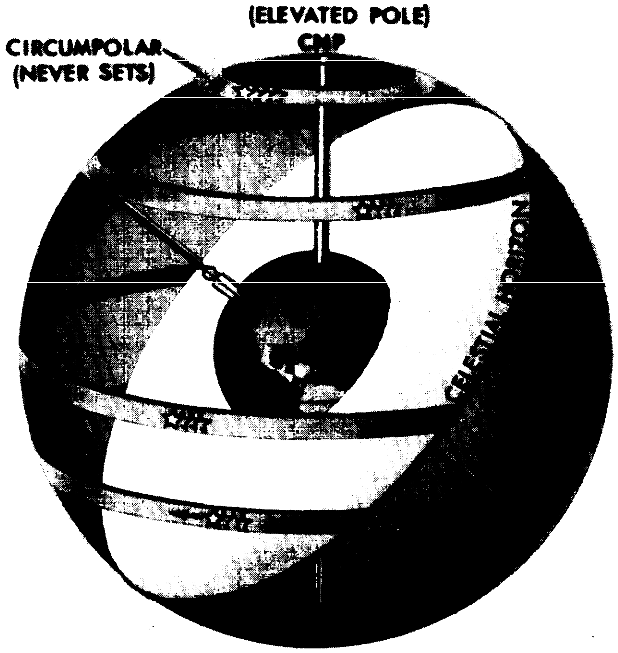


Figure 10-3. Some Bodies are Circumpolar.

After half a year, when the Earth has reached the opposite extreme of its orbit, its dark side is turned in the opposite direction in space and is facing a new field of stars. Hence, an observer at the equator will see an entirely different sky at midnight in June than the one which appeared at midnight in December. In fact, the stars seen at midnight in June are those which were above the horizon at midday in December, but were not visible because of the sun.

Seasons

The annual variation of the Sun's declination and the consequent change of the seasons are caused by the revolution of the Earth (figure 10-4). If the equinoctial coincided with the ecliptic, the Sun would always be overhead at the equator, and its declination would always be zero. However, the Earth's axis is inclined to the plane of the Earth's orbit at an angle of about 66 1/2°; and the plane of the equator is inclined to it at an angle of about 23 1/2°. Throughout the year, the axis points in the same direction. That is, the axis of the Earth in one part of the orbit is essentially parallel to the axis of the Earth in any other part of the orbit (figure 10-5).

In June, the North Pole is inclined toward the Sun and the South Pole away from the Sun, so that the Sun is at a maximum distance from the plane of the equator. About June 22, at the solstice, the Sun has its greatest northern declination. At this

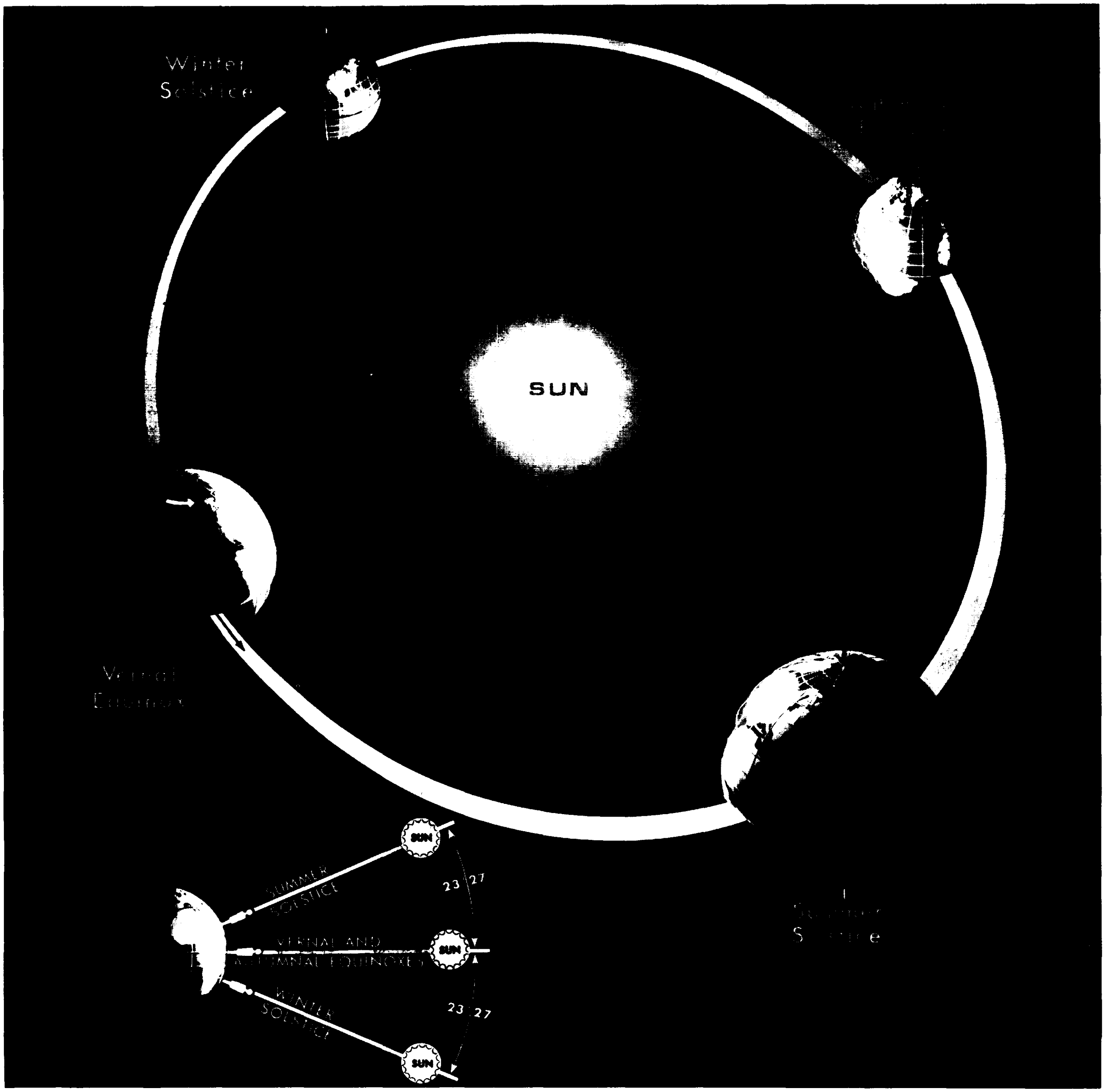


Figure 10-4. Seasonal Changes of Earth's Position.

time in the Northern Hemisphere, the days are longest of any time during the year and the nights are shortest, while in the Southern Hemisphere, the nights are longest and the days shortest. This is the beginning of summer for the Northern Hemisphere and of winter for the Southern Hemisphere. A half year later, the axis is still pointing in the same direction in space; but, since the Earth is at the opposite extremity of its orbit and hence on the opposite side of the Sun, the North Pole is inclined away from the Sun while the South Pole is toward it. At the winter solstice, about December 21, the Sun has its greatest southern declination. Then, in the Northern Hemisphere, days are shortest and nights longest, and winter is beginning to set in.

Halfway between the two solstices, the axis of the Earth is inclined neither toward nor away from the sun, and the Sun is on the plane of the equator.

CELESTIAL COORDINATES

Celestial bodies and the observer's zenith may be positioned on the celestial sphere using a coordinate system similar to that

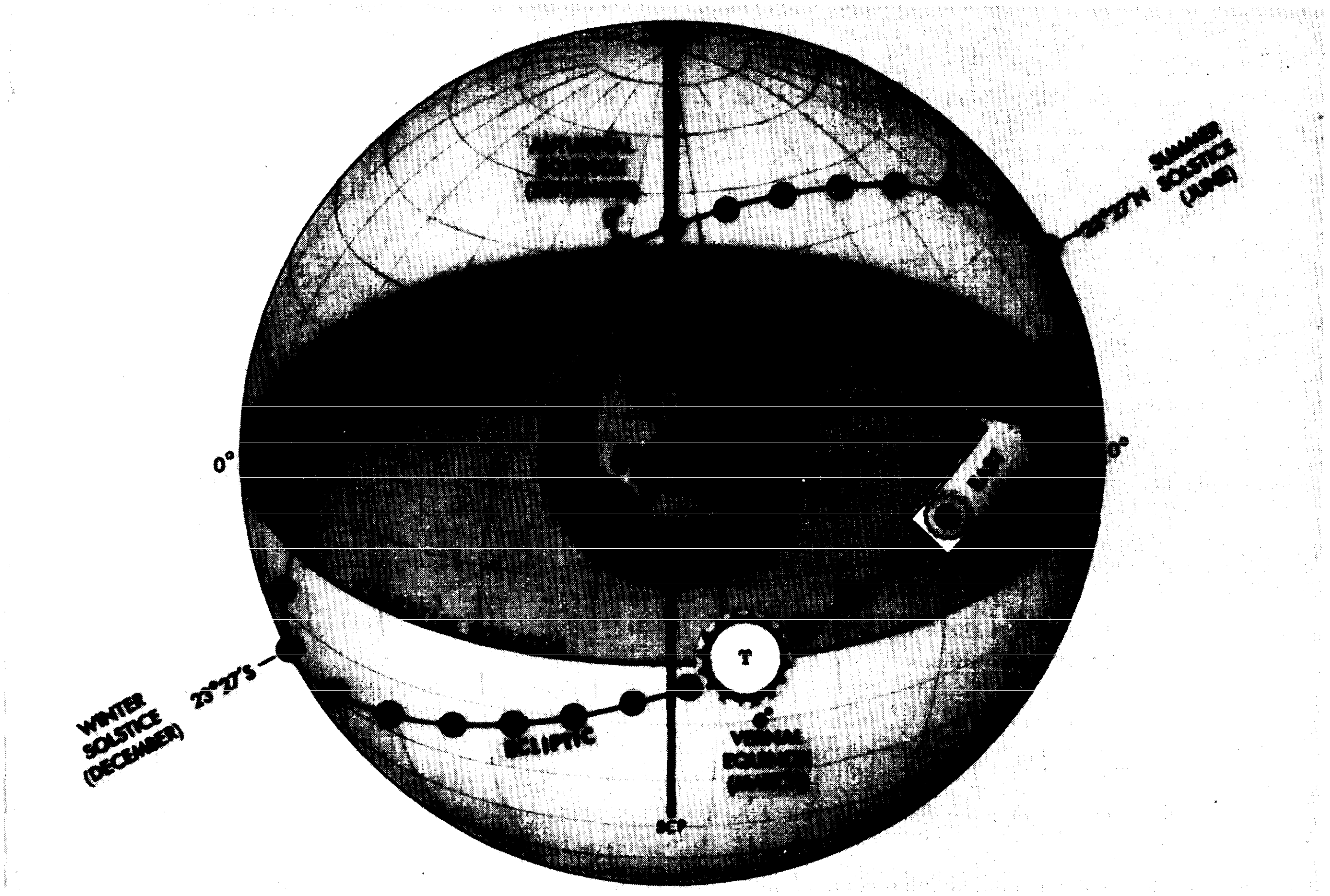


Figure 10-5. Ecliptic with Solstices and Equinoxes.

of the Earth. Lines of latitude on Earth are projected onto the celestial sphere as parallels of declination. Lines of longtitude establish the celestial meridians. A line extended from the observer's zenith, through the center of the Earth, will intersect the celestial sphere at the observer's *nadir*.

Celestial meridians are divided into two parts; the upper and the lower branch. The upper branch is the half of the celestial meridian divided at the poles containing the observer's zenith. The lower branch is the part remaining, and contains the nadir. As a whole, the observer's celestial meridian is a great circle containing the zenith, the nadir, and the celestial poles (figure 10-2).

A second great circle on the celestial sphere is the *hour circle*. An hour circle is a great circle containing the celestial body and the celestial poles. Unlike celestial meridians which remain stationary, hour circles rotate at a standard rate of 15 degrees per hour. Hour circles also contain upper and lower branches. The upper branch contains the body and is the half divided at the poles. The remaining half is the lower branch. Again, the only exception to the standard rate is the Moon (figure 10-2).

The location of any body on the celestial sphere can be described relative to the celestial equator and the Greenwich celestial meridian using declination and Greenwich Hour Angle (GHA).

Declination: The declination of a celestial body is the angular distance the body is north or south of the celestial equator measured along the hour circle. It ranges from 0 to 90 degrees and corresponds to latitude.

Greenwich Hour Angle: The angular distance measured westward from the Greenwich celestial meridian to the upper branch of the hour circle. It has a range of 0-360 degrees.

The Air Almanac lists the Greenwich Hour Angle and the declination of the Sun, Moon, four planets, and Aries. The latitude of the subpoint of the body is derived from the declination. Longitude is derived from the GHA. Although GHA correlates to longitude, it is not exact. GHA is always measured westward from Greenwich celestial meridian, and longitude is measured in the shortest direction from the Greenwich meridian to the observer's meridian.

The following are examples of converting the celestial coordinates of a body to the corresponding terrestrial coordinates of its subpoint. If the GHA is less than 180 degrees, then the subpoint is in the Western Hemisphere and GHA = Long. When the GHA is greater than 180 degrees, the subpoint of the body is located in the Eastern Hemisphere and Long = 360 − GHA. Again, declination and latitude equate (figure 10-6).

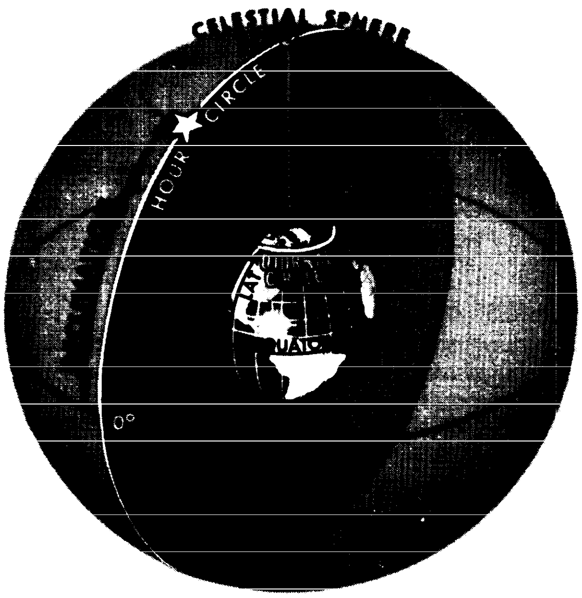


Figure 10-6. Declination of a Body Corresponds to a Parallel of Latitude.

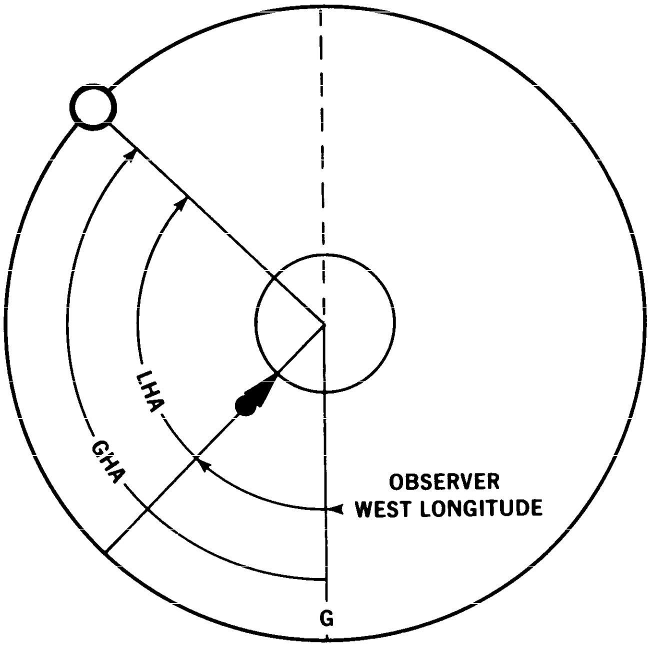


Figure 10-8. LHA = GHA − West Longitude.

GHA = 135° − 00′	Subpoint location: 135 − 00W
Dec = S13 − 15	13 − 15S
GHA = 290° − 00′	Subpoint location 070 − 00E
Dec = N11 − 32	11 − 32N

In addition to Greenwich Hour Angle (figure 10-7), there are two special hour angles used in celestial navigation. The first is Local Hour Angle or LHA. LHA is the angular displacement measured from the observer's celestial meridian clockwise to the hour circle of the body. LHA is computed by applying the local longitude to the GHA of the body (figure 10-8). In the Western Hemisphere, LHA = GHA − W Long, and in the Eastern Hemisphere, LHA = GHA + E Long (figure 10-9). When the LHA = 0, it means that the hour circle of the body is collocated with the upper branch of the celestial meridian of the observer, and the body is in transit. An LHA = 180 puts the hour circle coincident with the lower branch of the celestial meridian of the observer.

The second special hour angle is the sidereal hour angle (SHA). SHA is used in conjunction with the first point of Aries.

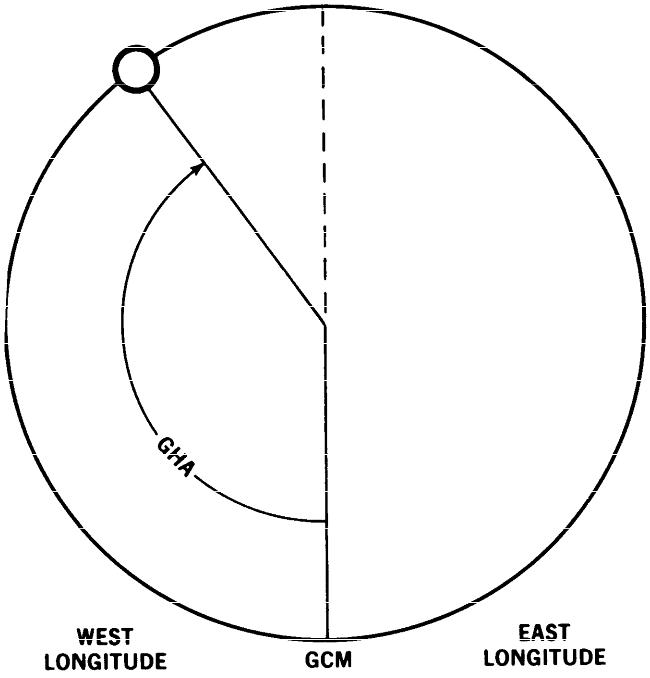


Figure 10-7. Greenwich Hour Angle.

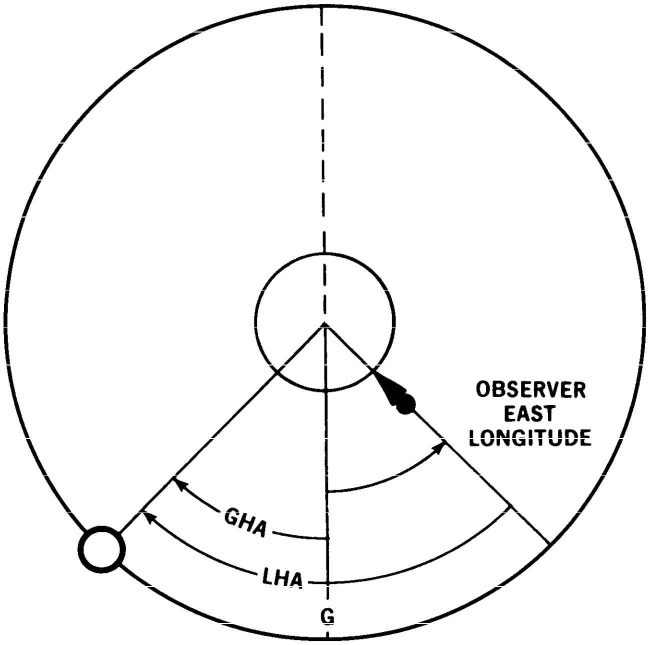


Figure 10-9. LHA = GHA + East Longitude.

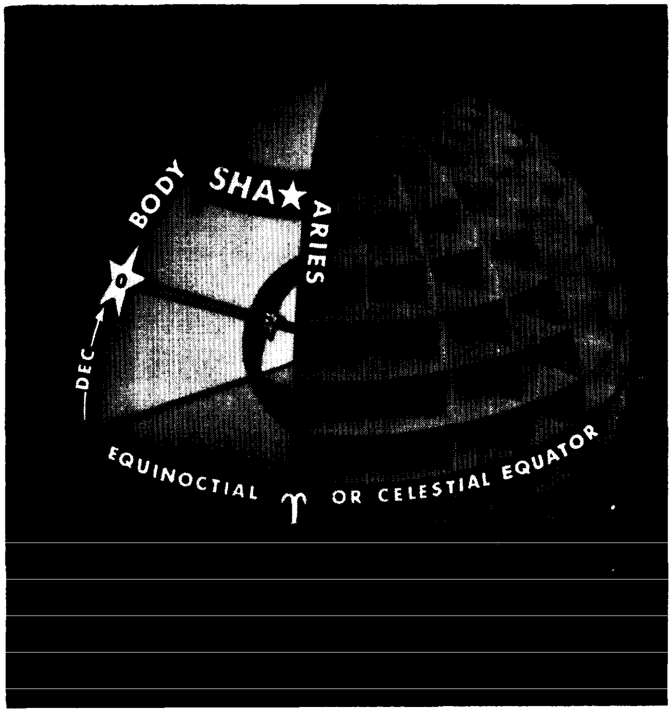


Figure 10-10. Sidereal Hour Angle.

The first point of Aries, more commonly referred to as Aries, is also the vernal equinox or first day of spring. Aries is established at the point where the Sun appears to cross the celestial equator from south to north. Though not absolutely stationary relative to the stars, the first point of Aries changes so slowly that it may be thought of as a fixed point on the celestial equator for a period as long as a year. The SHA is the angular measurement from the hour circle of Aries to the hour circle of the star in question (figure 10-10). Since both Aries and the stars are located on the celestial sphere, they move at the same rate and the SHA remains a constant figure for that year. SHA is normally used to accomplish an HO 249 vol II or III solution with a star. The SHA and declination of any navigational star are listed in the Air Almanac and the HO 249 vol I.

THE CELESTIAL LOP

All of the celestial concepts and assumptions are explained to help clarify the derivation of the celestial LOP. In a simplified explanation, the celestial LOP is a circle plotted with the center at the body's subpoint and a radius equal to the distance from the observer to the subpoint. To accurately compute this distance and the direction to the subpoint of the body, the navigator must initially position the subpoint of the body, and then measure the angular displacement of the body above the horizon. GHA and declination are used to position the body, and the sextant is used to compute the angular displacement above the horizon. This is a quick explanation of the concepts involved in obtaining a celestial LOP. A basic knowledge of the precepts used to derive this LOP will enable the navigator to appreciate celestial navigation and will aid in detecting errors. The next section will explain how the angular displacement is measured.

Figure 10-11. Celestial Horizon is 90° from Observer Zenith and Nadir.

CELESTIAL HORIZON

Now that the celestial body and the observer's zenith are positioned on the celestial sphere, a sextant is used to measure the angular displacement of the body above the horizon. The celestial horizon is a plane passing through the Earth's center and is perpendicular to the zenith-nadir axis. At the Earth's surface, the visual horizon approximates this plane. Figure 10-11 depicts the zenith-nadir axis and the celestial horizon. The angular displacement as viewed through a sextant is the height observed, or Ho. Ho is measured along the vertical circle above the horizon. The vertical circle is a great circle containing the

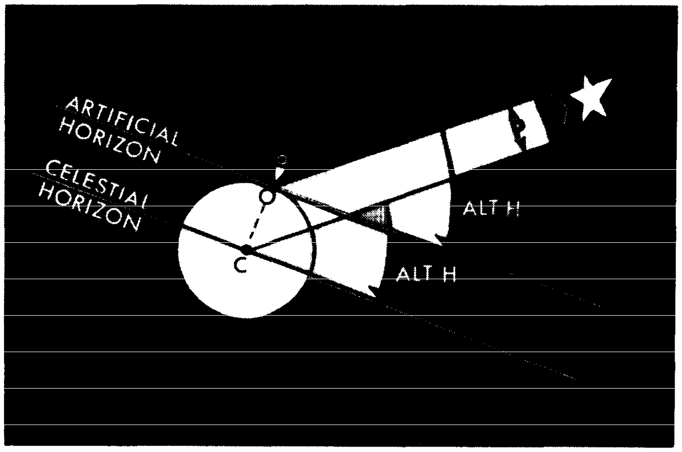


Figure 10-12. Parallel Lines Make Equal Angles with Parallel Planes.

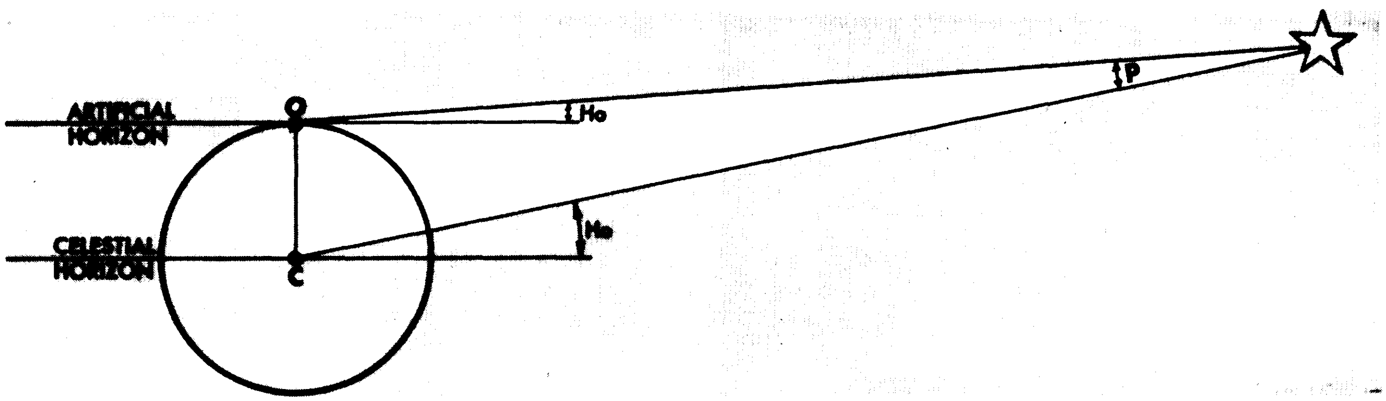


Figure 10-13. Parallax.

zenith, nadir, and celestial body, and its center is the center of the Earth. The altitude of a body is the same whether it is measured at the surface of the Earth from the artificial horizon or at the center of the Earth from the celestial horizon. Since these horizons are parallel, if the light rays from the body are parallel, the altitudes will be the same. Figure 10-12 shows that the angle for light rays arriving at different points on the Earth in reality is very small.

This angle between light rays is called parallax. In figure 10-13, parallax is shown at its maximum value; that is, when the observer and the subpoint are separated by 90°. In this situation, tangent (tan) p is equal to OC (radius of the Earth) over the distance C*. The radius of the Earth is a very small distance compared to the distance to any of the stars. Thus, the angle p is very small. For the Sun, one of the closest celestial bodies used in navigation, tan p equals 3,940 divided by 93,000,000 or 0.000042. The angle p then equals approximately 9″ of arc or 0.15 nautical mile. The angle is so small that it is negligible. Therefore, for practical work, the observed altitudes from either the aritificial or celestial horizon are the same.

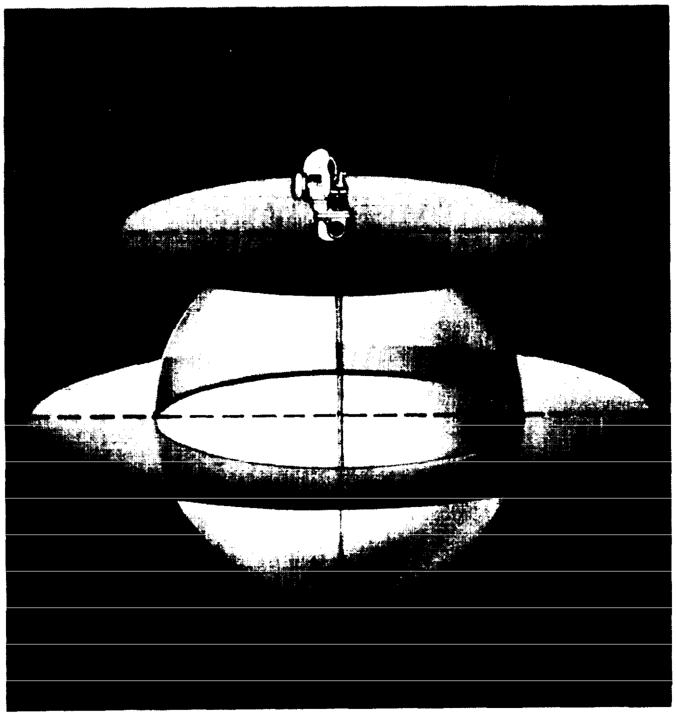


Figure 10-14. The Two Planes are Parallel.

The horizon most used by the navigator is the bubble or artificial horizon. As in a carpenter's level, a bubble indicates the apparent vertical and horizontal. By means of the bubble, the navigator can level the sextant and establish a reference plane parallel to the plane of the celestial horizon. This plane is the artificial horizon. The artificial horizon is established by the bubble in the sextant. Notice in figure 10-14 that the plane of the bubble horizon and the plane of the celestial horizon are parallel and are separated by the radius of the Earth. In comparison with the vast distances to the celestial bodies, the radius of the Earth is immeasurably small. Therefore, if two parallel circles on the Earth are separated by a linear distance equal to the radius of the Earth, these two circles must appear to coincide. Thus, the artificial horizon and the celestial horizon appear to coincide and can be considered identical.

Observed Altitude

There is a definite relationship between the Ho of a body and the distance of the observer from the subpoint (figure 10-15). When the body is directly overhead, the Ho is 90°, and the subpoint and the observer's position are identical. When the Ho is 0°, the body is on the horizon and the subpoint is 90° (5,400 NM) from the observer's position. This relationship is shown in figure 10-16, where C is the center of the Earth, AB is the observer's horizon, and S is the subpoint of the body. Since the sum of the angles in a triangle must equal 180°, the angle OX is equal to 180° − (Ho + p). The sum of the angles on a straight line is equal to 180°, so angle OXC is equal to Ho + p. The horizon AB being tangent to the Earth at 0 is perpendicular to OC, a radius of the Earth. Thus, angle OCX is equal to 90° (Ho + p). In the preceding discussion, it was shown that angle p is negligible, so this angle becomes 90° − Ho. The arc on the surface subtended by the angle OCX at the center of the Earth is arc OS. This arc then is equal to 90° − Ho.

The distance from the subpoint of the body to the observer is the zenith distance and is computed with the aid of the astrono-

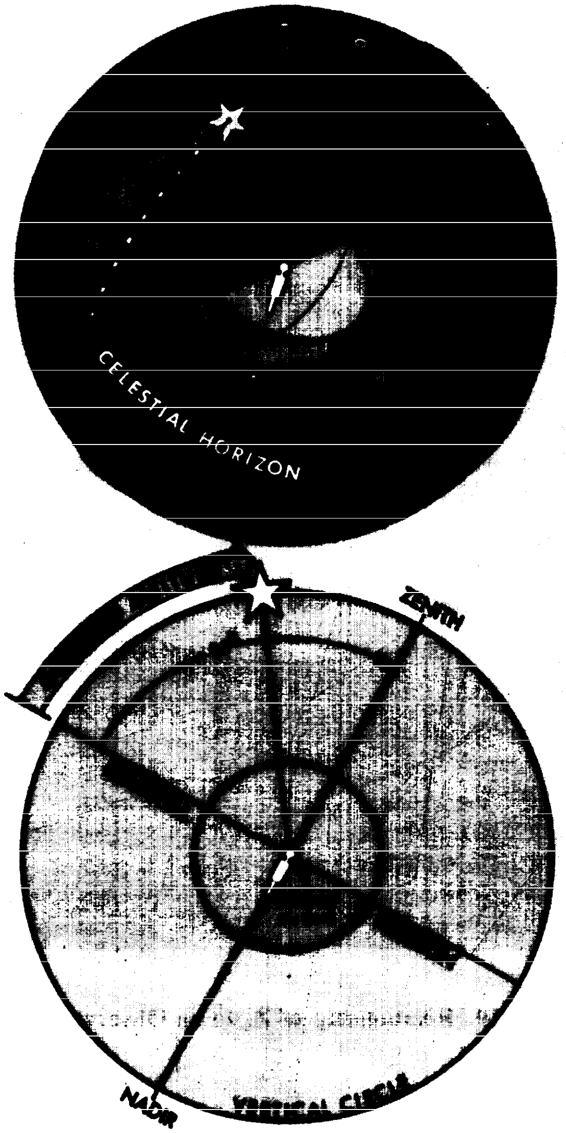


Figure 10-15. Measure Altitude from Celestial Horizon Along Vertical Circle.

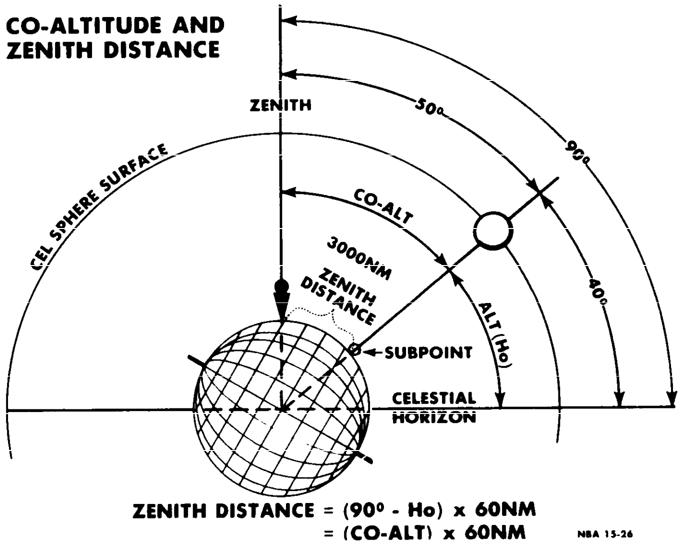


Figure 10-17. Co-Altitude and Zenith Distance.

mical triangle described in chapter 13. Basically, the zenith distance is equal to 90 degrees minus the Ho and is referred to as the co-altitude (figure 10-17). The degrees are then converted to nautical miles by multiplying the number of degrees by 60 and adding in the odd minutes of arc. Example:

Ho = 37 – 26

therefore, Co-altitude = 90 – 37:26

= 52 – 34

Zenith Distance = (52 × 60) + 34

= 3,154 NM

Zenith distance is the radius of the circle which becomes the celestial LOP. This circle is called the circle of equal altitude (figure 10-18), as anyone located on it and viewing the celestial body at a common time will view an identical Ho. This procedure determines the distance from the observer to the subpoint. The next consideration must be the direction from the observer to the body's subpoint.

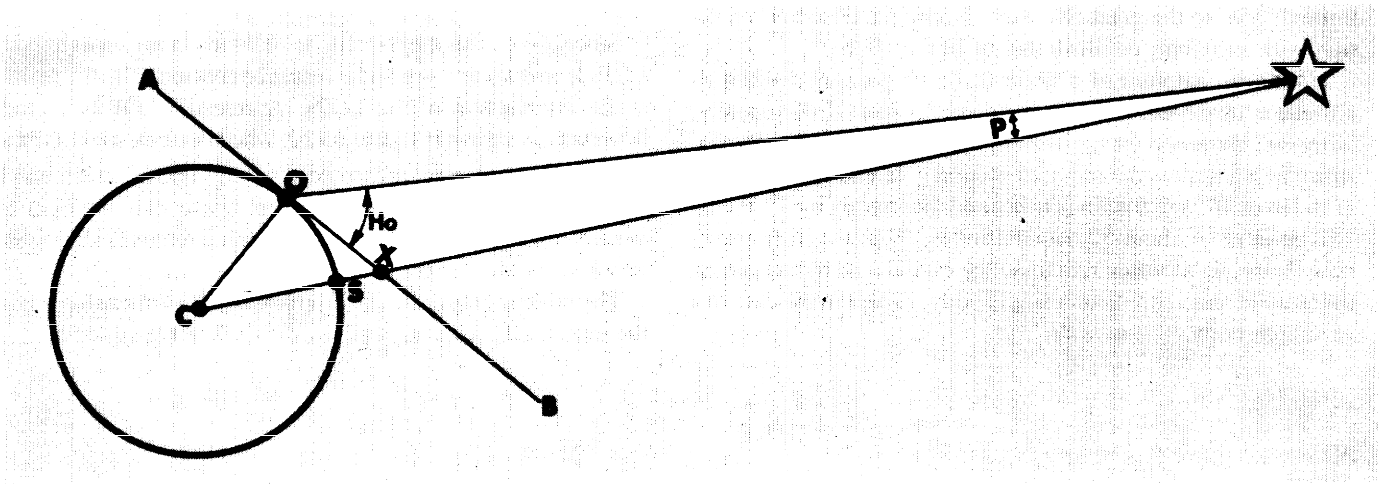


Figure 10-16. Finding Observed Altitude.

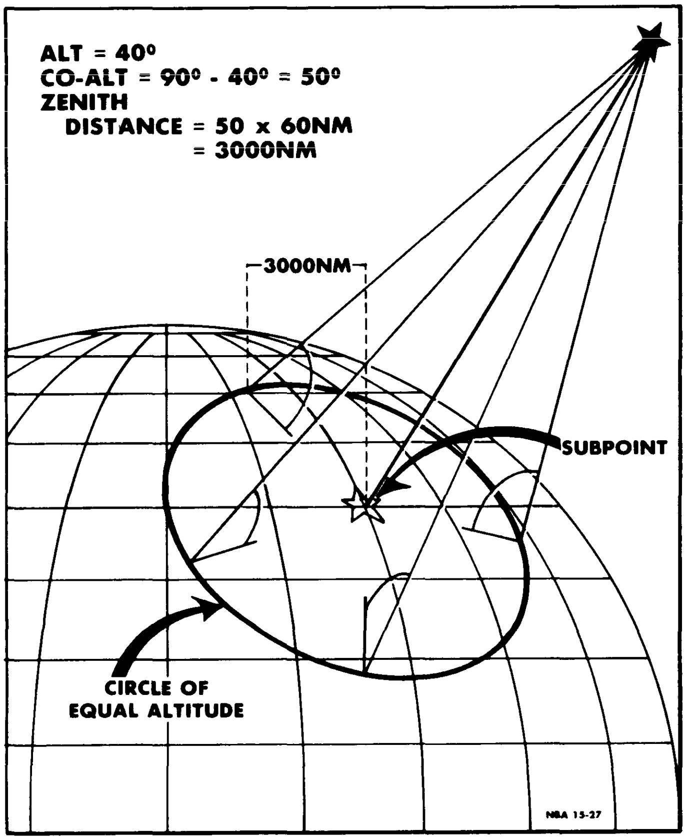


Figure 10-18. Construction a Circle of Equal Altitude.

True Azimuth

In celestial navigation, the direction of a body from an observer is called true azimuth (Zn). The true azimuth of a celestial body corresponds exactly to the true bearing of an object located at the subpoint. The true azimuth of a celestial body is the angle measured at the observer's position from true north clockwise through 360° to the great circle arc joining the observer's position with subpoint, as illustrated in figure 10-19.

If the true azimuth of a body could be measured when its altitude is observed, a fix could be established. Unfortunately, however, there is no instrument in the aircraft which will measure true azimuth to the required accuracy. If a body is observed at an Ho of 40° and the Zn is measured incorrectly by 1°, the fix will be in error about 50 nautical miles. With the instruments now in use, an accurate fix cannot be established by measuring the altitude and azimuth of a single body, except in the case of a very high body (85° to 90°).

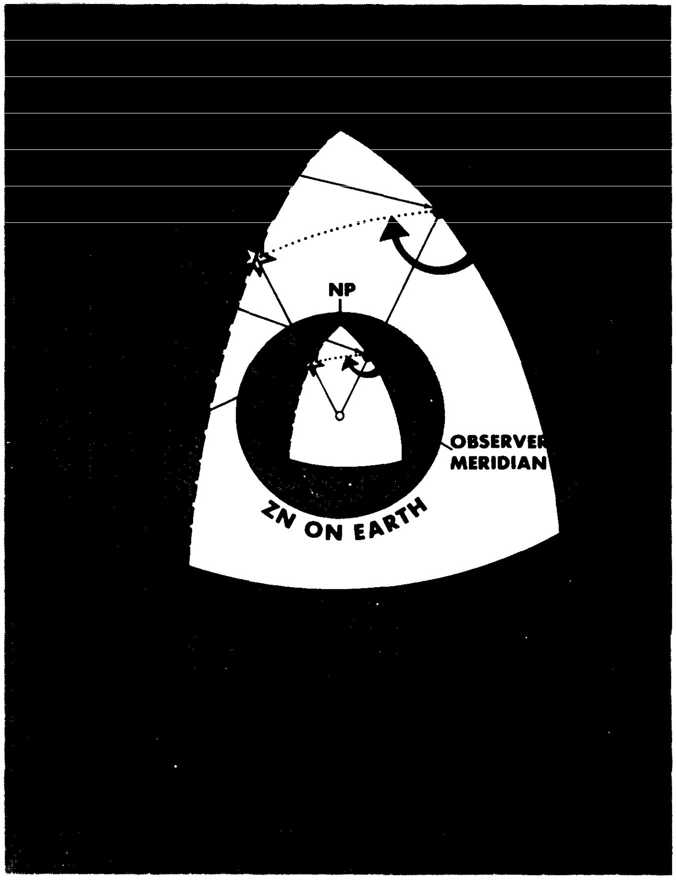


Figure 10-19. Relationship of Z_n to an Observer.

CELESTIAL FIX

Since a fix cannot normally be obtained from a single body, LOPs from two or more bodies must be crossed. The fix position is the intersection of the LOPs. A celestial LOP is a circle; however, as shown in figure 10-20, when two celestial LOPs are plotted, they intersect at two points, only one of which can be the observer's position. In practice, these two intersections usually are so far apart that dead reckoning removes all doubt as to which is the correct position.

The table in figure 10-21 summarizes the relationship among the terrestrial, celestial, and horizon reference systems.

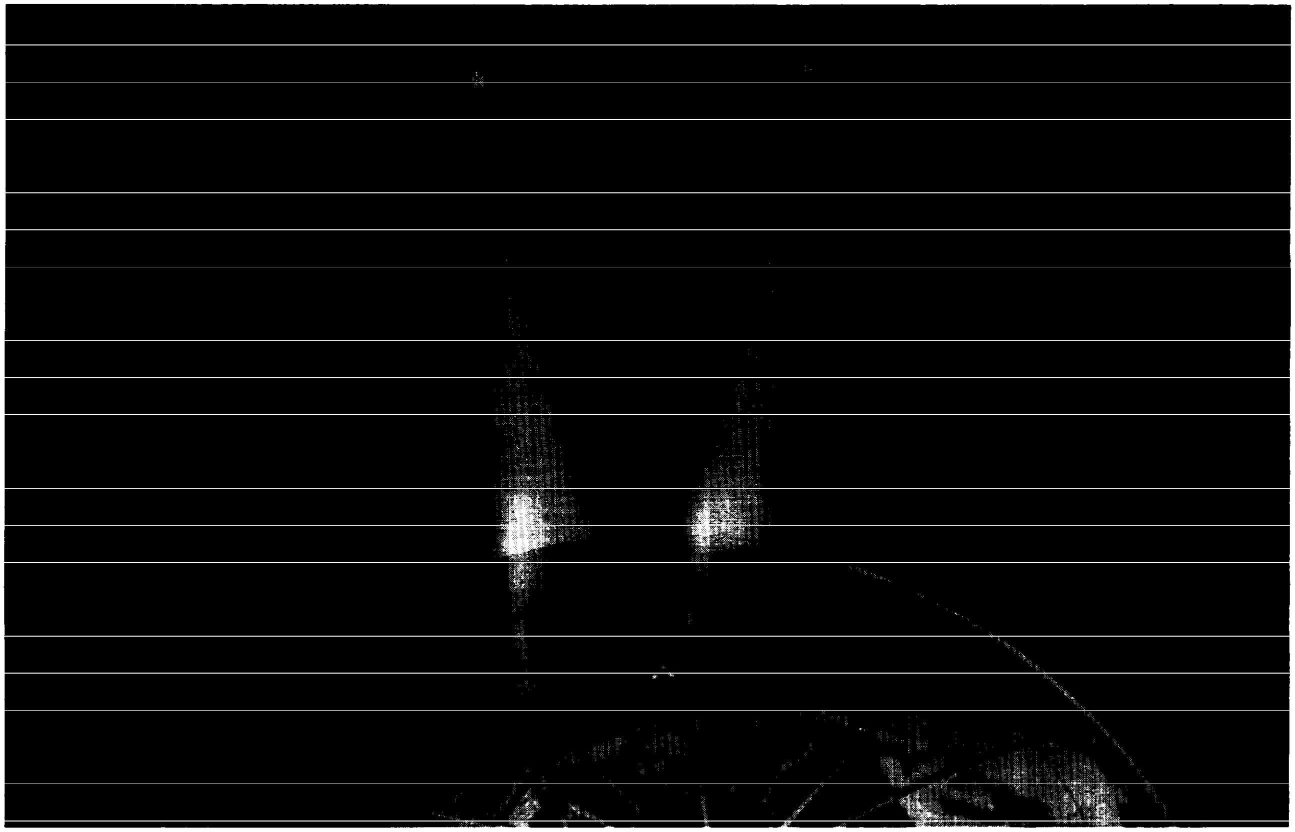


Figure 10-20. Celestial Fix with Two Bodies.

Earth	Celestial Equator	Horizon
equator	celestial equator	horizon
poles	celestial poles	zenith, nadir
meridians	hour circles, celestial	vertical circles
prime meridian	hour circle, Greenwich celestial meridian, local celestial meridian	principal vertical circle, prime vertical circle
parallels	parallels of declination	parallels of altitude
latitude	declination	altitude
co-latitude	polar distance	zenith distance
longitude	SHA, RA, GHA, LHA, t	azimuth, azimuth angle, amplitude

Figure 10-21. Correlation of the Three Reference Systems.

Chapter 11

COMPUTING ALTITUDE AND TRUE AZIMUTH

This chapter deals with the procedures and some of the tables used to compute a celestial line of position. Tables containing the required data for resolving the LOP were mentioned several times previously, including the Air Almanac, which has already been discussed.

Preceding the mechanics of using the tables, there is a brief explanation of the astronomical triangle upon which the tables are based. This includes a review of the determination of the LHA of Aries and the LHA of a star.

DERIVATION OF LHA AND THE ASTRONOMICAL TRIANGLE

The basic principle of celestial navigation is to consider yourself to be at a certain assumed position at a given time; then, by means of the sextant, determine how much your basic assumption is in error. At any given time, an observer has a certain relationship to a particular star. The observer is a certain number of nautical miles away from the subpoint, and the body is at a certain true bearing called azimuth or Zn, measured from the observer's position (figure 11-1).

Intercept

If the observer assumes to be at a given point (called the assumed position) at a given time, there exists at that instant a specific relationship between this assumed position and the subpoint. The various navigational tables provide you with this relationship by solving the astronomical triangle for you. From the navigational tables, you can determine how far away your assumed position is from the subpoint and the true bearing (true azimuth or Zn) of the subpoint from the assumed position. This means, in effect, that the tables give you a value called computed altitude (Hc) which would be the correct observed altitude (Ho) if you were anywhere on the circle of equal altitude through the assumed position. Any difference between the computed altitude (Hc) determined for the assumed position and the observed altitude (Ho) as determined by the sextant for the actual position is called intercept. Intercept is the number of nautical miles between your actual circle of equal altitude and the circle of equal altitude through the assumed position. It is by means of the astronomical triangle that you can solve for Hc and Zn in the HO 249 tables.

Construction of the Astronomical Triangle

Consider the solution of a star as it appears on the celestial sphere. Start with the Greenwich meridian and the equator. Projected on the celestial sphere, these become the celestial meridian and the celestial equator (called equinoctial) as shown in figure 11-2. Notice also in the same illustration how other

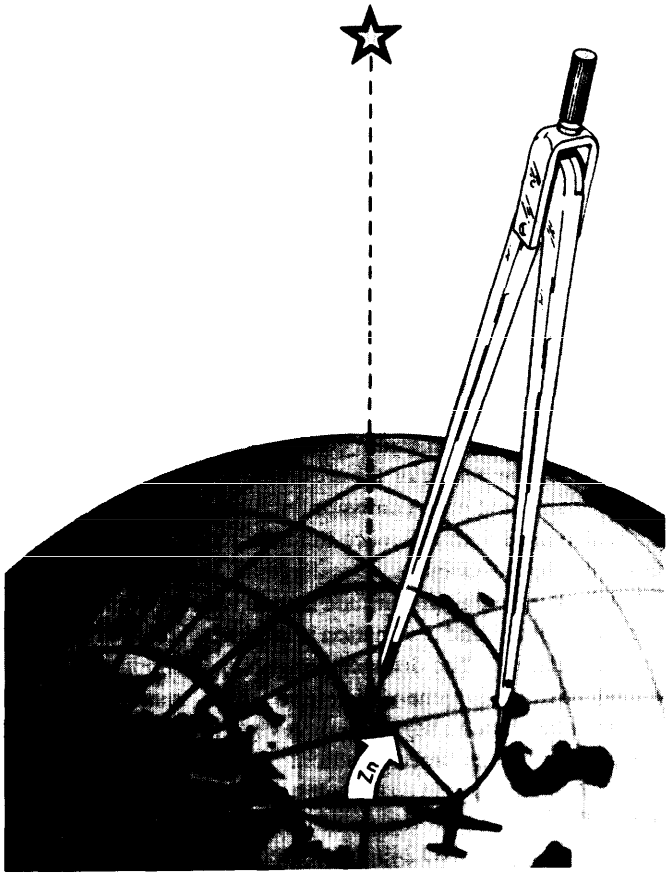


Figure 11-1. Subpoint of a Star.

known information is derived, namely the LHA of the star Aries—equal to the GHA of Aries minus longitude west. You can also see that if the LHA of Aries and SHA of the star are known, the LHA of the star is their sum. It should also be evident and the GHA of Aries plus SHA of the star equals GHA of the star. Also, the GHA of the body minus longitude west (or + longitude east) of the observer's zenith equals LHA of the body. These are important relationships that are used in the derivation of the Hc and Zn.

Figure 11-3 shows part of the celestial sphere and the astronomical triangle. Notice that the known information of the astronomical triangle is the two sides and the included angle; that is, Co-Dec, Co-Lat, and LHA of the star. Co-Dec, or polar distance, is the angular distance measured along the hour circle of the body from the elevated pole to the body. The side, Co-Lat, is 90° minus the latitude of the assumed position. The included angle in this example is the LHA ★ . With two sides and the included angle of the spherical triangle known, the third side and the interior angle at the observer are easily solved. The third side is the zenith distance, and the interior angle at the observer is the azimuth angle (∠Z). Instead of listing the zenith distance, the astronomical tables list the remaining portion of the 90° from the zenith, or the Hc. Hc equals 90° minus zenith distance of the assumed position, just as zenith distance of the assumed position equals 90° − Hc. Note, that when measured with reference to the celestial horizon, zenith distance is synonymous with co-altitude. Figure 11-4 is a side view of this solution.

So far, the astronomical triangle has been defined only on the celestial sphere. Refer again to figure 11-3 and notice the same triangle on the terrestrial sphere (Earth). The same triangle with its corresponding vertices may be defined on the Earth as follows: (1) celestial pole — terrestrial pole; (2) zenith of assumed position — assumed position; and (3) star — subpoint of the star. The three interior angles of this triangle are exactly equal to the angles on the celestial sphere. The angular distance of each of the three sides is exactly equal to the corresponding side on the astronomical triangle. Celestial and terrestrial terms are used interchangeably. For example, refer to figure 11-3 and notice that Co-Lat on the terrestrial triangle is also called Co-Lat on the celestial triangle. To be perfectly correct, the term on the celestial sphere corresponding to latitude on the Earth is declination; therefore, the celestial side could well be called, "co-declination of the zenith of the assumed position."

Rather than have this confusion, the terrestrial term "Co-Lat" is also used with reference to the celestial sphere, just as latitude of the subpoint is considered to be the declination amount from the equator. Latitude is used when referring to the observer or zenith, and declination is used when referring to the star or its subpoint. The distance between the subpoint and the assumed position is generally referred to as zenith distance (Co-Alt) rather than the segment of the vertical circle joining the subpoint and the assumed position. These angular distance terms are interchangeable on the celestial and terrestrial spheres.

The values of the Zn (true azimuth) and the interior angle (∠Z) are listed in the HO 249 tables depending upon whether or not a declination solution is desired. Volume I of the HO 249 lists the Zn rather than the interior angle. Volumes II and III of the HO 249 list the interior angle (∠Z) and it is necessary to follow rules printed on each page to convert the interior angle (∠Z) to true azimuth (Zn).

HO 249, VOLUME I

Volume I of HO 249 deals solely with the solution concerning selected stars and is considered separately from volumes II and III.

Volume I provides complete worldwide coverage from pole to pole for each degree of latitude. The LHA of Aries is listed in 1° increments from latitudes of 0° to 69° north and south inclusive. From 70° through 89° of latitude, the meridians are so close together that it is only necessary to tabulate the values of the LHA of Aries in even 2° increments. There are two pages devoted to each whole degree of latitude between latitudes 69°N and 69°S inclusive. From there to the pole, only one page is devoted to each whole degree of latitude.

The three stars marked by diamonds on each page provides sets for fixing purposes which are favorably situated in altitude and azimuth.

Entering Arguments

The entering arguments are the assumed latitude and the LHA of Aries (to whole degrees). At any one time, the navigator has the choice of the seven listed stars for that latitude plus Polaris. The names of the stars are in capital letters if the star is of first magnitude or brighter; the second magnitude stars are printed in small letters. The names of the stars are relisted every 15° of LHA of Aries (every 30° in the polar latitudes).

For the time the navigator expects to make an observation, commonly called a shot, he or she looks up the GHA of Aries and applies the approximate longitude to get a whole degree LHA of Aries. The navigator then enters volume I, HO 249, with the latitude closest to the DR latitude and the LHA of Aries to select the stars that will be shot.

Since a single celestial observation results in only one LOP, it is necessary to shoot two or more bodies to obtain a fix. Suppose the navigator wants to shoot at approximately 0230 GMT, he or she looks up the GHA of Aries (in the Air Almanac) and finds it to be 196°. The DR position for this time is 31°48′N, 075°26′W. A quick calculation shows that the LHA of Aries is approximately 121°, and the closest latitude is 32°N. Notice in the portion of the tables reproduced in figure 11-5 that the available stars at this position are Alkaid, Regulus, Alphard, Sirius, Rigel, Aldebaran, and Capella. Using Sirius, a shot is taken at 0231 and the Ho obtained is 37°50′.

GHA Aries for 0230 GMT	196°06′
Correction for 1 minute	+ 15′
GHA Aries for 0231 GMT	196°21′
Closest longitude to DR for whole LHA	− 075°21′W (assumed longitude)
LHA Aries for 0231 GMT	121°

The closest whole degree of latitude is 32°N; therefore, it is used as the assumed latitude. The assumed longitude is selected

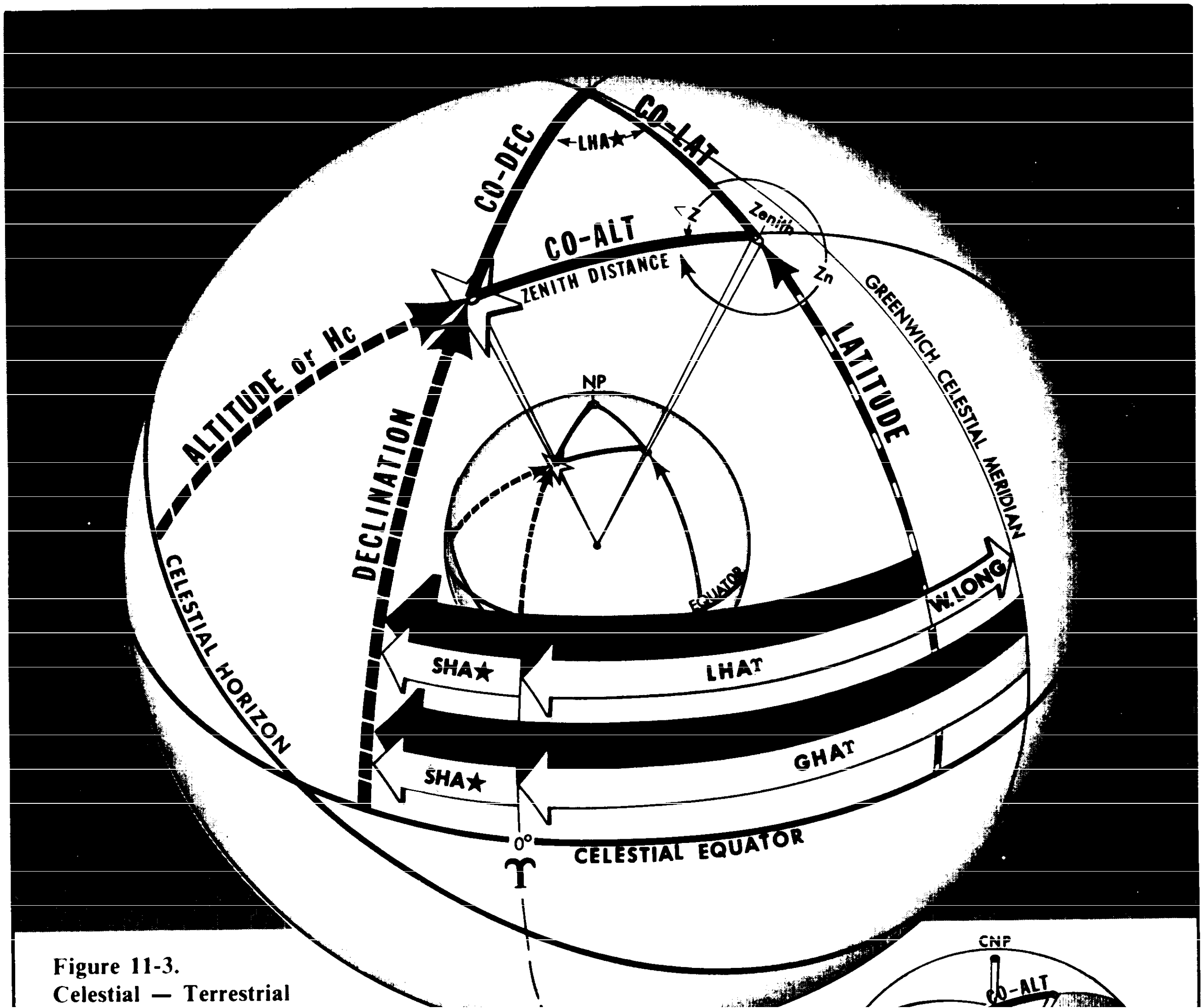


Figure 11-3.
Celestial — Terrestrial
Relationship.

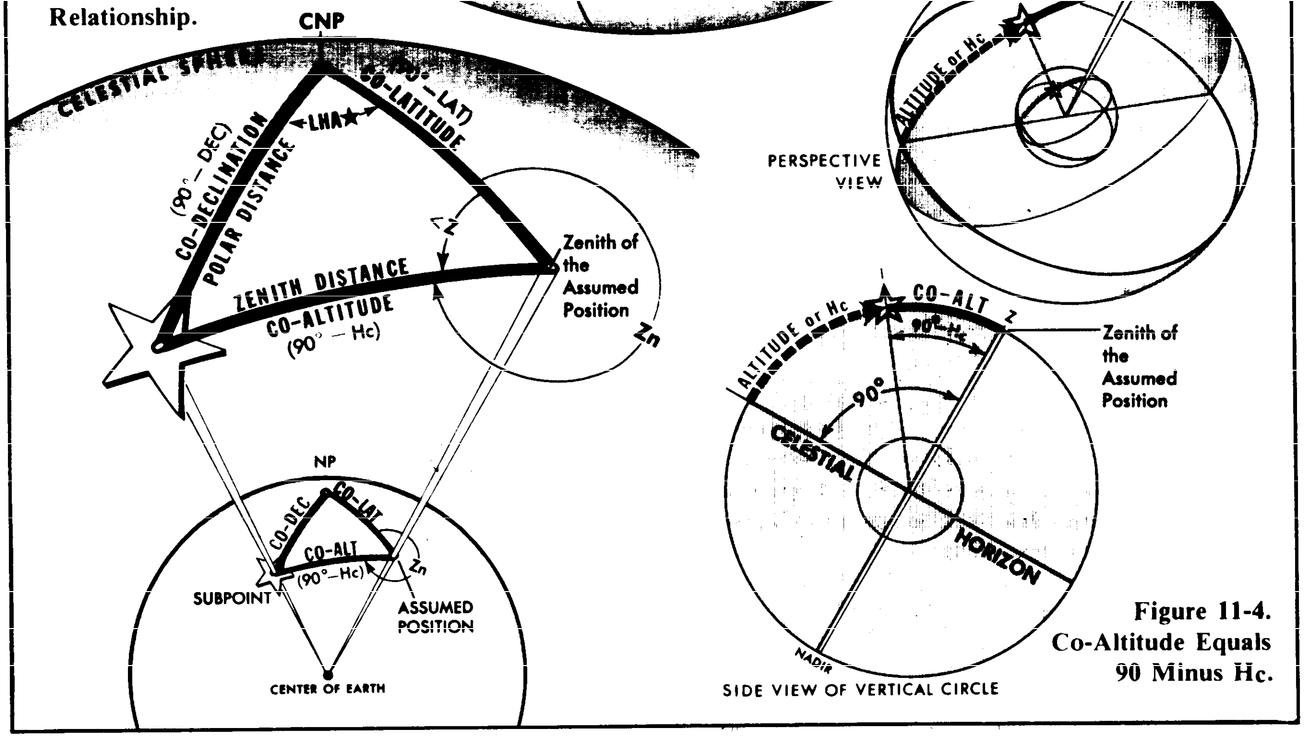


Figure 11-4.
Co-Altitude Equals
90 Minus Hc.

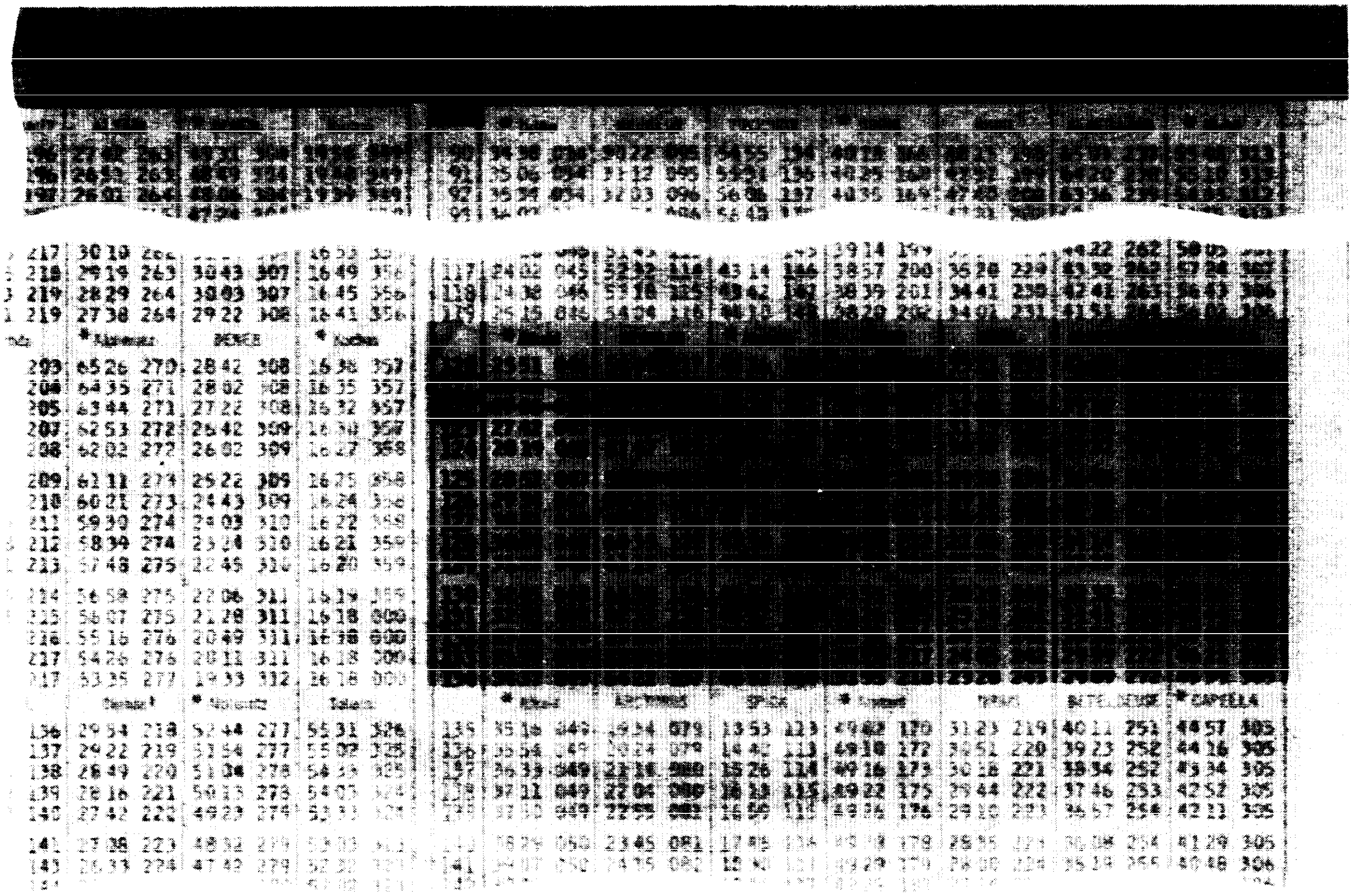


Figure 11-5. Enter Tables with LHA Aries and Latitude.

as the closest point that results in an LHA of Aries that is a whole degree (no minutes). The Hc of Sirius is listed as 37°40′. The Zn is 205°.

The second shot was taken at 0234 using Regulus; the Ho being 55°30′. A new DR position could be obtained for 0234 GMT, but the 0230Z DR position will suffice for this determination of Hc and Zn.

GHA Aries for 0230 GMT 196°06′
Correction for 4 minutes + 1°00′
GHA Aries for 0234Z 197°06′
Closest longitude for
whole LHA − 075°06′W (assumed longitude)
LHA Aries for 0234Z 122°

The assumed latitude is still 32°N and, in this case, 075°06′W is the assumed longitude since this is the closest longitude to the DR longitude that results in the LHA of Aries being a whole degree. The Hc of Regulus is listed as 56°19′, and the Zn is 119°.

The various corrections that must be applied as well as the plotting of the fix are discussed later.

Summary of Procedure

The steps in this procedure are as follows:

1. Using the Air Almanac, determine the GHA of Aries for the time of observation.
2. Assume a position as close as possible to the DR position at the time of the shot so that the latitude and LHA of Aries in whole degrees may be determined.
3. In the HO 249, turn to the page of the assumed latitude and, opposite the LHA of Aries, select the stars to be shot. In making the selection, assume that the LHA of Aries will change 1° every 4 minutes of time.
4. Shoot the body and record the time, Ho, and the name of the body.
5. For the time of the observation, obtain the GHA of Aries and apply the assumed longitude to determine the LHA of Aries.
6. Turn to the pages for the assumed latitude and, opposite the LHA of Aries in the column headed by the name of the star, find and record the Hc and Zn.

HO 249, VOLUMES II and III

Volume I of HO 249 consists of tables of Hc and Zn for selected stars. Since the declination and SHA of each star change slowly, these tables may be used for many years with only small corrections. The declination and SHA of a nonstellar body change rapidly, making a permanent format similar to volume I impossible for the Sun, Moon, and planets.

LAT. 40°

N. Lat. {LHA greater than 180° . . . Zn = Z
{LHA less than 180° . . . . . . Zn = 360 − Z

DECLINATION (0°-14°) SAME NAME AS LATITUDE

LHA	0°			1°			2°			3°			4°			5°			6°			7°			8°			9°			10°			11°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
70	15 11	+40	103	15 51	+40	102	16 31	+40	102	17 11	+39	101	17 50	+39	100	18 29	+39	99	19 08	+39	98	19 47	+38	98	20 25	+39	97	21 05	+38	96	21 42	+37	95	22 19	+38	94
71	14 27	39	103	15 06	40	102	15 46	39	101	16 25	40	100	17 05	39	99	17 44	39	99	18 23	38	98	19 01	39	97	19 40	38	96	20 18	38	95	20 56	38	95	21 34	37	94
72	13 42	39	102	14 21	40	101	15 01	39	100	15 40	39	100	16 19	39	99	16 58	39	98	17 37	39	97	18 16	38	96	18 54	38	96	19 32	38	95	20 10	38	94	20 38	37	93
73	12 57	39	101	13 36	39	100	14 15	40	100	14 55	39	99	15 34	39	98	16 13	38	97	16 51	39	96	17 30	38	96	18 08	38	95	18 46	38	94	19 24	38	93	20 02	37	92
74	12 11	40	100	12 51	39	100	13 30	39	99	14 09	39	98	14 48	39	97	15 27	39	97	16 06	38	96	16 44	38	95	17 22	38	94	18 00	38	93	18 28	38	93	19 16	37	92
75	11 26	+39	100	12 05	+40	99	12 45	+39	98	13 24	+39	97	14 03	+38	97	14 41	+39	96	15 20	+38	95	15 58	+38	94	16 36	+38	94	17 14	+38	93	17 52	+38	92	18 30	+37	91
76	10 41	39	99	11 20	39	98	11 59	39	98	12 38	39	97	13 17	39	96	13 56	38	95	14 34	38	94	15 12	39	94	15 51	38	93	16 29	37	92	17 06	38	91	17 44	37	90
77	09 55	40	98	10 35	39	98	11 14	38	97	11 52	39	96	12 31	39	95	13 10	38	95	13 48	38	94	14 26	39	93	15 05	38	92	15 43	37	91	16 20	38	91	16 58	37	90
78	09 10	39	98	09 49	39	97	10 28	39	96	11 07	38	96	11 45	39	95	12 24	38	94	13 02	39	93	13 41	38	92	14 19	38	92	14 57	37	91	15 34	38	90	16 12	37	89
79	08 24	39	97	09 03	39	96	09 42	39	96	10 21	38	95	10 59	39	94	11 38	38	93	12 16	39	93	12 55	38	92	13 33	38	91	14 11	37	90	14 48	38	89	15 26	38	89
80	07 39	+39	97	08 18	+38	96	08 56	+39	95	09 35	+39	94	10 14	+38	93	10 52	+38	93	11 30	+39	92	12 09	+38	91	12 47	+38	90	13 25	+38	89	14 03	+37	89	14 40	+38	88
81	06 53	39	96	07 32	39	95	08 11	38	94	08 49	39	94	09 28	38	93	10 06	39	92	10 45	38	91	11 23	38	90	12 01	38	90	12 39	38	89	13 17	37	88	13 54	38	87
82	06 07	39	95	06 46	39	94	07 25	38	94	08 03	39	93	08 42	38	92	09 20	39	91	09 59	38	91	10 37	38	90	11 15	38	89	11 53	38	88	12 31	37	87	13 08	38	87
83	05 21	39	95	06 00	39	94	06 39	38	93	07 17	39	92	07 56	38	91	08 34	39	91	09 13	38	90	09 51	38	89	10 29	38	88	11 07	38	88	11 45	37	87	12 22	38	86
84	04 36	38	94	05 14	39	93	05 53	38	92	06 31	39	92	07 10	38	91	07 48	39	90	08 27	38	89	09 05	38	89	09 43	38	88	10 21	38	87	10 59	38	86	11 37	37	85
85	03 50	+38	93	04 28	+39	92	05 07	+38	92	05 45	+39	91	06 24	+38	90	07 02	+39	89	07 41	+38	89	08 19	+38	88	08 57	+38	87	09 35	+38	86	10 13	+38	96	10 51	+38	85
86	03 04	38	93	03 42	39	92	04 21	38	91	04 59	39	90	05 38	38	90	06 16	39	89	06 55	38	88	07 33	38	87	08 11	38	86	08 49	38	86	09 27	38	85	10 05	38	84
87	02 18	38	92	02 56	39	91	03 35	39	90	04 14	38	90	04 52	38	89	05 30	39	88	06 09	38	87	06 47	38	87	07 25	38	86	08 03	38	85	08 41	38	84	09 19	38	83
88	01 32	38	91	02 10	39	91	02 49	39	90	03 28	38	89	04 06	38	88	04 44	39	87	05 23	38	87	06 01	38	86	06 39	39	85	07 18	38	84	07 56	38	84	08 34	38	8
89	00 46	39	91	01 25	38	90	02 03	39	89	02 42	38	88	03 20	39	88	03 59	38	87	04 37	38	86	05 15	39	85	05 54	38	85	06 32	38	84	07 10	38	83	07 48	38	8
90	00 00	+39	90	00 39	+38	89	01 17	+39	88	01 56	+38	88	02 34	+39	87	03 13	+38	86	03 51	+39	85	04 30	+38	85	05 08	+38	84	05 46	+39	83	06 25	+38	82	07 03	+38	82
91	-0 46	39	89	-0 07	38	89	00 31	39	88	01 10	38	87	01 48	39	86	02 27	38	86	03 05	39	85	03 44	38	84	04 22	39	83	05 01	38	82	05 39	38	82	06 17	39	81
92	-1 32	39	89	-0 53	38	88	-0 15	39	87	00 24	38	86	01 02	39	86	01 41	39	85	02 20	38	84	02 58	39	83	03 37	38	83	04 15	39	82	04 54	38	81	05 32	38	80
93	-2 18	39	88	-1 39	38	87	-1 01	39	87	-0 22	39	86	00 17	38	85	00 55	39	84	01 34	39	83	02 13	38	83	02 51	39	82	03 30	38	81	04 08	39	80	04 47	38	80
94	[illegible]		87	-2 25		87	-1 46		86	-1 08		85	-0 29		84	00 10		84	00 48	29	83	01 27		82	[illegible]		81	02 44		81	02 23	39	80	04 02		79

LHA	0°			1°			2°			3°			4°			5°			6°		
89	00 46	39	91	00 07	38	91	-0 31	39	92	[illegible]	38	93	-1 48	39	94	-2 27	38	94	-3 05	39	95
88	01 32	39	91	00 53	38	92	00 15	39	93	-0 24	38	94	-1 02	39	94	-1 41	39	95	-2 20	38	96
87	02 18	39	92	01 39	38	93	01 01	39	93	00 22	39	94	-0 17	38	95	-0 55	39	96	-1 34	39	9
86	03 04	39	93	02 25	39	93	01 46	38	94	01 08	39	95	00 29	39	96	-0 10	38	96	-0 48	39	9
85	03 50	-39	93	03 11	-39	94	02 32	-38	95	01 54	-39	96	01 15	-39	96	00 36	-39	97	-0 03	-38	9
84	04 36	39	94	03 57	39	95	03 18	39	95	02 39	39	96	02 00	38	97	01 22	39	98	00 43	39	98
83	05 21	38	95	04 43	39	95	04 04	39	96	03 25	39	97	02 46	39	98	02 07	39	98	01 28	39	99
82	06 07	39	95	05 28	38	96	04 50	39	97	04 11	39	97	03 32	39	98	02 53	39	99	02 14	40	10
81	06 53	39	96	06 14	39	97	05 35	39	97	04 56	39	98	04 17	39	99	03 38	39	100	02 59	39	10
80	07 39	-39	97	07 00	-39	97	06 21	-39	98	05 42	-40	99	05 02	-39	100	04 23	-39	100	03 44	-39	10
79	08 24	39	97	07 45	39	98	07 06	39	99	06 27	39	99	05 48	40	100	05 08	39	101	04 29	39	10
78	09 10	39	98	08 31	39	99	07 52	40	99	07 12	39	100	06 33	39	101	05 54	40	102	05 14	40	10
77	09 55	39	98	09 16	39	99	08 37	39	100	07 58	40	101	07 18	40	102	06 38	39	102	05 59	40	10
76	10 41	39	99	10 02	40	100	09 22	39	101	08 43	40	101	08 03	40	102	07 23	39	103	06 44	40	10
75	11 26	-39	100	10 47	-40	101	10 07	-39	101	09 28	-40	102	08 48	-40	103	08 08	-40	104	07 28	-40	104
74	12 11	39	100	11 32	40	101	10 52	39	102	10 13	40	103	09 33	40	104	08 53	40	104	08 13	40	10
73	12 57	40	101	12 17	40	102	11 37	40	103	10 57	40	103	10 17	40	104	09 37	40	105	08 57	40	10
72	13 42	40	102	13 02	40	103	12 22	40	103	11 42	40	104	11 02	40	105	10 22	41	106	09 41	40	10
71	14 27	40	103	13 47	40	103	13 07	41	104	12 26	40	105	11 46	40	106	11 06	41	106	10 25	40	10
70	15 11	-40	103	14 31	-40	104	13 51	-40	105	13 11	-41	106	12 30	-40	106	11 50	-41	107	11 09	-41	108

11°			°12			13°			14°			
11	39	99	271									
5 32	38	100	-6 10	39	100	272						
4 47	38	100	-5 25	39	101	-6 04	38	102	273			
4 02	38	101	-4 40	39	102	-5 19	38	102	-5 57	38	103	274
3 16	-39	102	-3 55	-39	102	-4 34	-38	103	-5 12	-39	104	275
31	39	102	-3 10	39	103	-3 49	39	104	-4 28	38	105	276
47	39	103	-2 26	38	104	-3 04	39	104	-3 43	39	105	277
1 02	39	104	-1 41	39	104	-2 20	39	105	-2 59	39	106	278
0 17	39	104	-0 56	40	105	-1 36	39	106	-2 15	39	106	279
0 27	-39	105	-0 12	-40	106	-0 52	-39	106	-1 31	-39	107	280
12	40	105	00 32	39	106	-0 07	40	107	-0 47	40	108	281
56	40	106	01 16	40	107	00 36	39	108	-0 03	40	108	282
2 40	40	107	02 00	40	108	01 20	40	108	00 40	40	109	283
3 24	40	107	02 44	40	108	02 04	40	109	01 24	41	110	284
08	-41	108	03 27	-40	109	02 47	-40	110	02 07	-41	110	285
4 51	40	109	04 11	41	109	03 30	40	110	02 50	41	111	286
5 35	41	109	04 54	41	110	04 13	40	111	03 33	41	112	287
6 18	41	110	05 37	41	111	04 56	41	112	04 15	41	112	288
7 01	41	111	06 20	41	112	05 39	41	112	04 58	42	113	289
7 44	-41	111	07 03	-42	112	06 21	-41	113	05 40	-42	114	290

S. Lat. {LHA greater than 180°. . . . . . . Zn=180−Z
{LHA less than 180°. . . . . Zn=180+Z

DECLINATION (0°-14°) **CONTRARY** NAME TO LATITUDE LAT. 40°

Figure 11-6. Enter Table with Latitude, Declination, and LHA.

Volumes II and III of HO 249 are declination tables adequate for determining the Hc and Zn of any celestial body within the declination range of 30° north to 30° south. They are intended primarily for use when observing nonstellar (solar system) bodies. Volume II provides for latitudes from the equator to 39° north or south, and volume III provides for latitudes from 40° north or south to the poles. Provision is made for observed altitudes from 90° to 3° below the horizon (7° from latitudes 70° to the pole). In view of refraction and of possible long intercepts, the tables are actually extended 2° below these limits.

Entering Arguments

Volumes II and III are entered with the LHA of the body, in contrast to volume I, which is entered with the LHA of Aries. The range extends from 0° through all LHAs applicable within the altitude limits of the body. Between latitude 70° and the pole, the LHA interval is 2°; for latitudes below 70°, the interval is 1°. Arguments of LHA of the body less than 180° appear on the left margin, and arguments greater than 180° appear on the right.

Several pages are devoted to each degree of latitude. Each page has 15 declination columns and is labeled with its value at the top and bottom. Each page is also marked "Declination Contrary Name to Latitude" or "Declination Same Name as Latitude."

The entering arguments of LHA of the body, for declination of contrary name to latitude, always increase from the bottom of the page on the left side, and decrease on the right. The opposite arrangement exists on pages where declination and latitude have the same name. Occasionally, one page will be blank in the middle and the top half will cover Declination Same Name as Latitiude; while the bottom half will be Declination Contrary Name to Latitude.

Azimuth angle (Z) is listed instead of true azimuth (Zn). Since true azimuth is used for plotting, it is necessary to convert azimuth angle to true azimuth. The rules for conversion are listed on the left-hand side at the top and bottom of every page. Notice that LHA and Zn will never occur on the same side of 180°.

Besides the listing of Hc and Z in volumes II and III of HO 249, there is also recorded a value of "d". This d-value is the change in altitude (Hc) with a 1° increase in declination. If the LHA and declination of the body and the latitude of the assumed position are each a whole number of degrees, the Hc and Z are found in the correct declination column opposite the LHA of the body on the page marked by the proper latitude value.

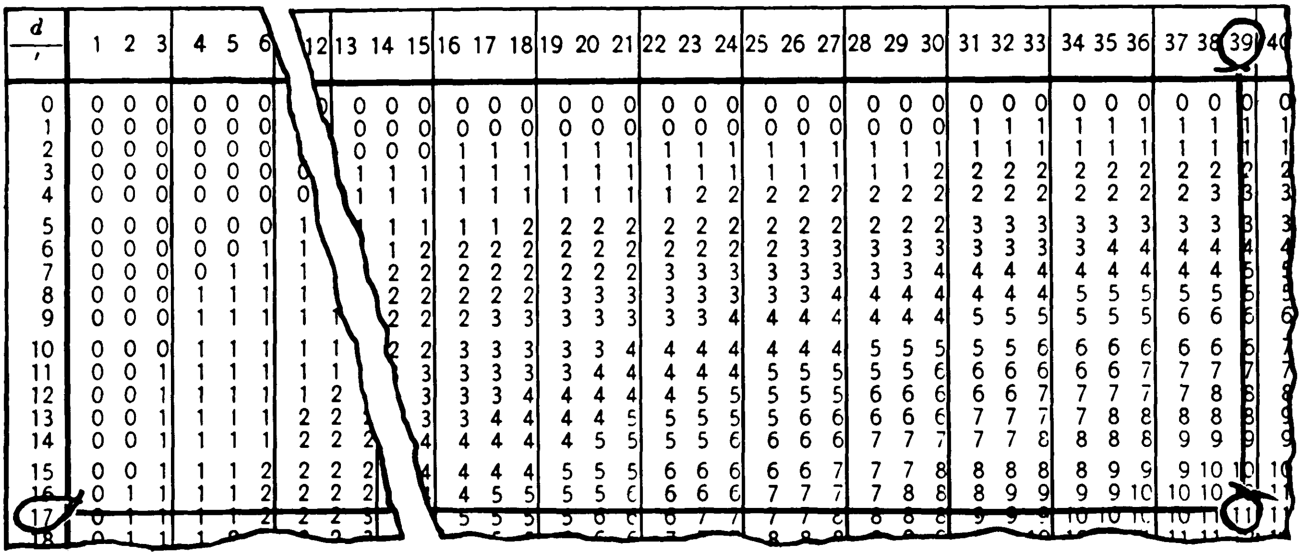
For example, refer to the portion of the table shown in figure 11-6. At a latitude of 40°N, if the LHA of a body is 86° and its declination is 5°N, the Hc is 06°16′ and the azimuth angle (Z) is 089°. The rule in the upper left-hand corner of the page applies for the conversion of Z to Zn. Zn = (360° − Z) or (360° − 089°) = 271°. Here again the position is assumed so that latitude and LHA are whole numbers.

Interpolation for Declination

When the declination of a body is a number of minutes in addition to a whole number of degrees, the altitude (Hc) is extracted for the whole number of degrees and corrected by interpolation for the additional minutes. There is rarely a need for interpolation of azimuth angle (Z), which is given only to the nearest degree.

Interpolation for Hc should always be made in the direction of increasing declination, in accordance with the sign of the d-value. Not all of the signs are printed; the sign is given at least once in each block of five entries, and can always be found by looking either up or down the column from the value of "d" in question. The correction to altitude for additional minutes of declination is proportional to "d" and proportional to the number of additional minutes.

In the previous example, the latitude was 40°N, the LHA of the body was 086°, and the declination was 5°N. Suppose the declination had been 5°17′N. The basic figures obtained would



d / ′	1	2	3	4	5	6				12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	4
0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0					0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
4	0	0	0	0	0	0	0				1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
5	0	0	0	0	0	0	1				1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
6	0	0	0	0	0	1	1					1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4
7	0	0	0	0	1	1	1					2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	5	5
8	0	0	0	1	1	1	1					2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5	5
9	0	0	0	1	1	1	1	1				2	2	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5	6	6	6	6
10	0	0	0	1	1	1	1	1				2	2	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	6	6	7
11	0	0	1	1	1	1	1	1					3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	6	7	7	7	7	7
12	0	0	1	1	1	1	1	2					3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	8	8	8
13	0	0	1	1	1	1	2	2					3	3	4	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	8	8	8	8	8	9
14	0	0	1	1	1	1	2	2	2				4	4	4	4	4	5	5	5	5	6	6	6	6	7	7	7	7	7	8	8	8	8	9	9	9	9
15	0	0	1	1	1	2	2	2	2				4	4	4	4	5	5	5	6	6	6	6	6	7	7	7	8	8	8	8	8	9	9	9	10	10	10
16	0	1	1	1	1	2	2	2	2					4	5	5	5	5	6	6	6	6	7	7	7	7	8	8	8	9	9	9	9	10	10	10		11
17	0	1	1	1	1	2	2	2	3					5	5	5	5	6	6	6	7	7	7	7	8	8	8	8	9	9	9	10	10	10	10	11	11	1

Figure 11-7. Table Performs the Multiplication.

be 06°16′ Hc and 089° Z as before, and the true azimuth would still be 271°. The Hc of 06°16′ is not correct for a declination of 5°17′N, but is correct for 5°N. The Hc change for an additional 1° of declination (d-value) is +39 minutes of altitude. However, the correction needed in this case is for 17 minutes of declination, not a whole degree. Consequently, the additional correction is 17/60 of +39′. To the closest whole number, this would be +11 minutes of altitude.

This multiplication can be done on the slide rule face of the DR computer, or by means of a table found in back of volumes II and III, HO 249. A portion of this table is shown in figure 11-7. Notice that there are no signs listed. The proper sign for the answer from this table is the same sign as the basic d-value. Values of "d" are given across the top of the table, and additional minutes of declination are given down the side of the table. In the table, the correction 11′ is found by looking across 17′ for declination and down 39′ for "d", to their intersection at 11′. Since the sign of the d-value is plus, this correction is added to the tabulated Hc. The correct Hc value then becomes 06°16′ + 11′ or 06°27′.

Following is a sample problem illustrating the solution. Refer to the portion of the tables in figure 11-8 for the solution. Suppose the Sun is observed at 1005 GMT. The DR position is 38°12′N, 101°47′E, and the Ho of the Sun is 10°52′.

Declination of the Sun for 1000Z	7°37′S
GHA Sun for 1000Z	326°53′
Correction to GHA for 5 minutes	+ 1°15′
GHA Sun for 1005Z	328°08′
Closest longitude for whole degree LHA	+ 101°52′E (assumed longitude)
	430°00′
	− 360°00′
LHA Sun for 1005Z	070°00′

The closest whole degree of latitude is 38°N; therefore, it is used as the assumed latitude. Since the assumed latitude is north and declination is south, the navigator must use the HO 249, vol II page for 38° latitude which is headed "Declination (0° − 14°) Contrary Name to Latitude." Following LHA 070° across the page to 7° declination, the navigator extracts:

Tab Hc	11°06′
d-value	−40
Z	108°
d-correction from table in back of HO 249 volume II (opposite 37′ and "d" 40	−25
Corrected Hc	10°41′
Zn using rule in the upper left-hand corner of the page	252°

Summary of Procedure

Before proceeding, review the procedures for finding the altitude (Hc) and true azimuth (Zn) of a body whose declination lies between 30°N and 30°S, using volume II or III of HO 249.

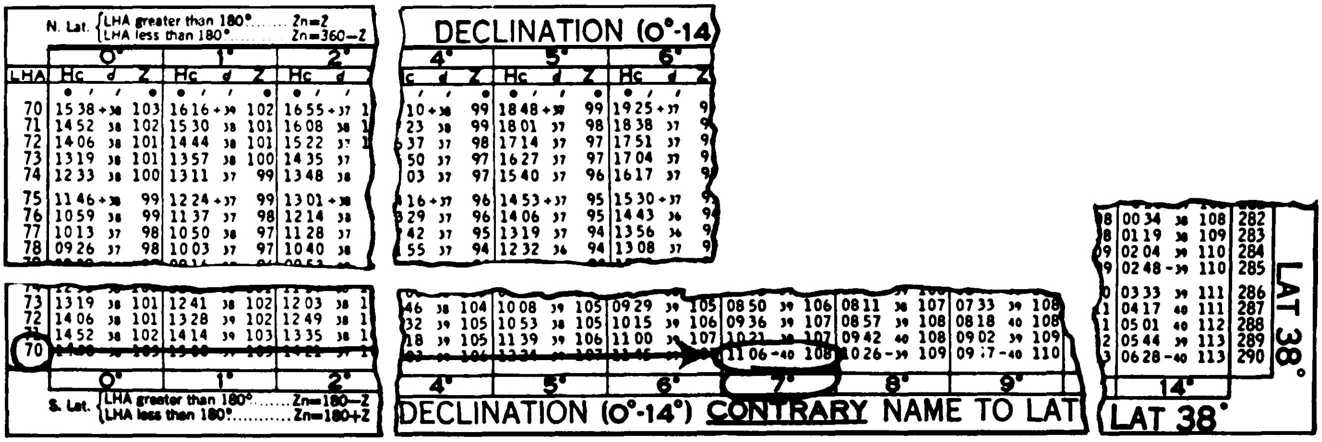
1. Shoot the body and record the time of observation, the body's name, and the Ho.

2. From the Air Almanac, ascertain the declination and GHA of the body for the time of the observation.

3. Assume a position as close as possible to the DR position so that the latitude is a whole number of degrees, and the longitude combined with the GHA of the body gives a whole number of degrees of LHA of the body. Find the LHA of the body for this position.

4. According to the assumed latitude, select the correct volume (II or III) and page which contains the correct arguments of declination and LHA of the body, temporarily disregarding the odd additional minutes of declination. Thus, if the declination were N19°55′, use the column for 19°. Select the table labeled "Declination Same Name as Latitude," if declination and latitude are both north or both south; or the table labeled "Declination Contrary Name to Latitude," if one is north and the other south. Opposite the LHA of the body, read the tabulated altitude, d-value, and azimuth angle in the column headed by the whole degrees of declination.

5. If the declination is not a whole number of degrees, determine the altitude correction for the additional minutes of declination. Enter the table in the back of the HO 249 volume with the value "d" and the number of additional minutes of



N. Lat. {LHA greater than 180° ...... Zn=Z; LHA less than 180° ...... Zn=360−Z}

	0°			1°			2°		
LHA	Hc	d	Z	Hc	d	Z	Hc	d	Z
	° ′	′	°	° ′	′	°	° ′	′	
70	15 38	+38	103	16 16	+39	102	16 55	+37	1
71	14 52	38	102	15 30	38	101	16 08	38	1
72	14 06	38	101	14 44	38	101	15 22	37	1
73	13 19	38	101	13 57	38	100	14 35	37	
74	12 33	38	100	13 11	37	99	13 48	38	
75	11 46	+38	99	12 24	+37	99	13 01	+38	
76	10 59	38	99	11 37	37	98	12 14	38	
77	10 13	37	98	10 50	38	97	11 28	37	
78	09 26	37	98	10 03	37	97	10 40	38	

DECLINATION (0°-14

4°			5°			6°		
c	d	Z	Hc	d	Z	Hc	d	Z
′	′	°	° ′	′	°	° ′	′	
10	+38	99	18 48	+37	99	19 25	+37	9
23	38	99	18 01	37	98	18 38	37	9
37	37	98	17 14	37	97	17 51	37	9
50	37	97	16 27	37	97	17 04	37	9
03	37	97	15 40	37	96	16 17	37	9
16	+37	96	14 53	+37	95	15 30	+37	9
29	37	96	14 06	37	95	14 43	36	9
42	37	95	13 19	37	94	13 56	36	9
55	37	94	12 32	36	94	13 08	37	9

LHA	Hc	d	Z	Hc	d	Z	Hc	d	Z
73	13 19	38	101	12 41	38	102	12 03	38	1
72	14 06	38	101	13 28	39	102	12 49	38	1
71	14 52	38	102	14 14	39	103	13 35	38	1
70	[illegible]								
	0°			1°			2°		

S. Lat. {LHA greater than 180° ...... Zn=180−Z; LHA less than 180° ...... Zn=180+Z}

Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
46	38	104	10 08	39	105	09 29	39	105	08 50	39	106	08 11	38	107	07 33	39	108
32	39	105	10 53	38	105	10 15	39	106	09 36	39	107	08 57	39	108	08 18	40	108
18	39	105	11 39	39	106	11 00	39	107	10 21	38	107	09 42	40	108	09 02	39	109
[illegible]									11 06	−40	108	10 26	−39	109	09 [illegible]7	−40	110
4°			5°			6°			7°			8°			9°		

DECLINATION (0°-14°) CONTRARY NAME TO LAT

	14°			
8	00 34	38	108	282
8	01 19	38	109	283
9	02 04	39	110	284
9	02 48	−39	110	285
0	03 33	39	111	286
1	04 17	40	111	287
1	05 01	40	112	288
2	05 44	39	113	289
3	06 28	−40	113	290

LAT 38°

LAT 38°

Figure 11-8. Declination (0°–14°) Contrary Name to Latitude.

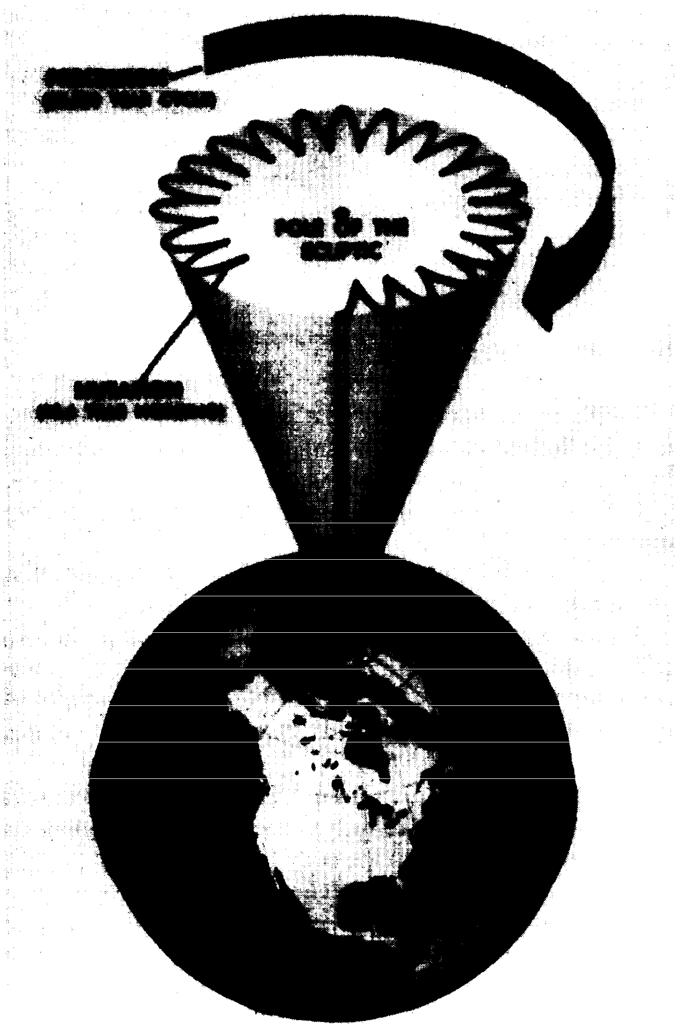


Figure 11-9. Wobble of Earth's Axis Takes Several Patterns.

declination. Apply the correction to the tabulated altitude (Hc) according to the sign of "d". This is the corrected Hc.

6. Convert azimuth angle (Z) to true azimuth (Zn) by means of the rule at the top or bottom of the page as appropriate.

This completes the solution for the declination tables. However, there is another point that must be discussed in regard to the solutions in volume I of HO 249 for the stars.

PRECESSION AND NUTATION

The Earth's axis does not maintain a fixed direction in space. Actually, the Earth is like a slow running gyro that is wobbling. There are several separate patterns that the wobble makes. Some of those patterns have short cycles, while others take hundreds of years to complete. Two of the many patterns are shown in figure 11-9. One involves small nodding motions while at the same time completing a larger circular path.

The navigator uses a correction called "precession and nutation" to account for these variations in the apparent position of the stars. This correction is applied only to celestial LOPs determined with HO 249, volume I.

Precession

Because of the equatorial bulge, the attractive forces of other solar system bodies, principally the Moon, are unbalanced about the center of the Earth. The imbalance is directed toward aligning the equator with the plane of the ecliptic. However, the rotation of the Earth transforms this force into an effect acting 90° away in the direction of rotation — a precessional effect. The result is that the poles describe a conical path westward about the ecliptic poles, as shown in figure 11-10 (the point 90° from the ecliptic). Consequently, the points of intersection of the equator with the ecliptic, or the equinoxes, travel in a westerly direction along the ecliptic. This travel is called *precession of the equinoxes,* and it amounts to approximately five-sixths (5/6) of a minute (50.26") annually. The equinoxes complete one revolution along the ecliptic in approximately 25,800 years.

The equator is used as a reference for declination and its movement, due to precession of the equinoxes, causes slight changes in the celestial coordinates of the stars, which otherwise appear fixed in space.

Nutation

As the relative positions and distances from the Earth to the Sun, Moon, and planets vary, so does the rate of precession. The only variation of importance in navigation is nutation. "Nutations," from the Latin "te ned," is a "nodding" of the poles; one oscillation occurring in about 18.6 years.

In figure 11-11, you can see that if the stars remain fixed and the equinoctial moves up and down, the declination of these bodies is changing. Nutation, being approximately perpendicular to the ecliptic, has an appreciable influence on declination. It is caused by complex gravitational forces among the Sun, Moon, and Earth, because of the fact that the Moon's orbit does not always lie in the plane of the ecliptic. The change of declination of the celestial bodies caused by the resulting wobble of the Earth's axis is called *nutation.*

Position Corrections

Because of precession and nutation, Hc and Zn for a star are accurate only at the instant, or epoch, at which the LHA and declination for the computations are correct. A position obtained at any other time with that Hc and Zn requires a correction. HO 249, volume I, contains Hcs and Zns calculated for an epoch year (midnight, 1 January, of that year) so, if the volume is used in any other year, the resultant position must be corrected. The precession and nutation corrections are combined and given in table 5 of HO 249, volume I.

Entering arguments for the table are year, latitude, and LHA of Aries, and the correction is presented in the form of a distance and direction to move the fix. The tabulated values show the

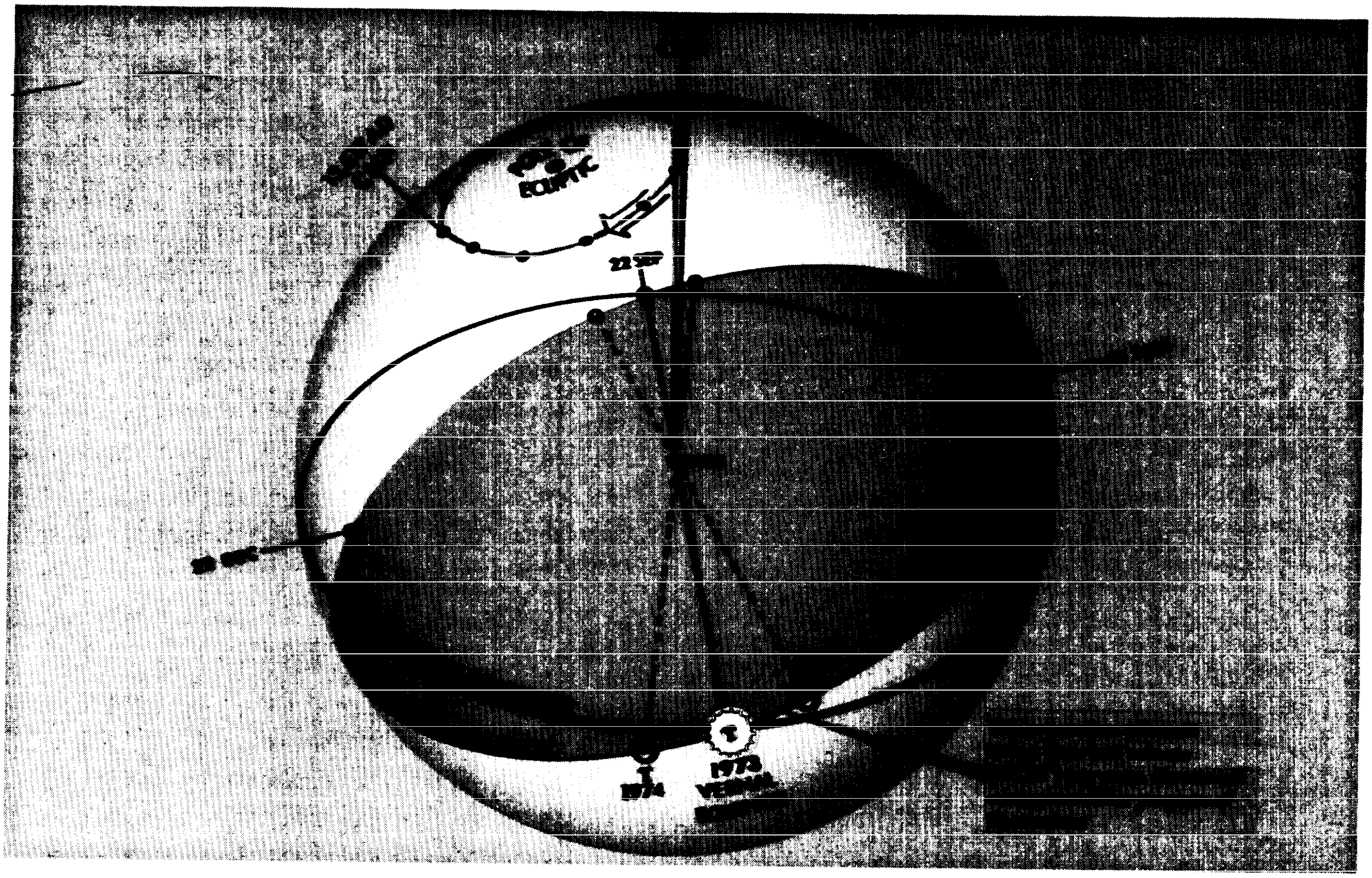


Figure 11-10. Precession of the Equinoxes.

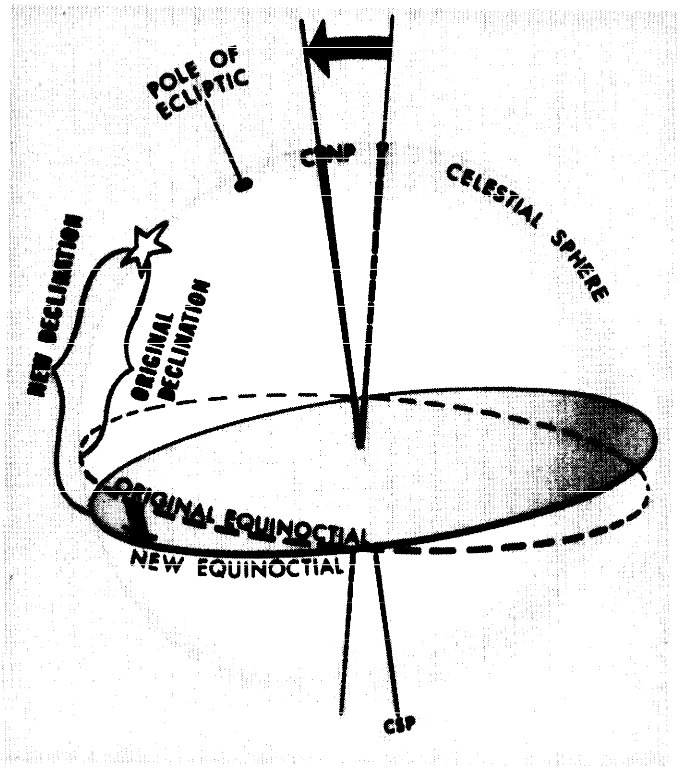


Figure 11-11. Nutation Changes the Declination.

distance, parallel to the ecliptic, between the observer's position in the year of the fix and the position in 1980 at the latitude and LHA of Aries.

Directions for using table 5 are printed in the introduction of HO 249, volume I. Only one point needs emphasis here: the table is to be used only for observations plotted with the aid of HO 249, volume I — never in conjunction with volumes II or III.

SUMMARY

This chapter has dealt with the astronomical triangle and how the HO 249 volumes assist the navigator in resolving the astronomical triangle to obtain an LOP or a fix. Solutions have been discussed involving stellar and nonstellar bodies utilizing HO 249 volumes I, II and II; and the fix corrections necessary when volume I is used. Succeeding chapters will discuss plotting of the celestial LOPs and techniques of precomputation.

Chapter 12

CELESTIAL PRECOMPUTATION

Celestial precomputation is neither new nor revolutionary. Actually, the tables necessary to do precomputation have been available since 1940, however, there was no operational requirement for precomputation at that time. With present day high-speed aircraft, however, the picture has changed radically. By the methods previously discussed, it is apparent that a great deal of work is accomplished after the last celestial observation is taken. The fix could easily be 10 to 20 minutes old, depending on the speed and proficiency of the navigator, by the time it is plotted on the chart. At a 600-knot groundspeed, a fix that is 15 minutes old is 150 miles behind the aircraft and could be of questionable value.

Another factor necessitating precomputation in high-speed aircraft lies in the very structure of the aircraft itself. There can be no projections such as an astrodome on these aircraft. The navigator will probably be using a periscopic sextant which could easily be the only means of viewing the heavens. With the limited field of view of the sextant, the correct star would be extremely difficult to find in the optics if the navigator did not know where to look.

PRESETTING THE SEXTANT

Precomputation greatly reduces both of the problems just mentioned. By completing most of the computations before shooting, the navigator can greatly reduce the time necessary to plot the fix after the last observation. Also, the problem of finding the star in the optics of the sextant is simplified. The procedure for finding the star is very similar to the heading check performed with the periscopic sextant, using the true bearing method as explained in chapter 14. In this case the Zn, known beforehand, is set into the sextant mount, and the Hc, which will approximate the Hs, is set into the sextant. Now, instead of sighting the body and determining the true heading, the true heading is set under the vertical crosshair and the selected body is found very close to the crosshairs in the sextant field of view.

To avoid erroneous settings of the azimuth window and to increase speed in setting up the sextant, the relative bearing method may be used. In this method, the azimuth window remains permanently at 360.0°, and the inverse (sextant) relative bearing is computed by the formula: IRB = TH − Zn.

The body sought will be found at its computed altitude when its IRB appears under the crosshairs.

PRECOMPUTATION TECHNIQUES

There are many acceptable methods of precomputation in general usage. However, these methods are basically either graphic, mathematic, or a combination of graphic and mathematic solutions. The method used by the practicing navigator will largely be determined by the type and speed of the aircraft, and by the type of mission flown.

Celestial corrections which are used in precomputation include atmospheric refraction, parallax of the Moon, instrument and acceleration errors, Coriolis and rhumb line, precession and nutation, motion of the observer, and wander. With precomputation, new corrections and terminology are introduced, which include fix time, solution time, observation time, scheduled time, and motion of the body adjustment.

Fix time is the time for which the LOPs are resolved and plotted on the chart. *Solution time* is the time for which the astronomical triangle is solved. *Observation time* is the mid-time of the actual observation for each celestial body. *Scheduled time* is the time for which the astronomical triangle is solved for each LOP in the graphic method. *Motion of the body correction* is used to correct for the changing altitude of the selected bodies from shot to fix time, and may be applied either graphically or mathematically.

Motion of the Body Correction

Motion of the body correction is applied graphically by moving the assumed position eastward or westward for time. This is possible because the GHA of Aries and, consequently, the subpoint of the body, moves westward at the rate of 1° of longitude per 4 minutes of time. In the graphic method, a scheduled time of observation is given to each body. If shooting is off schedule, the following rules apply: For every minute of time that the shot is taken early, move the assumed position 15′ of longitude to the east; for every minute of time that the shot is taken late, move the assumed position 15′ of longitude to the west.

When the latitude of the assumed position and the Zn of the body are known, the motion of the body can be computed mathematically. For 1 minute, the formula is: 15′ × cos lat × sin Zn. This correction has been computed and is shown in tabular form in figure 12-1.

If this table is not available to the navigator, the correction may be easily determined in the HO 249. For any stationary position (the assumed position), the LHA increases 1° in 4 minutes of time. Thus, the Hc in HO 249, for an LHA that is 1° less than the LHA used for precomputation, is the Hc for 4 minutes of time earlier than the solution time. The difference between the two Hcs is the value to apply to the Hc or Hs to advance or retard the LOP for 4 minutes of time. If the Hc decreases (Zn greater than 180°), the body is setting and the sign is minus to advance the LOP if the value is applied to the Hs. If the Hc increases (Zn less than 180°), the body is rising and the sign is plus to advance the LOP if the value is applied to the Hs.

In addition, motion corrections may be determined by using a modified MB-4 computer. This modification allows for greater

True Zn	Correction for 4 Minutes of Time																											True Zn
	Latitude																											
	0°	8°	16°	20°	24°	28°	30°	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°	60°	64°	68°	72°	76°	80°	84°	
°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	°
090	+60	+59	+58	+56	+55	+53	+52	+51	+50	+49	+47	+46	+45	+43	+42	+40	+39	+37	+35	+34	+30	+26	+22	+19	+15	+10	+6	090
095	60	59	57	56	55	53	52	51	50	48	47	46	44	43	42	40	38	37	35	33	30	26	22	18	14	10	6	085
100	59	59	57	56	54	52	51	50	49	48	47	45	44	43	41	40	38	36	35	33	30	26	22	18	14	10	6	080
105	58	57	56	54	53	51	50	49	48	47	46	44	43	42	40	39	37	36	34	32	29	25	22	18	14	10	6	075
110	56	56	54	53	52	50	49	48	47	46	44	43	42	41	39	38	36	35	33	32	28	25	21	17	14	10	6	070
115	54	54	52	51	50	48	47	46	45	44	43	42	40	39	38	36	35	33	32	30	27	24	20	17	13	9	6	065
120	+52	+51	+50	+49	+47	+46	+45	+44	+43	+42	+41	+40	+39	+37	+36	+35	+33	+32	+31	+29	+26	+23	+19	+16	+13	+9	+5	060
125	49	49	47	46	45	43	43	42	41	40	39	38	37	35	34	33	32	30	29	27	25	22	18	15	12	9	5	055
130	46	46	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	28	27	26	23	20	17	14	11	8	5	050
135	42	42	41	40	39	37	37	36	35	34	33	33	32	31	29	28	27	26	25	24	21	19	16	13	10	7	4	045
140	39	38	37	36	35	34	33	33	32	31	30	30	29	28	27	26	25	24	23	22	19	17	14	12	9	7	4	040
145	34	34	33	32	31	30	30	29	29	28	27	26	26	25	24	23	22	21	20	19	17	15	13	11	8	6	4	035
150	+30	+30	+29	+28	+27	+26	+26	+25	+25	+24	+24	+23	+22	+22	+21	+20	+19	+18	+18	+17	+15	+13	+11	+9	+7	+5	+3	030
155	25	25	24	24	23	22	22	22	21	21	20	19	19	18	18	17	16	16	15	14	13	11	9	8	6	4	3	025
160	21	20	20	19	19	18	18	17	17	17	16	16	15	15	14	14	13	13	12	11	10	9	8	6	5	4	2	020
165	16	15	15	15	14	14	13	13	13	13	12	12	12	11	11	10	10	10	9	9	8	7	6	5	4	3	2	015
170	10	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	5	5	4	3	3	2	1	010
175	+5	+5	+5	+5	+5	+5	+5	+4	+4	+4	+4	+4	+4	+4	+4	+3	+3	+3	+3	+3	+3	+2	+2	+2	+1	+1	+1	005
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	000
185	−5	−5	−5	−5	−5	−5	−5	−4	−4	−4	−4	−4	−4	−4	−4	−3	−3	−3	−3	−3	−3	−2	−2	−2	−1	−1	−1	355
190	10	10	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	5	5	4	3	3	2	1	350
195	16	15	15	15	14	14	13	13	13	13	12	12	12	11	11	10	10	10	9	9	8	7	6	5	4	3	2	345
200	21	20	20	19	19	18	18	17	17	17	16	16	15	15	14	14	13	13	12	11	10	9	8	6	5	4	2	340
205	25	25	24	24	23	22	22	22	21	21	20	19	19	18	18	17	16	16	15	14	13	11	9	8	6	4	3	335
210	30	30	29	28	27	26	26	25	25	24	24	23	22	22	21	20	19	18	18	17	15	13	11	9	7	5	3	330
215	−34	−34	−33	−32	−31	−30	−30	−29	−29	−28	−27	−26	−26	−25	−24	−23	−22	−21	−20	−19	−17	−15	−13	−11	−8	−6	−4	325
220	39	38	37	36	35	34	33	33	32	31	30	30	29	28	27	26	25	24	23	22	19	17	14	12	9	7	4	320
225	42	42	41	40	39	37	37	36	35	34	33	33	32	31	29	28	27	26	25	24	21	19	16	13	10	7	4	315
230	46	46	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	28	27	26	23	20	17	14	11	8	5	310
235	49	49	47	46	45	43	43	42	41	40	39	38	37	35	34	33	32	30	29	27	25	22	18	15	12	9	5	305
240	52	51	50	49	47	46	45	44	43	42	41	40	39	37	36	35	33	32	31	29	26	23	19	16	13	9	5	300
245	−54	−54	−52	−51	−50	−48	−47	−46	−45	−44	−43	−42	−40	−39	−38	−36	−35	−33	−32	−30	−27	−24	−20	−17	−13	−9	−6	295
250	56	56	54	53	52	50	49	48	47	46	44	43	42	41	39	38	36	35	33	32	28	25	21	17	14	10	6	290
255	58	57	56	54	53	51	50	49	48	47	46	44	43	42	40	39	37	36	34	32	29	25	22	18	14	10	6	285
260	59	59	57	56	54	52	51	50	49	48	47	45	44	43	41	40	38	36	35	33	30	26	22	18	14	10	6	280
265	60	59	57	56	55	53	52	51	50	48	47	46	44	43	42	40	38	37	35	33	30	26	22	18	14	10	6	275
270	−60	−59	−58	−56	−55	−53	−52	−51	−50	−49	−47	−46	−45	−43	−42	−40	−39	−37	−35	−34	−30	−26	−22	−19	−15	−10	−6	270

Observations Earlier than Solution Time - SIGNS AS GIVEN

Observations Later than Solution Time - SIGNS REVERSED

Figure 12-1. Correction for Motion of the Body.

accuracy and speed in computation of combined motions (motion of the observer and motion of the body) than the HO 249 tables. For a discussion of this modification, see Chapter 14, Special Celestial Techniques.

The main difference between the basic methods of precomputation is the manner in which the motion of the observer and the motion of the body corrections are applied. In the graphic method, both corrections are applied graphically by movement of the assumed position or the LOP. In the mathematic method, both corrections are applied mathematically to the Hc, the Hs, or the intercept after being obtained from tables, a modified MB-4 computer, or the HO 249.

Celestial Computation Forms

The following computation forms (figures 12-2, 12-3, and 12-4) are representative of those in use by MAC, SAC, and the Navy. To meet specialized operational requirements, major commands may prescribe and issue additional or substitute celestial precomputation forms. The following explanations are numbered to simplify location of the various blocks on the sample forms. (Not all blocks apply on every precomp.)

CELESTIAL COMPUTATION DATA			
BODY	3		
TIME	2		
LAT	11		
DEC	12		
GHA	5		
±360	6		
LONG $^{-W}_{+E}$	9		
LHA	10		
HC	17		
CORR	-36		
HC	17-36		
HO	38		
INT (T/A)	39		
ZN	19		
LONG/CONV	41		
GRID ZN	42		

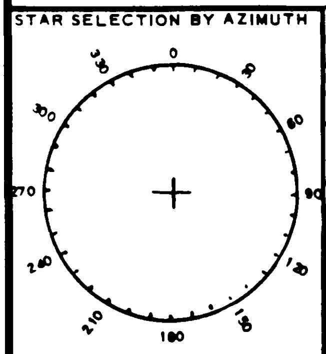
Figure 12-2. MAC Celestial Computation Form.

CELESTIAL PRECOMPUTATION	SHEET NO.

HO-249 PRECOMPUTATION - PERISCOPIC SEXTANT

NAVIGATOR	ALT MSL 22	DATE (Z) 1	FIX TIME 22 Z

STAR SELECTION BY AZIMUTH



TRACK	20	°
GS	21	K
CORIOLIS	23	R L
PREC/NUT	24	NM/°
DR LAT	4	N S
DR LONG	4	W E

			Polaris		
MOTION OBSERVER	26				
MOTION BODY	27				
4 MIN ADJUST	28				
X TIME	E L 29	E L	E L	E L	E L
TOTAL MOT. ADJUST.	30				
POLARIS/MOON PX SD	34 33		35		
REFR	31				
PERS/SEXT	32				
TOTAL ADJ →	36				
TH/GH	°	°	°	°	°
Zn/GZn (-)	19°	°	°	°	°
SRB	°	°	°	°	°
SRB$_O$	°				
Zn/GZn (+)	°				
TH/GH	°				
T/G TRACK	20				
Zn	19				
REL Zn	25				

REFRACTION TABLE *(Condensed)*

Ro	ALTITUDE MSL *(Thousands of Feet)* 0	20	25	30	35	40
	63°	46°	41°	36°	31°	26°
1	33°	19°	16°	14°	11°	9°
2	21°	12°	10°	8°	7°	5°
3	16°	8°	7°	6°	5°	3-10°
4	12°	7°	5°	4°	3-10°	2-10°

BODY	3		Polaris		
BASE GHA	5				
CORR	6				
SHA	7				
GHA	8				
ASSUM -W LONG +E	9				
LHA	10				
ASSUM LAT	11 ° N S				
DEC	12 N S	N S	N S	N S	N S
PLANNED TIME					
ACTUAL TIME					
TAB H_c	13				
CORR D DEC	14 15 16				
H_c	17				
TOTAL → ADJ	36				
ADJ H_c	17±36				
OFF TIME MOTION	37				
H_c	17±36 ±37				
H_o	38				
INT	39 T A	T A	40 T A	T A	T A
Zn	19 °	°	°	°	°
CONV +W ANGLE -E	41 °	°	°	°	°
GRID Zn	42 °	°	°	°	°

TIME	TH/GH °	GYRO °	PP: LAT N S	PP: LONG W E

CORIOLIS FACTOR *(CF)* TABLE

LATITUDE	10°	20°	30°	40°	50°	60°	70°	80° +
CF	.5	.9	1.3	1.7	2.0	2.3	2.5	2.6

CORIOLIS *(NM)* = *(GSK ÷ 100)* X CF.
EXAMPLE: LAT = 35° N; GS = 400K; CORIOLIS = 4 X 1.5 = 6NM RIGHT.

★ Figure 12-3. SAC Celestial Computation Form.

1. DATE - Place the Zulu date of the Air Almanac page used in this block.

2. FIX TIME - Greenwich mean time (coordinated universal time) of the computation.

3. BODY - The celestial body being observed.

4. DR. LAT LONG - The DR position for the time of the observation.

5. GHA - The value of GHA extracted from the Air Almanac (10-minute intervals).

6. CORR - The GHA correction for additional minutes of time to be applied to the GHA in block 5 and, if necessary, the 360° addition required to establish the LHA.

7. SHA - When a star is used in conjunction with volumes II or III, HO 249, Sidereal Hour Angle is placed in this block.

8. GHA - Corrected GHA (sum of blocks 5, 6, and 7).

9. ASSUM LONG $\substack{-W\\+E}$ — The assumed longitude required to obtain a whole degree of LHA.

10. LHA - LHA of the body (or Aries).

11. ASSUM LAT - The whole degree of latitude nearest the DR position.

12. DEC - The declination of the celestial body (not used with volume I, HO 249).

13. TAB Hc - The Hc from the appropriate page of HO 249, vol II or III.

14. D - The "d" correction factor found with previous Hc - include + or −, as appropriate. This value is used to interpolate between whole degrees of declination.

15. DEC - Minutes of declination from block 12.

16. CORR - This space is for the correction obtained from the "Correction to Tabulated Altitude for Minutes of Declination" table in volumes II and III, HO 249, using blocks 14 and 15 for entering arguments.

17. Hc - This is the corrected Hc - sum of blocks 13 and 16 or extracted from HO 249, volume I.

18. Z - Extracted from HO 249, volume II or III (not used with MAC or SAC precomp).

19. Zn - True azimuth of the celestial body from the formula in volumes II and III, HO 249; or directly from volume I.

20. TRACK - The true course (track) of the aircraft.

21. GS - The groundspeed of the aircraft.

22. FLT ALT - Aircraft altitude.

23. CORIOLIS - The Coriolis correction extracted from HO 249, the Air Almanac, or a Coriolis/rhumb line table.

24. PREC/NUT - Precession and nutation correction computed from the table in volume I, HO 249.

25. REL Zn or Zn-CUS - The difference between Zn and track, used to determine motion of the observer correction.

★26. MOTION OBSERVER/MOO - Motion of the observer correction for either 1 minute (using 1-minute motion correction table or modified MB-4 computer) or 4 minutes (using 4-minute correction table in HO 249) of time.

★27. MOTION BODY/MOB - Motion of the body correction for either 1 minute (using 1-minute motion correction table or modified MB-4 computer) or 4 minutes (using tabulated HC change for 1° of LHA or 4-minutes correction table in HO 249) of time.

★28. 1-MINUTE ADJUST - Algebraic sum of 26 and 27; may also be labeled 4-minute adjust on certain precomputation forms for use of 4-minute motion corrections extracted from the HO 249

29. X TIME - Time differnce between planned shot time and computation time.

★30. TOTAL MOT ADJUST/ADV/RET - Correction, based on combined motion of observer and body, for the difference between the time of the shot and fix time. The sign of this correction will be the same as the sign in block 28 if the observation was taken prior to the computation time; if it was taken later, the sign will be reversed.

31. REFR - Correction for atmospheric refraction.

32. PERS/SEXT - Sextant correction or personal error.

33. SD - Semidiameter correction for Sun or Moon.

34. PX - Parallax correction for Moon observation.

35. POLARIS/Q CORR - The "Q" correction for the time of the Polaris observation (extracted from HO 249 or the Air Almanac).

36. TOTAL ADJ - Algebraic sum of blocks 30, 31, 32, 33, 34, and 35 as applicable.

37. OFF-TIME MOTION - Motion adjustment for observation other than at planned time.

38. Hs - Height shot (sextant reading). Labelled Ho on MAC and SAC precomps.

39. INT - Intercept distance (NM) is the difference between the computed Hc and the Ho. Apply the HOMOTO rule to determine direction (T or A) along the Zn.

40. LAT - Polaris latitude.

41. CONV ANGLE $\substack{+W\\-E}$ — Convergence angle used in grid navigation.

42. GRID Zn - The sum of blocks 19 and 41.

Corrections Applied to Hc

In some methods of precomputation, corrections are applied in advance to the Hc to derive an adjusted Hc. When using corrections which are normally applied to Hs, the signs of the corrections are reversed if applied to Hc. For example:

Corrections Applied to Hs

Hs	31° 05
REFR	−01
PERS/SEXT	−05
Ho	30° 59
Hc	30° 40
INT	19T

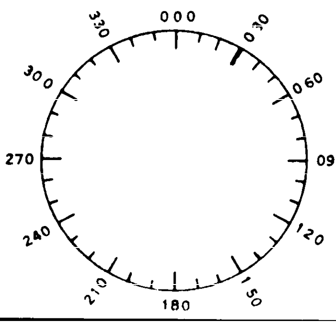
Corrections Applied to Hc

Hc	30° 40
REFR	+01
PERS/SEXT	+05
ADJ Hc	30° 46
Hs	31° 05
INT	19T

In both cases, the intercept is 19 towards. This example shows that it matters little in which manner observational errors are taken into account. As long as they are applied with the proper sign, the intercept remains the same. The following sample precomps use a common fix time (though computation times are different) and common observation times to facilitate comparison. NOTE: Atmospheric refraction correction must be ex-

H.O. 249 CELESTIAL SIGHT 4			DATE 1	NAME	POLARIS FORMAT
GMT	2				GMT
GHA	5				GHA
CORR	6				CORR
SHA •	7				
GHA	8				GHA
A LONG +E -W	9				A LONG
LHA	10				LHA
A LAT	11				
BODY	3				
DEC •	12	(15)			
HC/D •	13	14			
CORR •	16				
Hc	17				
Z •	18				
ZN	19				000
ZN-CUS	25		20/21 CUS/GS		CUS
ADV/RET 26	30		22 FLT ALT		ADV/RET
-REF	31				-REF
IC/PE	32				IC PE
SD +LL -UL •	33				
PIN A •	34			35	Q CORR
+ TOTAL CORR	36				+ TOTAL CORR
Hs	38				HS
Ho	38+36				
Hc	17				
INT A T	39			40	LAT
MOO 26 TOTAL MOB 27	37				
ADJ. INT.	39+37				

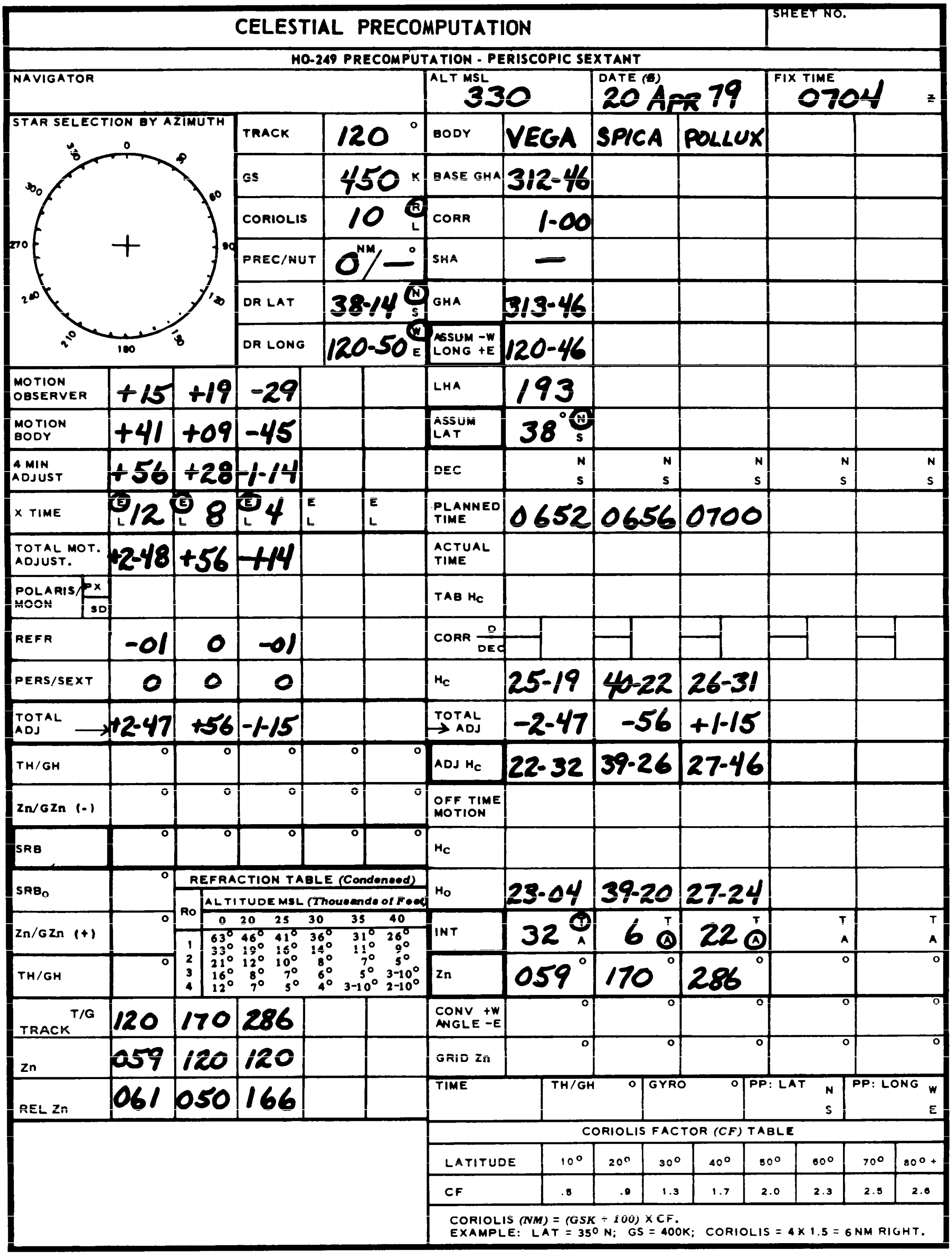
CORIOLIS 23 NM ______°
PREC/NUT 24 NM ______°



* USED WITH VOL II ONLY

HO MO TO

Figure 12-4. Navy Celestial Computation Form.



CELESTIAL PRECOMPUTATION

SHEET NO.

HO-249 PRECOMPUTATION - PERISCOPIC SEXTANT

NAVIGATOR	ALT MSL	DATE (Z)	FIX TIME
	330	20 APR 79	0704 Z

TRACK	120	°
GS	450	K
CORIOLIS	10	[✓ R] L
PREC/NUT	0 NM / —	°
DR LAT	38-14	[✓ N] S
DR LONG	120-50	[✓ W] E

MOTION OBSERVER	+15	+19	-29		
MOTION BODY	+41	+09	-45		
4 MIN ADJUST	+56	+28	-1-14		
X TIME	[✓ E] L 12	[✓ E] L 8	[✓ E] L 4	E L	E L
TOTAL MOT. ADJUST.	+2-48	+56	-1-14		
POLARIS/MOON PX SD					
REFR	-01	0	-01		
PERS/SEXT	0	0	0		
TOTAL ADJ →	+2-47	+56	-1-15		
TH/GH	°	°	°	°	°
Zn/GZn (-)	°	°	°	°	°
SRB	°	°	°	°	°
SRB$_O$	°				
Zn/GZn (+)	°				
TH/GH	°				
T/G TRACK	120	170	286		
Zn	059	120	120		
REL Zn	061	050	166		

REFRACTION TABLE *(Condensed)*

Ro	ALTITUDE MSL *(Thousands of Feet)*					
	0	20	25	30	35	40
1	63°	46°	41°	36°	31°	26°
2	33°	19°	16°	14°	11°	9°
3	21°	12°	10°	8°	7°	5°
4	16°	8°	7°	6°	5°	3-10°
	12°	7°	5°	4°	3-10°	2-10°

BODY	VEGA	SPICA	POLLUX		
BASE GHA	312-46				
CORR	1-00				
SHA	—				
GHA	313-46				
ASSUM LONG -W +E	120-46				
LHA	193				
ASSUM LAT	38° [✓ N] S				
DEC	N S	N S	N S	N S	N S
PLANNED TIME	0652	0656	0700		
ACTUAL TIME					
TAB Hc					
CORR D/DEC					
Hc	25-19	40-22	26-31		
TOTAL → ADJ	-2-47	-56	+1-15		
ADJ Hc	22-32	39-26	27-46		
OFF TIME MOTION					
Hc					
Ho	23-04	39-20	27-24		
INT	32 [✓ T] A	6 T [✓ A]	22 T [✓ A]	T A	T A
Zn	059°	170°	286°	°	°
CONV ANGLE +W -E	°	°	°	°	°
GRID Zn	°	°	°	°	°

TIME	TH/GH °	GYRO °	PP: LAT N S	PP: LONG W E

CORIOLIS FACTOR *(CF)* TABLE

LATITUDE	10°	20°	30°	40°	50°	60°	70°	80° +
CF	.5	.9	1.3	1.7	2.0	2.3	2.5	2.6

CORIOLIS *(NM)* = *(GSK ÷ 100)* X CF.
EXAMPLE: LAT = 35° N; GS = 400K; CORIOLIS = 4 X 1.5 = 6 NM RIGHT.

Figure 12-5. SAC Form — Early Observations.

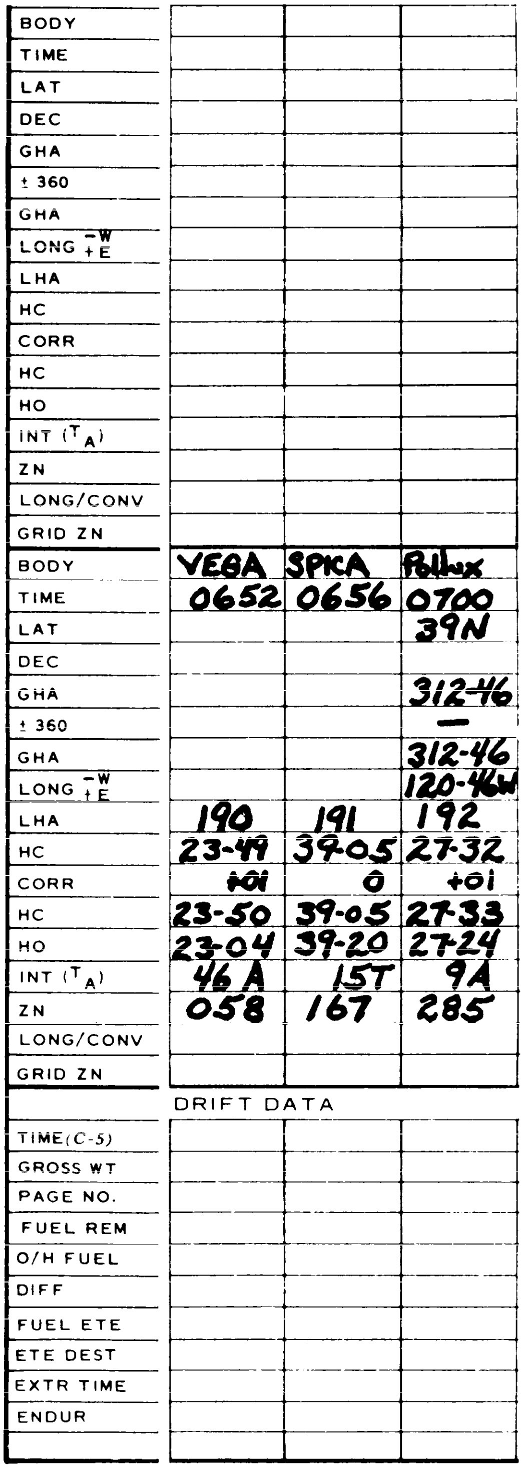
tracted for the actual Hs. It may then be applied to either Hc or Hs using the proper sign. Extracting the value for Hc may cause large errors, especially when the body is near the horizon.

Figure 12-5 is a sample three-star precomputation using a typical SAC form (figure 12-3). This form reflects the philosophy that the aircraft should alter at fix time; therefore, all observations are taken early and mathematically resolved to a common fix time. Note that all corrections to altitude of the body are applied to the Hc, and the sign of the correction has been reversed in this process. An advantage of this technique is that the fix may be plotted prior to the computation time. However, any minor errors in interpolation for motions are multiplied for the two earliest shots and may cause inaccuracies in the fix.

Figure 12-6 shows a MAC three-star precomputation using a three-LHA solution resolved graphically to computation time. The fix may then be moved for track and groundspeed to accommodate other LOPs. Each observation is taken "on time" and then plotted out of its own plotting position. The advantage to this precomp lies in its ease and speed of accomplishment, with relatively few opportunities for math errors to occur. The three assumed positions required for this solution, on the other hand, often cause large intercepts and may make star identification difficult if care is not taken in choosing the precomp assumed position.

Figure 12-7 is a sample Navy precomputation for three stars using the three-LHA method and mathematically adjusting the observations to computation time. Motion of the observer is used to advance or retard the observations for 4 minutes (reversing the sign for the late shot) and all corrections are applied to the sextant altitude. Using this method, the navigator is monentarily behind the aircraft; but the fix may be moved for track and groundspeed to any convenient time. This solution is very fast and accurate and uses only one assumed position.

Each of the above solutions fulfills its purpose within its mission requirements. When each one is adjusted to a common fix time of 0704, the resulting three positions fall within 2 nautical miles of N38.02 and W120.17.



BODY			
TIME			
LAT			
DEC			
GHA			
± 360			
GHA			
LONG $^{-W}_{+E}$			
LHA			
HC			
CORR			
HC			
HO			
INT ($^{T}_{A}$)			
ZN			
LONG/CONV			
GRID ZN			
BODY	VEGA	SPICA	Pollux
TIME	0652	0656	0700
LAT			39N
DEC			
GHA			312-46
± 360			—
GHA			312-46
LONG $^{-W}_{+E}$			120-46W
LHA	190	191	192
HC	23-49	39-05	27-32
CORR	+01	0	+01
HC	23-50	39-05	27-33
HO	23-04	39-20	27-24
INT ($^{T}_{A}$)	46 A	15T	9A
ZN	058	167	285
LONG/CONV			
GRID ZN			
	DRIFT DATA		
TIME(C-5)			
GROSS WT			
PAGE NO.			
FUEL REM			
O/H FUEL			
DIFF			
FUEL ETE			
ETE DEST			
EXTR TIME			
ENDUR			

Figure 12-6. MAC Form — Three LHA Solution.

Limitations of Precomputation

Precomputational methods lose accuracy when the assumed position and the aircraft's actual position differ by large distances. Another limiting factor is the difference in time between the scheduled and actual observation time. The motion of the body correction is intended to correct for this difference.

The rate of change of the correction for motion of the body changes very slowly within 40° of 090° and 270° true azimuth, and the observation may be advanced or retarded for a limited period of time with little or no error. When the body is near the observer's meridian, however, the correction for motion of the body changes rapidly, due in part to the fast azimuth change, and it is not advisable to adjust such observations for long (over 6 minutes) periods of time.

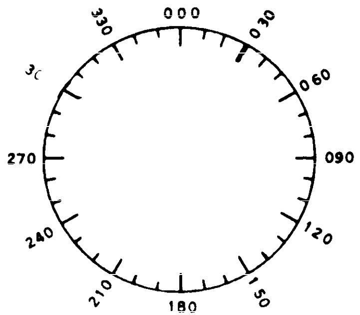
Errors in altitude and azimuth creep into the solution if adjustments are made for too long an interval of time. Because of these errors, the navigator should attempt to keep observation time as close as possible to computation time.

PREPLOTTING TRUE AZIMUTH (Zn)

In order to reduce, as much as possible, the time between the last observation and final fix plotting; many navigators preplot

H.O. 249 CELESTIAL SIGHT N38-31 W121-10	DATE 20 APR 79	NAME		POLARIS FORMAT
GMT	0652	0656	0700		GMT
GHA		310-16			GHA
CORR		1-30			CORR
SHA •		—			
GHA		311-46			GHA
A LONG +E -W		120-46 W			A LONG
LHA	190	191	192		LHA
A LAT		39-00 N			
BODY	VEGA	SPICA	POLLUX		
DEC •					
HC/D •					
CORR •					
Hc	23-49	39-05	27-32		
Z •					
ZN	058	167	285		0 00
ZN-CUS	062	120/450 CUS/GS	165		CUS
+14 -29 ADV/RET	+14	330 FLT ALT	+29		ADV/RET
-REF	-01	0	-01		-REF
IC/PE	0	0	0		IC PE
SD +LL -UL •	—	—	—		
PIN A •	—	—	—		Q CORR
± TOTAL CORR	+13	0	+28		± TOTAL CORR
Hs	23-04	39-20	27-24		HS
Ho	23-17	39-20	27-52		
Hc	23-49	39-05	27-32		
INT A/T	32 A	15 T	20 T		LAT
MOO / MOB TOTAL					
ADJ. INT.					

CORIOLIS 10 NM 210°
PREC/NUT 0 NM —°



COMPASS ERROR CHECK

EXPLEMENTARY RELATIVE BEARING (ERB)

TYPE COMP			
MERB			
+ ZN			
= MTH			
MCH			
CE			
-VAR			
DEV			

TRUE BEARING

TYPE COMP			
MCH			
-MTH			
CE			
-VAR			
DEV			

• USED WITH VOL II ONLY

HO MO TO

Figure 12-7. Navy Form — Three LHA Solution.

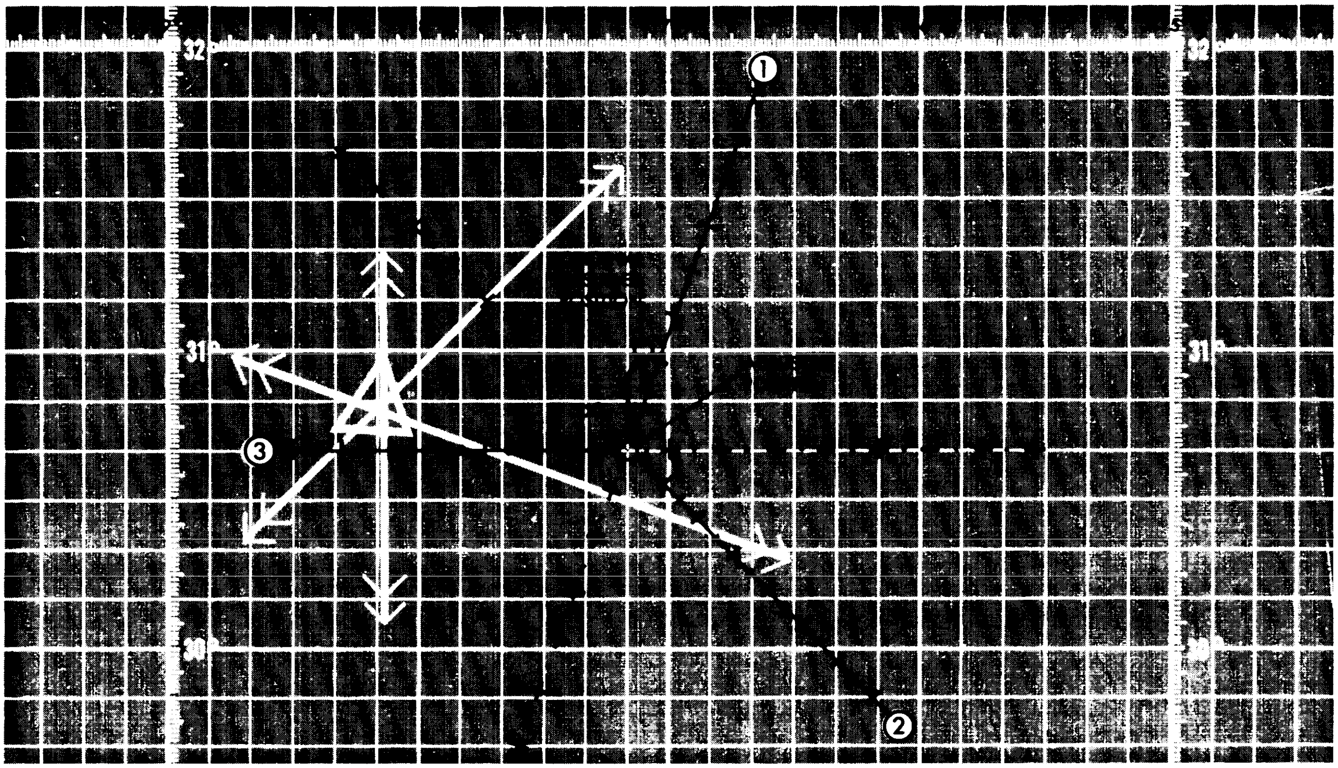


Figure 12-8. Fix Can Be Plotted Quickly.

the Zns of the bodies. This technique is best used when working on a constant scale chart and using a technique of precomputation that will give one assumed position. Before making any observations, plot the assumed position, correct it for Coriolis and precession/ nutation (if required), and draw the Zns of the bodies through this point. When going toward the body, use a solid line or a colored pencil; when going away from the body, use a dashed line or a different colored pencil to readily identify toward and away. Label each Zn as the 1st, 2d, or 3d as shown in figure 12-8, or use the names of the bodies. If desired, distances from the assumed position may also be marked off. Suppose the corrected assumed position is 30°40'N, 117°10'W and the following Zns were computed for the bodies:

1st shot Zn = 020°
2d shot Zn = 135°
3d shot Zn = 270°

(The original assumed position of 31°N, 117°08'W has been corrected for precession/nutation and for Coriolis/rhumb line error to obtain the plotting position.)

When the first intercept is found to be 10A, second intercept 40A, and the third intercept 50T, the fix may be plotted quickly by constructing perpendicular lines at the correct point on the respective Zn line. No direction or distance measurement is required after shooting - only the intercept is needed. This greatly reduces the time necessary to plot the fix. Since the dashed part of the Zn line is the away situation, it is used for the first two intercepts, while the solid or toward portion of the Zn line is for the third intercept.

SUMMARY

Celestial precomputation methods have been brought to the forefront with the proliferation of high-speed aircraft. The speeds at which aircraft now fly make it necessary to reduce the time between the last observation and the final fix.

The periscopic sextant may be the only means of viewing the sky. In this case, it is necessary to precompute the altitude and azimuth of a body in order to locate it.

One of the most important things to remember when precomputing is that corrections may be applied to either the Hc, Hs, or intercept. Particular attention must be paid to the sign of the correction. In addition to precomputation, the speed with which a fix is obtained may be increased by preplotting the true azimuths of the bodies.

Chapter 13

PLOTTING AND INTERPRETING THE CELESTIAL LOP

INTRODUCTION

This chapter will explain methods that will transform the tabulated and in-flight observation values into an aircraft position. The navigator is faced with two tasks: Plotting the resultant information onto a chart, and resolving this information into an aircraft position. There are two basic methods of obtaining a line of position: The subpoint method and the intercept method.

The Subpoint Method (figure 13-1)

A detailed explanation of the theory concerning this method is offered in chapters 10 and 11. Here is a summary of the steps involved:

1. Once the navigator has positively identified the body, the altitude is measured using a sextant.
2. Because no tabulated information for azimuth or elevation is required for this method, corrections for refraction, parallax, semidiameter, wander error, and sextant correction are applied directly to the Ho.
3. Subtract the resultant measurement from 90° to obtain the co-altitude. Multiply the number of degrees times 60 to convert to nautical miles (1° = 60 NM). Add any fractional portion of degrees to the previous value.

Example: Vega is observed at an altitude (Ho) of 88° 23′. Sextant correction is −03′.

88°23′ −03′ = 88°20′
90° − 88° 20′ = 1° 40′
1 × 60 = 60 + 40 = 100 NM

4. In this example, 100 NM represents the distance from the

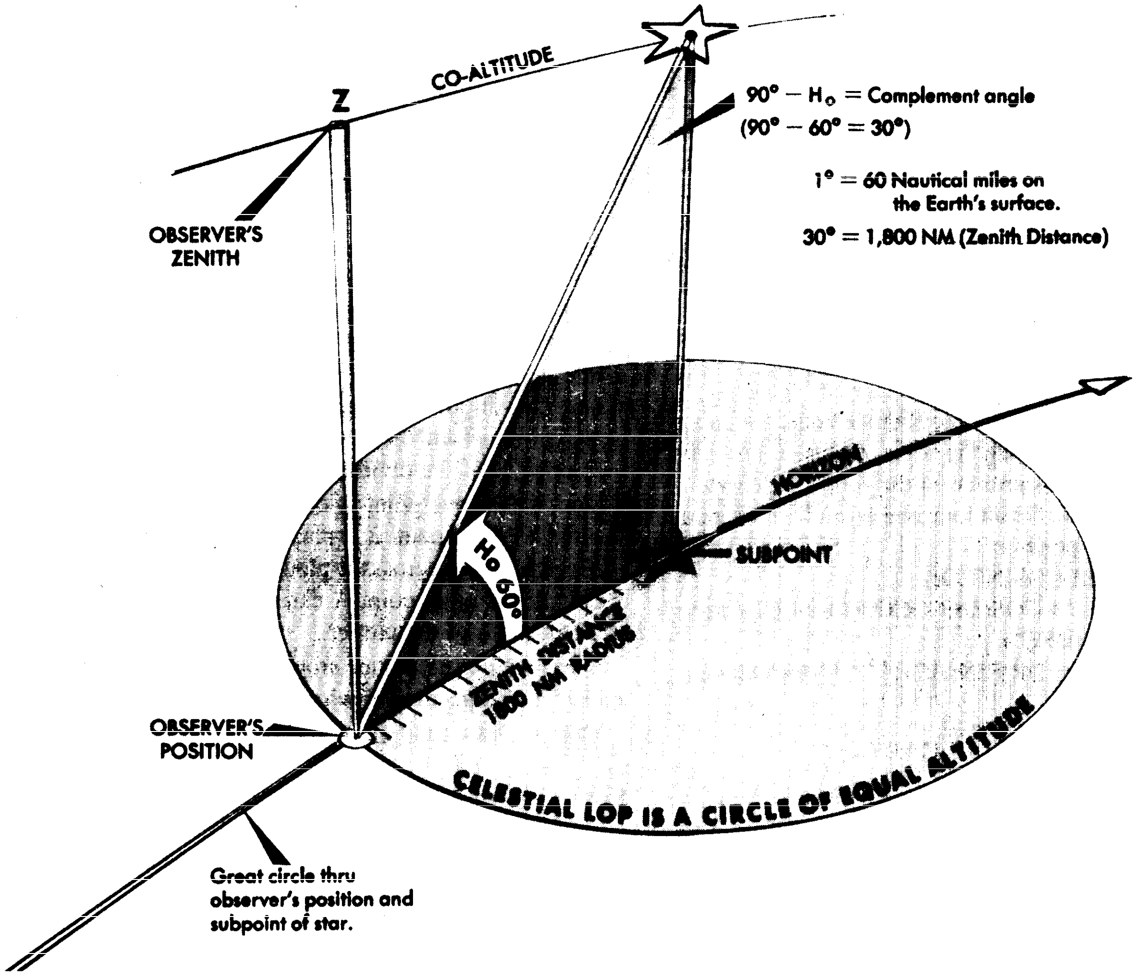


Figure 13-1. The Subpoint Method.

observer's position to the subpoint of the body. The coordinates of the body are its corresponding declination and GHA. For this example, Vega's Dec is N38°46'. The GHA is obtained by applying the SHA of Vega to the GHA of Aries.

Example: SHA = 080°59'
GHA Aries = 039°18'
GHA Vega = 120°17'

Subpoint of Vega is located at 38°46'N 120°17'W

The observer is now ready to apply the information:

1. Plot the subpoint on an appropriate chart.
2. Using dividers or compass, span the distance representing the co-altitude; in this case, 100 NM.
3. Using the body's subpoint (BS 38°46'N 120°17'W) as the center and 100 NM (co-altitude) as the radius. The circle is called the circle of equal altitude and the observer is located on that portion of the circle nearest the dead reckoning position.

There are definite advantages to this method. It requires no precomp values and plotting is very simple if the observer and body are reasonably close together. When the observer and body are separated by great distances, some disadvantages appear.

If a body is observed at 20° above the horizon, the observer is 4,200 nautical miles from its subpoint. To swing an LOP from this subpoint, the subpoint and the arc must be plotted on the same chart. To permit plotting of any LOP, the chart must cover an area extending more than 4,000 miles in every direction from the DR position. This means that the chart must be either of such large size that it cannot be spread out on a table in the aircraft, or of such small scale that plotting on it is inaccurate. To cover an area 8,000 miles across, a chart 4-feet square must be drawn to a scale of about 1:10,000,000. Furthermore, measuring would be difficult because of distortion.

Since a celestial LOP cannot always be drawn by swinging an arc from the subpoint, the intercept method — which is based on the same principles as the subpoint method — is often used.

Intercept Method (figure 13-2)

One may eliminate the need for plotting the body's subpoint and still draw the arc representing the circle of equal altitude. By using the trimetric relations present in the following formula, the observer may calculate the altitude and azimuth of the body for the dead reckoning position:

$$\mathrm{Hc} = \mathrm{SIN}^{-1}[\mathrm{SIN(DEC')SIN(LDr)} + \mathrm{COS(DEC')COS(LDr)COS(LHA)}]$$

$$\mathrm{Z} = \mathrm{COS(Z)} = [\mathrm{SIN(DEC')} - \mathrm{SIN(LDR)SIN(HC)}]/[\mathrm{COS(HcCOS(LDr)}]$$

$$\mathrm{ZN} = \begin{matrix} \mathrm{Z\ if\ SIN(LHA)} < 0 \\ 360 - \mathrm{Z\ if\ SIN(LHA)} \geqq 0 \end{matrix}$$

The calculations may be performed quickly using any of the programmable calculators, or they may be extracted from the HO 249 volume. This method enables the observer to use any of the navigational bodies available at the appropriate fix time. Here is a brief review:

1. Compute a DR for the time of the position using preflight or in-flight data.
2. Determine the necessary entering values for the HO 249 volume being used (LATITUDE, LHA, DEC contrary or same) and extract all the necessary values of Hc, Z, etc.
3. After making all the necessary conversions and corrections (see chapter 11), compare the Ho and corrected Hc. This difference is the intercept. If the Ho equals the corrected Hc, then the circle of equal altitude passed through the plotting position. If the Ho is greater than the Hc, the difference is plotted in the direction of the Zn. The Zn represents the azimuth from the observer's positions to the subpoint. If the Ho is less than the Hc, plot the difference 180° from the Zn.

NOTE: If HO is MOre, plot TOwards the subpoint

(HO MO TO)

Example: The assumed position is 38°N, 121°30'W for a shot taken at 1015 GMT on Aldebaran. The Ho is 32°14'. The Hc is determined to be 32°29' and the Zn 120°. A comparison of Ho and Hc determines the intercept to be 15 nautical miles away (15A).

Plotting LOP Using Zn Method (figure 13-3)

Step 1. Plot the assumed position and set the intercept distance on the dividers.

Step 2. Draw a dashed line through the assumed position toward the subpoint.

Step 3. Span intercept distance along dashed Zn line.

Step 4. Place plotter perpendicular to Zn.

Step 5. Draw LOP along plotter as shown.

Plotting LOP Using Flip Flop Method (figure 13-4)

Step 1. Plot the assumed position and set the intercept distance on the dividers.

Step 2. With point A of the dividers on the assumed position, measure 120° of the Zn and place point B of the dividers down, in this case, away from 120° or in the direction of 300° from the assumed position. Slide the plotter along the dividers until the center grommet and the 100/200 mile mark are lined up directly over point B of the dividers marking the intercept point.

Step 3. Remove point A of the dividers from the assumed position, keeping point B in place. Flip point A (that was on the assumed position) across the plotter, at the same time expanding the dividers so that point A can be placed on the chart at the 90°/270° mark of the plotter.

Step 4. Flop the plotter around and place the straight edge against the perpendicular which is established by the dividers.

Step 5. Draw LOP along the plotter as shown.

Summary of Intercept Method.

The main steps to remember when determining the LOP by the intercept method are:

1. For some assumed position near the DR position, find the altitude (Hc) and the true azimuth (Zn) of this body for the time of the observation. This is done with the aid of celestial tables such as HO 249, or a programmable calculator.

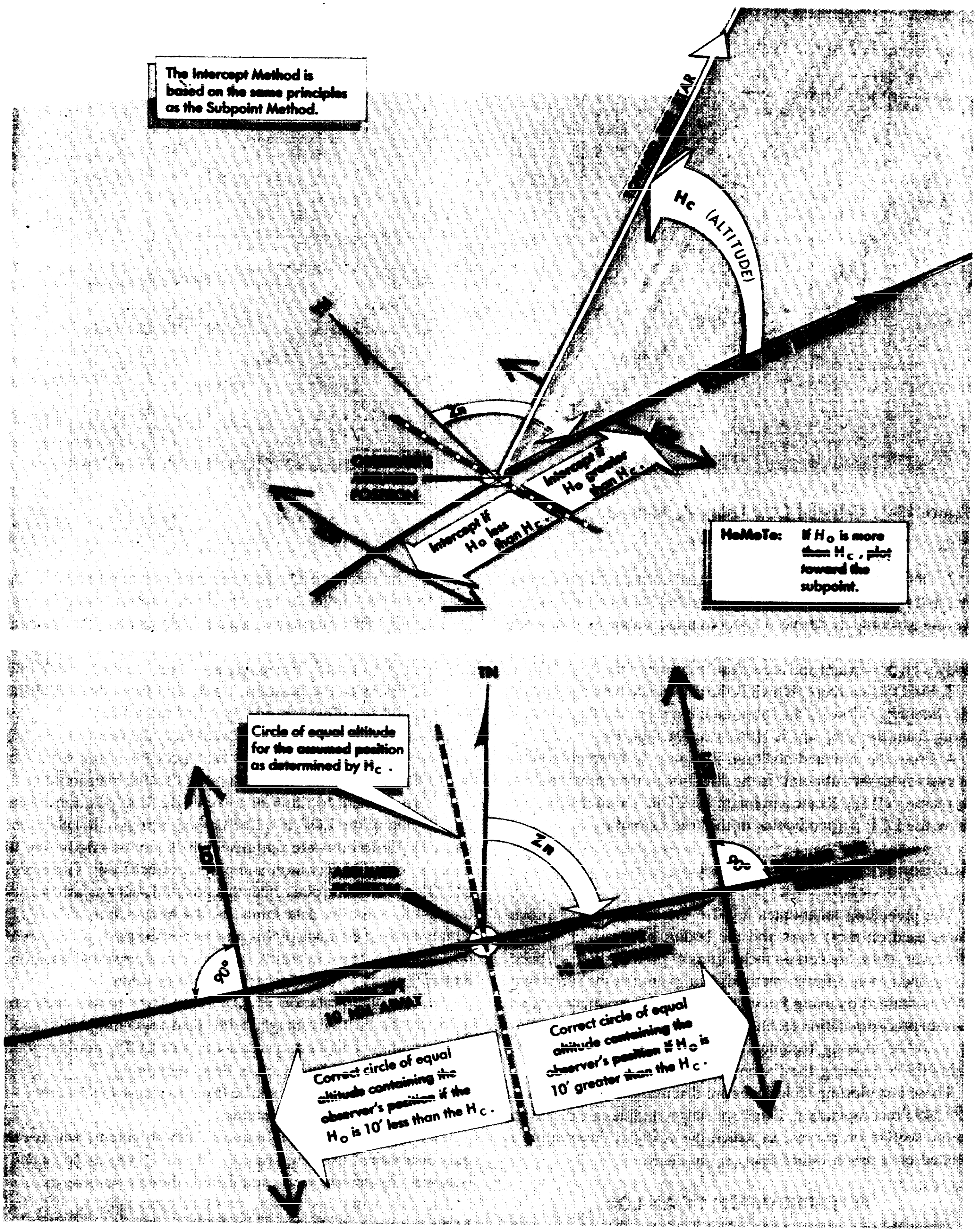


Figure 13-2. LOP Computed by Intercept Method.

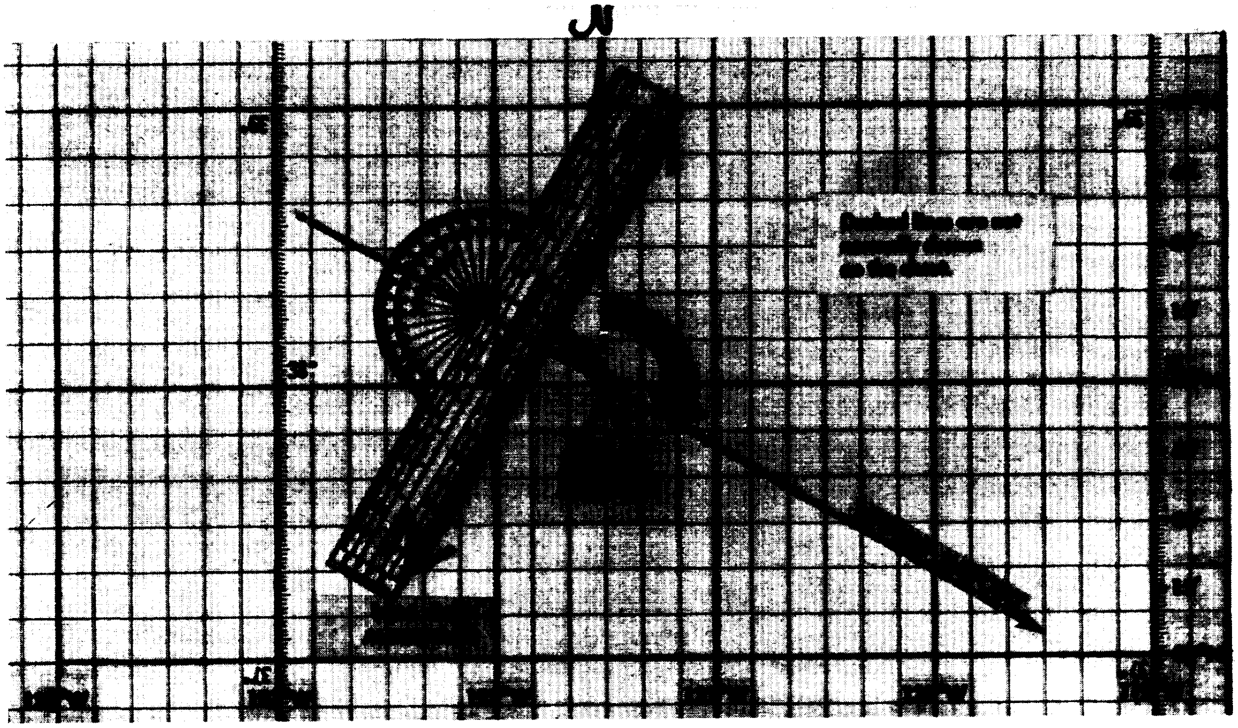


Figure 13-3. Celestial LOP Using Z_n Method.

2. Obtain needed corrections, sextant correction, refraction, etc, and apply these to the Hc by reversing the sign (remember, we are striving to derive a precomputed value to insure the correct body is shot). Measure the altitude (Ho) of the celestial body with the sextant and record the midtime of the observation.

3. Find the intercept, which is the difference between Ho and Hc. Intercept is toward the subpoint if Ho is greater than Hc, and away from the subpoint if Ho is smaller than Hc.

4. From the assumed position, measure the intercept toward or away from the subpoint (in the direction of the true azimuth or its reciprocal) and locate a point on the LOP. Through this point draw the LOP perpendicular to the true azimuth.

Additional Plotting Techniques

The preceding techniques involve the basic plotting procedures used on most stars and the bodies of the solar system. However, there are certain techniques of plotting that are peculiar to their own celestial methods; for example, the plotting of LOPs obtained by using Polaris which is discussed later. Also, certain precomputation techniques lend themselves more readily to other plotting techniques, such as preplotting the true azimuths or plotting the fix on the DR computer.

These last plotting techniques are discussed in the section on HO 249 Precomputation. Other special techniques are discussed in the section on curves, in which the celestial observation is plotted on a graph rather than on the chart.

INTERPRETATION OF AN LOP

Navigation has two aspects — the mechanical and the interpretive. The mechanical aspect includes operation and reading of instruments, simple arithmetical calculations, plotting, and log keeping. The interpretive aspect is the analysis of the data which have been gathered mechanically. These data are variable and subject to error. The navigator must convert them into probabilities as to the position, track, and groundspeed of the aircraft, and the direction and speed of the wind.

The more these data are subject to error, the more careful the interpretations must be, and the less mechanical the work can be. LOPs and fixes especially require careful interpretation.

It is convenient to think of a fix as the true position of the aircraft and of the LOP as a line passing through this position, but these definitions are optimistic. It is almost impossible to make a perfect observation and plot a perfect LOP. Therefore, an LOP passes some place near this position, but not necessarily through it, and a fix determined by the intersection of LOPs is simply the best estimate of this position on the basis of one set of observations. Thus, in reality, a fix is a most probable position, and an LOP is a line of most probable position.

The best interpretation of LOPs and fixes means they are used, to the best advantage, with dead reckoning. But good interpretation cannot compensate for poor LOPs, nor can good LOPs compensate for careless dead reckoning. To get good results, every precaution must be taken to insure the accuracy of LOPs and exact DR calculations.

Intelligent interpretation requires fine judgment, which can only be acquired from experience. The navigator can be guided, however, by certain well-established, though flexible rules.

The following discussion pertains especially to celestial LOPs and fixes. It also applies to LOPs and fixes established by radio, and, to some extent, to those obtained by map reading.

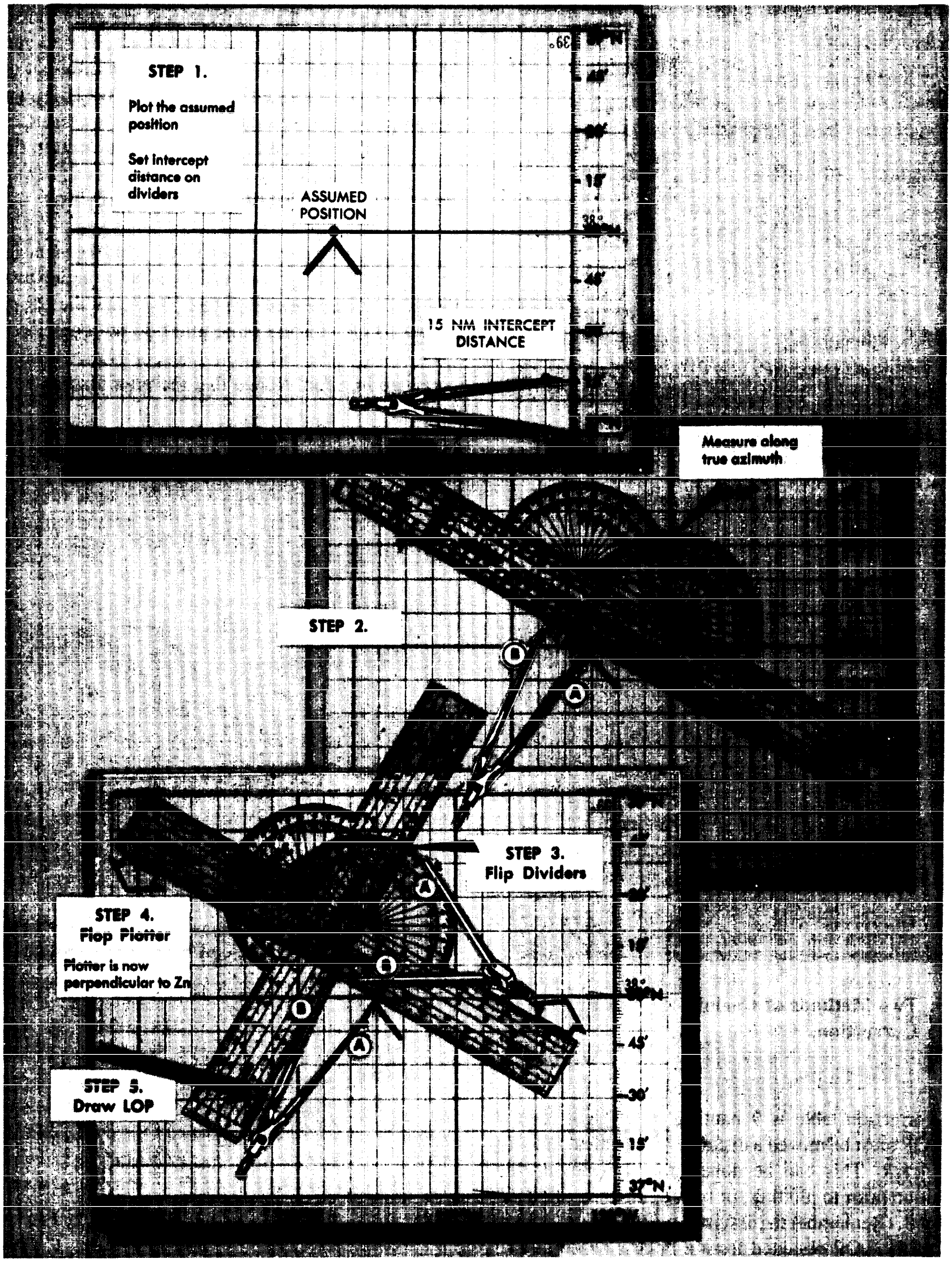


Figure 13-4. Plotting Celestial LOP Using Flip Flop Method.

Single LOP

Previous discussions dealt with the basic plotting of an LOP and errors in LOPs, but they did not show the actual mechanics of the plotted corrections which must be applied. The LOP must be corrected for Coriolis/rhumb line correction, and also for precession/nutation correction if it is based on an HO 249, volume I, star shot. Coriolis/rhumb line correction becomes a very significant correction at higher speeds and latitudes. For example, suppose the correction determined from the Coriolis/

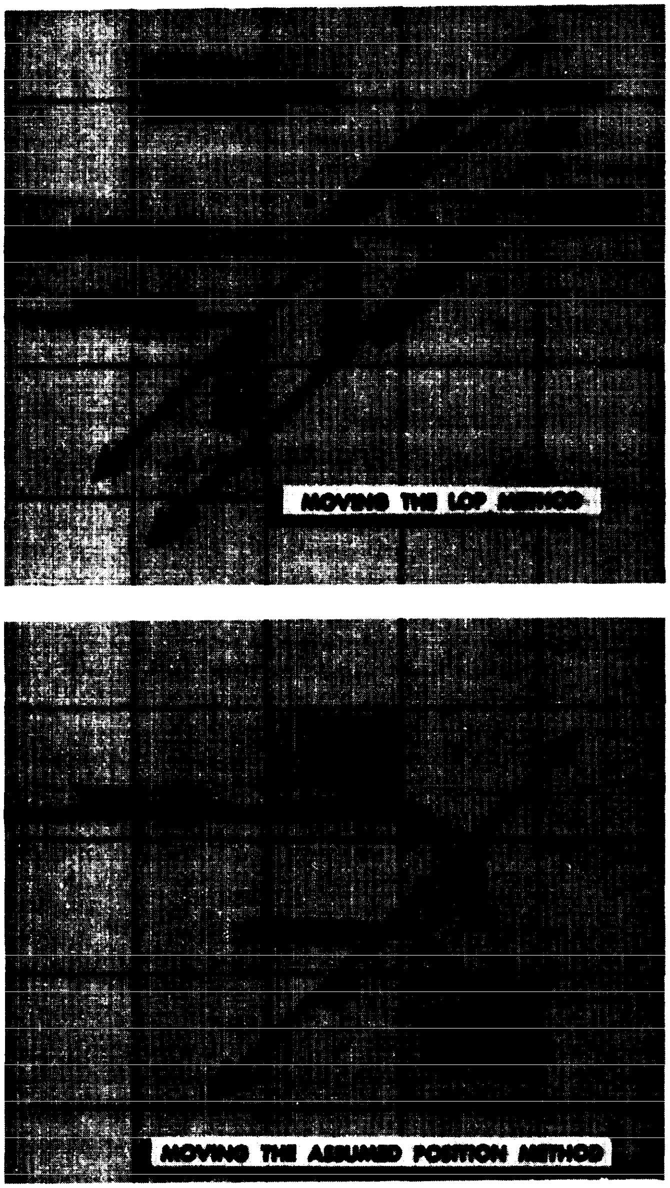


Figure 13-5. Two Methods of Coriolis/Rhumb Line Correction.

rhumb line correction table is 9 nautical miles right (of the track). The LOP must be moved a distance of 9 nautical miles to the right of track. This can be done either by moving the assumed position prior to plotting, or by moving the LOP itself after it is plotted. (Remember the assumed position is not used in the plotting of the LOP obtained from a Polaris observation.) Consider figure 13-5, which shows a track of 90°.

Notice that, in both methods, the corrected LOP is in the same place with respect to the original assumed position, and that the intercept value is the same. The resultant LOP is the same regardless of the method used.

If, in addition to the Coriolis/rhumb line correction, a precession/nutation correction of 3 nautical miles in the direction of 60° is required, it would have been further applied as shown in figure 13-6. Again, the corrected LOP is the same, using either method, because the intercept and resultant position of the corrected LOP to the original assumed position are the same. The corrected LOP alone gives very little information; hence, a position must be arrived at only after considering the LOP and the DR position for the same time. There is also a special use for the single LOP which is discussed in the section on landfalls.

Most Probable Position (MPP) By C-Plot

The most probable position is just what the name implies. It is not a fix; however, since it is the best information available, it is treated as such. Notice in figure 13-7A that the DR position and celestial LOP (for the same time) do not coincide.

Obviously, the DR information or celestial information, or both, are in error. Notice that the prior fix has no time on it.

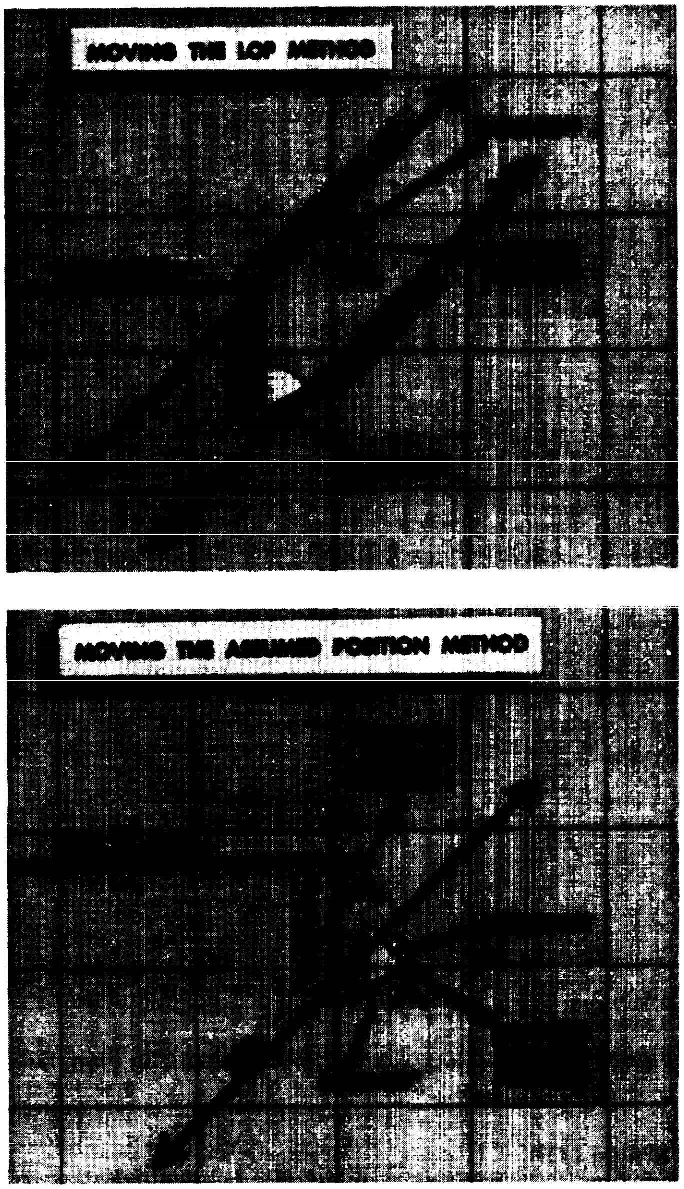


Figure 13-6. Two Corrections — Coriolis/Rhumb Line and Precession/Nutation.

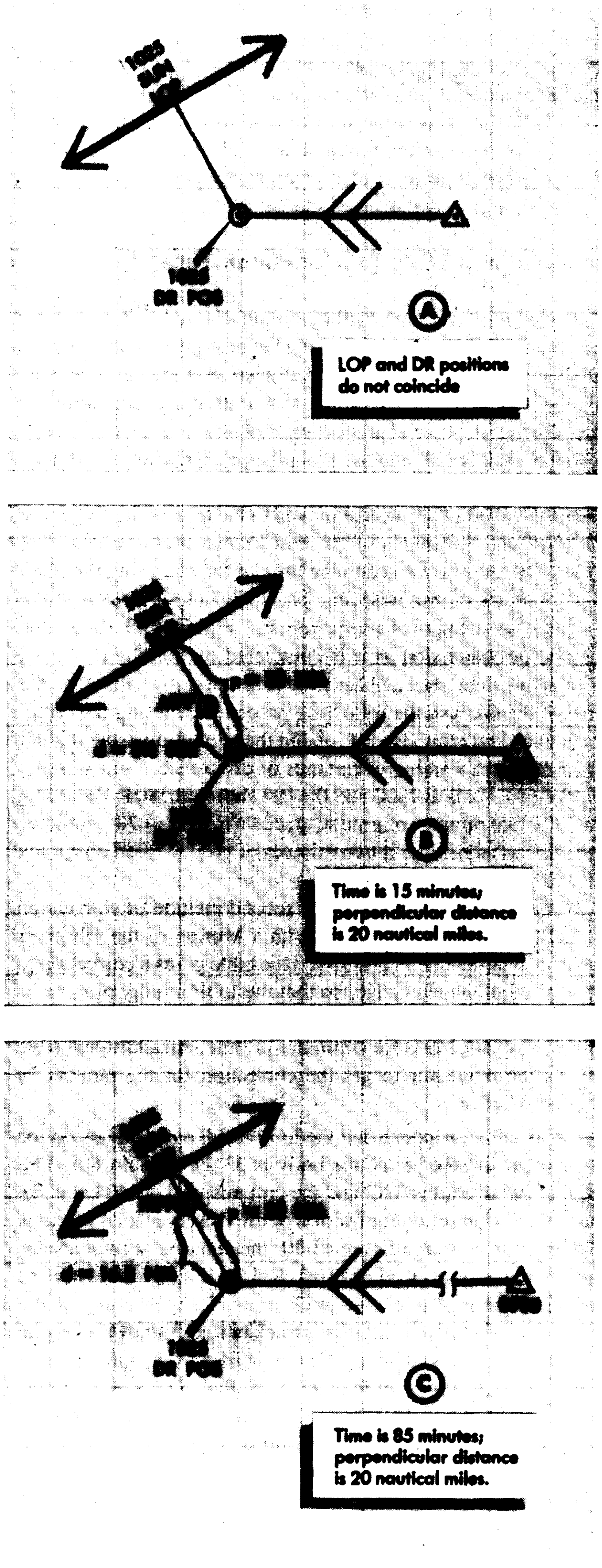


Figure 13-7. Most Probable Position (MPP) by C-Plot.

Suppose this prior fix had been for the time of 1010. It would then be very likely that most of the error is in the celestial information and the probable position is closer to the DR position than to the celestial LOP. On the other hand, suppose the prior fix had been for the time of 0900. Since the accuracy of the celestial information is unaffected by the time to the last fix, it would in this case be most likely that the actual position is closer to the LOP than to the DR position.

A formula has been devised to position the observer along the perpendicular to the LOP according to the time factor. The formula is

$$\frac{d}{t} = \frac{p}{t + p}$$

where t is time in minutes, p is the perpendicular distance between the DR position and the LOP, and d is the distance from the DR position for the time of the MPP measured along the perpendicular to the LOP. Look at figures 13-7B and C and see how the formula works for the two problems cited above if the perpendicular is 20 nautical miles in length. In figure 13-7B, t is 15 minutes and p is 20 nautical miles, so

$$\frac{d}{15} = \frac{20}{15 + 20} \qquad d = \frac{300}{35} = 8.57 \text{ NM}$$

and the MPP would be located along the perpendicular about 8½ nautical miles from the DR position.

Now, consider figure 13-7C where t is 1 hour 25 minutes or 85 minutes, p is 20 nautical miles and

$$20 + 85 \qquad d = \frac{1700}{105} = 16.2 \text{ NM}$$

In this case, the MPP would be over 16 nautical miles away from the DR position along the perpendicular to the LOP.

If the navigator prefers not to use the formula, a simple table can be easily constructed to solve for d with entering arguments of t and p as shown in figure 13-8. The table could easily be enlarged to handle larger values of t and p.

In most fixes, the DR position is so close to the LOP that the midpoint between these two can be considered the MPP. A good rule to use is to take the midpoint of the perpendicular if the total distance between the DR position and the LOP is 10 nautical

P ▼	"t"—TIME IN MINUTES			
	10m	15m	30m	60m
12	5	7	9	10
14	6	7	10	11
16	6	8	10	13
18	6	8	11	14
20	7	9	12	15
25	7	9	14	18
30	8	10	15	20
35	8	10	16	22
40	8	11	17	24
45	8	11	18	26
50	8	12	19	27
55	9	12	19	29
60	9	12	20	30

To the closest NM values of "d" in the formula.

Figure 13-8. To Solve for Distance ("d").

miles of less. If the value of p is greater than 10 nautical miles, the formula

$$\frac{d}{t} = \frac{p}{t + p}$$

or a table based on this formula should be used to determine the MPP.

Up to this point, determination of the MPP has been rather mechanical. Experienced navigators will frequently further adjust the position of the MPP for other factors not yet considered. For example, if the LOP is carefully obtained under good conditions or if it is the average of several LOPs, the navigator may further weight the MPP in the direction of the LOP by an amount that judgment dictates. However, the reverse may be true if the LOP is obtained under adverse conditions of rough air. In the latter case, the navigator might move the MPP closer to the DR position by some amount determined by sound judgment.

Further, consider the validity of the DR position in relation to factors other than time. A DR position at the end of 40 minutes would be more reliable with drift and groundspeed by timing than one based on metro information. These factors may also adjust the original MPP closer to or farther away from the DR position, along the perpendicular. However, these last mentioned factors are judgment values that come only with experience. In fact, the experienced navigator may mentally calculate all the factors involved and arrive at the final position of the MPP without recourse to a formula or table.

Finding a Celestial Fix Point

Up to this point, only the single celestial LOP and what to do with it have been considered. Now, the celestial fix should be considered. To establish a fix, two or more lines of position must be obtained. Since, in most cases, two or more LOPs cannot be obtained simultaneously, they must be converted to a common time. For example, an LOP obtained at 1010 must be converted to the LOP obtained at the fix time of 1014. There are several methods for making this conversion which are discussed in this chapter. Consideration is also given to the planning of the fix and the final interpretation of the fix itself.

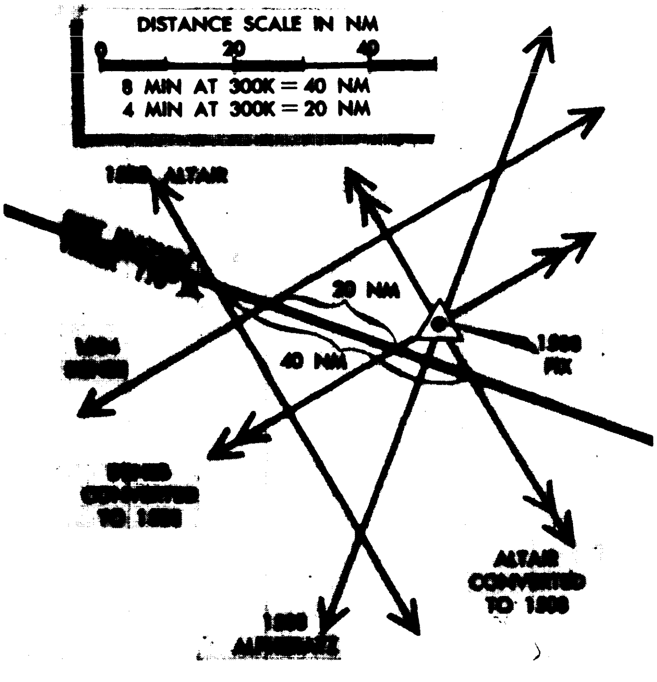


Figure 13-9. Conversion of LOPs to a Common Time.

Conversion of LOPs To A Common Time

Moving the LOP. One method of converting LOPs to a common time is to move the LOP along the best-known track for the number of minutes of groundspeed necessary for the time conversions. This method is similar to that used for correcting for Coriolis/rhumb line and precession/nutation. For example, suppose the track is 110° and the groundspeed 300 knots. LOPs are for 1500, 1504, and 1508, and a fix is desired at 1508. This means the 1500 LOP must be moved to the time of the fix, using the track and 8 minutes of the best known groundspeed. The 1504 LOP must be moved to the time of the fix, using the track and 4 minutes of groundspeed. The 1508 LOP is already at the fix time, so it requires no movement. Figure 13-9 shows the method of conversion as it is completed on the chart.

If, at any time, the LOP has to be retarded (moved back) to the time of the fix, use the following procedures. Using the reciprocal track and groundspeed, obtain the correction in the regular manner for the number of minutes of difference. For example, suppose the fix is at 1800 and the last shot is at 1802. Retarding the LOP two minutes of groundspeed on a track of 70° would be the same as advancing it two minutes of groundspeed on a track of 250°.

Motion of Observer Tables. A second method of conversion of LOPs to a common time is with a Motion of the Observer table such as the one in HO 249. This table gives a correction to be applied to the Ho or Hc, so that the LOP intially plots in its converted position. The correction obtained from table 1 in all volumes of HO 249 is for 4 minutes of time. An additional table allows the navigator to get the correction for the number of minutes needed.

For example, suppose that the LOP needs to be advanced for 11 minutes and the Ho of the body is 33°29′ and Zn 80°. The track of the aircraft is 020° and the groundspeed is 240 knots. In the table 1, Correction for Motion of the Observer for 4 Minutes of Time, illustrated in figure 13-10, the entering arguments are Rel Zn and groundspeed in knots. Rel Zn is azimuth relative to course (Zn minus track, or track minus Zn). Because of the mathematics involved, Zn minus track or track minus Zn may be used as entering arguments. Merely subtract the smaller angle from the larger and enter the table with the value found. In this case, Zn − track = 080° − 020° = 60° (Rel Zn) and groundspeed is 240 knots. Entering this table with these arguments, the correction listed is + 8 for 4 minutes of time.

Therefore, the correction needed to advance the LOP for 11 minutes is + 16′ (for 8 minutes), plus the correction needed for the additional 3 minutes which is obtained from the bottom portion of table 1. Enter this portion of the table with + 8 (value for 4 minutes) and 3 minutes. The correction in this case is + 6′, Correction for 4 Minutes of Time

Ground Speed in Knots

Rel. Zn	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600	630	660	690	720	750	780	810	840	870	900	Rel. Zn
°	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	°
000	+6	+8	+10	+12	+14	+16	+18	+20	+22	+24	+26	+28	+30	+32	+34	+36	+38	+40	+42	+44	+46	+48	+50	+52	+54	+56	+58	+60	000
005	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	355
010	6	8	10	12	14	16	18	20	22	24	26	28	30	32	33	35	37	39	41	43	45	47	49	51	53	55	57	59	350
015	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	48	50	52	54	56	58	345
020	6	8	9	11	13	15	17	19	21	23	24	26	28	30	32	34	36	38	39	41	43	45	47	49	51	53	55	56	340
025	5	7	9	11	13	15	16	18	20	22	24	25	27	29	31	33	34	36	38	40	42	44	45	47	49	51	53	54	335
030	+5	+7	+9	+10	+12	+14	+16	+17	+19	+21	+23	+24	+26	+28	+29	+31	+33	+35	+36	+38	+40	+42	+43	+45	+47	+48	+50	+52	330
035	5	7	8	10	11	13	15	16	18	20	21	23	25	26	28	29	31	33	34	36	38	39	41	43	44	46	48	49	325
040	5	6	8	9	11	12	14	15	17	18	20	21	23	25	26	28	29	31	32	34	35	37	38	40	41	43	44	46	320
045	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	35	37	38	40	41	42	315
050	4	5	6	8	9	10	12	13	14	15	17	18	19	21	22	23	24	26	27	28	30	31	32	33	35	36	37	39	310
055	3	5	6	7	8	9	10	11	13	14	15	16	17	18	20	21	22	23	24	25	26	28	29	30	31	32	33	34	305
060	+3	+4	+5	+6	[illegible]	+8	+9	+10	+11	+12	+13	+14	+15	+16	+17	+18	+19	+20	+21	+22	+23	+24	+25	+26	+27	+28	+29	+30	300
065	3	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16	17	18	19	19	20	21	22	23	24	25	25	295
070	2	3	3	4	5	5	6	7	8	8	9	10	10	11	12	12	13	14	14	15	16	16	17	18	18	19	20	21	290
075	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	285
080	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	280
085	+1	+1	+1	+1	+1	+1	+2	+2	+2	+2	+2	+2	+3	+3	+3	+3	+3	+3	+4	+4	+4	+4	+4	+5	+5	+5	+5	+5	275
090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	270
095	−1	−1	−1	−1	−1	−1	−2	−2	−2	−2	−2	−2	−3	−3	−3	−3	−3	−3	−4	−4	−4	−4	−4	−5	−5	−5	−5	−5	265
100	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	260
105	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	255
110	2	3	3	4	5	5	6	7	8	8	9	10	10	11	12	12	13	14	14	15	16	16	17	18	18	19	20	21	250
115	3	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16	17	18	19	19	20	21	22	23	24	25	25	245
120	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	240
125	−3	−5	−6	−7	−8	−9	−10	−11	−13	−14	−15	−16	−17	−18	−20	−21	−22	−23	−24	−25	−26	−28	−29	−30	−31	−32	−33	−34	235
130	4	5	6	8	9	10	12	13	14	15	17	18	19	21	22	23	24	26	27	28	30	31	32	33	35	36	37	39	230
135	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	35	37	38	40	41	42	225
140	5	6	8	9	11	12	14	15	17	18	20	21	23	25	26	28	29	31	32	34	35	37	38	40	41	43	44	46	220
145	5	7	8	10	11	13	15	16	18	20	21	23	25	26	28	29	31	33	34	36	38	39	41	43	44	46	48	49	215
150	5	7	9	10	12	14	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	43	45	47	48	50	52	210
155	−5	−7	−9	−11	−13	−15	−16	−18	−20	−22	−24	−25	−27	−29	−31	−33	−34	−36	−38	−40	−42	−44	−45	−47	−49	−51	−53	−54	205
160	6	8	9	11	13	15	17	19	21	23	24	26	28	30	32	34	36	38	39	41	43	45	47	49	51	53	55	56	200
165	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	48	50	52	54	56	58	195
170	6	8	10	12	14	16	18	20	22	24	26	28	30	32	33	35	37	39	41	43	45	47	49	51	53	55	57	59	190
175	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	185
180	−6	−8	−10	−12	−14	−16	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	−60	180

Correction for Less Than 4 Minutes of Time

Value from 4-minute Motion Tables (For values greater than 60′ see opposite page)

Interval of Time	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	Interval of Time
m s	′	′	′		′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	m s
0 10	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	0 10
20	0	0	0	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	20
30	0	0	1	1	1	2	2	2	2	2	3	3	3	4	4	4	4	4	5	5	5	6	6	6	6	6	7	7	7	8	30
40	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	40
50	0	1	1	2	2	2	3	3	4	4	5	5	5	6	6	7	7	8	8	8	9	9	10	10	10	11	11	12	12	12	50
1 00	0	1	2	2	2	3	4	4	4	5	6	6	6	7	8	8	8	9	10	10	10	11	12	12	12	13	14	14	14	15	1 00
10	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	10	11	12	12	13	13	14	15	15	16	16	17	18	10
20	1	1	2	3	3	4	5	5	6	7	7	8	9	9	10	11	11	12	13	13	14	15	15	16	17	17	18	19	19	20	20
30	1	2	2	3	4	4	5	6	7	8	8	9	10	10	11	12	13	14	14	15	16	16	17	18	19	20	20	21	22	22	30
40	1	2	2	3	4	5	6	7	8	8	9	10	11	12	12	13	14	15	16	17	18	18	19	20	21	22	22	23	24	25	40
50	1	2	3	4	5	6	6	7	8	9	10	11	12	13	14	15	16	16	17	18	19	20	21	22	23	24	25	26	27	28	50
2 00	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	2 00
10	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26	27	28	29	30	31	32	10
20	1	2	4	5	6	7	8	9	10	12	13	14	15	16	18	19	20	21	22	23	24	26	27	28	29	30	32	33	34	35	20
30	1	2	4	5	6	8	9	10	11	12	14	15	16	18	19	20	21	22	24	25	26	28	29	30	31	32	34	35	36	38	30
40	1	3	4	[illegible]	7	8	9	11	12	13	15	16	17	19	20	21	23	24	25	27	28	29	31	32	33	35	36	37	39	40	40
50	1	3	4	[illegible]	7	9	10	11	13	14	16	17	18	20	21	23	24	26	27	28	30	31	33	34	35	37	38	40	41	42	50
3 00	2	3	[illegible]	6	8	9	10	12	14	15	16	18	20	21	22	24	26	27	28	30	32	33	34	36	38	39	40	42	44	45	3 00
10	2	3	5	6	8	10	11	13	14	16	17	19	21	22	24	25	27	28	30	32	33	35	36	38	40	41	43	44	46	48	10
20	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30	32	33	35	37	38	40	42	43	45	47	48	50	20
30	2	4	5	7	9	10	12	14	16	18	19	21	23	24	26	28	30	32	33	35	37	38	40	42	44	46	47	49	51	52	30
40	2	4	6	7	9	11	13	15	16	18	20	22	24	26	28	29	31	33	35	37	38	40	42	44	46	48	50	51	53	55	40
50	2	4	6	8	10	12	13	15	17	19	21	23	25	27	29	31	33	34	36	38	40	42	44	46	48	50	52	54	56	58	50
4 00	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	4 00

Time of fix	Sign from 4-min. Table	To observed altitude	To tabulated altitude	To intercept
Later than observation	+ −	Add Subtract	Subtract Add	Toward Away
Earlier than observation	+ −	Subtract Add	Add Subtract	Away Toward

Figure 13-10. Entering Arguments are Relative Z_n and GS.

thus obtaining a total of + 22′.

Hence, the 11-minute correction totals + 22. By applying any other correction (refraction, sextant correction), a total adjustment is derived. By changing the sign, this total may be applied to the Hc. One may wish to apply the correction to the Ho. In this case, the sign of the adjustment would remain the same. One may also apply the adjustment to the intercept as the rules state in table 1. In each case, the resultant intercept would be the same.

Suppose the Hc was 33° 57′. Applying the correction − 22 yields 33° 35′. Comparing this with our Ho 33°29′ results in an intercept of 6 nautical miles away. If one decided to apply the correction to the Ho, + 22 + 33°29′ yields 33°51′. Comparing this to the Hc 33°57′ yields the same result — 6 nautical miles away.

In the sample problem, suppose the Hc was 33°57′. The intercept is 6 nautical miles away. If the original Ho 33°29′ had been used with − 22′ applied to the Hc, the navigator would have obtained an Hc of 33°35′ and still had an intercept of 6 nautical miles away.

When using the Motion of the Observer table and when the fix time is earlier than the observation (LOP to be retarded), the rule for the sign of the correction is also printed below table 1.

Moving the Assumed Position. Another method of converting LOPs to a common time is to move the assumed position. This method is recommended for shots 4 minutes apart computed to give all three bodies a single assumed position. However, it is not limited to that type of computation. The assumed position is moved along the best-known track at the best-known groundspeed. For example, again suppose the track is 330° and the groundspeed 300 knots. LOPs are for 1500, 1504, and 1508, and a fix is desired at 1508 (figure 13-11).

Since the first LOP would have to be advanced 40 nautical miles (8 min at 300k), the same result is realized by advancing the assumed position 40 nautical miles parallel to the best-known track. The 1504 LOP must be advanced 20 nautical miles; therefore, the assumed position is advanced 20 nautical miles parallel to the best-known track. The third shot requires no movement, and it is plotted from the original assumed position. It should be noted that the first shot is always plotted from the assumed position which is closest to destination. In this method, if observations are precomputed and the assumed position is moved prior to shooting, the following procedure is used when shooting is off schedule. For every minute of time that the shot is taken early, move the assumed position 15 minutes of longitude to the east. For every minute of time that the shot is taken late, move the assumed position 15 minutes of longitude to the west. In addition, the effected LOP must be moved along the best-known track for the number of minutes of groundspeed the observation was early or late. If the shot was early, advance the LOP; if the shot was late, retard the LOP.

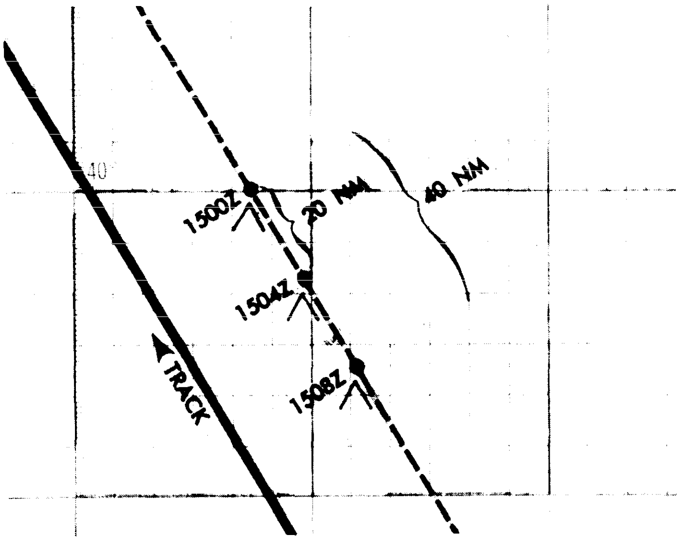


Figure 13-11. Moving Assumed Positions.

Planning the Fix. In selecting bodies for observation, one should generally consider azimuth primarily and such factors as brightness, altitude, etc — secondarily. If all observations are precisely correct in every detail, the resulting lines of position would meet at a point. However, this is rarely the case. Three observations generally result in lines of position forming a triangle. If this triangle is not more than 2 or 3 miles on a side under good conditions, and 5 to 10 miles under unfavorable conditions, there is normally no reason to suppose that a mistake has been made. Even a point fix, however, is not necessarily accurate. An uncorrected error in time, for instance, would require the entire fix to be moved eastward if observations were early and westward if observations were late, at the rate of 1 minute of longitude for each 4 seconds of time.

In a two-LOP fix, the ideal cut of the LOPs is 90°. Notice figure 13-12 that, with this cut, a 5-mile error in one LOP will cause a 5-mile error in the fix. If the acute angle between the LOPs is 30°, a 5-mile error in one LOP will cause a 10-mile error in the fix. Thus, with a two-LOP fix, an error in one LOP will cause at least an equal error in the fix; the smaller the acute angle between the LOPs, the greater the fix error caused by a given error in one LOP. Of course, if both LOPs are in error, the fix may be thrown off even more.

In a three-LOP fix, the ideal cut of the LOPs is 60° (star azimuths 120° apart). With this cut, a 3-mile error in any one LOP will cause a 2-mile error in the fix. With any other cut, a 3-mile error in any one LOP will cause more than a 2-mile error in the fix.

In a three-star fix, the cut will be 60° if the azimuths of the stars differ by 60° or if they differ by 120°. If there is any unknown constant error in the observations, all the Hos will be either too great or too small. Notice in figure 13-13 that, if stars are selected whose azimuths differ by 120°, this constant error of the Hos will cause a displacement of the three LOPs, either all toward the center or all away from the center of the triangle. In either case, the position of the center of the triangle will not be affected. Similarly, if the navigator uses any three stars, the azimuths of which do not fall with 180°, any constant error in observations will tend to cancel out.

The three-star fix has two distinct advantages over the two-star fix. First, it is the average of three observations. Second, the effect of constant errors of observation can be counteracted by selecting the stars carefully. There is also a third advantage.

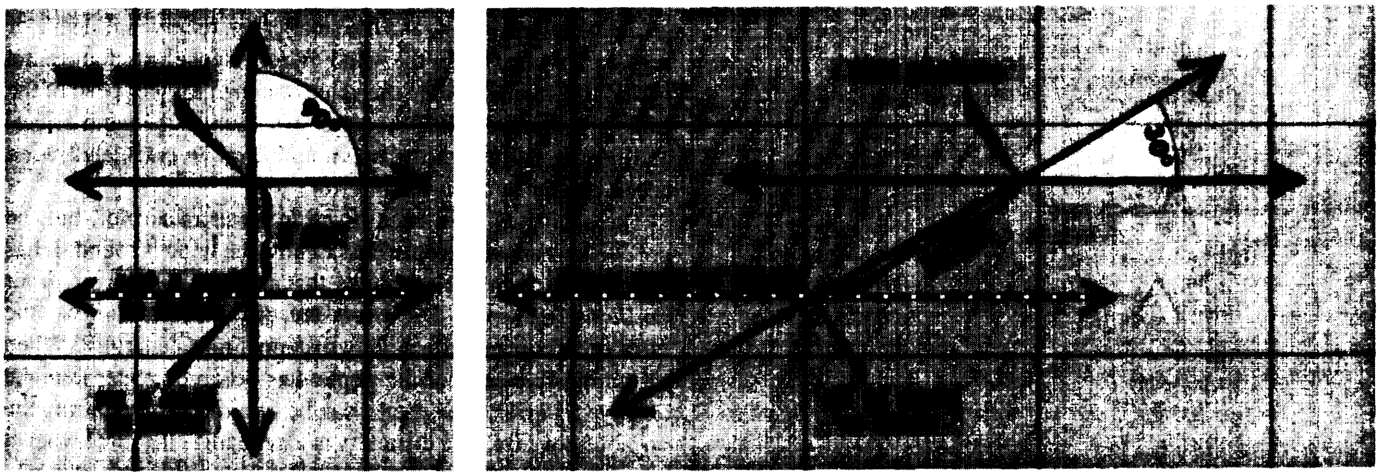
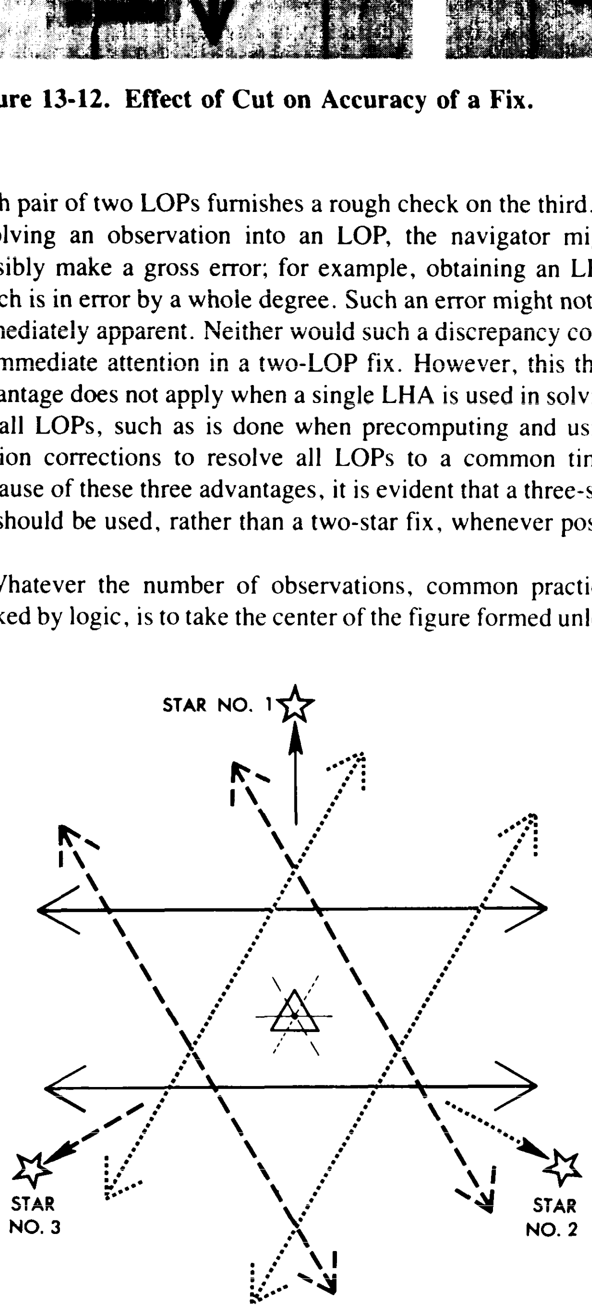


Figure 13-12. Effect of Cut on Accuracy of a Fix.

Each pair of two LOPs furnishes a rough check on the third. In resolving an observation into an LOP, the navigator might possibly make a gross error; for example, obtaining an LHA which is in error by a whole degree. Such an error might not be immediately apparent. Neither would such a discrepancy come to immediate attention in a two-LOP fix. However, this third advantage does not apply when a single LHA is used in solving for all LOPs, such as is done when precomputing and using motion corrections to resolve all LOPs to a common time. Because of these three advantages, it is evident that a three-star fix should be used, rather than a two-star fix, whenever possible.

Whatever the number of observations, common practice, backed by logic, is to take the center of the figure formed unless there is reason for deviating from this procedure. By "center" is meant the point representing the least total error of all lines considered reliable. With three lines of position, the center is considered that point, within the triangle, which is equidistance from the three sides. It may be found by bisecting the angles but, more commonly, it is located by eye.



The three stars are 120° apart.

Figure 13-13. Effect of Azimuth on Accuracy of Fix.

Effect of Fix Error. In determining track and groundspeed from departure to a fix, the greater the distance, the less the relative effect of a given fix error, and the more accurate the track and groundspeed determination. The same is true in determining track and groundspeed between fixes. However, when two points are subject to error, the track and groundspeed between them are twice as liable to error as when one point is definitely known.

In map reading, a fix is relatively accurate; therefore, the chief source of error in the calculated wind is inaccuracy in the true heading and the true airspeed. When using celestial means or the radio, fixes often are less accurate than are air positions. Since the fix and the air position may both be in error, the wind determined from them may be quite inaccurate. Consequently, the use of radio and celestial fixes requires better judgment than does the use of map reading fixes.

The magnitude of the error in a calculated average wind varies with the error of the fix and with the error of the air position. It varies also with the magnitude of the wind effect and with the length of the period over which the wind is being determined.

As shown in figure 13-14, with a given fix error, the greater the wind effect, the less the error in measured wind direction. The fix is 5 miles in error. With a 10-mile wind effect, the maximum error in measured wind direction is 30°; whereas with a 20-mile wind effect, the maximum error is about 14 1/2°. Wind effect is proportional to wind speed and to time. Therefore, the accuracy of measured wind direction increases with the speed of the wind and with the length of the period over which the wind is determined. If the wind is weak, small fix errors may be expected to cause apparent inconsistency of wind direction.

The magnitude of the actual wind speed has almost no effect on the accuracy of the calculated wind speed. No matter what the wind speed, a 10-mile fix error after an hour's flight can give

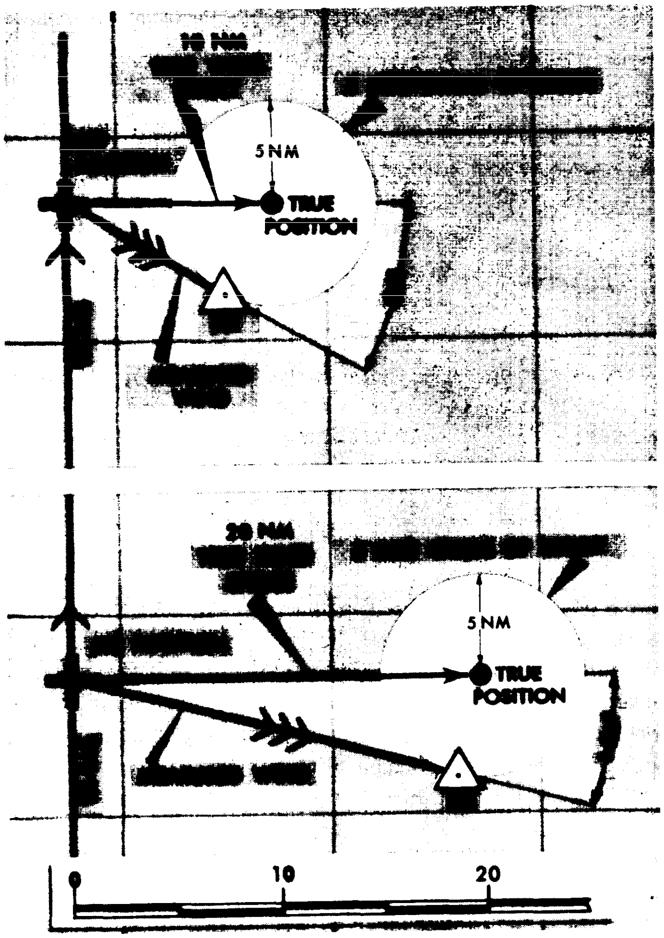


Figure 13-14. The Greater the Wind Effect, the Smaller the Error.

only a 10-knot error in calculated wind speed. The navigator is interested in the absolute error and not the percentage error in wind speed. A 10-knot absolute error always will cause a 10-mile position error after an hour; this is true whether the true wind speed is 1 knot or 100 knots.

The longer the period over which the wind is determined, the greater the wind effect, and the smaller the relative influence of a given fix error upon the wind effect. Hence, the longer the period, the more accurate the value obtained for the speed of the average wind. Doubling the time also doubles the wind effect, and hence, will halve the maximum error in calculated wind speed caused by a given fix error.

The examples have been given in terms of airplot, but the conclusions are valid regardless of how the wind is found. It has been assumed in the examples that there was no error in air positions. However, DR errors are cumulative; whereas, the error of a fix is not affected by distance from departure. When the cumulative error of the airplot has become greater than the average fix error, then results can be improved by restarting the airplot from a fix. The difficulty is to recognize that time when it comes.

SUMMARY

Because of all the factors involved, a certain amount of judgment is necessary, along with the proper use of the mechanics comprising celestial navigation. When using a single LOP or a fix, the navigator has to take into consideration the existing conditions and weigh the DR information against the information obtained from the LOP.

An accurate DR position should always be computed.

A formula has been devised to aid in determining an MPP from a single LOP, but the navigator may want to make further adjustments to the final position. The formula is

$$\frac{d}{t} = \frac{p}{t + p}$$

Remember, d is the distance measured along a perpendicular from the DR position to the LOP.

In the case of the two- or three-star fix, planning plays a very important part. Selecting stars whose azimuths differ by 120° for a three-star fix will minimize errors in the fix position. In two-star fixes, the ideal azimuth separation is 90°. Also, when dealing with more than one LOP, it is necessary to resolve the LOPs to a common time. This adjustment can be accomplished by moving the assumed position, by moving the LOPs, or by applying a correction factor to the Hc or Ho.

Chapter 14

SPECIAL CELESTIAL TECHNIQUES

This chapter has some techniques which may not be used every day and under all circumstances, but are valuable alternatives to normal precomping procedures. Most of these techniques save time by eliminating either some extractions or computations. Some navigational techniques and planning procedures are also discussed. A few references, which may prove helpful, are included at the end of the chapter.

LATITUDE BY POLARIS

Polaris is the pole star, or North Star. Because Polaris is approximately 1° from the North Pole, it makes a small diurnal circle and seemingly stays in about the same place all night. This fact makes Polaris very useful in navigation. With certain corrections, it serves as a reference point for direction and for latitude in the Northern Hemisphere.

Latitude by Polaris is a quick method of obtaining a latitude LOP—only the tables given in the Air Almanac are needed. Many navigators use a Polaris observation in almost every three-star fix.

There are a number of ways to get a latitude by Polaris, depending on the accuracy needed and the technique used to plot. Latitude by Polaris is accomplished by applying "Q" correction (figure 14-1) to the corrected Hc. This adjusts the altitude of the pole, which is equal to the navigator's latitude. This critical "Q" correction table is in the back of the Air Almanac, with entering arguments of LHA of Aries and corrected observed altitude (corrected sextant altitude in Air Almanac). The effect of refraction is not included, so the observed altitude must be fully corrected before using to enter the "Q" table.

Example: On 20 March 1979 for GMT 2230 at 50-27N 75-12W, with an observed altitude 50°-32′ at 33,000′, find latitude. (Exact latitude and longitude is used when working with Polaris.)

GHA	155-21
Longitude (West)	75-12
LHA	080-090
(True Course 095°, Groundspeed 380k, Coriolis/rhumb line 10R)	
Corrected Observed Altitude	50-32
Q (LHA 080-09)	-34
Latitude	49-58

Azimuth (LHA 80°, Latitude 50°)
= 359.0

In this case, refraction is 0′ and all information was taken from the Air Almanac. If "Q" correction table in star volume I is used, remember P/N (precession and nutation), as well as Coriolis/rhumb line, must be used in plotting the resultant LOP. This is because the HO 249 is for a 5-year period and, the further one gets from the Epoch year, the greater the error is when using the Polaris table. P/N compensates for this error.

When plotting Polaris, two techniques may be used. One is to plot the LOP as a line of latitude (corrected for Coriolis or rhumb line and accuracy, the actual azimuth of Polaris as obtained from the Azimuth of Polaris table may be used (figure 14-2).

A Polaris LOP may also be found by using the intercept method. Referring to the previous problem:

Assumed Latitude	50-27N
Q (Reversed Sign)	+34
Hc Polaris	51-01
Ho Polaris	50-32
Intercept	29A

This allows the Coriolis or rhumb line correction to be applied to the assumed latitude prior to plotting the LOP, thus saving time.

NOTE: Applying 29A to assumed latitude gives 49-58N, which is the same as previous answer, prior to plotting.

LHA METHOD OF OBTAINING FIX

A different method of obtaining a fix, rather than a single LOP as in the Polaris precomp, is the 3-LHA method of precomping used with the stars as shown in figure 14-3. The first step in obtaining a celestial fix in this manner is to solve a precomputation for the time of the fix. In solving for the time of 0500, an LHA of 102 is determined. LHAs for 0456 and 0452, 4 and 8 minutes prior to fix time, respectively, are found. Since theoretically we have 15′ of sky movement for every minute of time, the two corresponding LHAs would be 101 and 100. Enter volume I of the HO 249 and find the Hc and Zn for the respective LHAs.

When shooting the selected bodies, take care to shoot them exactly on the prescribed times. This will make motion of the body unnecessary. Motion of the observer is compensated for by moving the assumed positions for track and groundspeed. If a shot is taken off time (early, for example), remember the FEAST (Fast EAST) rule: a shot taken too fast, or early, has the assumed position moved 15′ of longitude east for each minute early to compensate for body motion. This adjusted position is

POLARIS (POLE STAR) TABLE, 1979

FOR DETERMINING THE LATITUDE FROM A SEXTANT ALTITUDE

L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q	L.H.A. ♈	Q
° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′	° ′	′
359 38	−42	81 54	−32	115 02	− 6	145 38	+20	188 49	+46	268 23	+28	300 29	+ 2	331 29	−24
1 46	−43	83 24	−31	116 12	− 5	146 54	+21	191 50	+47	269 47	+27	301 38	+ 1	332 48	−25
4 02	−44	84 51	−30	117 21	− 4	148 10	+22	195 22	+48	271 09	+26	302 47	0	334 07	−26
6 29	−45	86 18	−29	118 30	− 3	149 27	+23	199 45	+49	272 30	+25	303 57	− 1	335 28	−27
9 09	−46	87 42	−28	119 39	− 2	150 45	+24	206 38	+50	273 51	+24	305 06	− 2	336 50	−28
12 08	−47	89 05	−27	120 49	− 1	152 04	+25	219 17	+49	275 10	+23	306 16	− 3	338 13	−29
15 37	−48	90 27	−26	121 58	0	153 25	+26	226 10	+48	276 28	+22	307 25	− 4	339 37	−30
19 56	−49	91 48	−25	123 08	+ 1	154 46	+27	230 33	+47	277 45	+21	308 34	− 5	341 04	−31
26 43	−50	93 07	−24	124 17	+ 2	156 08	+28	234 05	+46	279 01	+20	309 43	− 6	342 31	−32
39 12	−49	94 26	−23	125 26	+ 3	157 32	+29	237 06	+45	280 17	+19	310 53	− 7	344 01	−33
45 59	−48	95 43	−22	126 35	+ 4	158 57	+30	239 49	+44	281 32	+18	312 02	− 8	345 33	−34
50 18	−47	97 00	−21	127 44	+ 5	160 24	+31	242 17	+43	282 46	+17	313 12	− 9	347 07	−35
53 47	−46	98 16	−20	128 54	+ 6	161 53	+32	244 35	+42	284 00	+16	314 22	−10	348 43	−36
56 46	−45	99 31	−19	130 03	+ 7	163 23	+33	246 44	+41	285 13	+15	315 33	−11	350 23	−37
59 26	−44	100 46	−18	131 13	+ 8	164 56	+34	248 47	+40	286 25	+14	316 43	−12	352 05	−38
61 53	−43	101 59	−17	132 23	+ 9	166 31	+35	250 43	+39	287 37	+13	317 54	−13	353 52	−39
64 09	−42	103 13	−16	133 33	+10	168 08	+36	252 35	+38	288 49	+12	319 06	−14	355 42	−40
66 17	−41	104 25	−15	134 44	+11	169 49	+37	254 22	+37	290 00	+11	320 17	−15	357 37	−41
68 18	−40	105 38	−14	135 55	+12	171 33	+38	256 06	+36	291 11	+10	321 30	−16	359 38	−42
70 13	−39	106 49	−13	137 06	+13	173 20	+39	257 47	+35	292 22	+ 9	322 42	−17	1 46	−43
72 03	−38	108 01	−12	138 18	+14	175 12	+40	259 24	+34	293 32	+ 8	323 56	−18	4 02	−44
73 50	−37	109 12	−11	139 30	+15	177 08	+41	260 59	+33	294 42	+ 7	325 09	−19	6 29	−45
75 32	−36	110 22	−10	140 42	+16	179 11	+42	262 32	+32	295 52	+ 6	326 24	−20	9 09	−46
77 12	−35	111 33	− 9	141 55	+17	181 20	+43	264 02	+31	297 01	+ 5	327 39	−21	12 08	−47
78 48	−34	112 43	− 8	143 09	+18	183 38	+44	265 31	+30	298 11	+ 4	328 55	−22	15 37	−48
80 22	−33	113 53	− 7	144 23	+19	186 06	+45	266 58	+29	299 20	+ 3	330 12	−23	19 56	−49
81 54		115 02		145 38		188 49		268 23		300 29		331 29		26 43	

Q, which does *not* include refraction, is to be applied to the corrected sextant altitude of *Polaris*.
Polaris: Mag. 2·1, S.H.A. 327°02′, Dec. N. 89°10·′2

AZIMUTH OF *POLARIS*

L.H.A. ♈	Latitude							L.H.A. ♈	Latitude						
	0°	30°	50°	55°	60°	65°	70°		0°	30°	50°	55°	60°	65°	70°
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	0·5	0·5	0·7	0·8	0·9	1·1	1·4	180	359·5	359·5	359·3	359·2	359·1	359·0	358·7
10	0·3	0·4	0·5	0·6	0·7	0·8	1·0	190	359·7	359·6	359·5	359·4	359·4	359·3	359·1
20	0·2	0·2	0·3	0·3	0·4	0·5	0·6	200	359·8	359·8	359·7	359·7	359·6	359·6	359·5
30	0·0	0·1	0·1	0·1	0·1	0·1	0·1	210	0·0	0·0	359·9	359·9	359·9	359·9	359·9
40	359·9	359·9	359·8	359·8	359·8	359·8	359·7	220	0·1	0·1	0·2	0·2	0·2	0·2	0·3
50	359·8	359·7	359·6	359·6	359·5	359·4	359·3	230	0·2	0·3	0·4	0·4	0·5	0·6	0·7
60	359·6	359·6	359·4	359·3	359·2	359·1	358·9	240	0·4	0·4	0·6	0·6	0·7	0·9	1·1
70	359·5	359·4	359·2	359·1	359·0	358·8	358·5	250	0·5	0·6	0·8	0·9	1·0	1·2	1·4
80	359·4	359·3	359·0	358·9	358·8	358·5	358·2	260	0·6	0·7	0·9	1·0	1·2	1·4	1·7
90	359·3	359·2	358·9	358·8	358·6	358·3	357·9	270	0·7	0·8	1·1	1·2	1·4	1·6	2·0
100	359·2	359·1	358·8	358·7	358·5	358·2	357·7	280	0·8	0·9	1·2	1·3	1·5	1·8	2·2
110	359·2	359·1	358·7	358·6	358·4	358·1	357·6	290	0·8	0·9	1·3	1·4	1·6	1·9	2·3
120	359·2	359·0	358·7	358·6	358·3	358·0	357·6	300	0·8	1·0	1·3	1·4	1·7	2·0	2·4
130	359·2	359·0	358·7	358·6	358·4	358·1	357·6	310	0·8	1·0	1·3	1·4	1·7	2·0	2·4
140	359·2	359·1	358·8	358·6	358·4	358·1	357·7	320	0·8	0·9	1·2	1·4	1·6	1·9	2·3
150	359·3	359·1	358·9	358·7	358·5	358·3	357·9	330	0·7	0·9	1·2	1·3	1·5	1·8	2·2
160	359·3	359·2	359·0	358·9	358·7	358·5	358·1	340	0·7	0·8	1·0	1·2	1·3	1·6	2·0
170	359·4	359·4	359·1	359·0	358·9	358·7	358·4	350	0·6	0·7	0·9	1·0	1·2	1·4	1·7
180	359·5	359·5	359·3	359·2	359·1	359·0	358·7	360	0·5	0·5	0·7	0·8	0·9	1·1	1·4

When Cassiopeia is left (right), *Polaris* is west (east).

Figure 14-1. Polaris Q Correction and Azimuth Tables from the Air Almanac.

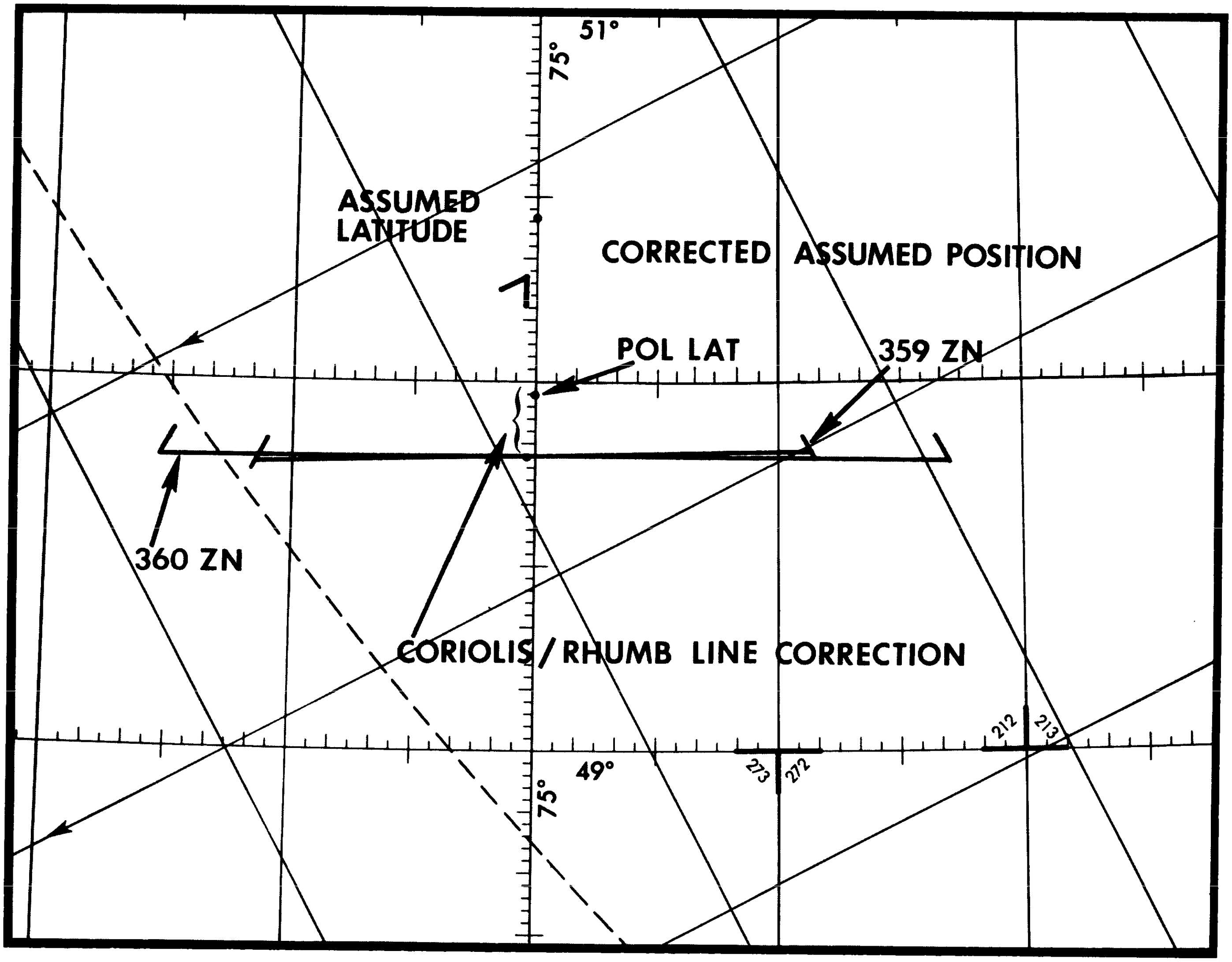


Figure 14-2. Polaris Intercept Assuming 360° Azimuth, Polaris Latitude Using Actual Azimuth.

then moved for track and groundspeed to account for motion of the observer (figure 14-4). NOTE: The plotting technique of using "flags" to designate shot sequence and direction of Zn is used throughout this chapter.

DAYTIME CELESTIAL TECHNIQUES

Daytime fixing, using celestial techniques, is rather limited because often only one body, the Sun, is visible. Ordinarily, three LOPs cannot be obtained for a fix from one body because the LOPs fall too nearly parallel to each other. There is a technique, however, which can be used to determine a fix from observations of one body.

The Noonday Fix

At low latitudes when the Sun passes close to the observer's position, usually within 10°, its azimuth changes rapidly before and after transit. Over a short period of time, the azimuth may change enough to allow a fix to be obtained. Since two of the LOPs must be moved by using dead reckoning information, the noonday fix may be less accurate than other celestial fixes. It is better, however, than the single LOP positions which are obtained during the other portions of the day.

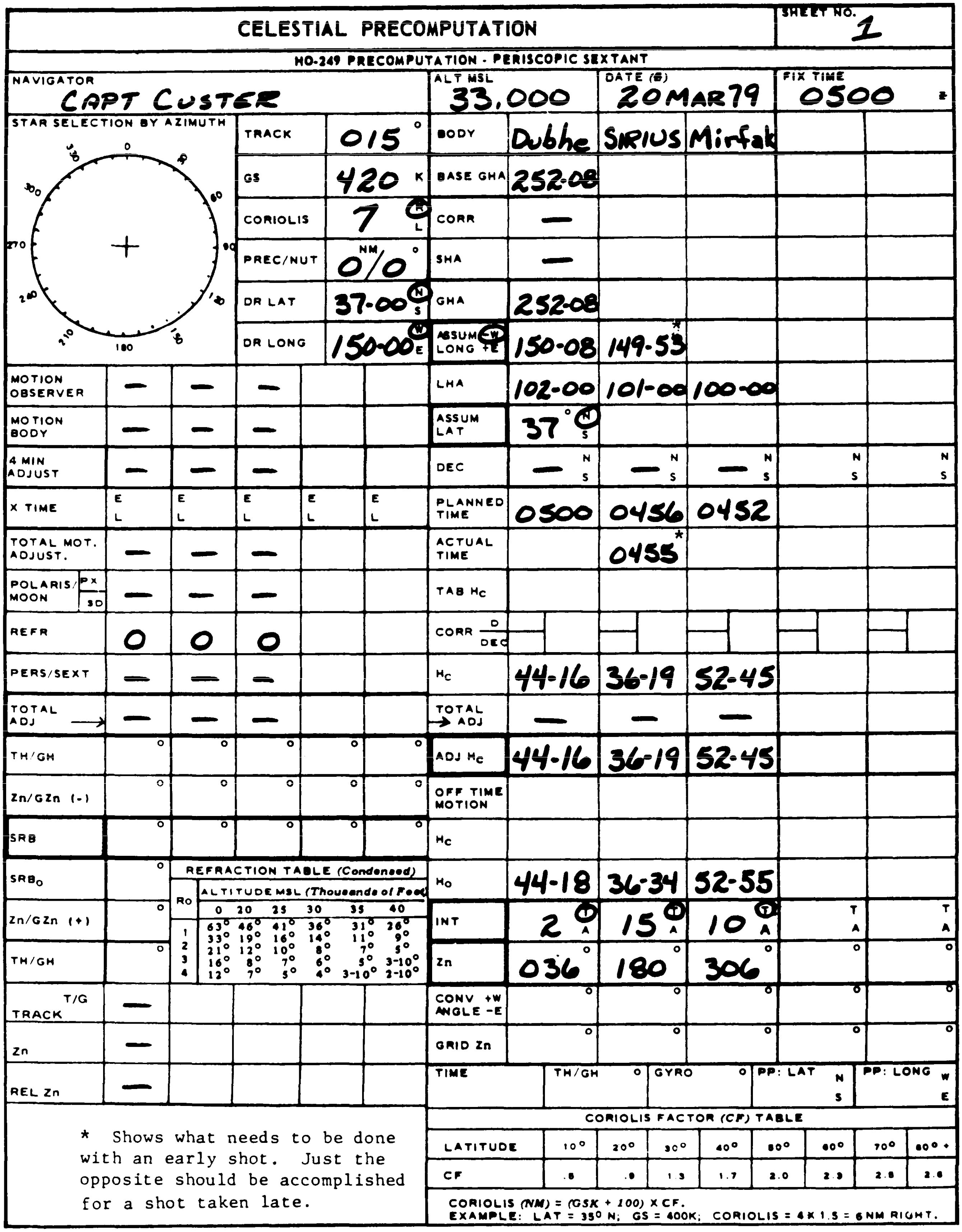
Intercept Method

The intercept method is normally used in obtaining a noonday fix. If the Sun passes close to the observer's position, within about 4°, the subpoint method of plotting the fix may be used.

This method differs from normal procedures in that three different precomps for three different times are computed. Because of the rapid change of the Sun's azimuth at or near transit, this variation is necessary. The procedure is:

Step 1. Determine the time of transit. This will be when the LHA is 360°.

Step 2. By inspection, select the LHA before and after transit for which the change in azimuth is 30° or more. Since 1° of LHA is equal to 4 minutes of time, the difference in transit LHA and



CELESTIAL PRECOMPUTATION

SHEET NO. 1

HO-249 PRECOMPUTATION - PERISCOPIC SEXTANT

NAVIGATOR	ALT MSL	DATE (G)	FIX TIME
CAPT CUSTER	33,000	20MAR79	0500 Z

STAR SELECTION BY AZIMUTH

TRACK	015°	BODY	Dubhe	SIRIUS	Mirfak		
GS	420 K	BASE GHA	252-08				
CORIOLIS	7 [✓ R] L	CORR	—				
PREC/NUT	0 NM/0 °	SHA	—				
DR LAT	37-00 [✓ N] S	GHA	252-08				
DR LONG	150-00 [✓ W] E	ASSUM LONG [✓ -W] +E	150-08	149-53 *			

MOTION OBSERVER	—	—	—			LHA	102-00	101-00	100-00		
MOTION BODY	—	—	—			ASSUM LAT	37° [✓ N] S				
4 MIN ADJUST	—	—	—			DEC	— N S	— N S	— N S	N S	N S
X TIME	E L	E L	E L	E L	E L	PLANNED TIME	0500	0456	0452		
TOTAL MOT. ADJUST.	—	—	—			ACTUAL TIME		0455 *			
POLARIS/MOON PX SD	—	—	—			TAB Hc					
REFR	0	0	0			CORR D/DEC					
PERS/SEXT	—	—	—			Hc	44-16	36-19	52-45		
TOTAL ADJ →	—	—	—			TOTAL → ADJ	—	—	—		
TH/GH	°	°	°	°	°	ADJ Hc	44-16	36-19	52-45		
Zn/GZn (-)	°	°	°	°	°	OFF TIME MOTION					
SRB	°	°	°	°	°	Hc					
SRB_O	°					Ho	44-18	36-34	52-55		
Zn/GZn (+)	°					INT	2 [✓ T] A	15 [✓ T] A	10 [✓ T] A	T A	T A
TH/GH	°					Zn	036°	180°	306°	°	°
T/G TRACK	—					CONV +W ANGLE -E	°	°	°	°	°
Zn	—					GRID Zn	°	°	°	°	°
REL Zn	—										

REFRACTION TABLE (*Condensed*)

Ro	ALTITUDE MSL (*Thousands of Feet*)					
	0	20	25	30	35	40
	63°	46°	41°	36°	31°	26°
1	33°	19°	16°	14°	11°	9°
2	21°	12°	10°	8°	7°	5°
3	16°	8°	7°	6°	5°	3-10°
4	12°	7°	5°	4°	3-10°	2-10°

TIME	TH/GH °	GYRO °	PP: LAT N S	PP: LONG W E

CORIOLIS FACTOR (*CF*) TABLE

LATITUDE	10°	20°	30°	40°	50°	60°	70°	80° +
CF	.5	.9	1.3	1.7	2.0	2.3	2.5	2.6

CORIOLIS (*NM*) = (*GSK + 100*) X CF.
EXAMPLE: LAT = 35° N; GS = 400K; CORIOLIS = 4 X 1.5 = 6NM RIGHT.

* Shows what needs to be done with an early shot. Just the opposite should be accomplished for a shot taken late.

MATHER TW FORM AUG 78 21a -1

★Figure 14-3. Example of Three LHA Method.

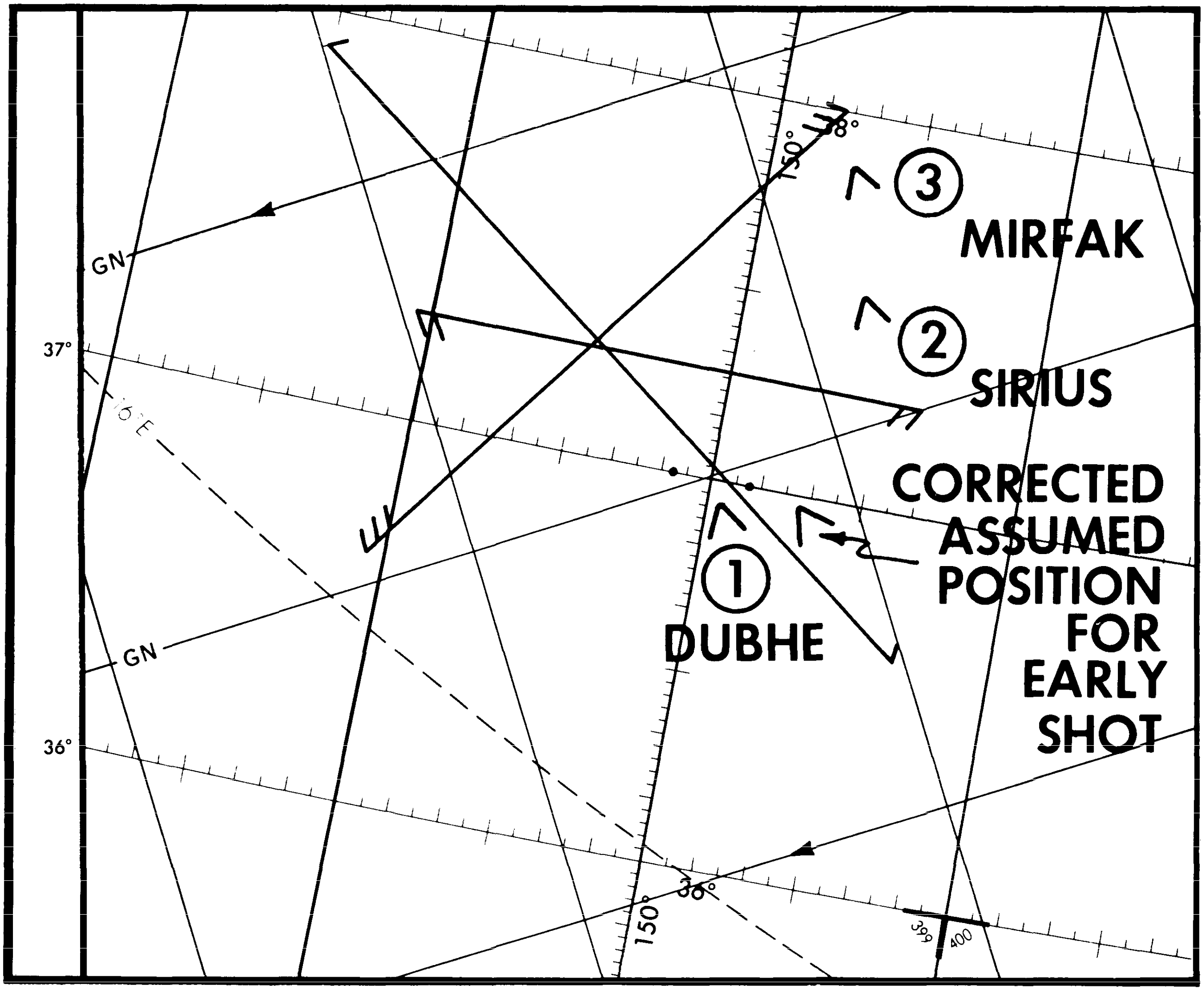


Figure 14-4. Three LHA Plotting With One Early Shot.

the new LHA can be converted to time in minutes. Thus, the time preceding and following transit can be determined.

Step 3. Plot the DR positions for times determined in step 2. Select the appropriate assumed positions necessary for the computation and plotting of the LOPs. The assumed position for time of transit is also plotted.

Step 4. After observations are made, determine the intercepts and azimuth for each LOP. Plot these data from the respective assumed positions.

Step 5. Resolve the LOPs to a common time, preferably that of the transit LOP.

NOTE: At 30° North latitude, the linear speed of the Sun is approximately 780 knots. Thus, on westerly headings in high-speed aircraft, the DR distance involved before encountering a 30° change in azimuth will be considerable.

Subpoint Method

When the observer is within approximately 4° of the subpoint of the body, the subpoint method of solution is normally used because the radius of the circle of equal altitude is so small that a straight line does not approximate the arc, and a straight line will not give an accurate LOP.

The procedure is:

Step 1. Plot the subpoints of the body for the time of the observations (using GHA + Dec).

Step 2. Find the co-altitude of the shots and convert it to nautical miles ((90° − Alt) x 60 NM).

Step 3. Advance the first subpoint and retard the third along the DR track, using the best-known track and groundspeed.

Step 4. Using a compass or pair of dividers, set the distance found from the co-altitude and strike it off from the resolved subpoints. Do this for each observation.

Step 5. The resulting intersection or triangle will give a noonday fix. If the LOPs form a triangle, the aircraft position is probably within the triangle.

The subpoint method is convenient because the HO 249 need not be used — only an Air Almanac is required. This method can also be used with a star near your assumed position and may be necessary if, for some reason, your HO 249 vol I is unavailable.

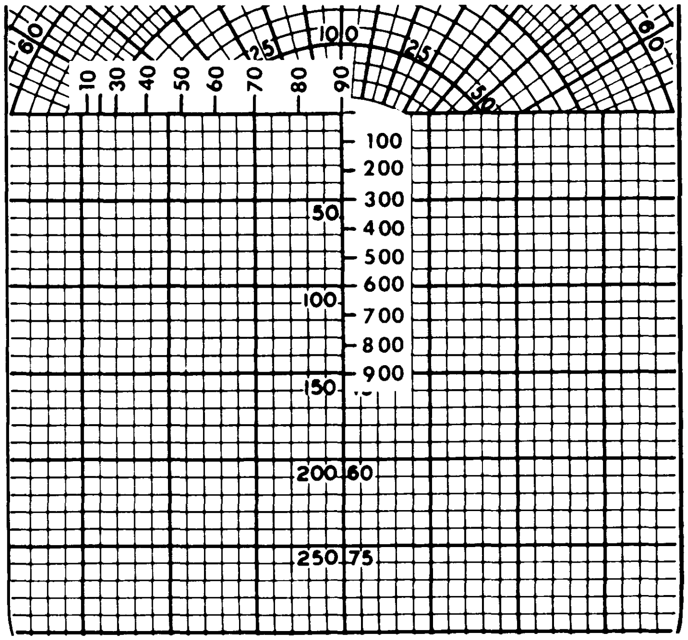


Figure 14-5. MB-4 1 Minute Celestial Motion Modification.

The star's declination and GHA are needed to determine if the observer is within 4° of the subpoint. The Air Almanac may be used to find the declination and SHA of the star. The SHA of the star is added to the GHA of Aries to find the GHA of the star.

ELIMINATING HO 249 MOTIONS

Many problems arise for navigators because of the many books, extractions, and computations needed to do celestial work. There are ways to reduce some of the work involved and, thereby, lessen the chance for error. Some of the methods we have already discussed are attractive for this very reason.

During daylight, a common technique used to eliminate some computations and extractions is to use a shot schedule of 4 minutes early, on precomp time, and 4 minutes late. This causes any motions that would be computed to have the same magnitude but an opposite sign (for the 4-minute early and late shots). Therefore, the motions need not be computed because they would cancel each other out. Of course, the on-time shot has no motions either.

At night, a similar method can be employed by shooting the same star 4 minutes early and late, with a different star shot on time. Once again, the work is reduced, but only two instead of three LOPs are obtained.

Rather than eliminating motions, your DR computer can be modified so both observer and body motions can be computed at one time, without entry into the HO 249.

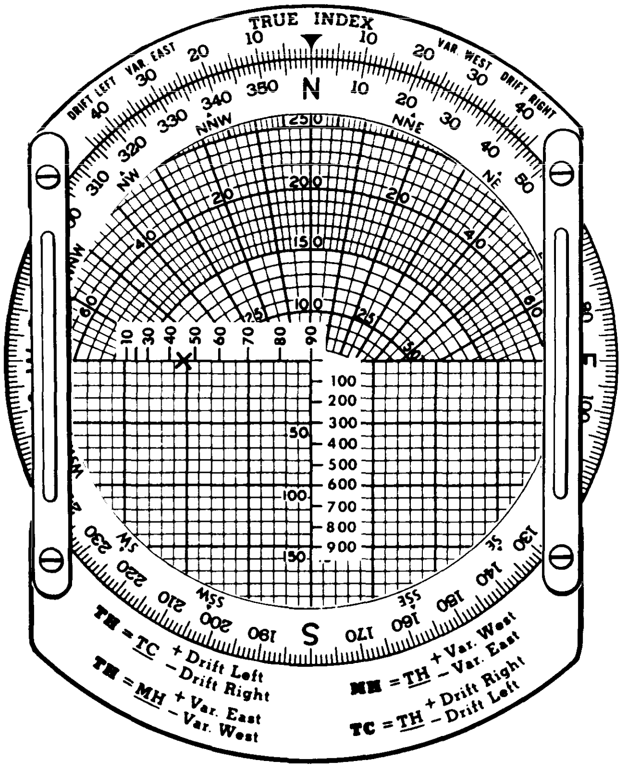
DR COMPUTER MODIFICATION

Make a groundspeed and latitude scale as shown in figure 14-5. After constructing these, the DR computer can be modified for quick, accurate computations of 1-minute motion adjustments.

Tape the groundspeed scale (0 through 900) along the center line of the grid scale. Match zero to zero, 300 to 50, and 600 to 100 as shown in figure 14-5. Then, tape the latitude scale along the zero grid line so that 90 degrees falls on the center line and the scale extends to the left as shown. Check the accuracy of your placement—30 latitude should fall 13 divisions left of center line. Juggle the scale as necessary to provide the greatest accuracy between latitudes 30 and 45.

To use the modified MB-4 computer for motion adjustments, complete the following instructions.

1. Set True North (if a grid solution, set the polar angle value of the assumed position) under the index. Place the grommet over the zero grid line. Mark a cross (+) at the assumed latitude (figure 14-6).
2. Set your track (or grid track) under the index and position the slide so the groundspeed is under the grommet. Place a dot on the zero point of the grid scale. (figure 14-7).
3. Place the Zn (or grid Zn) of the body under the index. Position the slide so the cross or the dot, whichever is uppermost, is on the zero line of the grid (figure 14-8).
4. The vertical distance between the zero line and the low mark is the combined 1-minute motion. Each line of the grid equals 1 minute of arc (1 mile). If the cross is on the zero line, the motion is positive. If the dot is on the zero line, the motion is

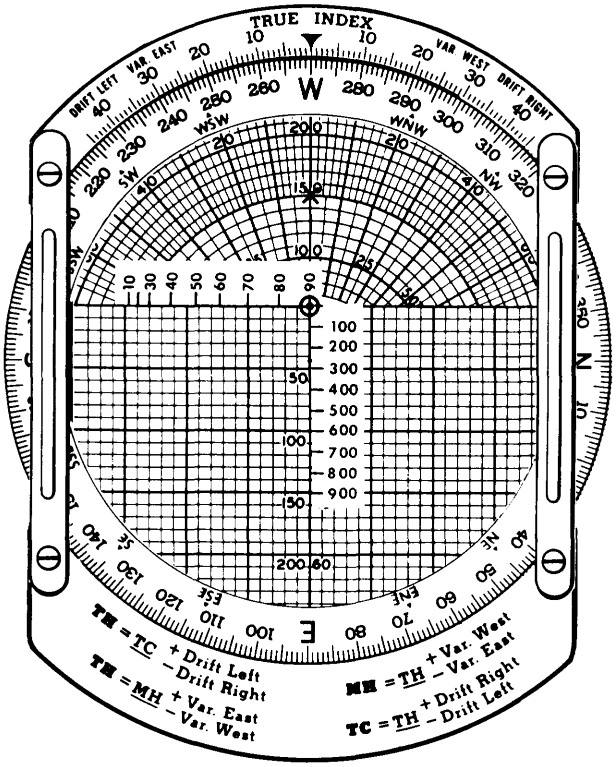


STEP ONE

SET NORTH UNDER TRUE INDEX AND GROMMET OVER ZERO GRID LINE, MARK A CROSS AT 45° LAT.

NST-2362

Figure 14-6. Celestial Motions — Step One.

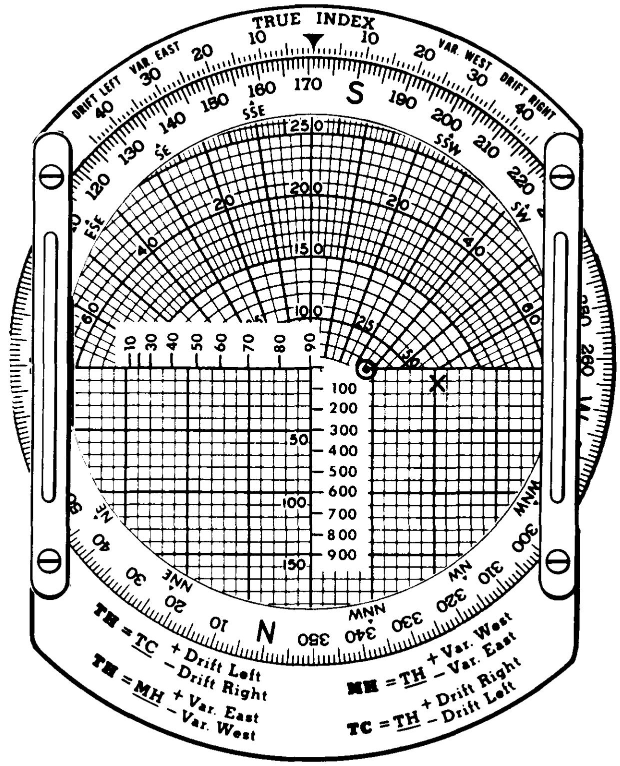


STEP TWO

SET TRACK 270 UNDER TRUE INDEX, MOVE SLIDE SO THAT GS 240 KTs IS UNDER GROMMET, MARK DOT ⊙ AT ZERO GRID LINE

NBT-2363

Figure 14-7. Celestial Motions — Step Two.



STEP THREE

SET Zn 171 UNDER TRUE INDEX. MOVE SLIDE SO THAT ⊙ DOT IS ON THE ZERO GRID LINE. READ COMBINED MOTION ADJUST OF MINUS 1.1.

NBT-2364

Figure 14-8. Celestial Motions — Step Three.

negative. These signs are correct for the SAC Form 289 when applied to the Hc. When solving for motions using grid, *all directions must be grid directions!*

Example

Given the following information, find the combined 1-minute motion adjustment.

Assumed Latitude	45° 10'N
True Track	270°
Groundspeed	240k
True Zn	171°

Combinations of Sun, Moon, and Venus

Fairly often, either the Moon or Venus or both of these bodies are visible during daylight hours and can be used to obtain an LOP. The possibility of fixes, using combinations of these bodies and the Sun, should always be considered when planning daylight celestial flights. When planning the flight, the navigator should use the sky diagrams in the Air Almanac to determine the availability of the Moon and Venus. If the bodies are available, they can be readily found by accurately precomputing their altitudes and azimuths.

When looking for Venus, take all the filters out of the sextant and point it at the precise location of the planet. A bright, small pinpoint of light will be visible, but hard to detect, unless sky conditions and separation from the Sun are ideal. With practice, acquisition should become easier, and you will be familiar with those conditions conducive to making a Venus shot successfully.

When using the Moon, as at night, it is wise to shoot the upper or lower limb and use semidiameter correction rather than try to estimate its center, except when the moon is full.

During the day when the Sun is high, the Moon or Venus, if they are available, can be used to obtain compass deviation checks. In polar regions during periods of continuous twilight, the Moon and Venus will be available if their declination is the same name as the latitude.

THE LANDFALL

Before the development of accurate methods of celestial navigation, ancient mariners had no way of checking their dead reckoning when out of sight of land. In crossing an ocean, they ran the risk of accumulating large DR errors. If their destination was on a continent or large island, the mariners could follow the coastline to destination. But, if the coastline first sighted was poorly charted, it was not possible to obtain a reliable position. Consequently, it was impossible to know which way to turn to reach destination. The mariners occasionally solved this problem by deliberately setting a course to one side of destination;

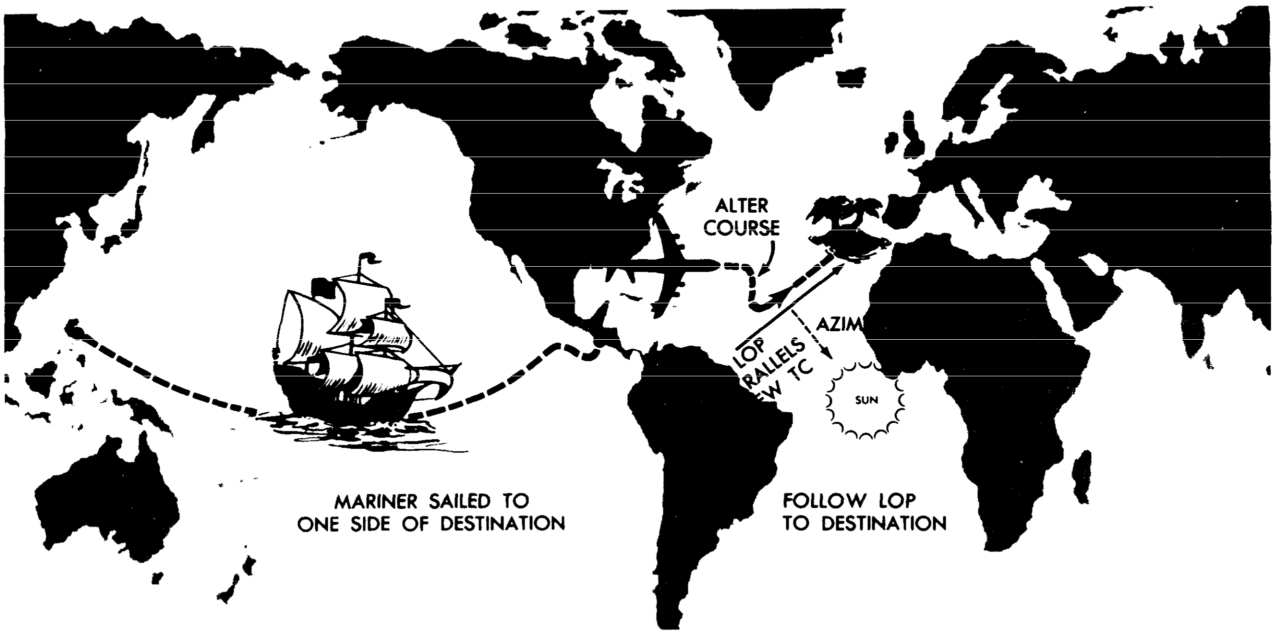


Figure 14-9. Making a Landfall.

then, upon reaching the coast, they knew which way to turn. This procedure is known as making a landfall. In figure 14-9, the mariner purposely sailed left of destination. Then, when striking the coast, the mariner knew that the first turn had to be to the right.

Like the mariner, the air navigator may reach a destination by using some LOP which passes through it. This LOP may be a coastline, a river, a railroad, a lightline, or a radio beam. Usually, it is accomplished by simply following the LOP. However, like the mariner, the navigator may set a course definitely to one side so that it becomes readily apparent which way the turn must be made to strike the LOP. When using a visible LOP in this manner, the navigator is flying a terrestrial landfall.

To an air navigator, "landfall" means "celestial landfall." A celestial landfall is similar to the terrestrial landfall except that it uses a celestial LOP, which is invisible.

The celestial landfall is the most certain method of reaching destination when there are no other means of supplementing dead reckoning except with LOPs from one celestial body.

If the navigator is aiming for a small island, course is more important than groundspeed. If the track is correct, the navigator will fly over the island sooner or later, no matter how inaccurate the ETA. but, if off course and the island is missed completely, an inaccurate groundspeed is of little consolation. If the LOPs were all perfect course lines, it would be comparatively easy to reach destination.

The cuts of the LOPs depend on the direction of the track relative to the azimuth of the Sun. If the navigator can set a departure time, it might be possible to reach the vicinity of destination when the LOPs give a favorable cut, but it would possibly be the time of day when the azimuth is changing most rapidly.

Another solution is to alter course near destination and approach destination from such a direction that the LOPs are course lines. This is a landfall. In figure 14-10, the LOPs were neither speed lines nor course lines, so the aircraft altered course in such a manner that the new course to destination was parallel to the LOPs.

In a landfall, course is of the utmost importance—ETA is secondary. The object of a landfall is to correct course by means of celestial LOPs so that the navigator will pass over destination. Essentially, the navigator flies along an LOP or celestial true course line, which passes through destination. Thus, the celestial landfall is the method of using celestial LOPs as course lines into destination, no matter how they cut the true course from departure to destination.

The celestial landfall presents two problems. The first problem is to get onto a Celestial true course to destination. In order to do so, the navigator must (1) know the position of the true course line; (2) must know when it is reached; and (3) must know when to fly on it. The second problem is to fly in the right direction on the true course line. It would be a fatal mistake in mid-Pacific to turn the wrong way and follow the true course line away from destination.

Although the landfalls work on the same principle, there are variations in procedure depending on whether the LOPs are more nearly course lines, or more nearly speed lines on the true course. Accordingly, landfalls are classified as course-line landfalls and speed-line landfalls.

Course-Line Landfall

Step 1. Refer to figure 14-10. Shoot and plot an LOP (A). Advance LOP (A) 10 minutes along track to establish LOP (A_1). This allows for working time. Plot LOP (A_2) through destination parallel to LOP (A). LOP (A_2) represents the celestial true course to destination.

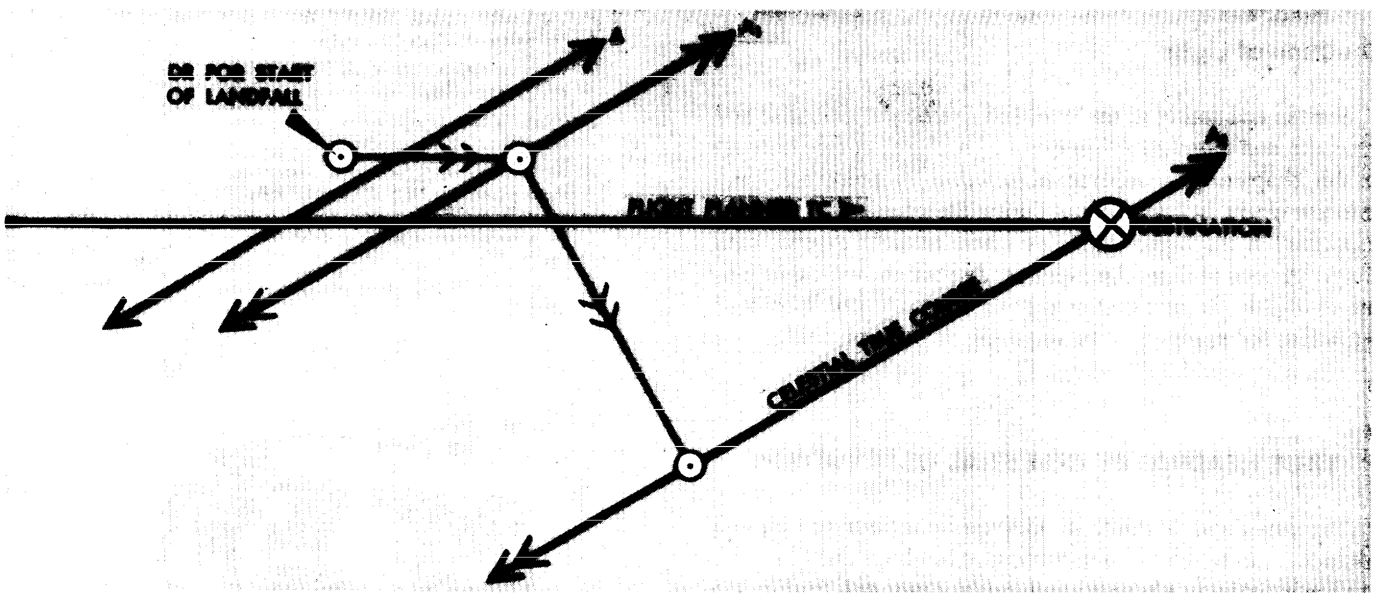


Figure 14-10. Course-Line Celestial Landfall.

Step 2. Determine the perpendicular true course to LOP (A_2) from LOP (A_1).

Step 3. Compute the ETA to the celestial true course (A_2). At the expiration of this ETA, alter onto the celestial true course to destination.

Step 4. Additional celestial observations should be taken to update the previous calculations.

NOTE: Celestial landfall procedures should be started at least 1 hour before the ETA to destination.

Speed-Line Landfall

Step 1. Refer to figure 14-11. Shoot and plot a line of position (A). Advance LOP (A) 10 minutes along track to establish LOP (A_1). This allows for working time. Plot LOP (A_2) through destination parallel to LOP (A).

Step 2. Plot a distance "d" from destination along LOP (A_2) representing 10% of the distance flown from the previous fix but not less than 60 NM. The direction which LOP (A_2) is changing must be considered to determine whether to alter right or left of the flight-planned true course, and to determine whether "d" is plotted right or left also.

Step 3. Alter heading at LOP (A_1) to the position on LOP (A_2) determined by "d".

Step 4. Repeat this procedure at least 30 minutes prior to the ETA to LOP (A_2) to establish LOPs (B), (B_1), and to compute a new celestial true course (B_2).

Step 5. Alter to destination upon intersecting LOP (B_2).

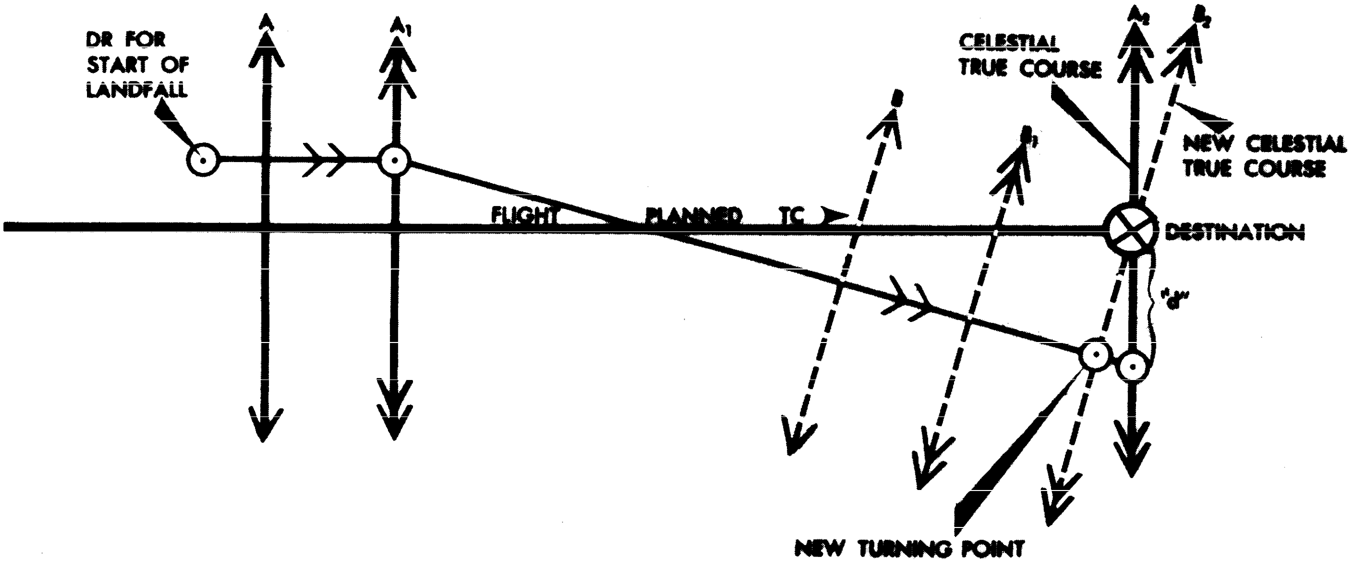


Figure 14-11. Speed-Line Celestial Landfall.

Duration of Light

Sunrise and sunset at sea level and at altitude; moonrise and moonset; and semiduration graphs will not be discussed in detail in this chapter. It is imperative, however, to preplan for any mission where twilight occurs during the course of the flight, especially at the higher latitudes where twilight extends over longer periods of time. An excellent discussion, with appropriate examples, is provided in the Air Almanac and should be sufficient for those missions requiring detailed planning.

TRUE HEADING BY CELESTIAL OBSERVATION

The periscopic sextant, in addition to measuring celestial altitudes, can be used to determine true headings and bearings. Any celestial body whose azimuth can be computed, can be used to obtain a true heading. Except for Polaris, the appropriate volume of HO 249 is entered to obtain Zn (true bearing). In the case of Polaris, the Air Almanac has an Azimuth of Polaris table. It does not require information from the HO 249 tables.

Three methods are used to obtain true headings with the periscopic sextant. Only the true bearing method requires precomputation of Zn. Postcomputation of Zn is possible with the relative bearing method and the inverse relative bearing method. The procedures are as follows:

True Bearing Method (TB)

1. Determine GMT and body to be observed.
2. Extract GHA from the Air Almanac.
3. Apply exact longitude to GHA to obtain exact LHA.
4. Enter appropriate HO 249 table with exact LHA, latitude, and declination. Interpolate if necessary and extract Zn (true bearing) and Hc (figure 14-12). If Polaris is used, obtain the azimuth from the Azimuth of Polaris table in the Air Almanac, and use your latitude instead of Hc (figure 14-13).
5. Set Zn in the azimuth counter window with the azimuth crank and set Hc in the altitude counter window with the altitude control knob.
6. Collimate the body at the precomputed time and read the true heading of the aircraft under the vertical crosshair in the field of vision. If you are using precomputation techniques, a true heading is available every time an altitude observation is made.

Relative Bearing Method (RB)

1. Bring the body into collimation.
2. Turn the azimuth crank (and the sextant as necessary), until 0° is under the vertical crosshair in the field of vision (figure 14-14).
3. At the desired time, read the relative bearing of the body in the azimuth counter window.
4. Compute Zn (true bearing) of the body and use the formula:

TH = Zn − RB

1. **Precompute the Zn of the body.**
2. **Using the azimuth crank, set the Zn of the body in the azimuth counter window.**
3. **Using the altitude control knob, set Hc in the altitude counter window.**
4. **Locate the body by turning the sextant until the approximate TH of the aircraft falls under the vertical crosshair. Body should be in the field of vision. Bring body into collimation.**
5. **Read exact TH under the vertical crosshair. (060°)**

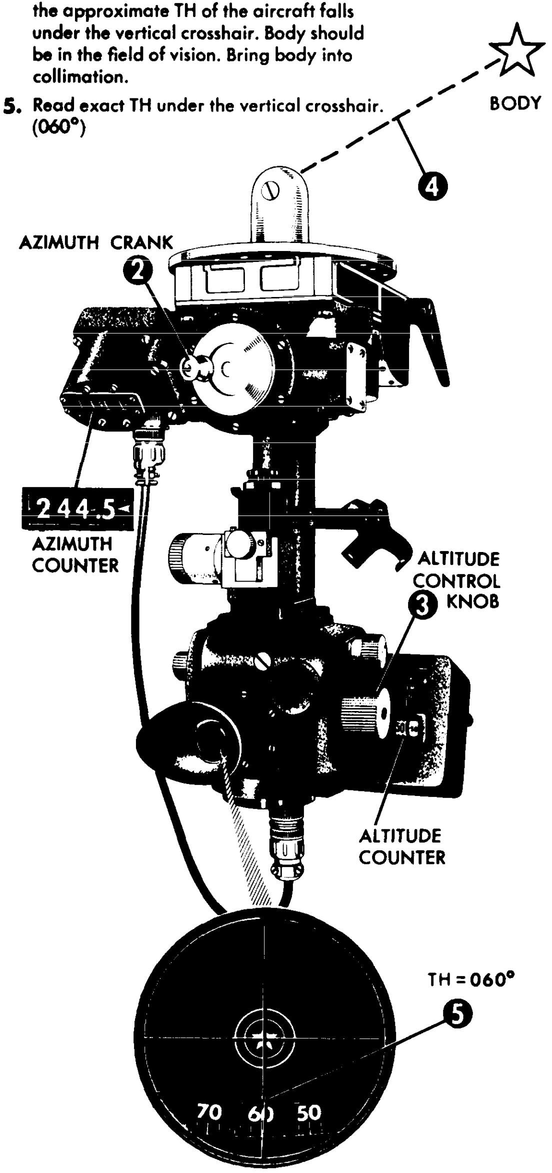


Figure 14-12. True Bearing Method (Except Polaris).

Inverse Relative Bearing Method (IRB)

1. Set 000° in the azimuth counter window with the azimuth crank (figure 14-15).
2. Collimate the body. At the desired time, read the bearing (IRB) under the vertical crosshair in the field of vision.
3. Compute Zn of the celestial body and use the formula:

TH = Zn + IRB

1. Precompute the Zn of Polaris.
2. Using the azimuth crank, set the Zn of Polaris into the azimuth counter window.
3. Using the altitude control knob, set your Latitude into the altitude counter window.
4. Locate Polaris by turning the sextant until the approximate TH of the aircraft falls under the vertical crosshair. Polaris should be in the field of vision. Bring Polaris into collimation.
5. Read the exact TH under the vertical cross-hair. (050°)

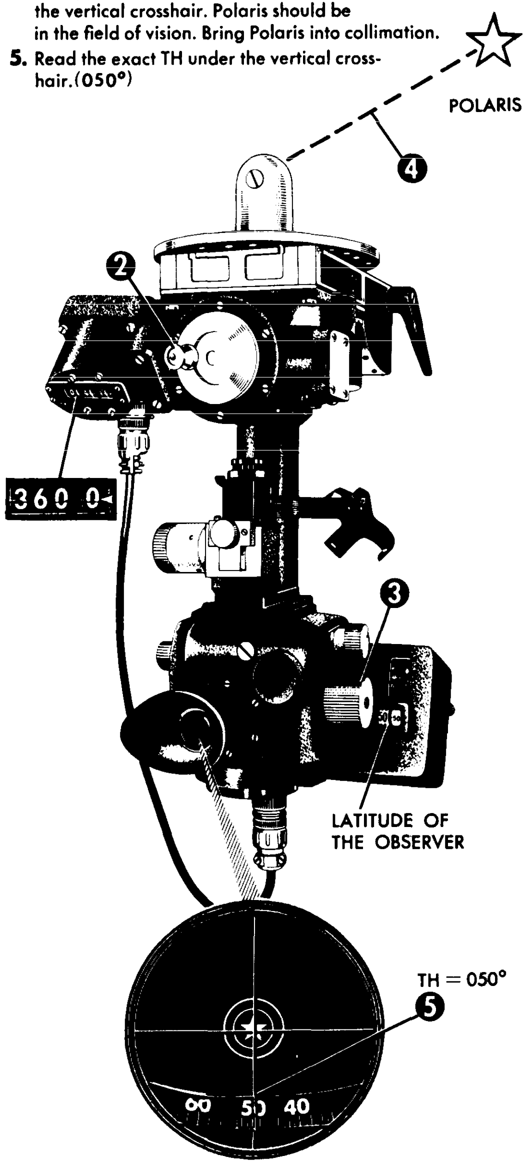


Figure 14-13. True Bearing Method (Using Polaris).

CELESTIAL NAVIGATION IN HIGH LATITUDES

Celestial navigation in polar regions is of primary importance because (1) it constitutes the principal method of determining position other than by dead reckoning, and (2) it provides the only means of establishing direction over much of the polar regions. The magnetic compass and directional gyro are useful in polar regions, but they require an independent check, which is provided only by celestial bodies. Celestial navigation is of such importance in polar regions that the navigator customarily devotes almost full time to it.

1. Turn crank until 0° is under vertical crosshair.
2. Read relative bearing in azimuth counter window (249°)
3. Compute ZN of body and solve formula: TH=Zn-RB

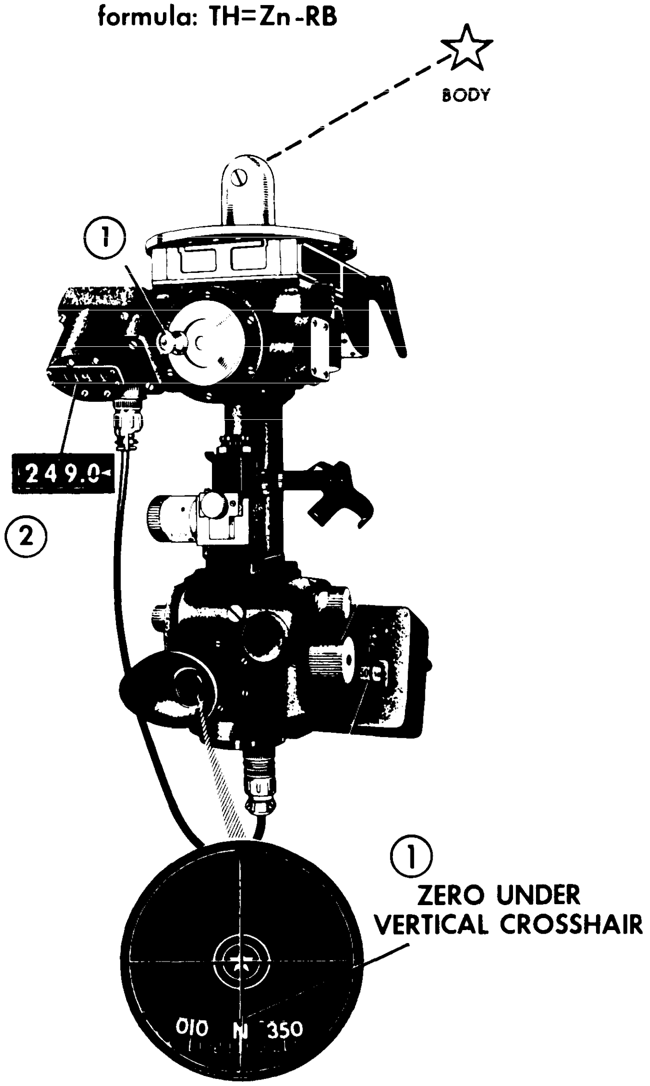
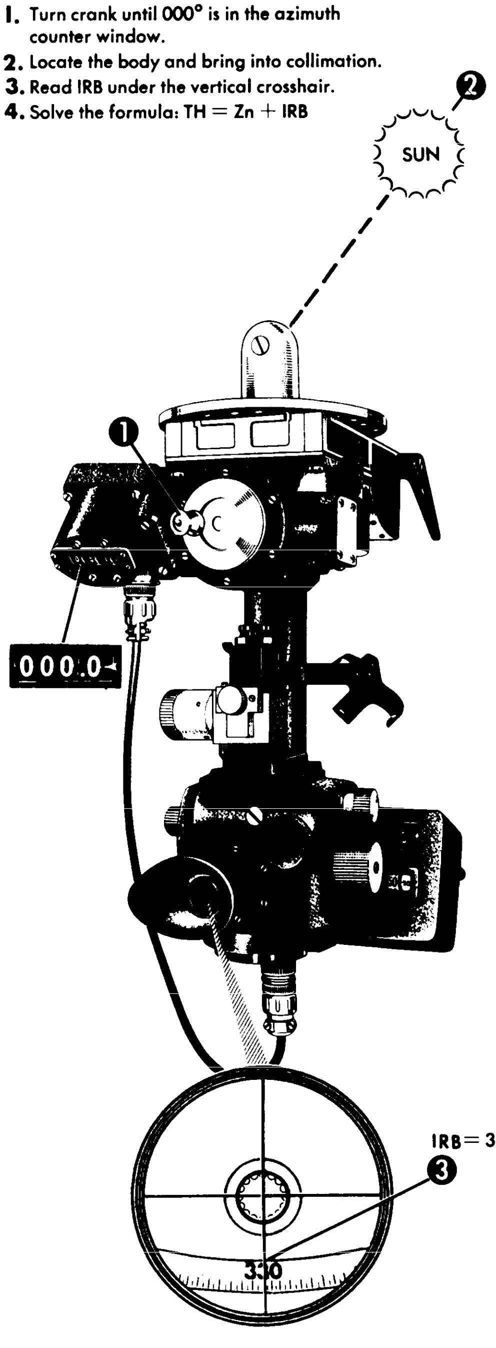


Figure 14-14. Relative Bearing Method.

Timepieces should be given special care. They should be wound regularly and their errors checked by time signal before each flight. They should not be exposed to very low temperatures. Below approximately −40° (F or C), a precision watch becomes unreliable. A wristwatch receives sufficient heat from the body, but any other timepiece should be protected from severe temperatures. This may be done by keeping it in an inside pocket where it will be warmed by body heat. Even though a watch may be operating properly, its rate may be altered considerably by a large change in temperature.

At high latitudes, the Sun's daily motion is nearly parallel to the horizon. In areas of continuous sunlight, the moment chosen as the start of the day is of little importance. Hence, GMT is



1. Turn crank until 000° is in the azimuth counter window.
2. Locate the body and bring into collimation.
3. Read IRB under the vertical crosshair.
4. Solve the formula: TH = Zn + IRB

Figure 14-15. Inverse Relative Bearing Method.

customarily used for flights. The motion of the aircraft in these regions can easily have greater effect upon altitude and true azimuth of the Sun than the motion of the Sun itself. At latitude 64°, an aircraft flying west at 400 knots keeps pace with the Sun, which appears to remain stationary in the sky. At higher latitudes, the altitude of a celestial body might be increasing at any time of day, if the aircraft is flying toward it, and a body might rise or set, at any azimuth, depending upon the direction of motion of the aircraft relative to the body.

Since the apparent motion of celestial bodies is nearly horizontal, and their azimuth relationship changes relatively little, it is not unusual for the same celestial bodies to be used for successive fixes throughout a flight in polar regions.

Observations can be made by the same instruments and techniques as in lower latitudes. However, a periscopic sextant is most suitable for polar regions because (1) it can be used for both altitude observations and heading checks, (2) it is easier to use for low altitudes often required during summer.

Bodies Available for Observation

During the continuous daylight of the polar summer, only the Sun is regularly available for observation. The Moon is above the horizon about half the time, but generally it is both visible and at a favorable position with respect to the Sun for only a few days each month.

During the long polar twilight, no celestial bodies may be available for observation by an ordinary sextant, although directional guidance can be obtained by means of an astrotracker. As in lower latitudes, the first celestial bodies to appear after sunset and the last to remain visible before sunrise are those brighter planets which are above the horizon.

Usually, a bright planet is visible throughout the twilight period, so that no break in routine need occur. Good advance flight planning can do much to avoid long periods without observations.

The Sun, Moon, and planets are never high in polar skies. Low altitude observations are routine, for often they are the only ones available. Particularly with the Sun, observations are made whenever any part of the celestial body is visible. If it is partly below the horizon, the upper limb is observed, and a correction of − 16′ for semidiameter is used in the SD block of the precomputation form.

During the polar night, stars are available. Polaris is not generally used because it is too near the zenith in the artic and not visible in the antarctic. A number of good stars are in favorable positions for observation. Because of large and somewhat unpredictable refractions in polar regions, particularly near the horizon, low altitudes (below about 20°) are avoided when higher bodies are visible.

Sight Reduction

Sight reduction in polar regions presents some slightly different problems from those at lower latitudes. Since low altitude observations are common, HO 249 is the most suitable method for continuous use because it provides for altitudes down to the visible horizon at flight altitudes. Remember, for latitudes greater than 69°N or 69°S, HO 249 tables have tabulated Hcs and azimuths for only even degrees of LHA. This concerns the navigator in two ways. First, it will be necessary to adjust assumed longitude so both a whole and even LHA is obtained for entry into HO 249. This will preclude interpolating. Second, the difference between successive, tabulated Hcs is for 2 degrees of LHA, or 8 minutes of time, so this difference must be divided in half when computing motion of the body for 4 minutes of time.

For ease of plotting, all azimuths can be converted to grid. In this connection, the longitude of the assumed position should be used to determine convergence—since the tabulated azimuth is for the assumed position, not the DR position. On polar charts, convergence is equal to longitude.

In computing motion of the observer, it is imperative that the navigator use the difference between grid azimuth and grid track, or true azimuth and true track, since this computation is based on relative bearing. True azimuth minus grid course does not give relative bearing.

Since low altitudes and low temperatures are normal in polar regions, refer to the refraction correction table and use the temperature correction factor for all observations.

In polar regions, Coriolis corrections reach maximum values and should not be overlooked.

Poles as Assumed Positions

Within approximately 2 degrees of the pole, it is possible to use the pole as the assumed position. With this method, no tabulated celestial computation is necessary, and the position may be determined by use of the Air Almanac alone.

At either of the poles of the Earth, the zenith and the elevated poles are coincident, and the plane of the horizon is coincident with the plane of the equator. Vertical circles coincide with the meridians and parallels of latitude coincide with declination circles. Therefore, the altitude of the body is equal to its declination, and the azimuth is equal to its hour angle.

To plot any LOP, an intercept and the azimuth of the body are needed. In this solution, the elevated pole is the assumed position. The azimuth is plotted as the GHA of the body, or the longitude of the subpoint. The intercept is found by comparing the declination of the body, as taken from the Air Almanac, with the observed altitude of the body. To summarize, the pole is the assumed position, the declination is the Hc, and the GHA equals the azimuth.

For ease of plotting, convert the GHA of the body to grid azimuth by adding or subtracting 180° when using the North Pole as the assumed position. When at the South Pole, 360° - GHA of the body equals grid azimuth. The result will allow the use of the grid lines for plotting the LOPs. When using grid azimuth for plotting, apply Coriolis to the assumed position (in this case—the pole). Precession/nutation corrections are not necessary since current SHA and declination are used. Motion of the observer tables may also be used in precomputation, since grid azimuth relative to grid course may be determined. Motion of the body is zero at the poles.

SUN		MOON	
H_c (DEC)	23°12'N	H_c (DEC)	10°57'N
H_o	22°04'	H_o	9°56'
INTERCEPT	68 NM AWAY	INTERCEPT	61 NM AWAY
GHA	168	GHA	236
	+180		−180
Grid ZN	348	GRID ZN	056

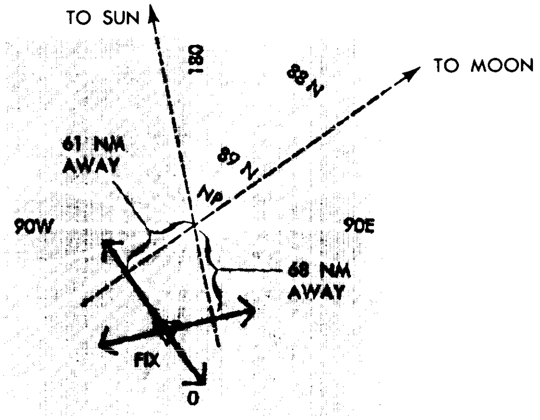


Figure 14-16. Using Pole as Assumed Position.

When a celestial body is observed, note the exact GMT. From the almanac, extract the proper declination and GHA. Plot the azimuth. Compare Ho and Hc to obtain the intercept. When the observed altitude (Ho) is greater than the declination (Hc), it is necessary to go from the pole toward the celestial body along the azimuth. If the observed altitude is less than the declination, as is the case with the Sun in figure 14-16, it is necessary to go from the pole away from the body along the azimuth. Draw the LOPs perpendicular to the azimuth line in the usual manner. It is not necessary to be concerned about large intercepts; they have no bearing on the accuracy of this type of fix. Observations on well-separated bearings give a fix that is as good close to the pole as it is anywhere else.

SUMMARY

Any of the techniques discussed here, if used on a regular basis, can be just as accurate as normal precomping procedures, and save some time as well. These techniques are not all inclusive. There are many commercial publications available as a source for celestial navigators. Another good source is your contemporaries - navigators in the field who have practiced, and are using, proven celestial techniques which may not have been covered here.