CHAPTER 6

Lines of Position, Bearings and Fixes

BEARINGS AND LINES OF POSITION

Dead reckoning is fundamental to navigation. DR positions based solely on time, speed, and direction are the foundations of navigation. The skill of the navigator depends upon his ability to measure, interpret, correct, and translate these data into useful and reliable information. Dead reckoning is seldom exact, and the longer DR is carried from a fix, the less reliable it becomes. Individual small errors tend to accumulate until the total error becomes dangerously large.

To keep the total error at a minimum, a competent navigator employs every means of finding his actual position in relation to the ground. In flights over land, with suitable visibility, an air navigator can frequently identify his position by means of recognizable landmarks. An accurate position determined without reference to any former position is called a *fix*.

If a fix is well defined, the navigator knows his position as precisely as at the time he took off. Such a fix serves as a new point of departure, canceling all previous errors in DR and becoming the origin of a new DR plot. A series of fixes improves the accuracy of later DR positions by giving better information concerning track, groundspeed, and wind.

Lines of Position

A navigator often has knowledge of his position without knowing precisely where he is. For example, he might recognize a river crossed in flight without knowing exactly where the crossing was made. He then has a definite clue to his position, but he does not have a fix. A fix is a point; the river is a line. A line indicating a series of possible

Figure 6-1. Two Intersecting LOPs Establish a Fix

positions of the aircraft is called a *line of position (LOP)*.

If a navigator can identify his position along an LOP, he then has a fix. Suppose a navigator is flying above a railroad as illustrated in figure 6-1. Even if he does not have an exact position along the railroad, he has a visual LOP. He is somewhere along this line. Now if he sees the railroad cross another railroad below the aircraft, he then knows exactly his position on the two railroads and has a fix. Thus, two intersecting LOPs establish a fix.

LINES OF POSITION BY BEARINGS. A common method of determining a line of position is to establish the direction of the line of sight to a

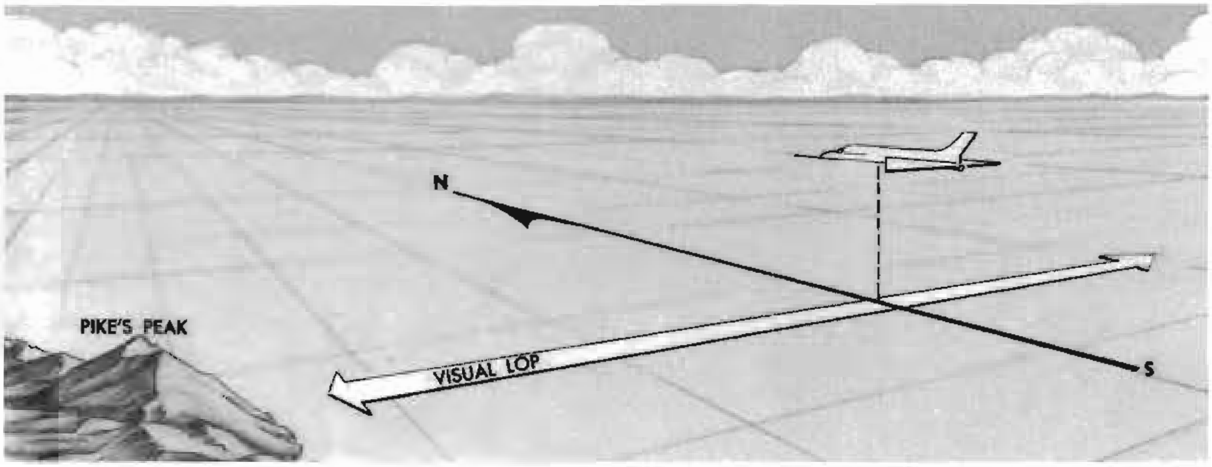


Figure 6-2. Establish a Visual LOP

known, fixed object by means of a driftmeter. The illustration in figure 6-2 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 must have been on the line of position; otherwise the bearing would have been different. A bearing is a locus of possible positions of the aircraft.

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 6-3, the relative bearing of the object is shown as 070°. Before the relative bearing is plotted, it must be converted to true bearing by adding to it the momentary true heading of the aircraft when the bearing was taken (dropping 360° when the sum 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 to be on a true heading of 210° when the bearing was taken, the corresponding true bearing of the object is 280°.

The basic equation for TB may be rearranged to compute any other item it contains. Thus:

$$TH = TB - RB,$$
or
$$RB = TB - TH.$$

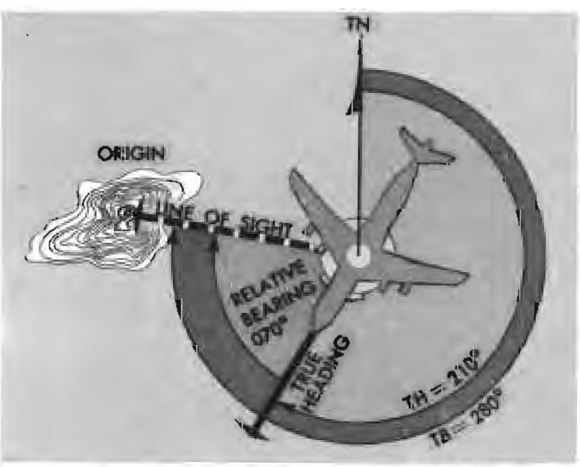


Figure 6-3. True Bearing Equals Relative Bearing Plus True Heading

Plotting the LOP

As previously stated, two intersecting LOPs determine the position of the aircraft. The only other possible point from which to begin the plotting is the object on which the bearings were taken. 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.

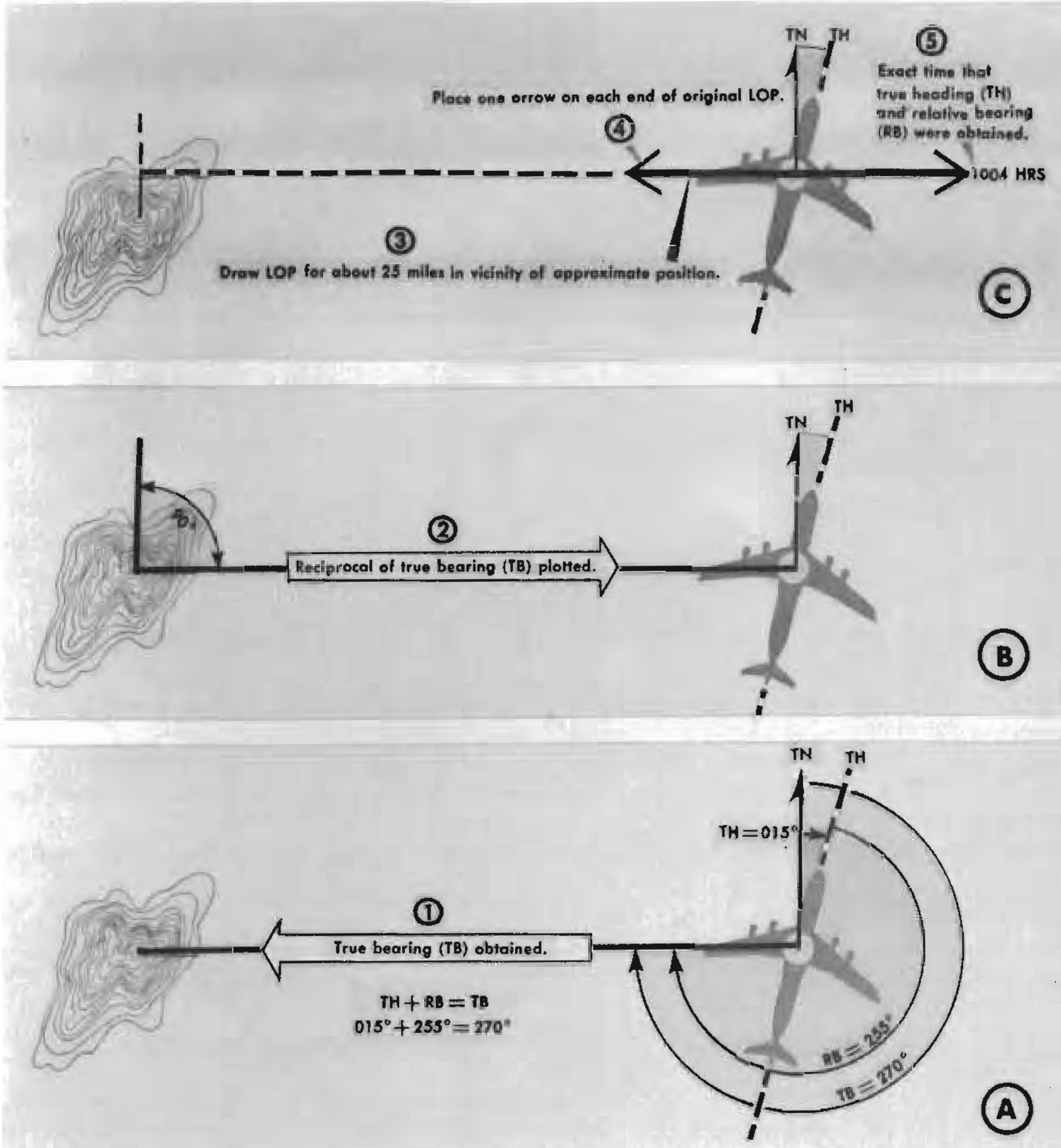


Figure 6-4. Procedures for Plotting LOP

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

- The position of the source 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 6-4 shows the procedure to follow.

Use 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 define either the track or the groundspeed—not both. It may not clearly define either. The evidence obtained from an LOP depends upon the angle at which it intersects track, and LOPs are sometimes classified according to this angle.

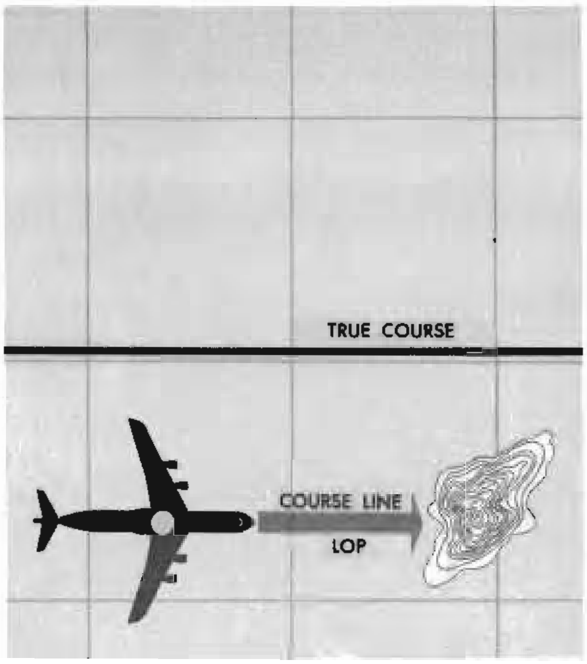


Figure 6-5. LOP Parallel to Track Is Course Line

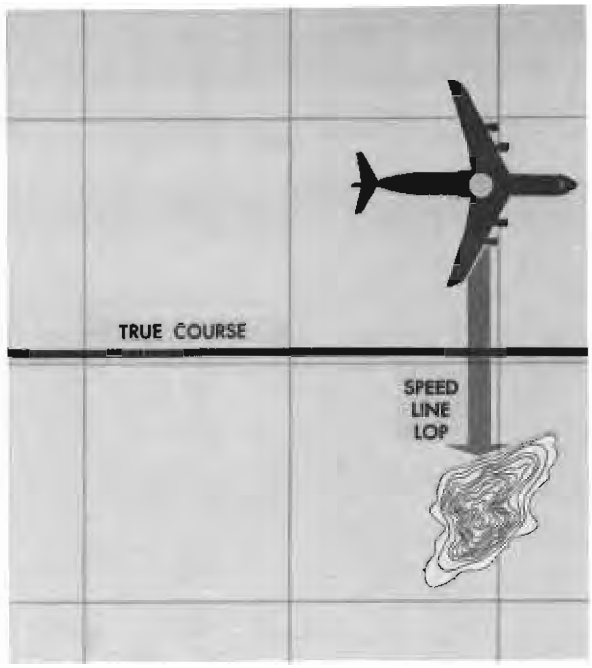


Figure 6-6. LOP Perpendicular to Track Is Speed Line

COURSE LINE. An LOP which is parallel or nearly parallel to the course is called a course line (figure 6-5). It gives information 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 6-6), since it indicates how far the aircraft has traveled along the track, and thus is a

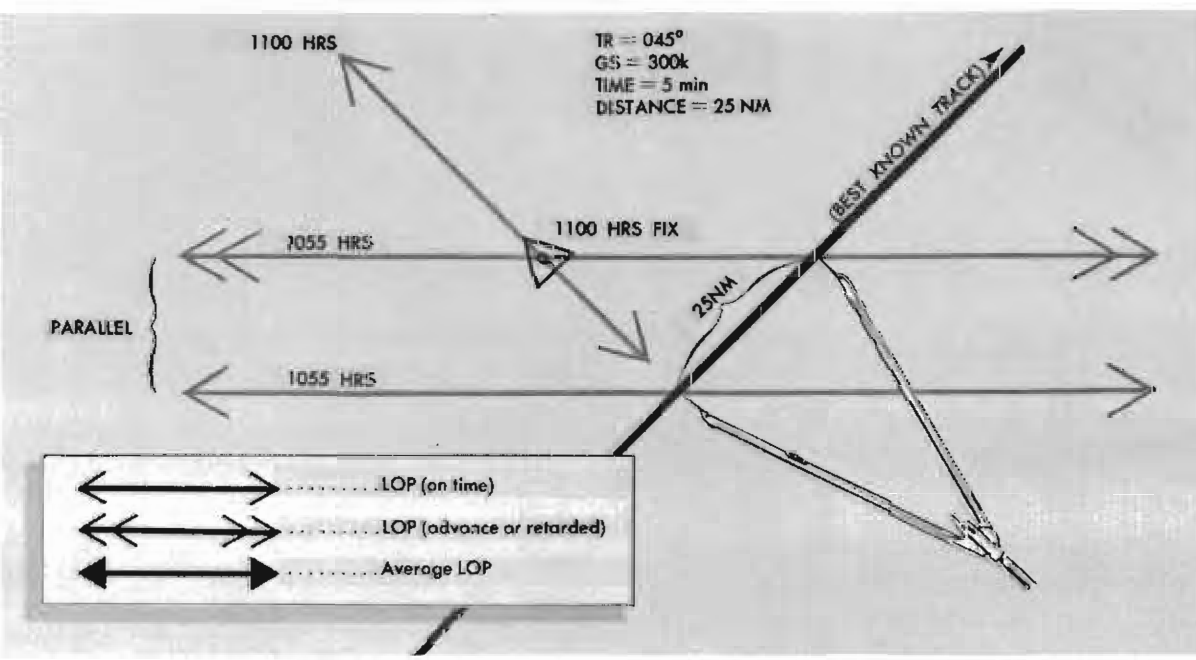


Figure 6-7. Adjusting LOPs for Fix

measure of groundspeed. It does not indicate whether the aircraft is to the right or left of the course. When a speed line intersects the track at an angle less than 90°, an accurate groundspeed is obtained only if distance is measured along the track.

FIXES

Adjusting LOPs for a Fix

Sometimes it is impossible for an air navigator without assistance to obtain more than one LOP at a given time. Unless a second LOP is obtained simultaneously, the intersection of the two lines does not constitute a fix because the aircraft is moving between the times of the two observations.

The illustration in figure 6-7 shows a bearing taken at 1055 and another at 1100. At 1055 when the first bearing is taken, the aircraft is somewhere along the 1055 line of position (single barbed LOP), and at 1100 it is 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 LOPs must either be observed at the same time or adjusted for 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 6-7 shows how this is done. The desired time of the fix is 1100.

1. Determine the time to advance the LOP (5 minutes) and multiply this time by the groundspeed of the aircraft (300 knots).
2. Take the distance computed in the first step and lay it off in the direction of the track of the aircraft (45°).
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.

For purposes of plotting, the advanced LOP is usually labeled 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, usually results in a triangle, and the triangle may be large enough to vary the position of the fix considerably. The procedure most universally adopted by Air Force navigators is to place the fix at the center of the triangle. The illustration in figure 6-8 shows the technique for finding the center of the triangle by bisecting the angles of the triangle. The point of intersection of the bisectors is the position of the fix.

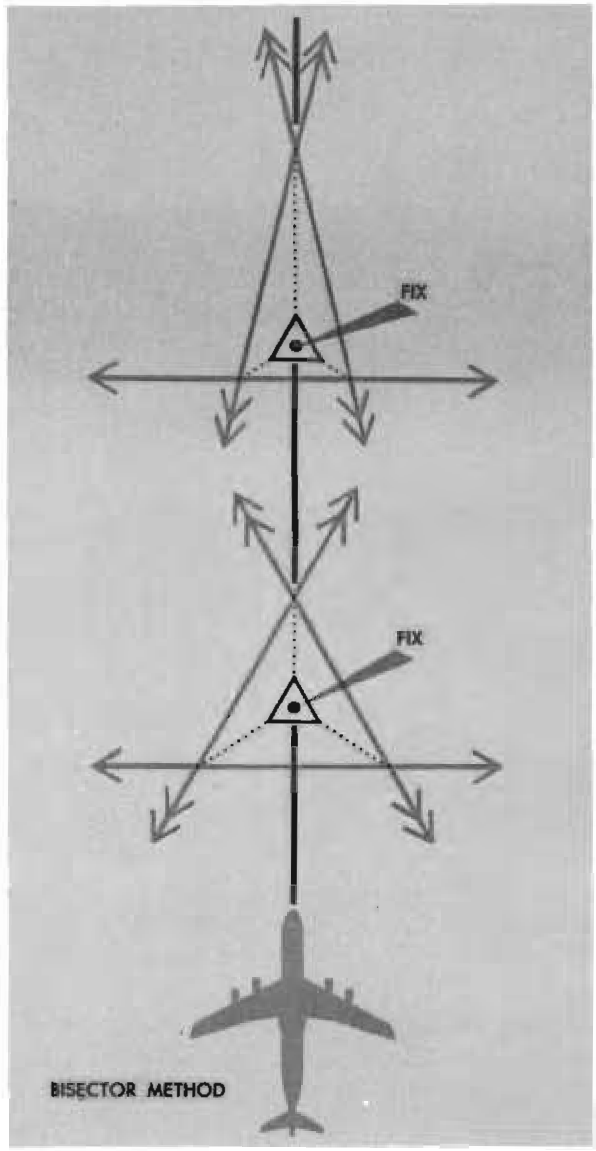


Figure 6-8. Use Center of Triangle for Fix

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

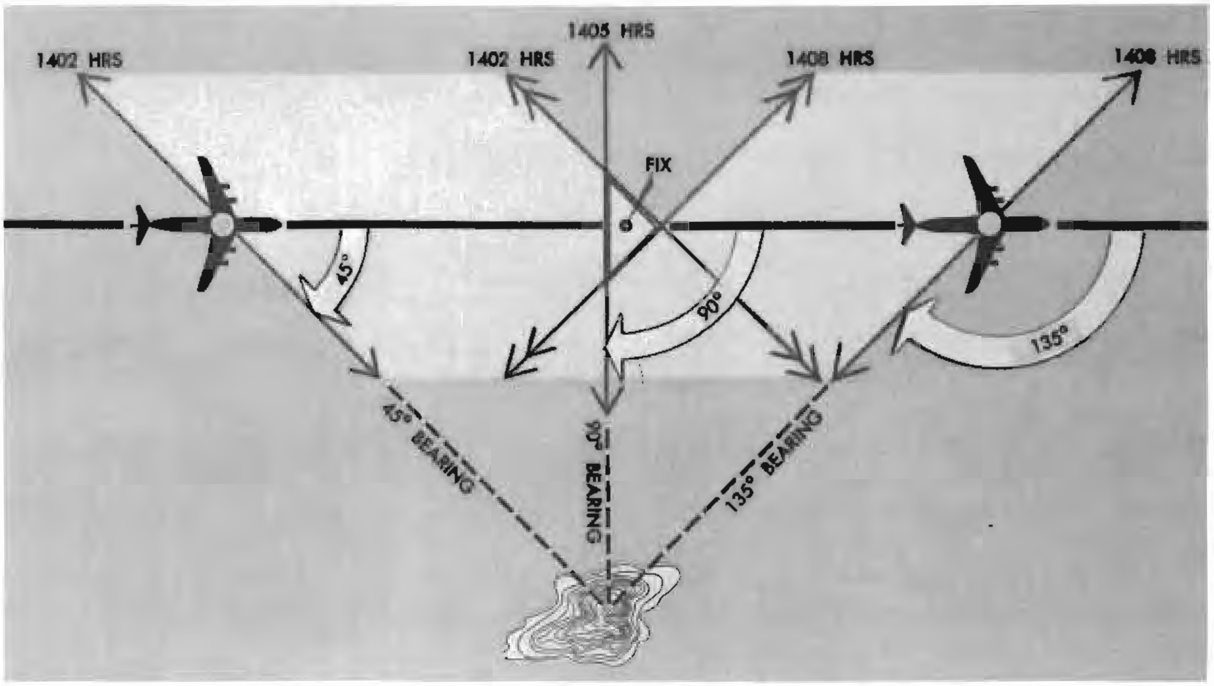


Figure 6-9. The Running Fix

135° from the aircraft. The lines are then advanced or retarded to the same time. The resulting fix is termed a *running fix,* though the position is actually not an absolutely reliable fix because the advance of the earlier line is dependent upon track and groundspeed which may not be known precisely. For short intervals, the error is small, and the accuracy is almost equivalent to a fix. The running fix is illustrated in figure 6-9.

Accuracy of a Fix

The accuracy of a fix can sometimes be improved by the use of a little foresight. If the direction of motion is known more accurately than the groundspeed, a course line should be adjusted since any error in the groundspeed will have little effect on the position of the adjusted line. If, however, it is desired 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 7

Map Reading

Map reading is the determination of aircraft position by matching terrain or manmade features with their corresponding symbols on a chart. It is one of the more basic aids to DR. The degree of success in map reading depends upon the navigator's proficiency in chart interpretation, his ability to estimate distance, and the availability of landmarks.

CHECK POINTS

Check points are landmarks used to fix the position of the aircraft or to check on its position and direction of travel. Basically, a check point 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 check points at anticipated times is a confirmation of the accuracy of the wind prediction and indicates reliability of the predicted track and groundspeed. If cheek points are crossed but not at the predicted time, the groundspeed is in error. If the aircraft passes near but not over a check point, the track anticipated was not made good.

The prudent navigator is quick to observe and evaluate the differences between predictions and actualities in flight. He does not ignore even small variations from anticipated performance, for these are the factors that influence his future judgment. Small errors can become cumulative and may eventually result in the aircraft becoming lost.

If the navigator is doubtful of his position, he must look for related details before the check point can be positively identified. Generally it is better to seleet a feature of 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.

Check points 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 7-1, 7-2, 7-3, and 7-4 compare various chart and corresponding photo areas and list the features to look for when identifying landmarks as check points.

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 ehart 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.

When there is any uncertainty of position, every possible detail should be checked before identifying a check point. The relative positions of roads, railroads, airfields, and bridges make good check points. Intersections and bends in 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 check point within the large landmark to fix the position of the aireraft.

When a landmark is not available as a reference

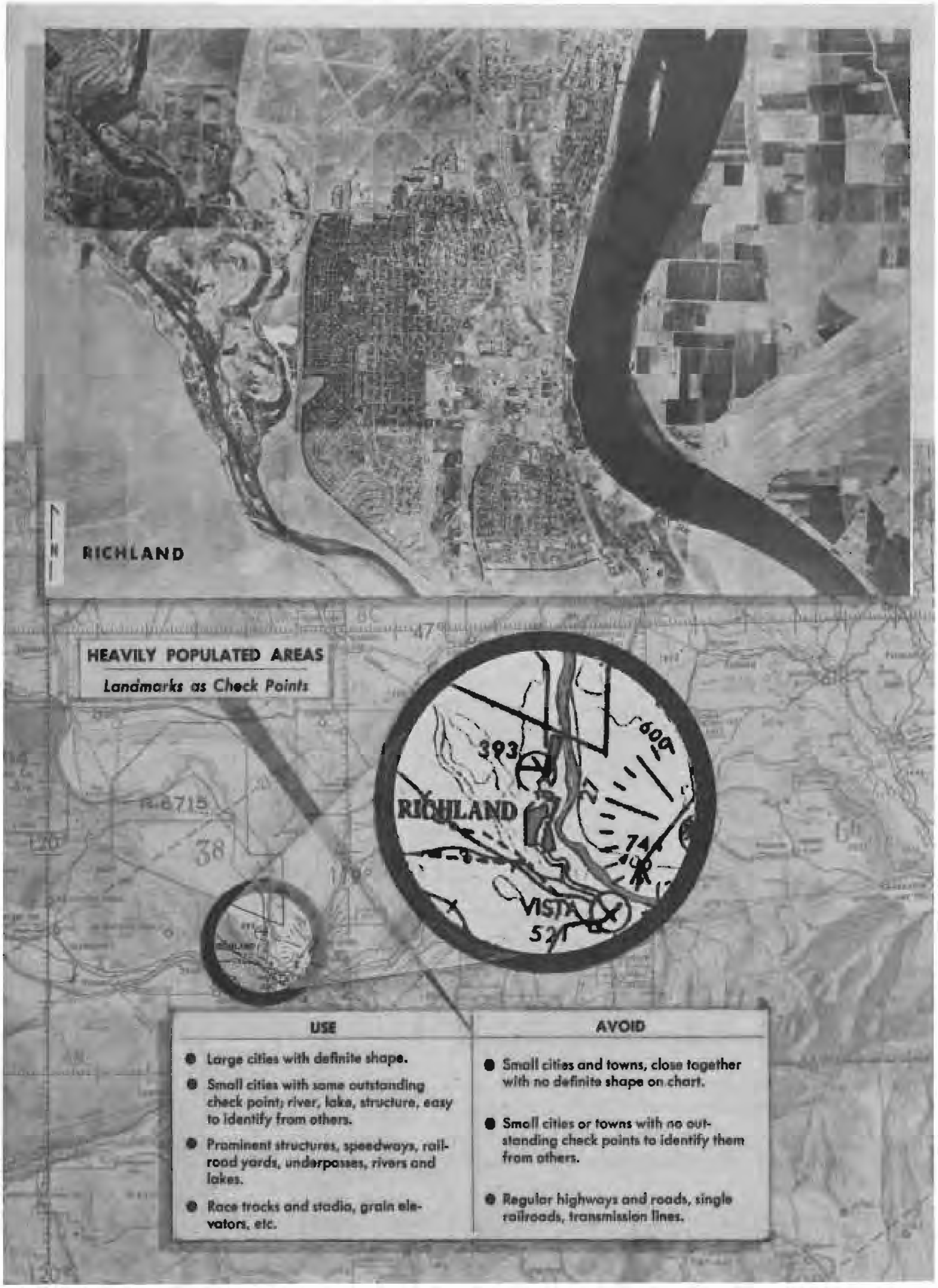


Figure 7-1. Landmarks as Check Points, Heavily Populated Areas

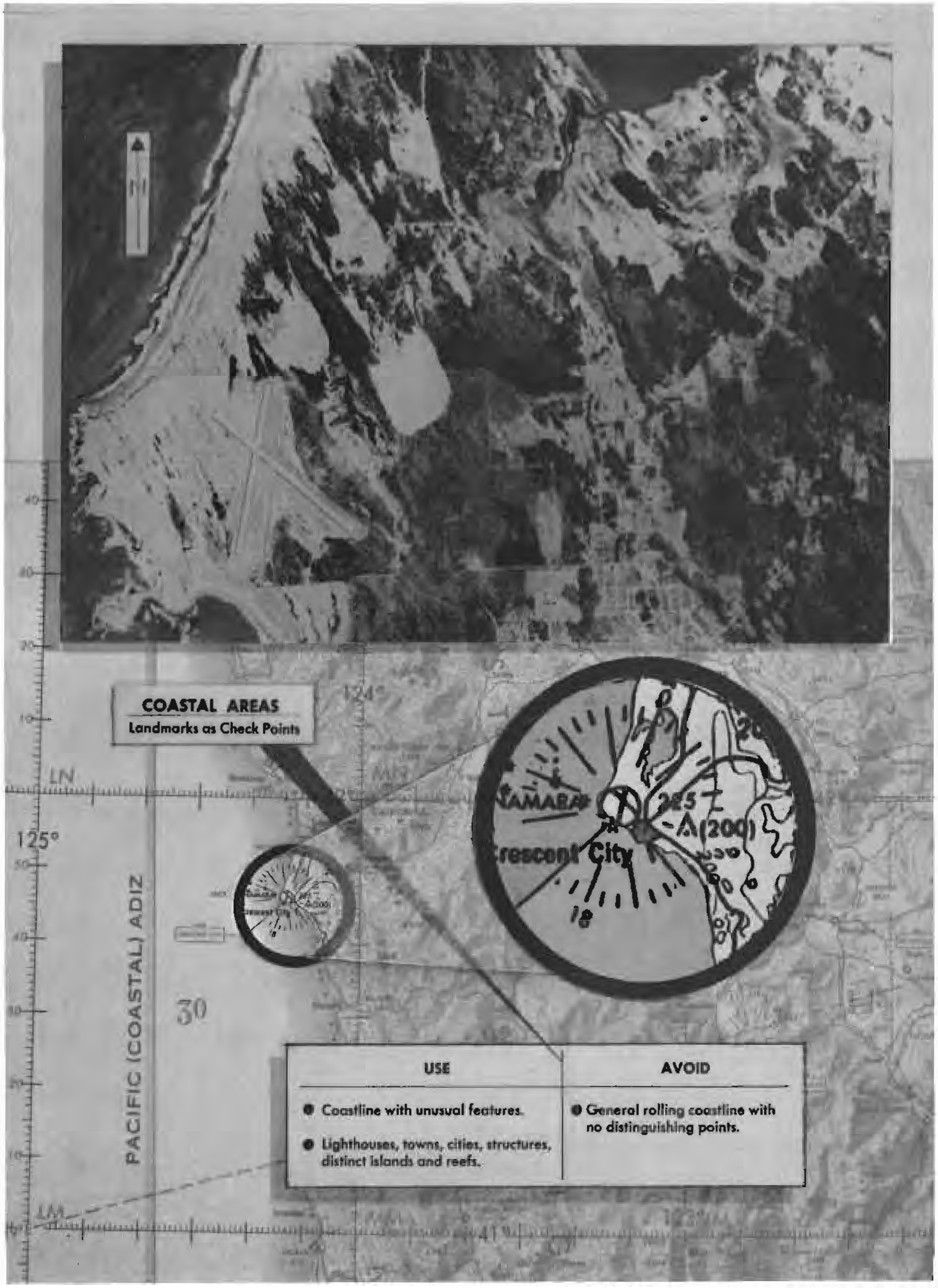


Figure 7-2. Landmarks as Check Points, Coastal Areas

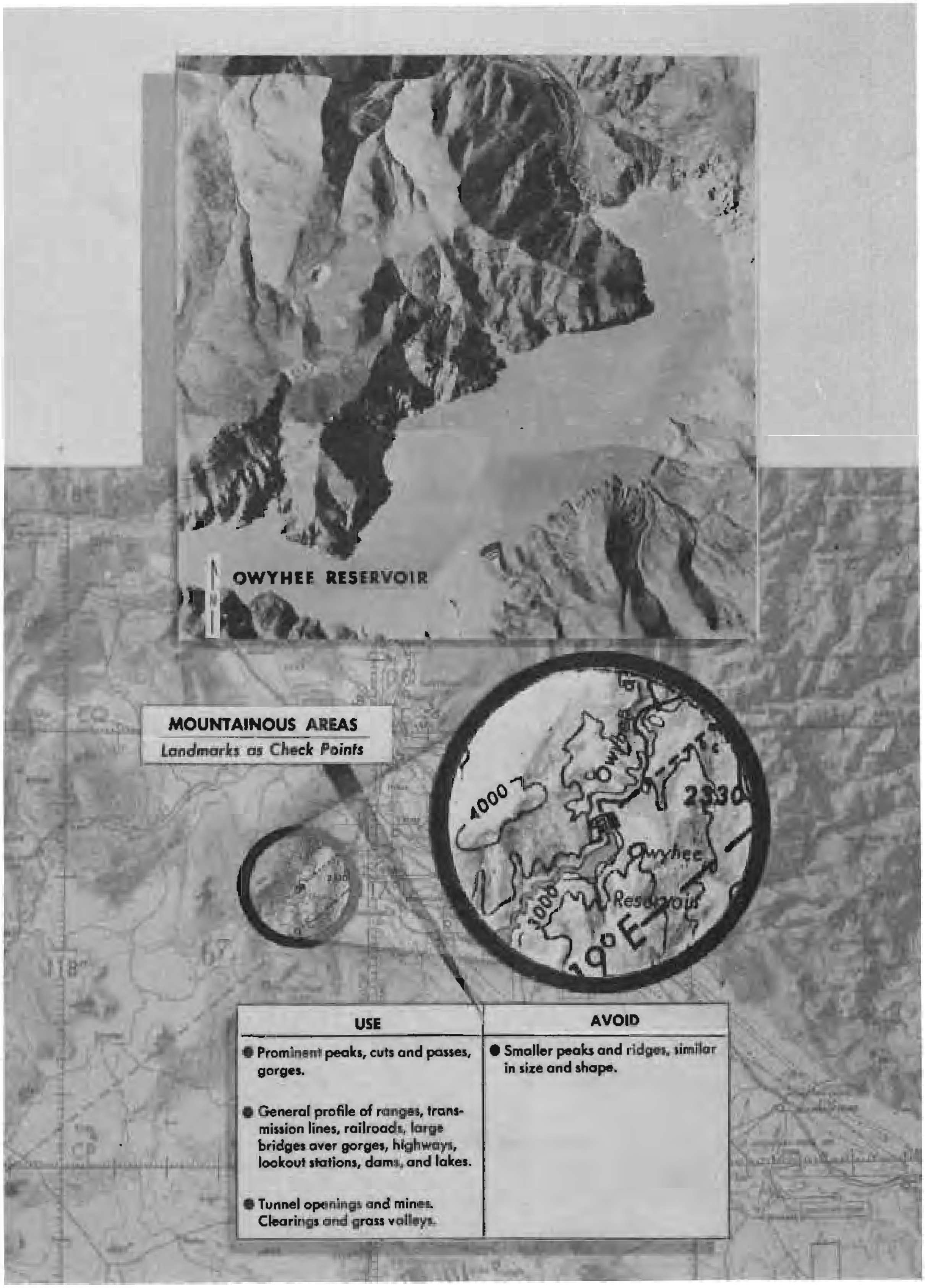


Figure 7-3. Landmarks as Check Points, Mountainous Areas

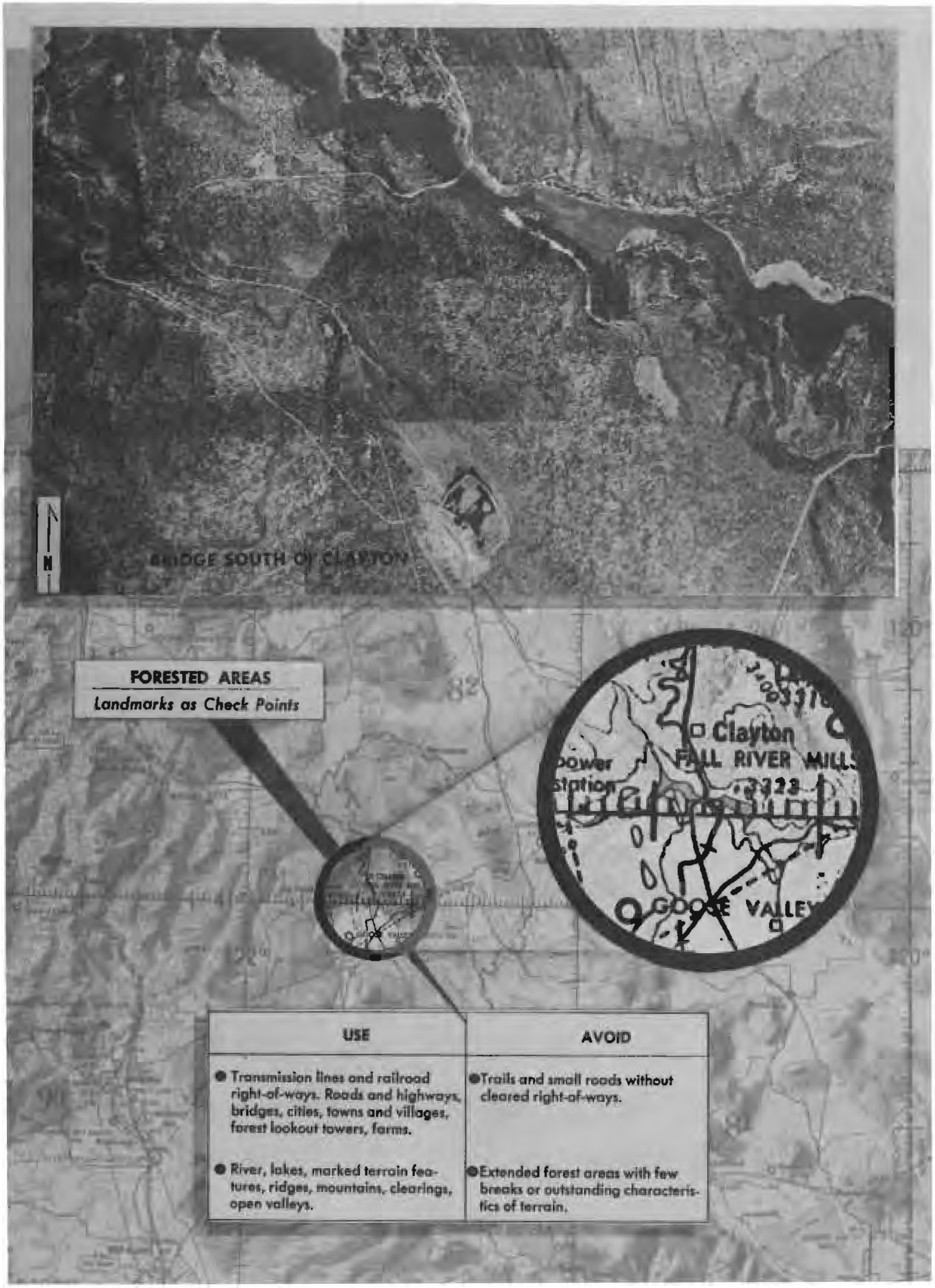


Figure 7-4. Landmarks as Check Points, Forested Areas

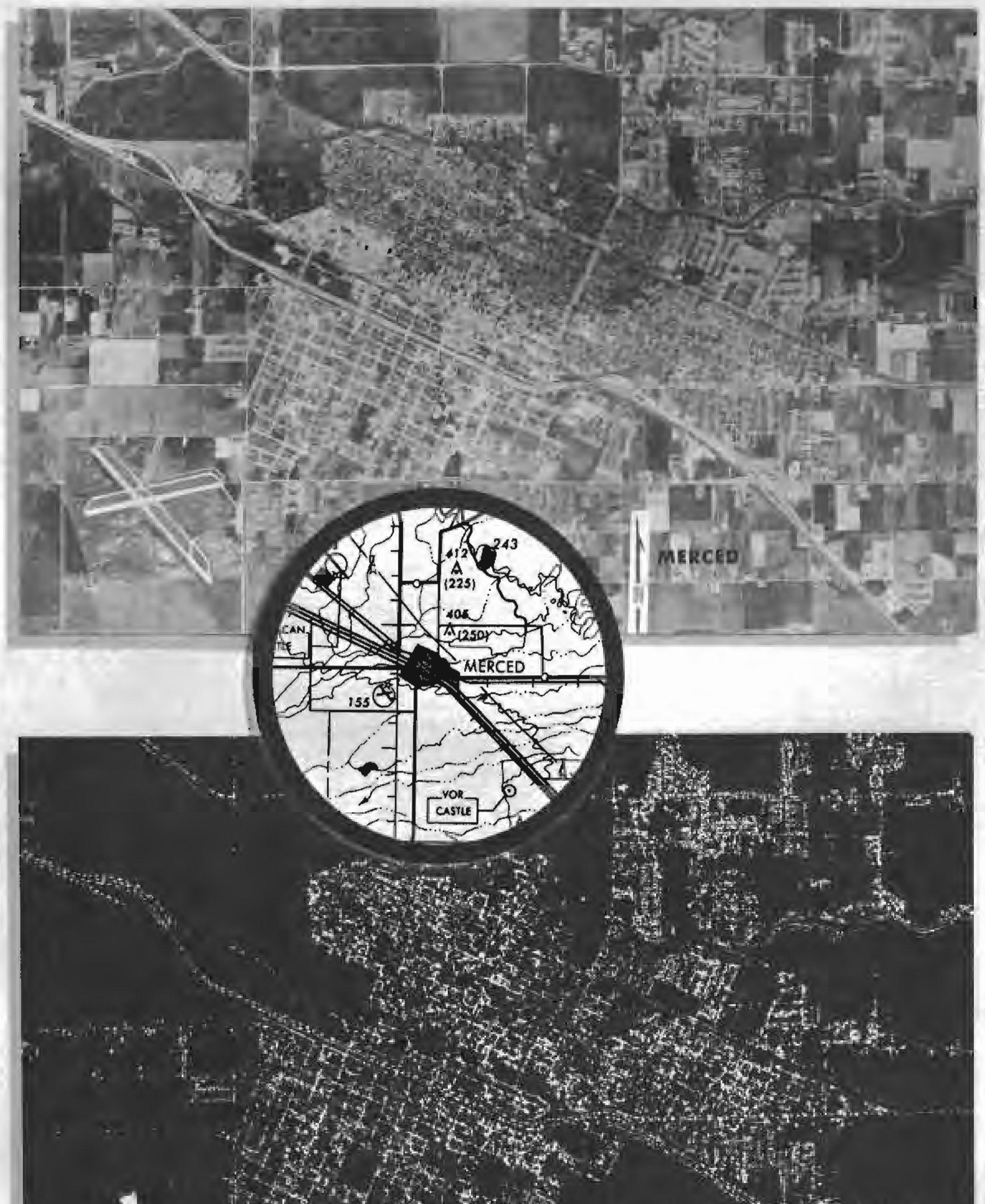


Figure 7-5. Landmarks at Night

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.

Low Level Map Reading

On low level flights the navigator may encounter additional difficulties. Accurate drift observations are hampered by the speed with which the ground seems to rush by. Air turbulence increases the difficulty of instrument observations. The circle of visibility is reduced, and those objects that are visible disappear so rapidly that only the boldest outlines and most conspicuous patterns can be recognized.

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 check points. It is sometimes desirable to draw drift lines 5° on each side of the course line to assist the navigator in estimating drift and making necessary corrections.

A prominent landmark such as a high mountain peak or a tower may provide convenient heading references if ahead of the aircraft. Sometimes a coastline, river, highway, or railroad can be followed.

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

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. The navigator should preserve his 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 7-5 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 check points. 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 usually 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 7-6, 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. They make good check points, however, because they appear as clear areas.

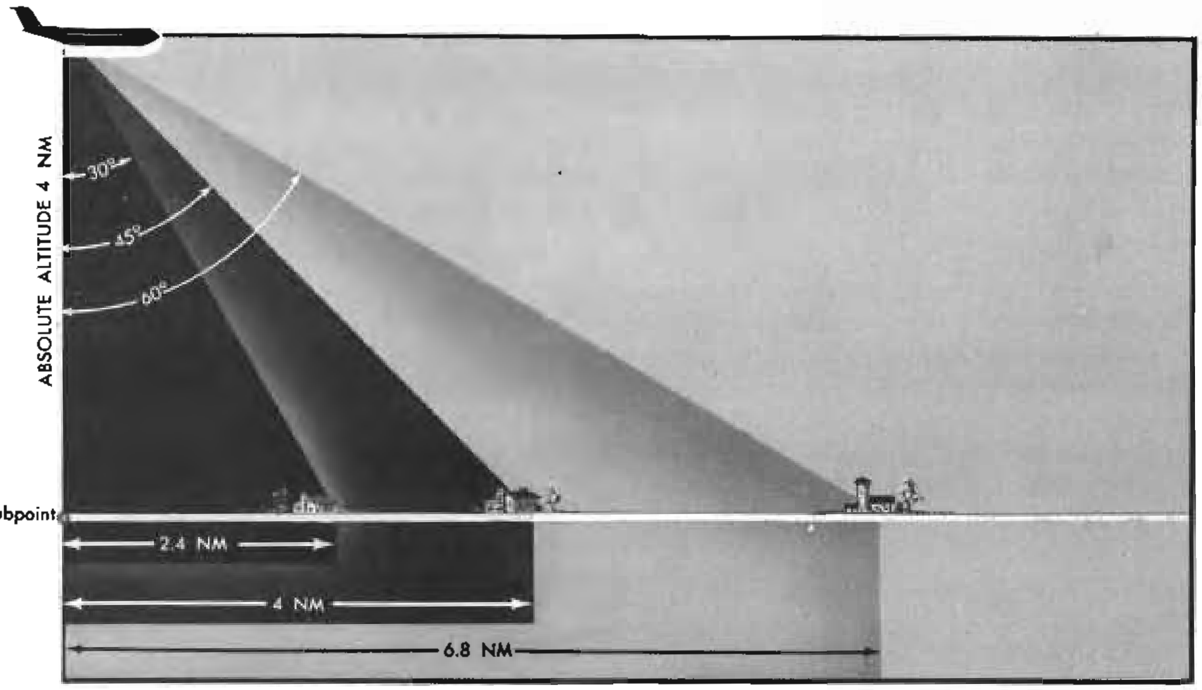


Figure 7-6. Estimating Distances

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, and seasonal changes may alter the terrain appearance or hide it completely from view.

In high latitudes, the navigator finds few distinguishable features from which to determine his position. Manmade 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 exist in limited variety are difficult to distinguish from each other. As illustrated by figure 7-7, 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 check points are few and far between.

Map reading in high latitudes is further complicated by inadequate charting. Some polar areas, as shown in figure 7-7, 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.

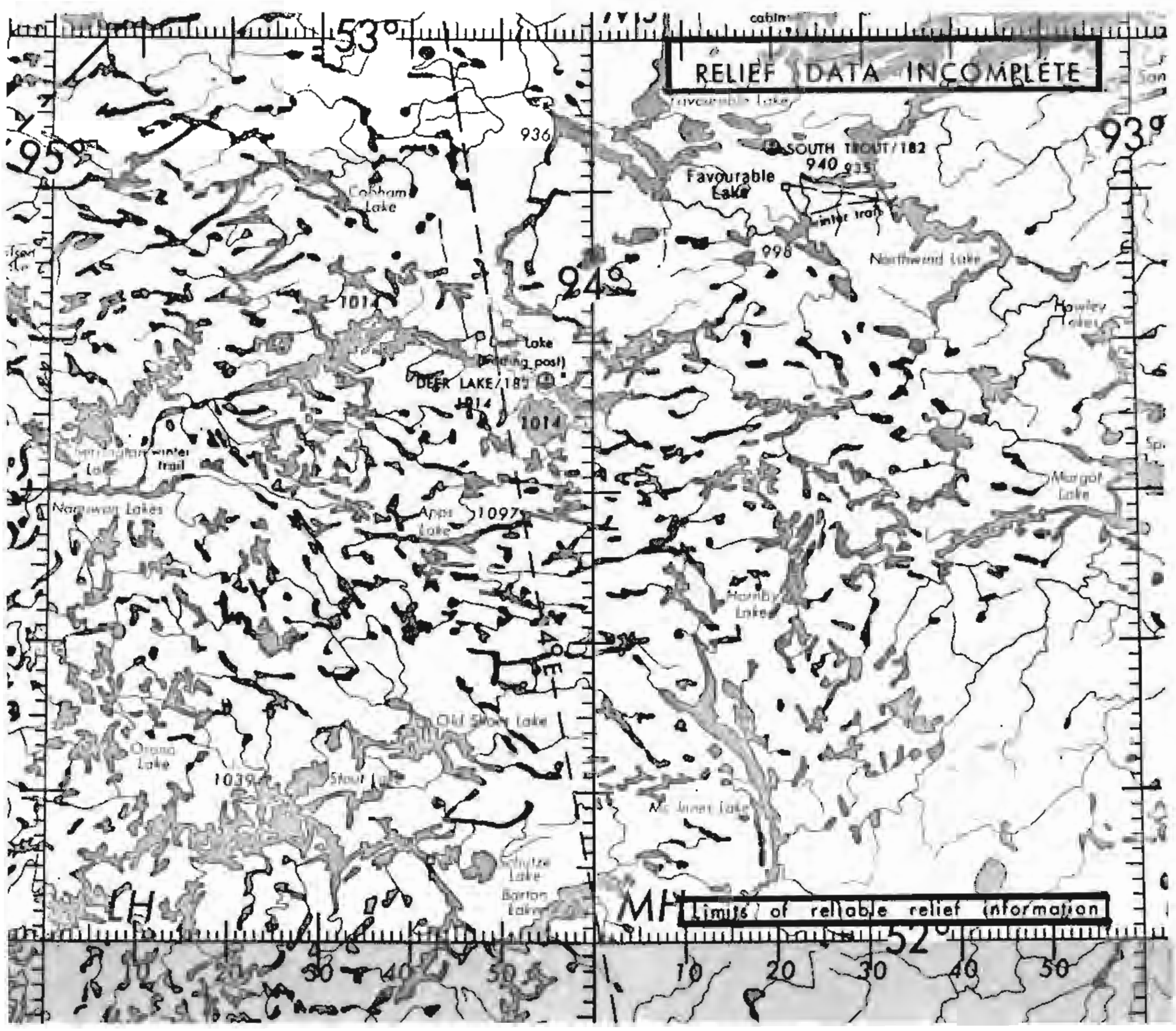


Figure 7-7. Natural and Cultural Features in High Latitudes

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 ten feet, the new shore line would be the ten-foot contour line. Similarly, the 20, 30, 40, etc., foot contour lines could be 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.

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 one 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 being used to show lower areas with a gradual increase in density/darkness 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 route 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.

CHAPTER 8

Practical Application of DR and Map Reading (Sample Navigation Mission)

Previous chapters have been devoted to various parts of basic navigation—maps and charts, plotting equipment, DR computer and the wind triangle. Standing alone, these parts have little practical value; when used in combination, they form the basis of all navigation, Dead Reckoning. This chapter is devoted to combining these parts of DR and also shows the use of map reading as an aid to DR. To illustrate the procedures, a cruise portion of a sample navigation mission is used. Only the cruise portions are covered since procedures related to mission planning, takeoff, and climb are explained in detail in later chapters.

FLIGHT PLANNING

For the sample mission, departure has been selected at coordinates 29-58N, 94-13W with destination at 31-36 1/2N, 84-06W. The mission is planned for a cruising altitude of 9,000 feet with a true airspeed of 220 knots. In planning the mission, the navigator first checks with the weather forecaster and finds he can expect stratus and cumulus clouds with bases at 4,000 feet and tops generally at 8,000 feet. Isolated thunderstorms are reported about halfway to destination, with conditions becoming scattered to clear during the last half of the mission.

Winds obtained are as follows:

Altitude in Feet	Departure W/V	Temperature in °C	Destination W/V
8,000	150/35	+11	230/30
10,000	150/35	+ 6	210/30
12,000	130/45	+ 2	210/35

The navigator is using an ONC chart for this mission since the primary aid to DR is Map reading. Departure and destination are plotted and the true course drawn between them. The navigator measures the true course and finds it to be 079°. Since this is a single leg mission only one true course is required. On a mission with several legs, each turning point and each course line would be constructed. In flight planning, the length of a leg or the operational conditions also dictate whether the navigator uses an average wind between departure and destination, or uses predicted metro winds for segments of each leg. The same holds true for variation when flight planning. On a long navigation leg, use of average variation causes the aircraft to swing off course, although it does have the advantage of not requiring frequent heading changes.

This mission is relatively short, lending itself to use of average winds and variation. However, the navigator wishes to stay as close as possible to true course, therefore he plans his initial heading using metro winds and variation at departure. He further determines flight plan distance to be 530 nautical miles and desired indicated airspeed for flight altitude to be 190 knots.

INFLIGHT PROCEDURES

Takeoff is accomplished at 0956 hours. Using a standard departure from the field, an on-course climb to flight level is begun. The navigator records T.O. time in the ACTUAL portion of AF Form 21, Navigator's Log, and ETA in the PROPOSED section as shown in figure 8-1, line

ACTUAL

	TIME	POSITION	TC	W/V DC	TH	VAR	MH	DEV	CH	TEMP / ALT	IAS / CORR	TAS	AIR DIST	TIME	GND DIST	GS
A	0956	←				TAKE OFF										→
B	1013	△	←			CLIMB										→
C	1020	C K S.			088½	-7½	081	-1	080	+5 / 9M	190 / 0	221				
D	1030	D/D		168/30 +8	088	-7	081	-1	080	+5 / 9M	190 / 0	221		(-1)		
E	1045	⊙	080	168/30 +8	088	-7	081	-1	080	+5 / 9M	190 / 0	221		:31	112½	218
F	1055	GSXT		+5					080	+5 / 9M	189 / 0					216
G	1105	GSXT		+3						+5 / 9M	187 / 0					214
H	1115	⊙	083	164/16 +4	087	-6	081	-1	080	+5 / 9M	188 / 0	218		:30	108	215
I	1123	△							080	+5 / 9M	189 / 0					
J	1130	+			086	-5	081	-1	080	+5 / 9M	189 / 0	220	26	:07		
K	1138	+			040	-5	035	0	035	+5 / 9M	190 / 0	221	29	:08		
L	1142	+			014	-4	010	0	010	+5 / 9M	190 / 0	221	15	:04		
M	1147½	△+		233/28	065	-5	060	0	060	+5 / 9M	190 / 0	221	20	:05½		
N	1155	⊙ A/H	063	233/28 +1	064	-4	060	0	060	+5 / 9M	190 / 0	221		:07½	31	249
O	1157	△							102	+6 / 8.5M	188 / 0					
P	1208½	△							102	+6 / 8.5M	188 / 0			:11½	44	229
Q	1224	△	102	228/14 +3	105	-3	102	0	102	+6 / 8.5M	188 / 0	217		:27	101	225
R	1229	⊙ A/H	101	228/14 +3	104	-2	102	0	102	+6 / 8.5M	188 / 0	217		:05	19	225
S	1246	△	226	228/14 0	226	-3	223	0	223	+8 / 8.5M	188 / 0	215		:17	57	201

PROPOSED

	TC	W/V DC	TH	VAR	MH	GS	NEXT CK PT / CK PT OR DEST	DIST	TIME	ETA	REMARKS
A	079	167/23 +8	087	-8	079	162	L.O. / TURNER AFB	49 / 530	18 / 2:37	1014 / 1233	
B	078	150/35 +9	087	-7	080	207	TURNER AFB	482	2:19	1232	L.O. = 1010 CH = 080
C											CAS = 190
D											LL +6 RL +5
E						218	TURNER AFB	369	1:42	1227	
F											216/.706 = 7900/25.7
G											214/.706 = 7800/25.6
H						215	TURNER AFB	264	1:14	1229	
I											
J											CH 035
K											CH 010
L											CH 060
M											
N	098	233/28 +5	103	-3	100	240	TURNER AFB	134	:33½	1228½	CH 102
O											
P							EDISON	58	:15	1223½	
Q						225	TURNER AFB	31	:08	1232	
R	226	228/14 0	226	-3	223	201	GRAHAM AFB	57	:17	1246	CH 223
S											OVER GRAHAM AFB

Signature and Rank

AF FORM MAY 63 21 PREVIOUS EDITIONS OF THIS FORM WILL BE USED UNTIL STOCK IS EXHAUSTED

Figure 8-1. Sample Mission, Navigator's Log

A. At 1010 hours the aircraft reaches flight altitude and leveloff is accomplished. At this time the navigator reads the compass at 080°, leveloff time and compass heading are then recorded in the PROPOSED section of the navigator's log under REMARKS. Since the navigator wishes to establish his position as soon as possible after leveloff, he obtains and plots a map reading fix for 1013 hrs (figure 8-2). This fix is recorded in the ACTUAL section of the log for the time of 1013 (figure 8-1, line B). Since the fix shows the aircraft to be on course, the navigator then computes his distance to destination from the fix. Using preflight wind and groundspeed he finds the ETA to be 1232.

Instrument Entries

From this point on, the frequency of instrument readings or averages of readings is dependent upon navigation methods, mission conditions, unit procedures, or personal preference. If instrument readings remain fairly constant then fewer entries are needed.

Deviation Check

The principle of and reasons for compass deviation are explained in Chapter 4, and the methods of obtaining this deviation are fully explained in Chapter 15. For purposes of this mission it will suffice to say that the navigator obtains a true heading (TH) with a periscopic sextant, applies spot variation to obtain magnetic heading (MH), and then compares the MH to the compass heading (CH), which is taken at the same time as the true heading (TH). On this mission the navigator takes a deviation check at 1020 and determines compass deviation to be —1°. At the same time he computes pertinent airspeed information and records all readings as shown in figure 8-1, line C.

There is no set rule to guide the navigator in taking deviation checks, however, a general rule to follow is to obtain an initial deviation check, and an additional one each time the compass heading changes by more than 15°.

DR Positions

Positioning of the aircraft enroute is a continuous process. Frequency of positioning information depends primarily on flight conditions and types of fixing aids available to the navigator. The following general rules of frequency may be applied:

- Every half hour, if there is no significant change in flight conditions.
- Whenever heading is altered, either at a predetermined point or for some other reason.

Significant changes in flight conditions may be defined as a wind shift that would alter drift more

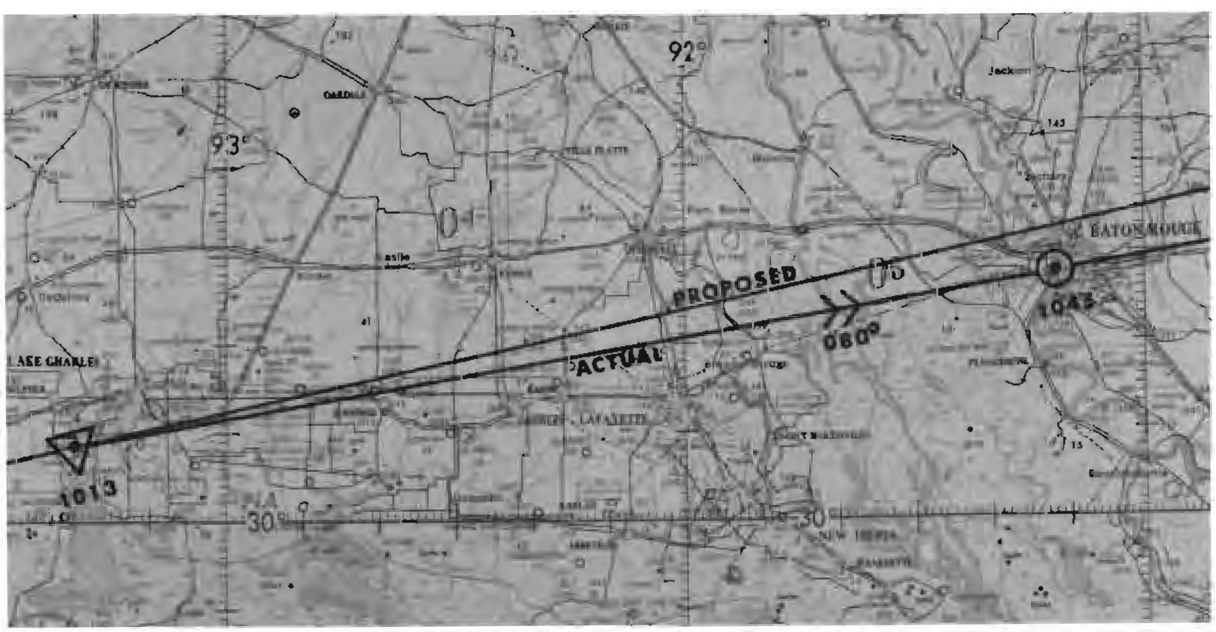


Figure 8-2. Level-Off Fix Is Plotted at 1013

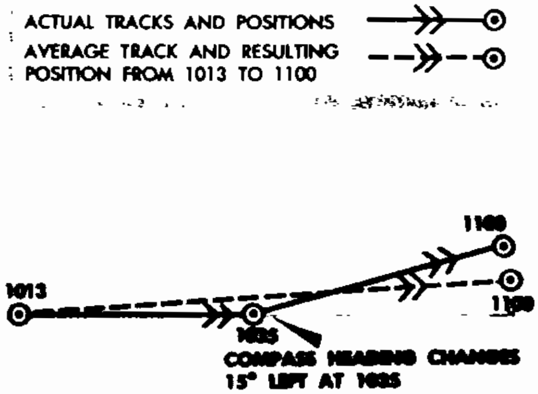


Figure 8-3. Inaccuracy Caused by Use of Average Heading

than 3°, a change in airspeed of more than 10 knots, or a change in CH of more than 8°. To allow too much of a change in flight conditions without obtaining a position causes navigation inaccuracies if the navigator attempts to average out the changes at a later time. Figure 8-3 illustrates an exaggerated form of the inaccuracy caused by use of average heading.

Determination of Wind and Groundspeed

Double drifts or groundspeeds by timing with a driftmeter are primarily applicable to training situations; however, they are a basic procedure for determining wind and groundspeed and thus should be familiar techniques to the navigator.

On the sample mission the navigator directs the pilot to fly a double drift (D/D) at 1030 hours. He has previously determined on-course drift to be +8°, and now reads drift on the left leg as +6° and drift on the right as +5°. He has now logged enough information to compute the wind (figure 8-1, line D). This includes true heading, true airspeed and drift on all legs. In addition, he has logged one minute of lost forward motion to compensate for time lost in the double drift.

At 1045 the navigator obtains a DR position (figure 8-1, line E). To obtain this position he applies the D/D wind to TH and TAS to determine average track and groundspeed (GS) from the 1013 fix. Although elapsed time is 32 minutes, forward motion is computed for only 31 minutes, since 1 minute is subtracted for the time lost in the D/D. The track and distance plotted in figure 8-2 are 080° and 112½ NM. From the DR position the navigator measures distance to destination and using the D/D wind and groundspeed computes a new ETA.

Groundspeed by Timing

The navigator obtains two groundspeeds by timing at 1055 and 1105. Together with drift and instrument readings this information is logged as illustrated in figure 8-1, lines F and G. Using the formula for groundspeed by timing the average of the two groundspeeds is determined to be 215 knots.

At 1115 he computes his second DR position (figure 8-1, line H). This position is based upon 30 minutes elapsed time (1045-1115), at a groundspeed of 215 knots. At this time he also computes a new ETA to destination. Plotting of the 1115 position is shown in figure 8-4.

At this time the navigator notes that isolated thunderstorms lie across the heading of the aircraft. Since his DR indicates that the aircraft is to the right of course, he notifies the pilot that heading alterations to circumnavigate the thunderstorms should be made to the left. Because it is probable that numerous heading alterations will be required to circumnavigate the weather, he also desires to secure a map reading fix from which to start airplot.

At 1123 the navigator locates his position as illustrated in figure 8-5. Fix information consisting of time, fix symbol, and instrument readings, is logged as shown in figure 8-1, line I.

Airplot

The problem of the navigator would be very simple if he could plot the ground position of the aircraft with respect to its movement through the air mass (TH and TAS). But the movement through the air mass (wind) complicates the problem. Previously, the wind vector and the air vector (TH and TAS) have been combined on the DR computer to determine the ground vector (Track and GS) for a DR position.

Under certain conditions it is faster and easier to solve navigation problems by the use of airplot. Airplot is the graphic solution of the wind triangle on a chart or computer for the purpose of finding a DR position or a wind. It must be understood that airplot is not a different method of navigation,

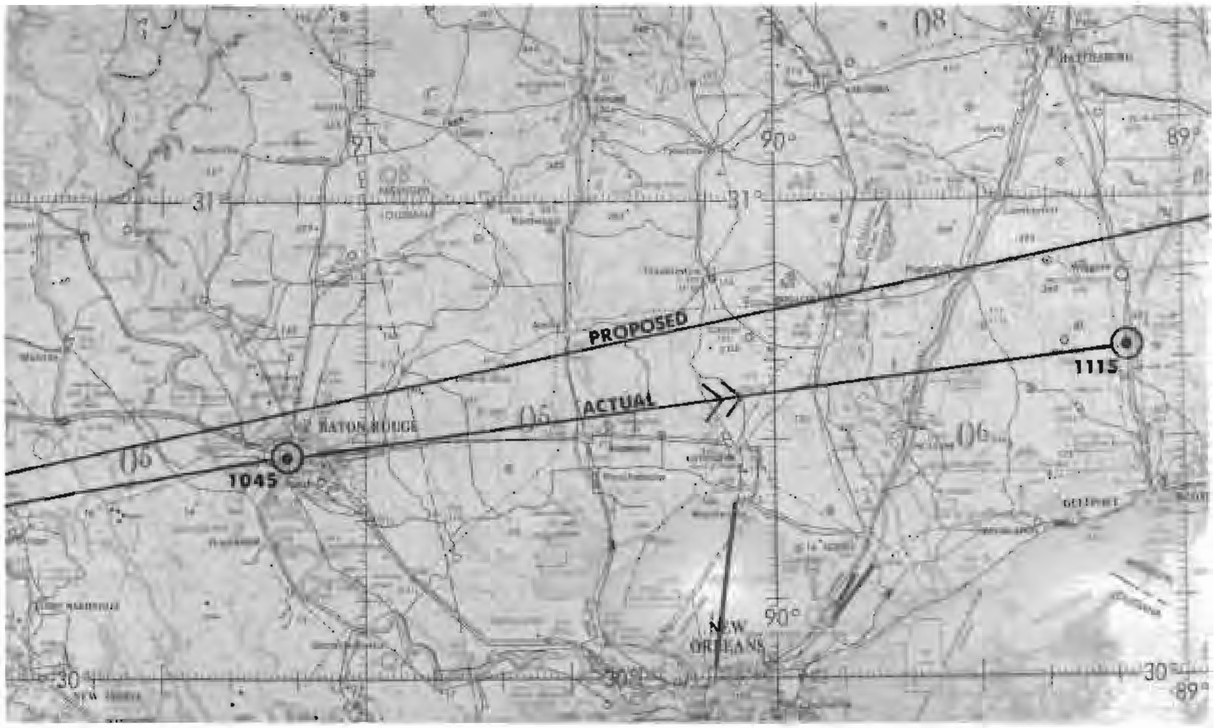


Figure 8-4. Plotting 1115 DR Position

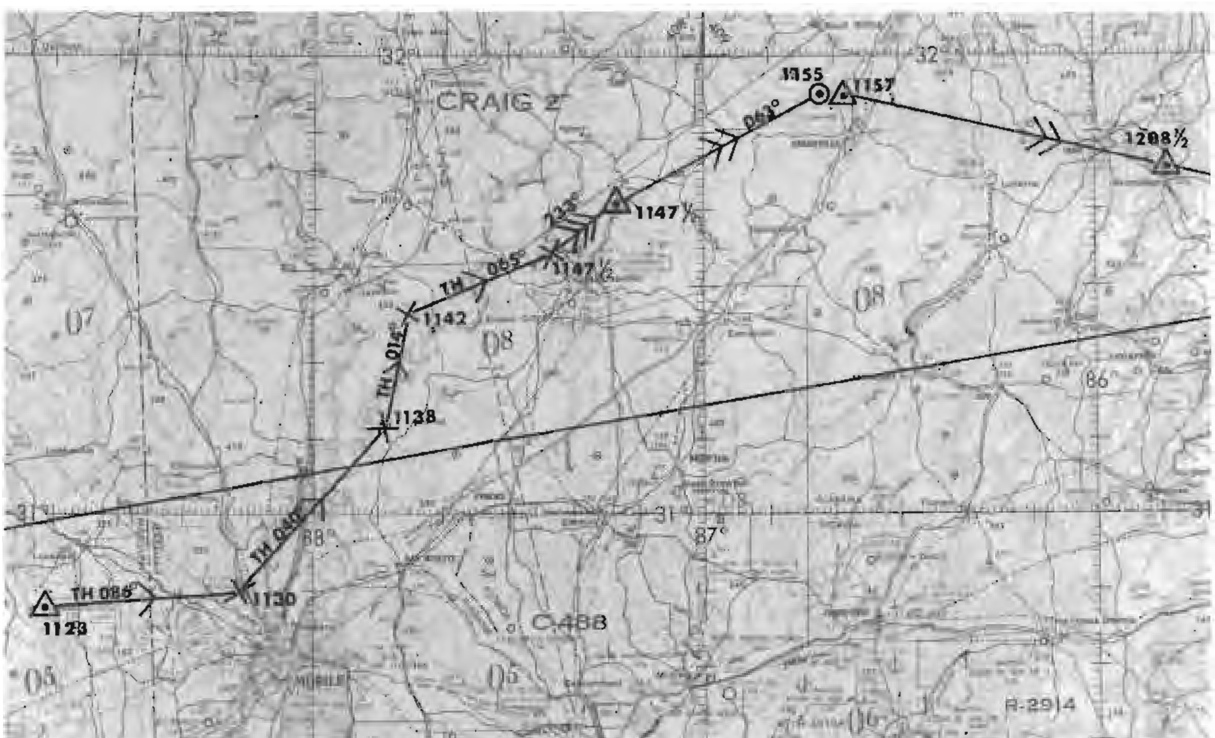


Figure 8-5. Airplot Is Started at 1123 Fix

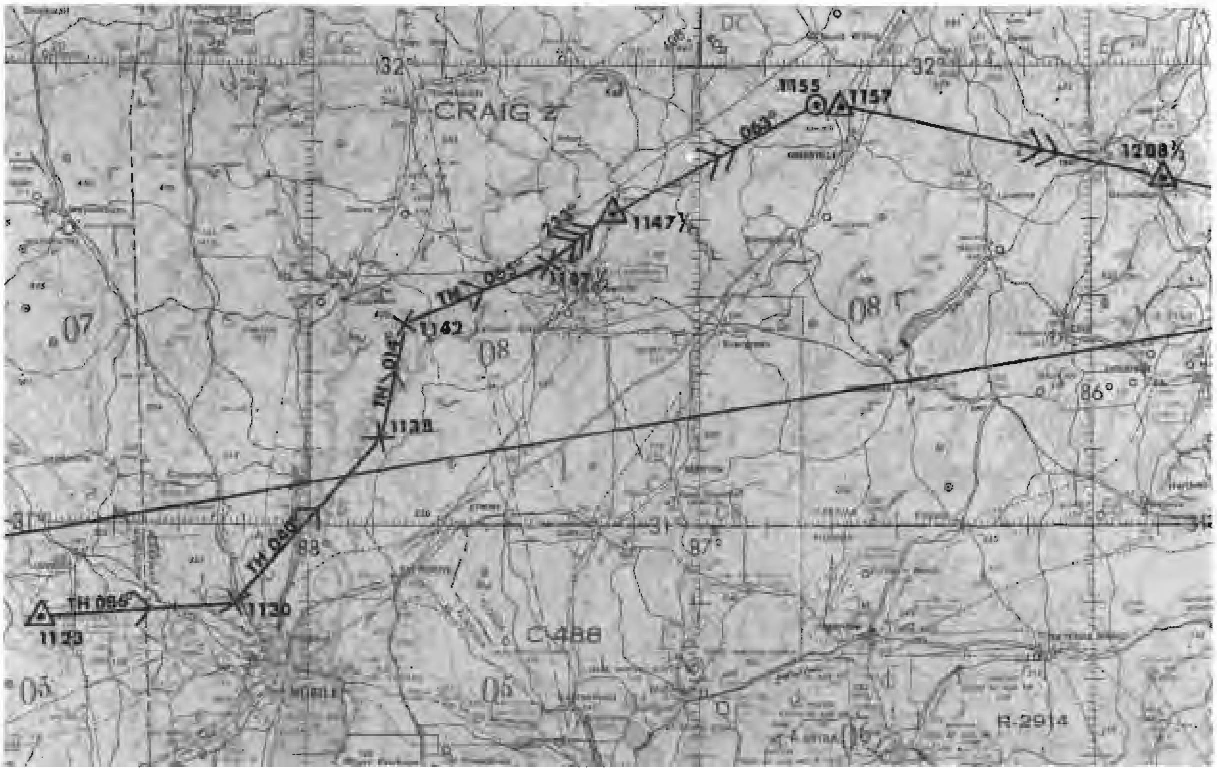


Figure 8-5 (Repeated)

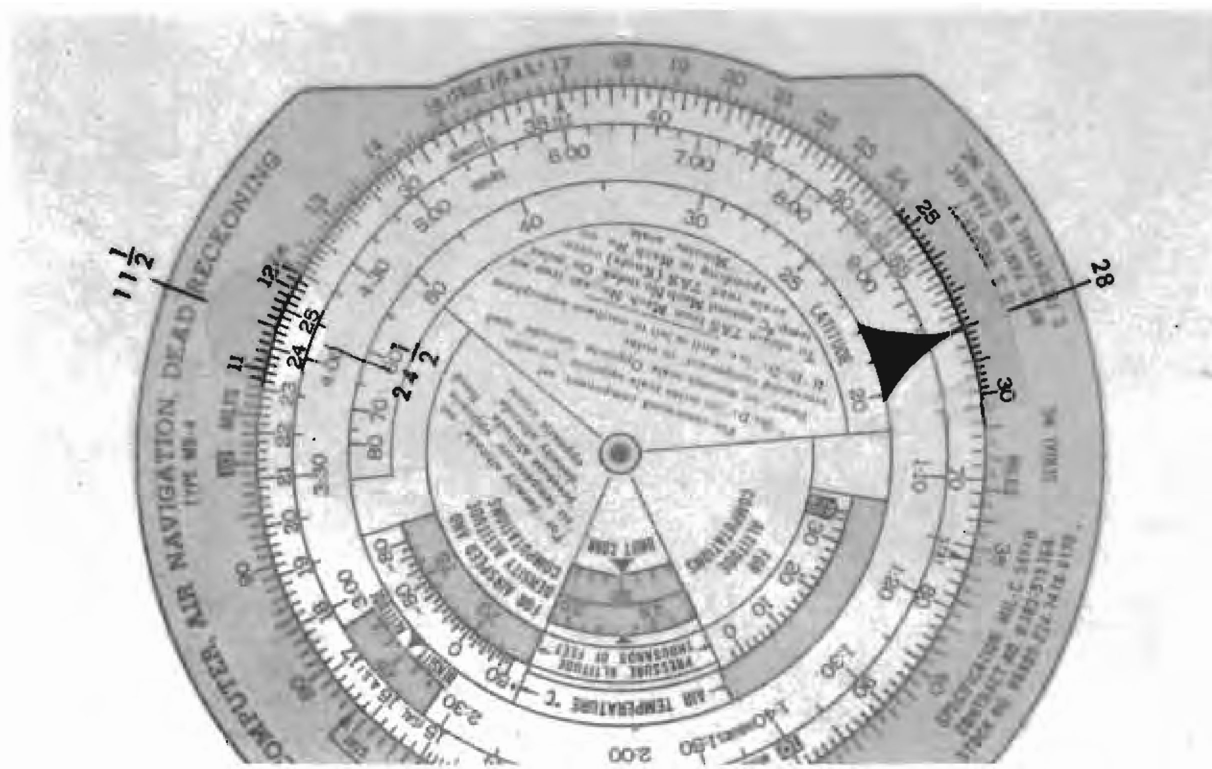


Figure 8-6. Wind Speed Is 28 Knots

but merely a difference in the application of the vectors of the wind triangle.

Airplot becomes useful when the heading of the aircraft changes radically and frequently. It then becomes much easier to follow the movement of the aircraft through the air mass using TH and TAS than computing a DR position each time the heading changes.

Obviously, airplot must be done quickly and accurately so it may be completed with an accurate DR position from which the heading to destination can be resumed. The basic reason that airplot is faster than groundplot is that wind effect is not considered until all heading changes have been completed. At that time the net wind effect for the period of airplot is applied to the final air position to determine a ground position.

AIRPLOT ON CHART. To be accurate, airplot must be started at a known position—in this case the 1123 fix as illustrated in figure 8-5. The navigator had previously decided he would begin airplot at his first fix after the 1115 DR position. The movement of the aircraft is represented on the chart by a series of vectors based on TH and TAS.

At 1130 the pilot alters heading to 035° to circumnavigate weather. Thus the first air vector is found using TH and TAS for seven minutes (1123-1130). The information is logged as illustrated in figure 8-1, line J. An examination of this line entry reveals that the navigator is recording only the minimum amount of information necessary to compute the air vector. Extensive logwork is time consuming and is one reason why airplot is faster than groundplot.

At 220 knots (TAS) the aircraft has travelled 25 air miles in seven minutes. The air vector is plotted on a TH of 086° as shown in figure 8-5.

At 1138 the aircraft changes compass heading to 010°. Again the navigator plots the air vector. He finds that he has travelled 29 air miles (1130-1138) on a true heading of 040°. Each time an air position is completed, the navigator uses a plus sign indicating the air position, and connects the two air positions with a line labeled with a single arrow for an air vector.

At 1142 the pilot alters the aircraft compass heading to 060°. The navigator plots the completed air vector of 15 air miles on a TH of 014° (1138-1142). Since the new heading will safely circumnavigate the weather, the navigator begins procedures to obtain a map reading fix from which he can compute a heading to destination.

ESTABLISHING POSITION. After a period of airplot two methods are commonly used to establish aircraft position. The first method is to use the last known wind and plot a proportionate amount of this wind using the amount of time spent in airplot. The wind vector is plotted from the last air position with the tail of the vector representing air positions; the head of the vector will then be the ground position for that time.

The second method is to simply use the last air position as a starting point. This method is usually satisfactory only if the time spent in airplot is short and the wind speed is light. In the case of high winds the air position can be considerably in error from the actual ground position.

At 1147½ the navigator obtains a map reading fix over a small railroad bridge, as shown in figure 8-5. An air position is plotted for the same time. The air vector will be 20 air miles on a TH of 065° (1142-1147½). The fix and air position are logged on the same line as shown in figure 8-1, line M. The vector between these two positions represents net wind effect for the time spent in airplot. When converted to an hourly increment, it provides wind speed and direction.

To obtain an airplot wind, the navigator measures the direction of the wind vector, remembering that the wind always blows from the air position to the ground position. The direction of the vector as measured on the chart is 233° (labeled with 3 arrows representing wind) as shown in figure 8-5. The length of the vector represents the wind effect on the aircraft from the time airplot was started till the time it is completed. The navigator finds this vector to be 11½ nautical miles long which represents the wind effect for 24½ minutes (1123-1147½). These two figures are then set on the slide rule side of the DR computer and the speed of the wind is read over the 60 minute index. The proportion for this particular problem provides an answer of 28 knots as shown in figure 8-6.

AIRPLOT ON WIND SIDE OF COMPUTER. Plotting air vectors on the grid of the computer and obtaining a resultant air vector is exactly the same as the method used in obtaining a vector average of winds.

When plotting air vectors on the grid of the

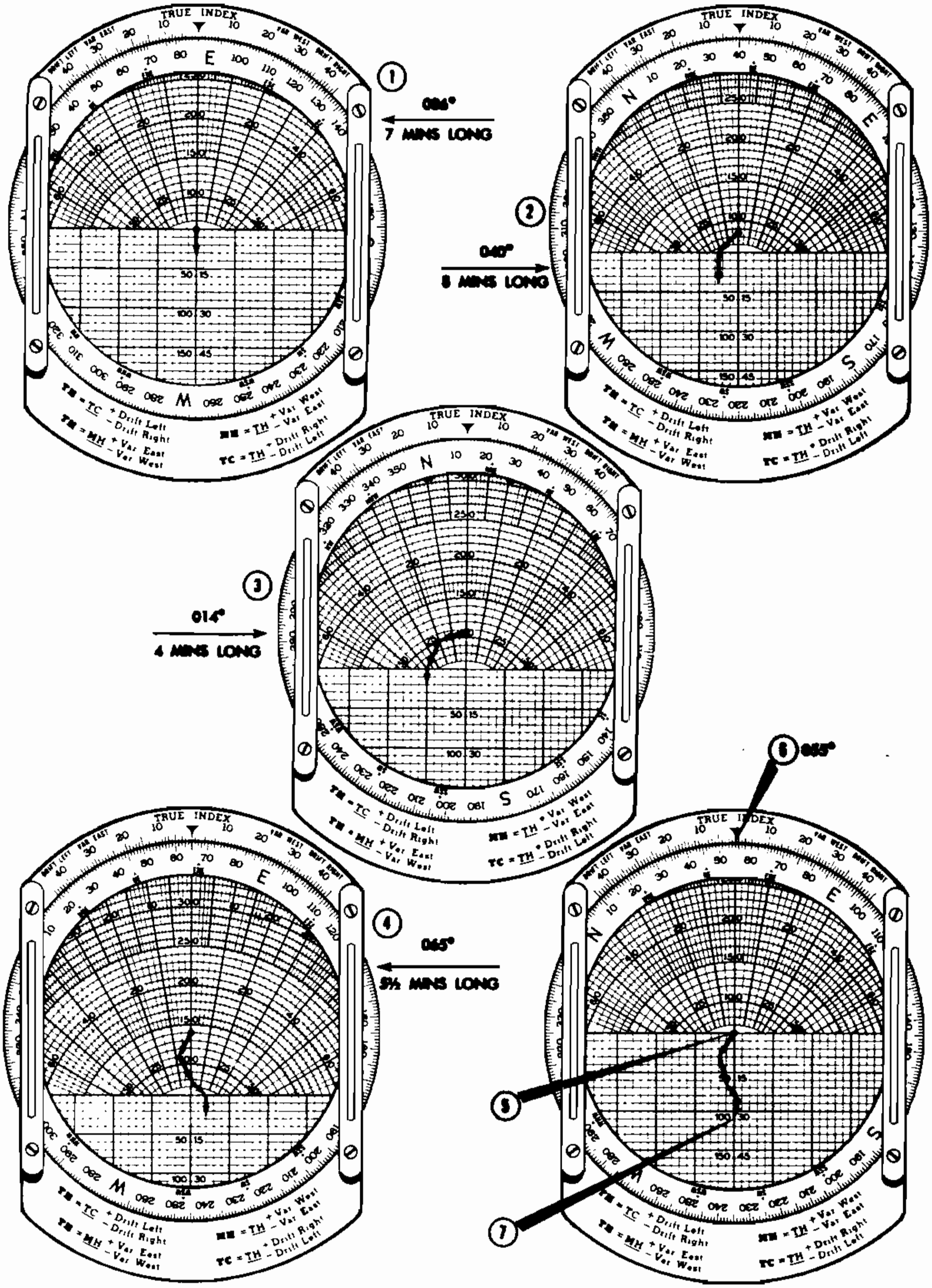


Figure 8-7. Airplot on Wind Side of Computer

computer, the navigator will find that he must usually halve the air miles to get them all on the computer. This increases the chänge for errors, therefore, an easier and quicker way has been devised. Instead of plotting air miles, the navigator plots minutes; in other words, time is plotted as the magnitude of the vector. Using this method shown in figure 8-7, the airplot problem for this mission would be solved as follows·

1. Using the grid side of the wind slide, set the first TH (086°) under the computer index. Draw down from the grommet a vector of seven representing minutes on the first heading (1123-1130). Each horizontal grid line represents 2 minutes.

2. Set the second TH (040°) under the index. Adjust the slide so that the head of the first vector is on the zero grid line. Draw down, from the head of the first vector, a second line representing 8 minutes on the second heading (1130-1138).

3. Set the third TH (014°) under the index. Adjust the slide so that the head of the second vector is on the zero grid line and draw the third vector for four minutes (1138-1142).

4. Set the fourth and last TH (065°) under the index, adjust the slide so the head of the third vector is on the zero grid line. Draw a vector down from the head of the third vector for five and one-half minutes which represents the time on the fourth heading (1142-1147½).

5. Set the slide so that the grommet is again on the zero grid line.

6. Turn the compass rose so the head of the fourth and last vector is on the center line directly below the grommet. The direction under the index (055°) is the resultant TH for the entire time of the problem.

7. Count the total minutes from the grommet to the head of the last vector. This time (22 minutes) is then set up on the slide rule side of the computer with average TAS during the entire period of airplot to obtain the air miles for the length of the resultant air vector. At an average TAS of 221 knots for the 22 minutes, the aircraft traveled 81 nautical miles. Remember, even though airplot was conducted for 24½ minutes, the resultant is for 22 minutes.

If extremely frequent heading changes and short periods of time are anticipated or encountered, the navigator would be wise to use the computer to follow the aircraft by airplot. It is faster and, if care is taken in plotting the vectors, the computer method is nearly as accurate as plotting the individual vectors on the chart. Theoretically either method will yield the same results, but the small scale of the computer grid prevents equal accuracy. For example, on the sample mission it is found that the resultant air vector of 055° and 81 air miles would give an air position approximately one-half mile away from the one determined by conventional plotting methods.

ALTER HEADING TO DESTINATION. The navigator decides he will alter to destination at 1155. With the information obtained from the 1147½ fix, he obtains a DR position for 1155. By assuming that the aircraft would stay on the same heading and airspeed until that time, the navigator can compute a track and groundspeed using the airplot wind obtained at 1147½. He computes a distance of 31 nautical miles for seven and one-half minutes on a predicted tract of 063° (1147½-1155). He logs this information as shown in figure 8-1, line N.

The computation of a new MH and an estimated time of arrival (ETA) to destination (Turner AFB) from the 1155 DR position is very similar to a preflight problem. The navigator measures the new true course and distance between the two positions and logs it in the proposed portion of the log as shown in figure 8-1, line N. Again assuming an indicated airspeed of 190 knots, altitude of 9000 feet, and temperature of +5°, he computes a TAS of 221 knots. With the latest wind (the airplot wind) he can compute a predicted drift correction (DC) and groundspeed, and work from TC to MH by applying the DC and variation to obtain an MH to fly. The ETA again is computed using the latest airplot wind.

Map Reading as an Aid to DR

At 1157, two minutes after the alter heading, the navigator obtains a fix over a bend in the road (figure 8-5). This information is logged as shown in figure 8-1, line O. At 1208½ another fix is obtained on a railroad 2 nautical miles north of Brundidge (see figure 8-8). The navigator computes a GS from the 1157 fix, and an ETA to a new check point at Edison for 1223½ (figure 8-1, line P).

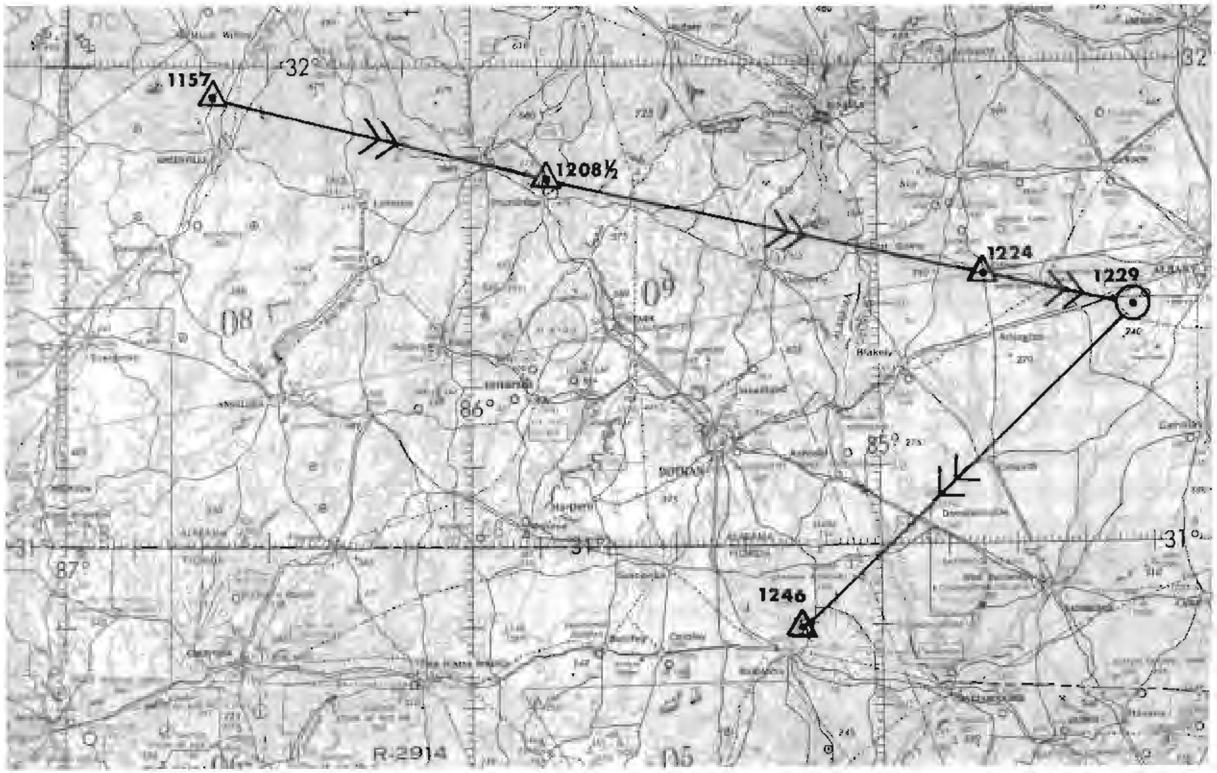


Figure 8-8. Alter Heading at 1229

At 1224 the aircraft is directly over Edison (figure 8-8). At this time the pilot informs the navigator that Air Traffic Control is diverting the aircraft to a new destination (Graham Air Field). The navigator decides to alter heading to the new destination at 1229. He computes a DR position for this time (figure 8-8). Working ahead, he logs information pertinent to this position as shown in figure 8-1, line R. All information necessary to alter heading to the new destination is computed and logged, to include course, heading, groundspeed, and ETA. At 1229 heading is altered to the new destination.

In this sample problem no log and chart entries have been made between 1229 and 1246. However, in actual practice the navigator would continue to record instrument readings and obtain fixes as necessary to direct the aircraft into destination.

SUMMARY

There are many procedures and many means of using dead reckoning and map reading techniques. However, throughout the Air Force, navigators use the same terminology and the same standard log and chart symbols. A log and chart should contain enough accurate entries to fully reconstruct a mission. Good discipline in keeping an adequate log and chart contributes to the overall efficiency of every navigator and aids in successful mission completion.

CHAPTER 9

Radio

The first airborne radio was used to enable the pilot to keep informed of weather along his flight path. 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.

World War II also fostered the principle of another radio aid to navigation called Consol. This principle originated with the Germans and was improved by the British in post war years. The United States version is called Consolan.

The rapid growth of 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 communications equipment.

The terms VOR, TACAN, Consol, Consolan, and IFF/SIF are explained and discussed in this chapter.

FUNDAMENTALS

Frequency Classification

Energy in the frequency range 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 a 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 Heinrich Rudolph Hertz, discoverer of electromagnetic waves.

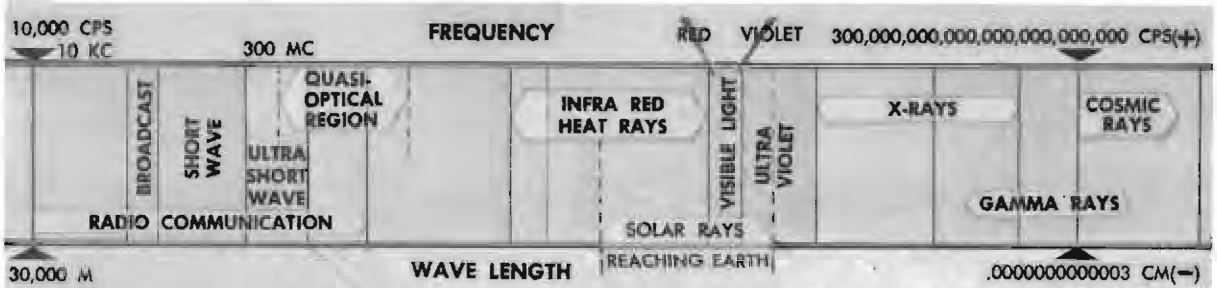
The range of frequencies used in radio communication is called the *radio spectrum.* Radio frequencies extend from approximately 10 kHz to 300,000 mHz and have been arbitrarily divided into bands. See figure 9-1.

Properties

Radio waves, like light waves, undergo reflection, refraction, diffraction, and absorption, and become attenuated (reduced in amplitude) as they travel from the source of radiation. See figure 9-2.

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 (an antenna) near the surface of the earth would travel in all directions horizontally and vertically in a series of ever-expanding, concentric spheres. A small portion of one of these spheres is termed a *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



BAND	ABBRE-VIATION	Frequency range	WAVE LENGTH Longest	Shortest
AUDIO	AF	0.02 to 20 kHz	∞	20,000 m
RADIO				
Very low frequency	VLF	10 to 30 kHz	30,000 m	10,000 m
Low frequency	LF	30 to 300 kHz	10,000 m	1,000 m
Medium frequency	MF	300 to 3,000 kHz	1,000 m	100 m
High frequency	HF	3,000 to 30,000 kHz	100 m	10 m
Very high frequency	VHF	30 to 300 mHz	10 m	1 m
Ultra high frequency	UHF	300 to 3,000 mHz	100 cm	10 cm
Super high frequency	SHF	3,000 to 30,000 mHz	10 cm	1 cm
Extremely high frequency	EHF	30,000 to 300,000 mHz	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 9-1. Electromagnetic Spectrum

the various strata or layers of ionized gases which surround the earth called the ionosphere.

DIFFRACTION. Diffraction of electromagnetic energy 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.

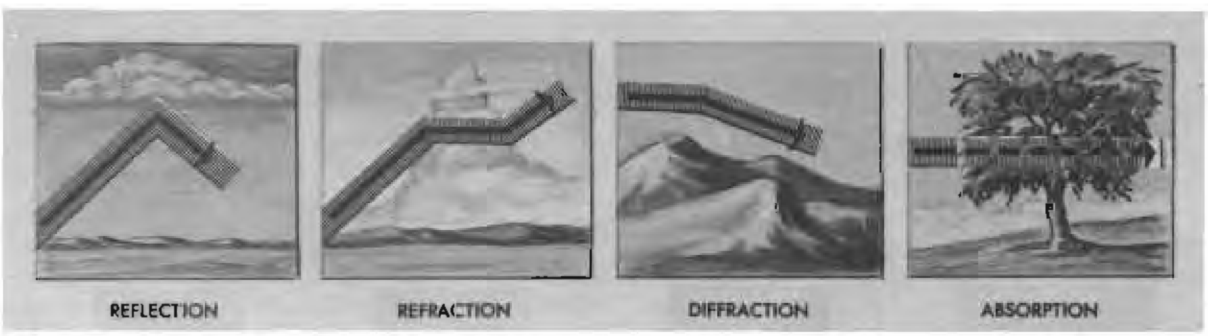


Figure 9-2. Properties of Radio Waves

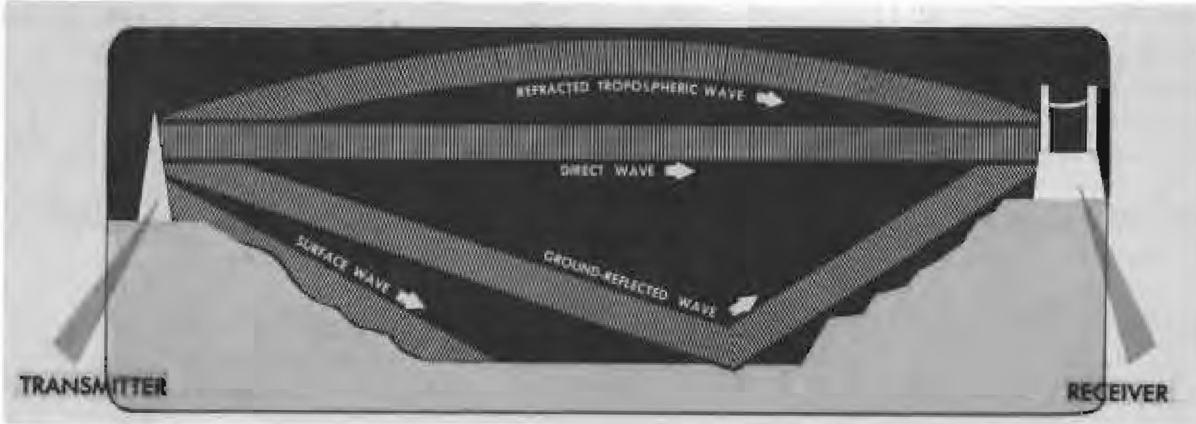


Figure 9-3. Ground Waves, Sky Waves, and Direct Waves

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 9-3).

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

Sky Waves. Sky waves are radio waves which are refracted by the earth's atmosphere. Radio communication 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 upon the degree of ionization, wave radiation angle, and the transmission frequency of the signal.

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

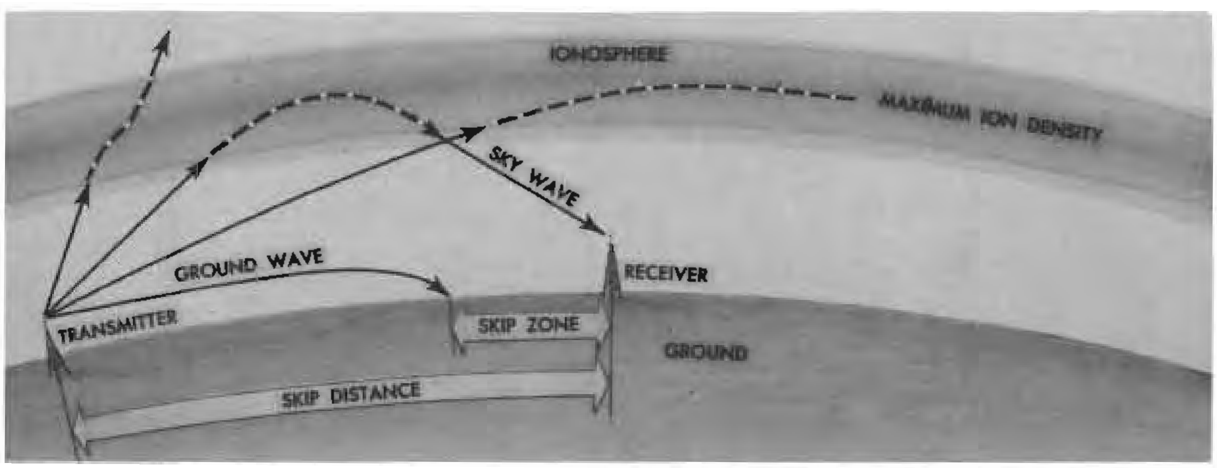


Figure 9-4. Skip Distance and Skip Zone

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 9-4.

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 the time during sunset and sunrise when ground waves and sky waves overlap because of rapid changes occurring 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 as 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 lies 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 communication is called *jamming.* More detailed information on interference and jamming is presented in Chapter 25.

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 electrical disturbance rather than to the desired station. In thunderstorm areas, LF and MF communications may become garbled or covered by static.

Antennas

Antennas may be classified as either nondirectional or directional.

NONDIRECTIONAL ANTENNAS. A nondirectional antenna is one which radiates or receives radio energy equally well 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 the LF and MF bands for marine and aeronautical navigation beacons and for commercial broadcast stations. Figure 9-5 shows the transmission pattern of a vertical antenna.

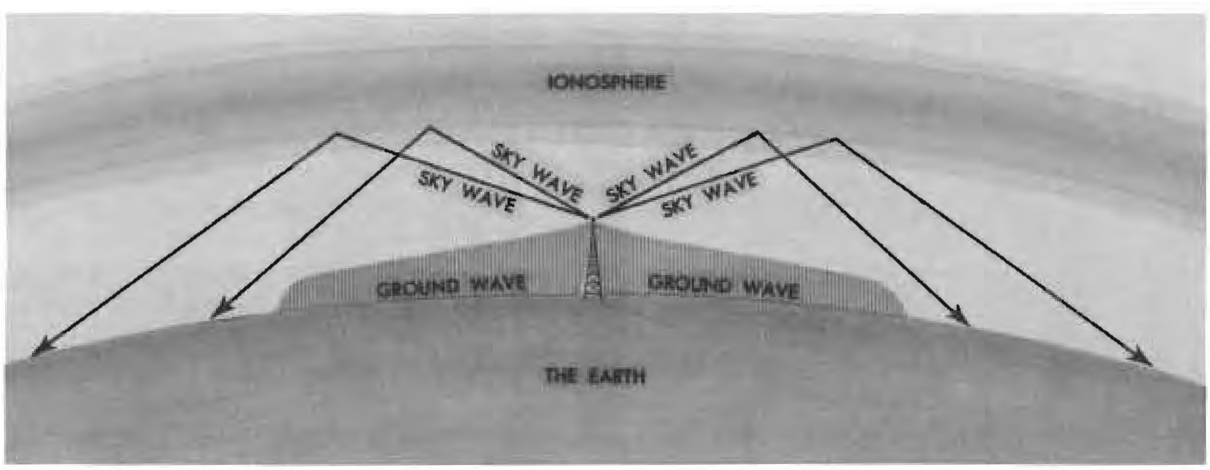


Figure 9-5. Transmission Pattern of a Vertical Antenna