Chapter 15

STAR IDENTIFICATION

You can locate the navigational stars in the heavens by the use of constellations, by pointer systems, or by the geometric patterns they form. You can also locate celestial bodies by computing their altitudes and azimuths and inserting this information into a periscopic sextant. Therefore, a knowledge of their appearance within the field of view of the periscopic sextant is important.

STAR CHART AND LOCATION DIAGRAMS

Since the many stars and planets look very much alike, their identity is not as readily apparent as that of the Sun or the Moon. To aid the navigator, the Air Almanac contains:

- A Navigational Star Chart
- Sky Diagrams
- A Planet Location Diagram
- Star Recognition Diagrams

Navigational Star Chart

The Navigational Star Chart shows stars in their correct positions according to their declination and SHA. The stars of each constellation are connected by dotted lines, and the names of the constellations are given.

Sky Diagrams

The sky diagrams are useful in selecting the most suitable stars and planets for navigation, particularly when part of the sky is obscured. Shown on the diagrams are the 57 selected navigational stars, the Sun, the Moon, the four planets (Venus, Mars, Jupiter, and Saturn), and the North and South Celestial Poles. For each month, there is a series of diagrams depicting the sky for different latitudes at 2-hour intervals throughout the day.

Planet Location Diagram

The planet location diagram shows the daily relative positions of the Sun, the Moon, the four planets, and the stars Aldebaran, Antares, Spica, and Regulus. In addition, the first point of Aries is also shown for reference. This diagram should be used in conjunction with the sky diagrams.

Star Recognition Diagrams

The star recognition diagrams contain sextant views of the navigational stars with northern or southern declination, respectively. By orienting the diagram to the observer's zenith, the relative positions of the stars within the sextant field of view may be determined.

SEASONAL STAR CHARTS

The seasonal star charts shown in figures 15-1 through 15-4 assist the navigator in star identification. The major constellations and other stars visible during each season are shown on each chart. If the chart for the current season is held overhead, with the top of the chart oriented to the north, the chart will indicate the positions of the stars.

The names of the stars and constellations appear relative to the bodies to which they apply. The broken lines connect stars of some of the more prominent constellations. The solid lines point out certain useful relationships and indicate the celestial equator. The celestial poles are marked by crosses.

These charts are designed so that the center of the chart coincides with the observer's celestial meridian at midnight of midseason. Each chart extends 20° beyond both poles and 4 hours (60°) either side of the meridian at the equator. This coverage does not, of course, coincide with the visible sky which is always a hemisphere.

The bodies on the celestial meridian above the zenith are north of the observer; those below are south. The observer's zenith is a function of latitude. If the observer's latitude is 30° N, the zenith is 30/90, or ⅓ the distance from the equator to the North Pole.

The center of the chart will coincide with the observer's celestial meridian at the following local mean times:

LMT	Spring Stars	Summer Stars	Autumn Stars	Winter Stars
1800	22 June	21 Sep	21 Dec	22 Mar
2000	22 May	21 Aug	21 Nov	20 Feb
2200	22 Apr	22 July	21 Oct	20 Jan
0000	23 Mar	22 June	22 Sep	22 Dec
0200	21 Feb	23 May	22 Aug	22 Nov
0400	21 Jan	22 Apr	23 July	22 Oct
0600	22 Dec	23 Mar	22 June	21 Sep

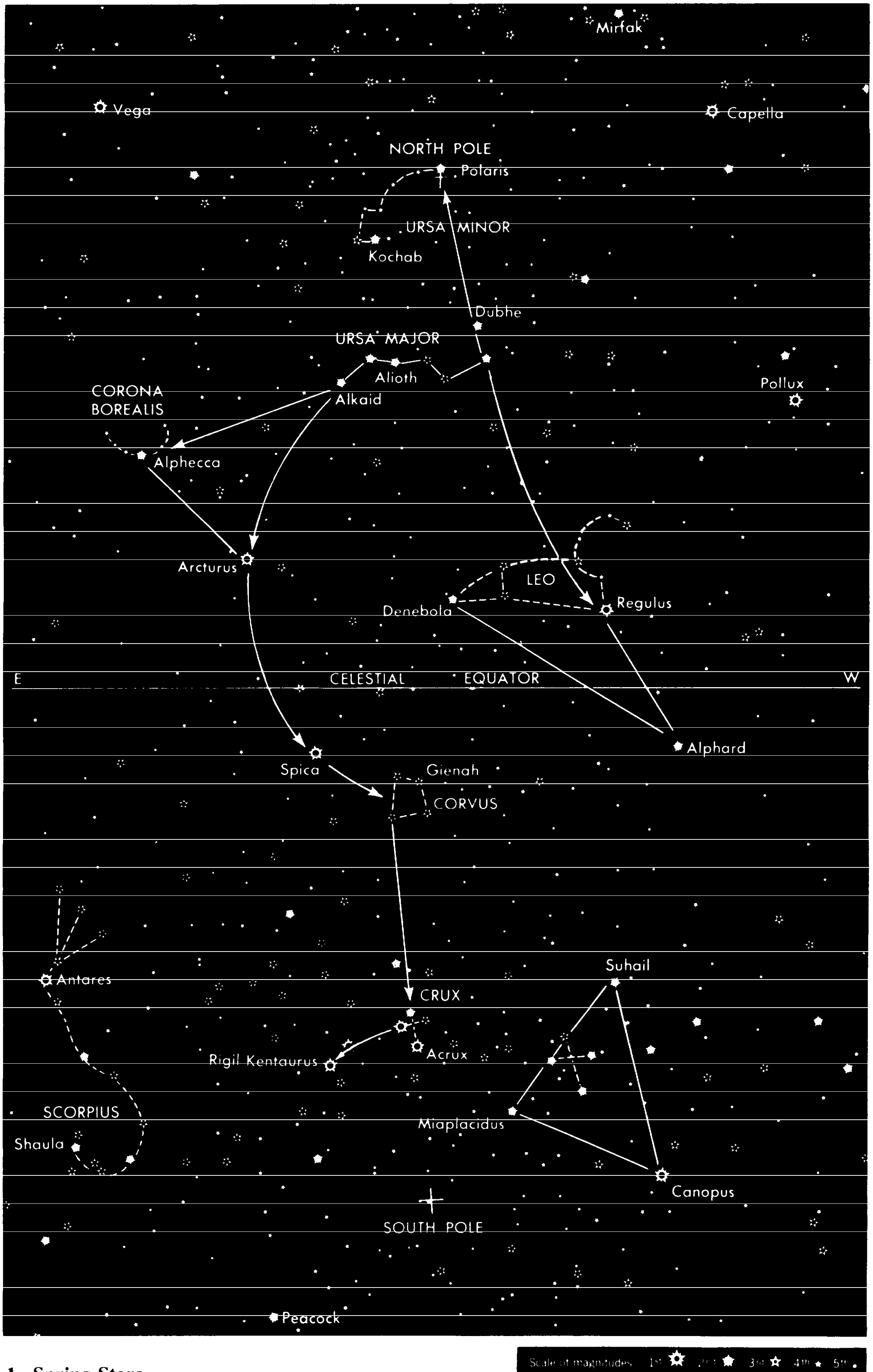


Figure 15-1. Spring Stars.

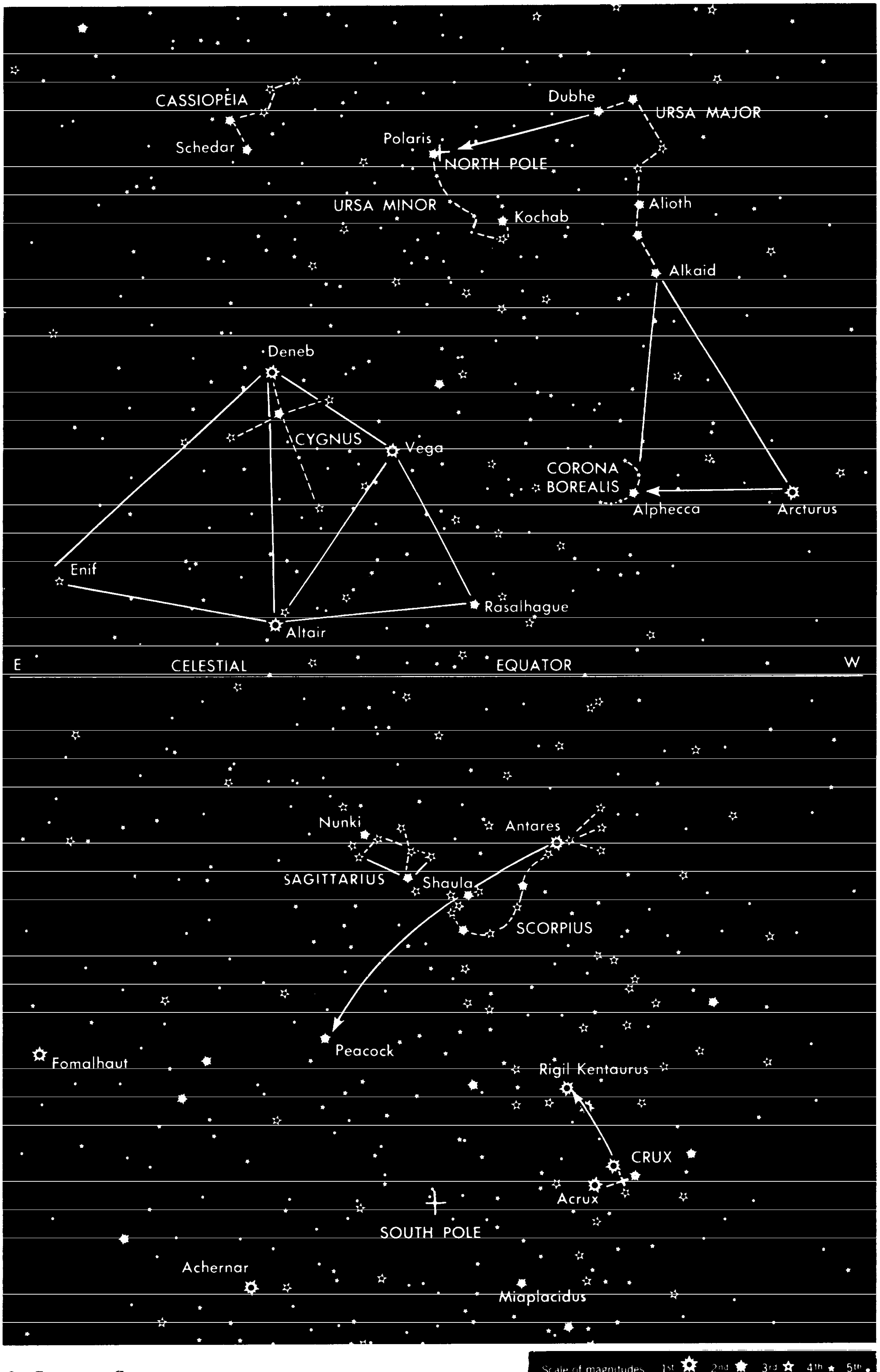


Figure 15-2. Summer Stars.

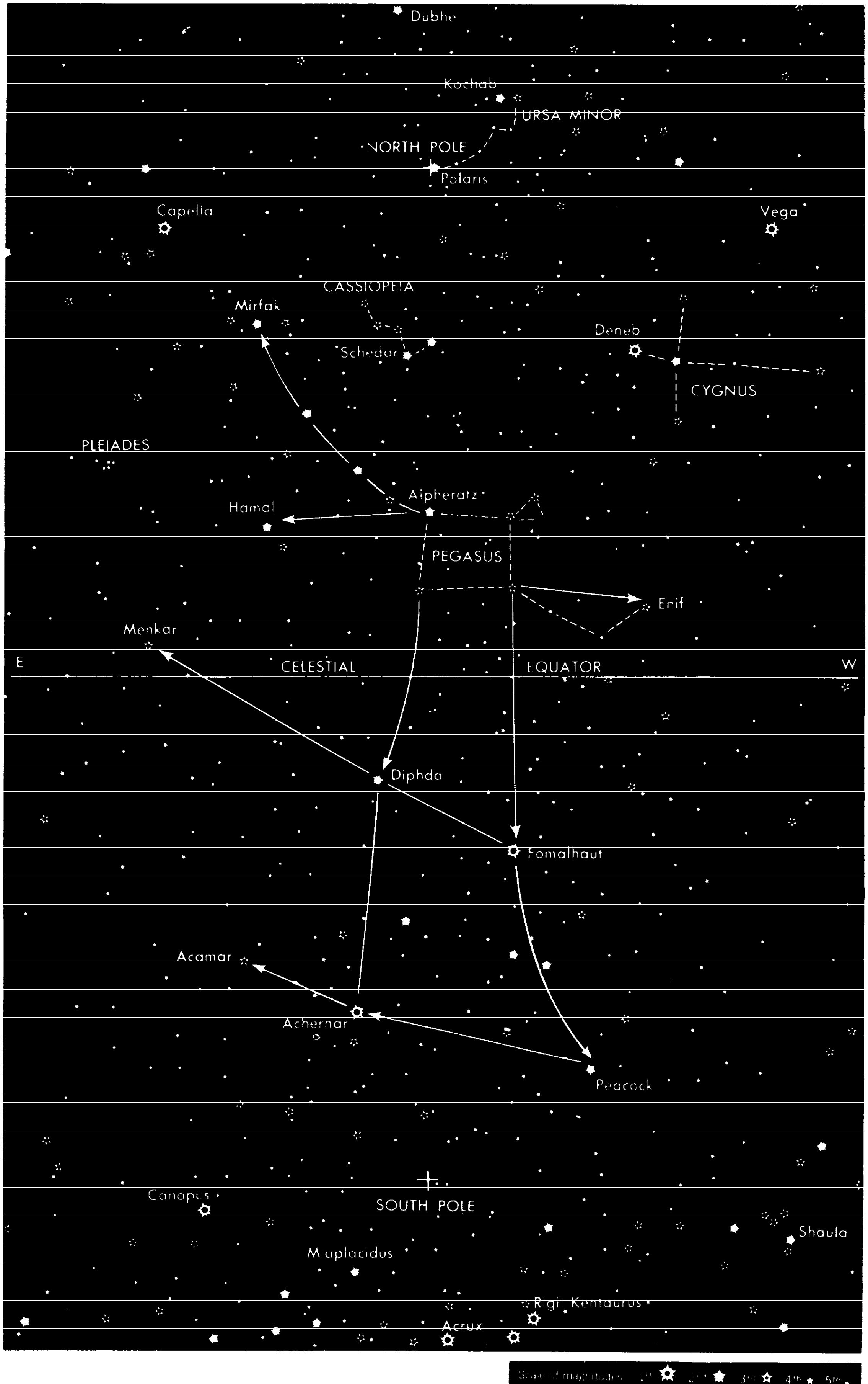


Figure 15-3. Autumn Stars.

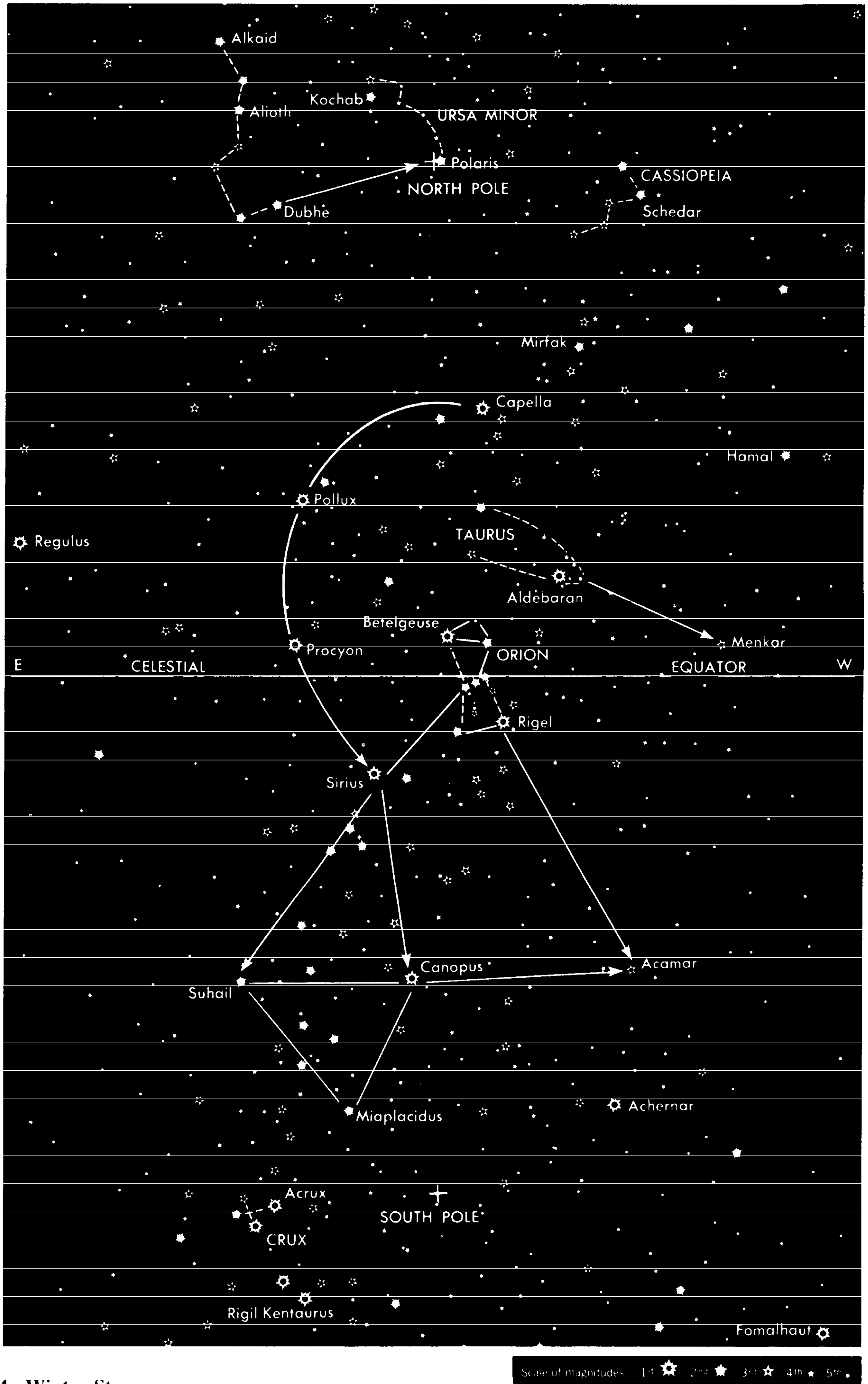


Figure 15-4. Winter Stars.

STAR IDENTIFICATION CHARTS

In addition to the Air Almanac's star recognition diagrams, the following star identification charts may be used to determine the sextant's field-of-view pattern for the HO 249, vol 1 stars and Polaris.

Each chart shows the first, second, third, and fourth magnitude stars that are visible within a sextant having a 15° field of view, when the desired star is in the center. Lines, depicting the better known constellations have been included to make the star patterns more meaningful.

The stars are shown as they would appear from the North Pole. For other latitudes, the accompanying tables of position angles tell how much the charts should be rotated to give the correct presentation for the time of the observation. Dashes in the tables indicate that the star is below the horizon at those points. To use the charts, enter the table with the nearest values of latitude and LHA of Aries to find the position angle. (Though interpolation may be used, it is not normally necessary to do so.) Then, rotate the chart until this position angle is at the top. The star pattern which results is the one which will appear in the sextant field of view.

For example, a navigator located at 51°N latitude has precomped for an LHA of Aries of 115°. Dubhe is one of the diamond stars in the HO 249 vol 1, and the navigator wishes to determine how it will appear in the sextant field of view. By entering the position angle table for Dubhe with 50°N and 120° LHA of Aries, the navigator extracts a position angle of 095°. Rotating the chart until 095° is at the top, the navigator finds that the Big Dipper should appear to the right of the field of view with the handle pointing down.

SUMMARY

In order to obtain an accurate star shot, it is first necessary to observe the correct star. Even with the technique of presetting the periscopic sextant, it is essential that the navigator be able to visually pick out the desired star from its background among other celestial bodies. When using a periscopic sextant, the best way to identify the correct star is by recognizing the unique "pattern" formed by the stars in the sextant's field of view. To aid the navigator in star identification, several references are available. These are the Air Almanac, seasonal star charts, and star identification charts.

Chapter 16

SEXTANTS AND ERRORS OF OBSERVATION

SEXTANTS

For hundreds of years, mariners have navigated the seas keeping track of their positions by use of the sextant. This instrument measured the altitude of celestial bodies (angular distance above the horizon) and the information derived from this measurement was used to determine the position of the vessel. All celestial navigation follows this rule. Today's navigator measures the altitude of the celestial bodies in much the same manner as did Magellan, Columbus, and other famous navigators.

However, there is a difference between air and marine celestial navigation. Because the marine navigators are on the surface of the ocean, they can establish their horizon by referring to the natural horizon. In an aircraft, this is impossible because altitude and aircraft attitude induce error. In the sextant designed for air navigation, a bubble, much like that used in a carpenter's level, determines an artifical horizon which is parallel to the celestial horizon. The bubble chamber is so placed in the sextant that the bubble is superimposed upon the field of vision. Both the celestial body and the bubble are viewed simultaneously, making it possible to keep the sextant level while sighting the body.

Sextants are subject to certain errors that must be compensated for when determining LOPs. Some of these errors are instrument errors while others are induced by the various in-flight conditions. The first half of this chapter discusses the sextant and the second half explains sextant errors.

The Bubble Sextant

The aircraft bubble sextant measures altitude above a horizontal plane established by a bubble. The Air Force uses several types of bubble sextants, all of which are indirect sighting. This means the navigator does not look directly toward the celestial body, but always looks in a horizontal direction as shown in figure 16-1. The image of the body is reflected into the field of view when the field prism is set at the correct angle. In the bubble sextant, the bubble and body are visible in the same field of view.

Although the Air Force uses several sextant models, the basic components of all the sextants are similar in nature. The sextant system essentially consists of four parts: the mount, the sextant, the electrical cables, and the carrying case.

The Mount

The mount as shown in figure 16-2, is fastened permanently to the top of the fuselage of the aircraft. A shutter door is built into the mount to close the opening through which the tube of the periscopic sextant protrudes. This shutter door is controlled by the sextant port lever (refer to item 1, figure 16-2) on the mount. The mount has a gimbal mechanism which allows the sextant to be tilted from the vertical in any direction. This permits a celestial body to be observed throughout the normal oscillations of an aircraft. A drain plug, 2, is provided at the low point in the shutter well for draining out water which may have collected in the mount.

The sextant is held in the mount by two locking pins, 4, located in a movable collar on the bottom of the mount. One pin locks the sextant into the mount and holds it in the retracted position; the other pin locks the sextant in the extended position. These pins are spring-loaded and must be pulled out to release the sextant. Located next to these locking pins is a friction clamping lever, 3, which provides the observer with the option of locking the sextant at a fixed azimuth or, when the tension is released, the sextant may be rotated through 360 degrees of azimuth. The azimuth scale, 10, and azimuth counter, 6, will move when the azimuth crank, 5, is rotated. The azimuth scale can be read against a lubber line (index line), 11. The azimuth scale read against the lubber line and the azimuth counter reading should be the same.

Power is supplied from the aircraft through a cable connection, 9, on the side of the mount. A switch, 8, on the side of the mount controls power to both the mount and the sextant. The mount has one lamp that illuminates the azimuth counter window. Another cable, 7, is connected to the socket on the underside of the mount and supplies power to the sextant itself.

The Periscopic Sextant

The periscopic sextant is an optical instrument which enables locating and determining true azimuth, relative bearing, altitude angle of a celestial body and an aircraft's true heading. The sextant provides an angle of observation from below the horizon to directly overhead, as compared to an artificial horizon.

Accurate observations can be obtained from the various bubble sextants by using proper collimation techniques, and by using the proper size bubble. Collimation is effected when the

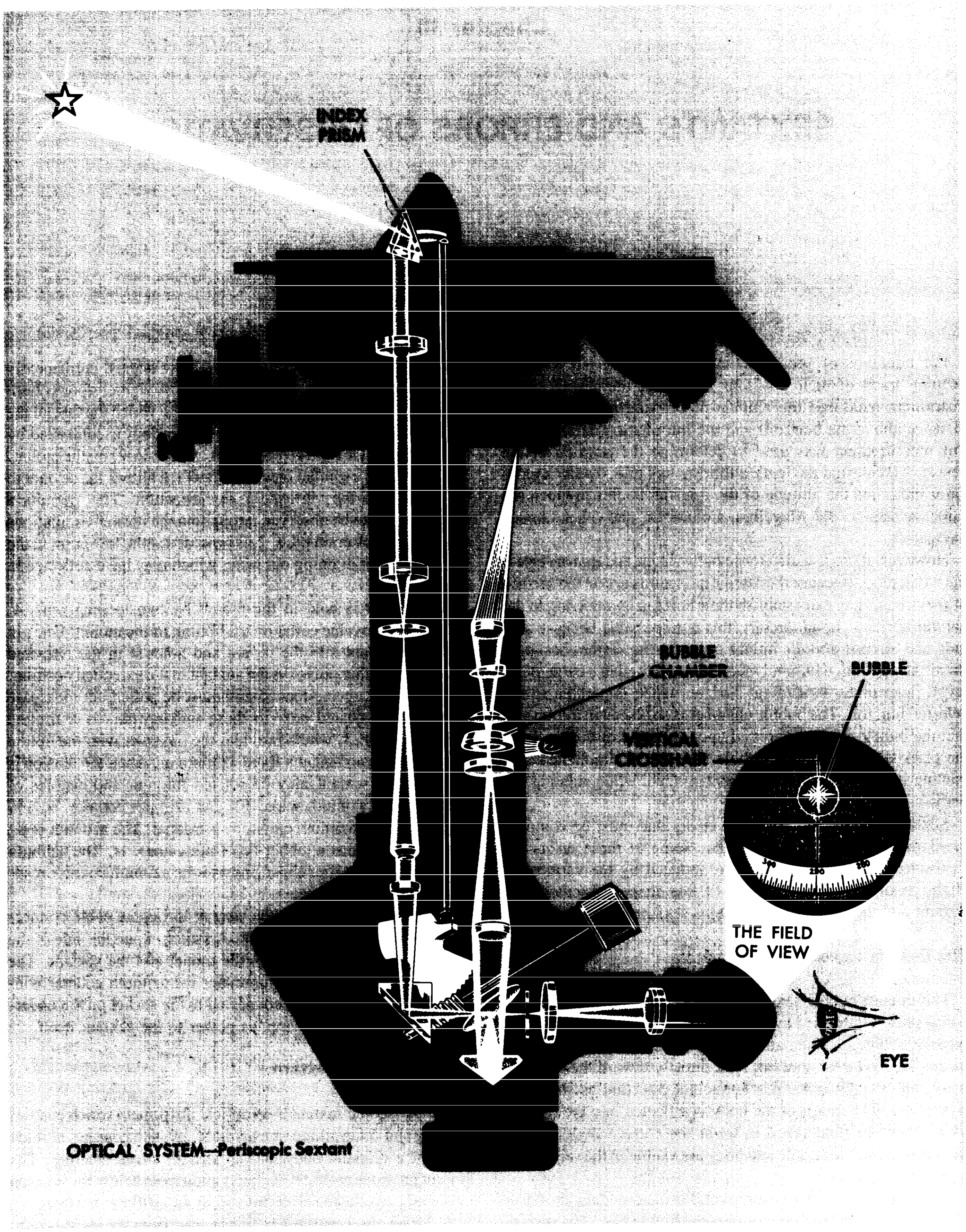
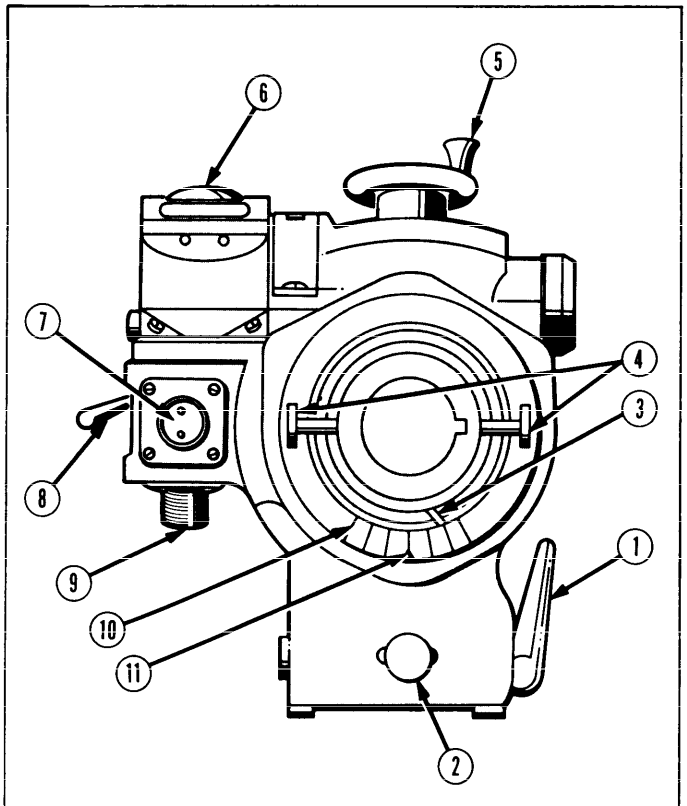


Figure 16-1. Body Is Not Sighted Directly.



1. SEXTANT PORT LEVER
2. DRAIN PLUG
3. FRICTION CLAMPING LEVER
4. LOCKING PINS
5. AZIMUTH CRANK
6. AZIMUTH COUNTER
7. POWER TO SEXTANT
8. POWER SWITCH
9. POWER FROM AIRCRAFT
10. AZIMUTH SCALE
11. LUBBER LINE

Figure 16-2. Periscopic Sextant Mount.

body is placed in the center of the bubble. For greatest accuracy, the bubble should be in the center of the field. The error will be small if the bubble is anywhere on the vertical line of the field, as long as it does not touch the top or bottom of the bubble chamber. Figure 16-3 shows examples of correct and incorrect collimation.

Bubble size affects the accuracy of a sextant observation. The ideal situation for collimation is to have a small bubble for ease in determining the center. However, too small a bubble is sluggish. For accuracy it is better to have a bubble that is active. Experience has shown that best results can be obtained with a bubble approximately one and a half times the apparent diameter of the Sun or Moon. The field prism is geared to an altitude scale so that when the body is collimated the altitude can be read from the scale.

An averaging mechanism is also incorporated which allows the navigator to take a series of observations over a period of time. The bubble and resultant artificial horizon are affected by the continuous motion of the aircraft. This movement resolves itself into a cycle in which the aircraft rolls, yaws, and pitches. In order to obtain an accurate reading, it is necessary to sight the body for a period of time during this cyclic movement and to average the results of a series of sightings. An averaging device has been incorporated in the sextant so an average reading can be obtained.

The sextant (figure 16-4) is actually a low-power periscope with a 15° field of view. All lens surfaces in the sextant are coated to mimimize light loss. To prevent condensation when the tip of the sextant is extended into cold air, the tube is filled with a dry gas and sealed. To remove moisture and check on the dryness of the gas inside the tube, a desiccant (composed of silica gel) is used and can be seen in the periscopic end of the sextant, or in some models, on the sextant body. When the silica gel is pink, there is moisture in the tube and the sextant should be rejected.

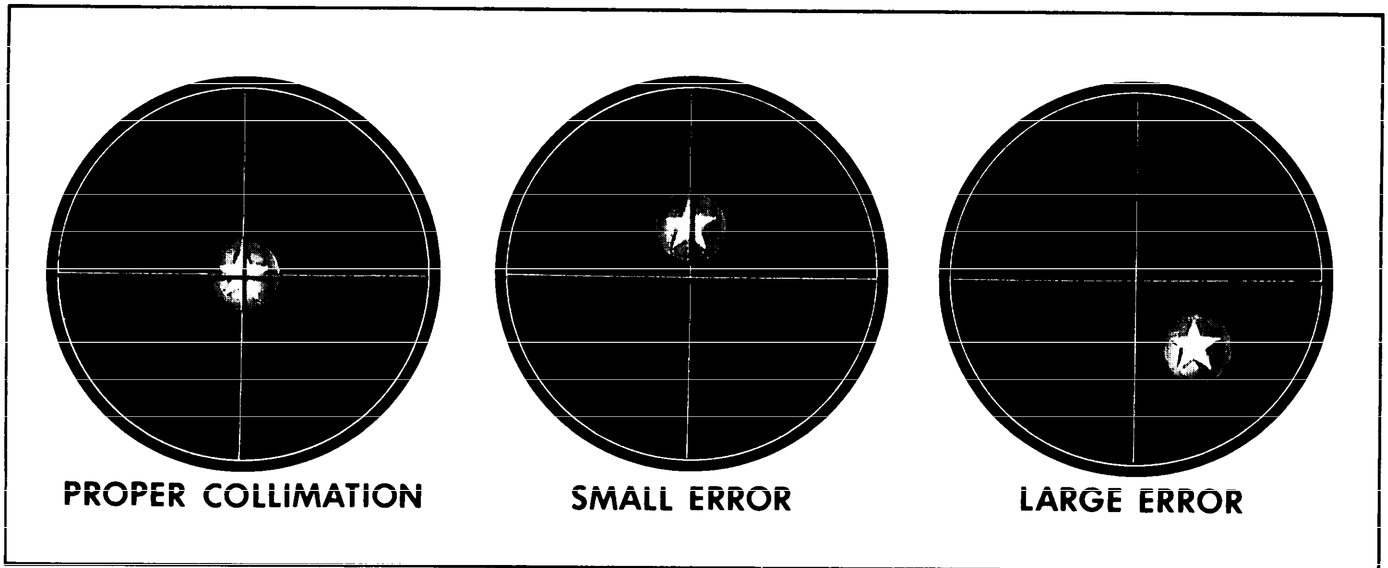
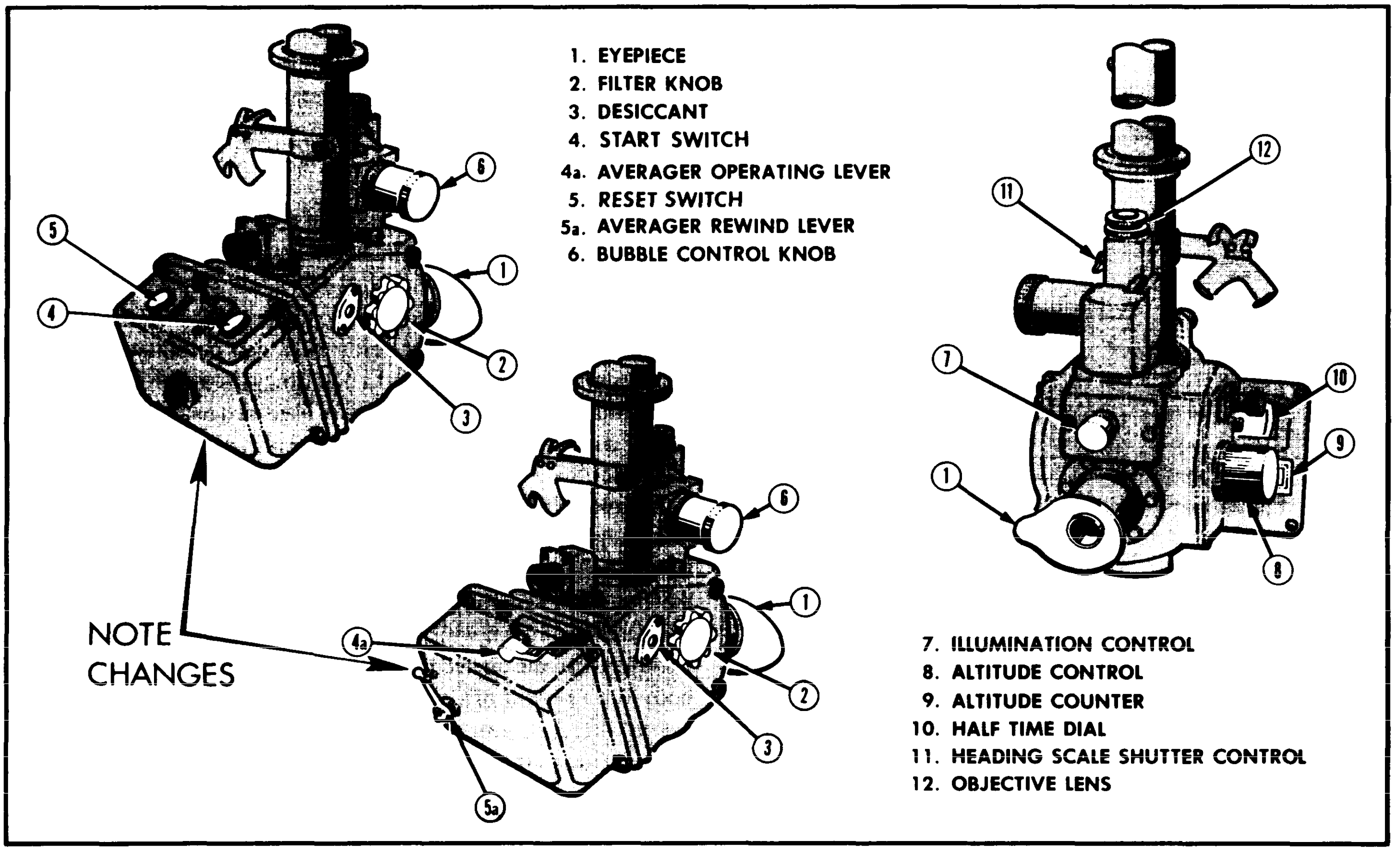


Figure 16-3. Correct and Incorrect Collimation.



★Figure 16-4. Periscopic Sextant.

Refer to figure 16-4. An eyepiece, 1, rotates to focus on the eyesight of the individual observer. Filters, 2, or shade glasses are provided for selective use in the optical system so that the intensity of the Sun's light might be adequately reduced. The filter control, 2, is located on the left of the sextant.

★Most sextants currently in use have been modified with an electronic device for accomplishing all the functions of the averaging mechanism. General differences in these and the unmodified sextants are addressed in this discussion.

★A start switch, 4 (a start/stop or averager operating lever, 4A, on unmodified sextants), starts and stops the operation of the sextant. Adjacent to this switch is the reset switch, 5 (the averager rewind lever, if unmodified, 5A, located below the averager operating lever). The reset switch/averager rewind lever has four functions. When depressed and released, it does the following:

- Removes the shutter from the field of vision.
- Zeroes and resets (rewinds if unmodified) the timer.
- Zeroes the averager and places initial values in registers and data memory (realigns indices on unmodified sextants).
- Disconnects the altitude control knob from the averager.

The bubble size control should be left in the full increase position after adjustments have been made. With the control in the full increase position, an aneroid is locked to the bubble chamber to compensate for changes in ambient pressure and temperature.

★On the front of the sextant, there is a rheostat control, 7, which varies the intensity of the light in bubble chamber. The altitude knob, 8, is located on the side of the sextant. It is used to keep the observed body in vertical collimation during the period of the observation. At the end of the scheduled observation, it is used to adjust the altitude counter until the exact average indication appears, or to align the indices on unmodified sextants. The body's altitude is read in the altitude counter, 9. Directly behind the altitude knob is the averager display, 10 (half-time dial and indices if unmodified). The averager display/half-time dial is graduated from 0-60, and indicates the halftime of the observation. The indices, when aligned, permit the direct reading of the observed altitude on the altitude dial.

★In the periscope sextant, the averaging is accomplished by microprocessor (Deimel-Black ball integrator if unmodified) which effects a continuous moving averager over any observation period up to 2 minutes. This system has many advantages over other known averaging devices: it is very simple to operate, a single switch (or lever) sets and (or) winds the mechanism, and no other presetting of the sextant, timing mechanism, or averaging is necessary. It is continuously integrating altitude against elapsed time. After at least 30 seconds, it may be stopped at any time up to 2 minutes. The average altitude may be read directly from the counter. A half-time clock (dial or unmodified sextants) will indicate the half-time of the observation. The time indication may be added directly to the time of starting the observation to compute the mean time of the observation. At the end of the observation, the averager energizes a solenoid (actuates a lever if unmodified) which drops a shutter across the field of view, indicating the end of the observation. Although it is possible to utilize an instananeous shot, the normal timed observation lasts for 2 minutes. It is impossible to time any observation for less than 30 seconds.

A heading scale shutter (diffuser lever) control, 11, provides a convenient means of blocking out the bright illumination on the azimuth scale for night celestial observations. The objectives lens, 12, is located just above the heading scale shutter control. The lens aligns the azimuth scale of the sextant with the longitudinal axis of the aircraft. The lens can be rotated with the fingers in order to calibrate the azimuth scale on a known bearing while looking through the eyepiece. The objectives lens can remove up to 2° azimuth error in the azimuth ring. A locking ring beneath the lens prevents accidental movement. A dial lamp located on the right side of the sextant provides three beams of light to illuminate the averager indicators, the altitude counter, and the watch clip. The watch clip is made to hold a master watch.

Electrical Cables

Cables provide power for sextant illumination. Other than lighting, the sextant is mechanically powered and can operate independently of aircraft power. Even if electrical power is lost, the sextant can still be used with a flashlight. There are two cables used in the sextant system. One connects power to the mount and the other connects the mount to the aircraft electrical system.

Sextant Case

The case provides shock-absorbent storage for the sextant when it is not in use. The sextant fits into form-fitting foam blocks and is secured by straps. The case also contains spare bulbs for sextant illumination and provides storage for the electrical cable.

ERRORS OF SEXTANT OBSERVATION

If collimation of the body with the bubble and reading the sextant were all that had to be done, celestial navigation would be simple. This would mean that LOPs accurate to within 1 or 2 miles could be obtained without any further effort. Unfortunately, considerable errors are encountered in every sextant observation made from an aircraft. A thorough understanding of the cause and magnitude of these errors, as well as the proper application of corrections to either the Hc or Hs, will help minimize their effects. (Any correction applied to the Hs may be applied instead to the Hc with a reverse sign.) Accuracy of celestial navigation, therefore, depends upon thorough application of these corrections, together with proper shooting techniques.

The errors of sextant observation may be classified into four groups: (1) parallax error, (2) refraction errors, (3) acceleration errors, and (4) instrument errors.

Parallax Error

Parallax in altitude is the difference between the altitude of a body above a bubble horizon at the surface of the Earth, and its calculated altitude above the celestial horizon at the center of the Earth. All Hcs are given for the center of the Earth. If the light rays reaching the Earth from a celestial body are parallel, the body has the same altitude at both the center and the surface of the Earth. For most celestial bodies, parallax is negligible for purposes of navigation.

Parallax Correction for the Moon. The Moon is so close to

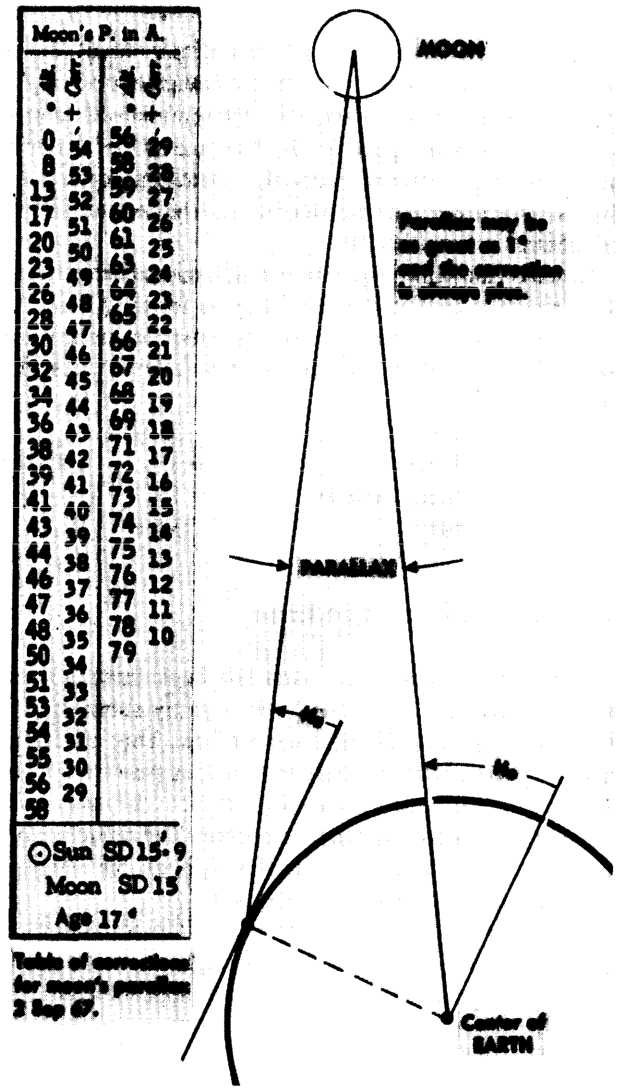


Figure 16-5. Correction for Moon's Parallax.

the Earth that its light rays are not parallel. The parallax of the Moon may be as great as 1°; thus, when observing the Moon, a parallax correction must be applied to the Hs. Figure 16-5 shows that the Moon appears at a lower altitude from the surface of the Earth than it would appear from the center of the Earth; therefore, the correction is always plus. The amount of this correction varies with the altitude and with the distance of the Moon from the Earth. The correction varies from day to day because the distance of the Moon from the Earth varies. Corrections for the Moon's parallax in altitude are given on the daily pages of the Air Almanac and are always added, algebrically, to sextant altitudes. The values of parallax for negative altitudes are obtained from the Air Almanac for the equivalent positive altitudes.

Semidiameter Correction. Another correction found on the daily pages of the Air Almanac is the semidiameter correction. It is needed when shooting the upper or lower limb of the Moon or the Sun.

It is more likely to occur on observations of the Moon because, when the Moon is not full (completely round), the center is difficult to estimate. Therefore, the navigator observes either the upper or lower limb and applies the semidiameter correction listed in the almanac page for the time and date of the observation. If the upper limb is observed, subtract the correction from the Hs; if the lower limb is observed, add the correction to the Hs or subtract it from the Hc.

Listed on the same page is the semidiameter correction for the Sun, which is applied the same way as for the Moon.

Example: The upper limb of the moon as observed on 2 September 1979 at 30,000 feet is 33°41′. Apply these corrections as:

Hs	33°41′
Parallax	+45
Semidiameter	−15′
Ho	34°11′

Atmospheric Refraction Error

Still another factor to be taken into consideration is atmospheric refraction. If a fishing pole is partly submerged under water, it appears to bend at the surface. This appearance is caused by the bending of light rays as they pass from the water into the air. This bending of the light rays, as they pass from one medium into another, is called refraction. The refraction of light from a celestial body, as it passes through the atmosphere, causes an error in sextant observation.

As the light of a celestial body passes from the almost perfect vacuum of outer space into the atmosphere, it is refracted as shown in figure 16-6 so that the body appears a little higher above the horizon that it really is. Therefore, the correction to the Hs for refraction is always minus. The higher the body above the horizon, the smaller the amount of refraction and, consequently, the smaller the refraction correction. Moreover, the greater the altitude of the aircraft, the less dense the layer of atmosphere between the body and the observer; hence, the less the refraction.

The appropriate correction table for atmospheric refraction is listed inside the back cover of all four books used for celestial computations; namely, the Air Almanac, and each of the three volumes of HO 249. This table, shown in figure 16-7, lists the refraction for different observed altitudes of the body and for different heights of the observer above sea level. The values shown are subtracted from Hs or added to Hc.

Acceleration Error

Presently, the only practical and continuously available reference datum for the definition of the true vertical is the direction of the gravitational field of the Earth. Definition of this vertical establishes the artificial horizon. It is also fundamental that the forces caused by gravity cannot be separated by those caused by accelerations within the sextant. A level or centered bubble in the sextant indicates the true vertical only when the instrument is at rest or moving at a constant velocity in a straight line. Any outside force (changes in groundspeed or changes in track) will

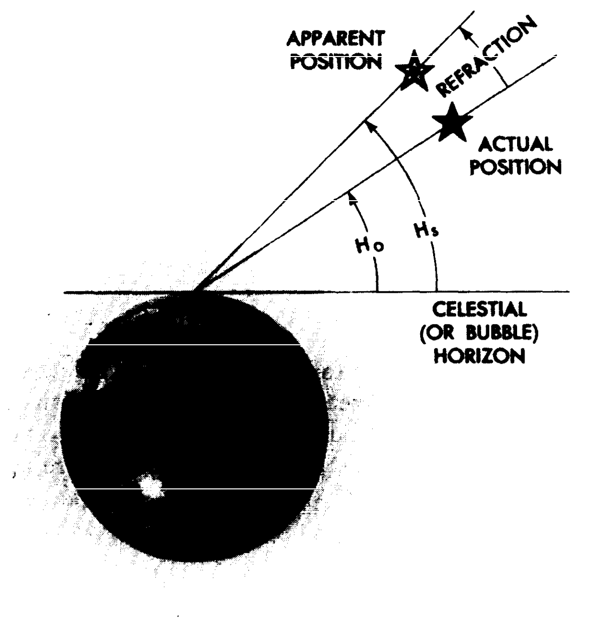


Figure 16-6. Error Caused by Atmospheric Refraction.

affect the liquid in the bubble chamber and, consequently, displace the bubble.

When the sextant is moved in a curved path (Coriolis, changes in heading, rhumb line) or with varying speed, the zenith indicated by the bubble is displaced from the true vertical. This presents a false artificial horizon above which the altitude of the celestial body is measured. Since the horizon used is false, the altitude measured from it is erroneous. Therefore, the accuracy of celestial observations is directly related to changes in track and speed of the aircraft. Acceleration errors have two principal causes: changes in groundspeed and curvature of the aircraft's path in space.

The displacement of the liquid and the bubble in the chamber may be divided into two vectors, and each vector may be considered separately. These vectors may be thought of as a lateral vector (along the wings) and a longitudinal vector (along the nose-tail axis of the aircraft). Any change in groundspeed can cause a longitudinal displacement. This change can be brought about by a change in the airspeed or the wind encountered, or the change in groundspeed brought about by a change in heading due to other factors (gyro precession, rhumb line error, etc). A lateral displacement results from a number of causes, most of which will occur in spite of any efforts to hold them in check. These causes are Coriolis, rhumb line, and wander errors.

Coriolis Force

Any freely moving body traveling at a constant speed above the Earth is subject to an apparent force which deflects its path to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere. This apparent force and the resulting acceleration were first discovered shortly before the middle of

TABLE 5.—Refraction

To be subtracted from sextant altitude

R_0	0	5	10	15	20	25	30	35	40	45	50	55
	Height above sea level in thousands of feet											
	Sextant Altitude											
′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	90	90	90	90	90	90	90	90	90	90	90	90
1	63	59	55	51	46	41	36	31	26	20	17	13
2	33	29	26	22	19	16	14	11	9	7	6	4
3	21	19	16	14	12	10	8	7	5	4	2 40	1 40
4	16	14	12	10	8	7	6	5	3 10	2 20	1 30	0 40
5	12	11	9	8	7	5	4	3 10	2 10	1 30	0 39	+0 05
6	10	9	7	5 50	4 50	3 50	3 10	2 20	1 30	0 49	+0 11	−0 19
7	8 10	6 50	5 50	4 50	4 00	3 00	2 20	1 50	1 10	0 24	−0 11	−0 38
8	6 50	5 50	5 00	4 00	3 10	2 30	1 50	1 20	0 38	+0 04	−0 28	−0 54
9	6 00	5 10	4 10	3 20	2 40	2 00	1 30	1 00	0 19	−0 13	−0 42	−1 08
10	5 20	4 30	3 40	2 50	2 10	1 40	1 10	0 35	+0 03	−0 27	−0 53	−1 18
12	4 30	3 40	2 50	2 20	1 40	1 10	0 37	+0 11	−0 16	−0 43	−1 08	−1 31
14	3 30	2 50	2 10	1 40	1 10	0 34	+0 09	−0 14	−0 37	−1 00	−1 23	−1 44
16	2 50	2 10	1 40	1 10	0 37	+0 10	−0 13	−0 34	−0 53	−1 14	−1 35	−1 56
18	2 20	1 40	1 20	0 43	+0 15	−0 08	−0 31	−0 52	−1 08	−1 27	−1 46	−2 05
20	1 50	1 20	0 49	+0 23	−0 02	−0 26	−0 46	−1 06	−1 22	−1 39	−1 57	−2 14
25	1 12	0 44	+0 19	−0 06	−0 28	−0 48	−1 09	−1 27	−1 42	−1 58	−2 14	−2 30
30	0 34	+0 10	−0 13	−0 36	−0 55	−1 14	−1 32	−1 51	−2 06	−2 21	−2 34	−2 49
35	+0 06	−0 16	−0 37	−0 59	−1 17	−1 33	−1 51	−2 07	−2 23	−2 37	−2 51	−3 04
40	−0 18	−0 37	−0 58	−1 16	−1 34	−1 49	−2 06	−2 22	−2 35	−2 49	−3 03	−3 16
45		−0 53	−1 14	−1 31	−1 47	−2 03	−2 18	−2 33	−2 47	−2 59	−3 13	−3 25
50		−1 10	−1 28	−1 44	−1 59	−2 15	−2 28	−2 43	−2 56	−3 08	−3 22	−3 33
55			−1 40	−1 53	−2 09	−2 24	−2 38	−2 52	−3 04	−3 17	−3 29	−3 41
60				−2 03	−2 18	−2 33	−2 46	−3 01	−3 12	−3 25	−3 37	−3 48
65							−2 53	−3 07	−3 19	−3 31	−3 42	−3 53
	Height above sea level in thousands of feet											
	0	5	10	15	20	25	30	35	40	45	50	55
f	Temperature in degrees Celsius (centigrade)											
0.8	+47	+36	+27	+18	+10	+ 3	− 5	−13	For these heights no temperature correction is necessary: take f=1.0 and use $R=R_0$.			
0.9	+26	+16	+ 6	− 4	−13	−22	−31	−40				
1.0	+ 5	− 5	−15	−25	−36	−46	−57	−68				
1.1	−16	−25	−36	−46	−58	−71	−83	−95				
1.2	−37	−45	−56	−67	−81	−95						
1.3												

R_0	$R=R_0\times f$					
	0.8	0.9	1.0	1.1	1.2	1.3
′	′	′	′	′	′	′
0	0	0	0	0	0	0
1	1	1	1	1	1	1
2	2	2	2	2	2	3
3	2	3	3	3	4	4
4	3	4	4	4	5	5
5	4	5	5	5	6	6
6	5	5	6	7	7	8
7	6	6	7	8	8	9
8	6	7	8	9	10	10
9	7	8	9	10	11	12
10	8	9	10	11	12	13
12	10	11	12	13	14	15
14	11	13	14	15	17	18
16	13	14	16	18	19	21
18	14	16	18	20	22	23
20	16	18	20	22	24	26
25	20	22	25	28	30	32
30	24	27	30	33	36	39
35	28	31	35	38	42	45
40	32	36	40	44	48	52
45	36	40	45	50	54	58
50	40	45	50	55	60	65
55	44	49	55	60	66	71
60	48	54	60	66	72	78
65	52	58	65	72	78	84
	0.8	0.9	1.0	1.1	1.2	1.3
f	Refraction $R=R_0\times f$					
0.8 0.9 1.0 1.1 1.2 1.3	When R_0 is less than 10′ or the height is greater than 35,000 ft. take f=1.0 and use $R=R_0$.					

Choose the column appropriate to height, in units of 1,000 feet, and find the range of altitude in which the sextant altitude lies; thus find R_0. This is the refraction corresponding to the sextant altitude unless conditions are extreme. In that case find f from the lower table corresponding to the range of temperature for the appropriate height, and use the table on the right to find R. Example: at a height of 30,000 feet and temperature (−) 60° C a celestial body is observed at altitude (−) 2°36′. R_0 is 50′, f is 1.1, and R is 55′. Subtracting this from the sextant altitude gives (−) 3°31′.

Figure 16-7. Corrections for Atmospheric Refraction.

the nineteenth century by Gaspard Gustave de Coriolis (1792-1843) and given quantitative formulation by Ferrel. The acceleration is known as Coriolis acceleration (or force) or simply Coriolis, and is expressed in Ferrel's law.

The navigator must realize that the bubble sextant indicates the true vertical only when the instrument is at rest or moving at a constant speed in a straight line as perceived in space. If the Earth were motionless, this straight path in space would also be a straight path over the surface of the Earth; conversely, a straight path over the motionless Earth would also be a straight path in space.

When the aircraft is flying a path curved in space to the left, the fluid in the bubble chamber is deflected to the right and the bubble is deflected to the left of the aircraft's path over the Earth. When the aircraft is flying a curved path in space to the right, the reverse is true.

In figure 16-8, the aircraft is represented as flying on a curved path to the left. Note that in the inset representing the bubble chamber, the heavy black bubble is indicated in its approximate position representing the true vertical.

The observer always seeks to center the bubble and, on this beam shot facing to the right side of the aircraft to observe the body, he or she would tip the sextant up. This would tilt the bubble horizon from its true position, producing a smaller sextant reading than the true value. Following the rule—the smaller the Ho, the greater the radius of the circle of equal altitude—the LOP will fall farther from the subpoint than the true LOP. Obviously, if the erroneous LOP falls farther from the subpoint, it will fall to the to the left of the true LOP and the correction to the right is valid. Corrections for Coriolis error are shown in the inside back cover of the almanac as well as in all volumes of HO 249.

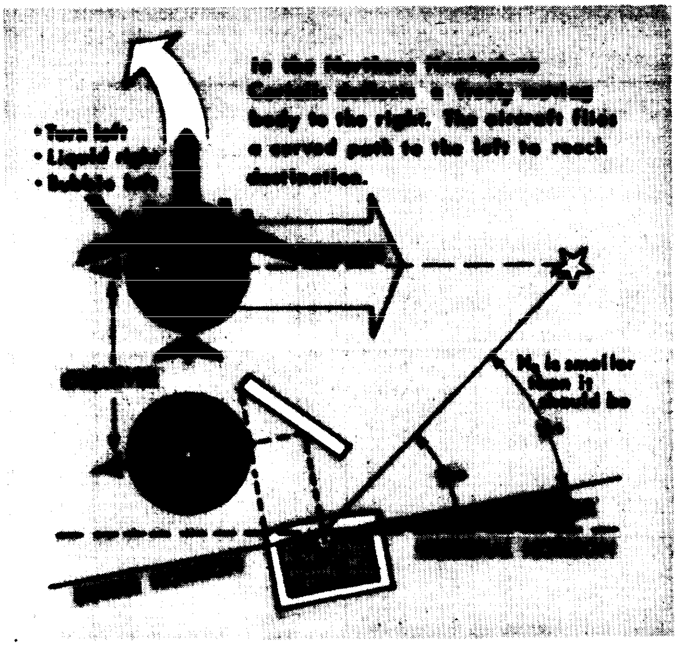


Figure 16-8. Error Caused by Coriolis Force.

Coriolis acceleration is:

- Directly proportional to the straight-line velocity.
- Directly proportional to the angular velocity of the Earth.
- Directly proportional to the sine of the latitude.
- At right angles to the direction of motion of the aircraft and, therefore, it can only influence its direction—never its speed.

For example, in the case of a B-52D flying at 500 knots groundspeed at 33-53N 117-16W, the Coriolis correction is 8NM which is then plotted to the right of track.

Rhumb Line Error

However, the straight Coriolis table 16-9 found in the Air Almanac or HO 249 has a limited application. As long as a constant true heading is flown, the path of the aircraft will be a rhumb line. Because a rhumb line on the Earth's surface is a curve, it is also a curved line in space. If the aircraft is headed in a general easterly direction in the Northern Hemisphere, the apparent curve is to the left and becomes an addition to the Coriolis error. By the same token, if headed in a westerly direction in the Northern Hemisphere, the apparent curve is to the right, or opposite that of Coriolis force as shown in figure 16-10.

CORIOLIS (*Z*) CORRECTION

To be applied by moving the position line a distance *Z* to starboard (right) of the track in northern latitudes and to port (left) in southern latitudes.

G/S KNOTS	Latitude 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	G/S KNOTS	Latitude 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
	′	′	′	′	′	′	′	′	′	′		′	′	′	′	′	′	′	′	′	′
150	0	1	1	2	3	3	3	4	4	4	550	0	3	5	7	9	11	12	14	14	14
200	0	1	2	3	3	4	5	5	5	5	600	0	3	5	8	10	12	14	15	16	16
250	0	1	2	3	4	5	6	6	6	7	650	0	3	6	9	11	13	15	16	17	17
300	0	1	3	4	5	6	7	7	8	8	700	0	3	6	9	12	14	16	17	18	18
350	0	2	3	5	6	7	8	9	9	9	750	0	3	7	10	13	15	17	18	19	20
400	0	2	4	5	7	8	9	10	10	10	800	0	4	7	10	13	16	18	20	21	21
450	0	2	4	6	8	9	10	11	12	12	850	0	4	8	11	14	17	19	21	22	22
500	0	2	4	7	8	10	11	12	13	13	900	0	4	8	12	15	18	20	22	23	24

Figure 16-9. Coriolis (Z) Correction.

Figure 16-10. Coriolis/Rhumb Line Errors in the Northern Hemisphere.

GROUND SPEED 300 KNOTS

TR. → LAT. ↓	270 270	260 280	250 290	240 300	230 310	220 320	210 330	200 340	190 350	180 0	170 10	160 20	150 30	140 40	130 50	120 60	110 70	100 80	90 90
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.6
20	2.2	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.1	3.1	3.2	3.2
30	3.2	3.2	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1	4.2	4.3	4.4	4.5	4.6	4.6	4.7	4.7
40	4.0	4.0	4.0	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.8	5.9	6.0	6.1	6.1	6.2
50	4.5	4.5	4.5	4.7	4.8	5.0	5.2	5.5	5.7	6.0	6.3	6.6	6.8	7.0	7.2	7.4	7.5	7.6	7.6
60	4.6	4.6	4.7	4.9	5.1	5.4	5.7	6.0	6.4	6.8	7.2	7.6	7.9	8.2	8.5	8.8	8.9	9.0	9.0
70	3.8	3.8	4.0	4.3	4.6	5.1	5.6	6.1	6.8	7.4	8.0	8.6	9.2	9.7	10.2	10.5	10.8	10.9	11.0
80	0.3	0.4	0.8	1.3	2.0	3.0	4.0	5.2	6.4	7.7	9.0	10.3	11.5	12.5	13.5	14.2	14.7	15.0	15.1
89	**67.2**	**66.1**	**62.6**	**57.4**	**50.1**	**40.2**	**30.0**	**17.9**	**5.3**	7.9	21.0	33.6	45.7	55.9	65.8	73.1	78.3	81.8	82.9

GROUND SPEED 650 KNOTS

TR. → LAT. ↓	270 270	260 280	250 290	240 300	230 310	220 320	210 330	200 340	190 350	180 0	170 10	160 20	150 30	140 40	130 50	120 60	110 70	100 80	90 90
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1.9	1.9	1.9	2.0	2.1	2.3	2.4	2.6	2.8	3.0	3.1	3.3	3.5	3.7	3.8	3.9	4.0	4.0	4.0
20	3.6	3.6	3.7	3.9	4.1	4.4	4.7	5.1	5.4	5.8	6.2	6.6	7.0	7.3	7.6	7.7	7.9	8.0	8.1
30	5.0	5.0	5.2	5.4	5.8	6.3	6.7	7.3	7.9	8.5	9.1	9.7	10.3	10.8	11.2	11.6	11.8	12.0	12.1
40	5.8	5.9	6.1	6.5	7.0	7.7	8.4	9.2	10.1	11.0	11.8	12.7	13.5	14.2	14.9	15.5	15.8	16.0	16.1
50	5.7	5.8	6.1	6.6	7.4	8.3	9.3	10.5	11.8	13.0	14.3	15.6	16.7	17.7	18.6	19.4	19.9	20.2	20.3
60	4.2	4.3	4.8	5.6	6.6	8.0	9.4	11.1	12.9	14.7	16.5	18.3	20.0	21.5	22.8	23.9	24.6	25.1	25.2
70	**0.9**	**0.6**	0.2	1.3	3.0	5.2	7.5	10.2	13.1	16.0	19.0	21.8	24.5	26.8	29.0	30.7	31.8	32.6	32.9
80	**18.0**	**17.5**	**15.9**	**13.6**	**10.1**	**5.6**	**0.8**	4.8	10.7	16.8	22.8	28.7	34.3	39.1	43.6	47.1	49.4	51.0	51.5
89	**334.8**	**329.2**	**313.0**	**288.9**	**254.5**	**208.2**	**160.1**	**103.6**	**44.6**	17.0	78.7	137.6	194.1	242.2	288.5	322.9	347.0	363.2	368.8

Figures in **BOLD FACE** type are plotted in a direction opposite to that of coriolis force.

*Coriolis corrections alone are the figures in the 0° or 180° column.

Figure 16-11. Combined Coriolis/Rhumb Line Correction.

There are notable exceptions to this. When flying north or south, the aircraft is flying a great circle and there is no rhumb line error. Also, when steering by a free-running, compensated gyro, the track approximates a great circle and eliminates rhumb line error.

Prior to the wide use of high-speed aircraft, the rhumb line error was not considered because, at speeds under 300 knots, the error is negligible. However, at high speeds or high latitudes, rhumb line error is appreciable. For example, at 60° north latitude with a track of 100° and a groundspeed of 650 knots, the Coriolis correction is 15 nautical miles right and the rhumb line correction is 10 nautical miles right.

The correction for rhumb line error and Coriolis correction can be found in the combined Coriolis/rhumb line table shown in figure 16-11.

Step 1. Enter the nearest latitude on the left side. Interpolate if necessary.

Step 2. Enter the nearest track across the top of the chart.

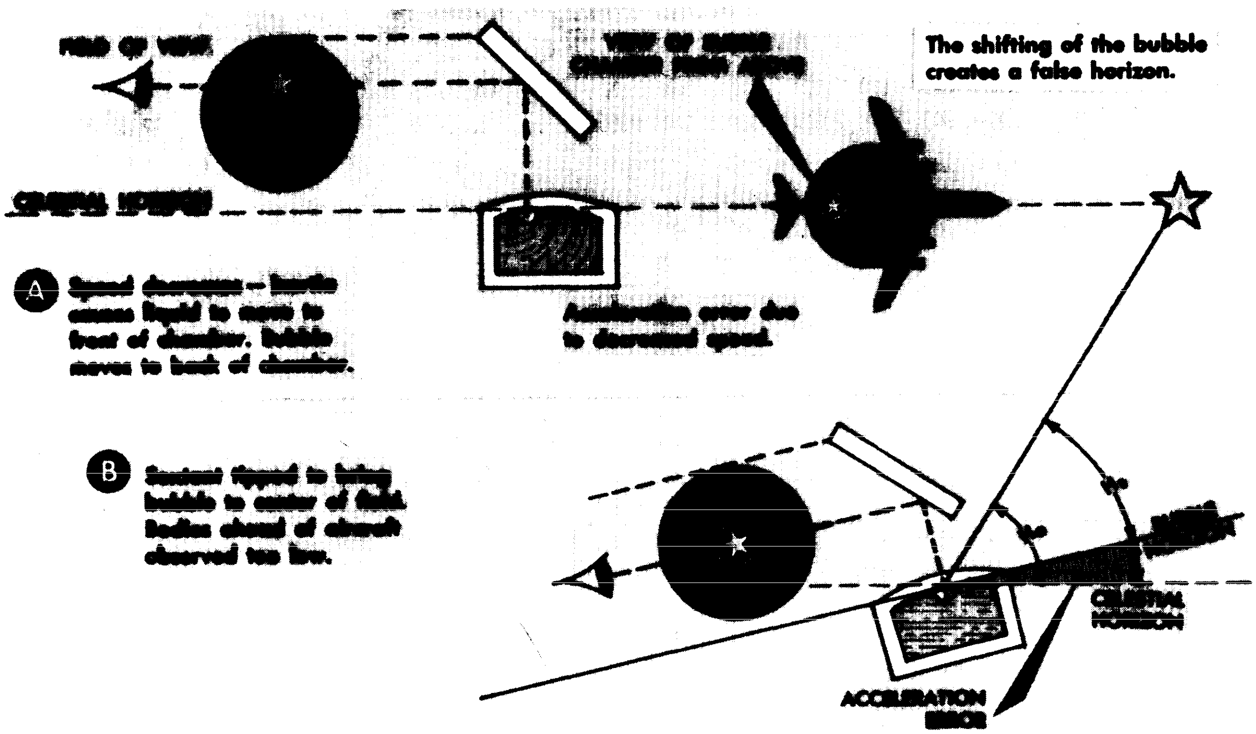


Figure 16-12. Acceleration/Deceleration Errors.

Interpolate if necessary.

Step 3. Choose the closest Groundspeed Extract Rhumb Line/ Coriolis Correction; i.e., 50N, Track 080, GS 500 = 14.3 Right.

Groundspeed Acceleration Error

This error is caused primarily by changes in airspeed or changes in wind velocity. The easiest method to prevent changes of airspeed is through good crew coordination and conscientious throttle control.

Changes in wind velocity with resultant changes in groundspeed are more difficult to control. The change in groundspeed (acceleration - deceleration) will cause the liquid to be displaced, with the subsequent shifting of the bubble creating a false horizon. Notice in figure 16-12 how the horizon is automatically displaced by keeping the bubble in the center while these changes are taking place. A very simple rule applies to acceleration and deceleration forces. If the aircraft accelerates while a celestial observation is in progress, the resultant LOP will fall ahead of the actual position. Accelerate — Ahead. The more the LOP approaches a speed line, the greater the acceleration error will become. Refer to figure 16-13:

1. Enter with Zn-TR.
2. Extract acceleration error, apply sign.
3. For example, Track 080, Zn 060, GS beginning of shot 500 knots, GS end of shot 515.

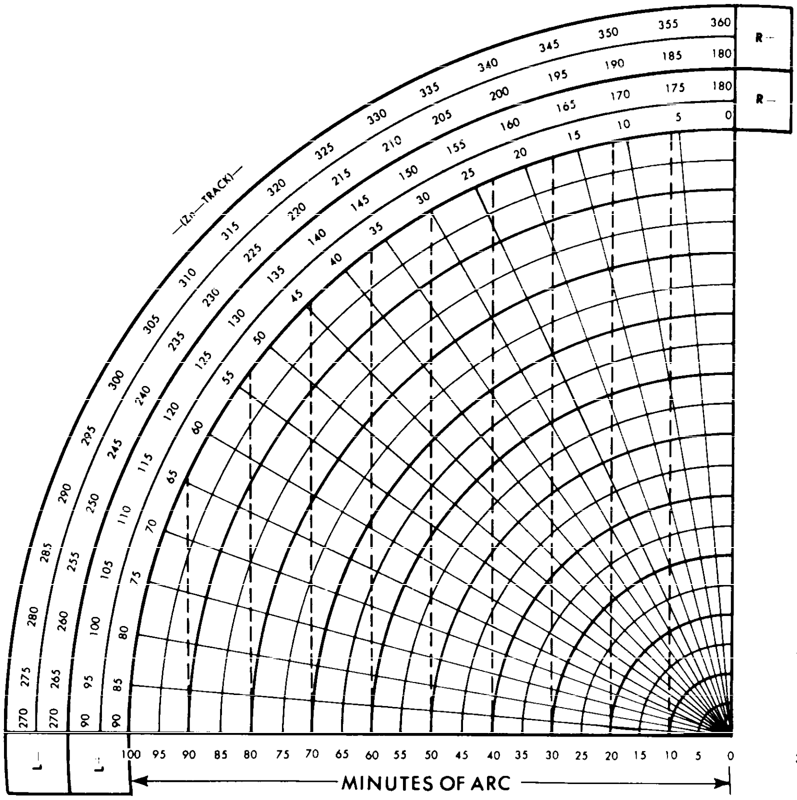
060° − 080° = 340° = −1.40

515 − 500 = 15 knots

−1.40 × 15 = −21 correction to the Ho.

ZN-TR −/+	+/−	Groundspeed Acceleration Error/Knot
000/180 005/175	180/360 185/355	1.50
010/170 015/165	190/350 195/345	1.48
020/160 025/155	200/340 205/335	1.40
030/150 035/145	210/330 215/325	1.30
040/140 045/135	220/320 225/315	1.15
050/130 055/125	230/310 235/305	0.97
060/120 065/115	240/300 245/295	0.75
070/110 075/105	250/290 255/285	0.51
080/100 085/095	260/280 265/275	0.26
090/090	270/270	0.00

Figure 16-13. Groundspeed Acceleration Error.



WANDER IN DEGREES PER 2 MINUTES

GROUND SPEED ▼ / TRACK CHANGE PER 2 MINUTES	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
300	0	1′	1.5′	2.5′	3′	4′	5′	5.5′	6.5′	7′	8′
325	0	1	1.5	2.5	3.5	4.5	5	6	7	7.5	8.5
350	0	1	1.5	3	3.5	4.5	5.5	6.5	7.5	8.5	9
375	0	1	2	3	4	5	6	7	8	9	10
400	0	1	2	3	4	5.5	6.5	7.5	8.5	9.5	10.5
425	0	1	2	3.5	4.5	6	7	8	9	10	11.5
450	0	1	2.5	3.5	4.5	6	7	8.5	9.5	10.5	12
475	0	1	2.5	3.5	5	6	7.5	8.5	10	11	12.5
500	0	1.5	2.5	4	5.5	6.5	8	9	10.5	12	13
525	0	1.5	3	4	5.5	7	8.5	9.5	11	12.5	14
550	0	1.5	3	4.5	6	7	8.5	10	11	13	14.5
575	0	1.5	3	4.5	6	7.5	9	10.5	12	13.5	15
600	0	1.5	3	4.5	6.5	8	9.5	11	12.5	14	16
625	0	1.5	3.5	5	6.5	8	10	11.5	13	15	16.5
650	0	1.5	3.5	5	7	9	10.5	12.5	14	15.5	17
675	0	2	3.5	5.5	7	9	10.5	12.5	14	16	17.5
700	0	2	3.5	5.5	7.5	9	11	13	14.5	16.5	18.5
725	0	2	3.5	5.5	7.5	9.5	11.5	13.5	15	17	19
750	0	2	4	6	8	10	12	13.5	15.5	17.5	19.5

INSTRUCTIONS

1. Enter the "Wander in Degrees per 2 Minutes" Table with track change per 2 minutes and groundspeed in knots to obtain the total correction in minutes of arc ( ).
2. Enter the bottom of the graph with the factor just obtained and follow the arc around to intersect the line labeled with the value of Zn-track.
3. Follow the vertical line down from the point obtained in Step 2 to get the correction to Ho with the given sign according to a turn to the left or to the right.

Figure 16-14. Wander Correction Tables.

Wander Error

A change in track can be produced by changes in the wind velocity, by heading changes between limits of the autopilot, by heading changes produced from changing magnetic variation, and by heading changes derived from pilot manual steering errors. As with the Coriolis force and rhumb line errors, correction tables have been developed for wander error. Values extracted from the wander correction table, shown in figure 16-14, are to be applied to the Ho.

Use the following information as entering arguments for the determination of the correction taken from the table:

The heading at the beginning of the observation was 079.3°.

The heading at the end of the observation was 081.3°.

The observation was taken over a 2-minute period.

The groundspeed was 450 knots.

The true azimuth of the body was 130°.

Following the instructions shown at the bottom of the table, enter the numerical portion of the table with the values of groundspeed and the change of track per 2 minutes. In this case, the groundspeed is 450 knots and the change in track per 2 minutes is 2°. Since the heading at the end of the observation is greater than the heading at the beginning, the change is 2° to the right. Notice that you must know whether the change is to the right or to the left to determine the sign of the correction. The factor obtained from the table is $12 \times 2 = 24$.

Next, enter the graph portion of the table with the value of the factor (24) and the value of the azimuth of the body minus the value of track. The graph is so constructed that it must be entered with Zn − Tr. In this case, the azimuth is 130° minus a track of 080°; the value thus determined is 050°. Following the rules set down in steps two and three at the bottom of the table, the correction found is 19′. Since the change in track is to the right, the correction is subtracted from the Ho. This is determined by referring to the signs shown at the ends of the arc in the table. Figure 16-15 shows the effect of this correction.

If the heading and airspeed are the same at the beginning and the end of a shooting period, there will be no wander error. This

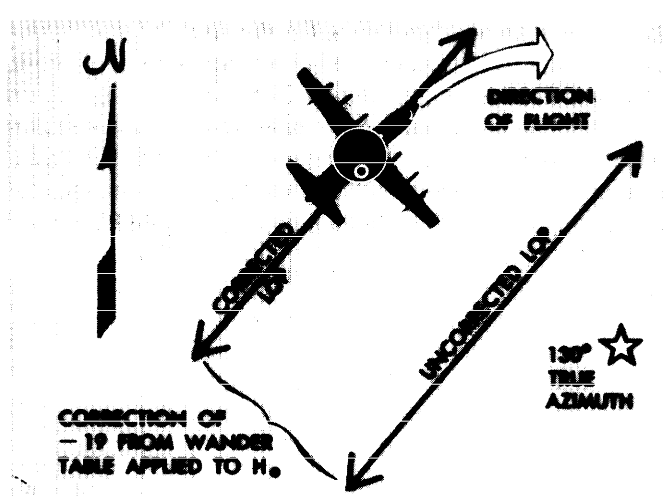


Figure 16-15. Wander Correction Applied to H_O.

is assuming that a change in heading produces an equal change in track, and a change in airspeed produces an equal change in groundspeed. However, this only applies if the body is continuously collimated during the observation time.

The amount of force applied over a given time to displace the liquid, and subsequently the bubble, in one direction will be equalized by an amount of force over a given time in the opposite direction to bring the aircraft back to its original heading. Therefore, if the heading (track) and airspeed (groundspeed) are the same at the beginning and end of a shooting, there will be no acceleration error caused by heading or airspeed changes, and no correction is necessary for wander or groundspeed change (a constant wind is assumed over the shooting period).

Instrument Error

Index error is usually the largest mechanical error in the sextant. This error is caused by improper alignment of the index prism with the altitude counter. No matter how carefully a sextant is handled, it is likely to have some index error. If the error is small, the sextant need not be readjusted; rather, each Hs can be corrected by the amount of the error. This means that the index error of the sextant must be known to obtain an accurate celestial LOP.

Another mechanical error found in sextants is backlash. This is caused by excessive play in the gear train connecting the index prism to the altitude counter.

Usually, index and backlash errors are nearly constant through the altitude range of the sextant. Therefore, if the error at one altitude setting is determined, the correction can be applied to any Hs or Hc. The correction is of equal value to the error but of opposite sign.

The sextant should be checked on the ground before every flight during which the navigator expects to rely on celestial observations. Preflighting the sextant can determine the sextant error of an individual instrument. The sextant error can also be determined in flight and a correction can be applied to the precomp to compensate for the error. To determine the error and correction in flight, one must have a celestial LOP, a Zn, and the actual (or best known) position of the aircraft at the same time. Refer to figure 16-16. The fix symbol represents the best known position at the time of the celestial LOP.

To determine the actual value of the correction, measure the shortest distance between the position and the LOP. This tells you how many minutes of arc (nautical miles) the Ho must be adjusted on subsequent shots to get an accurate LOP (in this case, the value is 10′). To determine whether this value must be added or subtracted, note whether the LOP needs to be adjusted toward the Zn or away from the Zn. Remember the rule HOMOTO? It applies here, too. If the LOP needs to be moved towards the Zn in order to be made more accurate, the Ho needs to be made larger—thus the correction is added to the Ho to make the Ho value increase. If the LOP needs to be moved away from the Zn, the correction will be subtracted from the Ho to make the Ho less. In figure 16-16, the LOP needs to be moved 10 miles toward the Zn in order to be accurate; thus, the sextant error correction is + 10 and can be used on subsequent shots take by the same sextant.

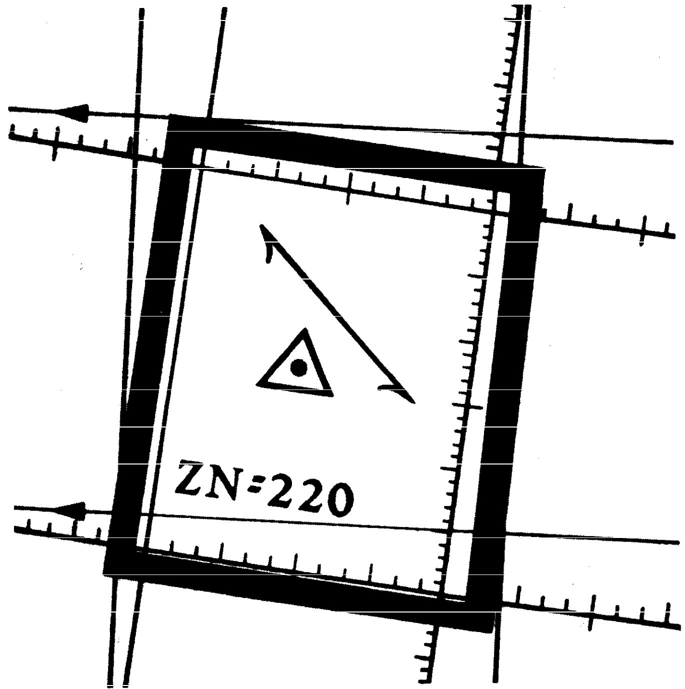


Figure 16-16. Determining Sextant Error Correction.

An important thing to remember is that the sextant error correction assumes conditions will be consistent. As a technique, it is wise to obtain several LOPs with a sextant, noting the sextant errors on each, before establishing a value to be carried on the precomp. Once using that correction, make sure you use the same sextant. You may find your sextant error will change during flight, which is usually a result of improper collimation techniques. As long as that error is changing consistently, you may change your sextant error correction accordingly.

Chapter 17

GRID NAVIGATION

The original purpose of grid navigation was to ease the difficulties facing the navigator during high latitude flights. Grid navigation has since been found helpful at all latitudes. This is particularly true on long routes because a great circle course is flown whenever grid is used for a heading reference. Grid is simply a reorientation of the heading reference; it does not alter standard techniques for obtaining fix information.

PROBLEMS ENCOUNTERED IN POLAR NAVIGATION

Two factors peculiar to polar areas which make steering more difficult than usual are (1) the magnetic compass becomes highly unreliable, and (2) geographic meridians converge at acute angles. The combined effect of these two factors makes steering by conventional methods difficult if not impossible. Each factor is examined below.

Unreliability of Magnetic Compass

Maintaining an accurate heading in high latitudes is difficult when a magnetic compass is used as the heading indicator. Built to align itself with the *horizontal* component of the Earth's magnetic field, the compass instead must react to the strong *vertical component* which predominates near the magnetic poles. Here, the horizontal component is too weak to provide a reliable indication of direction. As a result, compass performance becomes sluggish and inaccurate. The situation is further aggravated by the frequent magnetic storms in the polar regions which shift the magnetic lines of force.

But even if these conditions did not exist, the mere proximity of the magnetic poles would sharply reduce compass usefulness. While the aircraft may fly a straight course, the compass indicator would swing rapidly, faithfully pointing at a magnetic pole passing off to the left or right. (To cope with the unreliable magnetic compass, we will use gyro information for our heading inputs.)

A similar difficulty arises from the manner in which geographic meridians sharply converge at the true poles.

Problem of Converging Meridians

The nature of the conventional geographic coordinate system is such that all meridians converge at the poles. Each meridian represents a degree of longitude; each is aligned with true north and true south. On polar charts, the navigator encounters one degree of change in true course for each meridian crossed; thus, the more closely the aircraft approaches a pole, the more rapidly it crosses meridians. Even in straight-and-level flight along a great circle course, true course can change several degrees over a short period of time. The navigator is then placed in the extremely peculiar position of having to constantly change the aircraft's magnetic heading in order to maintain a straight course.

For precision navigation, such a procedure is clearly out of the question. Notice in figure 17-1 that the course changes 60° between A and B, and much nearer the pole, between C and D, it

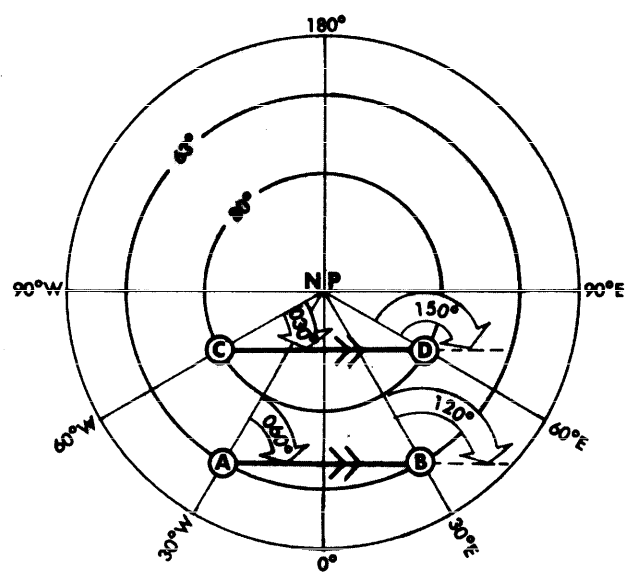


Figure 17-1. Converging Meridians.

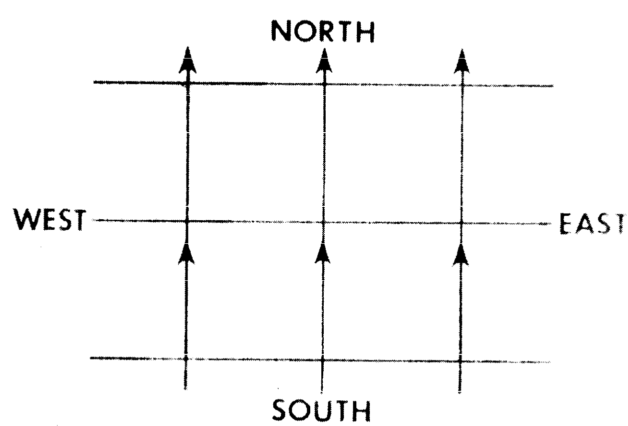


Figure 17-2. USAF Grid Overlay.

Figure 17-3. True Direction of Great Circle Course Changes.

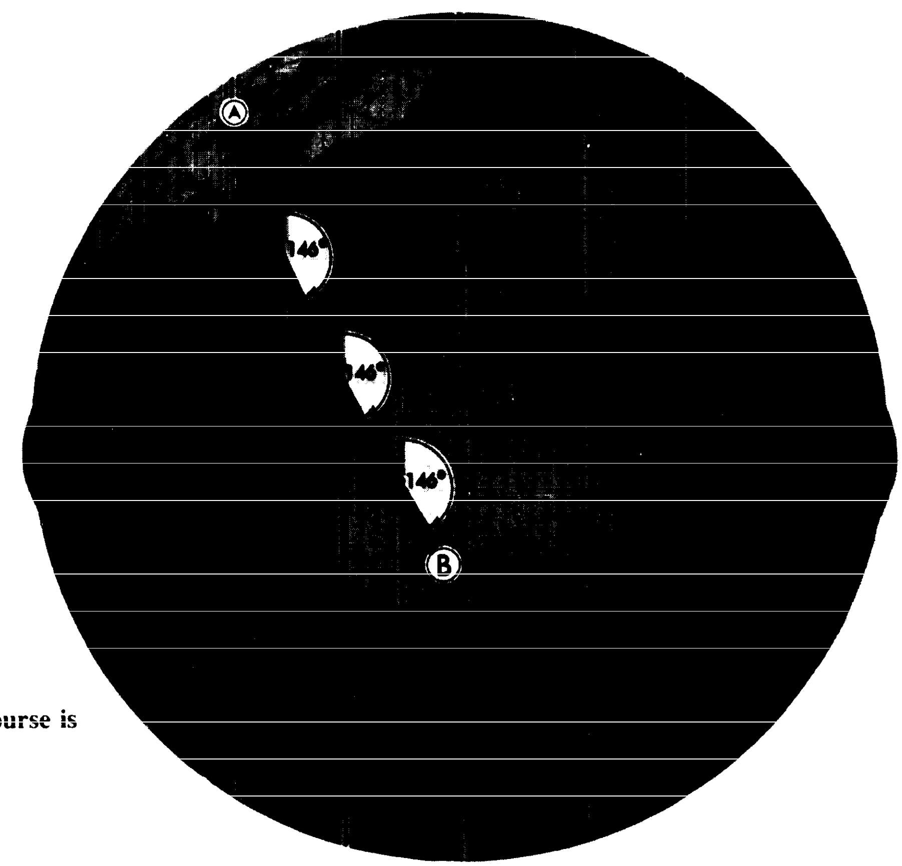


Figure 17-4. Grid Direction of Great Circle Course is Constant.

changes 120°. To cope with the problem of converging meridians, we will use the USAF Grid Overlay.

GRID CHART PROJECTIONS

The three polar projections most commonly used in polar areas for grid navigation are the transverse Mercator, the polar stereographic, and the polar gnomonic. The transverse Mercator and polar stereographic projections are used in flight; the polar gnomonic is used only for planning. The Lambert conformal projection is the one most commonly used for grid flight in subpolar areas. The division between polar and subpolar projections varies among the aeronautical chart series. For example, the division is at 70° of latitude for the JN series, at 80° of latitude for the ONC and PC series, and at 84° of latitude for the 1510 AIR series.

USAF GRID OVERLAY

The graticule of the USAF grid overlay eliminates the problem of converging meridians (figure 17-2). It is a square grid and, though its meridians are aligned with grid north (GN) along the Greenwich meridian, they do not converge at grid north.

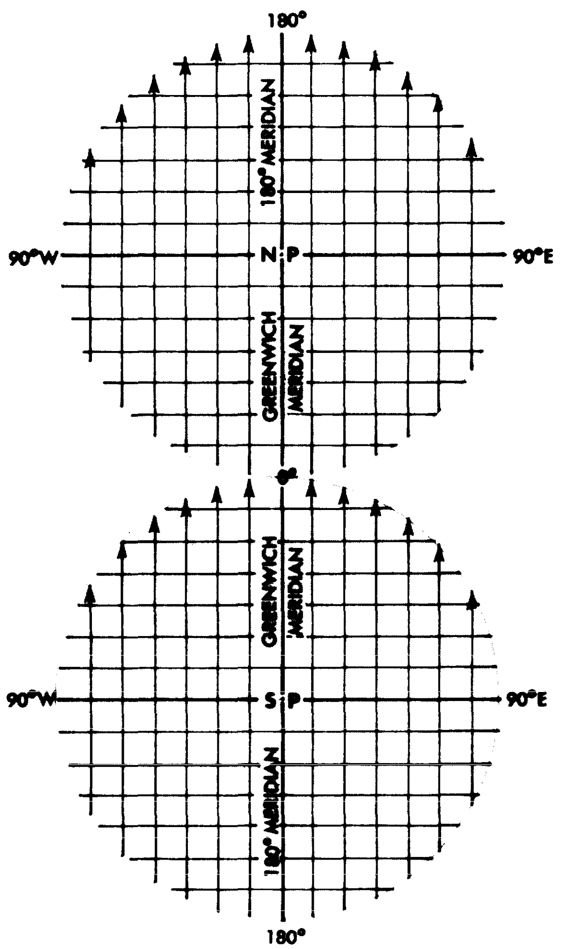


Figure 17-5. Orientation of Grid North.

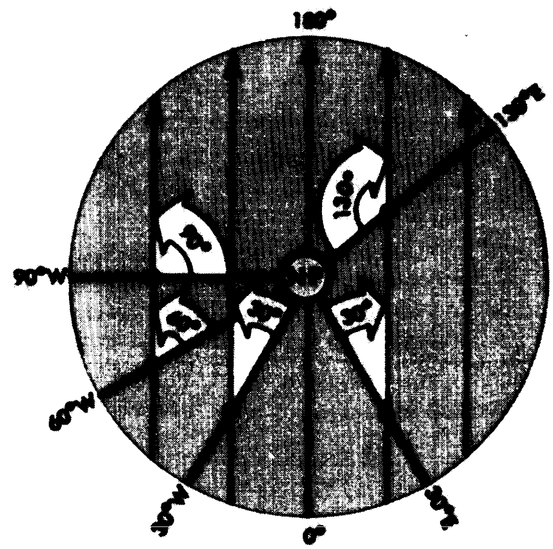


Figure 17-6. Grid North/True North Relationship on Typical Polar Projection.

While the USAF grid overlay can be superimposed on any projection, it is most commonly used with the polar stereographic (for flights in polar areas) and the Lambert conformal (for flights in subpolar areas). This is because a straight line on these projections approximates a great circle. In figures 17-3 and 17-4, you can see that, as the great circle course crosses the true meridians, its true direction changes but its grid direction remains constant.

All grid meridians are parallel to the Greenwich meridian, and true north along the Greenwich meridian is the direction of grid north over the entire chart as shown in figure 17-5.

Relationship of Grid North to True North

Because grid meridians are parallel to the Greenwich meridian, the angle between grid north and true north is governed by the navigator's longitude and the convergence factor of the chart.

Convergence Factors of 1.0. Figure 17-6 shows that charts having convergence factors of 1.0 display the grid north (GN) to true north (TN) relationship as a direct function of longitude. In the Northern Hemisphere at 30°W, grid north is 30° west of true north; at 60°W, GN is 60° west of TN. Similarly, at 130°E longitude, GN is 130° east of TN.

In the Southern Hemisphere, the direction of GN with respect to TN is exactly opposite.

Figure 17-7 illustrates the geometric relationship between grid north and the convergence of true meridians.

Convergence Factors of Less than 1.0. Figure 17-8 shows a chart with a convergence factor of less than 1.0, with a USAF grid overlay superimposed on it. The relationship between GN and TN on this chart is determined in the same manner as on charts with a convergence factor of 1.0. On charts with a convergence factor of less than 1.0, the value of the converg-

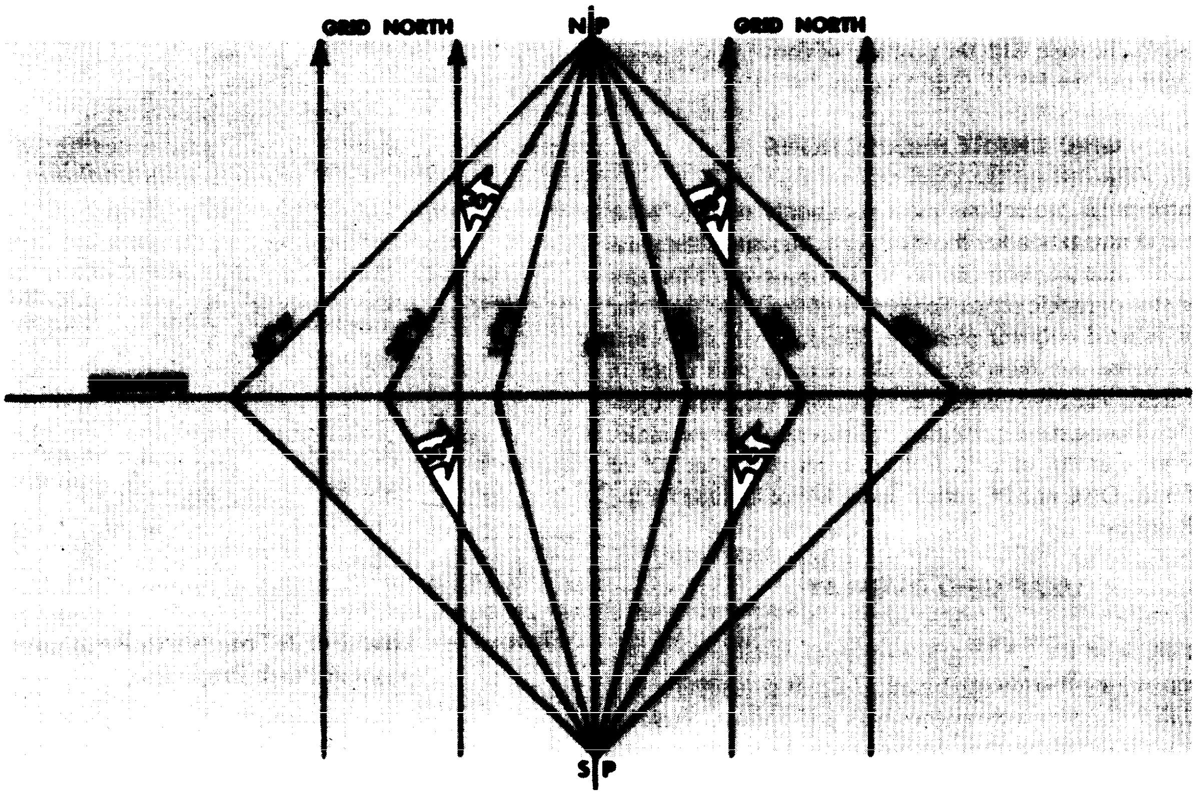


Figure 17-7. Grid North/True North Relationship in all Quadrants of the Sphere.

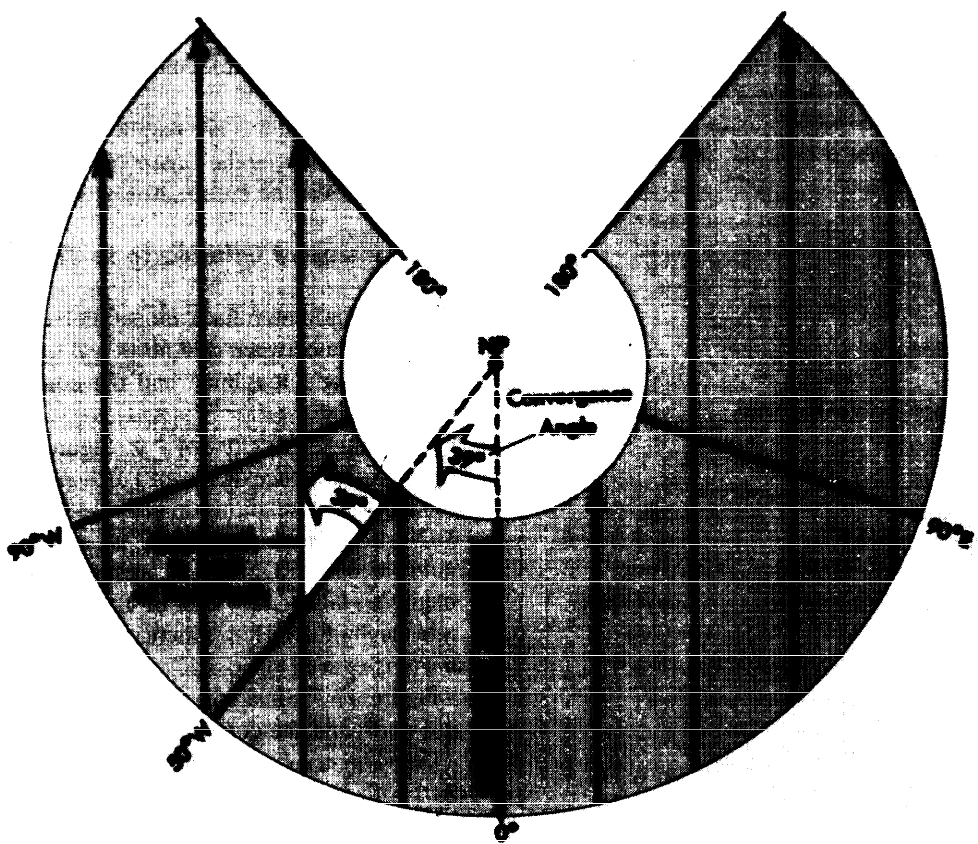


Figure 17-8. Grid Overlay Superimposed on Lambert Conformal (Convergence Factor 0.785).

ence angle at a given longitude is always smaller than the value of longitude, and is equal to the convergence factor times the navigator's longitude.

Relationship of Grid Direction to True Direction

The navigator uses the following formulas to determine grid direction.

In the Northern Hemisphere:

Grid direction = true direction + west longitude × convergence factor

Grid direction = true direction − east longitude × convergence factor

In the Southern Hemisphere:

Grid direction = true direction − west longitude × convergence factor

Grid direction = true direction + east longitude × convergence factor

Polar Angle

Polar angle can be used to relate true direction to grid direction. Polar angle is measured clockwise through 360° from GN to TN as illustrated in figure 17-9. It is simple to convert from one directional reference to the other by use of the formula:

Grid direction = true direction + polar angle.

To determine polar angle from convergence angle, apply the following formulas illustrated in figure 17-10.

In the Northwest and Southeast Quadrants:

Polar angle = convergence angle.

In the Northeast and Southwest Quadrants:

Polar angle = 360° − convergence angle.

Chart Transition

Since the relationship of the true meridians and the grid overlay on subpolar charts differs from that on polar charts because of different convergence factors, the overlays do not match when a transition is made from one chart to the other. Therefore, the grid course (GC) of a route on a subpolar chart will be different than the GC of the same route on a polar chart.

The chart transition problem is best solved during flight planning.

1. Select a transition point common to both charts.
2. Measure the subpolar GC and the polar GC.
3. Compute the difference between the GCs obtained in step 2. This is the amount the compass pointer must be changed at the transition point.
4. If the GC on the first chart is *smaller* than the GC on the second chart, *add* the GC difference to the compass pointer reading and reposition the compass pointer; if the GC on the first chart is *larger*, *subtract* the GC difference.

Rule: Small GC to larger GC; ADD
Larger GC to smaller GC; SUBTRACT

Example:

1. Chart transition from a subpolar to a polar chart.
2. GC on subpolar chart is 316°.

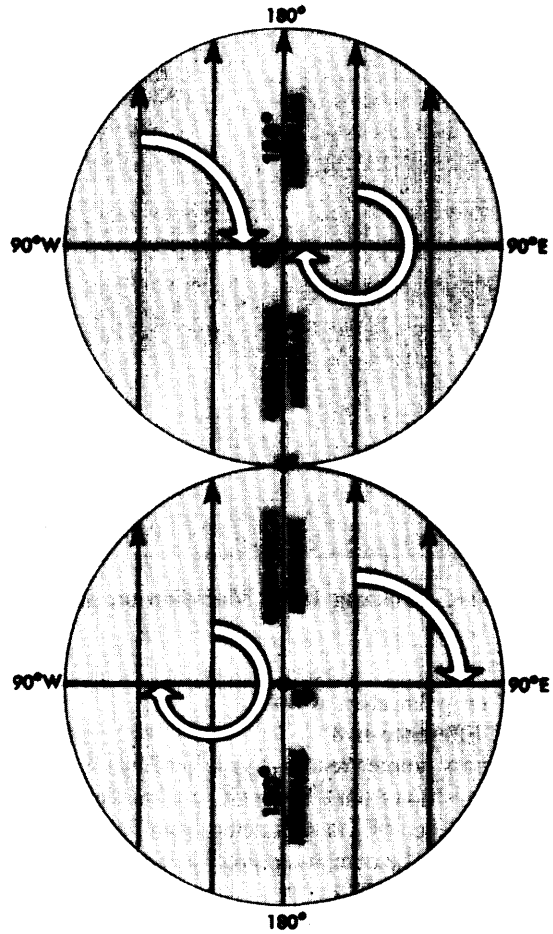


Figure 17-9. Polar Angle Measured Clockwise from Grid North to True North.

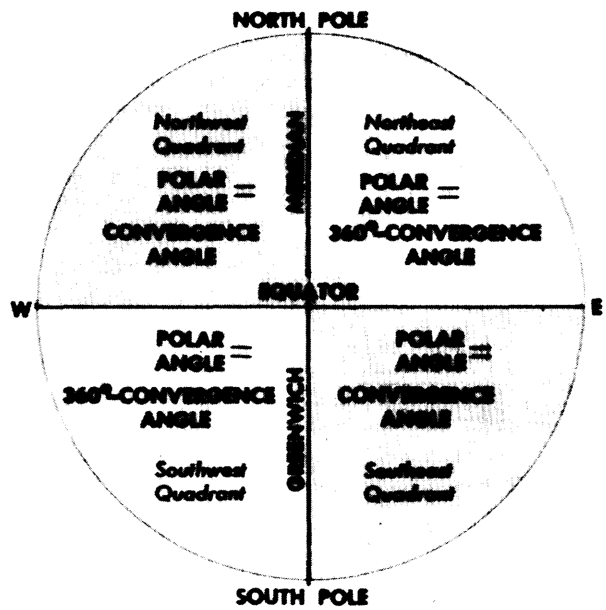


Figure 17-10. Polar Angle.

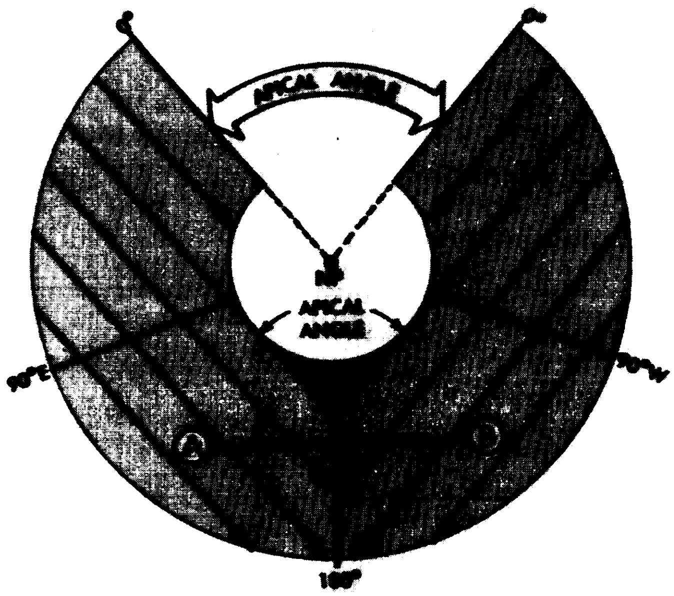


Figure 17-11. Crossing 180th Meridian on Sub-Polar Chart.

GC on polar chart is 308°.
GC difference is 8°

3. Compass pointer reading (grid heading) is 320°.

4. The transition from a larger GC to a smaller GC; therefore, the GC difference (8°) is subtracted from the compass pointer reading (320°). The compass pointer is then repositioned to the new grid heading (312°).

CAUTION

Do not alter the aircraft's heading; instead, reposition the compass pointer to the new grid heading.

Crossing 180th Meridian on Subpolar Chart

When a flight crosses the 180th meridian on a subpolar grid chart, the grid heading changes because of the convergence of grid meridians along this true meridian. When a navigator using a subpolar chart crosses the 180th meridian *on an easterly heading* (A to B in figure 17-11), *the apical angle must be subtracted* from the grid heading. Conversely, the *apical angle must be added* to the grid heading when on a westerly heading (B to A in figure 17-11). The apical angle can be measured on the chart at the 180th meridian between the converging GN references. The angle can also usually be found on the chart border. The angle also can be computed by use of the following formula:

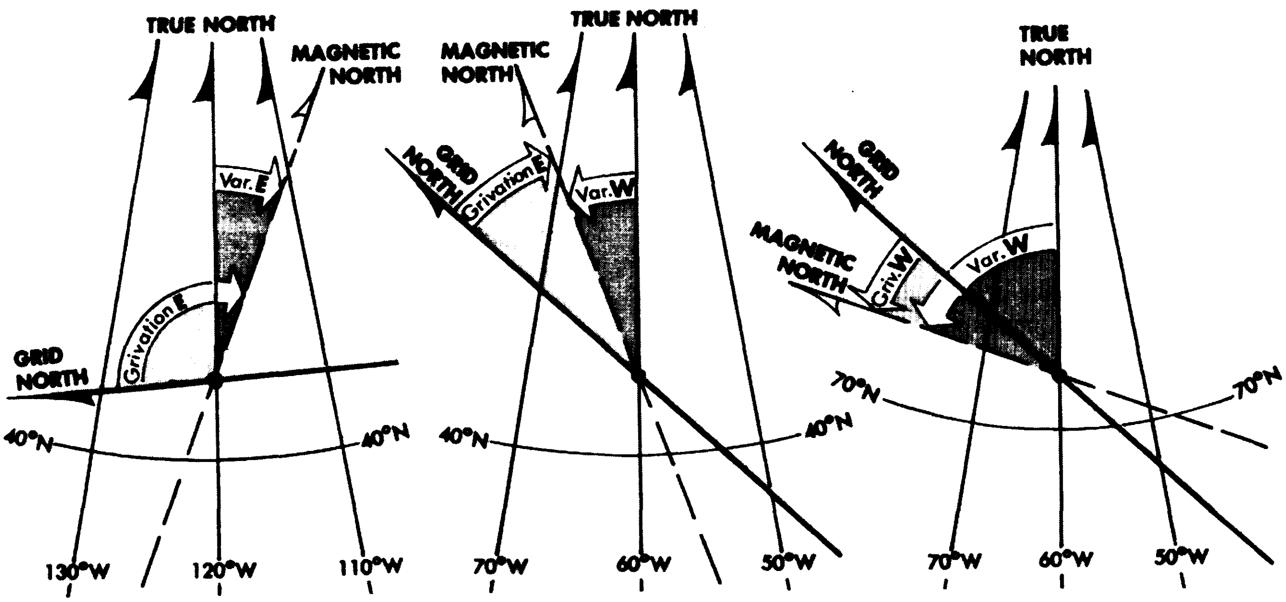


Figure 17-12. Grivation.

Apical angle = 360° − (360° × convergence factor).
Example:
Given: Chart convergence factor = .785
Find: Apical angle

$$\text{Apical angle} = 360° - (360° \times 0.785) = 360° - 283° = 77°$$

CAUTION

Do not alter the aircraft's heading when crossing the 180th meridian; instead, simply reposition the directional gyro compass pointer to the new grid heading.

Grivation

The difference between the directions of the magnetic lines of force and grid north is called grivation (GV). Grivation is similar to variation and used to convert magnetic heading to grid heading and vice versa. Figure 17-12 shows the relationship between GN, TN, and MN. Lines of equal grivation (isogrivs) are plotted on grid charts.

The formulas for computing grivation are:

$$\text{Grivation} = (-\text{W conv angle}) + \begin{matrix} +\text{W} \\ -\text{E} \end{matrix}\ \text{variation}$$

$$\text{Grivation} = (+\text{E conv angle}) + \begin{matrix} +\text{W} \\ -\text{E} \end{matrix}\ \text{variation}$$

In the Southern Hemisphere, reverse the signs of west and east convergence angles in the formula above. If grivation is positive, it is W grivation; if grivation is negative, it is E grivation. For example, if our variation is 17 degrees east and our convergence angle is 76 degrees west, using the formula:

Grivation = (− West conv angle) + (− East variation)
Grivation = (− 76) + (− 17) = −93
Grivation = 93° East

To compute magnetic heading from grid heading, use the formula:

$$\text{Magnetic heading} = \text{Grid heading} \begin{matrix} +\text{W} \\ -\text{E} \end{matrix} \text{grivation}$$

GYRO PRECESSION

To eliminate the difficulties imposed by magnetic compass unreliability in polar areas, the navigator disregards the magnetic compass in favor of a free-running gyro. Gyro steering is used because it is stable and independent of magnetic influence.

When used as a steering instrument, the gyro is restricted so its spin axis always remains horizontal to the surface of the Earth and is free to turn only in this horizontal plane. Any movement of a gyro spin axis from its initial horizontal alignment is called precession. The types of precession are:

1. Real precession.

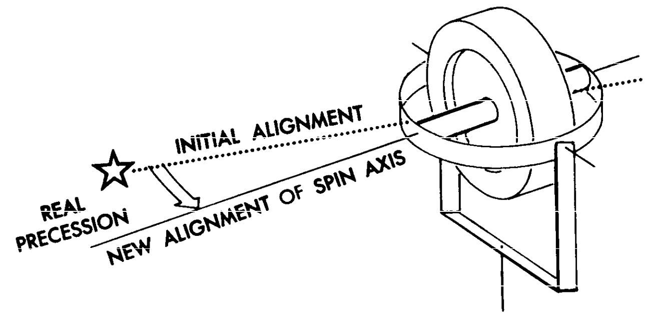


Figure 17-13. Real Precession.

2. Apparent precession, which includes:
   a. Earth rate precession.
   b. Transport precession.
   c. Grid transport precession.

Total precession is the cumulative effect of real and apparent precession.

Real Precession

Real precession, illustrated in figure 17-13, is the actual movement of a gyro spin axis from its initial alignment in space. It is caused by such imperfections as:

1. Power fluctuation.
2. Imbalance of the gyro.
3. Friction in gyro gimble bearings.
4. Acceleration forces.

As a result of the improved quality of equipment now being used, real precession or gyro drift is considered to be negligible. Some compass systems have a real precession rate of less than 1° per hour. Electrical or mechanical forces are intentionally applied by erection or compensation devices to align the gyro spin axis in relation to the Earth's surface. In this manner, the effects of gyro drift and apparent precession are eliminated and the gyro can then be used as a reliable reference.

Apparent Precession

The spin axis of a gyro remains aligned with a fixed point in space, while the navigator's plane of reference changes, making it *appear* that the spin axis has moved. Apparent precession is this *apparent* movement of the gyro spin axis from its initial alignment.

Earth Rate Precession. Earth rate precession is caused by the rotation of the Earth while the spin axis of the gyro remains aligned with a fixed point in space.

Earth rate precession is divided into two components. The tendency of the spin axis to tilt up or down from the horizontal plane of the observer is called the vertical component. The tendency of the spin axis to drift around laterally; that is, to change in azimuth, is called the horizontal component.

Generally, when Earth rate is mentioned, it is the horizontal component which is referred to, since the vertical component is of little concern to the navigator.

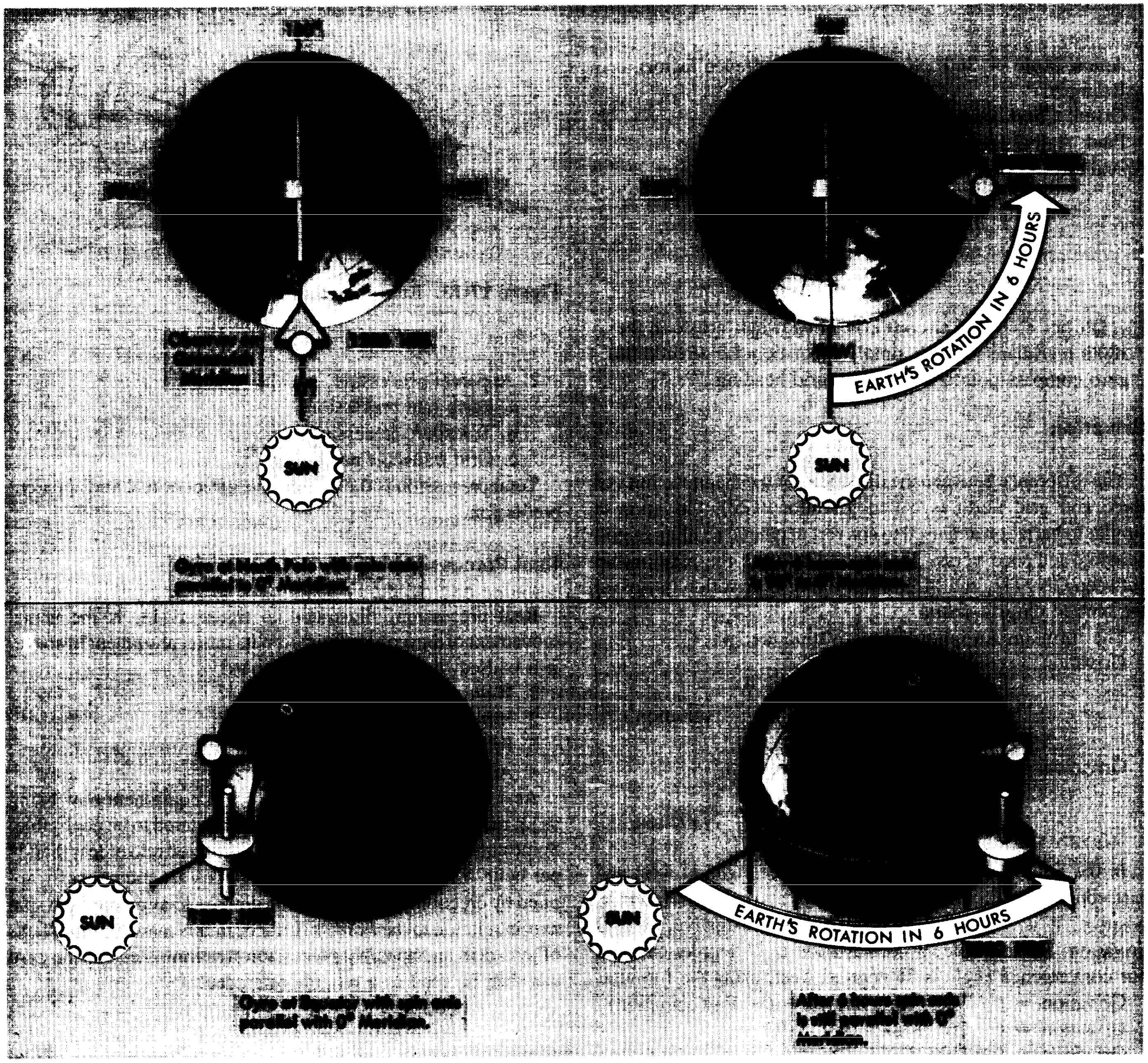


Figure 17-14. Initial Location of Gyro Affects Earth Rate Precession.

A gyro, located at the North Pole with its spin axis initially aligned with a meridian, appears to turn 15.04° per hour in the horizontal plane, because the Earth turns 15.04° per hour. As shown in figure 17-14A, the apparent relationship between the Greenwich meridian and the gyro spin axis will change by 90° in 6 hours, though the spin axis is still oriented to the same point in space. Thus, apparent precession at the pole equals the rate of Earth rotation.

At the equator, as shown in figure 17-14B, no Earth rate precession occurs *in the horizontal plane* if the gyro spin axis is still aligned with a meridian and is parallel to the Earth's spin axis.

When the gyro spin axis is turned perpendicular to the meridian, as illustrated in figure 17-15, maximum Earth rate precession occurs *in the vertical component*. But the directional gyro does not precess vertically because of the internal restriction of the gyro movement in any but the horizontal plane. Thus, for practical purposes, Earth rate precession is only that precession which occurs in the horizontal plane. Figure 17-15 illustrates Earth rate precession at the equator for 6 hours of time.

Earth rate precession varies between 15.04°/hr at the poles and 0°/hr at the equator. It is computed for any latitude by multiplying 15.04° times the sine of the latitude.

For example, at 30° N, the sine of latitude is 0.5. The horizontal component of Earth rate is, therefore, 15°/hour right × −0.5 or 7½°/hour right at 30°N as shown in figure 17-16.

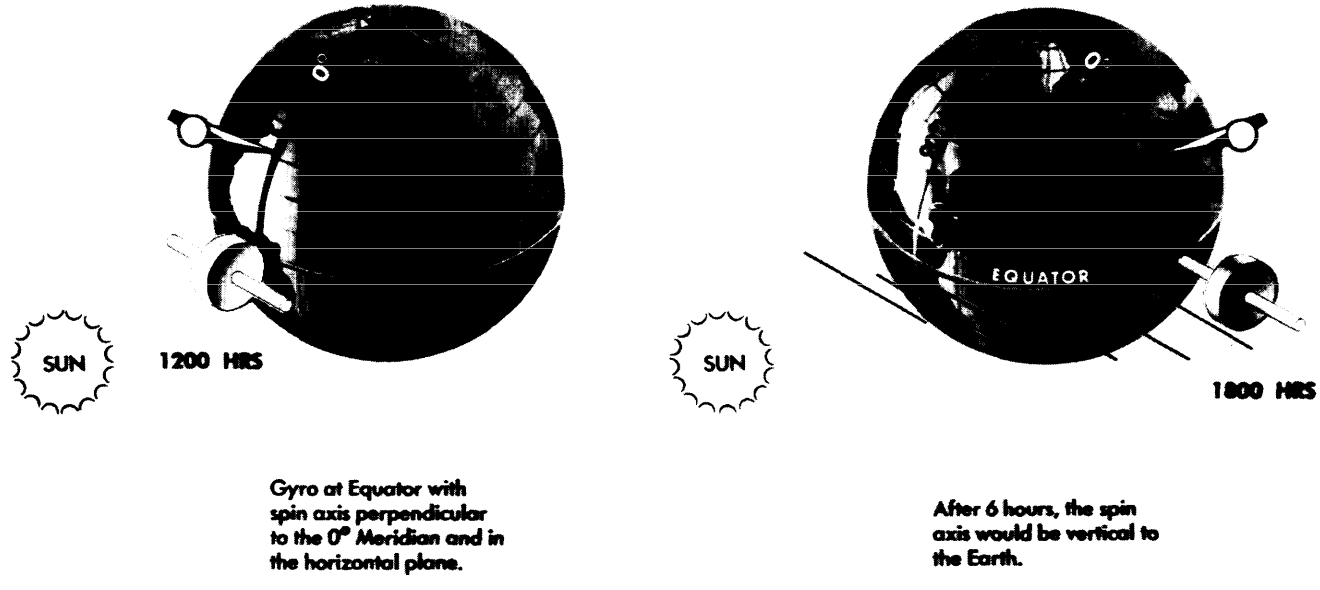


Figure 17-15. Direction of Spin Axis Affects Earth Rate Precession.

Obviously, if the gyro is precessing relative to the steering datum of grid or true north, an aircraft steered by the gyro will be led off heading steadily at the same rate. To compensate for this precession, an artificial real precession is induced in the gyro to counteract the Earth rate. At 30° north latitude, Earth rate precession is equal to 15° $\times$ sin lat (.5) = 15 $\times$ .5 or 7.5° per hour to the right.

Hence, if at 30° north latitude a real precession of 7.5° left per hour is induced in the gyro, it will exactly balance and offset Earth rate effect. In ordinary gyros, a weight is used to produce this effect but, since it is fixed, the correction is good for only one latitude. The latitude chosen is normally the mean latitude of the area in which the aircraft will operate. Gyros, such as that of the N-1 compass system, have a latitude setting knob which the navigator may use to adjust for the Earth rate corrections.

Earth Transport Precession (Horizontal Plane). This form of apparent precession results from transporting a gyro from one point on the Earth's surface to another. The gyro spin axis

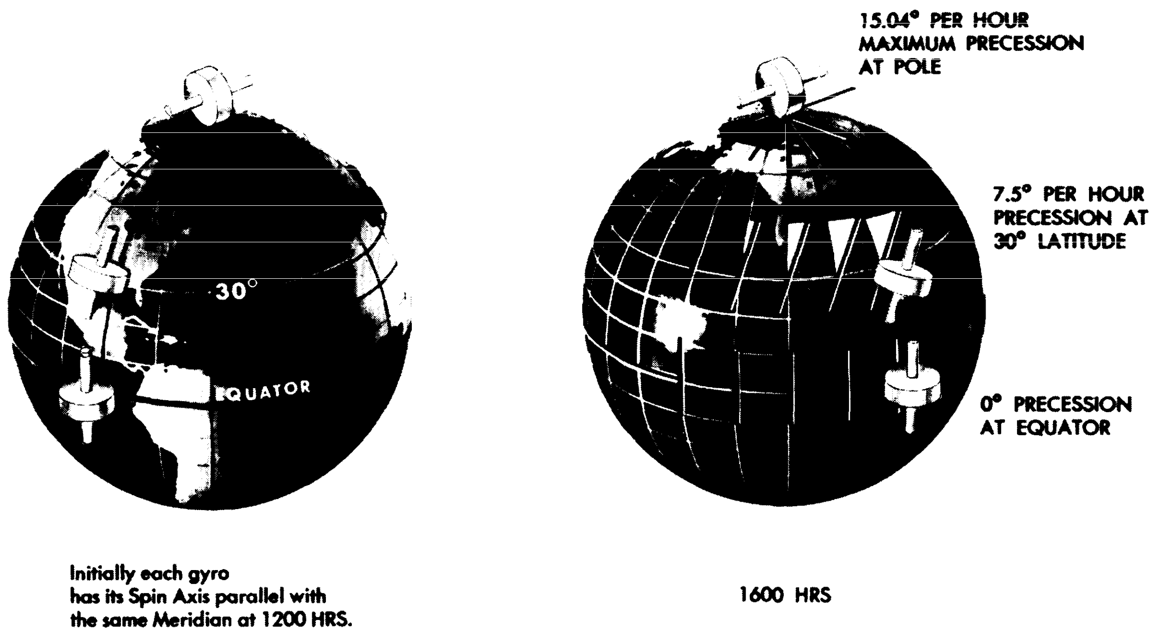


Figure 17-16. Earth Rate Precession Varies According to Latitude.

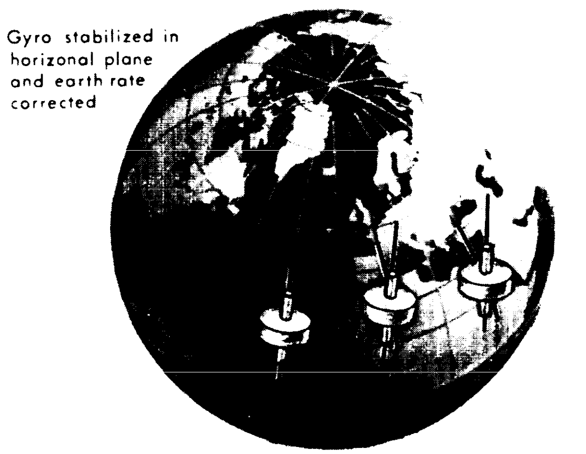


Figure 17-17. Earth Transport Precession.

appears to move because the aircraft, flying over the curved surface of the Earth, changes its attitude in relation to the gyro's fixed point in space (figure 17-17).

Earth transport precession causes the gyro spin axis to move approximately 1 degree in the horizontal plane for each true meridian crossed. This effect is avoided by using grid north as the steering reference.

Grid Transport Precession. Grid transport precession exists because meridian convergence is not precisely portrayed on charts. The navigator wants to maintain a *straight-line* track, but the gyro follows a great circle track which is a *curved* line on a chart. The rate at which the great circle track curves away from a straight-line track is *grid transport precession.* This is proportional to the difference between convergence of the meridians as they appear on the Earth and as they appear on the chart, and the rate at which the aircraft crosses these meridians.

Summary (Types of Precession)

Real precession is caused by friction in the gyro gimbal bearings and dynamic unbalance. It is an unpredictable quantity and can only be measured by means of heading checks.

Earth rate precession is caused by the rotation of the Earth. It can be computed in degrees per hour with the formula: 15.04 × sine latitude (for practical purposes 15°/hr is used). It is to the right in the Northern Hemisphere; to the left in the Southern Hemisphere. All gyros are corrected to some degree for this precession, many by means of a latitude setting knob.

Earth transport precession (horizontal plane) is an effect caused by using true north as a steering reference. It can be computed by using the formula (change longitude/hr × sine mid-latitude). The direction of the precession is a function of the true course of the aircraft. If the course is 0° - 180°, precession is to the right; if the course is 180° - 360°, precession is to the left. This precession effect is avoided by using grid north as a steering reference.

Grid transport precession is caused by the fact that the great circles are not portrayed as straight lines on plotting charts. The navigator tries to fly the straight pencil-line course, the gyro a great circle course. The formula for grid transport precession is change longitude/hr (sin lat-η), where the η is the map convergence factor. The direction of this precession is a function of the chart used, the latitude, and the true course. Direct substitution into the formula will produce an answer valid for easterly courses; such as, 0° - 180°. For westerly courses, the sign of the answer must be reversed.

GYRO STEERING

Gyro steering is much the same a magnetic steering, except that grid heading is used in place of true heading. Grid heading has the same relation to grid course as true heading has to true course.

The primary steering gyro in most aircraft provides directional data to the autopilot and maintains the aircraft on a preset heading. When the aircraft alters heading, it turns about the primary gyro while the gyro spin axis remains fixed in azimuth. If the primary gyro precesses, it causes the aircraft to change its heading by an amount equal to the precession.

THE GYRO LOG

The gyro log is a record of the precession occurring in the gyro, the primary steering instrument that is being used to direct the aircraft.

At the beginning of a grid navigation leg, the navigator turns the aircraft to the departure magnetic heading (MH). The departure MH is computed by applying the grivation at departure to the grid heading (grid course + drift) at departure. As soon as possible after departure, a celestial heading check is obtained to determine the aircraft's actual grid heading (GH). The heading is then set into the aircraft's gyro compass. In our example, figure 17-18, the GH is 244. The gyro is set to 244, and the gyro reading (GR) is also 244. For the heading shot, the navigator records the time of the observation (1655) in block 1 and the celestial heading (244) in blocks 2 and 3. Block 4 and 5 are zero because there is no information to predict the precession and, therefore, it is assumed to be zero.

At 1700, the navigator obtains an initial grid fix, with the appropriate information in the navigator's log. Refer to figure 17-19. For the alter heading (A/H) after the fix, the precession correction for the time of the next leg (1/2 PREC CORR) is assumed to be zero, and the initial grid heading (A GY H on log)

GYRO STEERING DATA SHEET

NAME		Z DATE		MISSION NO	ACFT NO
TIME 1.	1655	1740	1820		
GH 2.	244	250	214		
PRIMARY GYRO GR 3.	244	246	211		
PRIMARY GYRO PREC 4.	ϕ	+4	+3		
PRIMARY GYRO RATE 5.	ϕ	6R	4½R		

Fig 17-18. Gyro Steering Data Sheet.

MISSION INFLIGHT LOG

TIME	POS SYM	PRESENT POSITION	T.C. OR G.C.	W/V / DC	T.H. OR G.H.	VAR OR ½PREC CORR	M.H. OR A GY H	DEV	CH	TAS	AIR DIST.	DIST. / TIME	GS	NEXT CHECK PT / ACTION PT	DIST	TIME	ETA	TEMP / ALT	REMARKS
1700	Δ			360/25	244					420								33.0	
	A/H		243	+3	246	ϕ	246			420			430	B / C	170	+24	1724 / 1800		1705 GR 246 DOP
1740	Δ			340/35	250					420									
	A/H		242	+5	247	-1	246			420			422	C	140	+20	1800		1742 GR 246 DOP
1800	⊙		242	340/35 / +5	247	-1	246			420									
	A/H		210	340/35 / +4	214	-3	211			420			440	D	257	+35	1835		1800 GR 211
1820	Δ			320/45	214					420									
	A/H		211	+6	217	-1½	215½			420			432	D	115	+16	1836		

Figure 17-19. Mission In-flight Log.

is 246. The aircraft should be turned to this heading as soon as practicable.

The navigator should establish a pacing plan for obtaining heading shots, rating the gyro, and fixing. the gyro log and navigator's log illustrated were completed while maintaining 40-minute pacing.

At 1740, another heading shot determines a grid heading of 250, but the gyro reading indicates 246. The gyro is immediately reset to 250. In block 2, the navigator records the grid heading and in block 3, the gyro reading. The navigator now computes the gyro precession (GP), by use of the formula:

GP (block 4) = GH − GR

250 − 246 = 4° precession for the gyro.

Because this precession occurred over a 40-minute period, the hourly precession rate is 6° per hour.

When gyro precession is plus, precession is to the right; when it is minus, precession is to the left. To compute the average heading flown for this period of time, the following formula may be used:

Average heading = 246 + (1/2 = + 4°) = 246 + 2° = 248.

Average gyro heading + 1/2 precession. A fix is taken at 1740 and a new grid course is obtained from this position. The new grid course is 242 and, correcting for drift, the grid heading becomes 247. The precession for the next time period can be forecasted and compensated for. For normal 40-minute pacing, the gyro would precess 4° and, if initial heading were 247, at the end of 40 minutes, the grid heading would be 4° greater or 251, and the average heading would be 249°. In order to fly an average heading of 247, the GH must be decreased by 2 degrees or − 1/2 the precession for the next time period. For the actual navigator log, a scheduled alter heading is planned for 1800, so that the time period is 20 minutes. The expected precession for the 20 minute period is + 2, and − 1/2 precession for the next period becomes:

− 1/2 precession = − 1/2 × (+2°) = −1° and average gyro heading = 247 − 1 = 246.

Precession must be accounted for in the heading outbound from 1800 alter heading. The average grid heading on the next leg is 214. The 40-minute fixing schedule will be continued and the next fix will be at 1820. We must correct for 20 minutes of precession. The precession correction for this leg = − 1/2 × 2° = − 1 and the outbound heading would be 214 − 1 = 213. However, the gyro has also precessed since the reset at 1740 and this precession must not be overlooked. For the 20-minute time period from 1740 to 1800, the gyro has processed at 6° right per hour, + 2°, and the actual grid heading is 2° larger than the gyro reading. If a turn is made to a gyro reading of 213 at 1800, the actual grid reading would be 215. In order to fly an average heading of 214, the outbound heading must be decreased by a total of 3° or turn to a gyro reading of 211 at 1800.

At 1820, the navigator obtains a fix and heading check, and resets the gyro. The new precession rate is 4 1/2° right precession per hour. The next time period is again 40 minutes, so that − 1/2 precession correction for this leg = − 1/2 × 3° = − 1 1/2° which is applied to the grid heading of 217 to give an outbound heading of 215 1/2, and the aircraft should be turned to this heading as soon as possible.

After the navigator has taken the final grid fix, the gyro compass can be set and slaved to the magnetic heading.

FALSE LATITUDE

A second method of compensating for precession while in flight involves the use of false latitude inputs into the gyro compass. Most gyro compasses have a latitude control which allows the navigator to compensate for Earth rate precession (ERP). Normally, the latitude control is set to the actual latitude of the aircraft. However, other values may be set. For example, if the aircraft is at 30° north and the latitude control knob is set to 70° north, the gyro will overcorrect for ERP. Since ERP is right in the Northern Hemisphere, the correction will be to the left. Thus, setting a higher than actual latitude will correct for right precession over and above that for ERP.

Since ERP = 15°/hr × sine latitude, a table such as figure 17-20 can be developed to use this procedure.

FALSE LATITUDE CORRECTION TABLE

NORM LAT (N)	OBSERVED PRECESSION RATE O/HR										EARTH RATE
	1°		2°		3°		4°		5°		
	−	+	−	+	−	+	−	+	−	+	
75	64	↑	56	↑	51	↑	44	↑	39	↑	14.5
70	61	90	54		48		42		37		14.1
65	57	75	51		45		40		35		13.6
60	53	69	47	90	42		37		32		13.0
55	49	63	43	73	38	90	34		29		12.3
50	44	56	39	64	35	75	30	90	26		11.5
45	39	51	35	57	30	65	26	77	22	90	10.6
40	35	45	31	51	26	57	22	65	18	77	9.4
35	30	40	26	45	22	51	18	57	14	65	8.6
30	26	35	22	39	18	44	14	50	10	56	7.5
25	21	29	17	34	13	39	9	44	5	49	6.3
20	16	24	12	28	8	33	4	37	0	43	5.1
15	11	19	7	23	3	27	0	32	4	36	3.9
10	6	14	2	18	2	22	5	26	9	30	2.6
5	1	9	4	13	7	17	10	21	16	25	1.3
0	4	4	8	8	12	12	16	16	20	20	0

REVERSE N/S SWITCH IN OUTLINED COLUMNS

INSTRUCTIONS
(FOR FALSE LATITUDE TABLE)

ENTER WITH DESIRED LATITUDE SETTING AND THE OBSERVED HOURLY PRECESSION RATE.

NOTE

DIRECTION OF PRECESSION IS IMPORTANT: SELECT CORRECT COLUMN.

IN SOUTH LAT., REVERSE +/−COLUMN HEADINGS.

EXAMPLES

NORMAL LATITUDE SETTING 65 NORTH: PRECESSION+3 DEGREES PER HOUR. FALSE LATITUDE SETTING =90 DEGREES NORTH.

NORMAL LATITUDE SETTING 10°NORTH: PRECESSION−4 DEGREES PER HOUR. FALSE LATITUDE SETTING=5 DEGREES SOUTH.

Figure 17-20. False Latitude Correction Table.

SUMMARY

The USAF grid overlay and the free-running gyro are used to overcome the difficulties of converging meridians and the unreliability of the magnetic compass when navigating in high (polar) latitudes. When gyro steering is used, the navigator maintains a gyro log and records the precession of both the primary and secondary gyros. The gyro log provides the navigator with the information necessary to predict values when it is impossible to obtain heading checks because of overcast conditions or twilight. By maintaining a log on the secondary gyro, the navigator can change gyros in case of malfunction of the primary gyro. He or she uses the information recorded in the gyro log in conjunction with the navigator's log to plot position and compute winds, headings, alterations, and ETAs. The navigator must execute the proper correlation between the navigator's log and the gyro log to accomplish grid navigation successfully.

Chapter 18

OVERWATER AIDS

This chapter deals with navigation using pressure differential techniques and navigation using LORAN and Consol.

PRESSURE DIFFERENTIAL TECHNIQUES

Pressure differential flying is based on a mathematically derived formula. The formula predicts wind flow based on the fact that air moves from a high pressure system to a low pressure system. This predicted wind flow, the geostrophic wind, is the basis for pressure navigation. The formula for the geostrophic wind (modified for a constant pressure surface) combined with in-flight information makes available two aids to navigation: Bellamy drift and the pressure line of position (PLOP).

Both are obtained by substituting specific in-flight information into the basic formula. Bellamy drift gives information about aircraft track by supplying net drift over a past period. Using the same basic information, the PLOP provides a line of position that is as valid and is used as any other type of LOP.

Constant Pressure Surface

To understand pressure differential navigation, one should be aware of some basics about the constant pressure surface. The constant pressure surface is one on which the pressure is the same everywhere, even though its height above sea level will vary from point to point as shown in figure 18-1. Therefore, a constant reading will be indicated on the pressure altimeter. A constant pressure surface is shown on a constant pressure chart (CPC) as lines which connect points of equal height above sea level. These lines are referred to as contours (figure 18-2) and have the same significance as contour lines on maps of land areas. The intersections of mean sea level with constant pressure surfaces forms isobars. A comparison of isobars and contours is shown in figure 18-3. The geostrophic wind will blow along and parallel to the contours of a constant pressure chart just as it blows along and parallel to the isobars of a constant level chart.

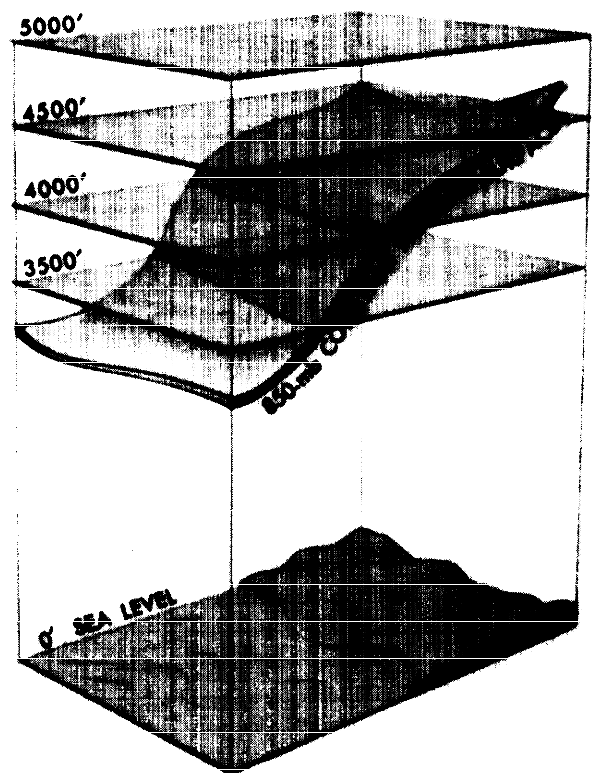


Figure 18-1. Constant Pressure Surface.

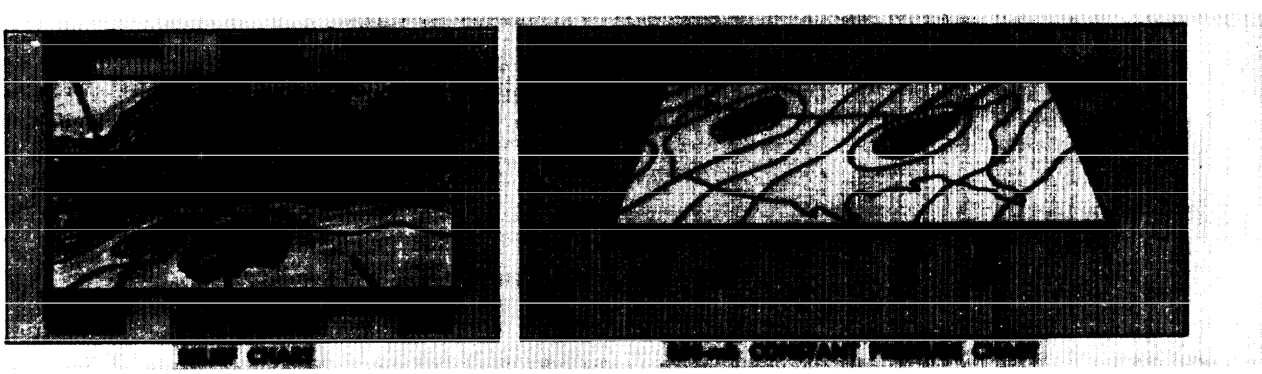


Figure 18-2. Contours.

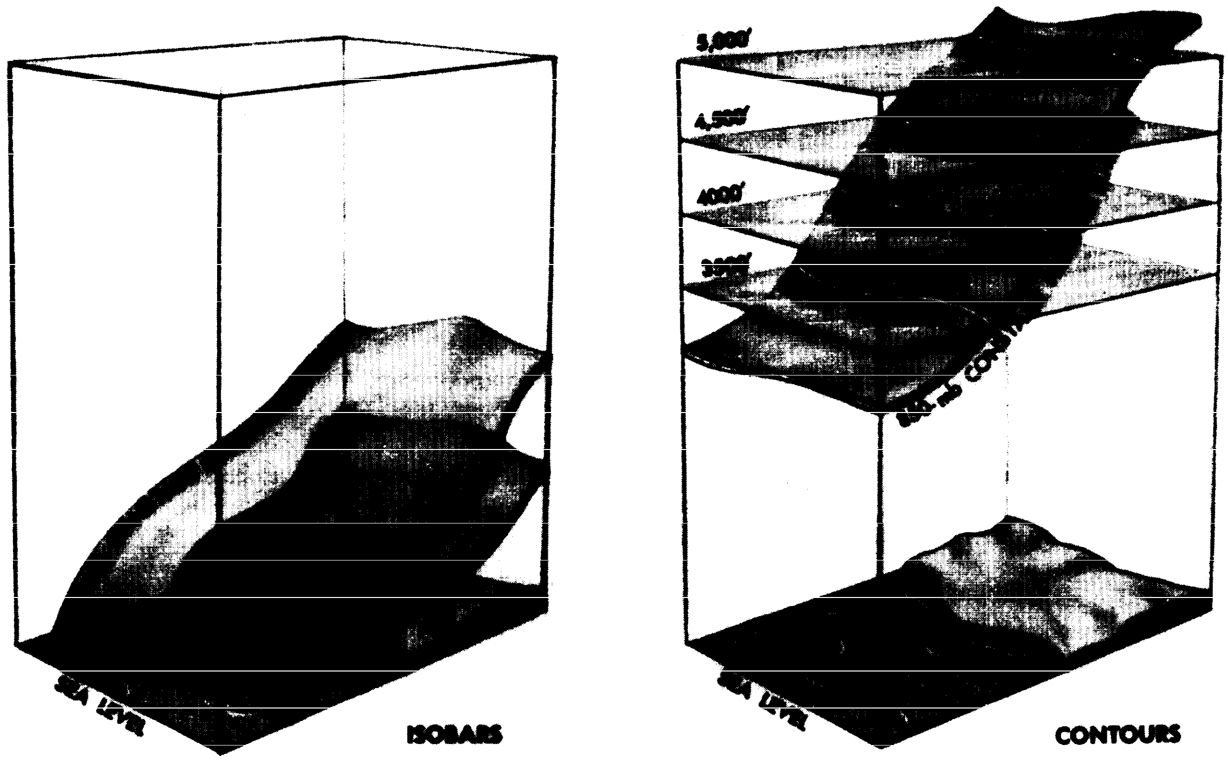


Figure 18-3. Comparison of Isobars and Contours.

Geostrophic Wind

The shape and configuration of the constant pressure surface determines the velocity and direction of the geostrophic wind. An aircraft flying with a constant altimeter setting on the pressure altimeter will automatically follow the configuration of the constant pressure surface and, in so doing, will change its true height as the contours change (figure 18-4). The slope of the

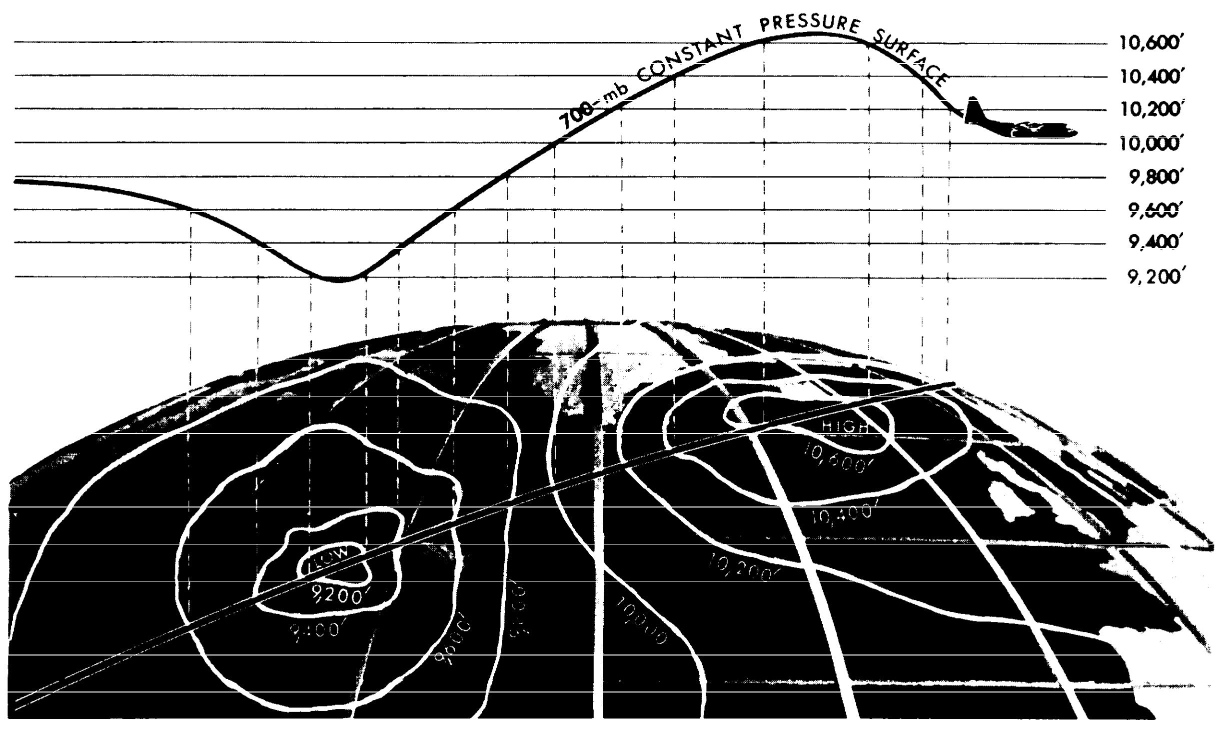


Figure 18-4. Changing Contours of Constant Pressure Surface.

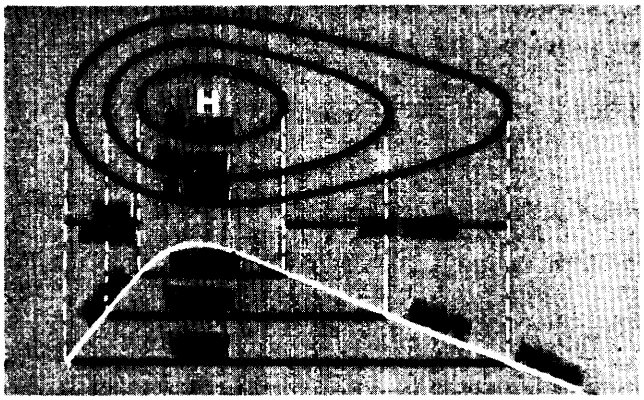


Figure 18-5. Pressure Gradient.

pressure surface, also known as the pressure gradient, is the difference in pressure per unit of distance as shown in figure 18-5.

The pressure gradient force or slope of the pressure surface and Coriolis combine to produce the geostrophic wind. One assumption made about the geostrophic wind is that the contours are relatively straight and parallel. The speed of the geostrophic wind is proportional to the spacing of the contours or isobars. Closely spaced contours form a steep slope (higher gradient) and produce a stronger wind. Conversely, widely spaced contours or isobars produce relatively weak winds.

Figure 18-6 is a simple illustration of the manner in which the geostrophic wind is produced. A parcel of air at point A is being propelled (as nature says it would) from the higher pressure towards the lower pressure by the pressure gradient force (PGF). Because the parcel of air is in motion, Coriolis force (CF) comes into play. The resultant of these two forces is wind (W). At point D, where PGF and CF are equal, the wind is blowing parallel to the contours and is a portion of the geostrophic wind by definition.

This wind is blowing parallel to the contours and the lower pressure is to the left with the *higher pressure* to the right. *Buys-Ballot's Law* states that in the Northern Hemisphere, with one's back to the wind, lower pressure is to the left as shown in figure 18-7. The opposite is true in the Southern Hemisphere where Coriolis deflection is to the left. Further observation of figure 18-7 will show that, as you enter a low or a high system, your drift will be right or left, respectively. The opposite is true as you exit the systems.

If the geostrophic wind is to be an accurate approximation of the actual wind, certain factors must be considered. It is essential that contours be relatively straight and parallel (otherwise centrifugal force becomes a factor and this is not accounted for in the geostrophic wind formula). Because the geostrophic wind is based on a constant pressure surface, flying a constant pressure altitude cannot be overemphasized. A minimum of 2 to 3 thousand feet above the surface will usually eliminate distortion introduced through surface friction. In the area of the equator (20° N to 20° S), Coriolis force approaches zero, thereby invalidating the geostrophic wind as a factor in navigation; but pressure differential navigation is reliable in midlatitudes.

Pressure Computations and Plotting

In determining a PLOP or Bellamy drift by pressure differential techniques, the navigator makes use of the crosswind component of the geostrophic wind over a given period of time. The determination of the crosswind component of the geostrophic wind requires specific data for use in the geostrophic wind formula or ZN equation.

$$ZN = \frac{K\ (D_2 - D_1)}{ETAS}$$

This formula, when solved, will give the direction and crosswind displacement effect—the ZN of the pressure system through which the aircraft has flown. To solve the equation and obtain the resultant ZN, the navigator must understand how to obtain and apply such special factors as "D" soundings, effective TAS (ETAS), effective air path (EAP), effective air distance (EAD) and "K" values.

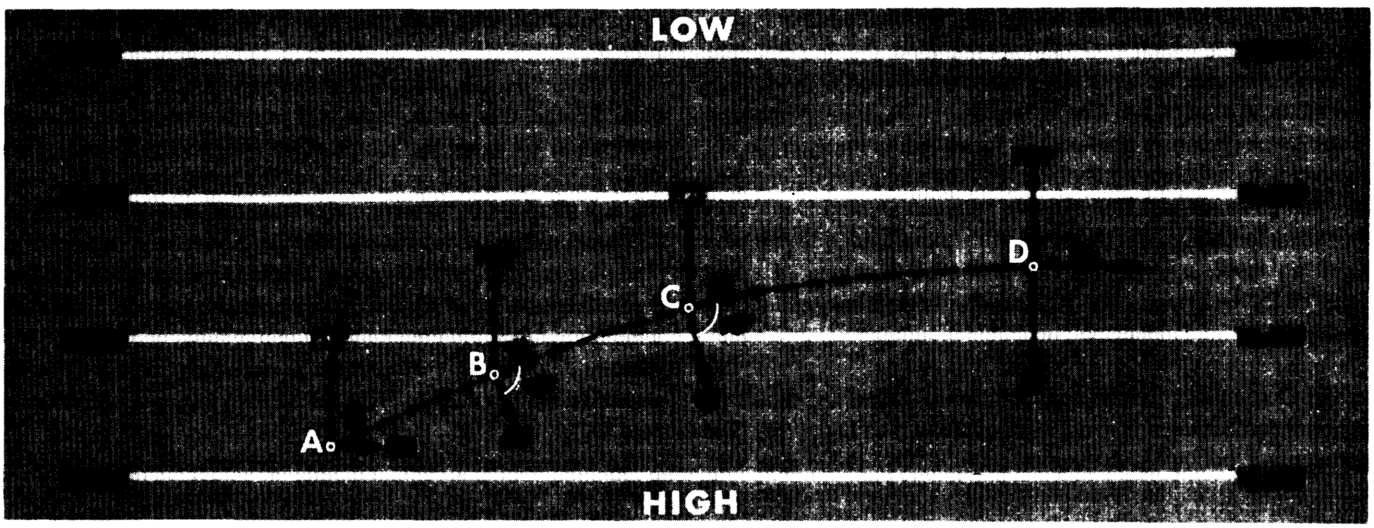


Figure 18-6. Geostrophic Wind.

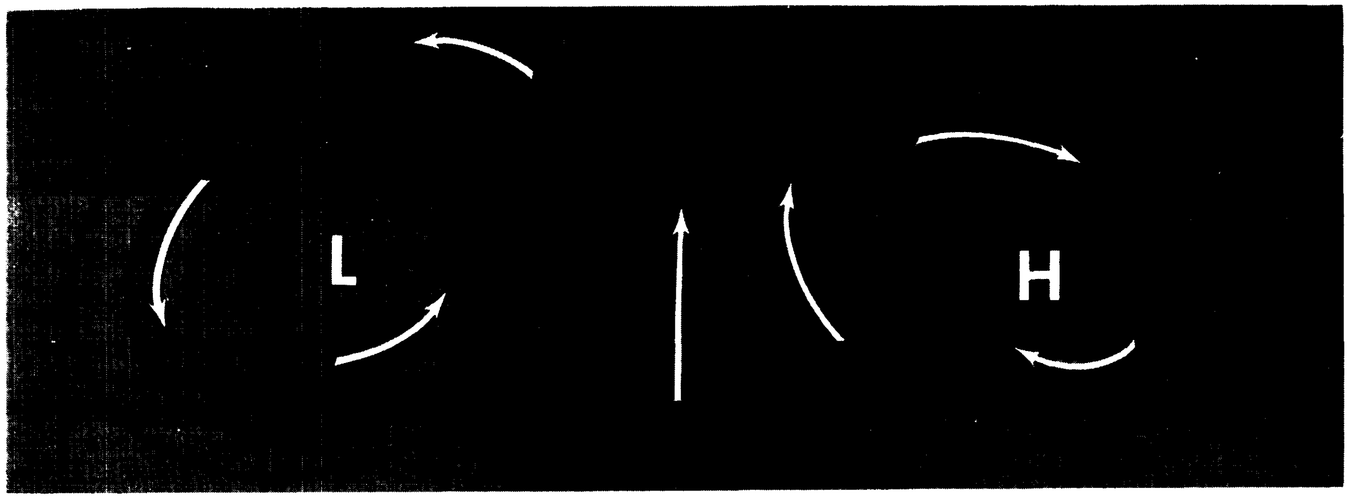


Figure 18-7. Buys-Ballot's Law.

"D" Soundings

The symbol "D" stands for the difference between the true altitude of the aircraft and the pressure altitude of the aircraft. There are two methods for obtaining D values. The first involves the use of an absolute altimeter to measure true altitude on overwater flights and the pressure altimeter to measure pressure altitude. The second method would be used if the absolute altimeter became unuseable and involves using outside air temperature (OAT) readings to determine equivalent D values.

For both methods, the D value is expressed in feet as a plus or minus value. To determine the correct D sounding using the altimeter method, assign a plus (+) to true altitude, a minus (−) to pressure altitude, and algebraically add the two. The correct sign can be applied by remembering the key word TAMPA (true altitude minus pressure altitude).

The first D sounding is obtained in conjunction with the fix when the pressure differential navigation leg is started. It is called D_1. The second D sounding, D_2, is obtained in conjunction with fix for which the PLOP will be used. It is important to remember to use the same time interval between D soundings and the time of each fix. The value, $D_2 - D_1$, is an expression of the slope (pressure gradient) experienced by the aircraft. By algebraically subtracting D_1 from D_2, the navigator determines the change in aircraft true altitude between D_1 and D_2. When this altitude change is compared with the distance flown, the resulting value becomes an expression of the slope. A large value of $D_2 - D_1$ indicates whether the aircraft has been flying upslope (+) or downslope (−).

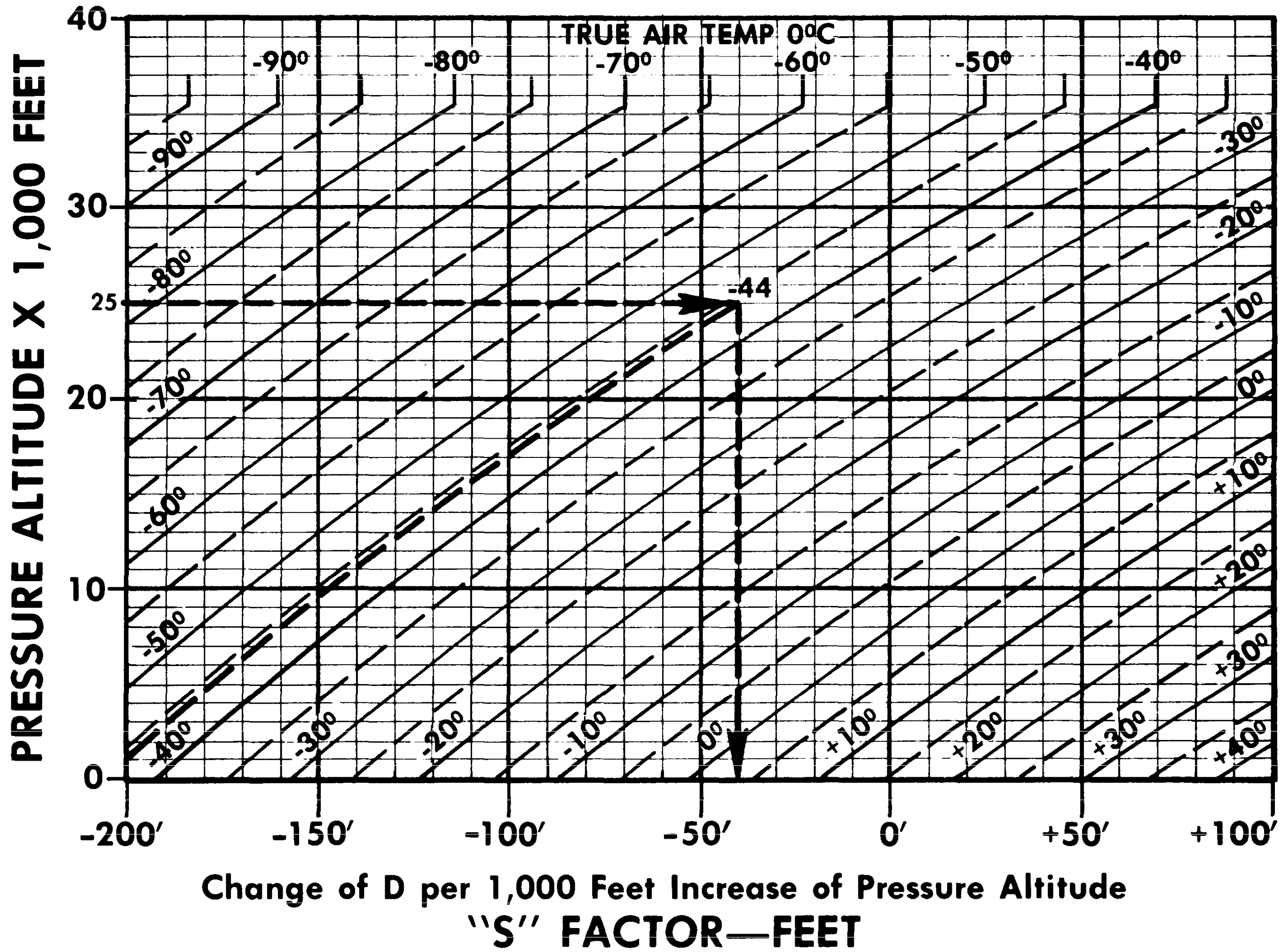
The D sounding for the next position is called D_3; the slope experienced between D_2 and D_3 is expressed as $D_3 - D_2$. For consecutive positions, it becomes $D_4 - D_3$, $D_5 - D_4$, etc. However, if D_2 is considered unreliable, D_3 could be compared with D_1.

To obtain an accurate D sounding, it is advisable to take several readings, obtain the D value for each reading, and arrive at a D sounding for the *midtime* of the readings. This method readily identifies discrepancies in reading. In addition, when any D sounding varies by 40 feet or more from the average of the other soundings, discard it and use the average of the remaining D soundings. It is important to take readings carefully. An erroneous reading of either altimeter will produce an incorrect D sounding and consequently an inaccurate LOP. A gentle tapping of the pressure altimeter before reading it will reduce hysteresis error.

The aircraft should maintain a constant pressure altitude to insure consistent D soundings. If it becomes necessary to change altitude en route, start with a new D at the new altitude, or correct the previous reading to the new altitude by use of a pastagram. With the aid of the pastagram, pressure differential may be continued accurately even though conditions necessitate en route changes of altitude. The pastagram is designed to use average altitude and average temperature change information to determine a correction to be applied to the D sounding taken prior to the altitude change. Figure 18-8 contains an example of a pastagram, along with instructions for its use and a sample problem.

Another possible difficulty is the loss of the absolute altimeter. Should this occur, it is still possible to utilize pressure navigation by using the temperature gauge. The D values for this method are based on a plateau of sea level, thereby eliminating any relationship to terrain elevation and true altitude. Thus, the temperature method is equally valid over land or terrain of changing or unknown elevation. These D values are still based on the formula "true altitude minus pressure altitude." Altitude should remain fairly constant between periods of D value computation. If a change of altitude is necessary, a new D value should be obtained at the level-off point to restart the problem (a new D_1).

An example of a table used for the temperature method is found in figure 18-9. TAS should remain fairly constant throughout the problem, especially at the times of the two readings. Entering arguments to obtain a D value are OAT gauge readings and the pressure altimeter reading. Once the D value is



PASTAGRAM. With the aid of the pastagram, pressure differential may be continued accurately, even though conditions necessitate en route changes of altitude.

Directions:

1. After level off, average the PA and SAT of the climb (or descent).

2. Enter PASTAGRAM with average PA.

3. Proceed horizontally to average SAT.

4. Proceed vertically to find "S" factor.

5. Multiply "S" factor by number of thousands of feet of PA change.

6. Apply result to "D" reading prior to altitude change.

7. Use adjusted "D" reading in normal way in connection with next reading.

EXAMPLE: D_1 = +1,000 feet
TAT= -44°C average
PA = 25,000 feet average
Altitude change = +2,000 feet
(that is, 24,000 to 26,000 feet)
D_2= +1,250 feet

a. Enter PASTAGRAM at 25,000 feet and go horizontally to SAT (-44°), then proceed vertically to obtain "S" factor (-40 feet).

b. Multiply times altitude change in thousands (-40 x 2 = -80).

c. Algebraically add to D_1 (+1,000 + (-80) = +920).

d. D_2 - D_1 = +1,250 - (+920) = +330.

e. Apply value to "D" reading taken prior to the altitude change to be ready for the next pressure readings after level off, at new altitude.

Figure 18-8. Pastagram.

PRESSURE PATTERN BY TEMPERATURE CHANGE

1. Should the Radar/Radio altimeter become unusable it is possible to utilize pressure pattern as an additional aid to navigation by using the temperature gauge. "D" values are based on a plateau of sea level; thus eliminating all relationship to terrain elevation. The temperature is equally valid over land or terrain of changing or unknown elevation. "D" values are based on the formula "true altitude minus pressure altitude."

2. Altitude should remain fairly constant between periods of "D" value computation. If a change of altitude is desired, the D_2 minus D_1 should be computed prior to the altitude change and a new "D" value computed at the level-off point to restart the problem (D_1). Entering arguments to determine the "D" value are OAT gauge reading and pressure altimeter reading. The formula D_2 minus D_1 is used to obtain "difference" in "D" reading for two periods of time.

3. The tables are designed for a TAS of 450 knots but will work fairly accurate within +50 knots. TAS must remain constant throughout the problem, especially at the times of the two readings. SAC Form 120, Pressure Pattern Navigation Worksheet, can be used to record temperature and pressure readings.

EXAMPLE:

Plot fix or DR position for 0900, at 38-00N, 098-00W. Record the altimeter reading and the OAT gauge reading. Assume the altimeter read 30,100 feet and OAT read -30 degrees. Entering the table under OAT -30 and an altitude of 30,000 feet, obtain a figure of -928. *Since the altimeter read 100 feet higher than 30,000 feet, apply the change of 24 feet, which is decreasing with a decrease of temperature.* Thus -928 plus 24 equals a "D" value of -904 (D_1). At 0930 again record the altimeter and OAT gauge readings. Assume 30,000 feet and an OAT of -32. Entering the table obtain a "D" value of -1193 which becomes D_2. Algebraically subtracting D_2 minus D_1 or -1193 -(-904), obtain a D_2 minus D_1 of -289 feet. Compute the ZN in the normal manner.

NOTE:

Pressure Pattern Tables are based on standard day conditions. The navigator must exercise analytical judgment in resolving positions from PLOPS to preclude weighing erratic results from extreme pressure conditions.

PRECOMPUTED D VALUES FOR PRESSURE PATTERN NAVIGATION

GAUGE OAT	ALTIMETER READING 26000′	*	27000′	*	28000′	*	29000′	*	30000′	*
-29	-1522	15	-1371	17	-1198	20	-1001	21	-795	24
-30	-1632	15	-1487	17	-1319	19	-1128	20	-928	24
-31	-1741	14	-1602	16	-1440	19	-1235	20	-1060	23
-32	-1851	13	-1717	16	-1561	18	-1382	19	-1193	23
-33	-1960	13	-1832	15	-1682	17	-1508	18	-1325	22

* CHANGE PER 100 FEET

Figure 18-9. Pressure Pattern by Temperature Change.

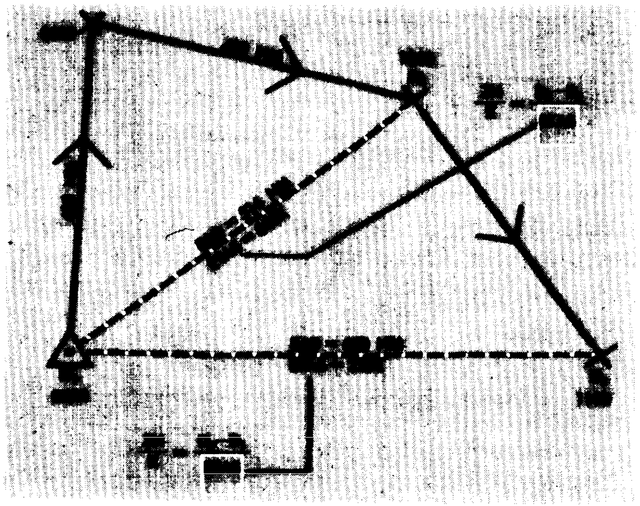


Figure 18-10. Effective True Airspeed.

$\frac{D_2 - D_1}{Y} = \frac{BDCA}{1}$		$\frac{ZN}{K} = \frac{D_2 - D_1}{ETAS}$		
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				
TA				
−PA				
DIFF				

K FACTORS	
LAT	K
20°	63
21°	60
22°	57.5
23°	55
24°	53
25°	51
26°	49
27°	47.5
28°	46
29°	44
30°	43
31°	42
32°	40.5
33°	39.5
34°	38.5
35°	37.5
36°	36.5
37°	35.5
38°	35
39°	34
40°	33.5
41°	33
42°	32
43°	31.5
44°	31
45°	30.5
47°	29.5
49°	28.5
51°	28
53°	27
55°	26
57°	25.5
59°	25
65°	24
70°	23
75°	22
90°	21.5

Figure 18-11. Typical Pressure Pattern Worksheet/K Factors Table.

obtained, the problem is solved in the normal manner using the ZN equation.

Effective True Airspeed

In determining a pressure line of position, the navigator must compute the effective true airspeed from the last D sounding. The ETAS is the true airspeed that the aircraft would have had to make good, had it flown straight from D_1 to D_2. See figure 18-10. If the aircraft has maintained a constant true heading between D soundings, the effective true airspeed equals the average true airspeed. But, if the aircraft has altered heading one or more times between the D soundings, the effective true airspeed is derived by drawing a straight line from the fix at the first D sounding to the final air position. This line is called the effective air path. Effective true airspeed is computed by measuring the effective air distance and dividing it by the elapsed time (in hours). In figure 18-10, an aircraft flew at 400 knots TAS from the 0820 fix to the 1020 air position via a dogleg route. The effective air distance is 516 nautical miles; consequently, the effective true airspeed is 258 knots. In the illustration, the navigator considered the D_2 sounding unreliable and correctly compared D_3 with the D_1 sounding.

K Factor

The constant (K) has been determined by taking into account the values of the Coriolis constant and the gravity constant for particular latitudes. K equals $\frac{21.49}{\text{sin midlatitude}}$; where midlatitude is the average latitude between D_1 and D_2.

It is put in tabular form for the convenience of the navigator as shown in figure 18-11. In the table, this constant is plotted against latitude since Coriolis force varies with latitude. In using the ZN formula, the table is entered with midlatitude and the corresponding K is extracted. On new DR computers, a subscale of latitude has been constructed opposite the values for K factors on the minutes scale.

Slope is properly expressed by vertical and horizontal displacement in the same units; however, the navigator expresses horizonal displacement in nautical miles and vertical displacement in feet. The K factor has been adjusted by a factor so that, with slope expressed in feet and distance in nautical miles, the

K Factors 20° and Below	
LAT	K
20°	63
19°	66
18°	69.5
17°	73.5
16°	78
15°	83
14°	89

Figure 18-12. K Factors Table Below 20°.

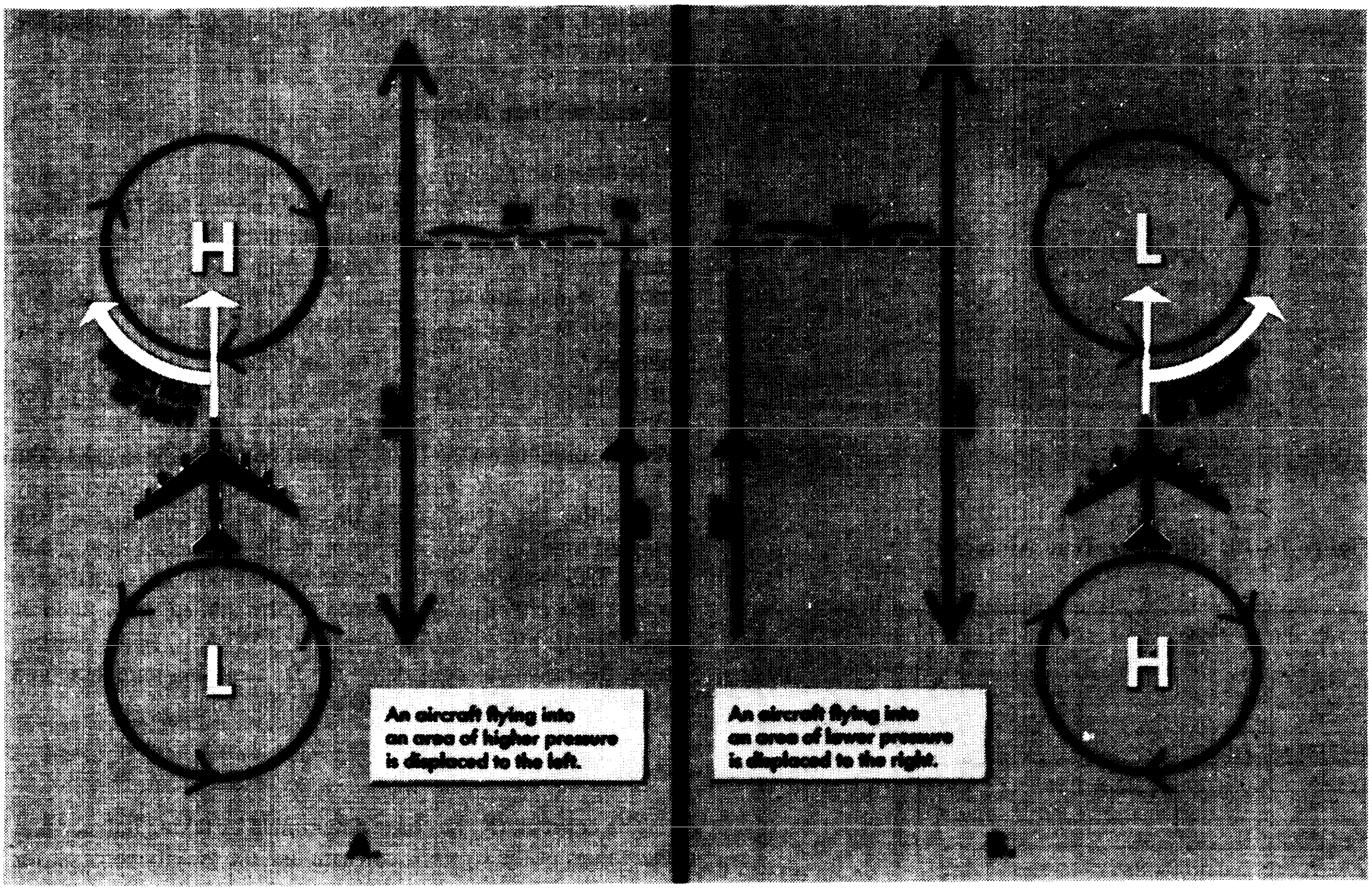


Figure 18-13. Z_n Displacement in Northern Hemisphere.

geostrophic wind speed is computed in knots. Thus, the K factor cannot be used with statute miles to solve for the geostrophic wind in statute miles per hour. *For training purposes only,* the K factors for 20° N or S to 14° N or S are listed in figure 18-12.

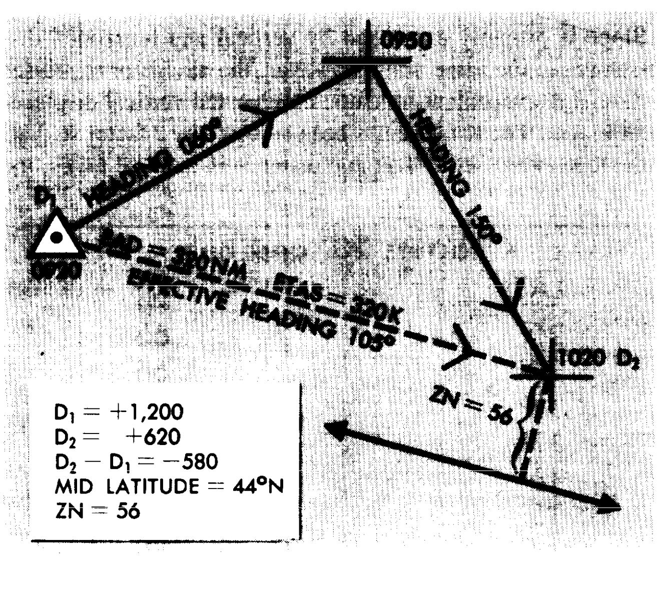


Figure 18-14. Plotting the PLOP.

Crosswind Displacement (ZN)

ZN is a displacement value derived from soundings at two air positions. It is the displacement from the straight line air path between the soundings. Therefore, a PLOP must be drawn parallel to the effective air path.

With all the necessary values available, the ZN formula can be rearranged for convenient solution on the DR computer as follows:

$$\frac{ZN}{K} = \frac{D_2 - D_1}{ETAS}$$

Printed instructions on the face of newer computers specify that to compute crosswind component, set air miles flown (effective air distance) on the minutes scale opposite $D_2 - D_1$ on the miles scale. The crosswind component (V) is not to be confused with crosswind displacement (ZN). The crosswind component (V) is crosswind velocity in knots. This component (V) must then be multiplied by the elapsed time between D_2 and D_1 in order to compute the crosswind displacement (ZN). If effective true airspeed is substituted for air miles flown (effective air distance) on the MB-4 computer, the ZN can be read over the K factor (or latitude on the subscale).

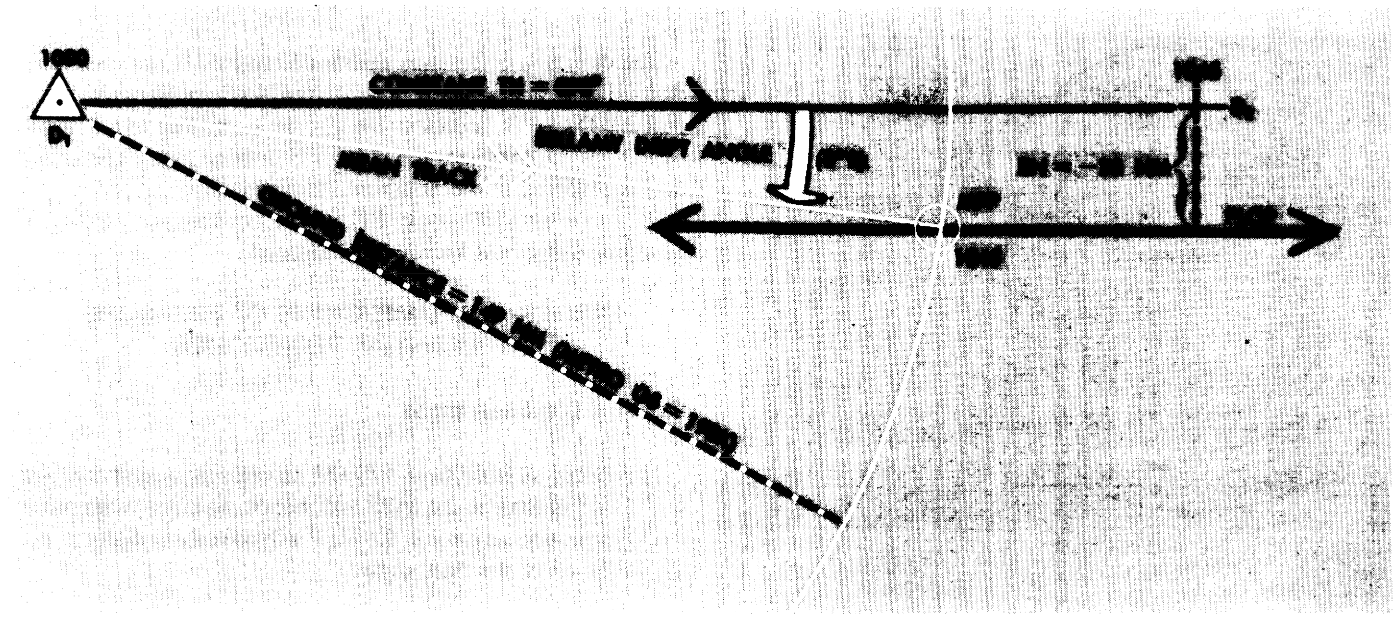


Figure 18-15. Solution of Bellamy Drift Using PLOP.

PRESSURE LINE OF POSITION (PLOP)

Once ZN is determined, it can be plotted to obtain a pressure line of position (PLOP).

The direction of this displacement must also be determined; that is, the navigator must determine whether the aircraft has drifted right or left of the effective air path. Recall that wind circulation is clockwise around a high and counterclockwise around a low in the Northern Hemisphere; the opposite is true in the Southern Hemisphere. Thus, in the Northern Hemisphere, when the value of D increases (a positive $D_2 - D_1$), the aircraft is flying into an area of higher pressure and the drift is left (see figure 18-13A). When the value of D decreases (a negative $D_2 - D_1$), the aircraft is flying into an area of lower pressure and the drift is right (see figure 18-13B).

Always plot the PLOP parallel to the effective air path, and not necessarily parallel to the present true heading. This is shown in figure 18-14. Once plotted, a PLOP is used in the same manner that any LOP is used. It can be crossed with another LOP to form a fix or it can be used with a DR position to construct an MPP.

BELLAMY DRIFT

Bellamy drift is a mean drift angle calculated for a past period of time. It is named for Dr John Bellamy who first demonstrated that drift could be obtained from the use of pressure differential information. Bellamy drift is used in the same way as any other drift reading.

The primary advantage of Bellamy drift is its independence from external sources. An undercast, overcast, or poor radio transmission will not adversely affect the drift. The accuracy of Bellamy drift is comparable to other drifts and depends largely on the skill of the navigator.

In figure 18-15, a PLOP has been plotted from the following information:

D_1 at a fix at 1000 hrs

D_2 at an air position at 1045 hrs

ZN = − 20 NM

Constant TH of 090°

Next, construct an MPP on the PLOP. This is done by swinging an arc, with a radius equal to the ground distance traveled, from the fix at the first D reading to intersect the PLOP. The ground distance traveled can be found by multiplying the best known groundspeed (groundspeed by timing, metro groundspeed, etc) by the time interval between readings. The mean track is shown by the line joining D_1 and the MPP. The mean drift is the angle between true heading and the mean track (8° R). Thus, the Bellamy drift is 8° right.

Computer Solution of Bellamy Drift

Solving the Bellamy drift angle on the DR computer is a relatively simple process. The center vertical line on the slide represents true heading. The ZN must be plotted at right angles to the true heading. This can be done by drawing the ZN vector down from the grommet and rotating the transparent face 90°. For convenience, one of the cardinal headings is placed under the true index when the ZN is drawn in to make it simple to rotate the face through 90°.

It makes no difference whether the face is turned to the right or left, as the sense of the drift is not taken from the DR computer. The sense is determined by the same considerations governing the plotting of the PLOP ($D_2 - D_1$ negative, Northern Hemisphere, drift right).

The slide is then positioned so that the ground distance is under the end of the ZN vector and the drift angle is read at the end of the ZN vector.

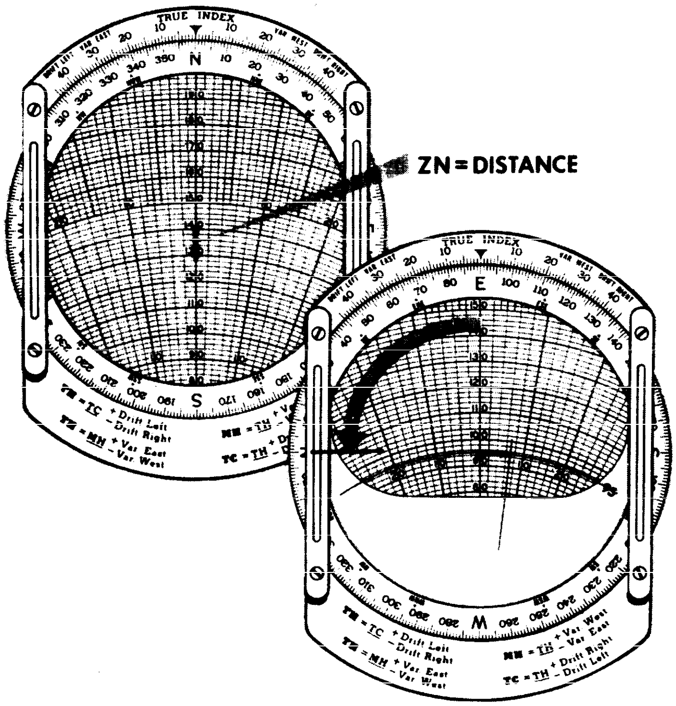


Figure 18-16. Computer Solution of Bellamy Drift.

Example (figure 18-16)

Given: Northern Hemisphere
ZN − + 12.1
Time = 0:30
GS = 190 Knots
Find: Ground Distance = 95 NM
Drift = 7° left

Bellamy drift may also be determined on the slide rule side of the DR computer by placing the ZN over the ground distance and reading the Bellamy drift angle opposite 57.3. This can be set up in a formula as follows:

$$\frac{BD}{57.3} = \frac{ZN}{\text{Ground Dist NM}}$$

The previous example would be set up as shown in figure 18-17. The answer 7.3 can be read over 57.3 on the minutes scale or under the index of the DRIFT CORR window.

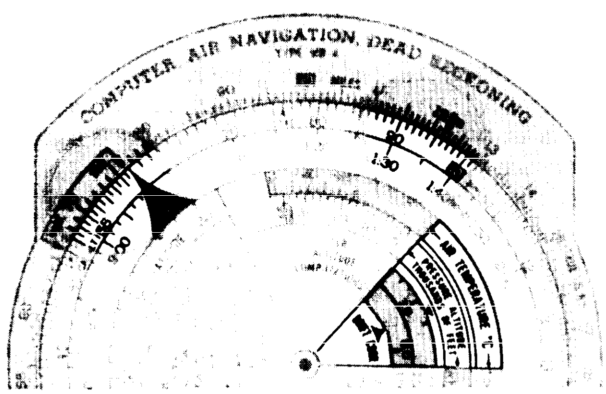


Figure 18-17. Mathematical Solution of Bellamy Drift.

The direction of Bellamy drift is determined in the same way that ZN direction is determined. In the Northern Hemisphere, a positive $D_2 - D_1$ indicates the aircraft is drifting left; a negative $D_2 - D_1$ indicates the aircraft is drifting right. The situation is reversed in the Southern Hemisphere.

To obtain an MPP, apply BD to true heading and plot a DR position, using best known groundspeed.

ERRORS AND LIMITATIONS OF PRESSURE DIFFERENTIAL TECHNIQUES

Ground Distance Error

In plotting an MPP from a PLOP, an error in ground distance will cause an error in the MPP and, hence, an error in the mean track. However, an error in the MPP will not substantially affect the accuracy of the drift angle.

Tactical Limitations

Bellamy drift has one main limitation. For drift to be determined on each leg of a flight by the Bellamy method, the heading taken up by the aircraft must be maintained long enough to permit a pair of soundings with a time separation of at least 20 minutes.

Some economy of effort will result if a sounding is taken immediately before or after a turn. This sounding may be used, with negligible error, as reference for determining drifts on both legs. Some error will be caused by the difference between the height of the constant pressure surface at the sounding position and the height at the turning point. If not more than a minute or two elapses between turn and sounding, however, the ZN is unlikely to be in error by more than a mile (assuming crosswind is less than 60 knots), and the effect on drift will be correspondingly small, especially if TAS is high.

Summary

ZN is a displacement in nautical miles perpendicular to the effective air path. This means that airplot must be used and a known position is required at the time of D_1.

Determine the D value by computing readings from the radio altimeter with simultaneous readings from the pressure altimeter, D = TA − PA. Use a series of comparisons to aid in picking out any erroneous readings. If any D value varies by 40 feet or more from the average of the series, discard it and average the remaining values. Consistent errors in the altitudes will not affect the accuracy of the ZN, but changing the setting of either altimeter after the first D reading will cause inaccuracy.

The ZN is obtained by using the equation

$$ZN = \frac{K\,(D_2 - D_1)}{ETAS}$$

which can be arranged for convenience in using the DR computer,

$$\frac{ZN}{K} = \frac{D_2 - D_1}{ETAS}$$

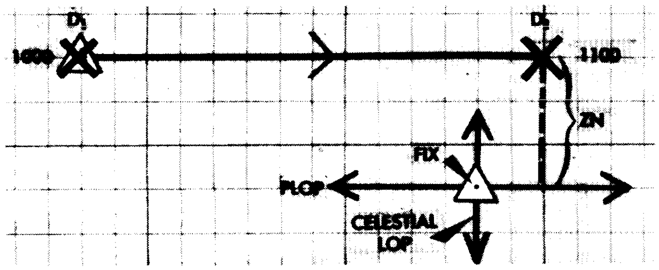


Figure 18-18. Fix Using PLOP and Celestial LOP.

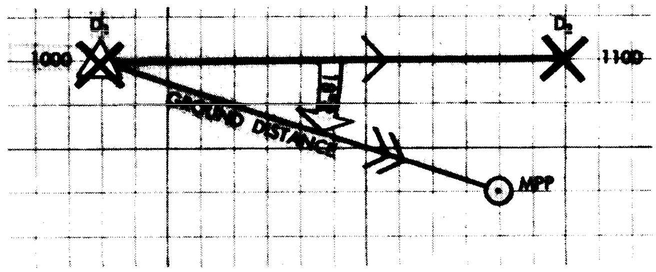


Figure 18-19. MPP by Bellamy Drift.

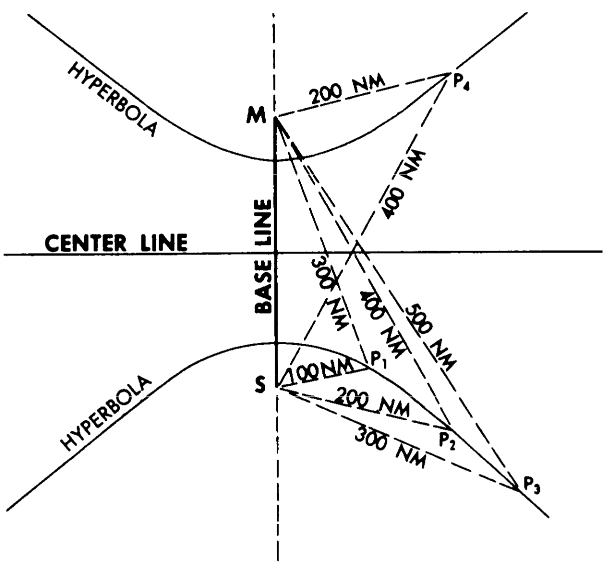
Determine effective true airspeed by using the effective air distance and time. Measure effective air distance along a straight line between the two points in question. After the value of ZN is determined, plot the PLOP parallel to the effective air path. In the Northern and Southern Hemispheres, the sign of the ZN is the sign of the drift correction. Once the PLOP is plotted, treat it like any other LOP.

If the absolute altimeter becomes unuseable, it is still possible to utilize pressure pattern as an aid to navigation by using the temperature gauge. With this method, temperature and pressure altitude are used to find equivalent D soundings. Lastly, if a change of altitude is necessary, pressure may be restarted at the new altitude, or the D sounding prior to the altitude change may be corrected by means of a pastagram.

Though the use of the PLOP is often preferred to BD, there are two main uses for Bellamy drift:

1. It is often computed to cross-check the drift that is determined from a fix.

2. Bellamy drift may be plotted as an LOP and then crossed with an LOP from another fixing aid. Figure 18-18 shows a fix determined by use of a PLOP and a celestial LOP; figure 18-19 shows an MPP determined by Bellamy drift.



AT P_1, 300 NM − 100 NM = 200 NM
P_2, 400 NM − 200 NM = 200 NM
P_3, 500 NM − 300 NM = 200 NM
P_4, 400 NM − 200 NM = 200 NM

Figure 18-20. LORAN Hyperbolas.

LORAN

The name LORAN is derived from the words **LO**ng **RA**nge **N**avigation, which is an appropriate description of the hyperbolic system of electronic navigation. It provides lines of position over the surface of the Earth. Over water, usable LORAN signals can be received at ranges up to 2,800 miles.

The relatively long range of LORAN is made possible by employing low frequency radio waves. At these frequencies, radio waves are capable of following the curvature of the earth.

LORAN lines of position can be crossed with each other, or with lines of position determined by any other means, to provide fixes. Unlike celestial lines of position (LOPs), LORAN lines are stationary with respect to the Earth's surface. Their determination is not dependent upon compass or chronometer, and it is not necessary to break radio silence to obtain them. It is possible to receive LORAN signals in all weather, except during very severe electrical disturbances. There are presently two types of LORAN in use, LORAN-C and LORAN-D.

PRINCIPLES OF OPERATION

Since the speed of radio waves is virtually constant and quite accurately known, the time needed for a signal to travel a given distance can be determined with considerable accuracy. Conversely, the measurement of the time needed for a radio signal to travel between two points provides a measurement of distance between them. All points having the same difference in distance from two stationary points, called foci, lie along an open curve called a hyperbola. Actually, there are two curves or parts to each hyperbola, as shown in figure 18-20, each representing the same time difference, but with the distance interchanged. Thus, the difference in the distances (200 NM) from the two stations is the same at points P1, P2, P3, and P4.

The LORAN system consists of a series of sychronized chain (set) of radio transmitting stations which broadcast pulse signals similar to those used in radar, with a constant time interval between them. These transmitting stations are the foci. The aircraft has a combination radio receiver and time difference measuring device. The measurements made by this equipment are used for entering tables or charts to identify the hyperbola on which the receiver is located. (Since the Earth is not a perfect sphere, the hyperbolas are slightly irregular. This fact is considered when the hyperbolas are plotted on the charts.) Some receivers go one step further and provide this information to a

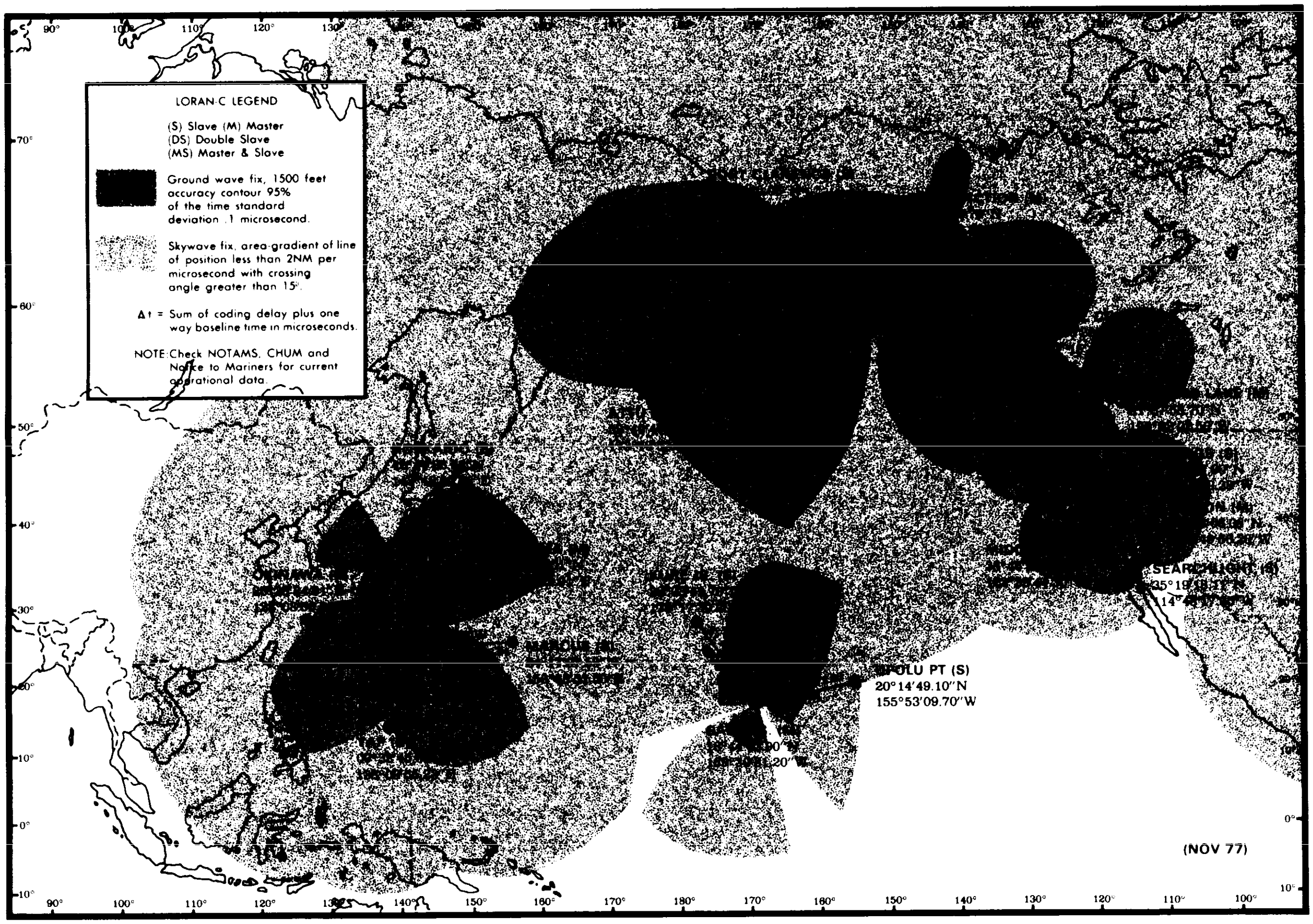


Figure 18-21. Pacific Area LORAN-C Coverage.

navigation computer for instantaneous latitude and longitude readouts.

LORAN determines the difference in distance by measuring the time interval in microseconds (μs), between the arrival of the first signal and the arrival of the second signal from a pair of synchronized transmitters. One of the two transmitters constituting a pair is designated the master (M), the other the slave (S). The direct line joining these two is called the base line. The continuations of this line beyond the transmitters are called the base line extensions. The perpendicular bisector of the base line is called the center line.

In some areas, a slave transmitter may be used as a slave for more than one master transmitter. It is then known as a double slave transmitter. Some master transmitters also may be used as slaves for other master transmitters. These are known as master slave transmitters.

LORAN-C uses an arrangement with one master and two to four slave transmitters per station. Figure 18-21 shows transmitter configurations of LORAN-C stations in the Pacific area.

Base Line Delay

If both signals were transmitted at the same instant, they would arrive together at any point along the center line. At any point nearer the master station, the master signal would arrive first, and at any point nearer the slave station, the slave signal would arrive first. Since both signals are alike, this arrangement would be unsatisfactory, as it would include an ambiguity which could be resolved only by knowing the approximate position of the receiver. Near the center line, reasonable doubt might exist as to which line to use. This ambiguity is eliminated by delaying transmission of the slave signal until the master signal arrives at the slave station. Radio waves travel at about 299,708 kilometers per second. Since this is equal to 161,829 nautical miles per second, the distance traveled in 1 μs is 0.162 nautical miles, or 6.18 μs are needed for a pulse to travel 1 nautical mile. Hence, the length of this delay is the time needed for the signal to travel the length of the base line or, in microseconds, 6.18 times the length of the base line in nautical miles. The length of the base line, and therefore the length of the delay, varies from one station pair to another. This delay is called the baseline delay.

Coded Delay

With the base line delay in use, the master station transmits a signal first. This signal travels outward in all directions. When this expanding wave front arrives at the slave station, the slave signal is transmitted. If no other delay were introduced, the signals would travel together along the slave base line extension, and the time difference would be zero. By the time the slave signal arrived at the master station, the master signal would be a distance away equal to twice the duration of the base line delay. With this arrangement, however, the time difference readings would be so small in some portions of the pattern that identity of each signal would not be apparent until the measurement was completed, or nearly so. To avoid this, a second delay is introduced. This is called the coded (or coding) delay. The effect of this delay is to increase all time difference readings by the amount of the coded delay, thus assuring a positive value throughout the pattern. The coded delay also could be used as a security measure against compromise of the system during time of war.

LORAN Reception

LORAN Receiver-Indicator. The LORAN receiver is similar to an ordinary radio receiver with the exception that there is no speaker. The output of the receiver is fed to a LORAN base indicator, which is an electronic device capable of measuring with high precision the time difference between the receptions of the master and slave signals. This indicator will measure the time difference by one of the following methods. The first method involves the use of a cathode-ray tube to provide a visual display of the incoming signals. By visually aligning these signals, a reading of the time difference measurement can be obtained. The second method is done automatically by the LORAN set and it provides readings of the time difference. The third type of system goes one step further and integrates with a computer to display latitude and longitude.

The readings obtained can be plotted on a LORAN plotting chart or, in the case of direct latitude/longitude readouts, can be plotted on any chart.

Factors Affecting LORAN Signals

Distance From Each Transmitter. The distance of the master and slave transmitters from the aircraft is one factor which affects LORAN signals. It is possible to receive a ground wave from one transmitter and a sky wave from the other. For example, when the ground wave from the slave transmitter is beyond the range of the aircraft receiver, the first pulse in the slave pulse train will be a sky wave, not a ground wave. A pulse train is the order in which the pulses appear on the trace.

Time of Day at Each Transmitter. Sky waves are normally received at night, but they are also received occasionally during daylight hours. It is not unusual for the first reflection of sky waves to occur in the late afternoon before sunset, and to continue into morning daylight for 3 or 4 hours. This is especially true when the transmitter is in an area which is still dark.

Intervening Land Masses. When a ground wave passes over land, its range is significantly reduced because of the attenuation properties of land. As little as 30 miles of land between the transmitter and the receiver can decrease ground wave range by as much as 150 miles. Ground waves which are normally received may not appear because of intervening land.

These factors—range, time of day, and intervening land—should be considered when the pulses on a LORAN indicator are interpreted.

Ground Waves and Sky Waves

The path over which LORAN signals travel affects their range, their characteristics, and the reliability of their time difference readings. Radio energy which travels along the surface of the Earth is called the ground wave, and that which is reflected from the ionosphere is called the sky wave. The sky wave is named after the atmospheric layer that reflects it and the number of hops (bounces) it takes. See figure 18-22 for examples of sky waves and ground waves.

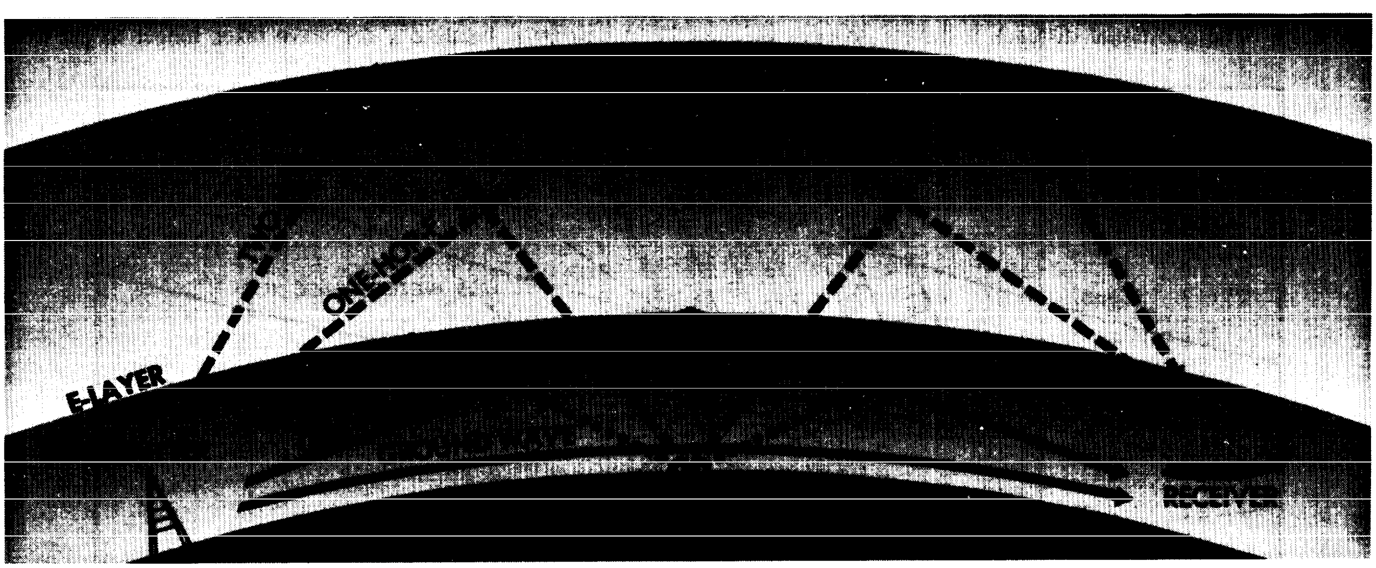


Figure 18-22. Both Ground Waves and Sky Waves May Be Received.

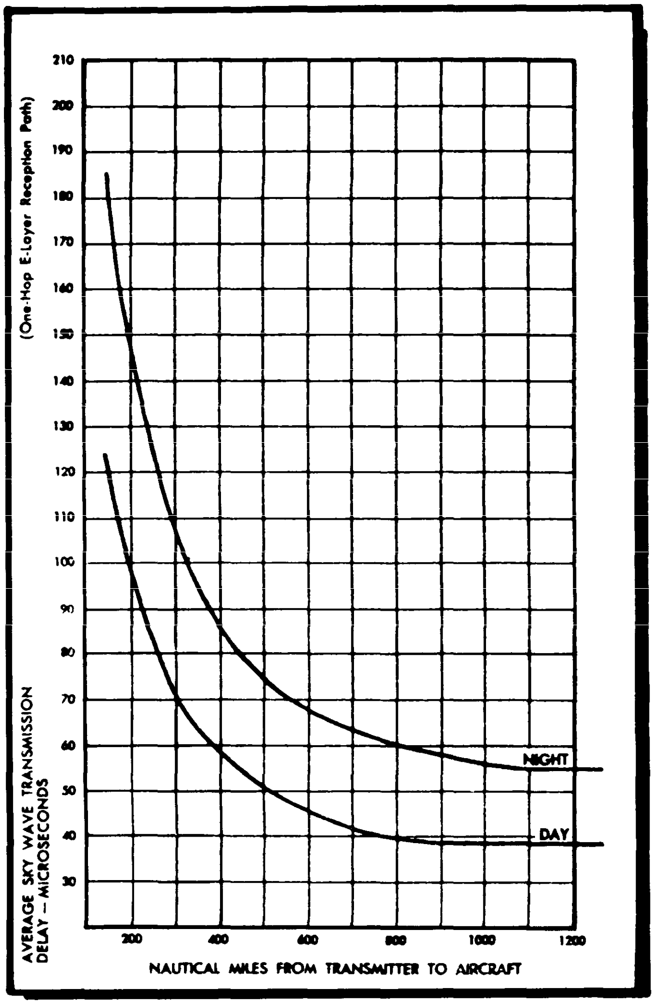


Figure 18-23. LORAN "C" Ground Wave-Sky Wave Correction Graph.

A LORAN pulse which travels to the ionosphere and back travels a greater distance than one which follows the surface of the Earth. The additional distance it travels depends on the height of the reflecting layer, the number of hops it takes, and the distance of the receiver from the transmitter. Because of these variables, sky wave time difference readings are not as accurate as ground wave readings. For this reason, ground waves should be used when available even though they may be considerably weaker than sky waves. When a LORAN receiver is within 250 miles of a LORAN transmitter, sky waves produce an unacceptable error in time.

When ground waves are not available, one-hop-E sky waves can be used to obtain LOPs with reasonable accuracy. But, when two-hop-E sky waves are used, the error is multipled to the point where the time difference readings produce unusable LOPs. The F-layer of the ionosphere is too unstable to provide reliable time difference readings, and is not applicable to LORAN-C.

LORAN-C

Identifying Sky Waves

Distance from the station and your position are the major determinants pertaining to whether you are receiving ground or sky waves. Sky waves are present both day and night. As a general rule, both are present within 1,000 NM, with the ground wave strong enought to use for LORAN-C. The area beyond 1,400 NM will usually be only sky waves. It is the area from 1,000 NM to 1,400 NM which poses the largest identification problem. In this area, the ground wave may or may not be available, which is why identification of the type wave is so important.

It is important at this point to look up the possible combinations of ground and sky waves and determine the expected values for each combination. This will aid in determining which combination is present.

LORAN microsecond time delays printed on the charts are for ground waves only. Therefore, corrections for sky wave and ground wave reception must be applied when applicable to obtained readings to plot on the chart. The reason this correction is necessary is because a sky wave takes longer to get from

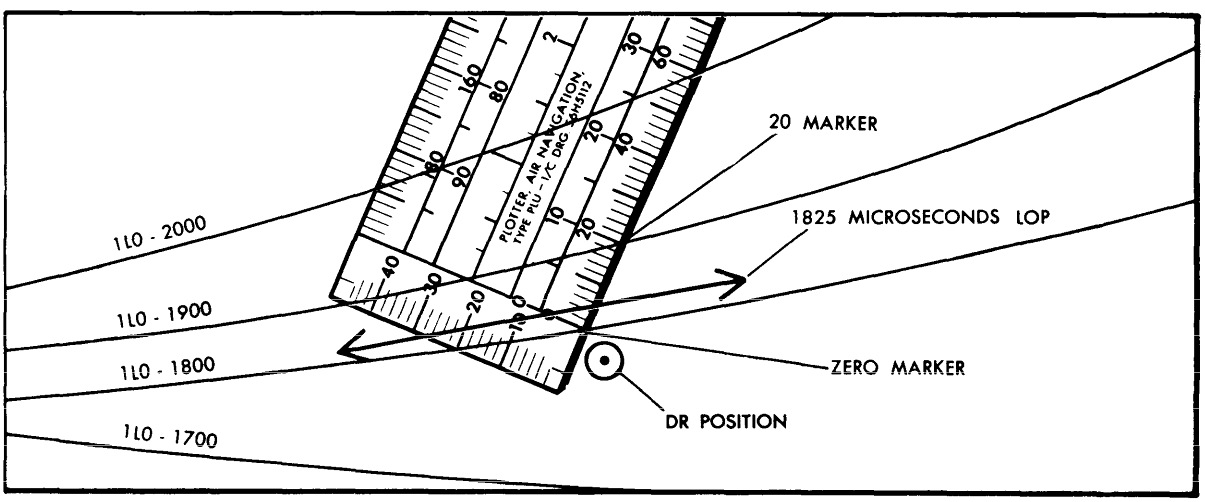


Figure 18-24. Interpolation Using Plotter.

transmitter to receiver because it must travel a longer distance (figure 18-22). The possible combinations are GS, (ground from the master, sky from slave), SG, (sky from master, ground from slave, and SS (sky from both master and slave).

To understand the GS, SG, and SS correction, let's consider a case with GS. The ground wave travels straight from the master to the receiver. The sky wave from the slave bounces off the ionosphere and then to the receiver, causing a longer time difference between the reception of the master and the slave. We, therefore, must subtract a correction for this situation from the obtained readings. This reading can be obtained using the graph in figure 18-23. In the case of SG, the same thing occurs except that the master signal is delayed, thus the reading obtained is less than what it should be. We, therefore, add the correction value obtained in figure 18-23. SS corrections are much smaller than GS and SG for apparent reasons. SS corrections can be found on individual LORAN charts for each chain depicted. A good rule is G master S slave subtract, SG add, and SS see chart. The only other consideration for the table in figure 18-23 is whether to use the day or night correction figure. To determine this, time at both the transmitter and the receiver should be considered.

Static

Static caused by a buildup of static electricity due to motion through a moist atmosphere can greatly diminish the maximum ranges stated earlier. This static usually causes interference with the received signal, and when strong enough can completely mask the LORAN signal. This masking looks very similar to "grass" around the signal, and can effectively hide the LORAN signal visually, and electronically. It is commonly known as "precipitation static noise."

Plotting the LOP

In most cases, a time difference reading does not fall exactly on a printed hyperbola of the chart. To plot the LOP, interpolate between two printed hyperbolas on either side of the time difference reading near the DR position. The LOP is then drawn parallel to the charted hyperbolas.

Plotter Method. There are several ways to interpolate between printed hyperbolas. In figure 18-24, a reading of 1825 μs has been obtained from station. To plot this LOP, subdivide the space between the 1800 and 1900 hyperbolas into increments by using the edge of a plotter and the graduations marked on it. Notice in figure 18-24 that, by placing the plotter diagonally across the 1800 and 1900 hyperbolas, the space is subdivided into a convenient number of increments—in this example, 10. The 1825 μs LOP is then easily located.

DR Computer Slide Method. Another way to interpolate between hyperbolas involves the use of the DR computer slide. Span the distance between the hyperbolas (in this example, 100 μs) with a pair of dividers. Then, place the divider points on the DR computer slide so that they span 10 drift lines, as shown in figure 18-25. Each drift line thus represents 10 μs. Adjust the dividers to measure the value being interpolated (40 μs) and, with the dividers, plot this distance on the chart from the hyperbola of lower value towards the hyperbola of higher value. *NOTE:* The interpolated distance must be plotted on the chart at the same place the original distance was spanned.

Proportional Formula Method. A proportion also can be used to determine the proper spacing for the interpolated LOP. Using the previous example, assume that the distance perpendicular to the LOPs from the 2700 hyperbola to the 2800 hyperbola is 62 NM. Set the following proportion on the DR computer:

$$\frac{62\ \text{NM}}{100\ \mu\text{s}} = \frac{X}{40\ \mu\text{s}}$$

$$X = 25\,\text{NM}$$

The 2740 LOP is located 25 miles toward the 2800 hyperbola from the 2700 hyperbola on the chart.

Homing

To home a destination by use of LORAN, select the hyperbola which is plotted through destination and passes near the aircraft present position. If destination does not lie on a printed hyperbola, interpolate between hyperbolas to obtain the correct time difference value for destination. All applicable corrections, sky wave and others, depending on the receiver, must be applied with their signs reversed to the hyperbola value.

When the correct time difference value has been determined and preset into the LORAN receiver, the aircraft heading is altered to intercept it. The direction to turn depends on the aircraft location relative to the desired hyperbola.

LORAN Charts

LORAN hyperbolas are usually printed in one of two ways on a LORAN chart. One method is to construct hyperbolas on the chart with 100 microsecond intervals, or some multiple of 100. The other is to print values in a way which allows the hyperbola to be constructed (see figures 18-26 and 18-27). Using these hyperbolas, one can construct LOPs on the chart to determine a fix position. These charts are usually labeled using microseconds. Figure 18-28 may be used to convert PRT to PRR and vice versa.

LORAN-C charts contain sky wave corrections for day and night use. These are printed at regular intervals on LORAN-C charts in those parts of the coverage area where either two sky waves or a ground/sky combination may be used. The following are examples of these corrections.

59,600 − Y +01 D

This indicates a sky/sky correction of +01 for daytime.

59,600 − Y +02 N

Correction for sky/sky match, nighttime.

59,600 − X SG +39 D

Sky wave from master, ground wave for slave daytime correction.

59,600 − X SG +56 N

Sky master, ground slave nighttime correction.

79,800 − Y GS −45 D

Ground master, sky slave daytime correction.

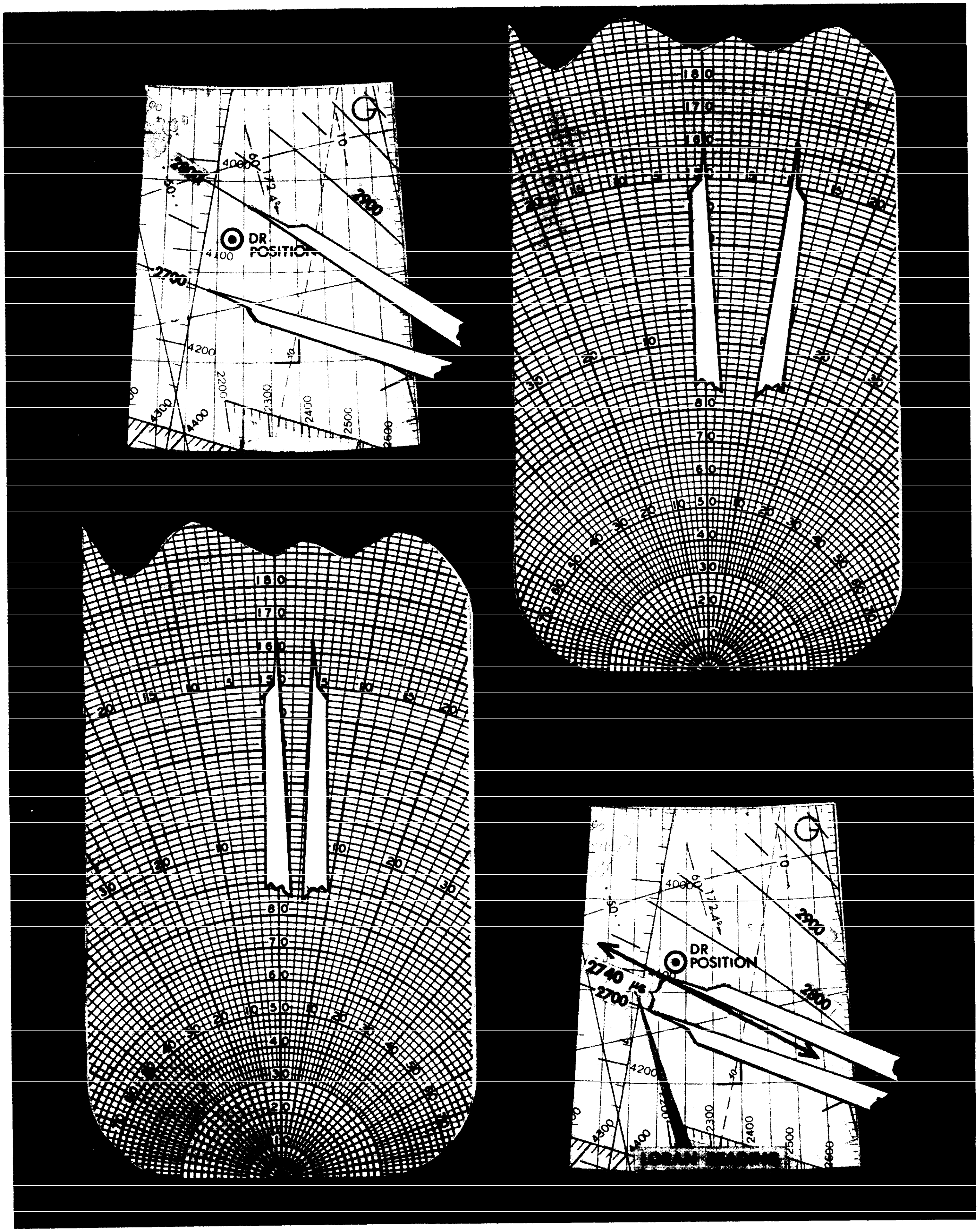


Figure 18-25. Interpolation Using Dividers and Computer Slide.

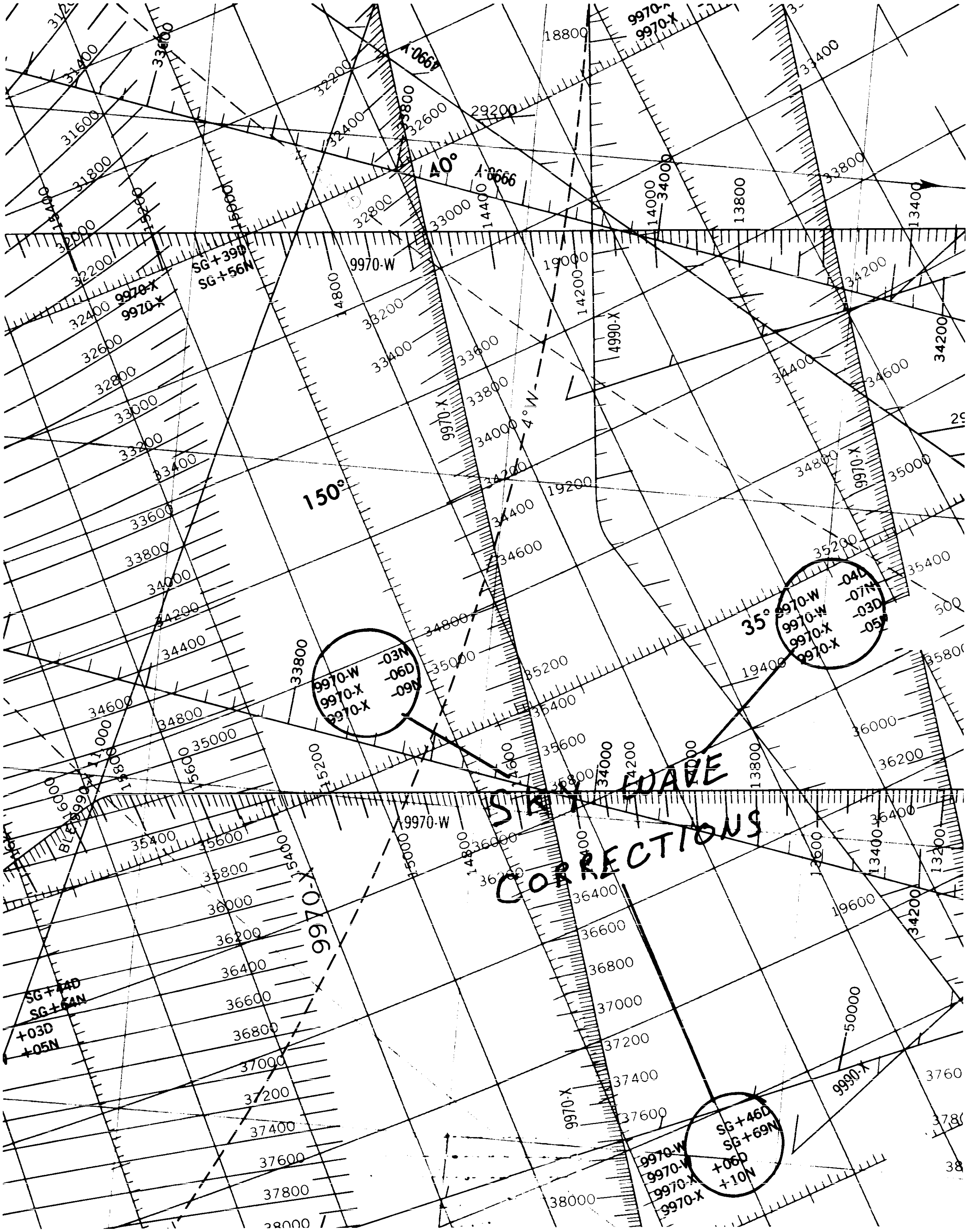


Figure 18-26. Sky Wave Corrections.

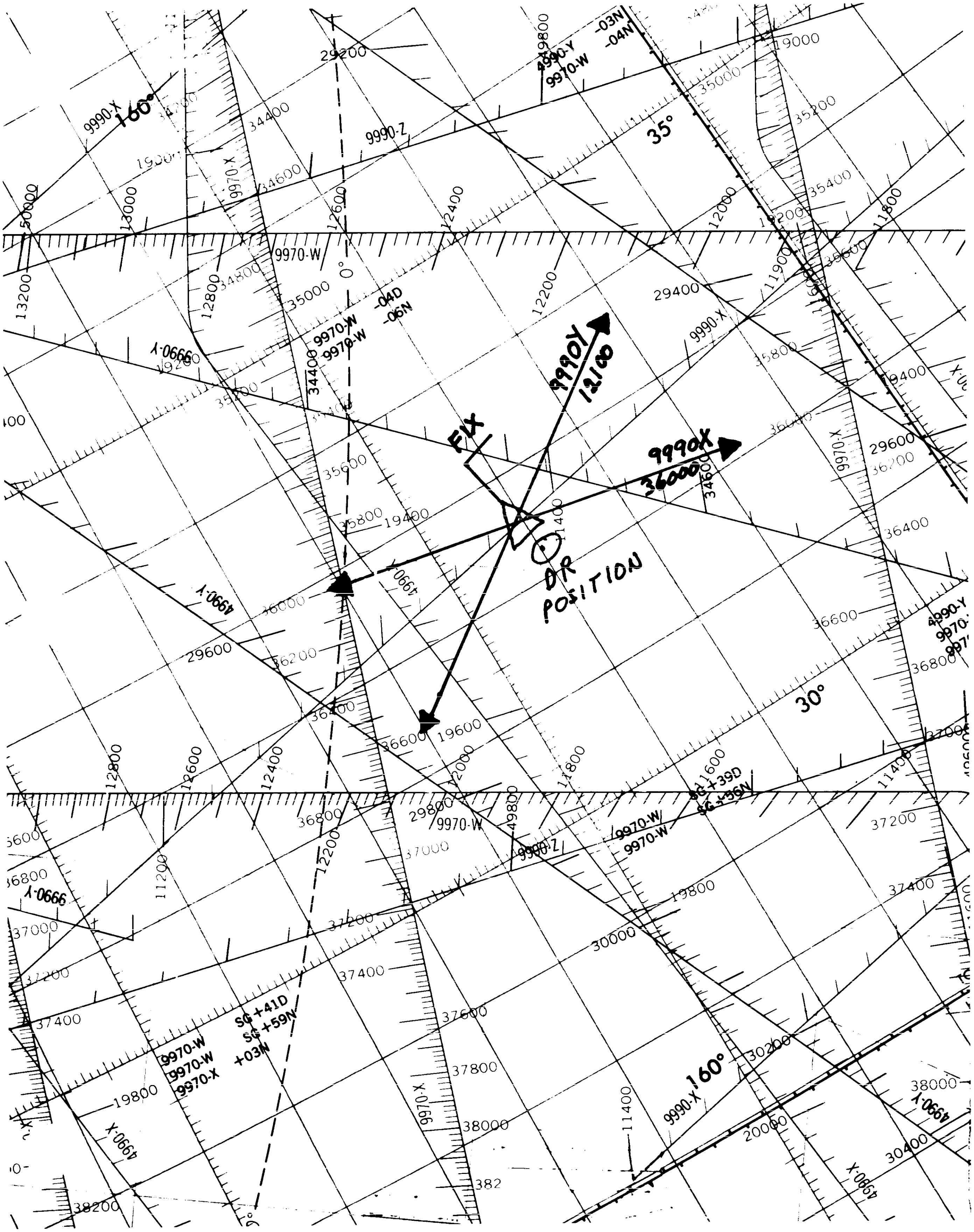


Figure 18-27. Hyperbolas Used to Determine a Fix.

BASIC PRR	SPECIFIC PULSE RECURRENCE RATE		PULSE RECURRENCE TIME (μs)
	STATION NUMBER	PULSES PER SECOND	
SS 10 pps	0	10.00	100,000
	1	10.01	99,900
	2	10.02	99,800
	3	10.03	99,700
	4	10.04	99,600
	5	10.05	99,500
	6	10.06	99,400
	7	10.07	99,300
SL 12½ pps	0	12.50	80,000
	1	12.52	79,900
	2	12.53	79,800
	3	12.55	79,700
	4	12.56	79,600
	5	12.58	79,500
	6	12.59	79,400
	7	12.61	79,300
SH 16⅔ pps	0	16.66	60,000
	1	16.69	59,900
	2	16.72	59,800
	3	16.75	59,700
	4	16.78	59,600
	5	16.80	59,500
	6	16.84	59,400
	7	16.86	59,300

BASIC PRR	SPECIFIC PULSE RECURRENCE RATE		PULSE RECURRENCE TIME (μs)
	STATION NUMBER	PULSES PER SECOND	
S 20 pps	0	20.00	50,000
	1	20.04	49,900
	2	20.08	49,800
	3	20.12	49,700
	4	20.16	49,600
	5	20.20	49,500
	6	20.24	49,400
	7	20.28	49,300
L 25 pps	0	25.00	40,000
	1	25.06	39,900
	2	25.12	39,800
	3	25.19	39,700
	4	25.25	39,600
	5	25.31	39,500
	6	25.37	39,400
	7	25.44	39,300
H 33⅓ pps	0	33.33	30,000
	1	33.44	29,900
	2	33.55	29,800
	3	33.66	29,700
	4	33.77	29,600
	5	33.88	29,500
	6	34.00	29,400
	7	34.11	29,300

Figure 18-28. LORAN-C Pulse Recurrence Rates Table.

If the receiver is located between sets of printed corrections, interpolation is necessary.

Because LORAN-C operates in the low frequency band between 90 and 110 kHz, it is less subject to attenuation, giving it greater range. This allows the base lines between transmitters to be longer, thereby reducing the number of stations required to provide complete coverage.

LORAN-C uses pulse groups instead of a single pulse for measurement of time differences. The use of pulse groups not only increases average transmitting power, but permits the measurement of time differences with accuracies not attainable before. Phased coding of the multi-pulsed groups permits station identification and discrimination between ground waves and sky waves.

The master transmitter of a particular LORAN-C network transmits nine pulses in its group; the slaves transmit eight pulses to a group. The additional pulse in the master group provides visual identification of the station (figure 18-29).

Transmission Irregularities

The accuracy of LORAN-C transmissions depends upon the

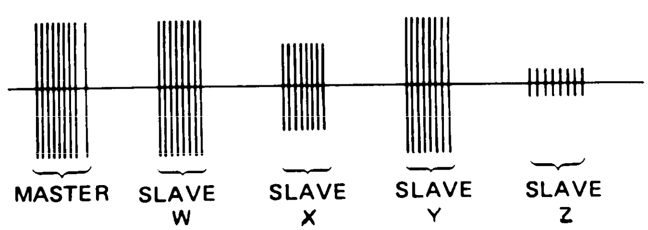
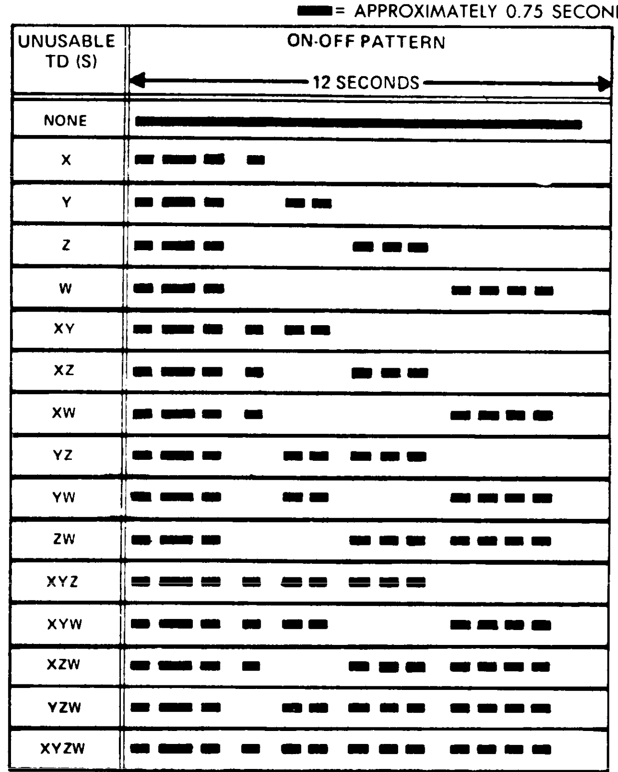


Figure 18-29. Typical Indicator Display — Time Base 1.

TABLE II.

MASTER STATION NINTH PULSE: ▬ = APPROXIMATELY 0.25 SECOND; ▬▬ = APPROXIMATELY 0.75 SECOND



SECONDARY STATION FIRST TWO PULSES:

TURNED ON (BLINKED) FOR APPROXIMATELY 0.25 SECONDS EVERY 4.0 SECONDS. ALL SECONDARIES USE SAME CODE, AUTOMATICALLY RECOGNIZED BY MOST MODERN LORAN-C RECEIVERS.

Figure 18-30. LORAN-C Blink Code.

correct tuning or synchronizing of the signals. LORAN-C transmitting stations use a "blink" code as a warning of transmission irregularities. Such irregularities could be:

- Station not transmitting.
- Incorrect phase coding.
- Incorrect number of pulses.
- Incorrect pulse spacing.
- Incorrect pulse shape.
- Observed time difference at monitor station outside specified limits.

Both master and slave stations of a pair blink if either station is operating incorrectly; readings obtained from that pair must be treated with caution until both stations have stopped blinking. When a slave station blinks, the first two of the eight pulses are transmitted for only ¼ second in every 4 seconds. The master station blinks the ninth pulse in a code, which is repeated in a 12-second cycle (figure 18-30).

Figure 18-31. LORAN C/D Receiver.

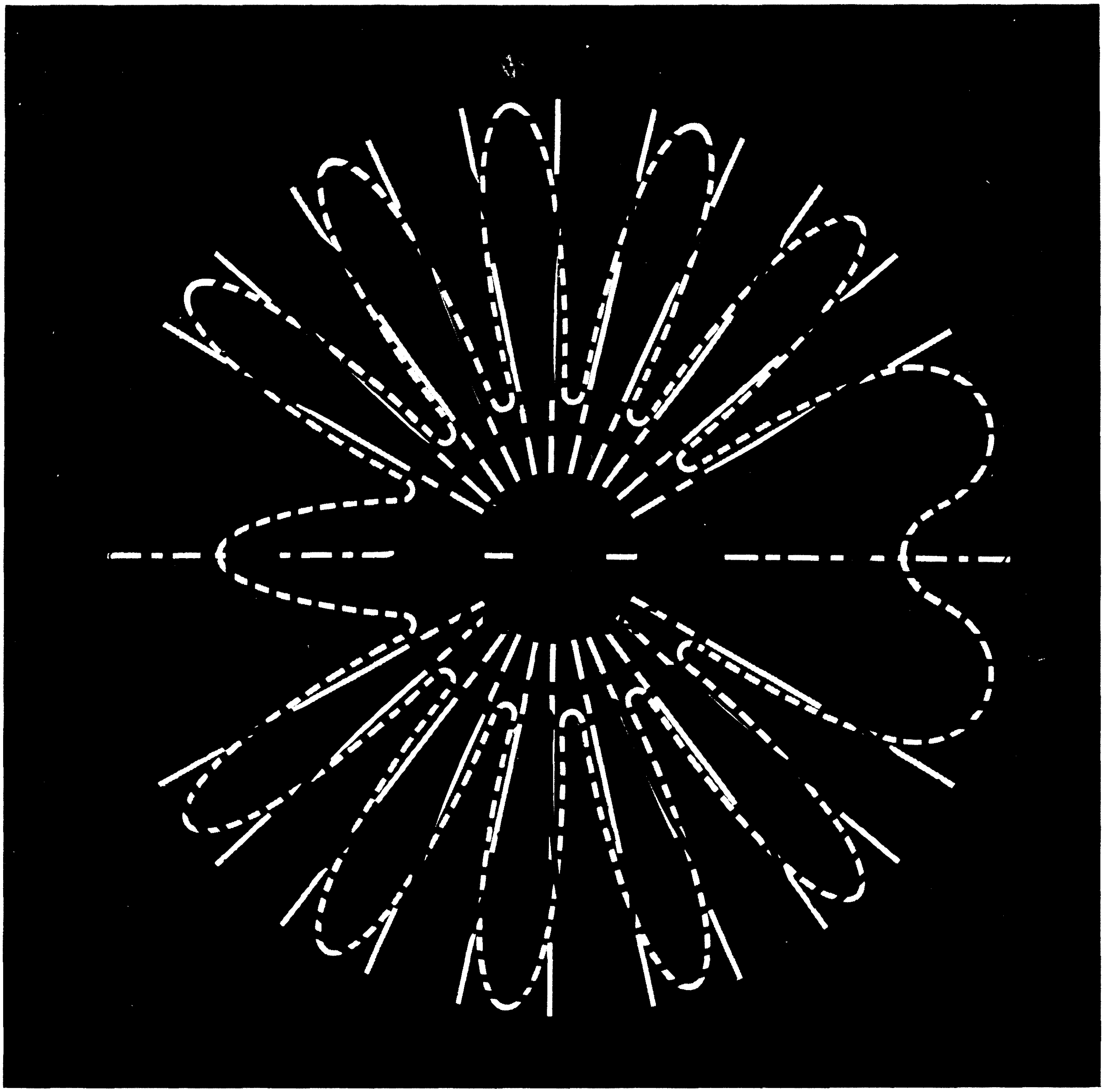


Figure 18-32. Consol Station.

The LORAN-C receiver performs four basic functions:

1. It measures and tracks the carrier phase difference of two station pairs.

2. It measures and tracks the envelope time difference of the same two station pairs.

3. It continuously adjusts the amplitudes of the three pulse groups in order to present signals of constant amplitude to the error detectors.

4. It continuously monitors any combination of the three pulses groups for evidence of sky wave tracking.

LORAN-D

LORAN-D is very similar in characteristics to its predecessor, LORAN-C. The LORAN-D system has relatively short range capability and is designed for tactical uses such as close air support and interdiction, reconnaissance, air drop, and rescue. LORAN-D transmitters may be transported to forward operating locations, and can be operational in short periods of time.

LORAN-D operates in the 90-110 kHz band and has transmission characteristics very similar to LORAN-C. The major dif-

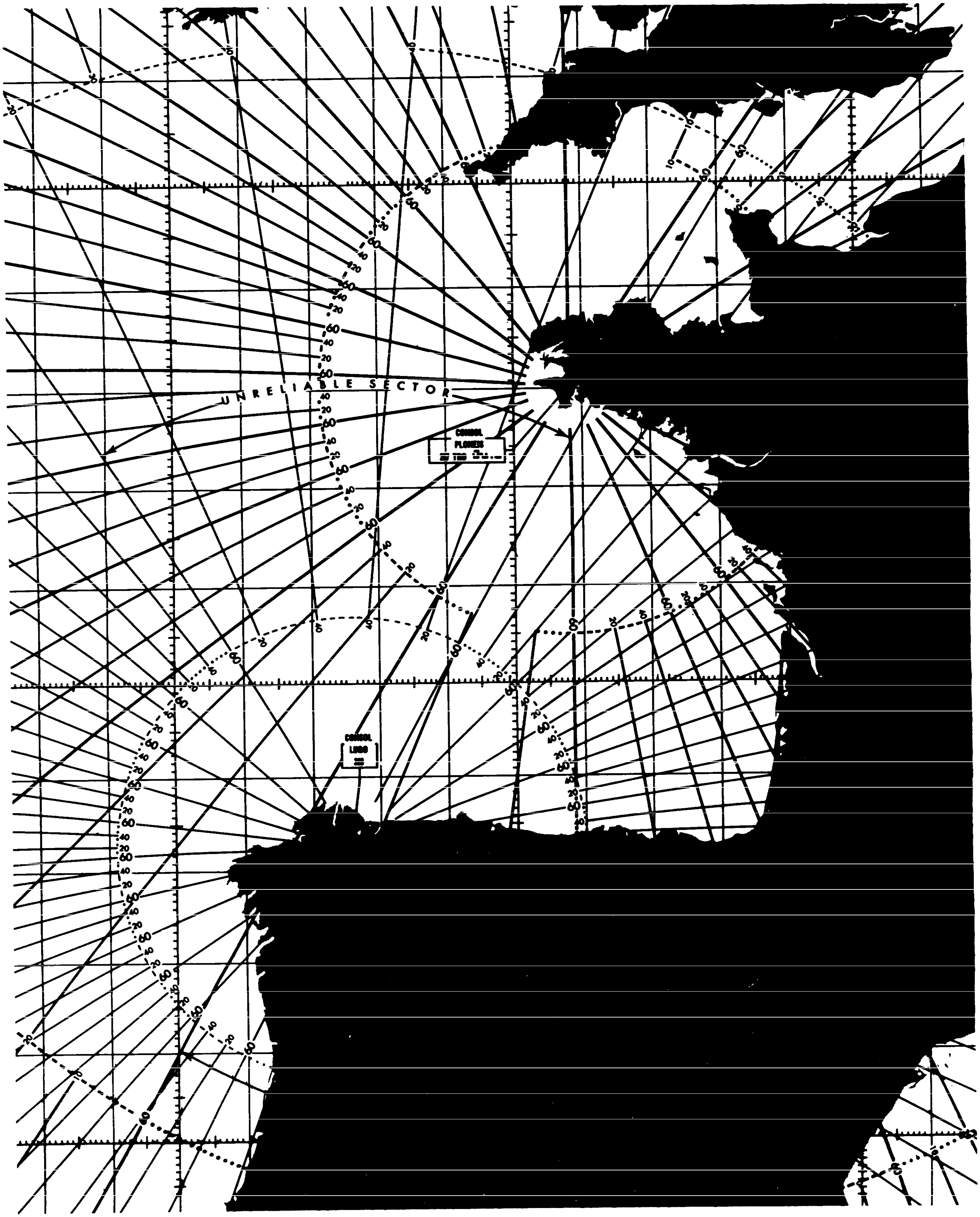


Figure 18-33. Consol Chart.

ference between the two systems is that LORAN-D transmits 16 pulses per group as opposed to 8 pulses per group transmitted by LORAN-C. LORAN-D is designed to provide precise navigation fixes (average predictable error of 600 feet) out to 250 nautical miles from the master station and usable fixes out to 500 nautical miles from the master station.

Combining LORAN-C/D makes possible more precise navigation and position fixing for a variety of missions. LORAN-C/D receivers (figure 18-31) provide continuous time difference measurements which, through the use of modern airborne computers, can provide readouts of aircraft position in latitude and longitude.

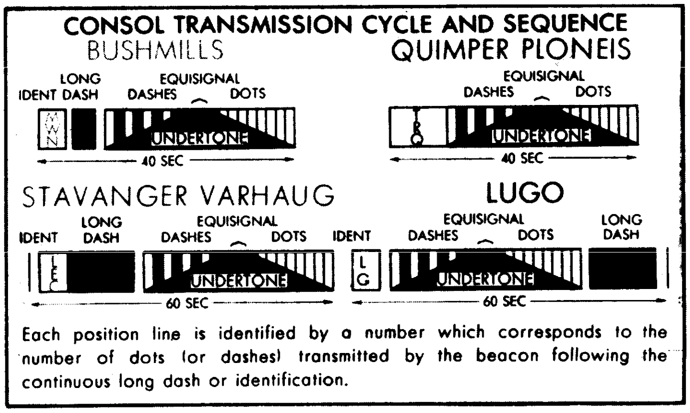


Figure 18-34. Consol Transmission and Sequence.

CONSOL/CONSOLAN

During World War II, Germany developed a navigation system called *Sonne*. Following the war the British further developed the system under the name *Consol* and several stations operating in the LF band have been installed in western Europe. The U.S. system called *Consolan*, also has several stations operating in the same band.

Consol and Consolan differ from other hyperbolic systems in that three antennas are located in a straight line (antenna base line) and are closely spaced. This aid is often considered directional rather than hyperbolic because great-circle bearings are plotted from the position of the center antenna.

The usable range of Consol and Consolan is approximately 1,000 miles during the day and 1,200 to 1,400 miles at night. Bearings are most accurate along a line perpendicular to the antenna base line and accuracy decreases toward the base line extensions. The total usable area is approximately 240° for Consol and 280° for Consolan. The usable circumference is divided into two sections, one on each side of the base line and centered on a perpendicular bisector to the base line (see figure 18-32). Two unreliable areas, of approximately 40° each for Consolan and 60° each for Consol, are centered on the base line extensions. Unreliable sections are labeled on Consol charts. A typical Consol chart is shown in figure 18-33.

In the daytime, at 1,000 miles from the station, LOP errors of from 6 miles at the bisector centerline to 24 miles at the outer edges of the usable areas (approaching the base line) are not uncommon. At night these LOP errors may increase to as much as 10 and 40 miles from the station. Interaction between sky waves and ground waves or high atmospheric noise can cause even larger errors.

Consol signals are transmitted as a series of dots and dashes. The phase of signals transmitted from the two end antennas is rotated with respect to the signal of the center antenna such that the radiation pattern consists of many lobes rotating around the middle antenna. Rotation is clockwise on one side of the base line and counterclockwise on the other side. Alternate lobes, or sectors, contain dot and dash signals which merge into a tone or *equisignal* at the sector boundaries.

The duration of a transmission sequence may be as short as 30 seconds or as long as a minute depending on the particular station being used. During each sequence, a total of 60 dots and dashes is transmitted. The transmission sequence, heard by the operator, is shown in figure 18-34.

To obtain LOPs from a Consol station, only an LF receiver equipped with a beat frequency oscillator (BFO) is needed. Tune the receiver to the desired station frequency and turn on the BFO (CW-Switch). If the receiver being used is equipped with both sensing and loop antennas, select the sensing antenna (ANT). *NOTE:* If excessive interference is present, selecting the loop antenna, after initial tuning, will sometimes improve reception.

The procedure for obtaining an LOP is shown in the following example:

1. Tune the LF receiver to the desired station frequency.
2. Identify the station.
3. Count the number of dots or dashes transmitted before the equisignal (for example, 15 dots are heard).
4. Note the time of the equisignal (this is the time of LOP).
5. Count the number of dots or dashes after the equisignal (dashes—39).
6. Total the number of characters received before and after the equisignal (dots and dashes—54). This total is subtracted from 60 and the remainder (6) is applied equally between the dots and dashes to obtain the corrected dot and dash count (18 dots and 42 dashes).
7. Plot an LOP representing the sum of dots and dashes (18 dots) heard before the equisignal. To plot the LOP, locate the number of dots (or dashes) on the chart which corresponds to those counted and draw a line as is shown in figure 18-35. A DR position or an ADF bearing to the station is used to determine in which dot (or dash) sector the LOP is located. Only a gross error in either the bearing to the station or the DR position could cause the LOP to be plotted in the wrong sector.

CAUTION

1. At night, always take a series of readings, particularly when 300 to 700 miles from the station. Wide variation in successive counts is an indication of ground wave/sky wave interference. These bearings should be used with caution or disregarded altogether.

2. Consol LOPs should never be used within 25 miles of the station.

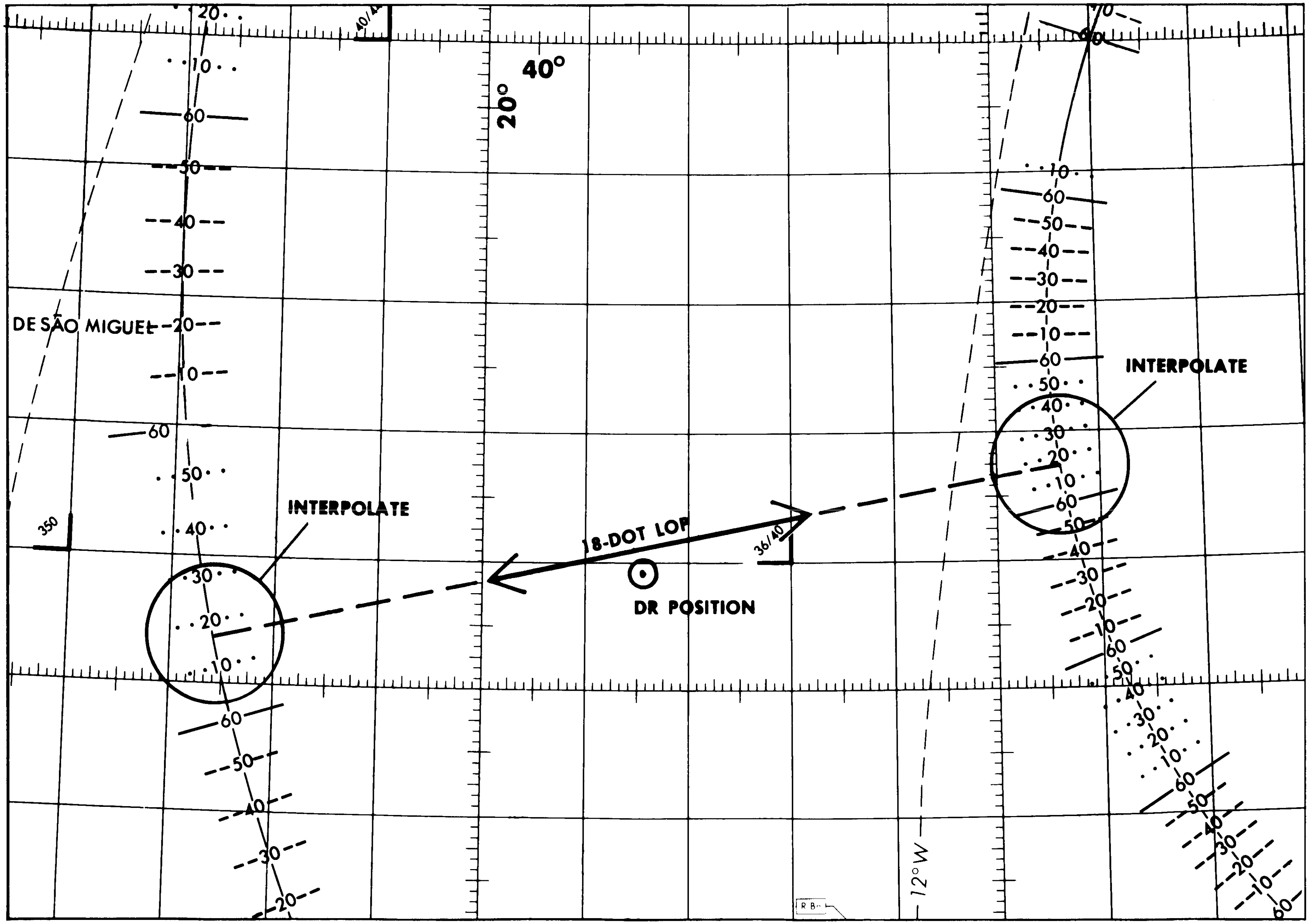


Figure 18-35. Plotting a Consol LOP.

Chapter 19

ADVANCED NAVIGATION SYSTEMS

Navigation systems have improved steadily over the years. However, the single most important technological advance was the development of minute electronic parts and circuitry. The hardware for an early analog computer was larger than an entire airplane. Today's computer can perform more and faster calculations and the entire unit may be installed in a space smaller than a sextant case. Prior to the development of miniature circuitry, such installations were either impractical or impossible.

CLASSIFICATION OF NAVIGATION SYSTEMS

Types of Systems

Navigation systems now in use can be classified as either self-contained or ground-referenced.

Self-Contained. A self-contained system is complete in itself and does not depend upon the transmission of data from a ground installation. However, some self-contained systems, such as search radar and Doppler radar, do require transmission of energy from the aircraft. Other self-contained systems, such as the inertial system and celestial-referenced aids, are completely passive in operation; that is, they do not radiate energy from the aircraft.

Aircraft equipped with self-contained systems can operate anywhere in the world without the assistance of ground-based aids. They have great flexibility since the accuracy of the system is not affected by the location of base line, blind spots caused by terrain, or bad weather.

Ground-Referenced. Ground-referenced aids include all aids which depend upon transmission of energy from the ground. For military purposes, the use of ground-referenced aids involves considerable risk, since in time of war the system provides a navigation aid for enemy as well as friendly forces. Other disadvantages of ground-referenced aids are the large installation and operating costs.

The Ideal System

Every navigation system has certain advantages and disadvantages. A particular navigation system is used in a situation where its advantages can be exploited while its disadvantages do not harmfully affect its use. In some cases, several aids must be provided to fulfill the requirements of different missions adequately. The ultimate objective of navigational research is to produce one system that can be used in any location to supply a complete navigational aid for all aircraft. If such an ideal system is developed, it should have the following characteristics:

Ground Information. The system must indicate the ground position of the aircraft.

Global Coverage. The ideal system must be capable of positioning and steering the aircraft accurately and reliably any place in the world.

Self-Contained. The ideal system must not rely upon ground transmissions of any kind.

Passive Operation. The system must not betray the position of the parent aircraft by transmitting signals of any kind.

Immune to Countermeasures. The system must not be susceptible to countermeasures of any type.

Useless to Enemy. The system must not provide navigational aid or intelligence of any kind to enemy forces.

Flexible. Unlike some navigational systems which place the aircraft or missle on the final heading very shortly after takeoff, the ideal system must be flexible. The system must track the aircraft even though unplanned deviations are made from the preflight course. The system must also be capable of operating at an altitude and at any speed within the capability of the aircraft.

AUTOMATIC ASTROTRACKER

The automatic astrotracker is an optical electromechanical system which provides a continuous true heading reference. Since it uses a celestial rather than magnetic reference, the astrotracker is independent of the Earth's magnetic field. It can therefore provide accurate navigation data in both hemispheres and in both polar regions.

The astrotracker can locate, lock on, and track celestial bodies of the first, second, or third magnitude. These include stars with the photomagnitude of Polaris or brighter, planets, and the Sun.

Components

The automatic astrotracker system includes the following groups:

- Astrotracker
- Control Group
- Indicator Group
- Amplifier and Computer Group
- Power Group

Astrotracker. The astrotracker, shown in figure 19-1, is com-

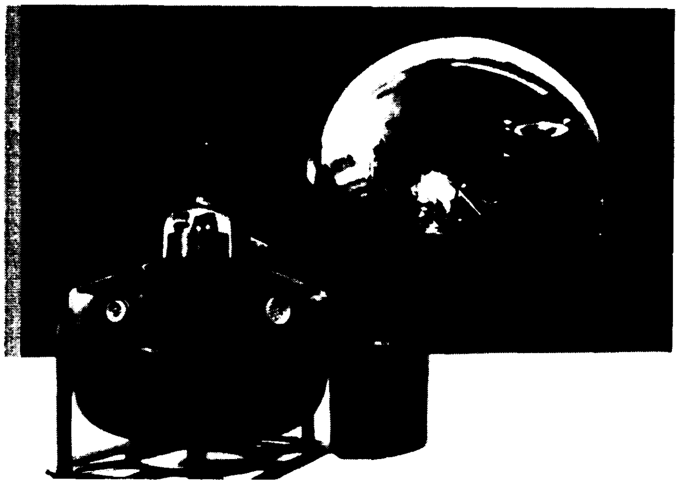


Figure 19-1. Astrotracker.

posed of a tracking telescope which is stabilized by a vertical reference gyro. A hemispherical glass dome is mounted at the top center of the astrotracker housing. The dome projects above the fuselage skin and admits light from celestial bodies to the

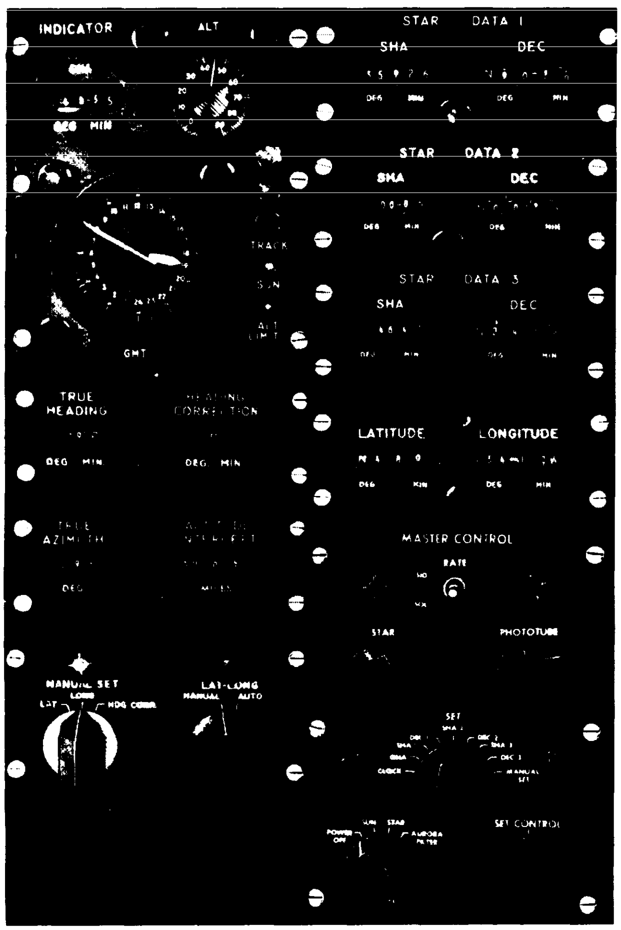


Figure 19.2. Astrotracker Control and Indicator Groups.

tracking telescope. The astrotracker modulates the light waves and a phototube converts the modulated signal to a usable electric signal for the computer group.

Control and Indicator Groups. The control group contains the control panels required for operating the astrotracker system and inserting the required input and computed output information (figure 19-2).

Power Group, and Amplifier and Computer Group. The power group supplies the required power to all astrotracker systems while the amplifier and computer group determines the output data of true heading, true azimuth, celestial altitude, altitude intercept, and heading correction.

Operation

To accomplish its function, the astrotracker system solves for the celestial values of altitudes and azimuth. It must have these necessary inputs: latitude, longitude, Greenwich hour angle, sidereal hour angle, and declination.

Inserting Information. Though normally supplied by automatic navigation computers, latitude and longitude can manually be inserted by the navigator. All celestial information can be obtained from the Air Almanac (GHA of the body, GHA of Aries, SHA, and declination). Stars available for tracking can be obtained from the morning, evening, and polar sky diagrams in the Air Almanac. The photomagnitude of stars (labeled S-4) are also listed in the Air Almanac. The phototube is used to convert the light from celestial bodies to an electrical signal. Its ability to sense light from celestial bodies differs from the ability of the eye to see the light. For example, Antares has a visual magnitude of 1.2 but a photomagnitude of 3.7.

Computing and Displaying Information. After the required information is inserted, a mechanical analog computer computes the true azimuth (Zn) and the computed altitude (Hc). These values are displayed for the navigator's reference as well as being used in the system to position the optical telescope in altitude and azimuth. However, to position the optical telescope in azimuth, the relative bearing of the body to the aircraft must be computed. The astrotracker system accomplishes this by subtracting the best available true heading from the true azimuth (Zn − TH = RB). The best available true heading used for the computation of relative bearing is supplied from an alternate true heading system. The selected body should then be within the optical telescope search pattern.

When the telescope locks onto the body, the astrotracker system computes two values: altitude intercept and heading correction. Altitude intercept is the difference between the computed altitude (Hc) which initially positioned the telescope and the actual altitude of the body. Heading correction is the difference between the computed relative bearing and the actual relative bearing of the body. Next, the astrotracker computes the true heading by applying the correction value to the best available true heading supplied by the alternate true heading system.

With the advent of high-speed aircraft, the need for accurate heading information becomes more and more acute. The astrotracker supplies this heading information with an accuracy of ± 6 minutes of arc.

Astrotrackers are also designed for space vehicles, missile guidance systems, and satellite applications. They can lock onto inertially stable star directions to serve as sensors of space vehicle attitudes. When used on nearby solar bodies, the direction information can be used with respect to solar coordinate systems to develop accurate position information as well as vehicle attitude.

INERTIAL NAVIGATION SYSTEM (INS)

Inertial navigation is now accepted as an ultimate in navigation systems for two reasons:

1. An inertial system neither transmits nor receives any signal, so it is unaffected by enemy countermeasures.
2. Theoretically, there is no accuracy limitation in an inertial system. Technology and manufacturing precision can be considered as the factors affecting accuracy.

An inertial navigator can measure groundspeed in the presence of wind and is completely independent of operating environments. The need for a system with these properties has spurred development to the point where the inertial navigator is as good as, or better than, other automatic navigation systems. The inertial navigator provides accurate velocity information instantaneously for all maneuvers, as well as an accurate attitude and heading reference.

Principles

The basic principle of inertial navigation is the measurement of acceleration or displacement, rather than the measurement of airspeed and wind velocity as is necessary in the use of dead reckoning. This measuring of displacement is done with accelerometers. The four basic components in any inertial navigation system are:

1. A stable platform oriented to maintain the accelerometers horizontal to the Earth and to provide azimuth orientation.
2. The accelerometers arranged on the platform to supply specific components of acceleration.
3. The integrators to receive the output from the accelerometers and to furnish velocity and distance.
4. A computer to receive the signals from the integrators and to change the distance traveled into position in the selected coordinates.

Figure 19-3 shows that the accelerometers are maintained horizontal to the Earth by means of a gyrostabilized platform. A signal is transmitted from the accelerometer to the integrators, which perform a double integration. Distance is fed into the computer where two operations are performed; first, a position is determined in relation to the reference system used, and second, a signal is sent back to the platform to reposition the accelerometer.

Accelerometer

Acceleration-measuring devices are the heart of all inertial systems. It is most important that all possible sources of error be eliminated and that the accelerometers have a wide range of measurements. Very slight accelerations or even decelerating quantities need to be recorded. Changes in temperature and pressure must not affect the output of acceleration. An accelerometer consists of a pendulous mass which is free to rotate about a pivot axis in the instrument. There is an electrical pickoff which converts the rotation of the pendulous mass about its pivot axis into an output signal. This output signal is used to torque the pendulum to hold it into position and, since the signal is proportional to the measured acceleration, it is sent to the navigation computer as an acceleration output signal (figure 19-4). However, the accelerometers cannot distinguish between actual acceleration and the force of gravity. Acceleration, to be meaningful, must be computed relative to the Earth. This means that the accelerometers must be kept level in relation to the Earth's surface (perpendicular to the local vertical) if acceleration in the horizontal plane is to be measured. The gyroscopes keep the accelerometers level and oriented in a north-south and east-west direction.

In an aircraft, acceleration must be measured in all directions. To do this, three accelerometers are mounted mutually perpendicular (orthogonal) in a fixed orientation. To convert acceleration into useful information, the acceleration signals must be processed to produce velocity and then the velocity information must be processed to get the distance traveled. It is true that if acceleration is integrated with respect to time, velocity results.

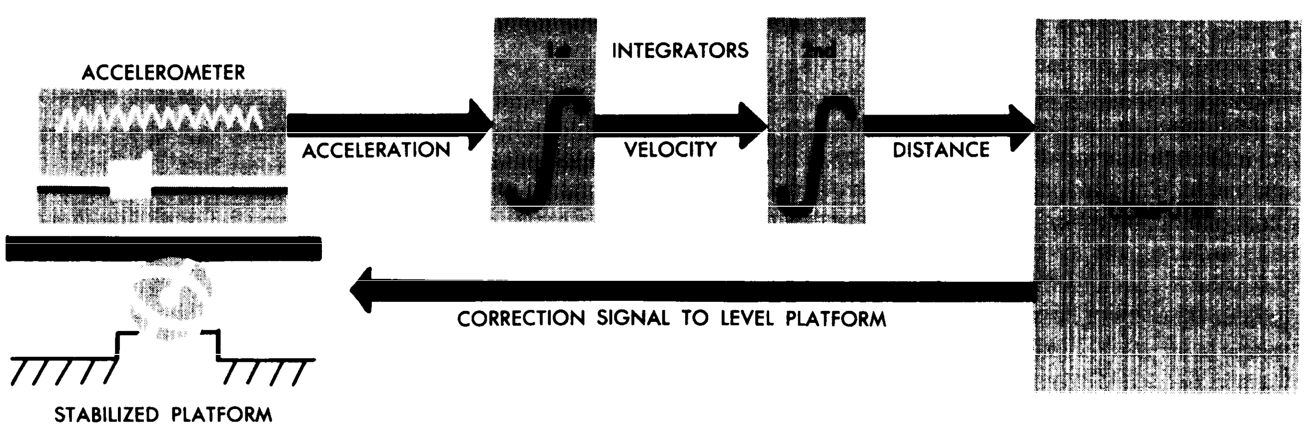


Figure 19-3. A Basic Inertial System.

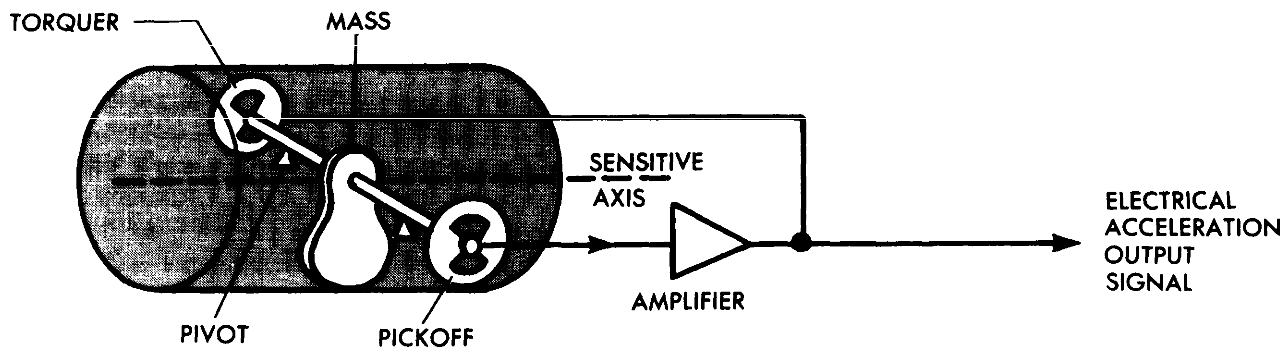


Figure 19-4. Accelerometer.

It is also true that if velocity is integrated, the result is distance. Any inertial system is based on the integration of acceleration to obtain velocity and distance. Acceleration is a vector quantity and has not only magnitude but also direction.

Integrator

The integration of both acceleration and velocity is very critical and the highest accuracy is essential. There are two types of integrators: the analog and the digital. One of the most used analog integrators is the RC amplifier, which uses a charging current stabilized to a specific value proportional to an input voltage. Another analog integrator is the AC tachometer-generator, which uses an input to turn a motor; the motor physically turns the tachometer-generator, producing an output voltage. The rotation of the motor is proportional to an integral of acceleration. Simply stated, the processing of acceleration is done with an integrator. All an integrator does is to produce an output which is the mathematical integral of the input, or in other words, the input signal multiplied by the time it was present (figure 19-5).

Stable Platform

Gyros are mounted on a platform with the accelerometers and control the orientation of the platform. All inertial systems use a gyro-stabilized platform to maintain accelerometer orientation. Each platform must contain a minimum of two gyros. If rate gyros are used, three gyros are needed. Each gyro must have its own independent operating loop. The effectiveness of the platform is determined by all parts of the platform, not just the gyros, to include torque motors, servo motors, pickoffs, amplifiers, and wiring. The gyro presents the major problems, particularly concerning precession. Many later developments have appeared, including the air-bearing gyro, which has only 1/10,000,000 the friction of a standard gyro and its real precession is negligible. Other gyros have real precession rates of less than 360 degrees in 40 years. Platforms have been used for years in bombing and fire control systems; autopilots use a basic platform. Inertial navigation simply requires a stable platform with higher specifications of accuracy.

A gyro-stabilized platform on which accelerometers are mounted is called a stable element. It is isolated from the aircraft's angular motions by gimbals. A simple diagram of a 2-degree-of-freedom gyro mounted on a single-axis platform is shown in figure 19-6.

A gyro tends to remain in its original position when it is up to speed. Any displacement of the stable element from its frame of reference is sensed by the electrical pickoffs in the gyroscopes. These electrical signals are amplified and used to drive the platform gimbals to realign the stable element.

More advanced inertial navigation systems have a four-gimbal platform in a three-axis configuration. The order of gimbal axis is as follows, starting with the innermost axis: azimuth, inner roll, pitch, and outer roll (figure 19-7).

The four-gimbal mounting provides a full 360-degree freedom of rotation about the stable element, thus allowing it to remain level with respect to local gravity and to remain oriented to true north. This is north as established by the gyros and

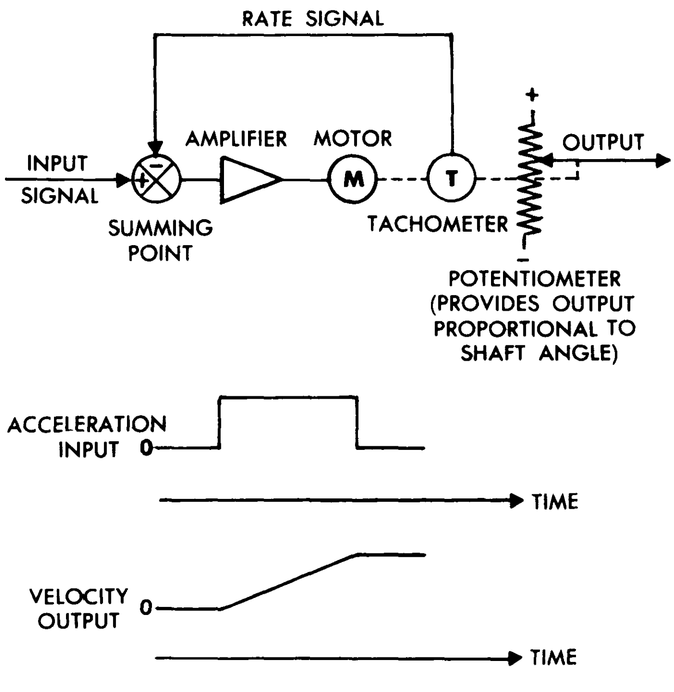


Figure 19-5. Integrator.

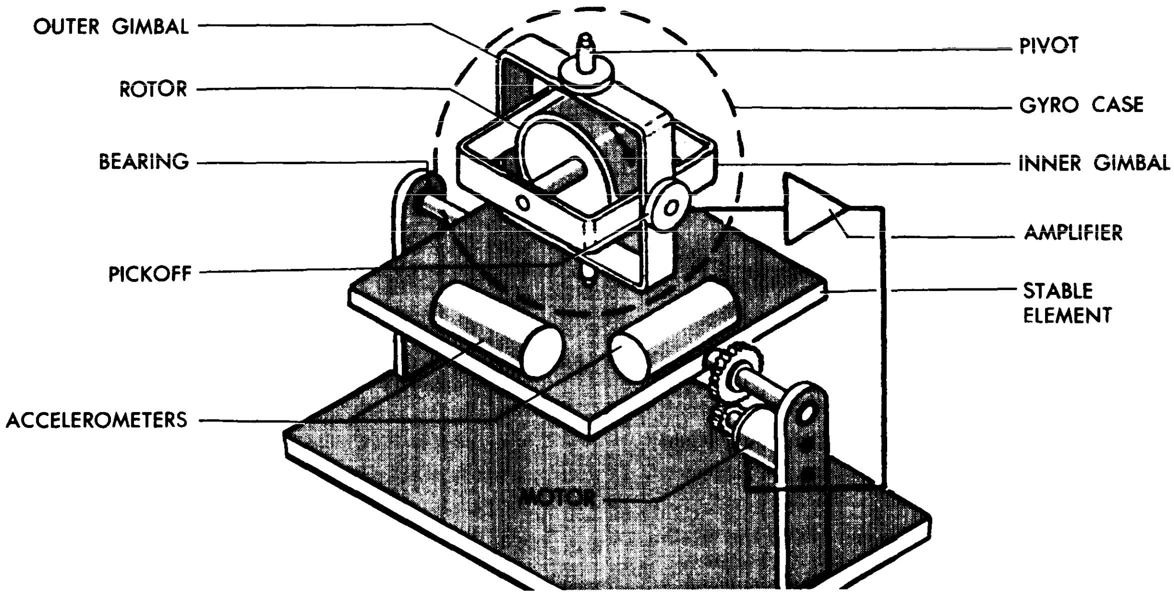


Figure 19-6. Stable Platform.

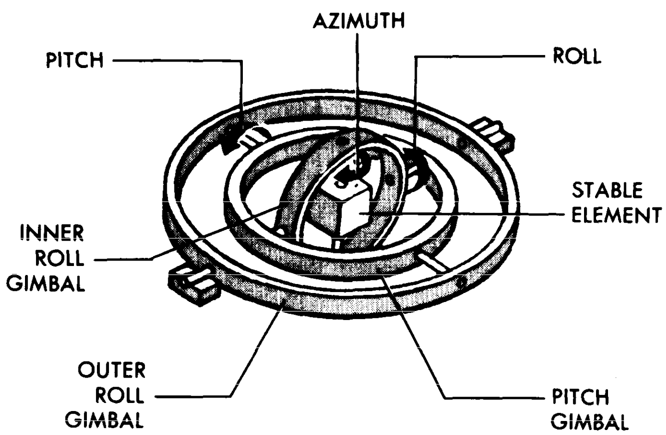


Figure 19-7. Gimbal Platform.

accelerometers, regardless of the in-flight attitude of the aircraft. The azimuth, pitch, and outer roll gimbals have 360-degree freedom of rotation about their own individual axis. The fourth or inner roll gimbal has stops limiting its rotation about its axis. This gimbal is provided to prevent gimbal lock, which is a condition that causes the stable element to tumble. Gimbal lock can occur during flight maneuvers, such as a loop, when two of the gimbal axis become aligned parallel to each other, causing the stable element to lose one of its degrees of freedom.

Measuring Horizontal Acceleration

The key to a successful inertial system is absolute accuracy in measuring horizontal accelerations. A slight tilt will introduce a component of Earth's gravity and incorrect acceleration will be measured (figure 19-8).

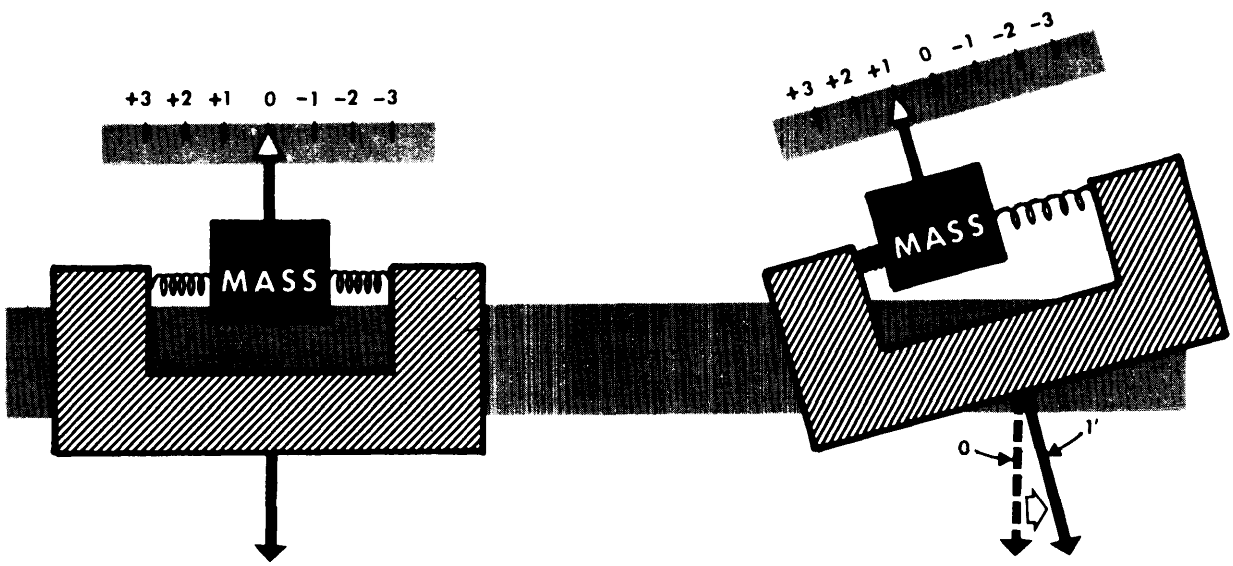


Figure 19-8. Effect of Accelerometer Tilt.

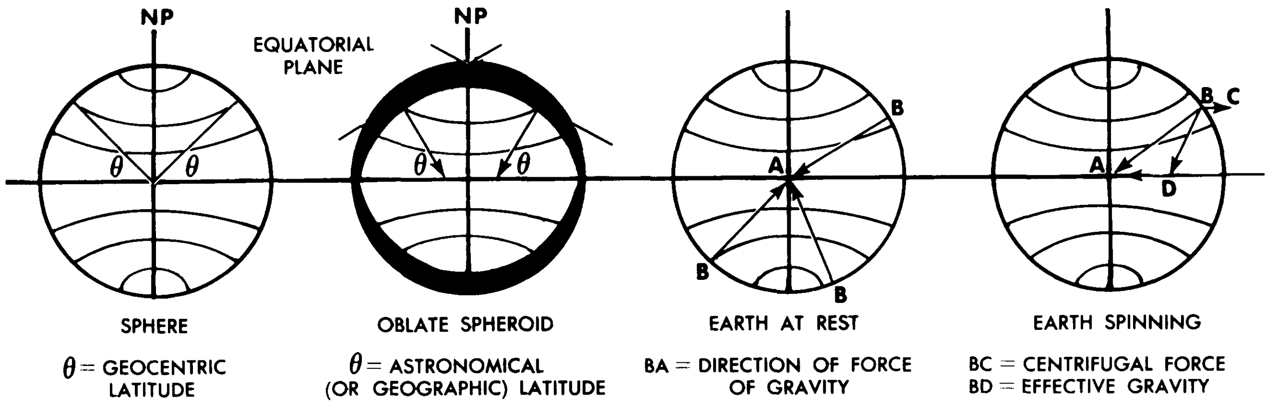


Figure 19-9. Effect of Earth Rotation on Gravity Field.

Keeping the accelerometers level is the job of the feedback circuit. The computer calculates distance traveled and, via the feedback link, moves the accelerometer through an equivalent arc. The problem of aligning the accelerometer using this method is complicated by the following factors:

- The Earth is not a sphere, but an oblate spheroid or geoid.
- The rotation of the Earth produces a centrifugal force which deflects the specific force of gravity.
- Because the Earth is not a smooth surface, there are local deviations in the direction of gravity.

The feedback circuit operates on the premise that the arc transversed is proportional to distance traveled. Actually, the arc varies considerably because of the Earth's shape; the variation is greatest at the poles. The computer must solve for this irregularity in converting distance to arc.

The accelerometers are kept level relative to astronomical rather than geocentric latitude. Using the astronomical latitude, the accelerometers are kept aligned with the local horizon and also with the Earth's gravitational field. The Earth's rotation produces a centrifugal deflection that causes gravity to be perpendicular to astronomical latitude (figure 19-9).

Local abnormalities in the Earth's gravitational field are of minor concern. They are compensated for only in vehicles with short inertial guidance terms, such as ballistic missiles.

Accelerometers are kept level by feedback from the computer. Feedback is needed because of two effects, both called apparent precession. If the inertial unit were stationary at one point on the Earth, it would be necessary to rotate the accelerometers to maintain them level, because of the Earth's angular rotation of 15 degrees per hour. Also, movement of the stabilized platform would require corrections to keep the accelerometers level. When using a local horizontal system in which the accelerometers are maintained directly on the gyro platform, the gyro platform must be precessed by a signal from the computer to keep the platform horizontal. Apparent precession is illustrated in figure 19-10.

A slight error in maintaining the horizontal would induce a major error in distance computation. If an accelerometer picked up an error signal of 1/100 of the G-force, the error on a 1-hour flight would be 208,000 ft. Dr Maxmillian Schuler, in 1923, showed that a pendulum with a period of approximately 84 minutes could solve the problem of eliminating inadvertent

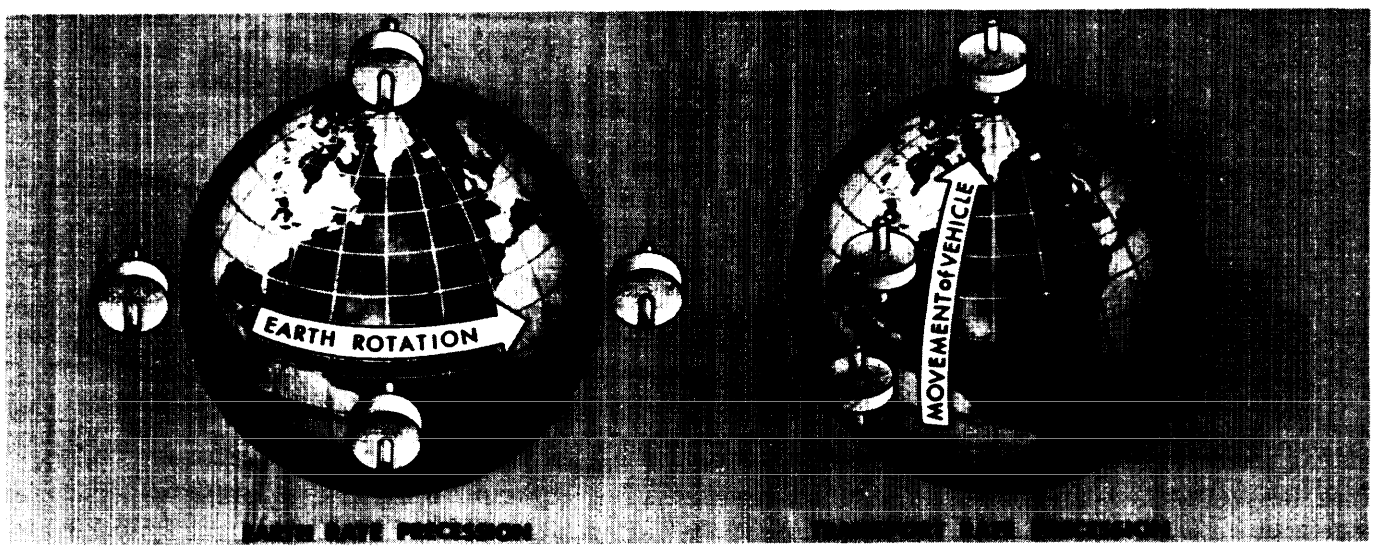


Figure 19-10. Apparent Precession.

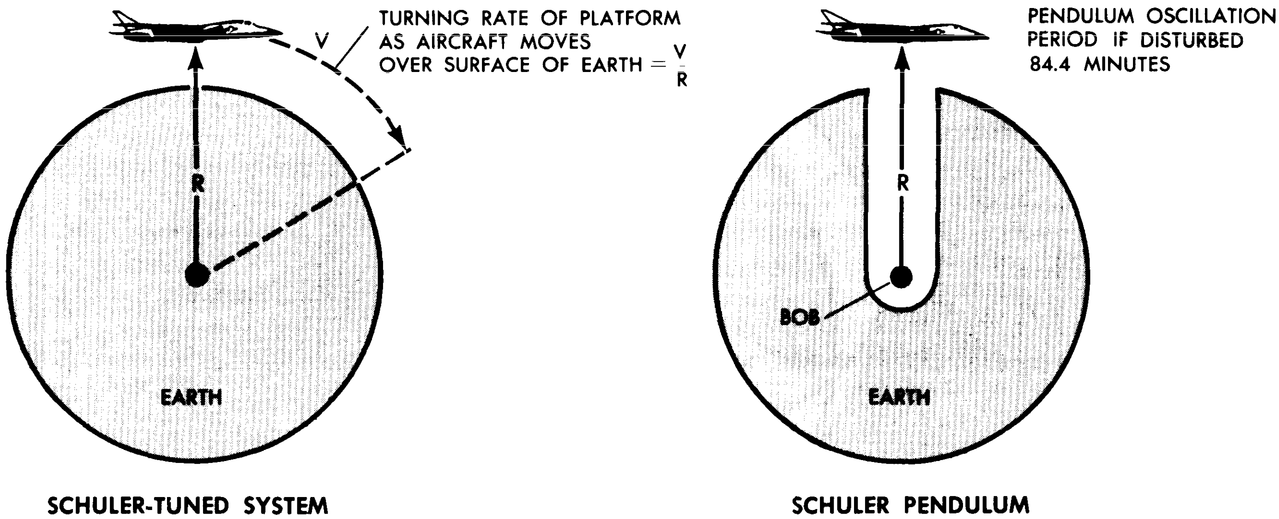


Figure 19-11. Schuler Pendulum Phenomenon.

acceleration errors. The fundamental principle of the 84-minute theorem is that if a pendulum had a radius equal to that of the Earth, gravity would have no effect on the bob because the center of the bob would be at the center of gravity of the Earth. If a pendulum has a period of 84 minutes, it will indicate the vertical regardless of acceleration of the vehicle. The Schuler pendulum phenomenon prevents the accumulation of errors caused by the measurement of gravity, although it will not compensate for errors in azimuth resulting from the precession of the steering gyro. The amplitude of the Schuler cycle depends upon the overall accuracy of the system. Figure 19-11 shows the Schuler-tuned system.

A gyro that is up to speed and is unslaved or not torqued, is space-oriented and will appear to move with respect to the surface of the Earth. This is undesirable for aircraft inertial navigators, because the accelerometers will not be kept perpendicular to the local vertical. To Earth-orient a gyro, the control of apparent precession is used. If a force is applied to the axis of a spinning gyro wheel which is free to move in a gimbaling structure, the wheel will move in a direction at right angles to the applied force. This is called "torquing" a gyro and can be considered as mechanized or induced precession. A continuous torque, applied to the appropriate axis by electromagnetic elements called torques, reorients the gyro wheel to maintain the stable element level, with respect to the Earth, and keeps it pointed north. An analog or digital computer determines the torque to be applied to the gyros through a loop that is tuned using the Schuler pendulum principle. The necessary correction for Earth rate depends on the position of the aircraft; the correction to be applied about the vertical axis depends on the velocity of the aircraft.

It is important that the stable element be accurately leveled with respect to the local vertical and aligned in azimuth with respect to true north. Precise leveling of the stable element is accomplished prior to flight by the accelerometers that measure acceleration in the horizontal plane. The stable element is moved until the output of the accelerometers is zero, indicating that they are not measuring any component of gravity and that the platform is level.

Azimuth alignment to true north is accomplished before flight by starting with the magnetic compass output and applying variation to roughly come up with true north reference. From this point, gyrocompassing is performed. This process makes use of the ability of the gyros to sense the rotation of the Earth. If the stable element is misaligned in azimuth, the east gyro will see the wrong Earth rate and will cause a precession about the east axis. This precession will cause the north accelerometer to tilt. The output of this accelerometer is then used to torque the azimuth and east gyro to insure a true north alignment and a level condition.

Solving Navigational Problem

The frame of reference of an inertial system will govern to some degree the uses of the system. The geographical coordinate system with north reference is the most common, but not the only system used. A north-oriented system requires that one accelerometer be mounted aligned to north and another mounted 90 degrees to the first, to sense east-west accelerations. This arrangement allows for any movement to indicate distance traveled east-west and north-south. Distance north-south is converted to coordinates by dividing miles traveled by 60 to obtain degrees; east-west travel requires that distance be multiplied by the secant of latitude and divided by 60 to obtain degrees. This is due to the convergence of meridians and is performed by computers. Although convenient, latitude and longitude reference has the distinct disadvantage of not being adaptable to use in the polar regions, because of convergence of longitudes. It is possible to offset the pole to a point on the equator. This offset would result in the polar areas being covered by a square grid. There is no specific reason to use a north-oriented system, for no external reference such as magnetic north is used in the inertial system. As a matter of fact, some inertial systems use a principle known as wander angle, which does not require the gyros to be oriented

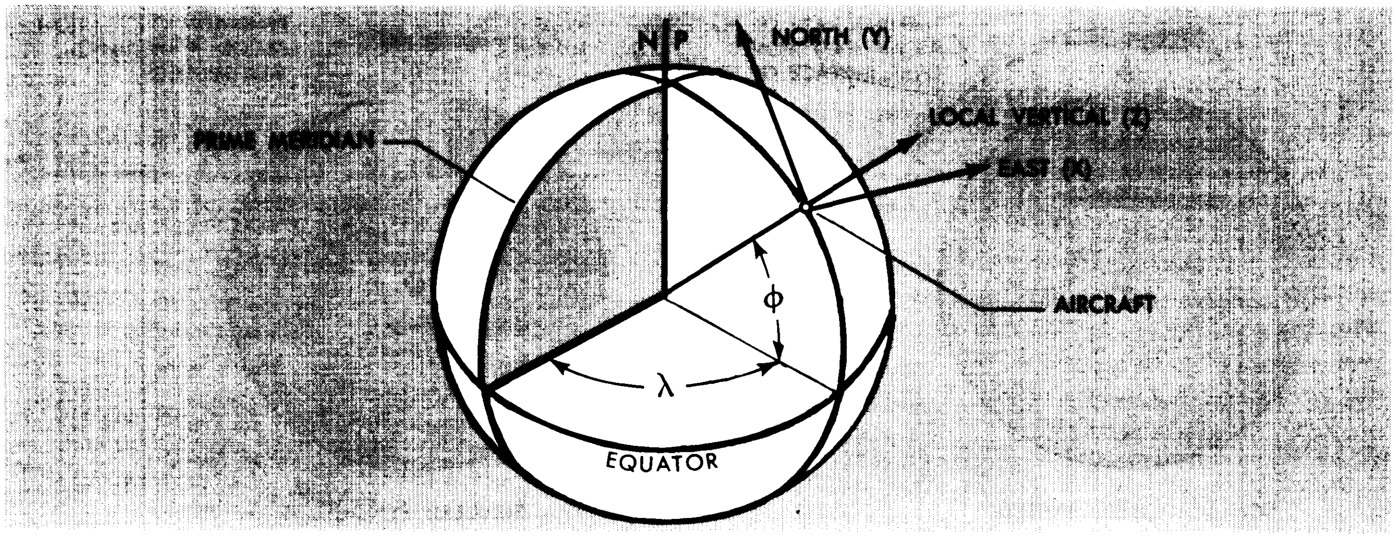


Figure 19-12. Geographic References.

to true north. A wander angle inertial system has the advantage of being able to operate in polar regions.

The Earth is not a perfect sphere but an ellipsoid, the equator diameter being 27 miles longer than the polar diameter. The inertial navigation system (INS) maintains a continuous local vertical reference and measures distance traveled over a reference spheroid which is perpendicular to the local vertical. This reference spheroid is mechanized by the INS computer. On this spheroid, the latitude and longitude of the present position are continuously measured by the integration of velocity. In figure 19-12, phi represents latitude and lambda represents longitude.

The axes are arbitrarily designed X, Y, and Z—which correspond to east, north, and local vertical respectively. This defines their positive directions. From now on, reference to velocities, attitude angles, and rotation rates will be about the X, Y and Z axes. The local vertical (Z) is established by platform leveling. This is the most fundamental reference direction. To complete platform alignment, north (Y) must be known; this is accurately established by gyrocompassing. However, prior to gyrocompassing, the platform is course aligned; which is rotating the platform about the vertical (Z) axis through an angle equal to magnetic heading, plus local variation, to an accuracy of .5 degrees or less. It should be pointed out here that gyrocompassing establishes platform alignment to the Earth's axis of revolution or North Pole. The INS is capable of doing this to an accuracy of 10 minutes of arc or less. After the platform is aligned, it remembers its alignment and always stays pointing to true north and the local vertical regardless of the maneuvers of

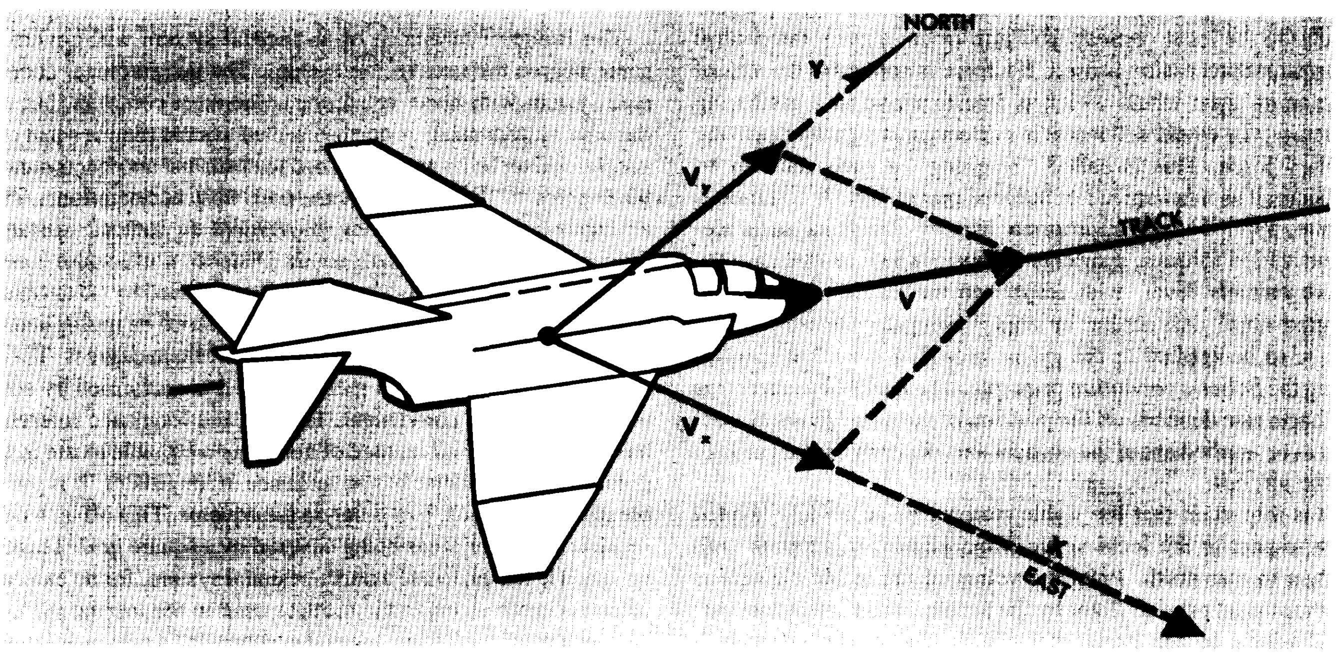


Figure 19-13. Measurement of Aircraft Groundspeed.

the aircraft.

Groundspeed components of velocity in track (V), are measured by the system along the X and Y axes, as shown in figure 19-13. These components, Vx and Vy include all effects on the aircraft such as wind, thermals, engine accelerations, and speed brake decelerations. The groundspeed (V) is usually displayed by some form of digital readout.

The angles between the aircraft attitude and the platform reference attitude are continuously measured by synchros. The aircraft yaws, rolls, and pitches about the platform in a set of gimbals, each gimbal being rotated through some component of attitude. True heading is measured as the horizontal angle between the aircraft's longitudinal axis and platform north. This is shown in figure 19-14. Roll and pitch angles are measured by synchro transmitters on the platform roll and pitch gimbals.

Computer

Three of the basic components in any inertial navigation system—accelerometers, integrators, and the stable element with its gyros—have been discussed. The fourth component is the computer.

The principle of inertial navigation does not include fixing en route; thus, there is a need for much greater accuracy in the computers used with inertial than in those used with other systems. The computer function is less complex than that of basic GPI (ground position indicator) units. Since the input from the integrators is already defined as distance, the operation requires only the solution of present position. The second function of the computer is to send a positioning signal to the stabilized platform. Additional operations may be performed by computers in selected units (solution and display of true headings, ground track, groundspeed, wind direction and velocity, etc) but the two functions described are the only ones required of computers related to all inertial systems.

Summary

Inertial navigation system technology has advanced very rapidly within the past few years. Inertia is rapidly becoming the basic element around which advanced navigation systems are designed. Inertial navigation systems with excellent reliability and present position errors of less than 3 NM per hr are currently employed in a number of operational aircraft and accuracies of 1 NM per hr and less are within the state of the art.

NAVIGATIONAL COMPUTER SYSTEMS

In the same way an autopilot frees a pilot from the manual operations of flying, a navigation computer system relieves the navigator of many manual operations required to direct the aircraft in flight. When automatic sensing devices like the Doppler and astrotrackers are tied into a navigation computer system, the navigator is automatically provided current readings of present latitude and longitude, groundspeed, and heading. The navigation computer system thereby eases the navigator's workload and frees him or her to make the decisions that are beyond the capability of computers.

Modern aircraft are capable of speeds and ranges which require the navigator to perform extensive calculations rapidly and accurately. Consider a flight from the United States to a foreign country. The route could pass through areas of land, water, and ice caps. The navigator must contend with overcast, undercast, day, and night, in addition to altitude changes, turning points, and mandatory ETA requirements. To handle all these conditions at the speed of sound or faster, the navigator uses automatic navigation computers.

The navigational computer system consists of:

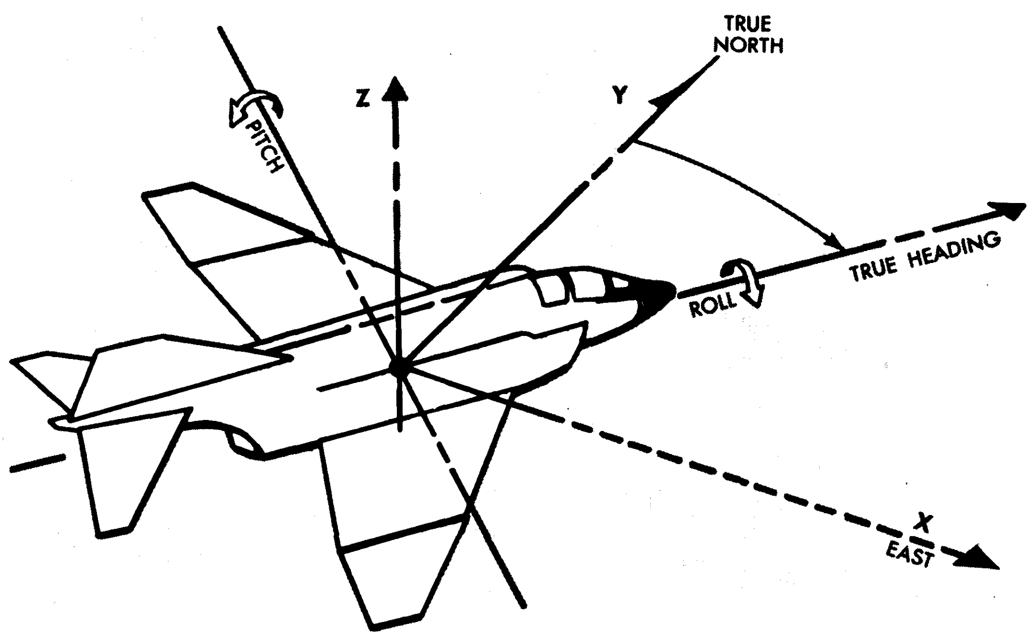


Figure 19-14. Measurement of Aircraft Attitude.

• The data-gathering units (sensors) such as radar, Doppler, and astrotracker.

• Computer units where the computations and comparisons are made.

• Navigation panels containing the dials and controls which give the navigator a system-monitoring and control capability.

Sensors

Radar. When a radar set is incorporated with the computer system, movable electronic crosshairs are displayed on the radarscope so that range and direction of radar returns can be measured and inserted into the computer (figure 19-15). The crosshairs consist of a variable range mark and a variable azimuth mark. They can be maneuvered with a crosshair control handle. On the radarscope, they resemble a single fixed range mark and a heading mark. By moving the crosshair control handle, the navigator simultaneously changes the position of the crosshairs and the corresponding coordinate measurements (east-west and north-south) being fed to the navigation computers. The function is completed almost instantaneously.

When the navigator positions the crosshairs on a given return, the computers determine the distance between the aircraft and the return. If the coordinates of the return have been set in the computer, the computer can maintain a running account of the aircraft latitude and longitude.

Doppler. Doppler radar's contribution to the computer system is groundspeed and drift. These two outputs can be put to several uses in the computer system. Doppler groundspeeds can be used to drive the present position latitude and longitude counters. Doppler outputs can be used in platform leveling and in checking inertial groundspeed in an inertial system. Doppler radar is an essential part of many navigation computer systems.

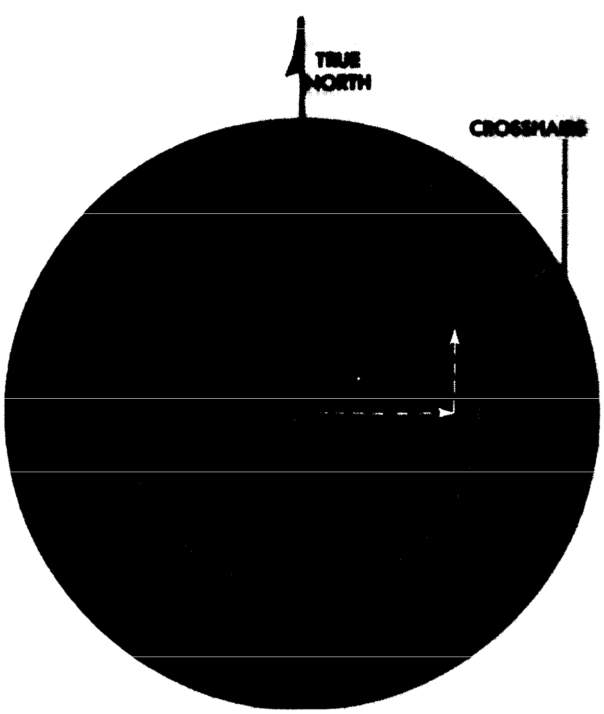


Figure 19-15. Radar Cross Hairs.

Astrotracker. The astrotracker is another data-gathering unit in a computer system. Its accurate measurement of true heading regardless of local magnetic variation makes the astrotracker a valuable addition. The navigation computer system can combine astrotracker true heading with Doppler drift to produce current aircraft track. The astrotracker also provides celestial LOP information which can be used by the navigation computer for fixing.

Inertial Navigation. The inertial unit is used to feed velocity information into the computers. Once the inertial sensor is leveled and in operation, it is used to continually update the present position counters.

LORAN. LORAN, discussed in chapter 18, fits well in an automatic computer system. Some computer systems have the coordinates of LORAN stations stored in them; during flight, the navigator selects the stations he or she wants to use and the computer does the rest. Fixing is automatic and occurs in somewhat the same way that a navigator takes a celestial fix. An assumed position is determined by the computers; the LORAN position is then applied to this assumed position. A series of credibility checks and approximations are applied automatically to the computer. The result is an accurate LORAN fix. When the computers function in the LORAN mode, continuous present position and groundspeed information is still available.

TACAN. TACAN can easily be added to a computer system. Since the TACAN output is given in the form of a range and bearing, the computers need only the coordinates of the TACAN station being used. This data can be set into the computer before the mission begins. Some corrections must be applied to TACAN outputs to increase accuracy. The bearings received from TACAN are magnetic; therefore, the computer must have an accurate magnetic variation value at all times. This is usually built into the computer. TACAN range output is expressed in slant range. The computer applies absolute altitude above the station to the slant range to produce exact ground range.

Computer Unit

The two basic types of navigation computers most used are the analog and the digital.

Analog. An analog computer is comparable to the navigator's handheld computer in that a graphic replica of the problem to be solved is constructed in order to find the answer. The analog computer is generally larger than the digital computer, partially because many components must be added to solve a wide variety of problems. Some of these computers weigh as much as 2,000 pounds. The analog computer has one main advantage; it is not as sensitive to temperature and pressure changes as the digital system.

Digital. The digital computer is generally lighter and more compact than the analog system. In some cases, the digital computer weighs less than 100 pounds. It computes navigation problems in a much different manner than does the analog computer. It is unnecessary to design a digital computer expressly for the navigation problems it is to solve. Properly

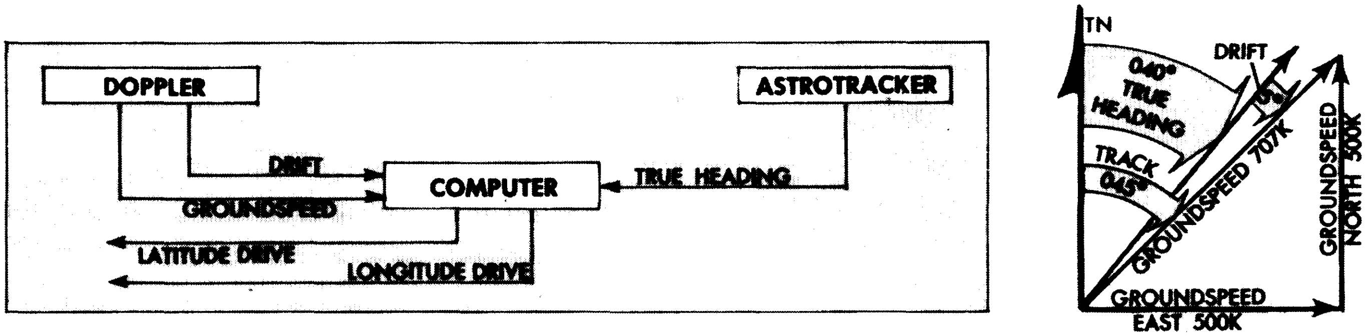


Figure 19-16. Present Position Counter Drive.

programmed, the same computer could be used in fields other than navigation. This is possible because the digital computer deals strictly with numbers. This requires that all inputs be changed to a numerical value before they are sent to the computer. All outputs likewise must be converted back to terms which are meaningful to the navigator.

DETERMINING POSITION

Regardless of computer type, the problems to be solved by a navigation computer remain the same. The ever-present problem facing the navigator is determination of aircraft position. With a computer system, it is not necessary to estimate a position based on a track and groundspeed derived from the last known position. The computer always displays the current position for convenient reading.

Example

Figure 19-16 illustrates an example which depicts determination of present position using astrotracker and Doppler information.

The astrotracker sends a true heading of 040° to the computer and the Doppler registers groundspeed of 707 knots and a drift of 5° right. The true heading and drift are combined in the computer to produce a value of track; in this case, 045°.

The groundspeed can be resolved around the direction of track to produce values of groundspeed to drive the latitude and longitude counters. In this case, the groundspeed north and east is 500 knots. Though this process seems basically simple, a few corrections must be applied to the groundspeed components before they are sufficiently accurate for present position drive. These corrections, done within the computer, include such things as compensation for convergence of meridians and for the imperfect shape of the Earth.

Determining Heading to Destination

Another question the navigator often faces is, "What is the heading to destination?" This question is also answered by many navigation computer systems. The computer first computes the required track, either rhumb line or great circle. To do this, it computes the direction and distance from the present latitude and longitude to the destination latitude and longitude. The present track, taken from the inertial system in this instance, is then compared to the required course to destination; the difference is a heading correction. Groundspeed may be applied to the distance to destination, and a time-to-go may be computed to provide a continuous ETA. Figure 19-16 illustrates some of the computer outputs associated with a typical INS. It is interesting to note that many of the new computers are equipped with an automatic troubleshooting system. In the event of a malfunction, the system may automatically shut down and display the location of the actual malfunction and some possible causes.

Navigation Panels

The navigation panels comprise the greatest part of the computer system visible to the navigator. Panel appearance and operation vary with each computer system. The multitude of counters, dials, switches, buttons, control knobs, and selectors give the navigator maximum use and control of the system. Selectors that determine which sensors will be used and which read-outs will be given, permit the navigator to switch from one mode of operation to another, as in figure 19-17.

The computer system aids the navigator in other ways. Most modern computers have limits built into them so they will not accept unreasonable information. For instance, if the coordinates of a fix point are set one degree of latitude in error, the computer rejects the fix because the information is totally incompatible with information already in the computer. A rapid change in groundspeed from a sensor might be rejected and that sensor output no longer used because it would be considered unreliable.

So far in this discussion, only basic navigation has been considered. A sophisticated computer system can solve ballistic problems and automatically release bombs and missiles. If the system is installed on a transport type aircraft, cargo drops and notification of bailout time to paratroops can be controlled by the navigation computer.

All computer systems do not contain all the sensors or have all the capabilities described above. The mission requirements of the aircraft dictate what the computer system should include. With advancements in science and engineering, automatic com-

TK-GS	TRACK AND GROUND SPEED AIRCRAFT IS MAINTAINING
HDG-DA	TRUE HEADING AND DRIFT ANGLE
XTK-TKE	DISTANCE FROM DESIRED TRACK IN NM.-DIFFERENCE BETWEEN DESIRED TRACK AND CURRENT TRACK
POS	PRESENT POSITION (LATITUDE AND LONGITUDE)
WPT	LATITUDE AND LONGITUDE OF SELECTED WAYPOINT
DIS-TIME	DISTANCE AND TIME TO NEXT CHECK POINT
WIND	CURRENT TRUE WIND. (REQUIRES INPUT OF TAS FROM BASIC INSTRUMENTS)
DSR TK STS	DESIRED TRACK TO NEXT CHECKPOINT AND MALFUNCTION STATUS
TEST	ENABLES TEST OF INTERNAL UNITS

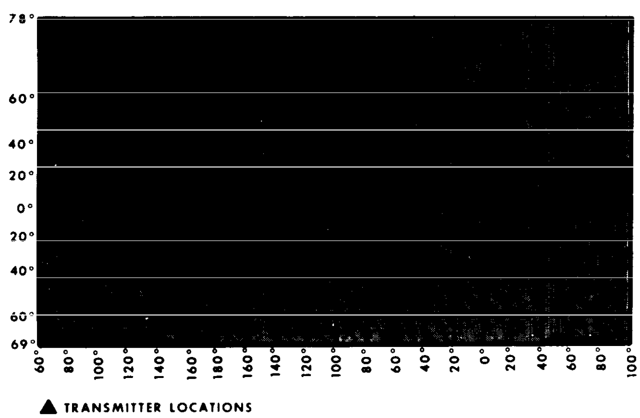
Figure 19-17. Typical Control Display Unit.

puter systems will have increased capabilities and uses. The systems will become lighter and more compact thereby increasing the practicability of installing them on more aircraft.

OMEGA

LORAN has significantly improved navigation over water and is very accurate up to 800 NM. However, at distances over 1,000 NM, skyways must be used and there is a resulting loss in position accuracy. Additionally, LORAN fixing requires considerable expertise by the navigator to interpret and align the pulses received on the LORAN's CRT. Omega is an accurate long-range alternative that overcomes both of these problems.

Increased range is a result of the ultra low frequency used by Omega transmitters. To get an accurate fix, a navigator needs to obtain simultaneous signals from three different Omega stations. Nevertheless, only eight Omega stations provide worldwide coverage (figure 19-18). These eight stations operate at



NAME	LATITUDE	LONGITUDE
NORWAY	N66°24'	E13°12'
LIBERIA	N06°18'	W10°36'
HAWAII	N21°24'	W157°48'
NORTH DAKOTA	N46°24'	W98°18'
LA REUNION	S21°00'	E55°18'
ARGENTINA	S43°06'	W65°12'
TRINIDAD (TEMPORARY)	N10°42'	W61°36'
AUSTRALIA (PROPOSED)	S38°29'	E146°56' (ESTIMATED)
JAPAN	N34°36'	E129°30'

Figure 19-18. Omega Transmitter Locations for World-Wide Navigation.

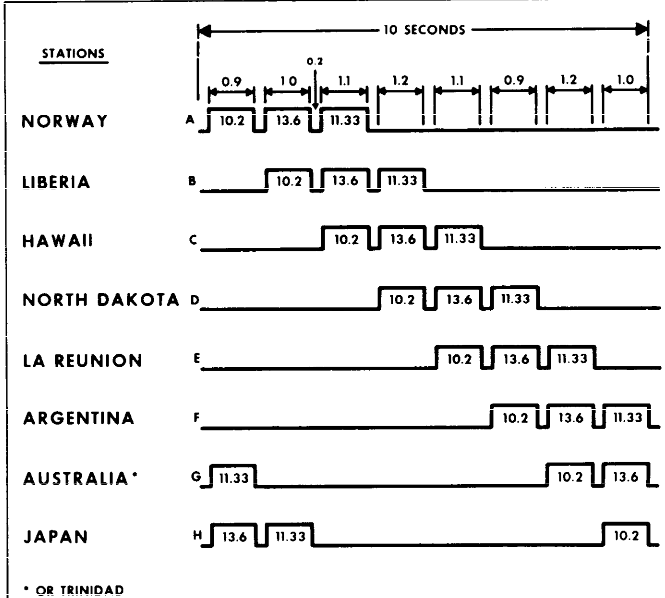


Figure 19-19. Omega Transmission Pattern.

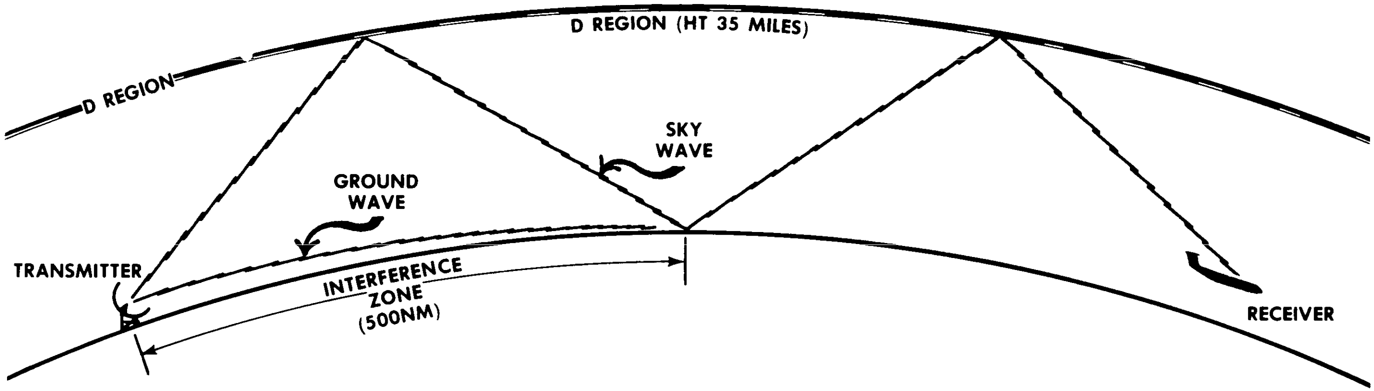


Figure 19-20. Idealized VLF Propagation Mode.

10-13 kHz and utilize a signal phase difference rather than a time-of-arrival signal like LORAN.

As shown in figure 19-19, station A (Norway) begins its transmission format on 10.2 kHz for 0.9 seconds, then is silent for 0.2 seconds, comes back on the air on 13.6 kHz for 1 second, again is silent for 0.2 seconds then transmits on the final frequency (11.33 kHz) and is silent for 6.6 seconds. The other stations sequence through their transmission in a similar manner. With the format, position information is updated every 10 seconds. Each station has a unique transmission which allows the automatic Omega receiver to identify the station being received.

Theory

Omega transmitting stations operate in the internationally allocated Very Low Frequency (VLF) navigational band between 10 and 14 kHz (figure 19-20). This very low frequency enables Omega to provide navigational signals at much longer ranges than other ground-based navigational systems. The eight transmitting stations provide worldwide coverage with an inherent potential fixing accuracy of 2 to 4 nautical miles 95 percent of the time.

Like LORAN, Omega is a hyperbolic radio navigation system. That is, the LOPs obtained are actually hyperbolas. In LORAN, the difference in arrival time of signal pulses from two stations is measured by matching the leading edges of the pulses on a CRT. In Omega, phase measurements using the entire pulse are made to measure this time difference. However, the Omega signals are in the form of sine waves that repeat themselves at a distance interval based on the wavelength of the frequency being transmitted. This repeating wave form leads to a repeating phase relationship every one-half wavelength, which in turn results in ambiguous lanes having the same phase measurements. Therefore, the correct lane corresponding to the actual position of the aircraft must be selected. This process is called initialization and is performed during turn-on of the equipment or after an extended period of signal outage. The three transmitted frequencies result in ambiguous lanes 72 NM in width. Thus, positional errors of 36 NM or greater must be corrected if slippage into the next lane is to be avoided.

Data collected at monitoring sites have shown that the transmitted Omega signal is very stable and predictable over long distances during most portions of the day. Omega signals are

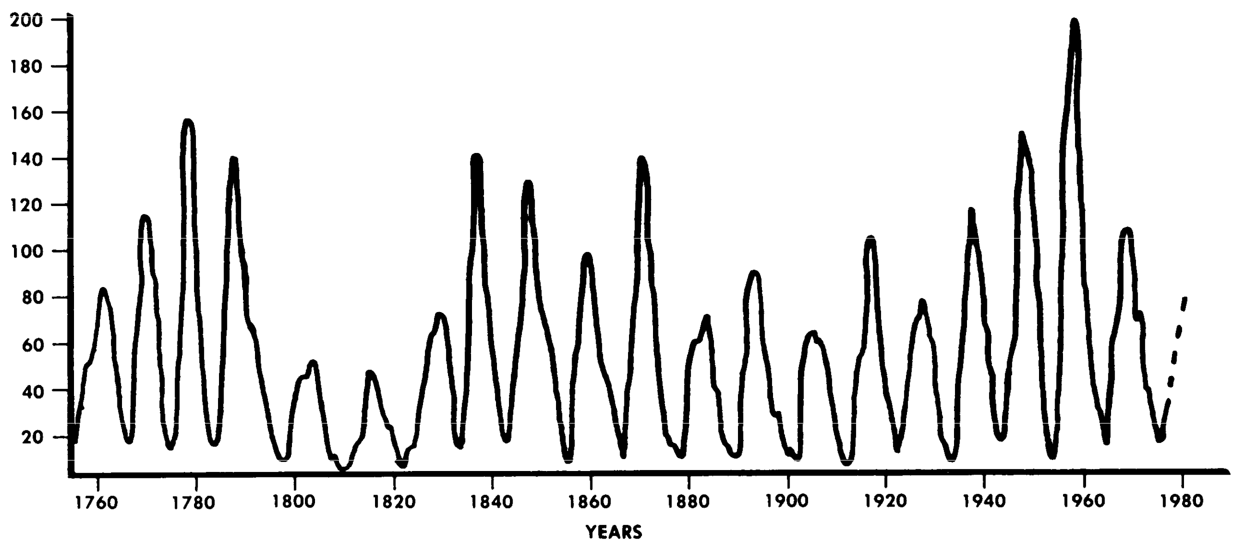


Figure 19-21. Solar Cycle History (1760-1980).

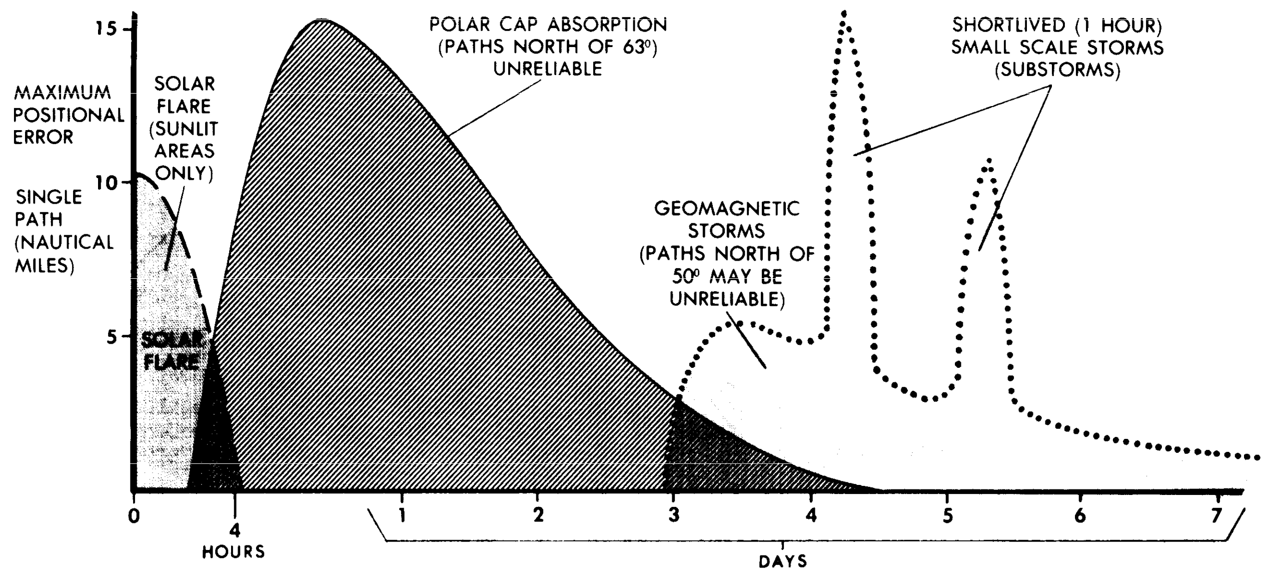


Figure 19-22. Sequence of Events with a Major Solar Flare.

propagated through what is known as the waveguide which exists between the Earth's surface and the lower D region of the ionosphere. Within the waveguide, Omega signals undergo changes in propagation velocity (and thus, changes in received phase relationships) due to contraction of the waveguide during daytime when the ionosphere lowers to within about 70 Km of the Earth's surface and expansion during nighttime when it moves to 90 Km above. These changes are predictable and are compensated within the automatic Omega receiver. The compensation is especially complicated for signals whose propagation path is partially sunlit and partially in darkness. Known ionosphere changes also occur with time of year and are also compensated within the receiver. This is why the automatic Omega receiver must be initialized with month and time.

Environmentally Induced Errors

There are three error-inducing environmental effects on Omega signals which have their origins in solar flares or sunspots. Impulsive solar activity follows closely what is called the solar "sunspot cycle." The Sun, over the past 200 years, has shown a preference for periods of "spottiness" interspersed with periods when no spots are visible. Over a period of time, a cyclical pattern with a mean period of 11.4 years between peaks has been observed (figure 19-21). As previously indicated, the accuracy of Omega fixing depends in large measure on our ability to predict signal propagation velocity as the ionosphere rises and falls with the diurnal cycle. However, ionospheric height is also affected by charged particles emitted by the Sun during solar flares. During a 3-year period centered on a sunspot maximum, a solar flare large enough to affect Omega signals can be expected to occur on the average of about once a day. When a major flare occurs, the sequence of events follows a generally predictable pattern (figure 19-22).

Sudden Ionospheric Disturbance (SID). With a large solar flare, powerful streams of X-rays immediately spread outward into space and intercept the Earth in its orbit. These X-rays are absorbed in the ionospheric D region resulting in an abrupt "lowering" of the upper boundary of the Omega signal waveguide (figures 19-23 and 19-24). This height change causes a phase shift in the received Omega signals which will not be compensated for in the automatic Omega receiver. The magnitude of navigational errors will depend on the strength of the flare and the length of the signal path which is sunlit. However, the error on a single path could be as much as 15 or 20 nautical miles. Because the occurrence of a SID will be detected about the same time as maximum position errors are encountered, there is little the navigator can do. Normally, a SID will only last 1 to 2 hours and the automatic Omega receiver will recover

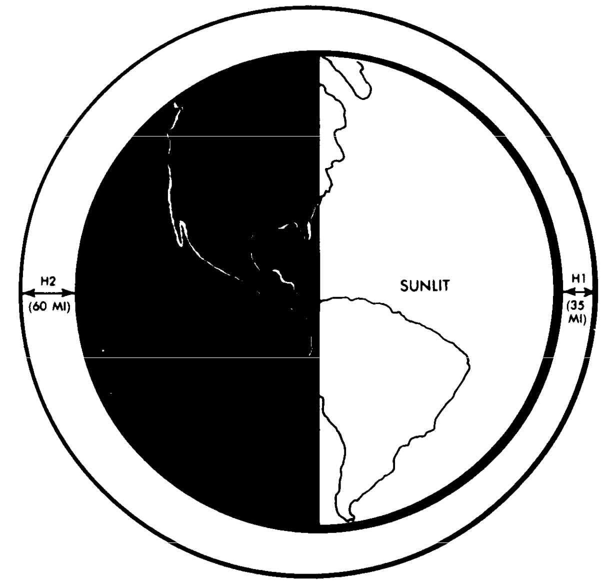


Figure 19-23. The D Region Height Variation from Day to Night.

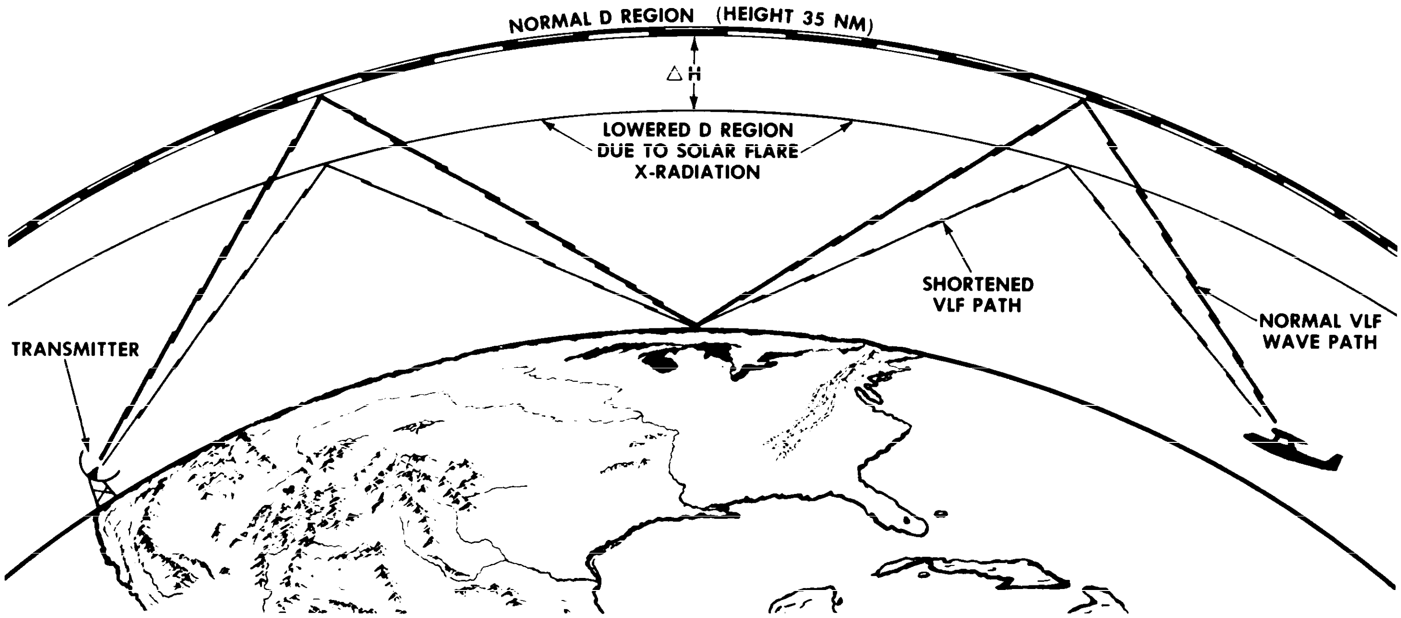


Figure 19-24. The Reduction in D Region Reflection Height with Increased Ionizing Radiations.

without intervention.

Polar Cap Anomalies (PCA). (Also known as polar cap absorption). About 2 hours after the arrival of X-rays from a major solar flare, as the SID is subsiding, charged particles begin to arrive at the Earth and are deflected to the polar caps by the Earth's magnetic field. With the onset of this phenomena, the ionosphere over the poles (generally above 65 degrees latitude) begins to lower relative to propagation of Omega signals. This condition may persist for 2 to 3 days and can result in single path errors of up to 6 nautical miles, but very large events may produce errors of 12 to 15 nautical miles. Further large solar flares may compound PCAs in progress such that polar transmission of Omega signals may be unreliable for 7 to 10 days at a time. The occurrence of a PCA can be determined from Omega propagation information broadcast on WWV at 16 minutes past each hour or by NOTAM. Navigator corrective action is to manually deselect all stations which are being received via a polar path while a PCA is in progress.

Geomagnetic Storms. Disturbances in the Earth's magnetic field may occur at any time, but the strongest storms are associated with major solar flares. Two or three days after a major flare, as PCA effects are subsiding, large volumes of low energy particles arrive at the Earth. These particles are also deflected by the Earth's magnetic field and they enter the upper atmosphere in the Auroral Zones (from the poles to 45-50 degrees latitude). With enough volume and impetus, they will enter the D region of the ionosphere where they will affect Omega signals for some 3 to 5 days. Short-lived (1 hour or so) bursts of geomagnetic activity often occur at times superimposed on a general major disturbance. These bursts of activity are called "substorms." Further major flares serve to compound events already in progress. During a 3-year period centered on solar flare maximum, the ionsphere may be disturbed in one area or another for up to 75 percent of the time. None of this disturbance is predictable, and thus none is compensated for in the automatic Omega receiver. The best navigator corrective action is to have a basic understanding of the described phenomena and deselect appropriate stations when their occurrence and (or) Omega fixing inaccuracies are suspected.

Modal Interference

Modal interference is a special form of signal interference wherein the various waveguide modes of signal propagation interfere with each other and irregularities appear in the phase pattern. Ideally, one mode would be completely dominant at all times and the resultant phase grid would be regular. In practice, competing modes do not completely disappear and three situations are recognizable. If the competing mode is very small, then the dominant mode will establish a nearly regular pattern as is intended, and usually this is what happens during almost equal to the dominant mode. The potentially serious case is that in which modal dominance can change. This may occur, for example, if one mode is dominant during the day and a second mode at night. Clearly somewhere during sunset and sunrise, the transition period, the two modes must be equal. Depending upon phasing of the modes at equality, abnormal transitions may occur in which cycles are "slipped" or lost. Positional errors of a full wavelength are possible under such conditions and use of a station so affected should be avoided. If this is not possible, particular attention must be given to proper land identification. Modal interference is primarily a nighttime phenomenon affecting transequatorial transmissions.

Wrong-Way Propagation

Omega navigation systems are subject to other propagation anomalies which are not conveniently categorized. One of these

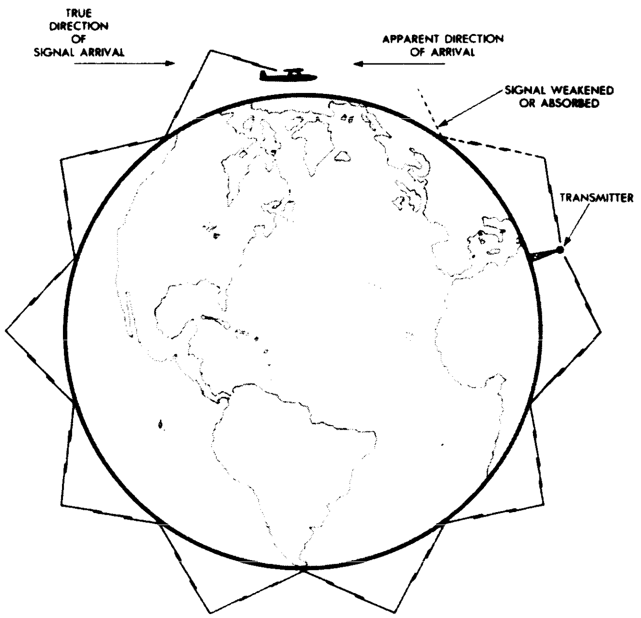


Figure 19-25. Schematic of "Wrong-Way" VLF Propagation.

is wrong-way propagation. Because Omega signals have extremely long range, the receiver can actually receive two signals from a transmitting station; one traveling direct from the station and the other traveling around the Earth and reaching the receiver from the opposite direction (figure 19-25). The automatic Omega receiver is programmed to use and apply compensations for the shortest path signal. It determines the shortest path by comparing relative signal strengths and assuming the strongest is the shortest path. However, for reasons not yet explained, signal attenuation along different propagation paths can differ by substantial amounts. Therfore, the reverse path signal can be stronger than the direct path signal. If this occurs, the receiver will use the wrong signal. This condition seems to be most common on nighttime Omega propagation paths and must be strongly considered when positional inaccuracies are suspected, as navigational errors of several nautical miles may result. When using an automatic Omega receiver, navigator corrective action is to carefully deselect received stations one at a time until the offending station is found.

Westerly Signal Traverse of the Magnetic Equator

Another Omega signal anomaly occurs when a signal crosses the magnetic equator from east to west at an angle of 45 degrees or less. After such a crossing, its observed phase has been found to be substantially different from its predicted phase (figure 19-26). The problem is most common during the nighttime hours. The physical reasons for this anomaly are unknown. It appears to be the result of an unusual interaction between the radio signal and the Earth's magnetic field such that a significant change in signal speed occurs. When this occurs, navigational accuracy is degraded by up to 6 nautical miles. As examples, errors could be expected along the east coast of the US if the Omega signals from Liberia were used. The same problem would arise in the vicinity of Australia if the Hawaiian signals were used. Navigator corrective action is to deselect the station.

Omega station deselection chart, Flip General Planning, includes an Omega station deselection chart which lists stations that should be deselected in various parts of the world. These stations were chosen for deselection because of potential wrong-way propagation or westerly traverse of the magnetic equator. This chart should be a primary reference for all flights utilizing Omega as a navigational aid. The chart also identifies stations which are being received via a polar path so that they can also be deselected when a PCA is in progress.

Equipment

The AN/ARN-131 airborne Omega receiver is a computerized, automatic navigation system in the style of previously mentioned INS systems. It consists of a control display unit (CDU), a receiver-processor, and an antenna (figure 19-27). The CDU may be located at either the navigator's or pilot's position. The receiver-processor, the heart of the system, is located under the flight deck in the avionics compartment. The H-field-type antenna is not as suceptible to precipitation static as the old long-wire LORAN antenna.

To operate the AN/ARN-131, the navigator needs only to (1) turn on the set and, (2) insert month, time of day, and approximate position. The "131" will then automatically select the best situations available, eliminate any invalid signals, synchronize the valid signals, and resolve the aircraft position. In addition, the computer will accept nine waypoints (checkpoints) for en

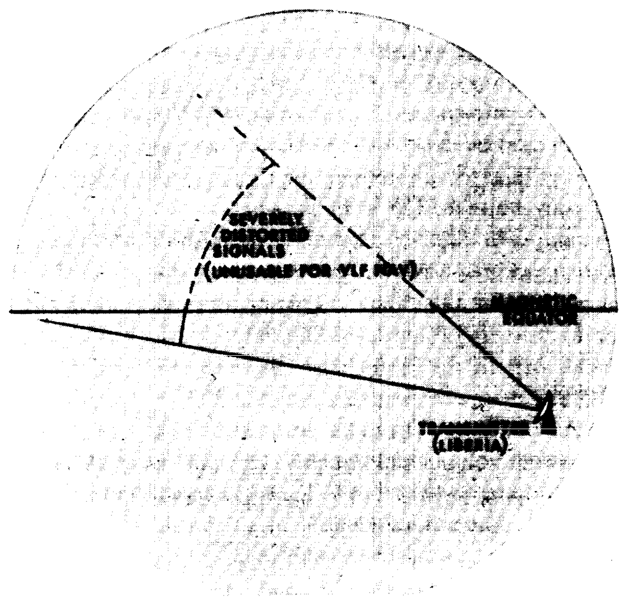


Figure 19-26. Schematic of Westward Traveling VLG Signal Crossing Geomagnetic Equator.

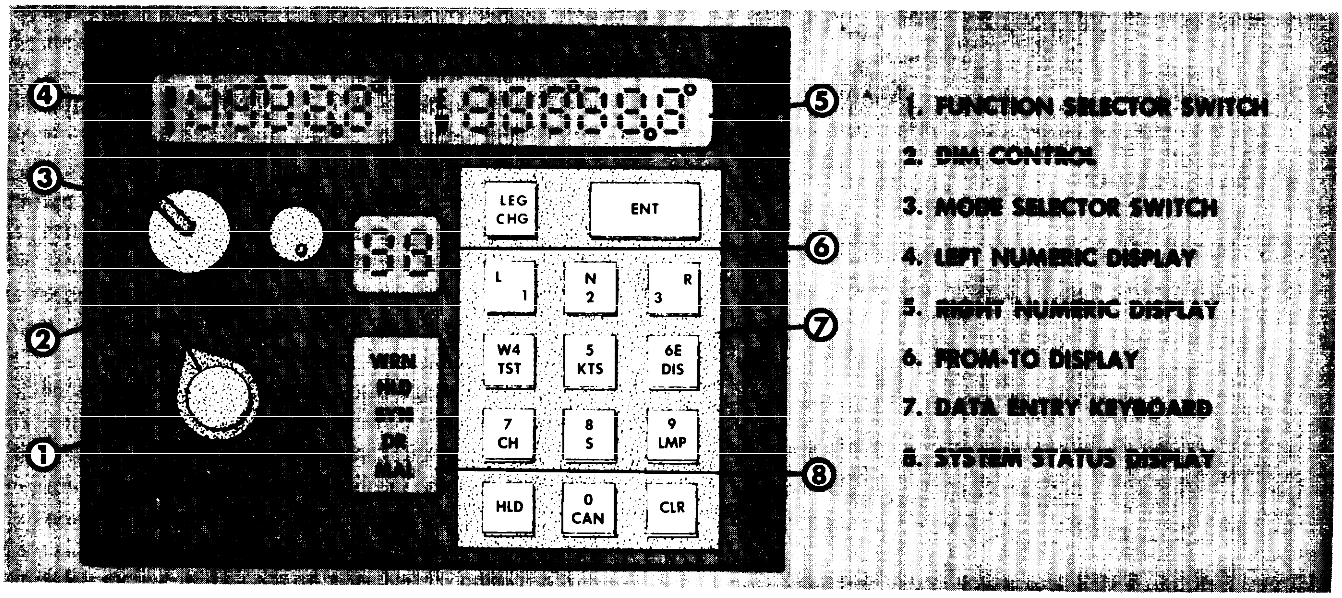


Figure 19-27. CDU Controls and Indicators.

route navigation and compute winds, desired headings, distances, and times (ETE/ETA) between waypoints.

NAVSTAR GPS

Navigators have been obtaining celestial LOPs from the Earth's only natural satellite (the Moon) for several centuries. One reason celestial navigation is so accurate is because the satellite's location can be precisely computed seconds, minutes, days, and even years in advance. Since 1956, hundreds of artificial satellites have been launched into orbit around the Earth. Like the Moon, the path of these satellites can also be accurately precomputed. If we were able to place electrical transmitters into several satellites, launch them in precisely controlled orbits, and equip a navigator with a receiver, we might be able to calculate LOPs from two or more satellites and accurately position our aircraft. Thanks to some recent developments in high-speed digital processing, improvements in orbit prediction and, most importantly, some significant improvements in the state of the art of spaceborne clocks have been achieved. The Navstar Global Positioning System (GPS) was born in June of 1977 with the launching of the first Navstar satellite.

The Satellites

The system consists of 24 navigational satellites launched into carefully conceived celestial orbits. The satellites are pictures in figure 19-28 and the constellation of 24 satellites is depicted in figure 19-29. The satellites orbit at an altitude of 12,900 nautical miles at a speed of 7,500 knots, thus making them very difficult targets to intercept. There will be eight satellites in each of three orbital planes spaced at intervals of 120 degrees of longitude. Such a configuration will insure that at least six satellites will be in view from anywhere on or near the Earth's surface.

Theory. Navstar GPS theory can best be explained by relating it to passive TACAN distance-measuring equipment (DME). TACAN DME theory states that a sphere of constant range

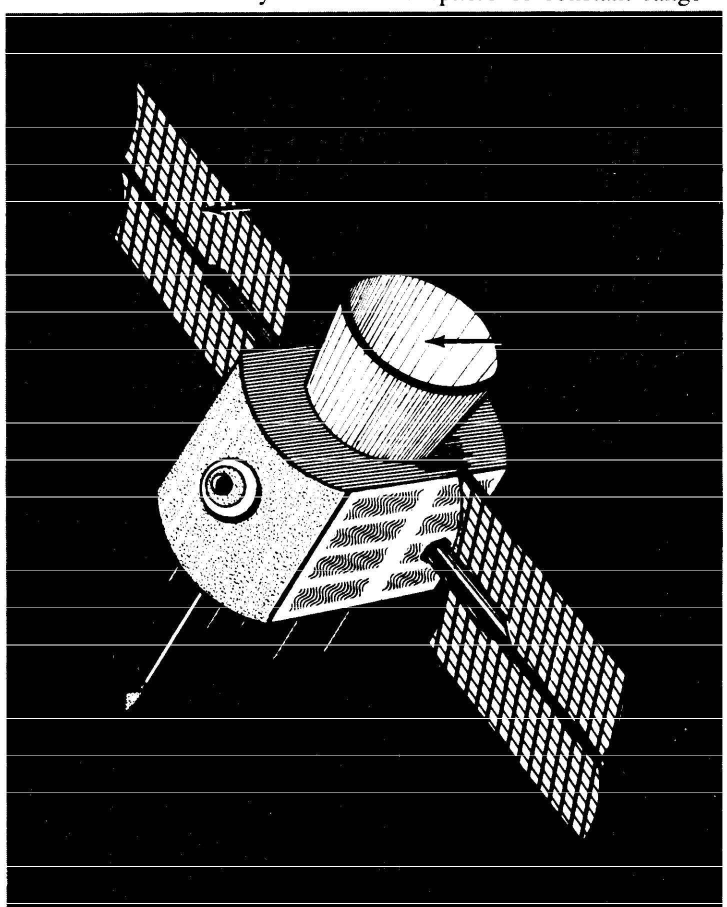


Figure 19-28. NAVSTAR Satellite.

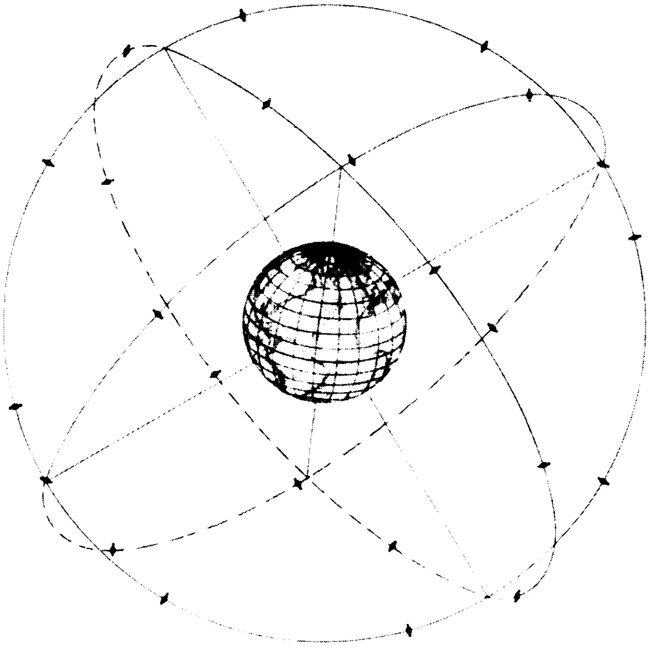


Figure 19-29. NAVSTAR Orbits.

(radius) from a TACAN DME station is described by the product of the speed of light and the time interval for the transmission, divided by two. In order to calculate the range, the receiver must know the time of the signal transmission from the satellite and the time of its signal reception. Therefore, each satellite carries a highly stable spaceborne atomic clock which generates a pseudorandom noise code (PRN). Due to the characteristics of the digital signal, the time of signal transmission is inherent in the transmitted signal from the satellites. The PRN code is used to provide a measure of protection against jamming and unauthorized use.

If the receiver possesses a stable clock synchronized with the satellite clock (this is not the case as will be explained later), it can subtract the time the satellite transmitted the signal from the time that the clock indicates that it received the signal. This time interval, multiplied by the speed of light, will produce a sphere of constant radius whose center is at the satellite on which the receiver is tuned. (Time delays due to the atmosphere and to the equipment must also be considered, but they are not essential to an understanding of basic GPS theory.) With two satellites in view, the user can calculate a line of position from the intersection of two spheres. A third satellite provides an additional sphere of position whose intersection with the other two will define a three-dimensional navigation fix. The accuracy of the navigation fix would be dependent on: (a) the accuracy of the measurement process (how accurately is the digital signal processed), (b) the accuracy of the satellite positions, and (c) the accuracy and stability of the satellites' clocks and the receiver clock. The user equipment is expected to be able to track the satellite's signal to within 3 nanoseconds (3×10^{-9}). This is equivalent to a 1 meter error in position.

If navigational accuracy on the order of 10 meters is desired, we must be able to establish satellite position at a particular time to within at least 10 meters. This is not a trivial problem. Since the satellite is moving and is subject to complex gravitational attractions and solar winds, measuring and predicting its position within 10 meters as a function of time is quite difficult. The ability to accurately determine satellite position at a particular time is one continuing development which has made GPS possible. Highly accurate satellite range rate measurements, combined with vastly improving estimation theory techniques such as Kalman filtering, have contributed to this success. Kalman filters use a sophisticated statistical weighting process of previous range and range rate measurements to predict what the satellite position will be at a particular time in the future. These Kalman filter techniques are accomplished by high-speed digital computers to give the ground-based satellite system monitor the ability to accurately predict individual satellite positions at all times. This information on future satellite positions, as well as time information, is uploaded to the satellites on a daily basis. The satellites will continuously transmit this information to all users.

The most important factor to be considered relates to the accuracy of time measurement. if the receiver expects to calculate an accurate surface or sphere of position by measuring the time difference between signal transmission and reception, all transmitters and receivers must be extremely well time synchronized. This synchronization will insure that all satellite signals are transmitted simultaneously. In order to establish LOPs with 10-meter accuracy, we must be able to measure a time difference on the order of a few nanoseconds (10^{-9}). Recently developed atomic spaceborne clocks have frequency stabilities on the order of 10^{-13} seconds per second for a period of about 1 day. Given such stabilities, a time hack once a day, or about 10^5 seconds after synchronization, will be accurate to about 10^{-8} seconds (10^{-13} sec/sec $\times$ 10^5 sec $=$ 10^{-8} sec). Very expensive cesium atomic clocks will be installed in the navigation satellite to achieve this level of accuracy.

To achieve 10-meter positioning accuracy would also require that all users have an atomic clock cómparable to the satellite clocks. This approach, however, would significantly increase receiver cost. The requirements for an expensive user clock can be eliminated by insuring that four satellites are visible to the user. By using four satellites, the user will be able to sychronize his or her clock to the satellite clocks each time a fix is taken. Because user time between fixes, as well as time synchronizations, may be on the order of 1 second, the clock must only have a short-term frequency stability of about 10^{-8} sec/sec to produce 10^{-8} seconds timing accuracy over the 1 second fix interval (10^{-8} sec/sec $\times$ 10^0 sec $=$ 10^{-8} sec). Quartz crystal clocks, which are considerably less expensive than atomic clocks, are currently available and can easily provide such accuracy.

Testing and System Development. The first satellite was launched in June 1977. The second and third satellites were launched in 1978 with the third satellite achieving final orbit in September. A test range at Yuma Testing Grounds, Arizona, has been fabricated for testing proposed satellite accuracies and dynamic receiver capabilities. Initial testing was conducted using a portable manpack navigation receiver mounted in a truck moving at 50 mph. Four signals are required to determine a receiver's latitude, longitude, altitude, and velocity (figure 19-30). Therefore, the manpack tests were only able to determine the latitude and longitude of the receiver. Nevertheless, horizontal position accuracies within 6-7 meters (20-23 feet) were obtained. Accuracy goal for the fully operational system has been set at 10 meters.

SUMMARY AND CONCLUSION

What does the advent of all this sophisticated equipment mean to the navigator and his or her role in the Air Force flying mission? Certainly, the accuracy of the new systems is unquestionable with Navstar GPS producing accuracies within meters. An INS backup could not be jammed or intercepted and would provide acceptable accuracy in all weather. New computers that take up less room than a sextant case can process multiple inputs from several sources (GPS, INS, Omega, Doppler, and LORAN). Additionally, they will also provide wind, heading, course, distance, and time information automatically.

Nevertheless, we must always consider the necessity of a human backup system. This is especially true on a complex navigation mission flown through a hostile environment. At this point, these sophisticated pieces of equipment would become the only tools that a navigator would use to make important decisions. Regardless of their accuracy or reliability, a navigator must still be available to make the most logical navigational decisions to successfully complete the mission.

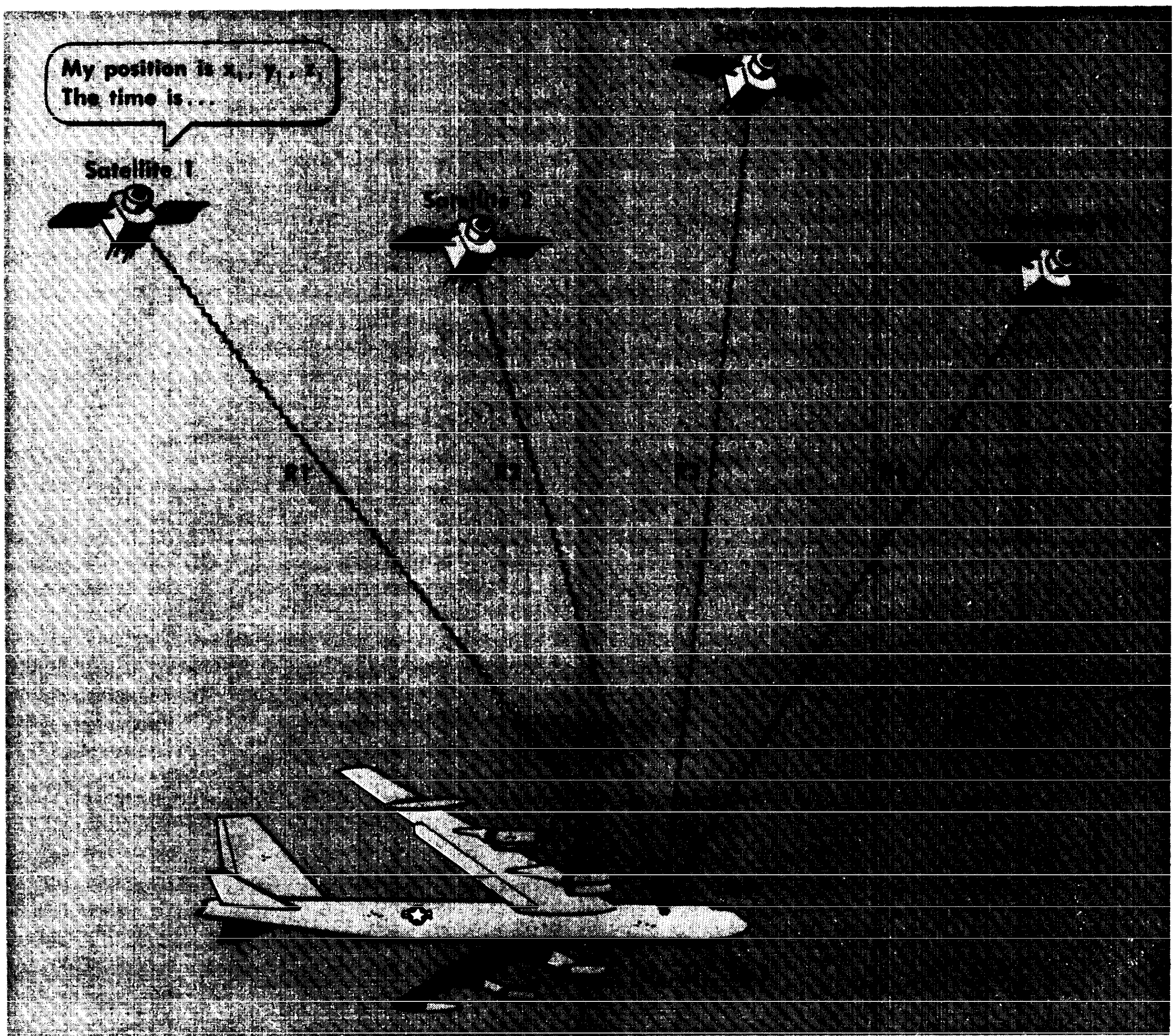


Figure 19-30. System Technique.

Chapter 20

LOW LEVEL NAVIGATION

FUNDAMENTALS

The main reasons for conducting low level operations are to gain the element of surprise, to avoid detection and interception, and to minimize the effect of enemy defenses. In addition, certain types of operations such as paradrops and aerial resupply missions demand a low level capability. The problem of performing accurate navigation at low altitudes differs considerably from that at higher altitudes. Low level navigation requires comprehensive flight planning, accurate dead reckoning, and extensive use of all available aids. The navigator must work very rapidly to obtain and interpret in-flight observations. In general, low altitude flying affects the navigation problem because of reduced radar range, reduced visual capability, potential adverse weather situations, and the need for reactive decision-making. In addition, the normal mechanics of navigation, such as writing, measuring, computing, and plotting, are made difficult to impossible by turbulence encountered at low altitudes.

PLANNING THE MISSION

The key to successful low level navigation is the careful and comprehensive planning accomplished prior to the flight. Every minute spent in flight planning helps to insure that the low level mission will be successful.

A. ONE-MINUTE TURN (6°/SECOND)*

GROUNDSPEED (KNOTS) / HEADING CHANGE	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	—	—	.1	.1	.1	.2	.2	.2	.3	.3	.4	.5
200	—	.1	.1	.2	.2	.3	.4	.4	.5	.6	.8	.9
300	.1	.1	.2	.3	.4	.5	.6	.7	.8	1.0	1.2	1.4
400	.1	.2	.3	.4	.5	.6	.7	.9	1.1	1.3	1.5	1.8
500	.1	.2	.4	.5	.6	.8	.9	1.1	1.3	1.6	1.9	2.3
600	.1	.3	.4	.6	.7	.9	1.1	1.3	1.6	1.9	2.3	2.8
700	.2	.3	.5	.7	.9	1.1	1.3	1.5	1.9	2.2	2.7	3.2
800	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.1	2.5	3.1	3.7
900	.2	.4	.6	.9	1.1	1.4	1.7	2.0	2.4	2.9	3.5	4.1
1000	.2	.5	.7	1.0	1.2	1.5	1.9	2.2	2.7	3.2	3.8	4.6
TIME BACK (ETA ADJUST TO START TURN)	1"	2"	3"	4"	5"	6"	7"	8"	10"	11"	14"	17"
TIME SAVED IN TURN	—	—	—	—	1"	1"	2"	3"	4"	6"	9"	13"
TIME REQUIRED TO COMPLETE TURN	2"	3"	5"	7"	8"	10"	12"	13"	15"	17"	18"	20"

For radius of turn, extract from 90° column (double for turn diameter)

B. TWO-MINUTE TURN (3°/SECOND)

GROUNDSPEED (KNOTS) / HEADING CHANGE	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	—	.1	.1	.2	.2	.3	.4	.4	.5	.6	.8	.9
200	.1	.2	.3	.4	.5	.6	.7	.9	1.1	1.3	1.5	1.8
300	.1	.3	.4	.6	.7	.9	1.1	1.3	1.6	1.9	2.3	2.8
400	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.2	2.5	3.1	3.7
500	.2	.5	.7	1.0	1.2	1.5	1.9	2.2	2.7	3.2	3.8	4.6
600	.3	.6	.9	1.2	1.5	1.8	2.2	2.6	3.2	3.8	4.6	5.5
700	.3	.7	1.0	1.4	1.7	2.1	2.6	3.1	3.7	4.5	5.4	6.5
800	.4	.8	1.2	1.6	2.0	2.5	3.0	3.5	4.3	5.1	6.1	7.4
900	.4	.9	1.3	1.8	2.2	2.8	3.3	4.0	4.8	5.7	6.9	8.3
1000	.5	1.0	1.4	2.0	2.5	3.1	3.7	4.4	5.3	6.3	7.7	9.2
TIME BACK (ETA ADJUST TO START TURN)	2"	3"	5"	7"	9"	11"	13"	16"	19"	23"	27"	33"
TIME SAVED IN TURN	—	—	—	1"	1"	2"	3"	5"	8"	12"	18"	26"
TIME REQUIRED TO COMPLETE TURN	3"	7"	10"	13"	17"	20"	23"	27"	30"	33"	37"	40"

For radius of turn, extract from 90° column (double for turn diameter)

C. FOUR-MINUTE TURN (1½°/SECOND)

GROUNDSPEED (KNOTS) / HEADING CHANGE	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	.1	.2	.3	.4	.5	.6	.7	.9	1.1	1.3	1.5	1.8
200	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.1	2.5	3.1	3.7
300	.3	.6	.9	1.2	1.5	1.8	2.2	2.6	3.2	3.8	4.6	5.5
400	.4	.8	1.2	1.6	2.0	2.4	3.0	3.5	4.3	5.1	6.1	7.3
500	.5	1.0	1.5	2.0	2.5	3.0	3.7	4.4	5.3	6.3	7.7	9.2
600	.6	1.2	1.7	2.3	3.0	3.7	4.5	5.3	6.4	7.6	9.3	11.0
700	.7	1.4	2.0	2.7	3.4	4.3	5.2	6.2	7.4	8.9	10.7	12.9
800	.8	1.6	2.3	3.1	3.9	9.9	6.0	7.0	8.5	10.1	12.3	14.7
900	.9	1.8	2.6	3.5	4.4	5.5	6.7	7.9	9.6	11.4	13.8	16.6
1000	1.0	2.0	2.9	3.9	4.9	6.1	7.4	8.8	10.6	12.7	15.4	18.4
TIME BACK (ETA ADJUST TO START TURN)	3"	7"	10"	14"	18"	22"	27"	32"	38"	45"	55"	66"
TIME SAVED IN TURN	—	—	1"	2"	3"	5"	7"	10"	16"	24"	36"	52"
TIME REQUIRED TO COMPLETE TURN	7"	13"	20"	27"	33"	40"	47"	53"	60"	67"	73"	80"

For radius of turn, extract from 90° column (double for turn diameter)

D. EIGHT-MINUTE TURN (¾°/SECOND)

GROUNDSPEED (KNOTS) / HEADING CHANGE	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
GROUND DISTANCE BACK TO START TURN (NM)												
100	.2	.4	.6	.8	1.0	1.2	1.5	1.8	2.1	2.5	3.1	3.7
200	.4	.8	1.2	1.6	2.0	2.4	2.9	3.5	4.3	5.1	6.1	7.4
300	.6	1.2	1.7	2.3	3.0	3.7	4.4	5.3	6.4	7.6	9.2	11.1
400	.8	1.6	2.3	3.1	3.9	4.9	5.8	7.0	8.5	10.2	12.3	14.7
500	1.0	2.0	2.9	3.9	4.9	6.1	7.3	8.8	10.7	12.7	15.4	18.4
600	1.2	2.3	3.5	4.7	5.9	7.3	8.7	10.6	12.8	15.2	18.4	22.0
700	1.3	2.7	4.0	5.5	6.9	8.6	10.2	12.3	15.0	17.8	21.5	25.7
800	1.5	3.1	4.6	6.3	7.9	9.8	11.7	14.1	17.0	20.3	24.6	29.4
900	1.7	3.5	5.2	7.0	8.9	11.0	13.1	15.9	19.2	22.8	27.6	33.0
1000	1.9	3.9	5.8	7.8	9.8	12.2	14.9	17.6	21.3	25.4	30.7	36.8
TIME BACK (ETA ADJUST TO START TURN)	7"	14"	20"	28"	36"	44"	54"	64"	76"	91"	109"	132"
TIME SAVED IN TURN	—	1"	2"	3"	6"	10"	14"	20"	32"	48"	72"	100"
TIME REQUIRED TO COMPLETE TURN	13"	27"	40"	53"	67"	80"	93"	107"	120"	133"	147"	160"

For radius of turn, extract from 90° column (double for turn diameter)

*NOTE: Use data from Table A to compute procedure turn information for non-charted turn rates. Multiply all distance and time increments extracted from this table by the number of minutes required to accomplish a 360° turn.

EXAMPLE: 12 minute turn (½°/sec), GS = 400 Knots, TH Change = 80°.
Ground distance back to start turn = .9 x 12 = 10.8 NM
Time back (ETA adjust to start turn) = 8" x 12 = 96" (1' 36")
Time saved in turn = 3" x 12 = 36"
Time required to complete turn = 13" x 12 = 156" (2' 36")
Radius of turn (90° column) = 1.1 x 12 = 13.2 NM
Diameter of turn = 2 x 13.2 = 26.4 NM

Figure 20-1. Procedure Turn Tables (Distance/Time Back).

Route Determination

Carefully select the routing with emphasis upon navigational checkpoints and safety of flight. Turning points should be over or close to identifiable points such as those which provide good land-water contrast or give good radar definition at maximum range.

Directness. To conserve time and fuel, the route must be as direct as possible. A direct route also minimizes the time spent within range of enemy defenses (surface-to-air missiles, all-weather interceptors, etc).

Procedure Turns. Compute procedure turns for all turning points since the aircraft must rollout on course. Figure 20-1 contains a series of tables which may be used to compute procedure turns. If heading and groundspeed change in flight, use the tables to recompute a new procedure turn.

Altitude. Terrain elevation, both along the intended flightpath and adjacent to it, is an extremely important factor when planning mission altitudes. Normal altitudes for low level combat missions are between 200 and 500 feet above ground level. On domestic training missions, planning must adhere to the flight rules contained in FLIP.

Altimeter Errors. Two types of altimeter error enter into consideration when planning a low level mission. They are caused by (1) differences in barometric pressure along the route of flight and (2) known deficiencies in the altimeter.

Navigators may obtain changes in barometric pressure along the route from the forecaster during the weather briefing or they can determine changes as they analyze in-flight weather before descending to the low altitude portion of the flight. Figure 20-2 illustrates a ''D''/Altimeter Setting Computation Graph which is used to compute the altimeter setting for low altitude. The procedure is based on readings taken at high altitude, before the final descent to low level.

The graph may be used to compute an altimeter setting for any true altitude. The data required for this computation are the ''D'' values for any two altitudes. Obtain these ''D'' values from the weather forecaster prior to departure, from the appropriate weather chart, from in-flight measured ''D'' values (by use of the radio altimeter or radar altitude measurements and pressure altimeter), or from in-flight weather forecast updates. ''D'' equals true altitude minus pressure altitude. Altitude as observed on the radio altimeter (or measured by the radar set) plus terrain elevation is true altitude. Pressure altitude is read from the altimeter when it is set at 29.92 (standard day).

Use of the graph involves three basic steps:

1. Plot ''D'' values at two or more altitudes, and join these values with straight lines, extending the lines to other altitude levels as desired.

2. Find the ''D'' value for some required intermediate altitude by graphical interpolation or by graphical extrapolation for some altitude beyond the plotted values.

3. Convert this ''D'' value to an altimeter setting.

Example:

Given: Radar measured ''D'' at 30,000 feet MSL = + 700 feet

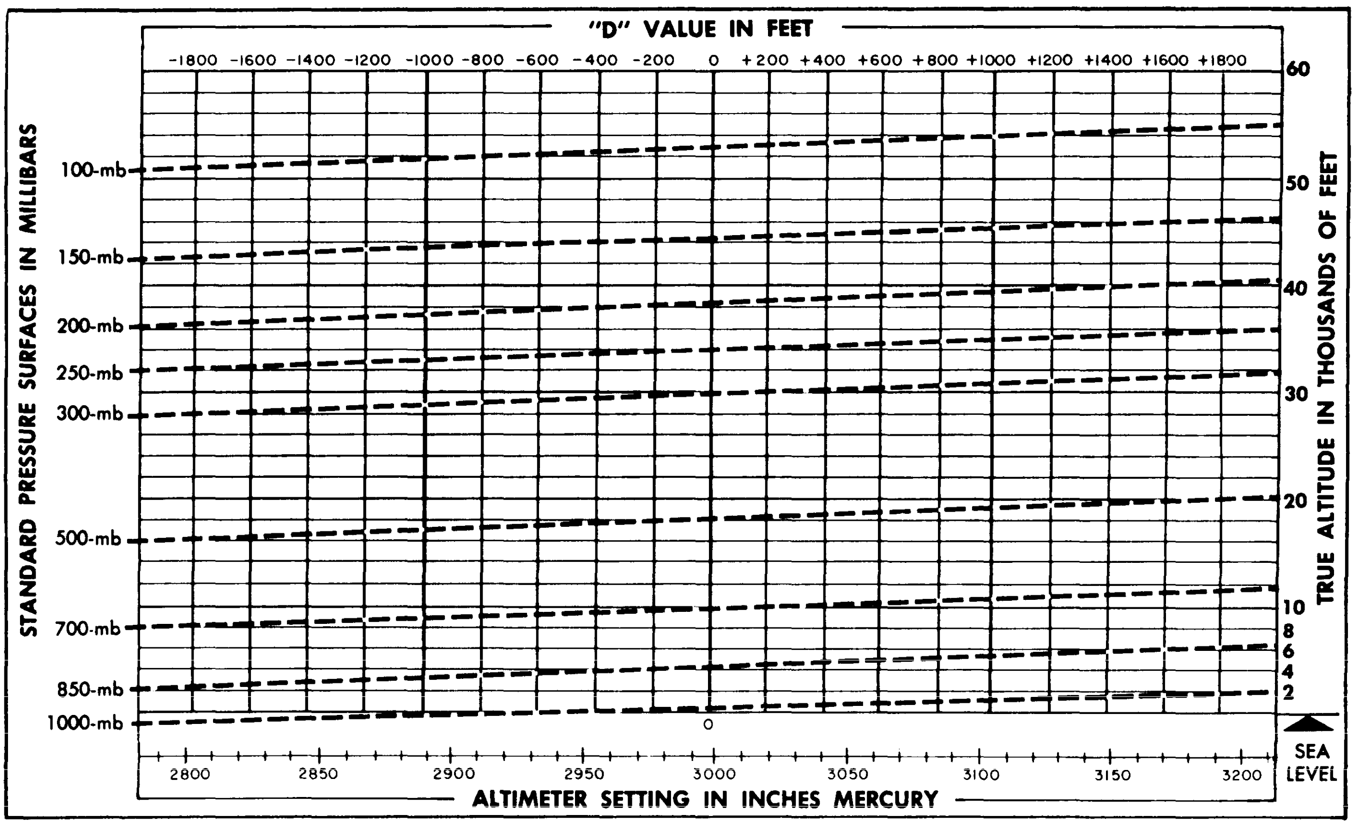


Figure 20-2. ''D''/Altimeter Setting Computation Graph.

Forecast ''D'' at 850 millibars = + 270 feet
Find: The altimeter setting for 10,000 feet MSL
Procedure:

1. Mark the intersection of 30,000 feet MSL and ''D'' of + 700 feet.
2. Mark the intersection of 850 mb and ''D'' of + 270 feet.
3. Draw a straight line between these two points.
4. Find the intersection of this line with 10,000 feet true altitude.
5. Read a ''D'' value of + 350 feet.
6. Read straight down the column to the bottom scale and find that the altimeter setting for a ''D'' value equal to + 350 feet is 30.30.

If the altimeter is set for 30.30, the altimeter should read 10,000 feet when the airplane is at a true altitude of 10,000 feet (plus or minus the altimeter error).

CAUTION

An altimeter setting computed by this method is accurate only for a given location at the altitude for which it was computed. For level-off at a low level flight altitude, an altimeter setting is also required for the level-off point.

In the example given, the level-off altimeter setting could be extrapolated from the graph by extending the line as required.

Airspeed. Normally, low level missions are flight planned for airspeeds which make mental DR computations simple. These are 240 knots (4 NM per minute), 300 knots (5 NM per minute), 360 knots (6 NM per minute), etc.

While it is important to maintain a constant GS for accurate dead reckoning, the navigator may have to vary the GS to control the time of arrival at turning points and over the target.

Fuel Planning. The problem of fuel consumption is a major consideration in low level planning. At low altitude, jet aircraft consume approximately twice the amount of fuel they use at high altitudes. In addition, combat sorties leave very small fuel tolerances for recovery. For this reason, the navigator must carefully plan all phases of the mission to conserve fuel. The navigator usually assists the pilot by closely monitoring fuel quantities.

The fuel consumption problem is further complicated by the variable load requirements for specific missions. Therefore, compute the required amount of fuel carefully and hold excess fuel to a minimum.

Weather Planning. On combat missions, there is no designated minimum ceiling and visibility condition for low level flight. The wind velocities encountered at low altitude over land are generally light. However, because of surface friction, particularly in rugged terrain, these winds tend to be very changeable. Because of this inconsistency and for reasons of simplicity, flight planning for high speed, low level missions over land is normally based on no-wind conditions.

In planning low level missions over water, however, inclusion of the wind in the flight plan is a matter of utmost importance. Overwater navigation depends entirely on dead reckoning because of the absence of checkpoints with which to establish fixes and to make course corrections.

Chart Selection

Several charts are appropriate for low altitude navigation. One chart, which is specially designed for low level use, is the Operational Navigation Chart (ONC). The 1:1,000,000 scale permits identification of all visual and radar significant features, and the chart has excellent cultural and relief portrayal. For increased detail or slower-speed aircraft, the Tactical Pilotage Chart (TPC) (1:500,000) or a Joint Operations Graphic (JOG) (1:250,000) may be used.

It is possible to ''mix'' navigation charts. The en route portion of the low level mission can be plotted on an ONC, while the TPC or JOG chart may be used for the target area or for specific identification of checkpoints. Aerial reconniassance photos are helpful, though not always available.

Annotate items of importance to navigation (turning points, descent points, high terrain, emergency airfields, etc) on the chart. Label preplanned fixes with planned range and bearing information. In all cases, the annotations should be neat and compact for quick reference. Since time is critical at high speeds and low altitudes, navigators must spend as little time as possible interpreting the information on their charts.

Planned Pacing

Navigators must choose suitable topographic or cultural returns for in-flight fixing and must determine a pacing schedule to accommodate these fixes. They must plan the entire mission before takeoff. Consequently, what they accomplish in the air is merely a follow-through of what they have previously flight-planned.

Since navigation demands flexibility, planning a pacing schedule involves two separate steps. First, a complete premission plan is based on expected in-flight conditions. Then, an alternate plan is constructed, in case the unexpected happens. For example, a 120-nautical mile navigation leg, flown at 360 knots, might accomodate three radar fixes. This plan becomes the primary pacing schedule for the leg. A secondary pacing plan might consider an unforeseen increase in groundspeed, and it would incorporate only two fixes.

Another instance of flexibility in planning might involve an excellent radar return, situated 20 miles from the planned course line. This return might provide a fix if the aircraft maintained its planned altitude. But, if the in-flight altitude is lower than anticipated, the return could be hidden by high terrain, or it may not appear at all. Consequently, an alternate radar return should be planned.

Route Study

To insure success in low level missions, the navigators must complete a thorough study of the route. To plan for en route fixing, they should have an idea of how every point along the route will appear, either on the radarscope or visually. They can often take advantage of directional characteristics of natural or cultural features during this route study to simplify the navigation problem in the air.

Radar Prediction. Radarscope interpretation can be preplanned for low level flights. The navigator should note significant returns such as land-water contrast, outstanding terrain features, and towns. The time of year is also important since radar returns during the winter may not appear the same as they do in other seasons of the year.

At low altitudes, the appearance of a radar return changes rapidly as the aircraft approaches or passes over or abeam of the return. Often, the best identifying features of a checkpoint cannot be distinguished by radar at low altitude. Because of this reduced radar range, the navigator should use dead reckoning procedures to verify and identify radar returns. Experience has shown that "no-return" areas, such as lakes and rivers, are more reliable for radar prediction and navigation because they furnish more accurate fixes than do towns or similar type returns. Tilt and gain settings are critical at low altitudes and must be closely monitored. Navigators can use radar navigation at low level very effectively in conjunction with the radar-computer unit.

Visual Prediction. In addition to the problems experienced in radar prediction, other problems are encountered when forecasting map reading fixes. Weather effects such as precipitation, smoke, haze, or blowing dust may obscure features intended for fixing. Visual navigation is especially difficult when looking into the Sun, particularly in haze conditions.

Celestial. The instability of the aircraft during low level operations precludes the use of celestial observations. If possible, compass deviation checks may be made shortly after takeoff. However, these checks are the exception rather than the rule if the entire flight is to be conducted at low level.

IN-FLIGHT PROCEDURES

Descent from Flight Altitude

Procedures for descent to low level altitudes are outlined in tactical manuals and aircraft flight manuals. During the descent, continual aircraft positioning will insure that the aircraft reaches the initial planned low level altitude.

Compute level-off altimeter settings using the "D"/Altimeter Setting Computation Graph shown in figure 20-2. Cross-

MILES FLOWN OR TO FLY	MILES OFF-COURSE															
	1	2	3	4	5	6	7	8	9	10	15	20	25	30	40	50
	CORRECTION (IN DEGREES) TO PARALLEL OR CONVERGE COURSE															
10	6	12	17	24	30	37	44	53	64	90						
20	3	6	9	12	14	17	20	24	27	30	49	90				
30	2	4	6	8	10	12	14	15	17	19	30	42	56	90		
40	1	3	4	6	7	9	10	12	13	14	22	30	39	49	90	
50	1	2	3	5	6	7	8	9	10	12	17	24	30	37	53	90
60	1	2	3	4	5	6	7	8	9	10	14	19	25	30	42	56
70	1	2	3	3	4	5	6	7	7	8	12	17	21	25	35	46
80	1	1	2	3	4	4	5	6	6	7	11	14	18	22	30	39
90	1	1	2	3	3	4	4	5	6	6	10	13	16	19	26	34
100	1	1	2	2	3	3	4	5	5	6	9	12	14	17	24	30
110	1	1	2	2	3	3	4	4	5	5	8	10	13	16	21	27
120	0	1	1	2	2	3	3	4	4	5	7	10	12	14	20	25
130	0	1	1	2	2	3	3	4	4	4	7	9	11	13	18	23
140	0	1	1	2	2	2	3	3	4	4	6	8	10	12	17	21
150	0	1	1	2	2	2	3	3	3	4	6	8	10	12	15	19
160	0	1	1	1	2	2	3	3	3	4	5	7	9	11	14	18
170	0	1	1	1	2	2	2	3	3	3	5	7	8	10	14	17
180	0	1	1	1	2	2	2	3	3	3	5	6	8	10	13	16
190	0	1	1	1	2	2	2	2	3	3	5	6	8	9	12	15
200	0	1	1	1	1	2	2	2	3	3	4	6	7	9	12	14

Figure 20-3. Off-Course Correction Tables.

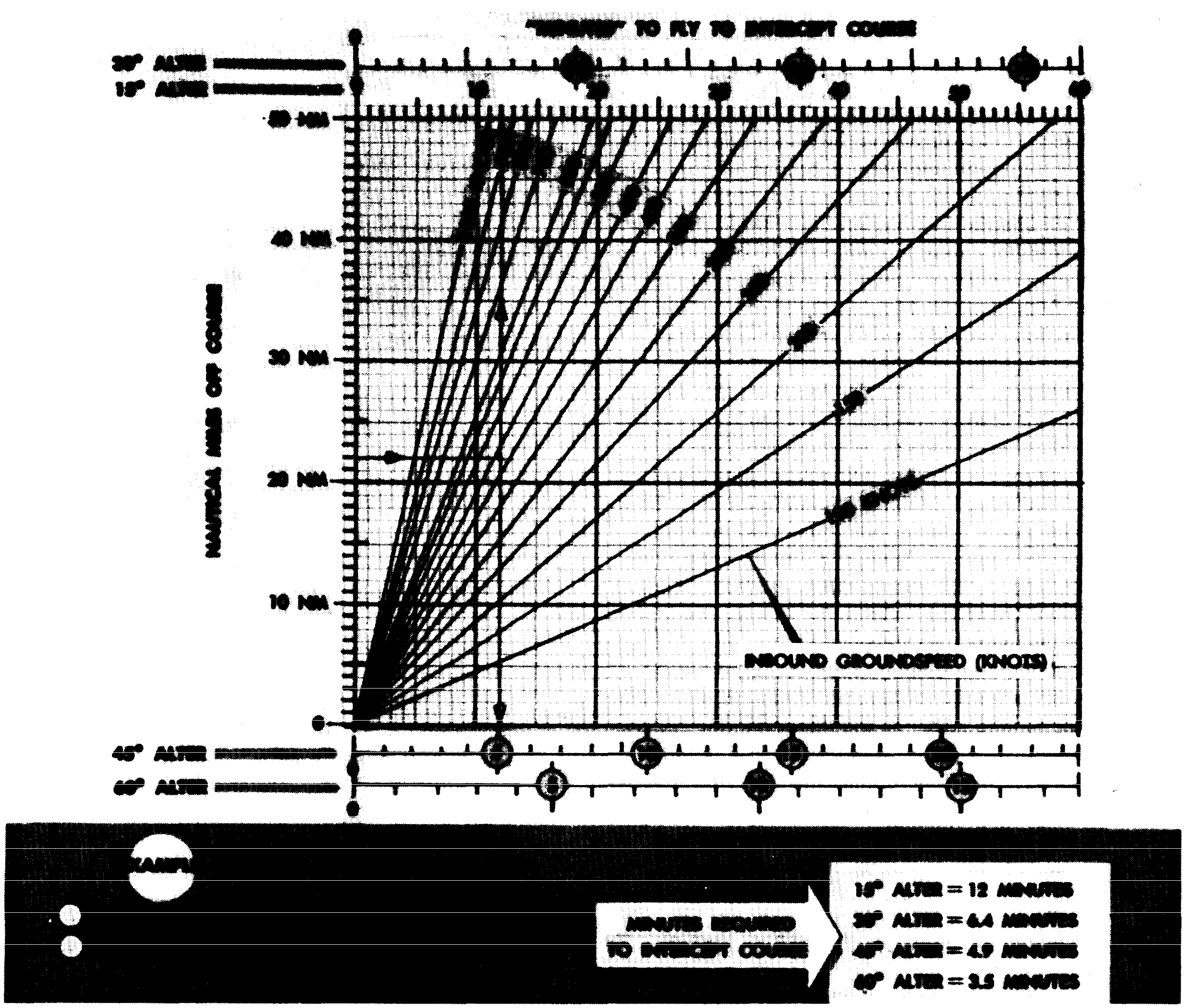


Figure 20-4. Correction to Intercept Course.

check these settings by adding the terrain elevation to the absolute altitude (measured by radar or radio altimeter) to obtain the true altitude. Set the true altitude in the altimeter and read the altimeter setting on the barometric scale.

Maintaining Track

To insure meeting controlled times ot arrival and to avoid terrain hazards, the low level flight must be flown exactly as planned. Every low level navigation leg is planned within a flight corridor for safety-of-flight reasons. There are several ways to maintain course, each of which has advantages and limitations. Some of the methods are described here.

Correction to a Point on Center Line. When radar is an available aid, the manual cursor can be used as a valuable tool in correcting the aircraft back to center line. The procedure first involves locating a suitable target on center-line and determining the intercept desired to return to center line. The intercept correction (degrees of heading change) is an arbitrary determination based primarily on the distance of the target from the aircraft. The closer the target is, the larger the correction should be. However, heading corrections should normally not exceed 45 degrees. When this procedure has been accomplished, all that is required is a movement of the manual cursor to the desired intercept angle on the side of the scope opposite the target from 360°, and turning the aircraft an equal number of degrees toward the radar return. When the target falls under the repositioned manual cursor the aircraft has returned to center line, and the heading correction should be taken out.

Example: Aircraft 3 NM right of course, target found 15 NM down course, 45 degree intercept. Move manual cursor 45 degrees right (045 bearing), turn aircraft 45 degrees left (315° heading). When target is under repositioned cursor the aircraft has returned to center line and heading correction should be taken out.

Thirty-Degree Intercept Method. The 30-degree intercept method can be used when no target is available on course line but the relative aircraft position left or right of course is known and the aircraft is paralleling center line. The steps involved to intercept course are first to determine the distance the aircraft is from center line then double the distance. Second, determine the time needed to fly the doubled distance by using the current GS. Third, determine what the drift-corrected MH should be to cause the aircraft to parallel course. Fourth, turn 30 degrees in the direction of the needed left or right in relation to drift-corrected MH. Fifth, when the computed time for the double distance has elapsed, turn to the desired MH and the aircraft will be on center line.

Example: Aircraft 3 NM right, GS 360 knot, MH 270 degrees. Turn to 240 degrees and hold correction for 1 minute. Then, after 1 minute has elapsed, return to MH 270.

Off-Course Correction Tables. Off-course corrections can also be determined using the table shown in figure 20-3. Enter from the top of the table with the miles off course, go vertically to the line representing miles flown, and read the correction to parallel. Do the same for the correction to converge, except that the "Miles Flown" represents miles to fly. Add the two corrections for the total course alter to converge.

Correction to Intercept Course. The graph shown in figure 20-4 is used when it is necessary to intercept course rather than converge at the turning point. To use this graph, the entering arguments are nautical miles off course and groundspeed. The table can be used for fixed alterations of 15°, 30°, 45°, or 60° Enter the graph on the left with nautical miles off course; go horizontally across the chart to the line representing groundspeed. Then, go vertically to the top or bottom (depending on the desired degrees to alter) to read the time required to intercept course. After the alter is made and the indicated time has elapsed, make an alter to the original (or corrected) heading to maintain desired course.

Time Control

To provide positive control of several aircraft flying related low level missions, each sortie is assigned a particular time to arrive at each designated turning point and over the target zone. Therefore, every ETA must be met within close tolerances.

Annotate route legs on the chart with a series of small "speed lines" drawn across the leg. Space these speed lines, or "time ticks", 1 minute apart according to forecast groundspeed; for example, 6 nautical miles apart for a planned groundspeed of 360 knots. These speed lines begin at the low level entry (starting) point and continue through the entire route to the target. With these speed lines, the navigator can check the time over each speed line and keep a running account of whether the aircraft is ahead of, or behind, the required time schedule. If the need for an increase in groundspeed is apparent, the navigator may increase airspeed or plan to turn short at the next turning point.

Once the need for a change of groundspeed is apparent, the navigator needs some established method to accomplish this change accurately and quickly. Two methods that are simple and accurate are the 10% method and the incremental method.

10% METHOD GRAPH
FLIGHT PLAN GS = 300
10% = 30 KNOTS

		Time to Hold Speed Change
	6	1 min
	12	2 min
	18	3 min
seconds	24	4 min
to	30	5 min
gain	36	6 min
or	42	7 min
lose	48	8 min
	54	9 min
	60	10 min

Figure 20-5. 10% Method Table.

Ten Per Cent Method. The navigator first must determine the amount of time to gain or lose. This amount is calculated by taking 10% of the flight-planned groundspeed. (10% × 300 knots = 30 knots). The rule states that holding the 10% increase or decrease of flight-planned ground speed for 10 minutes gain, or lose 1 minute. This also means that one can gain or lose 6 seconds for every minute the adjustment is maintained. To apply this method, the navigator determines the 10% factor during mission planning. (See figure 20-5.)

Example: In flight, the navigator determines he or she is 35 seconds late. The navigator now increases the flight plan groundspeed by 10% and holds it for 7 minutes.

Incremental Method. To determine the increment, you must find your miles per minute (300k = 5 miles per min). Multiply that by 10 to get the increment (5 × 10 = 50k). Determine time data ahead or behind, then convert to seconds (2 min = 120 secs). Divide this time by 10 to get the number of minutes to hold the correction. The rule of thumb states that if the increment is held for 1 minute, you will gain or lose 10 seconds. (See figure 20-6).

Both of these methods are based on flight planned groundspeed. The increase or decrease is applied to the flight planned GS not the GS currently being flown. If flight plan GS is 300 knots, using the 10% method to gain time, one would fly 330 knots.

Fixing

Low altitude radar or visual navigation is a combination of dead reckoning and precision fixing. The DR position is essential, since it is difficult to differentiate among returns at low levels. Without an accurate DR position, it is possible to misinterpret the pattern of returns surrounding the aircraft. To increase the chances of selecting correct returns and plotting accurate fixes, draw a line from the return through the course line, at a predetermined bearing. When taking a fix, plot distances from the returns on the preconstructed bearing lines.

Remember, both of these methods are based on flight planned groundspeed. All the work involved can be accomplished during mission planning. If one wishes, a graph can be constructed for reference in flight.

Estimating Distances. Estimating distance from the air is a skill that comes with practice and experience. The altitude of the aircraft determines the distance at which checkpoints or objects are visible. The higher the altitude, the farther one can see and, consequently, the shorter all distances appear. The best way to acquire this skill is to measure the distance between two landmarks on the chart along each leg of the route and compare this known distance with the way it actually appears from the aircraft.

Crew Coordination. Specific coordination must be effected between the navigator and other aircrew members. The relatively short period of time available to observe and identify checkpoints makes any possible assistance from other crewmembers of vital importance to the navigator. The success of the mission ultimately depends upon crew coordination.

INCREMENTAL METHOD

GS = 300 MILES/MIN. = 5 INCREMENT = 50

Time Ahead or Behind	Time To Hold Speed Change
10 sec	1 min
15	1 min 30 sec
20	2 min
25	2 min 30 sec
30	3 min
35	3 min 30 sec
40	4 min
45	4 min 30 sec
50	5 min
55	5 min 30 sec
60	6 min

Figure 20-6. Incremental Method Table.

SUMMARY

The most important phase of the low level mission is the flight plan. If the mission is planned well and there is good crew coordination, mission success is greatly enhanced. Consequently, navigators should (1) know what aids will be available, (2) be familiar with all phases of the particular mission and study them until a clear mental picture of the flight emerges, and finally, (3) maintain good, reliable in-flight DR procedures. If the navigator does all this, the low level mission will be greatly simplified. If not, the chances of success are proportionately reduced.

Chapter 21

AERIAL DELIVERY AND AIR REFUELING

INTRODUCTION

Placing a weapon on the target, aerial delivery of troops and supplies, or a photo reconnaissance mission require many of the same techniques. Typical mission profiles consist of high altitude flights to the general target area, then a descent and a low altitude flight to the target so as to avoid enemy detection and defenses. Timing on the low altitude portion of many aerial delivery missions is critical, and precise arrival over the target or drop zone must be carefully planned and executed.

The low altitude portion of the mission can be used to advantage in updating ballistics or computed air release point (CARP) information, as well as for turning on or rechecking camera equipment for a photo reconnaissance mission.

The solution of the ballistics for a bomb drop or the CARP for an aerial delivery requires similar data and methods of solution. Examination of the problem shows that locating the proper point in space from which to release is, in theory, a simple airplot problem. Any object dropped from an aircraft is affected by certain factors. Among these are aircraft airspeed, altitude above the target, air resistance upon the object being dropped, and wind effect. In photo reconnaissance, drift of the aircraft and altitude are significant in establishing the aircraft on the true heading so that the cameras are properly aligned to accomplish the mission.

Sophisticated computers have been designed that greatly simplify locating the release point. However, the navigator must still insure that timing and adherence to a preplanned route of flight to this release point are maintained. These, too, are important factors in a successful aerial delivery.

THE BOMBING PROBLEM

Precision bombing is the heart of the bombardier's profession. Quite literally, success as a navigator is measured in miles and minutes, but success as a bombardier is measured in feet and seconds; often fractions of seconds. The navigator rounds off many values and still turns out a first-rate job; the nature of the bombing problem forces the bombardier to observe exacting tolerances and eliminates the margin for guesswork.

Bomb-Nav System (BNS)

The bombing problem is mathematically resolved in the bomb-nav system computers to solve for what is technically termed the bomb resolver locus (BRL). This is the computed air position of the target. It is located upwind of the target by the

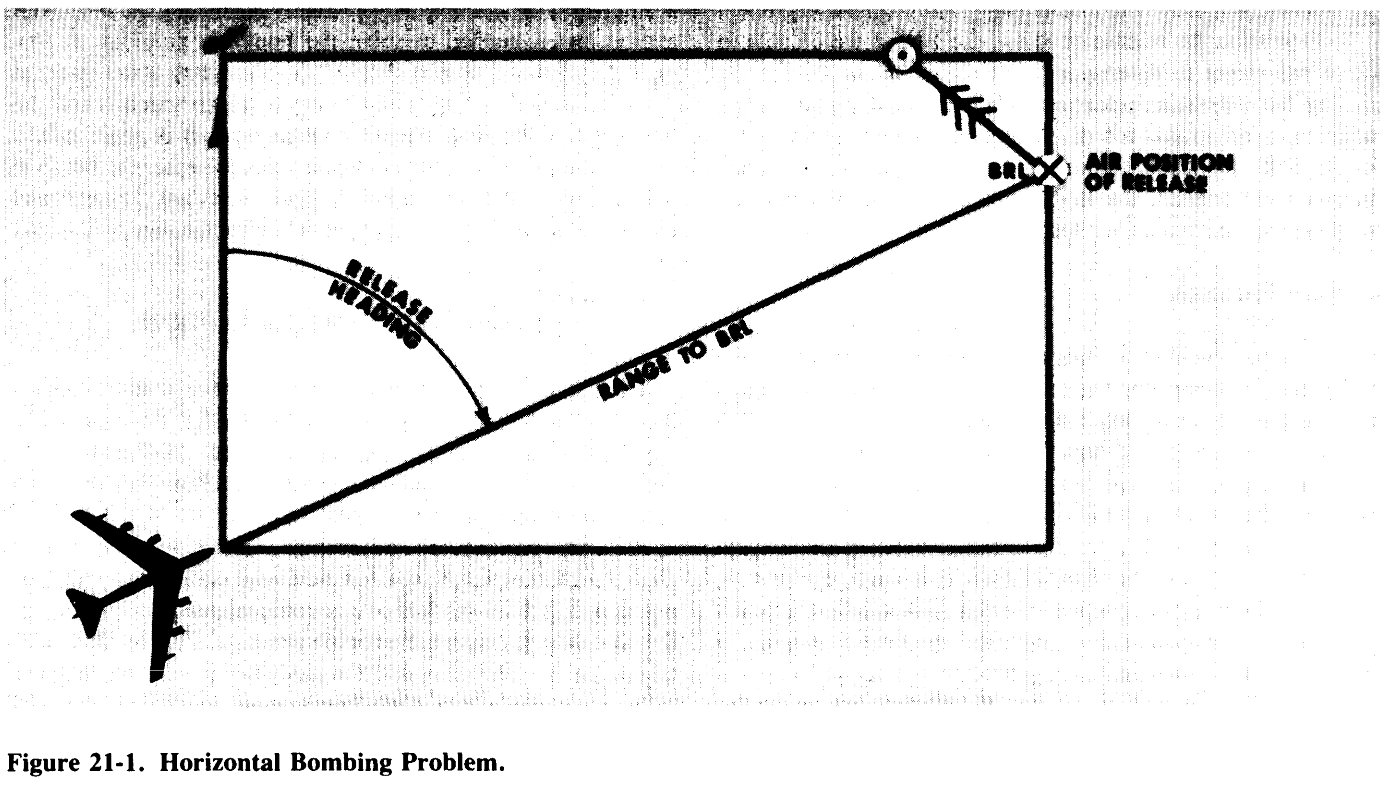


Figure 21-1. Horizontal Bombing Problem.

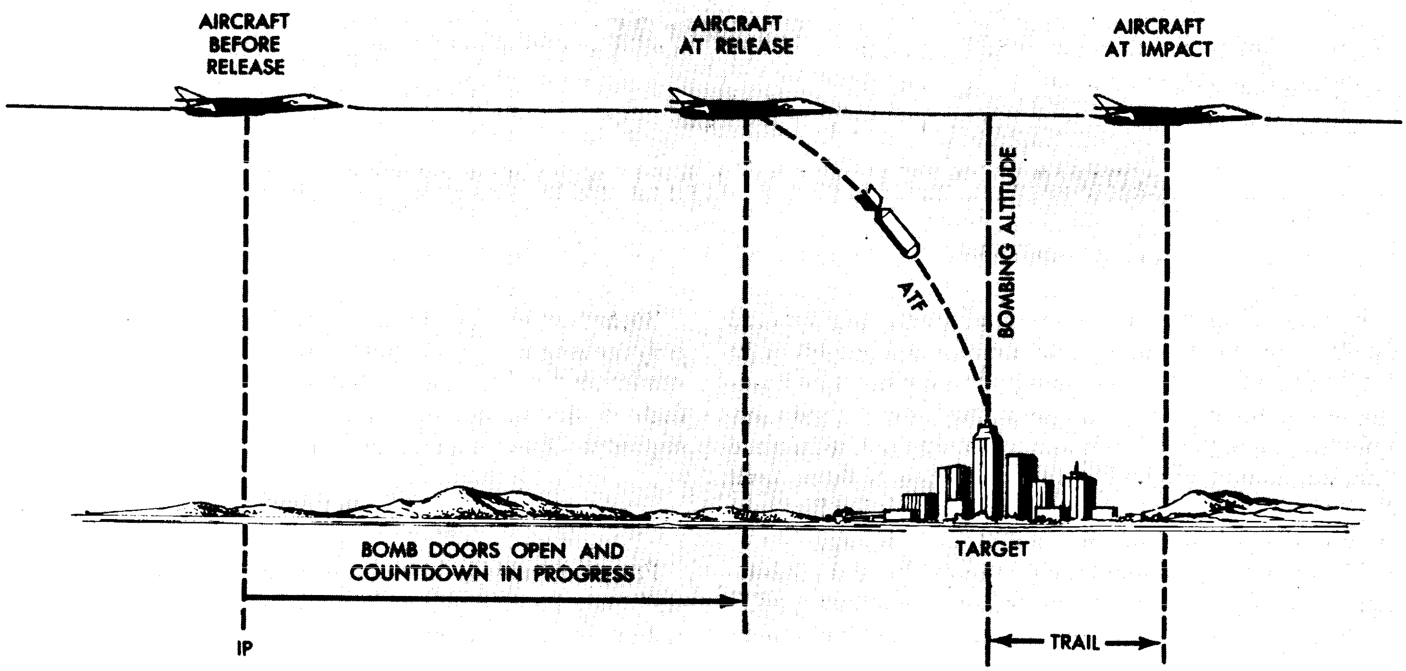


Figure 21-2. Vertical Bombing Problem.

amount of wind effect. Also computed by the BNS is the correct release heading of the aircraft and the time the weapon is to be released. The bombing problem can be viewed in two planes, horizontally and vertically, but both planes are solved simultaneously in the BNS (figures 21-1 and 21-2).

Horizontal Problem

To determine the release heading, the BNS must be able to locate the target to determine wind effect on the bomb. By placing the crosshairs (electronically generated signal on the radarscope) on a radar return, the operator identifies the target for the BNS. By resolving for wind effect on the bomb against time-to-go to impact, the BNS provides release heading and range to the bomb resolver locus.

Vertical Problem

The vertical problem is concerned with establishing the time of release. To determine the exact time of release, two things must be known: how long the weapon will be in the air from release until impact, and how far away in time the weapon is from the target. Released too soon, the bomb falls short; released too late, the bomb falls beyond the target. The time from release to impact is taken from ballistics tables and set into the computer. Because of the shape and size of a bomb and delivery with or without a chute, separate tables are consulted for each type bomb. The system then computes the time remaining to impact when the crosshairs are placed on the target.

To illustrate a typical bomb run, the bombardier places the crosshairs on the aiming plot and sets the bomb computers into operation. The pilot centers the directional indicator that aligns the aircraft on the computed heading for release, and may give the bombardier steering control of the aircraft by way of an autopilot hookup. The bombardier checks true airspeed and altitude to assure that the ballistics settings are still correct. At some value of range, depending upon the BNS in use, the timing meter will start; this provides the countdown to bomb release. While it appears only a matter of keeping the crosshairs on the aiming plot, the bombardier is actually furnishing the BNS with all the inputs needed to solve the bombing problem. A few seconds prior to "bombs away," the bomb bay doors open; at "bombs away," a signal is sent to the release circuits and the weapons are dropped. Steering of the aircraft is again turned over to the pilot for return to home base. Whether the bomb is delivered by a B-52 or an F-4, the principles are the same and the bombing problem is solved in a similar manner by computers.

COMPUTED AIR RELEASE POINT

The computed air release point system is the standard tactical drop system. Commonly referred to as a CARP, it is a scientific approach to a parachute bombing problem. Mathematical in nature, a CARP is based on average parachute ballistics and fundamental dead reckoning principles.

Aircraft commanders are responsible for insuring that a CARP solution is computed and used in all parachute operations not using a ground-marked or electronic release point; however, the navigator is responsible for the actual solution of the CARP (figure 21-3). The pilot and the navigator jointly confirm the offset distance for the CARP. The pilot assumes the responsibility for maintaining the offset distance and required track. The navigator picks the timing point, controls the time to release,

COMPUTED AIR RELEASE POINT COMPUTATIONS

DATE 29 AUG 84

NAVIGATOR'S NAME (*Print*)	CALL SIGN	ORGANIZATION	NAVIGATOR'S SIGNATURE
	AMOUR 11	41 MAS	

	FACTORS		STANDARD AND MODIFIED COMPUTATIONS		
1	DROP ALTITUDE		1100		
2	TERRAIN ELEVATION	+	387		
3	TRUE ALTITUDE		1487		
4	PRESSURE ALTITUDE VARIATION	+ A	120		
5	PRESSURE ALTITUDE		1607		
6	CORRECTED DROP ALTITUDE	B	1107		
7	TERRAIN ELEVATION	+	387		
8	INDICATED ALTITUDE		1494		
9	TRUE ALTITUDE TEMPERATURE		+10		
10	IAS/CAS/EAS		150		
11	TRUE AIRSPEED		153		
12	RATE OF FALL		34.2		
13	ADJUSTED RATE OF FALL	C	34.6		
14	ALTITUDE ABOVE POINT OF IMPACT	D	1177		
15	VERTICAL DISTANCE	–	540		
16	STABILIZATION ALTITUDE		637		
17	TIME OF FALL	E	18.4		
18	TIME OF FALL CONSTANT	+	14.4		
19	TOTAL TIME OF FALL		32.8		
20	BALLISTIC WIND		020/12		
21	DRIFT EFFECT @10	F	185		
22	DROP ALTITUDE WIND		020/15		
23	MAGNETIC COURSE		197°		
24	DRIFT CORRECTION		0		
25	MAGNETIC HEADING		197°		
26	GROUND SPEED		168		
27	EXIT TIME		6.3		
28	DECELERATION QUOTIENT	+	1.5		
29	FORWARD TRAVEL TIME		7.8		
30	FORWARD TRAVEL DISTANCE	G	738		
31	STOP WATCH DISTANCE		161		
32	STOP WATCH TIME	H	1.7		
33	USABLE DROP ZONE LENGTH	I	4175		
34	USABLE DROP ZONE TIME	H	44.1		
35	RED LIGHT TIME (*32 plus 34*)		45.8		

PREFLIGHT ALTIMETER SETTING	29.80		
DROP ZONE	SICILY DZ		
SCHEDULED DROP TIME(*s*)	1200Z		
LOAD	HE		
LOAD WEIGHT	6000 LBS		
PARACHUTE (*Type and number*)	2G 12D		
FLIGHT STATION OF LOAD	910		

FORMULAS

A. 29.92 / (29.80) + 12 ; ( ) / 29.92 –

B. Temperature / Pressure Altitude = Drop Altitude / (Corrected Drop Altitude) (*ALTITUDE WINDOW*)

C. Average Temperature / Average Pressure Altitude = (Adjusted Rate of Fall) / Rate of Fall (*DENSITY ALTITUDE WINDOW*)

D			
True Altitude	1487		
Minus Point of Impact Elevation	310		
(Altitude above Point of Impact)	1177		

E. Adjusted Rate of Fall / Stabilization Altitude = 1.0 / (Time of Fall)

F. Total Time of Fall / 1.78 = (Drift Effect) / Wind Speed

G. Groundspeed / 1.78 = (Forward Travel Distance) / Forward Travel Time

H. Groundspeed / 1.78 = Distance / (Time)

I			
Usable DZ Remaining (PI to TE)	4275		
Minus Safety Zone Distance	100		
Usable Drop Zone Length	4175		

RCRD DATA	SURFACE WIND			
	MEAN EFFECTIVE WIND			
	ALTITUDE WIND			
DROP DATA	BALLISTIC WIND USED (M) (I)			
	GROUND SPEED (C) (D) (S)			
	DRIFT (C) (D) (S)			
	GREEN LIGHT TIME (S) (V)			
	RED LIGHT TIME			
RESULTS	TOT			
	FORMATION POSITION (S) (V)			
	RAW CIRCULAR ERROR			
	CORRECTED CIRCULAR ERROR			

MAC FORM SEP 79 512 REPLACES MAC FORM 512, DEC 77, WHICH IS OBSOLETE AND MAC FORM 353, JUN 76, WHICH MAY BE USED

★ **Figure 21-3. Computations for Computed Air Release Point.**

and continually cross-checks the offset distance. Both pilot and navigator must have complete cooperation and teamwork.

Governing Factors

CARP is primarily concerned with the point of impact of the first parachute-supported object. The actual ground pattern of the remaining airdropped personnel and (or) equipment depends upon:

- Time lapse between the initial signal to jump or eject cargo, and the time of last exit.
- Aircraft stability from the computed air release point throughout the jump or ejection period.
- Uniformity of loads and (or) parachute types within elements.
- Glide angle of individual parachutes.
- Aircraft track along the drop zone.

Initial Point (IP)

The initial point must be chosen with care and must be a prominent yet a relatively small checkpoint, and should be located a sufficient distance from the drop zone to allow slowdown to drop airspeed, performance of slowdown maneuvers, and for any respacing of formation that might be required. The IP should be located as close as possible to the axis of the drop zone (DZ).

Timing Points

The location of the timing point should be as close as possible to the release point. It is difficult to position an aircraft exactly over a small geographical checkpoint without some type of sighting device; therefore, for precision drops, timing points should be used to determine when the aircraft has reached the computed air release point. When the computed air release point falls abeam a small, easily recognizable checkpoint, a timing point is unnecessary.

During daylight VFR conditions, the timing point is selected after computing and plotting the air release point. This timing point must be visible as the aircraft passes it, yet be as close to course as possible so that an accurately timed run can be made to the CARP.

For night operations or low visibility conditions, two timing points should be chosen prior to takeoff and marked by the combat control team. These timing points should be located equidistant from the designated point of impact back along the approach axis of the drop zone. The exact location of these timing points must be known by each crewmember.

Parachute Ballistics

The ballistics of different types of parachutes vary. Each parachute has been designed for a specific purpose and has its own peculiar characteristics. Personnel parachute ballistics are the most accurate as they open rapidly and are deployed by a static line of specified length. The parachute ballistics used in the solution of the CARP system for forward travel time and vertical distances are averages which are accurate enough to warrant their use on airdrops.

One important ballistic of parachutes, which is not considered in CARP and which cannot be taken into consideration in any parachute delivery technique, is the gliding characteristics of each parachute. A parachute glides in many different directions during its descent and these different directions tend to cancel out. If this were not the case, it would be extrememly difficult to obtain the desired accuracy, even if other variables (such as wind effect and aircraft positioning) were negligible. For example, the T-10 parachute has a gliding angle of 18 degrees from the vertical. This gliding effect of the parachutes is what makes them appear to drift under no-wind conditions.

Components

Vertical Distance—the distance in feet the parachute and load fall during the deceleration time.

Rate of Fall—the rate of fall expressed in feet per second of each particular parachute after it has become completely deployed as governed by the combined weight of the parachute and load. This rate of fall becomes the adjusted rate of fall when corrected for nonstandard temperatures.

Time of Fall Constant—the elapsed time from exit of the load until full deployment of the parachute minus a constant to compensate for the reduced forward speed and increased drift during the deceleration period.

Forward Travel Time—the time from green light (signal for release) to exit of the parachutist or equipment/supply bundle from the aircraft plus a deceleration constant to compensate for the reduced forward speed and the deceleration period (figure 21-4).

Forward Travel Distance—the distance along the track of the aircraft that the load travels from green light to full deployment. The forward travel time must be multiplied by groundspeed to obtain this distance. The forward travel time in seconds is converted to forward travel distance in yards on the computer by the formula:

$$\frac{\text{Groundspeed}}{1.78} = \frac{\text{Forward Travel Distance (Yards)}}{\text{Forward Travel Time (Seconds)}}$$

Drift Effect—the drift effect is the distance the parachute and load drift (under wind effect) during the total time of fall. This effect depends upon the total time of fall of the parachute load and the wind direction/velocity. Drift effect can be computed by using the following procedures.

Step 1. Find the time of fall by dividing the deployment altitude by the adjusted rate of fall to find the number of seconds required for the parachute to descend from that point where it is fully deployed to the ground. Since the parachute starts to drift as soon as it leaves the aircraft, add the time of fall constant to the time of fall to determine the total time of fall which is the number of seconds the load is falling free of the aircraft and affected by the wind.

Step 2. Then multiply the total time of fall by the wind velocity to find the wind effect. The formula is:

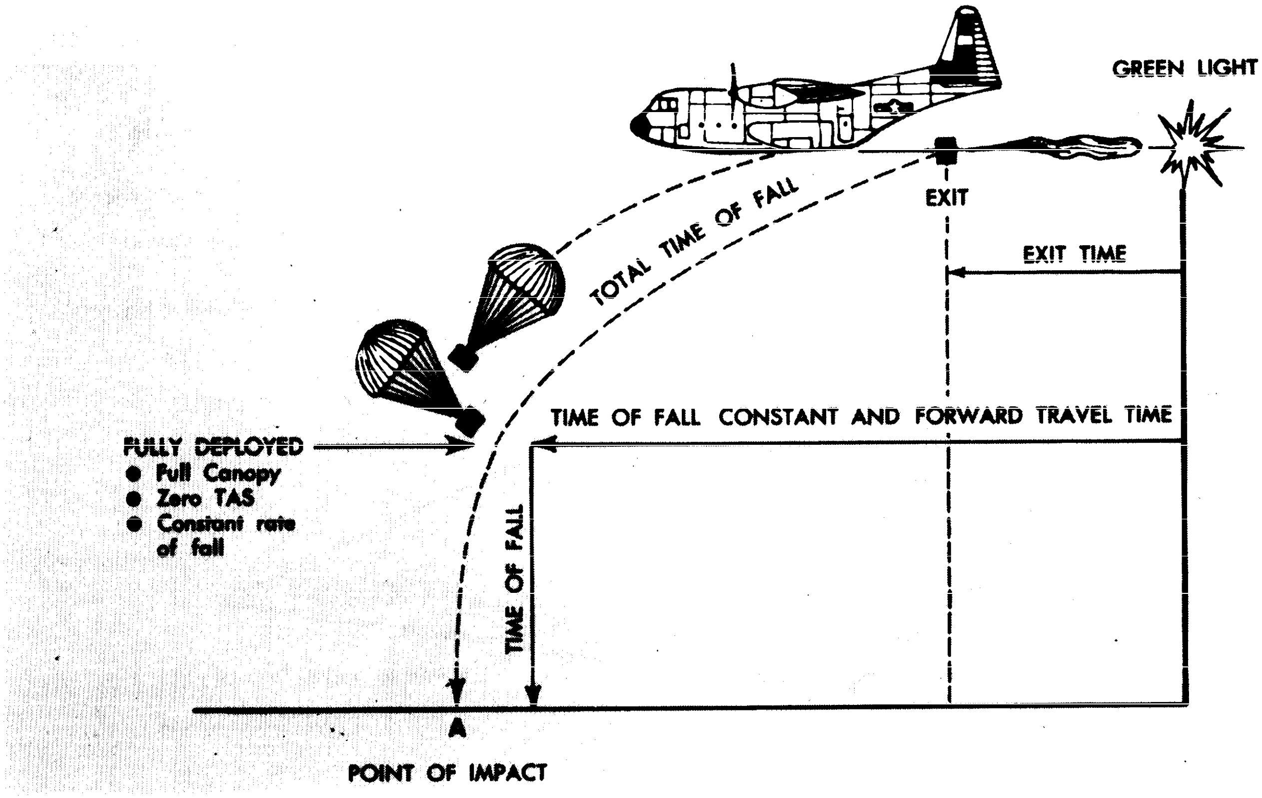


Figure 21-4. CARP Time Diagram.

$$\frac{\text{Wind Speed}}{1.78} = \frac{\text{Drift Effect (Yards)}}{\text{Total Time of Fall (Seconds)}}$$

Plotting CARP—the forward travel distance and drift effect have been discussed in the sequence in which they occur; however, the CARP is plotted as follows:

Step 1. Starting from the point of impact, plot the forward travel distance back along the DZ axis.

Step 2. Plot the drift effect upwind from the end of the forward travel vector. The end of the drift effect vector is the CARP (figure 21-5).

PHOTO RECONNAISSANCE

Tactical photo reconnaissance provides most, if not all, of the prestrike and poststrike photos of enemy troops and supplies, staging areas, behind-the-line enforcements, and the results of previous air and ground strikes against the enemy. The capability of the RF-4 to photograph moving targets is legendary and made possible by ultrasophisticated sensor systems. These reconnaissance sensors include optical cameras for day or night photography using flash cartridges, side-looking radar which affords the capability for recording moving vehicles several miles away, and infrared sensors which can detect even a single vehicle under a jungle canopy.

The primary sensors are the optical cameras which provide a varied coverage capability of many square miles; a mosaic shot at 30,000 feet for surveying a large area or a pinpoint photo of ¼-square mile area shot from 3,000 feet.

A camera such as the nose-mounted KS-87 can be fitted with one of four different lens focal lengths to photograph an area

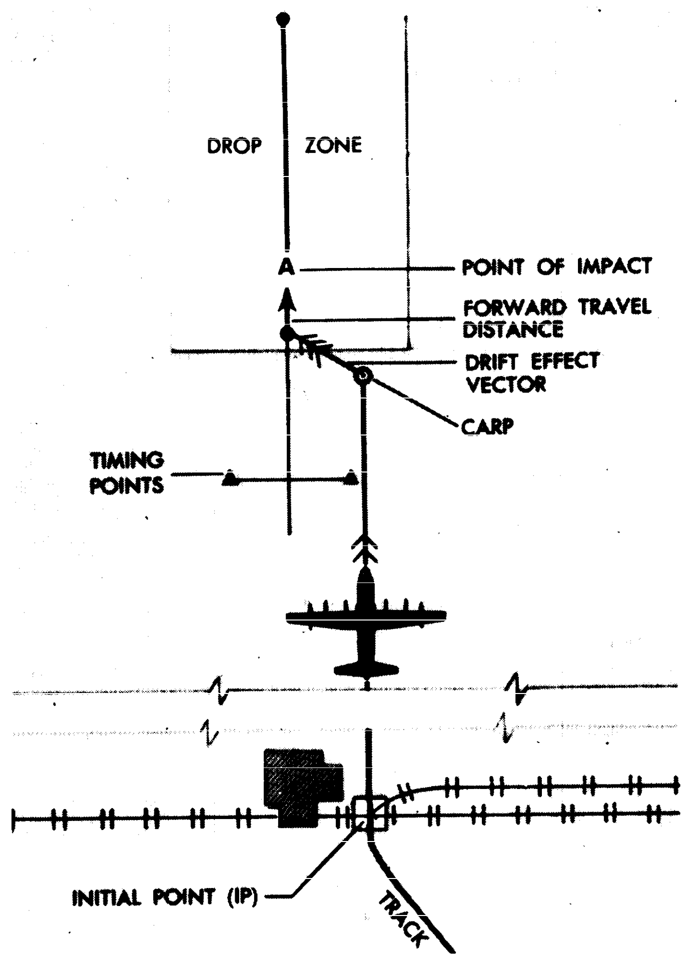
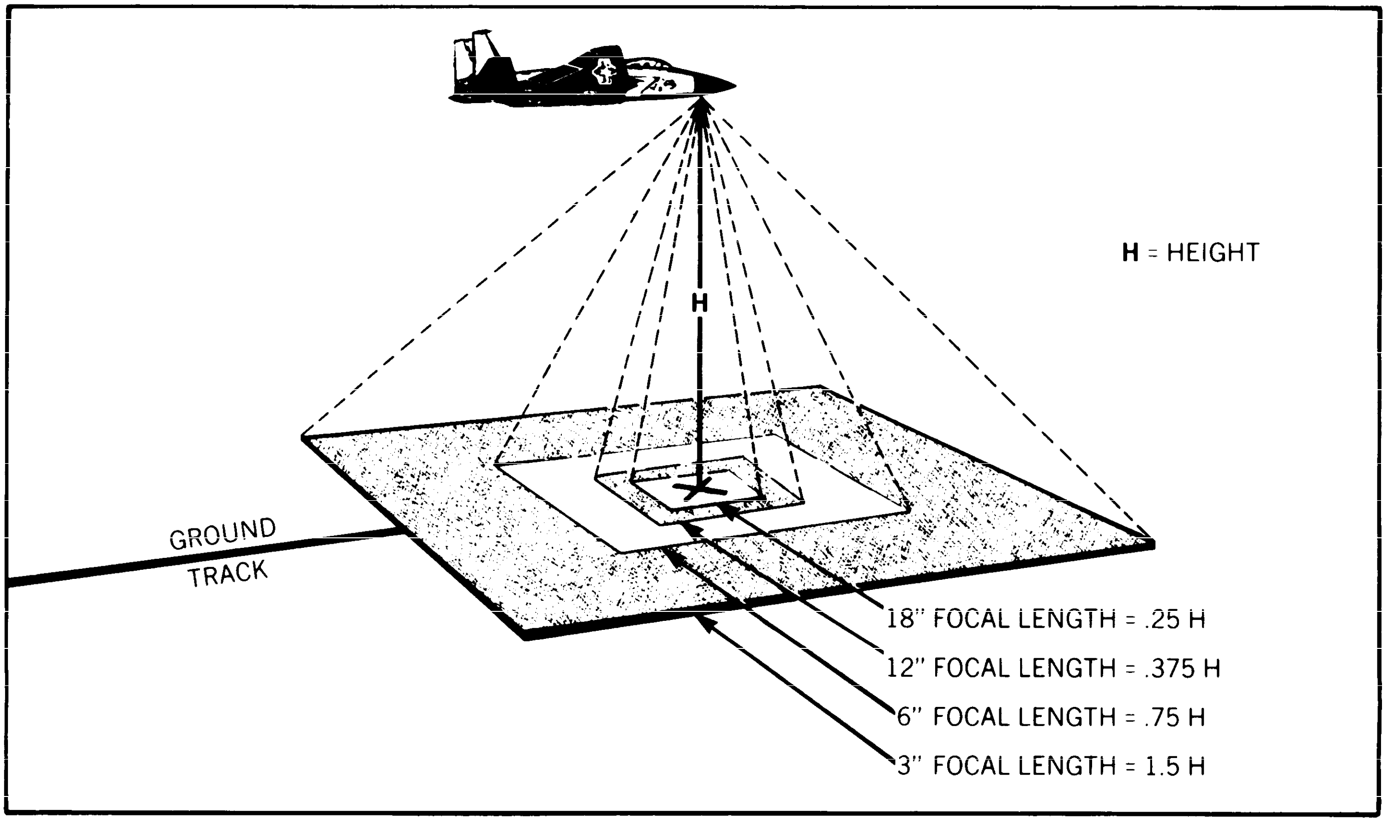


Figure 21-5. CARP And DZ Diagram.



★ **Figure 21-6. Night Photography (Pinpoint).**

equivalent to one-fourth of the aircraft altitude up to one and one-half times the aircraft altitude (figure 21-6). Flying at 10,000 feet with a 3-inch lens focal length camera, each frame will produce a picture 15,000 by 15,000 feet.

The optical system has the capability of processing its own film in flight, so that the film cartridge can be dropped via parachute to a remote outpost, providing instantaneous intelligence evaluation of the target area.

To provide complete coverage of the selected targets, three cameras may be used simultaneously. Infrared sensors are used in conjunction with these cameras to spot objects not seen by the eye or recorded by the cameras. A typical arrangement for a low-level run would include a nose-mounted camera which is aligned along the track of the aircraft; a centrally mounted, horizon-to-horizon panoramic camera that provides photography beneath and to the side of the aircraft; and two oblique cameras which produce images of the same general area but which will function also as a backup for the other units (figure 21-7).

While this setup allows planning flexibility, it does not allow for simple in-flight changes to the mission parameters. Predetermined altitude, airspeed, and available film footage are critical to each mission and the run must necessarily be accomplished as briefed.

To assure adequate detail of the target, the photo intelligence personnel will request a certain scale for the required photography. Based upon this, the crew will compute the airspeed, altitude, and number of feet of aircraft travel per frame exposed to arrive at a requirement for film footage. One mission alone can require as much as 1,000 feet of film.

The problem of assuring location and coverage of targets in daylight is usually solved by the pilot's use of the viewfinder; but, when using cartridges to illuminate the target on a night mission, the navigator must be depended upon to fully use every bit of professional knowledge and skill. To eject the flash cartridges at the correct interval to light the target, the initial point must be made good with split-second timing, the altitude cannot vary nor can the speed of the aircraft or the cartridges will fire sooner or later than the exact moment of target passage, and the mission will be something less than successful. Crew coordination deserves emphasis here and, as on any critical and highly demanding mission, the professional approach to the problem is the only method that will guarantee first-class photo intelligence results.

AIR REFUELING

Global air refueling has become the primary means of extending US air power worldwide. The decrease in operating bases on foreign soil and the application of aircraft for roles in command

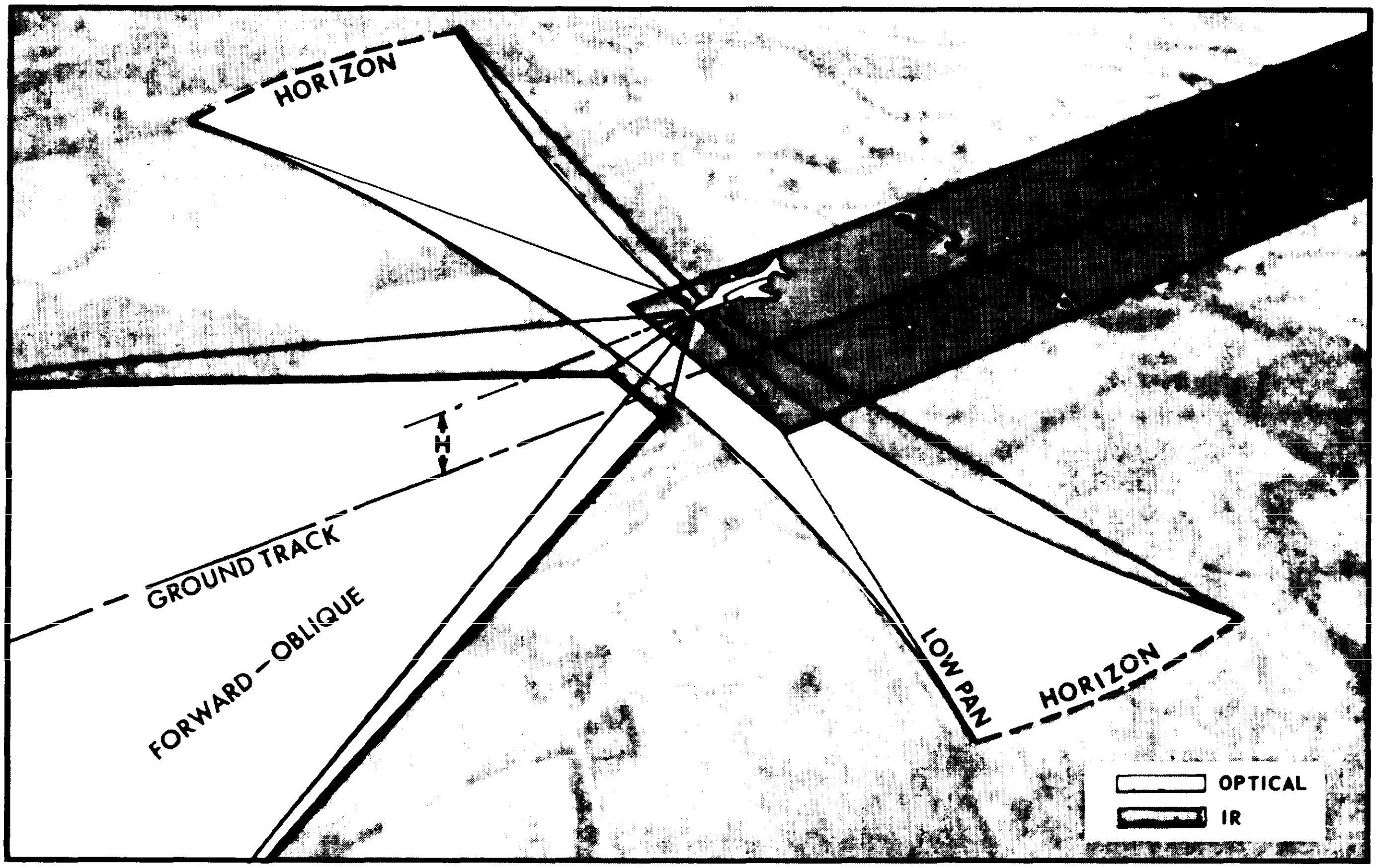


Figure 21-7. Multi-Sensor Low Altitude Profile (Camera Area Coverage).

and control, logistics, long range reconnaissance, etc, has expanded the role of air refueling to support all Air Force missions. While the SAC tankers crews' primary function remains the refueling of bombers in support of the SAC Emergency War Order (EWO), they are also called upon to provide support to a wide range of operations—operations that include most of the US Air Force's aircraft and some friendly foreign nations. The information contained in this section is general and nondirective in nature. Specific command directives should be consulted if aerial refueling operations are being planned.

MISSION PLANNING

Mission planning requires close coordination between the tanker crews and receiver crews. The crews should be thoroughly familiar with the following in order to adequately plan for the mission:

Rendezvous Initial Point (RZIP), if applicable
Air Refueling Initial Point (ARIP)
Air Refueling Control Point (ARCP)
Air Refueling Control Time (ARCT)
Air Refueling Altitude(s)
Air Refueling Abort Point
Air Refueling Exit Point
Number of receivers (each element/cell and total)
Tanker and receiver call signs
Standby tanker requirements
Cell or individual tactics
Rendezvous air refueling frequencies and beacon settings
Fuel off-load/on-load requirements
Air traffic control clearance limits
Recovery and emergency bases

Additionally, when ARCPs are located above 60° north latitude, polar navigation (USAF Grid) may be required. Grid courses may vary significantly from one type projection to another.

COMMUNICATIONS

★General

During air refueling operations, communications between tanker and receiver flight crews must be a highly coordinated effort. Unless otherwise directed, communication between tankers and receivers is maintained during all normal rendezvous, precontact, and air refueling operations. Voice transmissions should be held to the absolute minimum required. Receivers will normally make the following radio calls:

1. Initial radio contact a minimum of 15 minutes prior to the rendezvous control time.
2. After passing the ARIP, report commencing and completing all altitude changes to tanker leader, unless security would be compromised.
3. Suitably equipped receivers will call when inital beacon or air-to-air (A/A) TACAN contact with the tanker is established or if lost after once established.
4. When visual contact between tanker(s) and receiver(s) is established or lost.

5. When departing the ARIP.
6. The receiver flight leader will advise the tanker when to assume refueling airspeed (fighters and FB-111 only).
7. When the receiver is stabilized in the precontact position.
8. When contact or disconnect is made during air refueling.
9. To acknowledge when ready for contact.
10. To notify boom operator prior to using manual emergency boom-latching procedures.

Oral Communications

The following terminology will be used as a guide when oral instructions are necessary:

STABILIZE—Hold receiver steady in present position.
FORWARD—Move receiver forward.
BACK—Move receiver backward.
DOWN—Descend receiver.
UP—Ascend receiver.
RIGHT—Move the receiver right.
LEFT—Move the receiver left.

Visual Signals

Radio silence air refueling is conducted by use of visual signals. The following precautions and procedures are normally observed:

1. The method, time, and place of rendezvous and amount of fuel to be transferred should be covered in the briefing for each crew.
2. The receiver director lights (red only) may be actuated with the receiver director light switches, when in the ready condition, to aid in positioning the receiver. A steady red light will indicate a large correction, and a flashing red light will indicate a small correction in the direction indicated by the red director lights.

★3. During boom air refueling, the emergency breakaway switch will be used to flash the receiver director lights ON and OFF to signal a breakaway to the receiver. To signal a request for a disconnect, the switch will be held in the depressed position until the boom nozzle is free of the receptacle. This will extinguish all receiver director lights except the telescope background lights.

★4. If the need for an emergency breakaway occurs during planned radio silence air refueling, oral breakaway procedures should be initiated.

If an emergency air refueling is required without two-way radio communication or during practice radio silence air refueling, the visual signals shown in table 21-1 should be used:

RENDEZVOUS PROCEDURES

Track

When utilizing point parallel rendezvous procedures, the inbound track of receivers to the ARCP has a definite bearing on the success of the rendezvous. Receivers should pass over the

★ TABLE 21-1

VISUAL SIGNALS

LINE	A	B	C
		INDICATION	
	SIGNAL	BOOM AIR REFUELING	PROBE/DROGUE REFUELING
1	Boom in Trail (a) extended 10 feet	*Ready for Contact	
	(b) fully extended	1. Tanker Manual Operation without Tanker Disconnect Capability 2. Acknowledge Receiver's MBL Signal	*Ready for Contact
	(c) fully retracted	Offload Complete	Offload Complete
2	Boom Stowed (a) fully retracted	Tanker Air Refueling System Inoperative	Tanker Air Refueling System Inoperative
	(b) extended 5 feet	System Malfunction. Tanker and Receiver Check Air Refueling Systems	
3	Tanker Lower Rotating Beacon ON Flashing Receiver Director Lights	BREAKAWAY	BREAKAWAY
4	Receiver Director Lights Going OUT During Contact	Tanker Request for Disconnect. Receiver return to Pre-contact Position.	
5	Receiver Closing and Opening Receptacle Door when in Pre-Contact Position (FB-111A Flashing Light from Receiver Cockpit)	1. Manual Boom Latch 2. Acknowledge Tanker's Manual Operation Signal	
6	**Steady Light from Receiver or rock wings	Emergency Fuel Shortage Exists	Emergency Fuel Shortage Exists
7	Flashing light from C-130 receiver cockpit area	Initiate toboggan maneuver	

* Receiver(s) in the observation position will move to the precontact position in their briefed sequence only after insuring that the boom is in the ready for the contact position and the preceding receiver has cleared the tanker. The receiver will stablize in the precontact position, then move to the contact position. The boom operator will not give the ready for contact signal until the preceding receiver has cleared the tanker.

** If fuel shortage occurs at times other than scheduled air refueling, the receiver should be positioned so the signal may be seen from the tanker cockpit.

ARIP, if applicable, and make good the planned inbound track to the ARCP. If this is not possible due to weather, etc, tankers should be informed of the receivers' intentions as soon as practical.

Weather

Special weather services are required to support operations involving air refueling and certain weather support procedures should be used. It is paramount to the success of these operations that a single, coordinated forecast be provided to the agency having overall control (making launch decisions). It is also imperative that a close meteorological watch be maintained throughout an operation to aid in making recalls, diversions, etc, if unexpected weather conditions critical to the operation occur.

★Basic Rendezvous Procedures

The basic types of rendezvous procedures are point parallel, on-course, and en route refueling. All other procedures are modifications of the basic types. The type rendezvous utilized will be dictated by mission requirements, available equipment, and weather conditions.

When flying in cell, if either the tanker or receiver leader cannot make sufficient contact to effect the rendezvous, other airplanes in the cell will be directed to attempt contact. An airplane successful in establishing contact will advise the cell leader, who will either direct the rendezvous based upon that information to permit that airplane to effect the rendezvous.

★Point Parellel Rendezvous (Figures 21-8 and 21-9)

The tanker is responsible for the successful completion of the rendezvous.

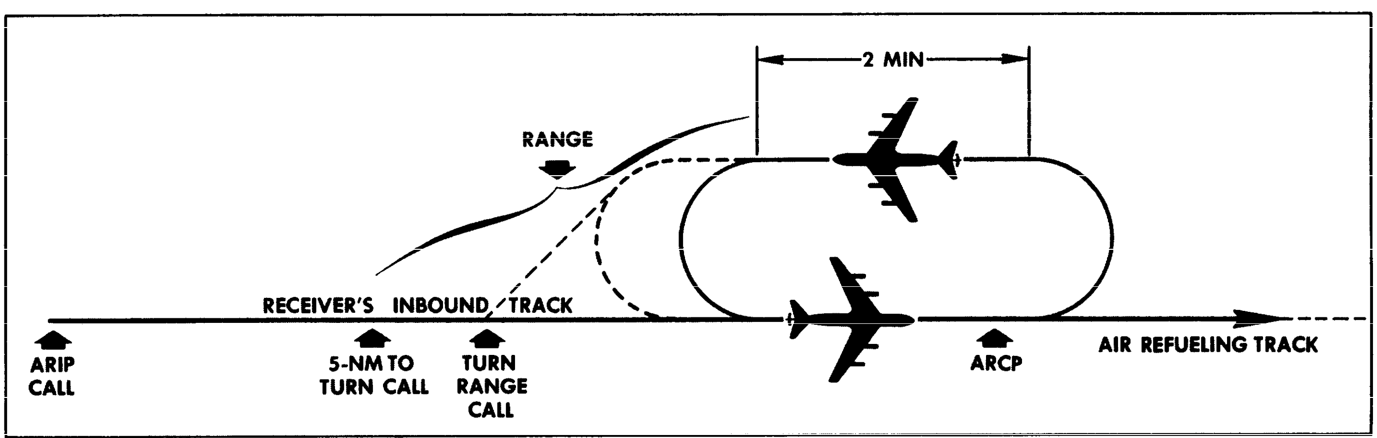
A successful point parallel rendezvous requires the tanker to maintain the proper offset and the receiver to fly the specified rendezvous track. The receiver will communicate with the tanker as far from the ARCP as possible. On the initial radio contact, the receiver will give range, if known, and other air refueling information including any required changes to the air refueling track. The tanker will inform the receiver of any change in ARCP and confirm air refueling altitude.

The tanker INS/DNS will be the primary means of maintaining the offset and the A/A TACAN will be the primary for range information. To provide A/A TACAN ranging, the tanker and receiver (one airplane per cell) will set the assigned A/A TACAN channels prior to the receiver departing the ARIP or at the receiver's ARIP call. A/ TACAN should be left in A/A until inside 1/2 NM. The accuracy of the primary rendezvous equipment should be cross-checked with as many other available aids as necessary. If primary equipment is degraded, the tanker crew must be prepared to use other means to accomplish the rendezvous.

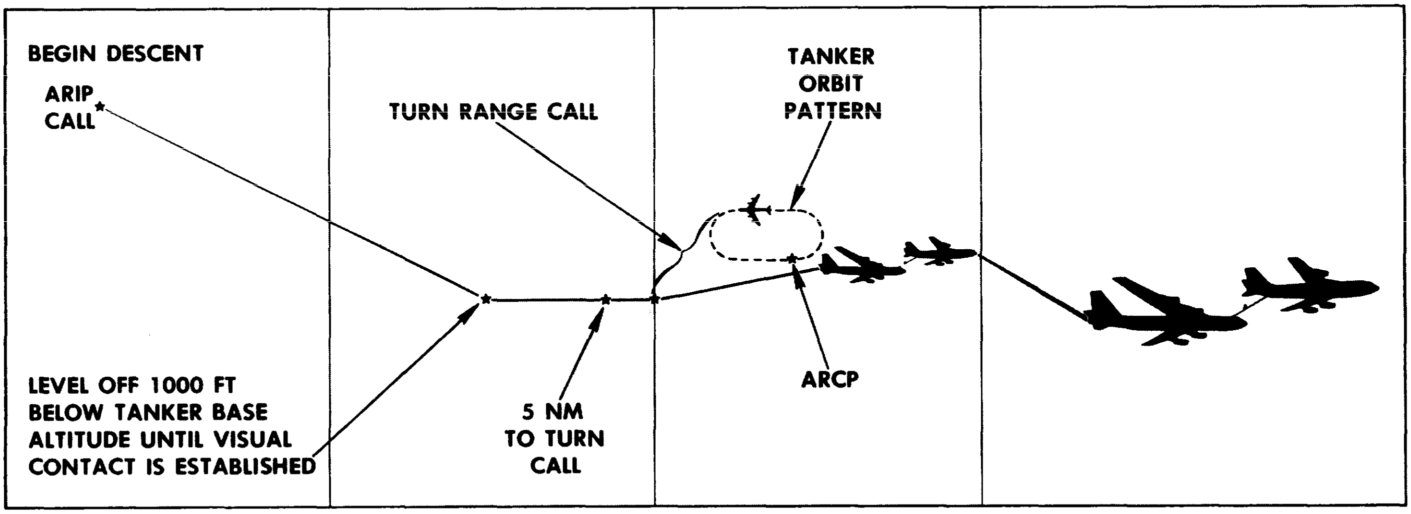
Both receiver and tanker will acknowledge initial beacon and (or) A/A TACAN contact by radio, transmitting in the blind, if necessary. Crewmembers must ensure rendezvous with the wrong airplane is not attempted. To aid the receiver in identifying the tanker, if the tanker does not receive a communication from the receiver by ARCT minus 10 minutes, the tanker will transmit in the blind giving the information normally given during rendezvous. The tanker will also flash the rendezvous beacon exactly 10 minutes before the ARCT for 1 minute with cycles of 15 seconds on and 15 seconds STDBY. Receivers will proceed from the ARIP to the ARCP using all navigational aids necessary to arrive over the ARCP via the inbound track. Receivers will begin descent at the ARIP. The receiver level off altitude will provide 1000 feet separation between the highest receiver and tanker leader base altitude (figure 3-2).

At the receiver's ARIP call, the tanker will turn to, or continue on, the reciprocal of the receiver's inbound track and will establish and maintain the proper offset until reaching the planned turn range. The offset is measured perpendicular to the inbound track.

Range will be measured directly from airplane to airplane. The tanker will call 5 NM prior to turn range and at the turn range. Receivers will monitor the range and make these calls if the tanker loses range information.



★Figure 21-8. Point Parallel Rendezvous.



★ Figure 21-9. Point Parallel Rendezvous Profile.

The tanker will turn inbound to the ARCP at the turn range and adjust to appropriate air refueling speed during the final portion of the turn. For fighters, speed will be adjusted at the direction of the receiver.

To help ensure safe separation when range between airplanes is not known and the receiver has to descend through air refueling altitude, tankers will not initiate final turn to refueling track unless receiver airplane has confirmed level at rendezvous altitude.

At the turn range call, the receiver will assume responsibility for closing on the tanker. The tanker will call the receiver when the tanker is halfway through the turn back to the ARCP and the receiver will respond with the forward range. This call is important for receiver spacing and is the most probable time for visual sighting.

With suitably equipped receivers, the last tanker in a cell will turn the radar/rendezvous beacon to operate, single code, on rollout to rendezvous/refueling heading. The receiver pilot will advise the tanker when visual contact is established.

Receivers will call 3, 2, 1, and 1/2 NM ranges (if applicable).

★On-Course Rendezvous

These procedures apply primarily to stream operation, that is, waves of airplanes flying the same track at the same altitude with separation being assured by timing. For ideal spacing in the refueling area, the tanker stream may be programmed to arrive over the rendezvous point (RZ) one minute ahead of the bombers. Upon reaching the RZ, odd numbered bomber and tanker cells will proceed to one refueling track and even numbered cells will proceed to the opposite track. At the RZ, the last tanker in each cell will set his APN-69 to transmit single code if requested by the receiver. Mated bomber and tanker cells will establish contact on their individual refueling frequency. The tanker wave leader, when crossing the RZ, will announce to his following cells that he is assuming a predetermined airspeed. The bomber wave leader, when crossing the RZ, will maintain altitude and increase airspeed as necessary to effect closure with the scheduled tanker cell. Individual cell leaders will maintain the briefed interval over the RZ. Tanker/receiver cell will adjust to air refueling formation at the ARIP or no later than 100 NM from the ARCP. Bomber cells will maintain altitude separation until attaining a position 5 NM in trail behind the mated tanker cell leader. When on the refueling track and the position of all tanker airplanes in the cell has been determined by BNS station keeping and (or) visual means, the bomber cell will descend at 280 KIAS, 2500 FPM, to a base altitude ensuring a 1000-foot altitude separation between the highest receiver and the lowest tanker. Closure to refueling position will be initiated from this position. Both tracks should be programmed to refuel at the same altitude. Normally this will be the tanker stream en route altitude.

Tanker cell leaders will operate APN-69 beacons and monitor a common interplane frequency during refueling.

Deviations for weather should be coordinated between cell leaders on both track to facilitate subsequent bomber stream join-up.

★En Route Rendezvous Procedures

An en route rendevzous is used when the tanker(s) and the bomber(s) fly individual flight plans to a common RZ, where join-up is accomplished, and continue en route cell formation to the ARCP.

These procedures provide an orbit delay en route to the ARCP. It is not appropriate to accomplish a point parallel rendezvous at the RZ because the length of the orbit legs cannot be extended. Depart the RZ to make good the ARCT or receiver ETA at the ARCP.

TURN RANGE/OFFSET CHART

TURN RANGE

		DRIFT CORRECTION HEADING INTO ARCP							NOTES
		+15	+10	+5	0	-5	-10	-15	
CLOSURE RATE	1000	22	23	25	26	28	30	32	3 NM ROLLOUT RANGE
	975	21	22	24	25	27	28	30	
	950	20	22	23	24	25	27	29	
	925	19	21	22	23	24	26	28	
	900	19	20	21	22	24	25	27	
	875	18	19	20	21	23	24	26	
	850	17	18	19	20	22	23	24	
	825	16	17	18	19	20	21	23	
	800	15	16	17	18	19	21	22	
	775	15	16	16	17	18	20	21	
	750	14	15	16	17	18	19	20	
	725	13	14	15	16	16	17	18	
	700	12	13	14	15	16	16	17	
	675	10	10	11	12	12	13	14	½ NM ROLLOUT RANGE (A-10, A-37)
	650	9	10	11	11	12	13	14	
	625	9	9	10	10	11	12	13	
	600	8	9	9	10	11	12	12	
	575	7	8	8	9	10	11	11	
	550	7	7	8	8	9	10	10	
	525	6	7	7	8	8	9	9	
	500	6	6	7	7	8	8	9	
	475	5	6	6	7	7	8	8	
	575	6	7	8	8	9	10	11	1 NM ROLLOUT BEHIND C-130
	550	6	6	7	8	9	10	11	
	525	5	6	6	7	8	9	10	
	500	5	5	6	6	7	8	9	
	475	4	4	5	5	6	7	8	

OFFSET

		DRIFT CORRECTION HEADING INTO ARCP							NOTES
		+15	+10	+5	0	-5	-10	-15	
TANKER TAS	460	7	8	9	11	12	14	16	30^{o} BANK
	440	6	7	8	10	11	13	15	
	420	6	7	8	9	10	12	14	
	400	5	6	7	8	9	11	12	
	380	5	6	6	7	9	10	11	
	360	4	5	6	7	8	9	10	
	340	4	4	5	6	7	8	9	
	320	3	4	4	5	6	7	8	
	300	3	4	4	5	5	6	7	
	280	3	3	4	4	5	6	6	
	260	2	3	3	4	4	5	5	
	240	2	2	3	3	3	4	4	

NOTE

Use drift correction inbound to the ARCP and closure rate (receiver TAS added to tanker TAS) to determine turn range. Use drift correction inbound to the ARCP and tanker TAS to determine offset.

When more than one tanker is involved, add 1 NM to the turn range for each additional tanker in the formation (except C-130 overtaking rendezvous).

★Figure 21-10. Turn Range and Offset Chart.

Either tanker(s) or bomber(s) may be scheduled to arrive at the RZ first, orbit if necessary, and then depart at a preplanned time.

The RZ will be located a minimum of 50 NM prior to the ARIP/SD. Tracks from the ARIP/SD may be established from any direction and need not necessarily be an extension of the air refueling track.

If orbit delays are required, they will be accomplished by orbiting at the RZ along an extension of the track from the RZ to the ARIP/SD. Orbit in a racetrack pattern using 30-degree banked turns and a maximum of 15 NM straight legs (unless operational directives specify longer straight legs). Orbit airspeed will normally be 275 KIAS or Mach 0.78 whichever is lower.

The following paragraphs outline procedures for accomplishing the en route rendezvous.

The join-up at the RZ may be accomplished by:

Timing so that bomber(s) and tanker(s) arrive at the RZ within 1 minute of each other utilizing normal procedures (for example, differential airspeed) to accomplish join-up.

A planned orbit delay, with tanker(s) and bomber(s) accomplishing join-up in the orbit.

If rendezvous or join-up is to be accomplished while in orbit, the AN/APN-69 beacon of the first orbiting airplane will be the primary equipment used to control positioning over the RZ. Length of orbit legs may be reduced, but not increased, if required to meet RZ rendezvous control time.

Assigned altitudes at the RZ will provide at least 1000 feet separation between affected airplanes (highest tanker and lowest bomber), with the receivers always at the highest altitude.

If radio communication between airplanes has not been established prior to the RZ rendezvous control time, or the adjusted RZ rendezvous control time, airplanes will maintain altitude and depart the RZ for the ARCP so as to make good the ARCT. Delays at the ARCP will be as specified for normal orbit procedures.

Once airplanes have departed the RZ, standard procedures apply.

Cells will echelon at the ARIP and start descent to base air refueling altitude by a point 80 NM prior to the ARCP using 2500 FPM rate of descent.

SUMMARY

Air refueling requires a coordinated effort between tanker and receiver crews in all phases, from mission planning on. Crews need to be thoroughly familiar with the correct communications procedures in flight.

★There are three basic rendezvous procedures—point parallel, on-course, and en route refueling. All other procedures are modifications of the basic types.

Chapter 22

WEATHER STATION SERVICES

As navigators gain experience, they are able to select the most accurate data available and integrate it into a system of navigation that best fits existing flight conditions. A knowledge of weather conditions that may be expected in flight is provided aircraft members by the base weather stations. Since weather is a prime factor affecting any flight, it is important that the navigators have a thorough understanding of weather information and the services available to them.

WEATHER CHARTS

The Air Weather Service (AWS) assembles weather information from all regions of the world to provide the Air Force with a worldwide forecasting service. This weather information is collected at regular and frequent intervals from thousands of observing stations. The Air Weather Service has comparatively few stations; therefore, it depends upon civilian weather services for data concerning North America. Ships, aircraft, and stations of other U S military services also furnish information. The surface and upper air data observed by stations throughout the world are collected and plotted on surface and constant pressure charts.

Surface Charts

The station circle illustrated in figure 22-1 is used on the facsimile surface charts. The facsimile surface chart (weather map) is distributed every 1 1/2 to 2 hours; from these charts, forecasters obtain a picture of conditions existing at the time of the observations.

When charts are prepared for facsimile transmission by the National Weather Service, AWS Weather Centrals, and Forecast Centers, only the most important information such as wind speed and direction, temperature, dew point, and existing weather is included. The weather analysis depicted on the surface chart in figure 22-2 illustrates:

- Surface frontal position
- Pressure system centers
- Precipitation areas and type
- Isobars (lines connecting points of equal pressure)

Weather which is hazardous to flight is indicated in red symbols.

Surface Prognostic Charts

Surface prognostic (forecast) charts are prepared by NMC, AWS Weather Centrals and Forecast Centers. They are transmitted via facsimile network and teletype bulletins.

These charts can also be prepared by the forecaster when circumstances require. Figure 22-3 shows a prognostic chart which depicts the expected position and orientation of fronts, pressure systems, cloud patterns, and other areas of weather significant to flying operations. Prognostic charts are valid for 12 to 72 hours after the time of preparation; most mission planning is based on a 12- or 18-hour prognostic chart.

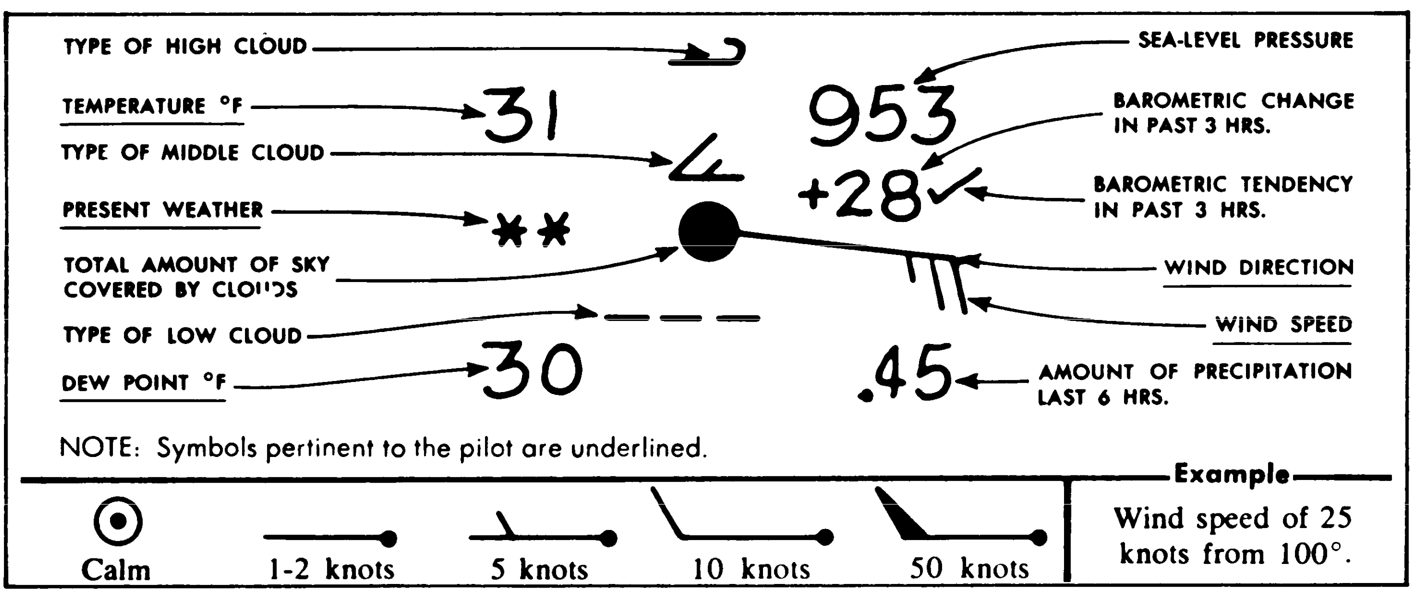


Figure 22-1. Plotted Data Around Station Circle on Facsimile Surface Chart.

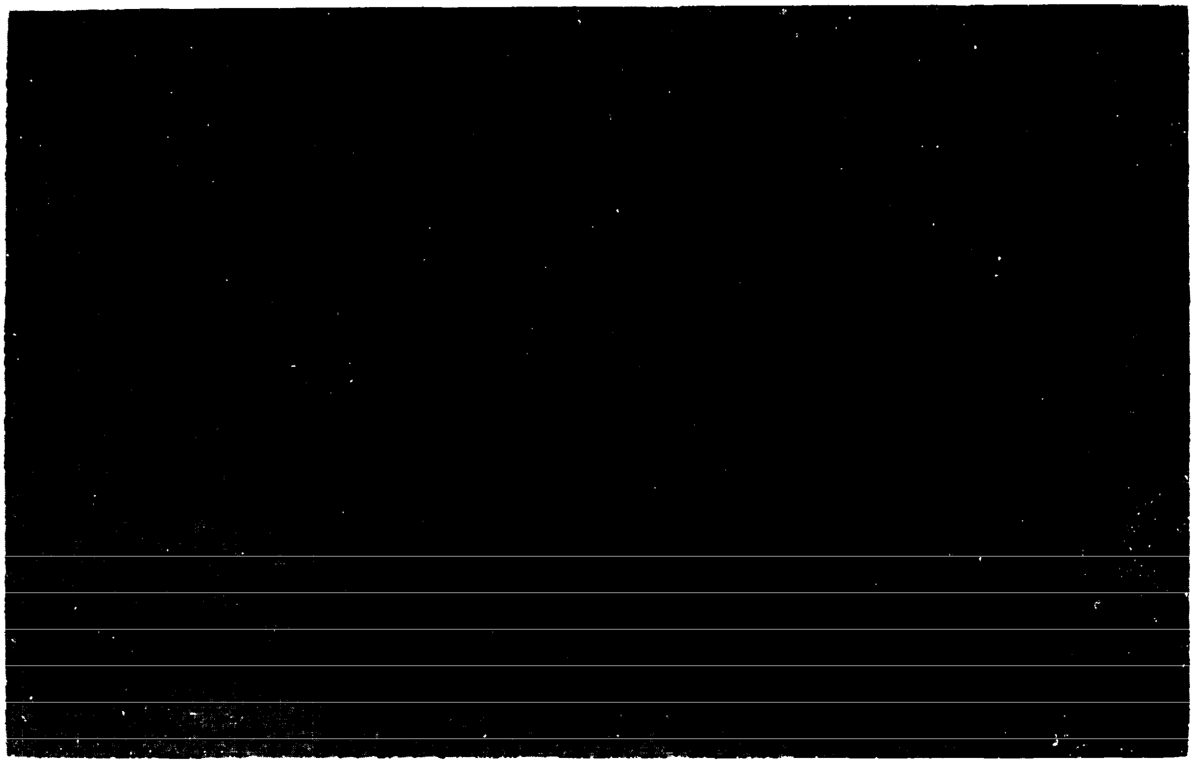


Figure 22-2. Surface Chart Prepared in Weather Station.

After careful study of current and prognostic charts, forecasters rely on their training, experience, and judgment to make local and operational forecasts.

Constant Pressure Charts

Upper air data for selected standard pressure levels are plotted on constant pressure charts and analyzed. The information is obtained by upper air soundings supplemented by aircraft inflight reports (AIREP). The aircraft report may be the only information available to the forecaster for overwater areas or in areas where there are minimum reporting stations.

The standard pressure levels, for which constant pressure charts (CPC) are constructed and transmitted on facsimile, are shown in figure 22-4. A typical constant pressure chart for the 300-mb level is illustrated in figure 22-5. These charts are prepared from 0000Z and 1200Z observations. The CPC analysis illustrates:

- Contour lines (lines of equal true altitude)
- Isotherms (lines of equal temperature)
- Isotachs (lines of equal wind speed)
- Height centers (highs and lows)
- Region of maximum wind

Current facsimile constant pressure charts are prepared with computer inputs. All of the foregoing five fields of data listed will not appear on any given chart but can be determined from any series of charts for all standard levels.

The constant pressure charts, together with surface charts and other charts and diagrams, present a three-dimensional picture of the atmosphere. The combined information from constant pressure charts and surface charts furnishes the user with:

- Wind direction and speed at specific levels.
- Temperature and dew-point depression (temperature dew-point spread).
- "D" value and expected drift.
- Intensity, speed, and direction of movement of frontal and pressure systems.
- Amount, type, and intensity of cloud forms and precipitation areas.
- Areas of thunderstorms.

From these charts, there are derived three general rules which the navigator can safely use for flight-planning purposes. These are:

1. The winds blow parallel to the contour lines.
2. The speed of the wind is proportional to the spacing of the contour lines; the closer the contour lines, the stronger the winds.

★ 3. In the Northern Hemishere, wind blows clockwise around a high and counterclockwise around a low. The opposite is true in the Southern Hemisphere.

Constant Pressure Prognostic Charts

Constant pressure prognostic charts are prepared by the National Meterological Center, AWS Weather Centrals and Forecast Centers; they are transmitted to field weather stations via facsimile network. A prognostic chart for the 300-mb level is illustrated in figure 22-6.

These prognostic charts indicate:

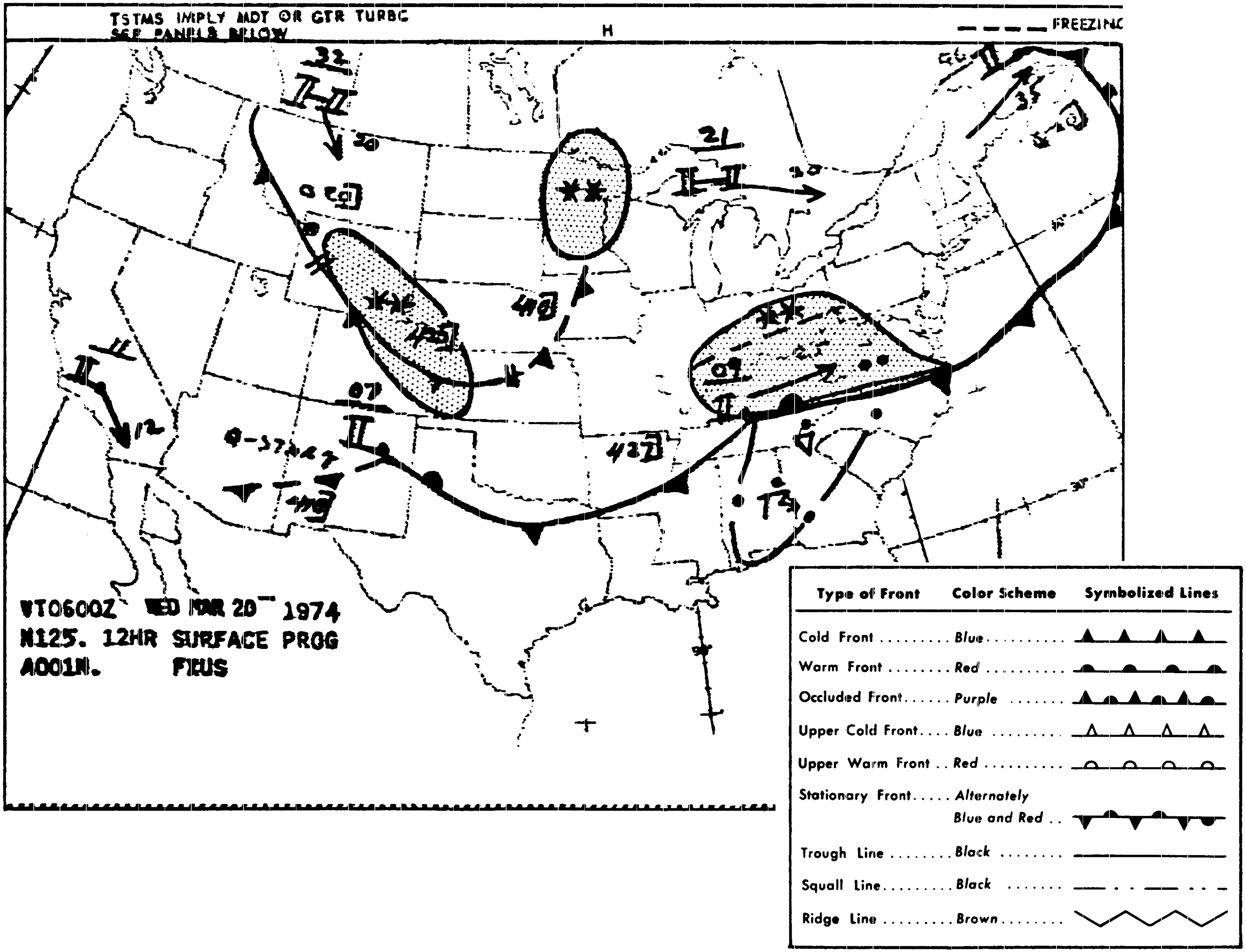


Figure 22-3. 12 Hour Surface Prognostic Chart.

Pressure Altitude (meters)	Pressure Altitude (feet)	Temperature (°C)	Pressure (mb)
16,180	53,083	−57	100
11,784	38,662	−57	200
9,164	30,065	−46	300
5,574	18,289	−21	500
3,012	9,882	− 5	700
1,457	4,781	+ 6	850

Mean Sea (59°F) 15°C; 29.92" Hg); 1013.25 mb Level.

Figure 22-4. Standard Pressure Levels.

- Forecast position and orientation of contours.
- Forecast position of trough lines and isotachs.
- Forecast position of circulation centers.

NOTE: Remember, prognostic charts represent weather conditions anticipated at a specific time, not average weather conditions over a period of time.

Winds Aloft Charts

Winds aloft charts are prepared four times daily from data obtained from upper air observations at 0000Z, 0600Z, 1200Z, and 1800Z. The information collected and plotted on winds aloft charts contains winds for selected levels in the troposphere and stratosphere. Some typical winds aloft charts are shown in figure 22-7.

NOTE: Winds aloft charts do not contain forecast winds; they contain actual winds which can be up to 12 hours old.

Despite the fact that winds from these charts are not necessarily current, they are important to aircrews for computing headings, altitudes, groundspeeds, and time en route. The detachment forecaster can provide valuable guidance or assistance in determining the accuracy and position of these winds.

Summary

With worldwide coverage and various facilities, the Air Weather Service provides vital weather information to aircrews

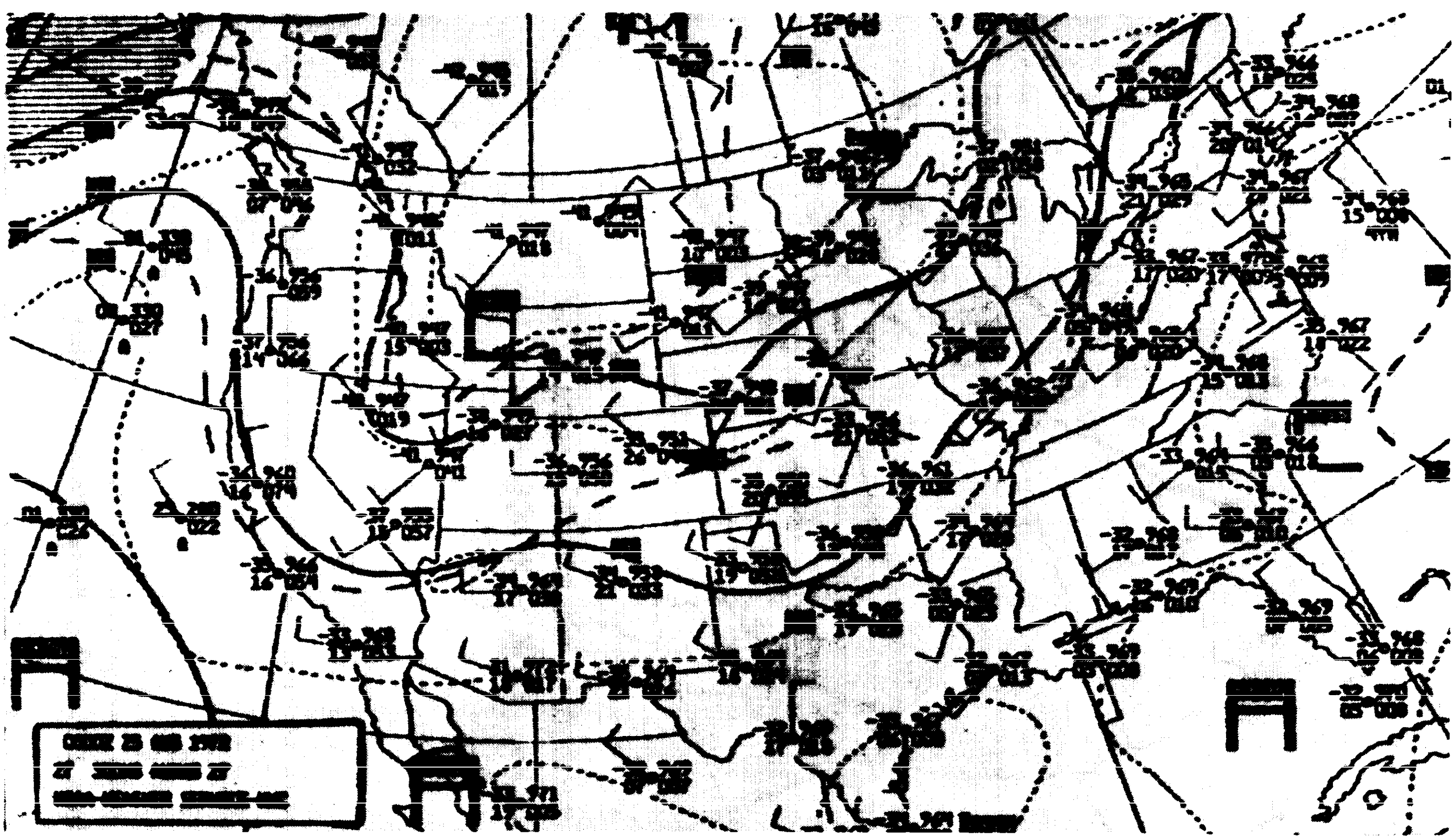


Figure 22-5. 300 – mb Constant Pressure Chart.

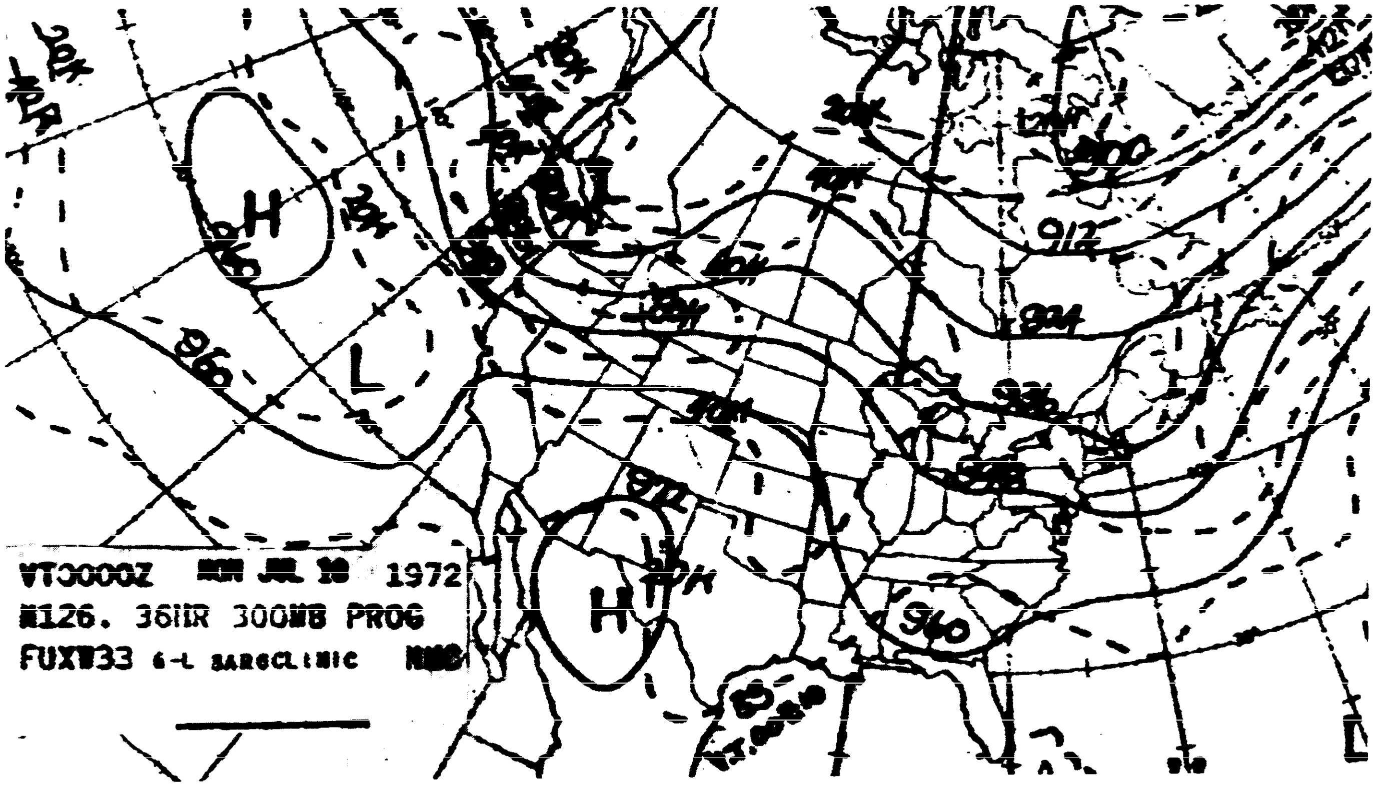


Figure 22-6. 300 – mb Prognostic Chart.

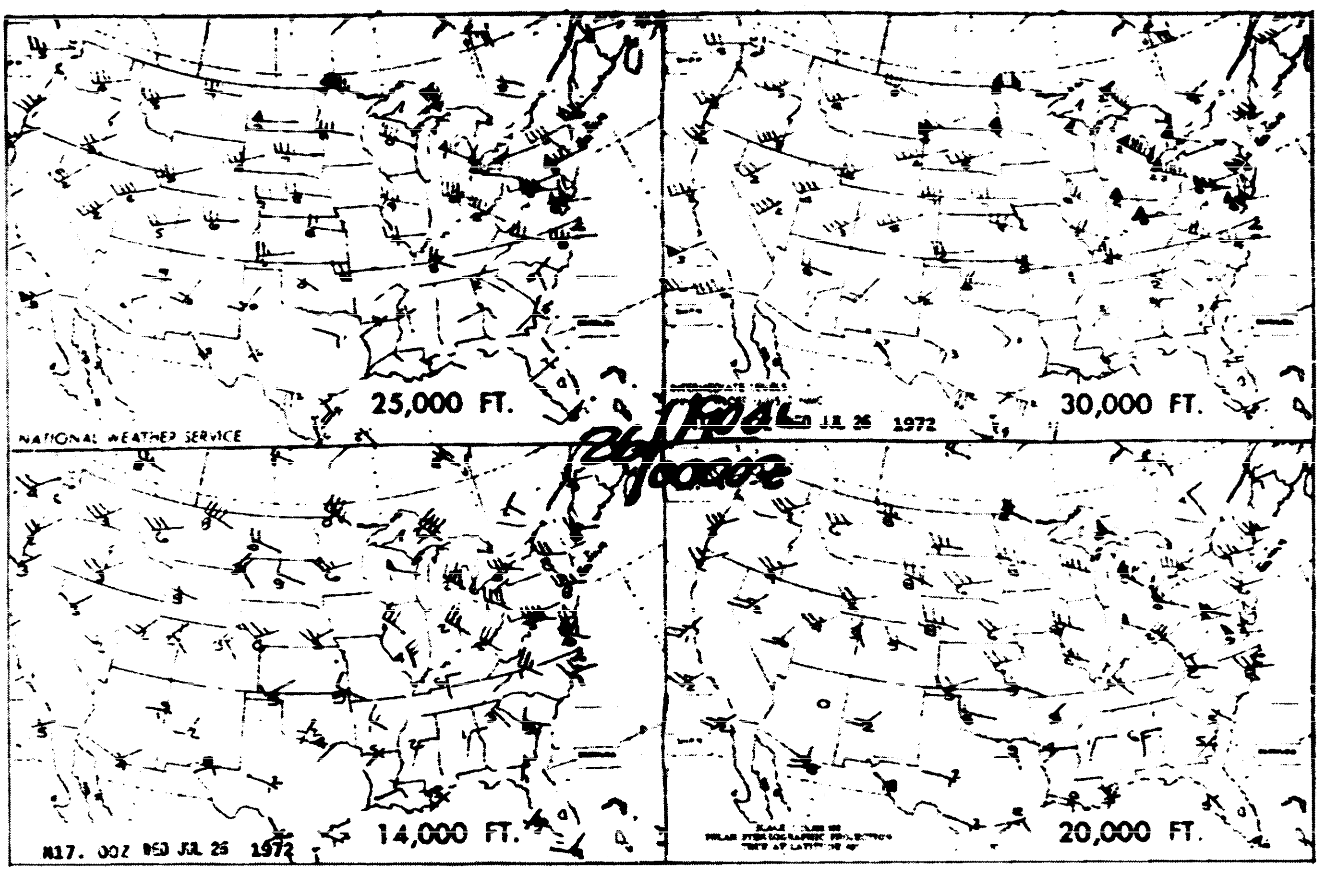


Figure 22-7. Winds Aloft Chart.

throughout the USAF. It is the job of the navigator to correctly interpret the information provided and use it to best advantage. The foregoing discussion is an introduction to the charts most often used. It is not a complete coverage of the subject. Some of the weather charts discussed in this chapter may not be displayed in all weather stations, but are available upon request.

WEATHER REPORTS AND SYMBOLS

Surface Observations

Surface weather observations are made hourly by Air Weather Service observers or National Weather Service personnel. When a weather element changes significantly, a special observation is taken. Automatic and continuous observations of such elements as the ceiling, visibility, wind, pressure, temperature, and dew point are made by weather instruments. These observations are placed in the hands of the using agencies almost instantaneously through the use of modern equipment.

Observations of vital interest to crewmembers are called Aviation Weather Reports. These reports are transmitted over a worldwide teletype network and received by individual weather stations in the aviation weather reporting code. The reports are collected in sequence and displayed for use by aircrews or by forecasters who brief aircrews.

Aviation Weather Reporting Code

The aviation weather reporting code shown in figure 22-8 is an international weather language. It provides weather personnel with information in a format that is easily understood. A typical report includes the following items:

- Sky condition and ceiling
- Visibility
- Weather and (or) obstructions to vision
- Temperature and dew point
- Wind
- Altimeter setting
- Remarks

METAR WEATHER REPORTS

Aircrews flying in overseas areas must be familiar with the METAR report (figure 22-9). This code is used by all AWS units outside continental North America, Hawaii, and Guam. Referenced tables are found in the section explaining the Terminal Aerodrome Forecast (TAF) discussed later.

The METAR code is similar to the standard format approved by the World Meteorological Organization and has two formats. The first is for longline teletypewriter dissemination of weather observations to other bases. The second format is for local dissemination and is relayed to pilots by controlling agencies.

RADAR REPORT (RAREP)

A network composed of National Weather Service and Air Weather Service radars is designed to observe precipitation patterns and provide areal coverage, height, intensity and precipitation movement information. Radar observations known as RAREPs are made normally at 40 minutes past each hour. Storm detection (SD) is the radar report identifier. This report is explained in figure 22-10.

These observations are used in preparing the radar summary chart. They should also be used to update these charts. It is wise never to rely entirely on the chart, especially if your route of flight is planned through an area of bad weather.

PILOT WEATHER REPORTS (PIREPS)

Weather observations made from the ground contain precise information that is most valuable for landings and takeoffs, approaches and departures. They do not, however, fully meet the need for information on weather conditions at flight altitude. Aircrews have a distinct advantage over ground observers in making weather observations. Not only do the aircrews usually have a broader horizon but, if they are flying above a cloud layer, they may see higher clouds or other phenomena which probably are unknown to the ground observer. Heights of upper cloud layers, turbulence, and icing frequently are evident only to airborne pilots, and their reports of these conditions are valuable to other pilots, controllers, and weather forecasters.

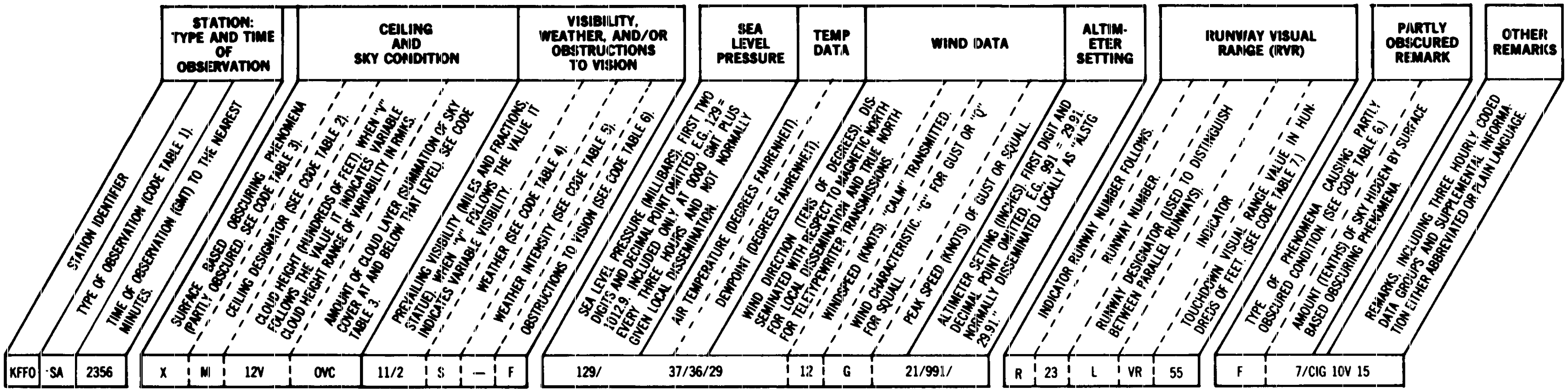
Air traffic control facilities (towers and centers) make wide use of pilot weather reports to expedite the flow of air traffic both in the terminal and in en route areas. For example, pilot weather reports of turbulence would be considered when assigning a departure route or flight altitude. Weather stations make extensive use of pilot weather reports in providing preflight briefing and in-flight services to pilots. The reports are broadcast regularly over selected navigational aids for the benefit of listening pilots and are transmitted on teletypewriter circuits for the benefit of other facilities. Weather stations use pilot weather reports in briefing pilots and in weather forecasting.

Pilot reports are required by AFR 60-16. The weather/NOTAM procedures section of the IFR Supplement will give the procedures and requirements for making PIREPS. AFR 60-16 states that pilots will brief forecasters at the destination airfield on weather conditions which promoted in-flight reports and provide them with any other information considered significant.

Local Dissemination of the PIREP

1. Station identification. (Station call letters.)
2. Identified — (PIREP).
3. Location and (or) extent. (The location and (or) extent relative to a nationally known weather reporting site. Distances are expressed in nautical miles.)
4. Time. (The time phenomena was observed in UTC.)
5. Phenomena.
6. Altitude of phenomena reported (above MSL).
7. Type of aircraft. (In reports of electrical discharge, contrails, turbulence, and icing, the type of aircraft is required.)

You should recall that altitudes are shown in hundreds of feet MSL. Visibilities are normally reported in statute miles; howev-



Code Table 1

TYPE OF OBSERVATION	
Indicator	Meaning
SA	RECORD
RS	RECORD-SPECIAL
SP	SPECIAL
L	LOCAL

Code Table 2

CEILING DESIGNATORS	
E	ESTIMATED
M	MEASURED
W	INDEFINITE

Code Table 3

SKY COVER CONTRACTIONS	
Contraction	Amount of Sky Cover (Tenths)
CLR	LESS THAN 0.1
SCT	0.1 TO 0.5
BKN	0.6 TO 0.9
A MINUS SIGN "-" PREFIXED TO SCT, BKN, OR OVC INDICATES ONE HALF OR MORE OF SKY COVER IS THIN (DOES NOT CONSTITUTE A CEILING).	
X	OBSCURED. INDICATES THAT SKY IS TOTALLY HIDDEN BY SURFACE BASED OBSCURING PHENOMENA.
—X	PARTLY OBSCURED. INDICTATES THAT 0.1 TO 0.9 OF THE SKY IS HIDDEN BY SURFACE BASED OBSCURING PHENOMENA.

Code Table 4

WEATHER SYMBOLS	
Symbol	Meaning
in Plain Language	TORNADO
	WATERSPOUT
	FUNNEL CLOUD
T+	SEVERE THUNDERSTORM
T	THUNDERSTORM
R	RAIN
RW	RAIN SHOWERS
L	DRIZZLE
ZR	FREEZING RAIN
ZL	FREEZING DRIZZLE
A	HAIL
IC	ICE CRYSTALS
S	SNOW
SW	SNOW SHOWERS
SG	SNOW GRAINS
SP	SNOW PELLETS
IP	ICE PELLETS
IPW	ICE PELLET SHOWERS

Code Table 5

WEATHER INTENSITIES	
Symbol	Intensity
— —	VERY LIGHT (USED ONLY IN CIVIL WEATHER REPORTS).
—	LIGHT
No Symbol	MODERATE
+	HEAVY
INTENSITY SYMBOLS ARE NEVER ASSIGNED TO "A" OR "IC."	

Code Table 6

OBSTRUCTIONS TO VISION	
D	DUST
F	FOG
GF	GROUND FOG
IF	ICE FOG
H	HAZE
K	SMOKE
BD	BLOWING DUST
BN	BLOWING SAND
BS	BLOWING SNOW
BY	BLOWING SPRAY

Code Table 7

RUNWAY VISUAL RANGE	
Symbol	Meaning
+	VALUE GREATER THAN HIGHEST REPORTED INCREMENT.
—	VALUE BELOW LOWEST REPORTED INCREMENT.
RVRNO	DATA FOR IN-USE RUNWAY NOT AVAILABLE.

Figure 22-8. Aviation Weather Report (Airways).

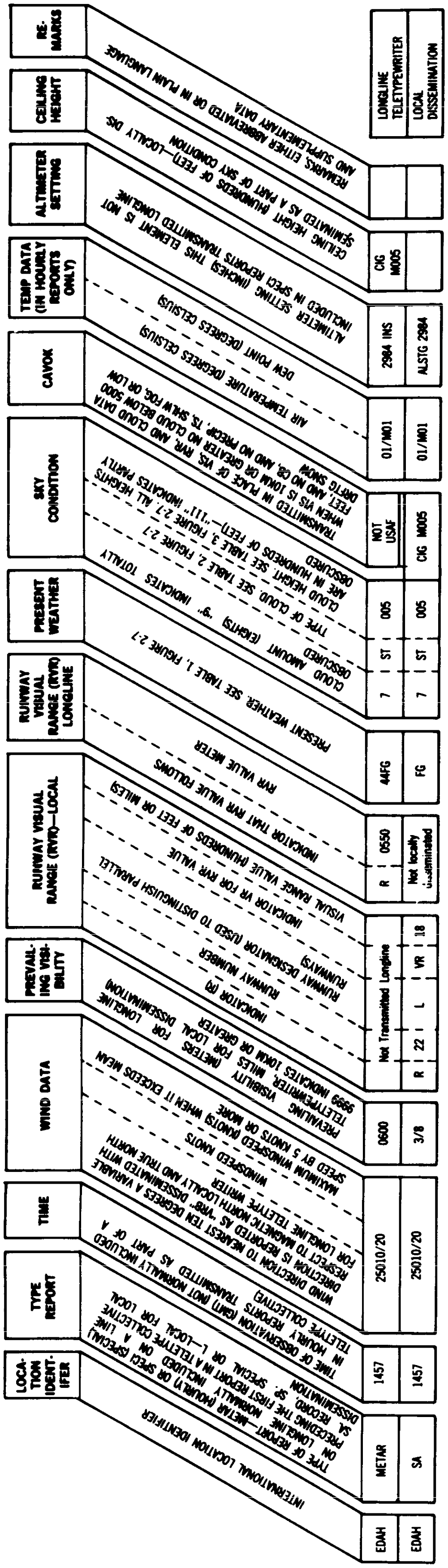


Figure 22-9. METAR Weather Report.

er, they are reported in nautical miles in the European and Mediterranean areas. Authorized word or phrase contractions, weather symbols with the appropriate intensity indicator, and international cloud abbreviations (CB, AC, AS, etc) are used. If a word or phrase contraction is not available, complete words are used. The letter "U" usually indicates some "unknown" value, for example, intensity (RWU), amount (15U20), or height (U). When type of aircraft is unknown, ACFT UNK is reported.

Examples:

1. Clear Air Turbulence (CAT) — A pilot in a B-52 reports to Carswell AFB that moderate clear air turbulence between 35,000 and 39,000 feet over Dallas was encountered at 1700 CST.

FWH PIREP OVR DAL 2300
MDT CAT 350-390 B52

2. Icing — A pilot of a T-43 reports to Randolph AFB that moderate rime icing 5 to 20 miles north of Randolph AFB at 3,000 feet was encountered at 0800 CST.

RND PIREP 5-20 N RND 1400
MDT RIME ICG 30 T-43

AVIATION WEATHER FORECAST

The aircrew planning a flight is also concerned with the forecast weather conditions along their route and at their destination and alternate. Through forecasts, they may be advised of the development of potentially hazardous weather by radio transmission during flight. Each of the many types of forecasts is designed to serve a specific function.

Teletype forecasts are given in two formats: Terminal Aerodrome Forecasts (TAF) and Plain Language Terminal Forecasts (PLATF).

The TAF code, in the same format as the METAR observation code, is used for the scheduling of flights. They are valid for 24 hours and forecast the following weather data: wind direction, speed, and maximum wind expected; prevailing visibility in meters; weather phenomena, including forms of precipitation and restrictions to visibility; eighths of sky coverage of each cloud layer expected over the station, with base-height of the layer and type of cloud; height and thickness of icing and turbulent layers; minimum altimeter setting expected; and pertinent clear language remarks.

The PLATF code, in a format found in the aviation weather report, is used in the recovery of aircraft and is valid for a period of 4 hours. The PLATF forecasts the following weather data: height of cloud bases; sky coverage; visibility; weather and obstruction to vision; wind direction and speed with gusts indicated by G; minimum altimeter setting; and any appropriate remarks.

FORECASTS

Terminal Aerodrome Forecast

The following codes are used in the Terminal Aerodrome Forecast (TAF). Refer to figure 22-11.

LOCATION IDENTIFIER	TIME OF REPORT	CHARACTER OF ECHOES	WEATHER AND INTENSITY	INTENSITY TENDENCY	LOCATION AND DIMENSIONS OF ECHOES	MOVEMENT	ECHO TOPS	REMARKS
EVV	1640Z	AREA 6	TRW+A	/+	4/125 221/115 100W	2715 CELLS 2325	MT 550 at 310/45	3/4 INCH HAIL 310/45

DECODED REPORT

Evansville Indiana hourly Radar Report (RAREP) taken at 1640Z. An area 6 tenths covered with echoes, containing thunderstorms producing heavy rainshowers and occasional hail at the surface. These echoes are increasing in intensity. Area extends from 4° 125 nautical miles to 221° 115 nautical miles, is 100 nautical miles wide. The area is moving from 270° at 15 knots, the cells within the area from 230° at 25 knots. Maximum top of the detectable moisture is 55,000 feet MSL at 310° 45 nautical miles. Hail ¾ inch in diameter was reported with this echo.

The above report is for the echo area in the radarscope picture. The slash mark (/) is used to separate the intensity of the echo from the intensity tendency.

TIME OF REPORT

Time of observation (24-hour clock) in Greenwich Mean Time. Observations are normally taken at 40 minutes past each hour. When a special observation is taken, the contraction SPL is placed between the Time of Report and Character of Echoes.

CHARACTER OF ECHOES

CHARACTER	DEFINITION	CONTRACTION
Isolated echo	Independent convective echo	CELL
Area	A grouping of related or similar echoes	AREA
Line	Related or similar echoes forming a line at least 30 miles long with a length-to-width ratio of at least 5 to 1	LN
Stratified elevated echo	Precipitation aloft	LYR
Spiral band area	Curved lines of echoes, including wall cloud, which occur in connection with hurricanes, tropical storms, and typhoons	SPRL BAND AREA
Fine line	Narrow, nonprecipitation echo associated with a meteorological discontinuity	FINE LN

NOTE: Echo coverage in tenths within an area, line or elevated echo is given by the number which immediately follows the word or contraction describing the character of the echoes. For example, AREA6 means that echoes cover 6 tenths of the outlined area.

PRECIPITATION SYMBOLS

IP ICE PELLETS	SW SNOW SHOWERS	ZR FREEZING RAIN
L DRIZZLE	T THUNDERSTORMS	ZL FREEZING DRIZZLE
RW RAIN SHOWERS	S SNOW	
R RAIN	A HAIL	

INTENSITY

LIGHT	–	VERY HEAVY	++	UNKNOWN	U
MODERATE	NO SIGN	INTENSE	X		
HEAVY	+	EXTREME	XX		

INTENSITY TREND

TREND	CONTRACTION
Increasing	+
Unchanging	NC
Decreasing	–
New	NEW

The intensity trend is evaluated in terms of a net change in the characteristic intensity equal to approximately one intensity category (light to moderate) during a specified time period, which is one hour for lines and areas and fifteen minutes for cells.

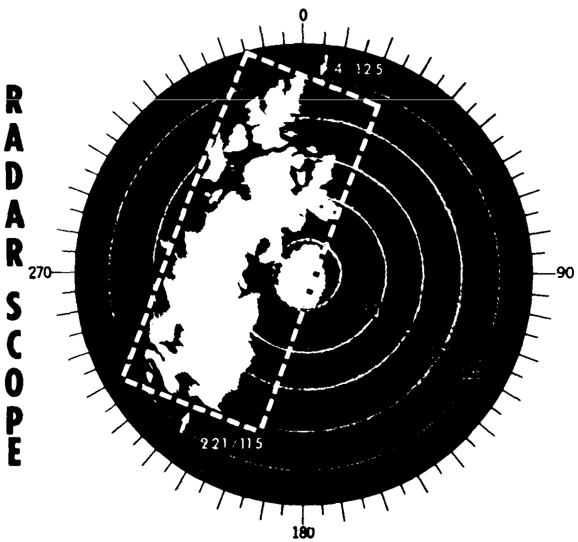
DIMENSIONS OF ECHOES

Width (W) or diameter (D) are reported in nautical miles. The average width of lines and rectangular areas, and the average diameter of cells and roughly circular areas, are reported.

MOVEMENT

Direction, to nearest ten degrees from which, and speed in knots with which, the echo is moving. Both cell and system movement are reported when available. Line movement is reported in terms of the component perpendicular to the axis.

RADAR SCOPE



ECHO PATTERN

LOCATION OF ECHOES

1. Locations of echoes are relative to the radar position. The azimuth in degrees true, and the distance in nautical miles, to salient points of the echoes are given.
2. If the echoes are arranged in a line, the azimuth and distance will be given to as many points along the axis of the line as are necessary to establish its shape.
3. If an irregularly shaped area is covered by echoes, the azimuth and range to salient points on the perimeter of the area will be reported as necessary to reconstruct the shape and size of the echo area.
4. If an area of echoes of roughly circular shape is observed, or if a single echo such as a thunderstorm cell is observed, the azimuth and range to the center of the area or cell will be reported.

ECHO TOPS

Maximum height of detectable moisture, in hundreds of feet above mean sea level. Tops are not reported beyond 125 nautical mile range.

UNUSUAL ECHO FORMATIONS

Certain types of severe storms produce distinctive patterns on the radar scope. For example, the hook-shaped echo associated with tornadoes and the spiral bands with hurricanes. The bright band is a narrow horizontal layer of intensified radar signal a short distance below the 0°C isotherm (Melting level). Unusual echo formations will be reported in remarks.

OPERATIONAL STATUS

STATUS	CONTRACTION
(1) Equipment performance normal on PPI scan; echoes not observed	PPINE
(2) Equipment out of service for preventive maintenance resulting in loss of PPI presentation. (The contraction is followed by a date-time group to indicate the estimated time when operation will be resumed.)	PPIOM
(3) Observation omitted for a reason other than those above, or not available.	PPINA
(4) Radar not operating on RHI mode; echo altitude measurements not available.	RHINO
(5) A-scope or A/R indicator not operating	ARNO
(6) Radar operating below performance standards	ROBEPS

A contraction pertaining to the operational status of the equipment is sent as required by the table above. In the above list, "PPI" refers to the radarscope (Plan Position Indicator); the additional letters refer to "no echo" (NE).

GENERAL NOTES

SD (Storm Detection)—Radar Report (RAREP) Identifier. Identifies the message as a RAREP.

When the report contains an important change in echo patterns, or some other special criteria given in the **Weather Radar Manual**, Part A has been met, it is designated as a special (SPL).

Intensity of precipitation at distances exceeding 125 nautical miles from a WSR-57 or other radar of similar sensitivity, or 75 miles from other radars, will be reported as unknown (U). Intensities of snow, hail, drizzle, and ice pellets are not reported.

One rainfall intensity category is selected to characterize each reported echo system. For convective systems, it is the maximum intensity in the system. For other systems, it is the intensity predominant in horizontal extent.

Persisting echoes are indicated in remarks.

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
SILVER SPRING, MD. 20910

Figure 22-10. Radar Reports.

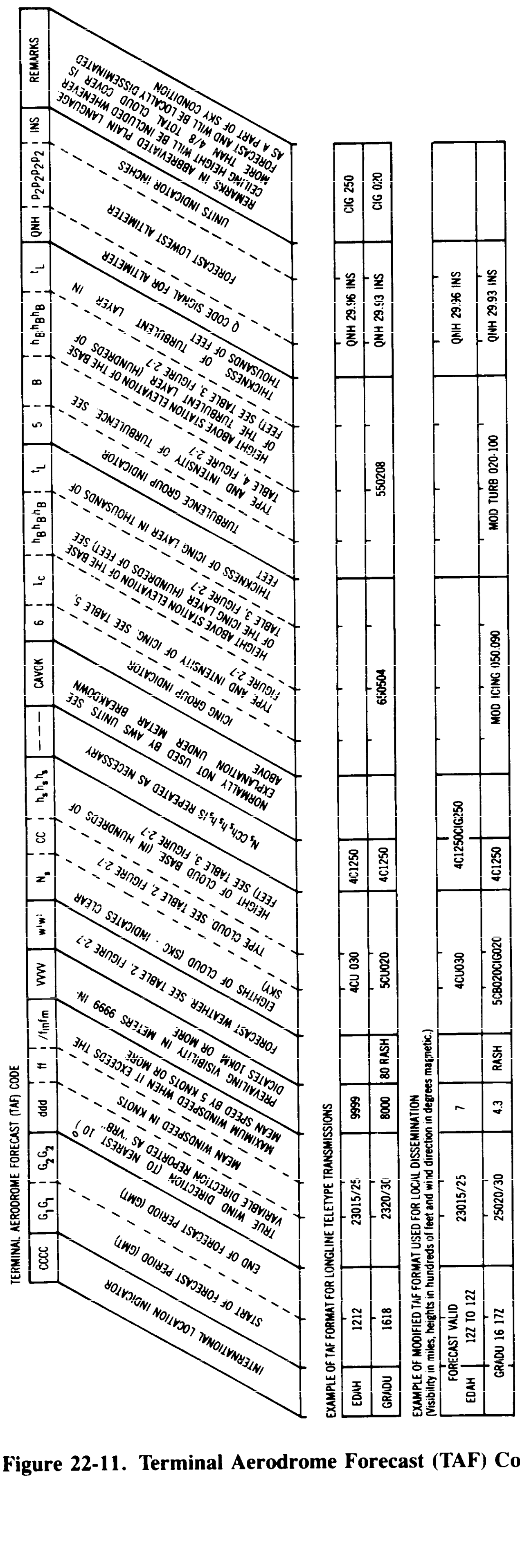


Figure 22-11. Terminal Aerodrome Forecast (TAF) Code.

TAF	Indicates an aerodrome forecast.
CCCC	International four-letter location indicator, such as KRND for Randolph AFB.
$G_1G_1G_2G_2$	Valid period of the forecast in UTC, G_1G_1 the beginning, G_2G_2 the ending of forecast period, such as 1212 period from 1200Z to 1200Z.
ddd ff/f_mf_m	Forecast surface wind ddd—True surface wind direction to the nearest 10 degrees. ff—Mean wind speed in knots. /f_mf_m—Maximum wind speed (peak gust speed) in knots, such as, 32015/25—wind direction 320° True, mean speed 15 knots, maximum wind speed 25 knots.
VVVV	Forecast prevailing visibility in meters. 9999 indicates visibility is 10 km (7 statute miles) or more (figure 22-12).
W^1W^1	Forecast weather decoded in both numbers and alphabetical codes (figure 22-13). 61RA would be decoded as light rain.
$N_sCCh_sh_sh_s$	Cloud layer forecast group in order of ascending cloud layer bases. When no clouds are forecast, SKC for clear sky will be entered. N_s—Total amount of cloud in eighths forecast for that level when more than 4/8 is forecast and a ceiling is expected. The ceiling will be identified in the remarks section as CIG with the height expected. No ceiling would be "CIG NO." When N_s = 9, the sky is forecast obscured, such as, 9// hshshs where hshshs is the vertical visibility. CC—Type of cloud forecast at that level. A two-level abbreviation code is used, such as, CU—cumulus (figure 22-14). hshshs—Height above station elevation of the base of the cloud layer. Example—8 ST 005 would be encoded 8/8 of stratus at 500 feet above the station (figure 22-15).
CAVOK	This code word, normally not used by AWS, is used by the National Weather Service for civilian forecasts and is used in place of VVVV, W W, and NsCC hshshs when the following are forecast at the same time: (a) Visibility 10 km or more (b) No cloud below 5,000 feet and no CB (c) No precipitation, thunderstorms, shallow fog, or low drifting snow
QNH $P_2P_2P_2P_2$INS	Forecast lowest altimeter setting inches such as QNH 2292INS.
GRADU	Used if the change is expected to take place at an approximately constant rate throughout the period of the Gradu (gradual) times.

STATUTE MILES	NAUTICAL MILES	METERS
	1/16 Mile Increment	
0	0.0	0000
1/16	0.05	0100
⅛	0.1	0200
3/16	0.15	0300
¼	0.2	0400
5/16	0.25	0500
⅜	0.3	0600
	⅛ Mile Increments	
—	0.4	0700
½	0.45	0800
—	0.5	0900
⅝	0.55	1000
—	0.6	1100
¾	—	1200
—	0.7	1300
⅞	—	1400
—	0.8	1500
1	—	1600
—	0.9	1700
1⅛	1.0	1800
1¼	1.1	2000
1⅜	1.2	2200
1½	1.3	2400
1⅝	1.4	2600
1¾	1.5	2800
1⅞	1.6	3000
2	1.7	3200
	¼ Mile Increments	
—	1.8	3400
2¼	1.9	3600
—	2.0	3700
2½	2.2	4000
	½ Mile Increments	
—	2.4	4500
—	2.5	4700
3	2.6	4800
—	2.7	5000
	1 Mile Increments	
4	3.0	6000
—	4.0	7000
5	4.3	8000
6	5.0	9000
7	6.0	9999
8	7.0	9999
9	8.0	9999
10	9.0	9999
11	10.0	9999
12	10.0	9999
13	11.0	9999
14	12.0	9999
15	13.0	9999
	5 Mile Increments	
20	15.0	9999
25	20.0	9999
30	25.0	9999
35	30.0	9999
40	35.0	9999
45	40.0	9999
50	45.0	9999
55	50.0	9999
60	50.0	9999
65	55.0	9999
70	60.0	9999
75	65.0	9999
80	70.0	9999
85	75.0	9999
90	80.0	9999
95	80.0	9999
100	85.0	9999

Figure 22-12. Reportable Visibility Values.

RAPID — Indicates fast-changing weather from one condition to another.

INTER — Intermittent conditions will not cover more than 30 minutes of any hour, or more than one-half of the period for which the conditions are forecast.

TURBULENCE — (Discussed in figure 22-16).

ICING — (Discussed in figure 22-17).

The following is an example of a scheduling (TAF) forecast:

TAF KRND 1212 18005 3000 44FG 3CU025 QNH 2996INS RAPID 18 35010 9999 WX NIL 5CU025 QNH 2998INS CIG025

It would be decoded as follows:

KRND—Forecast for Randolph AFB
1212—TAF valid 1200Z to 1200Z
18005—Surface winds, 180° at 5 knots
3000—Visibility, 3,000 meters
44FG—Fog, sky visible
3CU025—3/8 cumulus clouds, bases 2,500 feet
QNH 2996INS—Minimum altimeter setting of 29.96 inches
RAPID 18—Rapid change beginning at 1800Z
35010—Surface winds, 350° at 10 knots
9999—Visibility 10 km or more
WX NIL—No significant weather
5CU025—5/8 cumulus clouds, bases 2,500 feet
QNH 2998INS—Minimum altimeter setting is 29.98 inches
CIG025—Ceiling 2500 feet

Another example:

KBLV 1212 00000 5000 11MIFG 3CU025 QNH 2996INS
RAPID 16 25010 9999 WX NIL 4CU025 QNH 2998INS
GRADU 1719 27020/30 5000 80RASH 2CB025 4CU025 5AC120 550208
QNH 2992INS CIG025
GRADU 2223 25010 9999 WX NIL 3AC120 QNH 2995INS

DECODED:

KBLV—Forecast is for Scott AFB.
1212—TAF valid 1200Z to 1200Z.
00000—Winds calm.
5000—Visibility, 5,000 meters.
11MIFG—Weather, patchy ground fog.
3CU025—3/8 cumulus clouds, bases 2,500 feet.
QNH 2996INS—Minimum altimeter setting is 29.96 inches.
RAPID 16—Rapid change beginning 1600Z.
25010—Surface winds, 250° at 10 knots.
9999—Visibility, 10 km or more.
WX NIL—No significant weather.
4CU025—4/8 cumulus clouds, bases 2,500 feet.
QNH 2998INS—Minimum altimeter setting is 29.98 inches.
GRADU 1719—Gradually from 1700 to 1900Z. 27020/30—Surface winds 270° at 20 knots with gusts to 30 knots.
5000—Visibility, 5,000 meters.
80RASH—Weather, slight rain showers.
2CB025—2/8 cumulonimbus clouds, bases 2,500 feet
4CU025—4/8 cumulus clouds, bases 2,500 feet
5AC120—5/8 altocumulus clouds, bases 12,000 feet.
550208—Moderate turbulence in cloud from 2,000 feet through 10,000 feet.

In selecting codes, see explanatory notes on the following page.				SMOKE (FU) 04FU	HAZE (HZ) 05HZ	DUST (HZ) 06HZ	BLOWING DUST OR BLOWING SAND (BLSA) 07SA	DUST DEVILS (PO) 08PO	
MIST (FG) 10BR	SHALLOW FOG (OR ICE FOG) at the station and not deeper than six feet PATCHES (MIFG) 11MIFG	CONTINUOUS (MIFG) 12MIFG					THUNDERSTORM BUT NO PRECIPITATION (TS) or (TS+) 17TS	SQUALL (SQ) 18SQ	FUNNEL CLOUD, TORNADO, OR WATERSPOUT (TORNADO), ETC. 19FC
RECENT PRECIPITATION (at the station during the preceding hour but not at the time of observation)									
CONTINUOUS OR INTERMITTENT					SHOWERY				
DRIZZLE (or Snow Grains) 20REDZ	RAIN 21RERA	SNOW 22RESN	RAIN AND SNOW MIXED OR ICE PELLETS (type a) 23RERASN	FREEZING RAIN OR FREEZING DRIZZLE 24REFZRA	RAIN SHOWERS 25RESH	SHOWERS OF SNOW OR OF RAIN AND SNOW 26RESNSH	SHOWERS OF HAIL, SNOW PELLETS, or ICE PELLETS (type b) W or WO RECENT RAIN SHOWERS 27REGR		RECENT THUNDERSTORM W or WO RECENT PRECIPITATION 29RETS
DUSTSTORM OR SANDSTORM						DRIFTING SNOW		BLOWING SNOW	
LIGHT TO MODERATE during the past hour has:			HEAVY during the past hour has:						
DECREASED (SA) 30SA	SHOWN NO CHANGE (SA) 31SA	BEGUN OR INCREASED (SA) 32SA	DECREASED (SA+) 33XXSA	SHOWN NO CHANGE (SA+) 34XXSA	BEGUN OR INCREASED (SA+) 35XXSA	LIGHT TO MODERATE (DRSN) 36DRSN	HEAVY (DRSN+) 37DRSN	LIGHT OR MODERATE (BLSN-) or (BLSN) 38BLSN	HEAVY (BLSN+) 39BLSN
FOG OR ICE FOG								FREEZING FOG	
		during preceding hour has: BECOME THINNER		SHOWN NO CHANGE		BEGUN OR BECOME THICKER			
PATCHES not at the station and deeper than six feet (BCFG) 40BCFG	PATCHES at the station and deeper than six feet (BCFG) 41BCFG	SKY VISIBLE (FG) 42FG	SKY OBSCURED (FG) 43FG	SKY VISIBLE (FG) 44FG	SKY OBSCURED (FG) 45FG	SKY VISIBLE (FG) 46FG	SKY OBSCURED (FG) 47FG	SKY VISIBLE (FZFG) 48FZFG	SKY OBSCURED (FZFG) 49FZFG
DRIZZLE (NOT FREEZING)						FREEZING DRIZZLE		DRIZZLE AND RAIN MIXED	
LIGHT		MODERATE		HEAVY					
INTERMITTENT (DZ-) 50DZ	CONTINUOUS (DZ-) 51DZ	INTERMITTENT (DZ) 52DZ	CONTINUOUS (DZ) 53DZ	INTERMITTENT (DZ+) 54XXDZ	CONTINUOUS (DZ+) 55XXDZ	LIGHT (FZDZ-) 56FZDZ	MODERATE OR HEAVY (FZDZ) or (FZDZ+) 57XXFZDZ	LIGHT (RA-DZ-) 58RA	MODERATE OR HEAVY (RADZ-), (DZ+ RA), etc 59RA
RAIN (NOT FREEZING)						FREEZING RAIN		RAIN (OR DRIZZLE) AND SNOW MIXED	
LIGHT		MODERATE		HEAVY					
INTERMITTENT (RA-) 60RA	CONTINUOUS (RA-) 61RA	INTERMITTENT (RA) 62RA	CONTINUOUS (RA) 63RA	INTERMITTENT (RA+) 64XXRA	CONTINUOUS (RA+) 65XXRA	LIGHT (FZRA-) 66FZRA	MODERATE OR HEAVY (FZRA) or (FZRA+) 67XXFZRA	LIGHT (DZ-SN-), (RA-SN-) 68RASN	MODERATE OR HEAVY (RA-SN), (RA+SN), etc 69XXRASN
SNOW									
LIGHT		MODERATE		HEAVY					
INTERMITTENT (SN-) 70SN	CONTINUOUS (SN-) 71SN	INTERMITTENT (SN) 72SN	CONTINUOUS (SN) 73SN	INTERMITTENT (SN+) 74XXSN	CONTINUOUS (SN+) 75XXSN	ICE CRYSTALS (IC) 76IC	SNOW GRAINS (SG-), (SG), (SG+) 77SG		ICE PELLETS (type a; formerly sleet) (PE-), (PE), (PE+) 79PE
RAIN SHOWERS			RAIN AND SNOW SHOWERS MIXED		SNOW SHOWERS		SNOW PELLET OR ICE PELLET (type b, formerly small hail) SHOWERS with or without rain, or rain and snow mixed		HAIL (not associated with thunderstorm)
LIGHT (RASH-) 80RASH	MODERATE (RASH) 81XXSH	HEAVY (RASH+) 82XXSH	LIGHT (RASH-SNSH-) 83RASN	MODERATE OR HEAVY (RASH-SNSH), etc 84XXRASN	LIGHT (SNSH-) 85SNSH	MODERATE OR HEAVY (SNSH) or (SNSH+) 86XXSNSH	LIGHT (SNSH-PESH-) 87GR	MODERATE OR HEAVY (RASH-PESH), etc 88GR	WITH OTHER LIGHT PRECIP (GRSNSH-), etc 89GR
HAIL (not associated with thunderstorm)	THUNDERSTORM DURING PRECEDING HOUR but not at time of observation, with				THUNDERSTORM AT TIME OF OBSERVATION				
	RAIN AT TIME OF OBSERVATION				MODERATE		SEVERE	MODERATE OR SEVERE	SEVERE
ALONE OR WITH OTHER MODERATE OR HEAVY PRECIP (GR), (RASH+GR)etc. 90XXGR	LIGHT (RASH-), (RA-) 91RA	MODERATE OR HEAVY (RASH, (RA+), etc 92XXRA	HAIL WITH OTHER LIGHT PRECIP; OR LIGHT SNOW PELLET or ICE PELLET SHOWERS, SNOW OR RAIN AND SNOW MIXED (RASH-GR), (SNSH-), etc. 93GR	HAIL ALONE OR WITH OTHER MOD TO HVY PRECIP; OR MOD TO HVY SNOW PELLET OR ICE PELLET SHOWERS, SNOW, OR RAIN AND SNOW MIXED (GR), (SNSH), etc 94XXGR	WITH RAIN AND/OR SNOW (TSRASH-), etc 95TS	WITH HAIL, SNOW PELLET, OR ICE PELLET (type b) SHOWERS (TSGR), (TSPESH-), etc 96TSGR	WITH RAIN AND/OR SNOW (TS+SNSH), (TS+RASH+), etc 97XXTS	WITH DUSTORM OR SANDSTORM (TSSA), (TS+SA-), etc 98TSSA	WITH HAIL, SNOW PELLET, OR ICE PELLET (type b) SHOWERS (TS+GR), (TS+PESH), etc 99XXTSGR

Figure 22-13. Present Weather (W'W').

QNH2992INS—Minimum altimeter setting is 29.92 inches.
CIG025—Ceiling is 2,500 feet.
GRADU 2223—Gradually from 2200Z to 2300Z.
25010—Surface winds, 250° at 10 knots.

9999—Visibility 10 km or more.
WX NIL—No significant weather.
3AC120—3/8 altocumulus clouds, bases 12,000 feet.
QNH 2995INS—Minimum altimeter setting is 29.95 inches.

Code	Decode
CI	Cirrus
CC	Cirrocumulus
CS	Cirrostratus
AC	Altocumulus
AS	Altostratus
NS	Nimbostratus
SC	Stratocumulus
ST	Stratus
CU	Cumulus
CB	Cumulonimbus

Figure 22-14. Cloud Types.

PLATF Recovery Forecast

The second format for a teletype forecast is the Plain Language Forecast (PLATF). An explanation of the PLATF codes follows:

CCC	International location identifier.
$G^1G^1G^2G^2$	Beginning (G^1G^1), ending (G^2G^2) of forecast (GMT).
hh or hhh	Height of cloud bases in hundreds of feet above the ground. Same as aviation weather reports.
N	Sky cover. Same as aviation weather reports.
VV	Visibility—nearest reportable value in meters or fractions of miles. Variable visibility shown in remarks.
W_iW_i	Weather and obstruction to vision. Same as aviation weather reports.

Code Figure	Meters	Feet	Code Figure	Meters	Feet	Code Figure	Meters	Feet
000	30	100	031	930	3100	110	3300	11000
001	30	100	032	960	3200	120	3600	12000
002	60	200	033	990	3300	130	3900	13000
003	90	300	034	1020	3400	140	4200	14000
004	120	400	035	1050	3500	150	4500	15000
005	150	500	036	1080	3600	160	4800	16000
006	180	600	037	1110	3700	170	5100	17000
007	210	700	038	1140	3800	180	5400	18000
008	240	800	039	1170	3900	190	5700	19000
009	270	900	040	1200	4000	200	6000	20000
010	300	1000	041	1230	4100	210	6300	21000
011	330	1100	042	1260	4200	220	6600	22000
012	360	1200	043	1290	4300	230	6900	23000
013	390	1300	044	1320	4400	240	7200	24000
014	420	1400	045	1350	4500	250	7500	25000
015	450	1500	046	1380	4600	260	7800	26000
016	480	1600	047	1410	4700	270	8100	27000
017	510	1700	048	1440	4800	280	8400	28000
018	540	1800	049	1470	4900	290	8700	29000
019	570	1900	050	1500	5000	300	9000	30000
020	600	2000	055	1650	5500	310	9300	31000
021	630	2100	060	1800	6000	320	9600	32000
022	660	2200	065	1950	6500	330	9900	33000
023	690	2300	070	2100	7000	340	10200	34000
024	720	2400	075	2250	7500	350	10500	35000
025	750	2500	080	2400	8000	(etc.)	(etc.)	(etc.)
026	780	2600	085	2550	8500	990	29700	99000
027	810	2700	090	2700	9000	999	30000	100000
028	840	2800	095	2850	9500		or more	or more
029	870	2900	100	3000	10000			
030	900	3000						

Figure 22-15. Height Above Station Elevation of Base of Cloud Layer.

CODE	DECODE
0	None
1	Light turbulence
2	Moderate turbulence in clear air, infrequent
3	Moderate turbulence in clear air, frequent
4	Moderate turbulence in cloud, infrequent
5	Moderate turbulence in cloud, frequent
6	Severe turbulence in clear air, infrequent
7	Severe turbulence in clear air, frequent
8	Severe turbulence in cloud, infrequent
9	Severe turbulence in cloud, frequent

NOTE: AWS units will encode extreme turbulence by use of code figure 6, 7, 8, or 9 and adding "EXTRM TURB $h_Bh_Bh_B$ — $h_Bh_Bh_B$" in REMARKS.

Figure 22-16. Turbulence (B).

CODE	DECODE
*0	None or trace
1	Light icing
2	Light icing in cloud
3	Light icing in precipitation
4	Moderate icing
5	Moderate icing in cloud
6	Moderate icing in precipitation
7	Severe icing
8	Severe icing in cloud
9	Severe icing in precipitation

*WMO code figure 0 is no icing. AWS units will use 0 to indicate a trace of icing.

Figure 22-17. Icing (I_C).

ddff	Surface wind direction (dd) and speed (ff). True direction—nearest 10 degrees, speed in knots. Variable direction encoded as 99ff.
QNH P P P P	Minimum altimeter setting through the period.
Remarks	Conditions not adequately described such as MOD ICING 70-90.
ttZ	Change groups. tt is time of changes. Changes to the initial condition only for elements expected to change; the remaining elements are inferred as forecast not to change.

The following is an example of a recovery PLATF forecast: KBLV 0105 15SCT 20BKN 4TRW 3510G18 QNH 2991 INTER 0102 1TRW 3320G30 02Z 10BKN 15 OVC 2TRW INTER 0204 1OVC 1/8T + RW 3330G60 04Z 25 BKN 5RW QNH 2985

As the time changes, the missing information is inferred to indicate that the information is the same as the previous forecast, and is decoded in the following manner:

Time	Element	Inferred	Stated
0100Z	CLDS		1,500′ SCT 2,000′ BKN
	VSBY		4
	WX		TRW
	WIND		350°/10 knots gusting to 18 knots
	ALTSTG		29.91 INS (inches)
01-02Z	CLDS	1,500′ 2,000′ BKN	
INTER	VSBY		1
	WX		TRW
	WIND		330°/20 knots gusting to 30 knots
	ALTSTG	29.91 INS. (inches)	
0200Z	CLDS		1,000′ BKN 1,500′ OVC
	VSBY		2
	WX		TRW
	WIND	350°/10 gusting to 18 knots	
	ALTSTG	29.91 INS (inches)	
02-04Z	CLDS		100′ OVC
	VSBY		1/8
	WX		T + RW
	WIND		300°/30 knots gusting to 60 knots
	ALTSTG		29.91 INS (inches)
0300Z	Same as 0200Z with all elements inferred.		
0400Z	CLDS	2,500′ BKN	
	VSBY		5
	WX		RW
	WIND		350°/10 knots gusting to 18 knots
	ALSTG		29.85INS
0500Z	Same as 0400Z with all elements inferred.		

NOTE: 1. INTER valid 01 to 02Z and 02 to 04Z; "Mean" wind 350°/10 knots gusting to 18 knots for entire period.

WEATHER FOR FLIGHT PLANNING

Gathering Weather Data

Weather is an extremely important factor in planning any flight mission. These are the steps to follow in gathering weather data:

Step 1. Know exactly what weather information is needed. This normally consists of, but is not necessarily limited to, the weather and winds to expect en route, the weather at destination and alternate destinations, and the local weather for the time of takeoff and climb-out.

Step 2. Inform the weather forecaster of aircraft type, estimated time of departure (ETD), proposed route and flight altitude, estimated time en route (ETE), and any additional information that will help the weather forecaster visualize the flight. The more information given, the better the forecaster will be able to provide data pertinent to the flight.

Step 3. When the weather briefing is completed, insure that the following information is complete:

Weather for Takeoff and Climb

Surface temperature and pressure altitude (or density altitude)
Surface winds
Bases and tops of cloud layers
Visibility
Precipitation
Freezing level
Climb winds

Forecast Weather En Route

Bases, tops, type, and amount of each cloud layer
Visibility at flight altitude
Type, location, intensity, and direction and speed of frontal movement
Freezing levels
Temperatures and winds at flight altitude
Areas of hazardous weather (thunderstorms, hail, icing, and turbulence)
Areas of good weather (for use in event of an emergency landing en route).

Forecast Weather for Destination and Alternates

Bases, tops, type, and amount of cloud layers

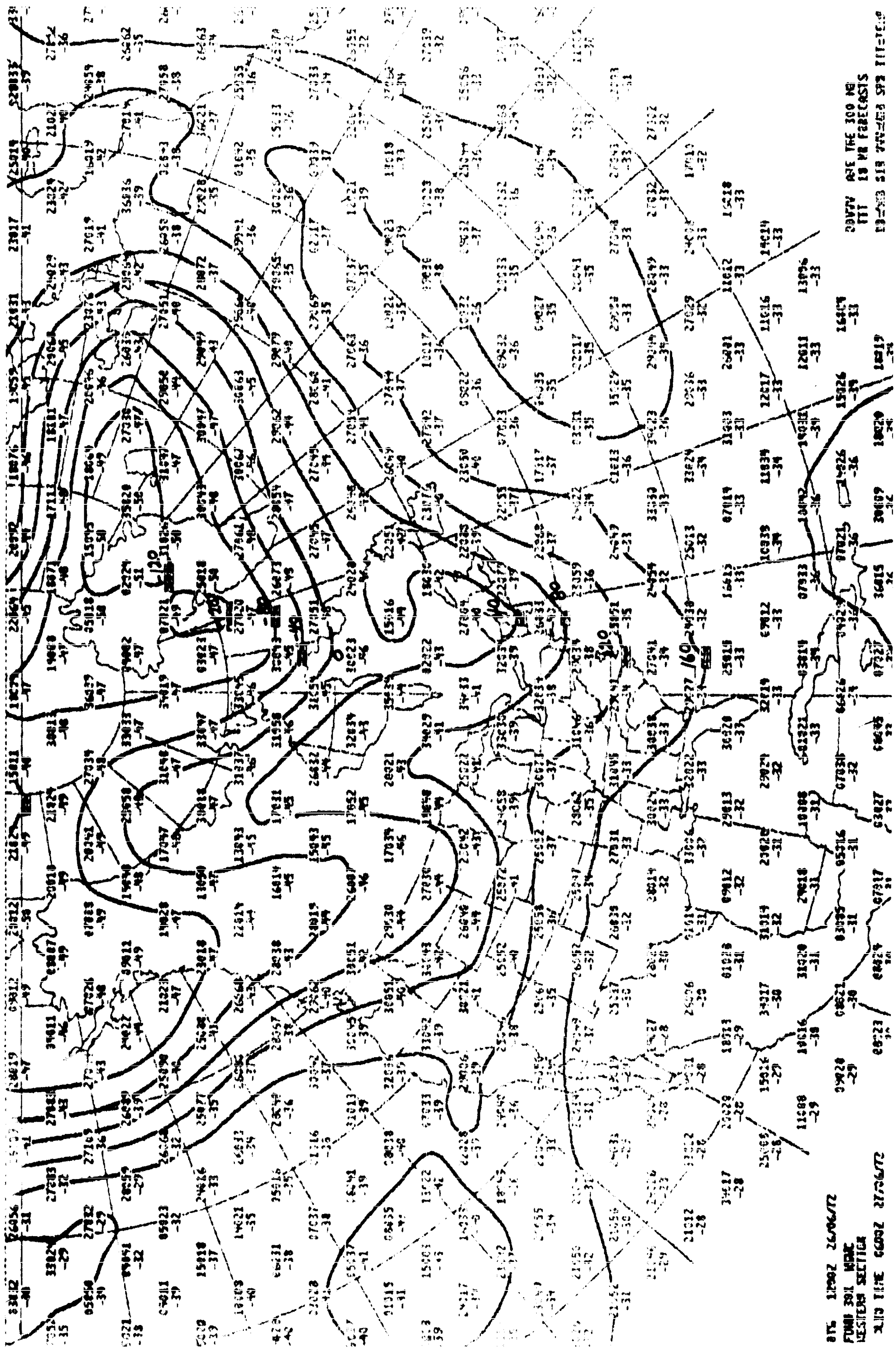


Figure 22-18. "D" Value Flow Chart.

OATUFGBC RHWWAAA3101 0050729-UUUU--RUWMDTA:
ZNR UUUU
O 050729Z JAN 79
FM AFGWO OFFUTT AFB NE
TO RUWMDTA/BASE WEA STA MATHER AFB CA
BT
UNCLAS AFGWC
* * * THIS CFP IS LABELED KMHR8125AHNL * * *
* * * ROUTE FORECAST MATHER TO HONOLULU * * *
* * * ROUTE OF FLIGHT (R-63) * * *
AFGWC TIME PHASED ROUTE FORECAST KOHR8125AHNL CFPI-0050729:2
DEPARTURE POINT KMHR
LAT 3858N LONG 12146W DEPT ALT 35000FT ETD 79 JAN 05 1500Z
ACCUMULATED TIMES ADJUSTED FOR 1 PCT ROUTE DEVIATIONS

LOCID	LAT	LONG	ALT	DDVVV	TTT	TAS	GS	DIS	TIM	TCS	MV	MHD	ETA
	3904N	12202W	350	24039	-54	426	406	014	002	296	-17	274	1502
	3742N	12301W	350	23039	-54	426	390	094	015	210	-17	195	1517
	3750N	12550W	350	24038	-54	426	395	134	021	274	-17	254	1538
	3635N	13004W	350	26040	-54	426	386	216	034	251	-17	234	1612
	3436N	13542W	350	27073	-53	427	359	299	050	248	-17	236	1702
	3223N	14104W	350	26088	-51	429	344	300	053	245	-16	233	1755
ETP	3013N	14537W	350	27110	-49	431	331	267	049	242	-15	236	1844
	2956N	14609W	350	27110	-49	431	333	032	006	239	-14	234	1850
	2718N	15059W	350	27134	-47	433	316	300	057	239	-14	239	1947
	2542N	15341W	350	26117	-46	434	327	174	032	237	-13	233	2019
	2403N	15619W	350	26094	-45	435	347	174	030	236	-13	229	2049
	2246N	15642W	350	26074	-45	435	394	080	012	195	-12	193	2101
	2150N	15658W	350	25062	-45	435	399	058	009	195	-12	190	2110
	2116N	15742W	350	25055	-45	435	384	053	008	230	-12	221	2118
	2103N	15801W	350	25051	-45	435	386	022	003	234	-12	224	2121
PHNL	2120N	15755W	350	25051	-45	435	462	018	002	018	-12	001	2123

ETP SUMMARY FWF -79, WF1 -69, WF2 -94, TIME 0344, DIST 1324
OVERALL TO PHNL AWF -78 T IS 2235 ATIM 0623 ETA 2123Z
AFGWC TIME PHASED ALTERNATE ROUTE FORECAST
DEPARTURE POINT PHNL
LAT 2120N LONG 15755W DEPT ALT 35000FT ETD 79 JAN 05 2123Z

LOCID	LAT	LONG	ALT	DDVVV	TTT	TAS	GS	DIS	TIM	TCS	MV	MHD	ETA
PHTO	1943N	15503W	001	23019	-10	467	474	188	023	121	-12	111	2146

OVERALL TO PHTO AWF -73 TDIS 2423 ATIM 0646 ETA 2146Z
AFGWC TIME PHASED ALTERNATE ROUTE FORECAST
DEPARTURE POINT PHNL
LAT 2120N LONG 15755W DEPT ALT 35000FT ETD 79 JAN 05 2123Z

Figure 22-19. Computer Flight Plan.

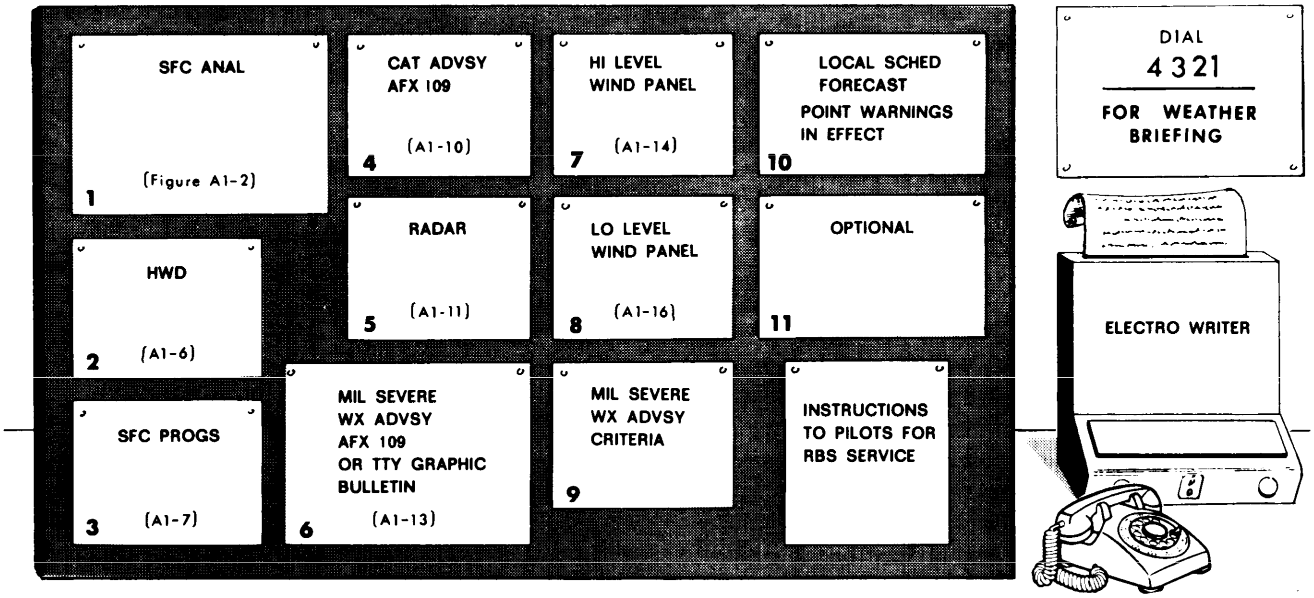


Figure 22-20. Standardized Pilot Briefing Display.

Visibility
Weather and obstructions to vision
Freezing level
Surface wind speed and direction
Forecast altimeter setting

Insure that all essential weather elements are included in the briefing and request clarification or additional information concerning any weather data about which there are doubts.

NOTE: If the time of departure is delayed longer than 1 1/2 hours after the time of the briefing, the weather must be revalidated.

In addition to forecaster briefings at the weather stations, some bases use closed-circuit television to brief aircrews. This gives the aircrews a visual weather briefing without going to the weather station. In addition, a small self-briefing weather display is often available to allow the crew to flight plan before getting the final weather briefing.

Applying Weather Data

Getting all the facts and applying them correctly is essential in flight planning. Departure weather can be the deciding factor when an emergency arises soon after takeoff. In some cases, the weather may deteriorate rapidly shortly after takeoff. The navigator must know the winds up to flight altitude in order to compute the distance flown and the fuel consumed during the climb to altitude.

A knowledge of the clouds at flight altitude gives the aircrew an idea of the areas of possible precipitation, icing, turbulence, and other hazards to flight. If the navigator has this knowledge, it increases his or her ability to make the proper operational decision in the event of an en route emergency.

"D" Value Flow Charts

A very useful weather chart for the navigator is the high altitude "D" value flow chart shown in figure 22-18. This chart, used primarily by the Strategic Air Command, contains the following information:

Contours (labeled in 200 or 400 feet "D" value intervals or true altitude of the pressure levels indicated)
Wind direction and speed
Temperatures (in degrees Celsius)
Centers of high and low true altitude

The data listed on these charts are invaluable for flight planning and in-flight computations. Remember, this is a prognostic chart; it can be made more useful by updating it with current information obtained during flight.

Computer Flight Plans

One of the newer and more sophisticated aids for the navigator is the Computer Flight Plan (CFP). The computer simulates the response of an aircraft to the environmental conditions likely to occur during a given flight. If given track, altitude, true airspeed, and time of departure, the computer may then determine the location of the aircraft and its groundspeed, heading, wind factor, remaining fuel load, and many other factors for any specified point along the route.

The CFP is used extensively by Strategic Air Command and Military Airlift Command on their long-haul flights. The use of this aid has materially reduced flight planning and forecaster preparation times with a substantial improvement in overall accuracy in many cases. During the winter months, however, errors in individual leg winds and associated wind factors may be large but, when averaged over several legs, the predicted wind factor will normally be very close to the actual value.

CFPs are most useful and accurate for the long flight. To obtain a Computer Flight Plan, the navigator should contact the local weather forecaster preferably 11 to 24 hours before takeoff. If the route is a nonstandard route, the forecast will require specific flight information—takeoff time, track (latitude and longitude, and ICAO identifiers if appropriate and desired) altitude, and true airspeed. A wide variety of navigational options and printout formats are available and may be requested. An example of a CFP is illustrated in figure 22-19.

Briefing Display Charts

The pilots or crewmembers, prior to calling for a weather briefing, should become familiar with all of the information available on the charts posted on the standardized pilot briefing display in the weather station. They should read the latest aviation weather reports, radar observations, and pilot reports for the route to acquaint themselves with an up-to-date picture of the correct weather condition. They should also study the terminal forecasts for destination and at least one alternate, if conditions indicate one may be needed.

The standardized pilot briefing display (figure 22-20) consists of the following:

1. Surface analysis (SFC ANAL).
2. Horizontal weather depiction chart (HWD).
3. Surface forecasts (SFC PROGS).
4. CAT, clouds, icing forecasts (CAT ADVSY).
5. Radar summary chart (RADAR).
6. Military weather advisory (MIL SEVERE WX ADVSY).

7-8. Winds aloft charts (HIGH LEVEL/LOW LEVEL WIND PANELS).

9. Military weather advisory criteria.
10. 24-hour local area forecasts and any weather warnings for the local area.
11. Optional chart.

SUMMARY

Aviation weather reports provide vital information to the aircrews when planning a flight. These reports can be used to obtain data pertinent to all phases of flight. Data obtained during weather briefing may be rapidly updated through use of the pilot-to-forecaster service.

It is essential that the navigator thoroughly understand all the factors of weather information that are required to plan a flight adequately. Getting all the facts and correctly interpreting them will insure successful completion of each phase of the flight.

Chapter 23

FORMULAS AND CONVERSIONS

Recent technological advances have made the programmable handheld computer readily available at a reasonable cost. Air Force Systems Command has certified numerous computers as acceptable for use in-flight. Using the formulas given in this chapter, the navigator has increased calculating power for both preflight and in-flight situations. In addition to ease of operation, both speed and accuracy will improve significantly over manual and slide rule computations. Also, the new handheld computers have capabilities never before available without expensive avionics. The following formulas are but a few to aid the navigator in both preflight and in-flight computations.

FLIGHT PLANNING

Given:
TC = True Course
TAS = True Airspeed
W/V = Wind
W = Wind Direction
V = Wind Velocity
DCA = Drift Correction Angle
GS = Groundspeed
TW = Tailwind Component
CW = Crosswind Component
DCA = TC − TH

$$DCA = SIN^{-1}\left[\frac{VSIN(TC - W - 180)}{TAS}\right]$$

$$GS = \frac{SIN\,[180 - TC + (W + 180) - DCA] \times TAS}{SIN\,[TC - (W + 180)]}$$

NOTE: All angles should be in degrees and velocities in knots.

$DCA = SIN^{-1}\,[(V/TAS)SIN\,(W - TC)]$
$TW = V\,COS\,(W - TH)$
$CW = V\,SIN\,(W - TH)$

$TH = TC + ARC\,SIN\,[(V/TAS)\,SIN\,(W - TC)]$
$MH = TH + Var$
$GS = TAS\,COS\,(TH - TC) - V\,COS\,(W - TC)$

IN-FLIGHT W/V DETERMINATION

Given:
TC = True Course
GS = Groundspeed
TAS = True Airspeed
TH = True Heading
★ D = Drift
★ D = TH − TC
DCA = TC − TH

$$V = \sqrt{GS^2 + TAS^2 - 2(GS)(TAS)(COS\,DCA)}$$

$$★ W = TC + SIN^{-1}\left[\frac{(TAS)\,SIN(D)}{V}\right] \quad TAS > GS$$

$$★ W = TC - SIN^{-1}\left[\frac{(TAS)\,SIN(D)}{V}\right] + 180 \quad TAS \leq GS$$

PRESSURE PATTERN

$$ZN = \frac{K(D_2 - D_1)}{ETAS}$$

$$K = \frac{21.49}{SIN\ (LAT)}$$

$$ETAS = \frac{AIR\ DISTANCE}{TIME\ RUN}$$

$$BD\ (Bellamy\ Drift) = \frac{(ZN)\ (57.3)}{GROUND\ DISTANCE}$$

★TAS/MACH

CAS = Calibrated Airspeed
M = Mach
IT = Indicated Air Temperature
CT = Temperature Rise ("+1" for most aircraft)
TAT = True Air Temperature, °Kelvin (Celsuis + 273.15)
REC = Aircraft Recovery Coefficient
Da = Density Altitude

$$M = \sqrt{5\left[\left(\frac{Po}{P}\left\{\left[1+.2\left(\frac{CAS}{661.5}\right)^2\right]^{3.5}-1\right\}+1\right)^{.286}-1\right]}$$

where $$\frac{Po}{P} = \frac{1}{\left[\frac{518.67-(3.566\times10^{-3}\times \text{Pressure Alt})}{518.67}\right]^{5.2563}}$$

$$TAS = 39M\sqrt{TAT\ in\ ^\circ K}$$

$$TAS = 39M\sqrt{(IT+273)\left[CT\left(\frac{1}{(1+(.2)(M)^2}-1\right)+1\right]}$$

$$Da = 145426\left[1-\left(\frac{P}{Po}\Big/\frac{TAT}{To}\right)^{0.235}\right]$$

True Air Temperature (°C)

$$TAT = (IT)\left[(REC)\times\left(\frac{1}{1+0.205\ M^2}-1\right)+1\right]-273.25$$

TURN PERFORMANCE

Definitions:
BANK = Bank angle in degrees
DIAM = Turn diameter in NM
TAS = True airspeed in knots
T = Time in minutes to complete 360° turn
N_s = Normal stall speed in knots
S_t = Stall speed in turn in knots

$$DIAM = \frac{TAS^2}{34208 \; TAN \; (BANK)}$$

$$T = \frac{.0055 \; TAS}{TAN \; (BANK)}$$

G_{force} = 1/COS (Bank)
$S_t = N_s \, G_{force}$

CELESTIAL PRECOMPUTATIONS

LAT = Latitude of Assumed Position/DR
LONG = Longitude of Assumed Position/DR
TC = True Course
GS = Groundspeed
DEC = Declination of the Body from Air Almanac
LHA = Local Hour Angle
LHA = GHA + E/ − W Long + SHA + corrections
Use Air Almanac for GHA/SHA
Hc (Height Computed) = SIN^{-1} [(SIN LAT) (SIN DEC) + (COS LHA) (COS DEC) (COS LAT)]

NOTE: Hc and Z will be displayed in degrees and decimal degrees. You must convert the decimal degrees to minutes. Once the azimuth angle (Z) has been determined by computation, the ambiguity caused by Lat and LHA can be resolved by following:
Zn = Z if SIN (LHA)<0
Zn = 360 − Z if SIN (LHA)≥0

$$Z \text{ (Azimuth Angle)} = COS^{-1}\left[\frac{(SIN\ DEC) - (SIN\ LAT)(SIN\ Hc)}{(COS\ Hc)(COS\ LAT)}\right]$$

Zn = Z(N LAT and LHA>180°)
Zn = 360 − Z(N LAT and LHA<180°)
Zn = 180 − Z(S LAT and LHA>180°)
Zn = 180 + Z(S LAT and LHA <180°)

★ MOTIONS

The formula for combined 1-minute motion can be separated as follows:
Motion of Body = 15 COS LAT SIN Zn
Motion of Observer = (GS/60) COS (TC − Zn)
These quantities, whether combined or used separately, must be added algebraically to the Ho and subtracted from the Hc.

To apply Coriolis/rhumb line correction to Ho, multiply Coriolis/rhumb line by (SIN(ZN-TC)). Note that P and N adjustments are not necessary with these computer applications since Hc is correct for fix time, not HO249 EPOCH year time.

1-Minute Motion = [(15 COS LAT)(COS(270 − Zn)] − [COS (TC-Zn)(GS/60)]
1-Minute Motion = [15 COS(LAT)SIN Zn] − [COS(TC − Zn)(GS/60)]
Coriolis = COS [(90 − TC − Zn)] [.02625 GS SIN LAT]
Rhumb line = [(.146 $(GS/100)^2$ (SIN TC) (TAN LAT)]
Coriolis = (.02625)(GS)(SIN LAT)
For combined Coriolis/rhumb line adjustment to assumed position, use:
Coriolis/rhumb line =
[(.02625)(GS)(SIN LAT)] + [.146$(GS/100)^2$] [(SIN TC) (TAN LAT)]

GREAT CIRCLE PLANNING

Given:
L_1 = Departure Latitude N and W = +
L_2 = Destination Latitude S and E = −
λ_1 = Departure Longitude
λ_2 = Destination Longitude Δt = time between positions
Li = Intermediate Latitude
λi = Intermediate Longitude
Hi = Initial True Heading
D = Distance in Nautical Miles
H = Heading Angle

$$D = 60 \text{ COS}^{-1} [\text{SIN } L_1 \text{ SIN } L_2 + \text{COS } L_1 \text{ COS } L_2 \text{ COS } (\lambda_2 - \lambda_1)]$$

$$H = \text{COS}^{1} \left[\frac{\text{SIN } L_2 - \text{SIN } L_1 \text{ COS } (D/60)}{\text{SIN } (D/60) \text{COS } L_1} \right]$$

$$Hi = H \text{ if SIN } (\lambda_2 - \lambda_1) < 0$$
$$= 360 - H \text{ if SIN } (\lambda_2 - \lambda_1) \geq 0$$

Given $(L_1\ \lambda_1)$, $(L_2\ \lambda_2)$ and λ_i—the following formula computes the latitude of L_i where λ_1 intersects the great circle defined by $(L_1 \lambda_1)$ and (L_2, λ_2).

$$L_i = \text{TAN}^{-1} \left[\frac{\text{TAN } L_2 \text{ SIN}(\lambda_i - \lambda_1) - \text{TAN } L_1 \text{ SIN}(\lambda_i - \lambda_2)}{\text{SIN } (\lambda_2 - \lambda_1)} \right]$$

(This formula can be very useful when matching charts of different projections or scales.)

RHUMB LINE PLANNING

Given:
Δt = time between positions
L_1 Dept Lat
L_2 Dest Lat
λ_1 Dept Long
λ_2 Dest Long
C = Rhumb line True Course
D = Rhumb line Distance
π = Pi (3.14159....)

$$C = \text{TAN}^{-1} \left[\frac{\pi (\lambda_1 - \lambda_2)}{180 \text{ Ln TAN } (45 + 1/2\, L_2) - \text{Ln TAN } (45 + 1/2\, L_1)} \right]$$

$$D = 60 (\lambda_2 - \lambda_1) \text{ COS } L_1; \text{ if } C = 0$$
$$\frac{60 (L_2 - L_1);}{\text{COS } C} \quad \text{otherwise}$$

COMPUTING POSITION BY DEAD RECKONING

$$L_2 = \left(\frac{\Delta t \times GS \times \text{COS(TC)}}{60} \right) + L_1$$

If TC = 90°, 270° $\quad \lambda_2 = \lambda_1 - \left(\frac{\Delta t \times GS \times \text{SIN(TC)}}{60 \text{ COS } L_1} \right)$

Otherwise:

$$\lambda_2 = \lambda_1 - \frac{180}{\pi} [\text{TAN(TC)} \times (\text{Ln TAN}(45 + 1/2\, L_2) - \text{Ln TAN}(45° + 1/2\, L_1)]$$

NOTE: The flightpath may not cross the North Pole

COURSE CORRECTION TO DESTINATION

Given:
M_1 = Intended magnetic course
M_2 = Magnetic course actually flown to current position
M_3 = Magnetic course to fly from current position to destination
DOC = Distance off course (+ left, − right)
D_1 = Distance flown to current position
D_2 = Distance from start to destination
D_3 = Distance from start to checkpoint
D_4 = Distance to go from current position to destination

$$M_1 = M_2 + \text{ARC TAN}\frac{DOC}{D_3}$$

$$M_3 = M_1 + \text{ARC SIN}\frac{DOC}{D_4}$$

$$D_3 = \sqrt{D_1^2 - DOC^2} \text{ if } D_1 \text{ is known}$$

$$D_4 = \sqrt{D_2 - D_3)^2 + DOC^2} \quad 0 \leq M_3 < 360°$$

Groundspeed and magnetic course from two TACAN radials and DME readings or two radar range and bearings.

Given:

D_1 DME#1, D_2 = DME #2
R_1 = Radial #1, R_2 = Radial #2

$$A = \frac{HA - HT}{6076}$$

HA = Height above MSL
HT = Height or elevation of the TACAN
T = Time run between radials and DMEs

$$GS = \frac{\sqrt{D_1^2 + D_2^2 - 2A^2 - 2\,(\sqrt{D_1^2 - A^2})\,(\sqrt{D_2^2 - A^2})\,(COS(R_1 - R_2))}}{T}$$

★ $$MC \text{ (mag course)} = R_2 - SIN^{-1}\left[\frac{(D_1)(SIN(R_1 - R_2))}{(GS)(T)}\right]$$

★ This computation is handy when flying from one radial and DME to another for computing the mag course and distance. The GS equation becomes distance if you do not divide by "T".

Figure 23-1. Elements of Course Correction Solution.

RATE OF CLIMB

TAS = True Airspeed in knots
ROC = Rate of climb in ft/min (+ or −)
D = Ground distance over which the altitude change (Δt) occurs.

$$ROC = \frac{TAS\ (\Delta\ Alt)}{60\,[D^2 + (\Delta Alt/6076)^2]^{1/2}}$$

TABLE OF WEIGHTS AND MEASURES

Weights

1 GRAM	0.035 OUNCES
1 KILOGRAM	2.2 POUNDS
1 CENTIMETER	0.3937 INCH
2.54 CENTIMETERS	1.0 INCH
1 METER	3.280 FEET
0.3048 METER	1 FOOT
0.9144 METER	1 YARD
1609.3 METERS	1 MILE (STATUTE)
1.852 KILOMETERS	1 NAUTICAL MILE
1.151 STATUTE MILE	1 NAUTICAL MILE

Liquid Measures

1 LITER	2.113 PINTS
1 LITER	1.057 QUARTS
1 LITER	0.264 GALLONS
0.946 LITER	1.0 QUART
3.785 LITERS	1.0 GALLON
1 GALLON JP-4	6.35 POUNDS @ 60° F
1 GALLON JP-5	6.8 POUNDS @ 60° F
1 GALLON JP-7	6.59 POUNDS @ 60° F
1 GALLON JP-8	6.7 POUNDS @ 60°F
1 GALLON JET A-1 FUEL	6.68 POUNDS @ 60° F

Conversion Factors

F = 9/5 C + 32
C = 5/9 (F − 32)

Mileage

KILOMETERS	STATUTE MILES	MILES NAUTICAL
1	0.62	.54
10	6.21	5.40
20	12.43	10.80
30	18.64	16.20
40	24.85	21.60
50	31.07	27.00
60	37.28	32.40
80	49.71	43.20
100	62.14	54.00
200	124.27	107.99

Temperature

CENTIGRADE	FAHRENHEIT
38	100.4
25	77
10	50
0	32

Standard Sea Level References (ICAO)

★ T_0 (temperature) = 15.0 C, 288.15K
a_0 (speed of sound) = 661.5 knots = 1116.4 ft/sec
P_0 (atmospheric pressure) = 14.696 psi = 29.92 in Hg
ρ_0 (atmospheric density) = .002376 Lb sec^2/ft^2

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

CHARLES A. GABRIEL, General, USAF
Chief of Staff

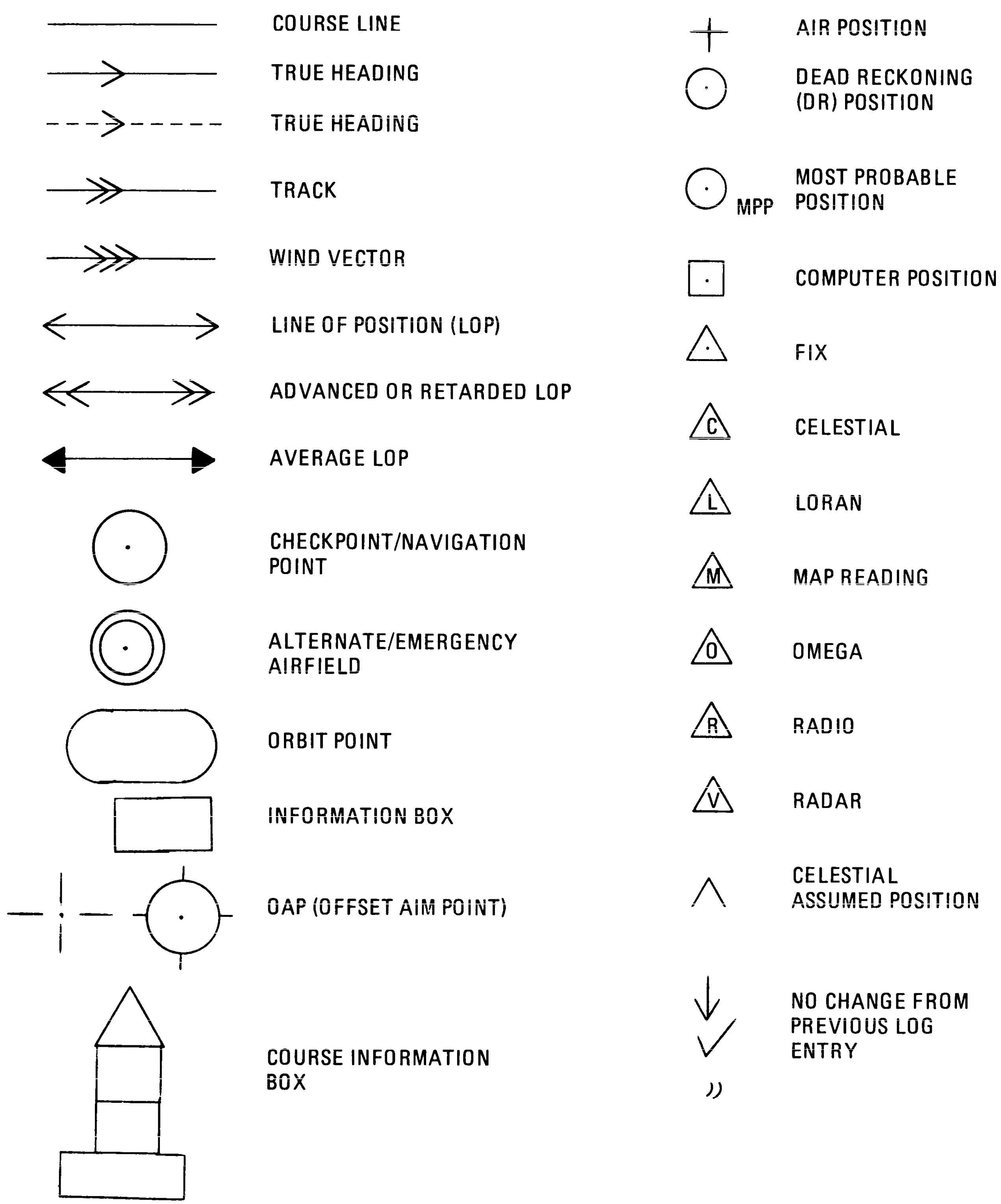
JAMES L. WYATT, JR., Colonel, USAF
Director of Administration

BY DIRECTION OF THE COMMANDER, NAVAL AIR SYSTEMS COMMAND

SUMMARY OF REVISED, DELETED, OR ADDED MATERIAL

All material has been revised and updated. The chapter on mission planning has been expanded. Chapters dealing with celestial information have been realigned to permit quick reference to specific information. Overwater navigation has been expanded to include a discussion of pressure pattern navigation using temperature change. A new chapter has been added on advanced systems which address the theory and application of systems such as the astro-tracker, INS, OMEGA, NAVSTAR, and navigation computers. The chapter on aerial delivery has been expanded and includes a discussion of basic aerial refueling rendezvous procedures. A new chapter on formulas and conversion has been added which presents a listing of many equations suitable for use with hand-held calculators.

SYMBOLS — CHART AND NAVIGATION



ABBREVIATIONS

A

AA	absolute altitude
A/C	alter course, aircraft, aircraft commander
ADC	automatic drift control
ADF	automatic direction finder
AF	audio frequency
AFC	automatic frequency control
A/H	alter heading
alt	altitude
AM	amplitude modulation, ante meridian
ant	antenna
AP	airplot, air position, assumed position
API	air position indicator
ARA	airborne radar approach
ARCP	air refueling control point
ARCT	air refueling control time
ARIP	air refueling intial point
ARTCC	Air Route Traffic Control Center
AS	airspeed
ATA	actual time of arrival
ATC	Air Traffic Control
ATF	actual time of fall
AVC	automatic volume control
AWS	Air Weather Service
az	Azimuth

B

BAS	basic airspeed
BAT	basic air temperature
BD	Bellamy drift
BFO	beat frequency oscillator
BMT	beginning of morning twilight
BNS	bomb-nav system
BPA	basic pressure altitude
BRL	bomb resolver locus
BTA	basic true altitude

C

CARP	computed air release point
CAS	calibrated airspeed
CCW	counterclockwise
CDI	course deviation indicator
CF	Coriolis force
CFP	computer flight plan
CH	compass heading
CI	climb
cm	centimeter
comp	computer, compass
corr	correction, corrected
CPC	constant pressure chart
CRT	cathode ray tube
CW	clockwise, continuous wave

D

"d"	correction to tabulated altitude for minutes of declination
D	D-soundings, difference between TA and PA
D_1, D_2, etc.	successive D readings
DA	density altitude, drift angle
DAS	density airspeed
DC	drift correction
DCA	drift correction angle
DD	double drift
Dec	declination
dept	departure
dest	destination
dev	deviation
DF	direction finder
DG	directional gyro
DH	desired heading
DMAAC	Defense Mapping Agency Aerospace Center
DME	distance measuring equipment
DR	dead reckoning
DZ	drop zone

E

E	east, error
EAD	effective air distance
EAP	effective air path
EAS	equivalent airspeed
EET	end of evening twilight
ETA	estimated time of arrival
ETAS	effective true airspeed
ETP	equal time point

F

FAA	Federal Aviation Agency
FAR	Federal Air Regulations
FH	final heading
FIO	Flight Information Office
FIR	Flight Information Regions
FLIP	Flight Information Publications
FM	frequency modulation
FSS	Flight Service Station

G

G	acceleration caused by gravity
GAT	Greenwich apparent time
GC	grid course
GCA	ground controlled approach
GEOREF	World Geographic Reference System
GH	grid heading
GHA	Greenwich hour angle
GMT	Greenwich mean time
GN	grid north

GP	gyro precession
GPI	ground position indicator
griv or GV	grid variation, grivation
GS	groundspeed
GST	Greenwich sidereal time

H

H	altitude, height, high
Hc	computed altitude (celestial)
HF	high frequency (3,000-30,000 kHz)
Hg	mercury
Ho	observed altitude
Hp	precomputed altitude (celestial)
Hs	sextant altitude (celestial)
Hz	cycles per second

I

IAS	indicated airspeed
IAT	indicated air temperature
ICAO	International Civil Aviation Organization
IF	intermediate frequency
IFF	Identification Friend or Foe
IFR	Instrument Flight Rule
IH	initial heading
ILS	instrument landing system
ind	indicated
INS	inertial navigation system
intcp	intercept
IP	initial point, identification of position
IPA	indicated pressure altitude
ITA	indicated true altitude

J-K

k	knots
K	constant
kHz	kilocycles (1000 cycles) per second
km	kilometer

L

L	low
lat	latitude
LAT	local apparent time
LCT	local civil time
LF	low frequency (30-300 kHz)
LHA	local hour angle
Lm	midlatitude
LMT	local mean time
Ln	LORAN
L.O.	level off
long	longitude
LOP	line of position
LOS	line of sight
L-R	left-right
LST	local sidereal time

M

m	meter
M	moment, Mach number
mb	millibar
MB	magnetic bearing
MC	magnetic course
MC&G	mapping, charting, and geodetic
MF	medium frequency (300-3000 kHz)
MGRS	Military Grid Reference System
MH	magnetic heading
mHz	megacycles per second
mm	millimeter
MN	magnetic north
mph	miles per hour
MPP	most probable position
ms	microseconds
MSL	mean sea level

N

N	north, nadir
NDB	non-directional beacon
NM	nautical miles
NMC	National Meteorological Center

O

OAT	outside air temperature

P

PA	pressure altitude, parallax
PAV	pressure altitude variation
PCA	positive control area
PGF	pressure gradient force
PLOP	pressure line of position
PM	pulse modulation, post meridian
pos	position
PPI	plan position indicator
pps	pulses per second
PR	position report
PRF	pulse recurrence frequency
PRR	pulse recurrence rate
PRT	pulse recurrence time
PW	pulse wave

Q

Q	correction applied to Ho of Polaris

R

r	radius
R	refraction
RB	relative bearing
RF	radio frequency
RMI	radio magnetic indicator
R/T	receiver/transmitter

S

S	south, speed
SD	semidiameter
SDC	single drift correction
sext	sextant
SHA	sidereal hour angle
SID	standard instrument departure
SIF	selective identification feature
SSB	single sideband
STC	sensitivity time constant

T

TA	true altitude
TAMPA	true altitude minus pressure altitude
TAR	terrain avoidance radar
TAS	true airspeed
TAT	true air temperature
TB	true bearing
TC	true course
TCA	terminal control area
temp	temperature
tgt	target
TH	true heading
TN	true north
TO	takeoff
TP	turning point
Tr	track
T/R	transmitter/receiver

U

UHF	ultra high frequency (300-3000 mHz)
UIR	Upper Information Region
UPS	Universal Polar Stereographic
UTM	Universal Transverse Mercator

V

var	variation, variable
VFR	Visual Flight Rule
VHF	very high frequency (30,000-300,000 kHz)
VLF	very low frequency (below 30 kHz)
VOR	VHF omnidirectional range (omnirange)
VRM	variable range marker

W

W	west
WAC	World Aeronautical Chart
WD	wind direction
WS	wind speed
W/V	wind velocity, wind vector

X-Y-Z

Z	azimuth angle
ZD	zenith distance, zone difference
Zn	true azimuth
ZN	pressure pattern displacement
ZT	zone time

EXPLANATION OF TERMS

AGIONIC LINE—A line on a chart joining points of no magnetic variation.

AIR ALMANAC—a joint publication of the US Naval Observatory and British Royal Observatory covering a four-month period. It contains tabulated values of the Greenwich hour angle and declination of selected celestial bodies, plus additional celestial data used in navigation.

AIR DISTANCE (AD)—Distance that is measured relative to the mass of air through which an aircraft passes; the no-wind distance flown in a given time (TAS × time).

AIRPLOT (AP)—A continuous plot of a graphic representation of true heading and air distance.

AIR POSITION (AP)—The no-wind position of an aircraft at a given time.

AIRSPEED (AS)—The speed of an aircraft relative to its surrounding air mass.

Calibrated Airspeed (CAS)—Indicated airspeed corrected for pitot-static installation and (or) the attitude of the aircraft.

Equivalent Airspeed (EAS)—Calibrated airspeed corrected for compressibility-of-air error.

Indicated Airspeed (IAS)—The uncorrected reading obtained from the airspeed indicator.

True Airspeed (TAS)—Equivalent airspeed corrected for density altitude (pressure and temperature).

AIRSPEED INDICATOR (ASI)—An instrument which gives a measure of the rate of motion of an aircraft relative to the surrounding air.

AIR TEMPERATURE

Basic Air Temperature (BAT)—Indicated air temperature corrected for the instrument error.

Corrected Mean Temperature (CMT)—The average between the target temperature and the true air temperature of flight level.

Indicated Air Temperature (IAT)—The uncorrected reading from the free air temperature gage.

True Air Temperature (TAT)—Basic air temperature corrected for the heat of compression error. Also known as outside air temperature (OAT).

AIRWAY—An air corridor established for the control of traffic and marked with radio navigation aids.

ALTER COURSE (A/C)—A change in course to a destination or a turning point.

ALTER HEADING (A/H)—The change in heading to make good the intended course.

ALTIMETER—A flight instrument that indicates the altitude above a given reference level or point. Altimeters generally are of two types, **absolute** and **pressure.**

Absolute Altimeter—The absolute or radar altimeter indicates the altitude above the terrain, land, or water directly below the aircraft. Operates on the principle of measuring the time for transmission and return of radio-frequency energy.

Pressure Altimeter—The pressure altimeter uses an aneroid barometer to measure atmospheric pressure. The altimeter is calibrated to indicate feet of altitude above a selected datum plane.

ALTIMETER SETTING (ALT Set)—Station pressure reduced to sea level, expressed in inches of mercury or millibars. When this value is set into the altimeter, the instrument reading is indicated true altitude.

ALTITUDE—The vertical distance of a level, a point, or an object considered as a point, measured from a given surface.

Absolute Altitude—The altitude above the terrain directly below the aircraft.

Pressure Altitude—The altitude above the standard datum plane. This standard datum plane is where the air pressure is 29.92 inches of mercury (corrected to plus 15° C).

Density Altitude—Pressure altitude corrected for temperature. Pressure and density altitudes are the same when conditions are standard (refer to standard atmosphere table.) As the temperature rises above standard, the density of the air decreases, hence an increase in density altitude.

Indicated Altitude—Altitude displayed on the altimeter.

Calibrated Altitude—Indicated altitude corrected for installation error. If an altimeter correction card is available, this definition may include scale error.

True Altitude—Calibrated altitude corrected for nonstandard atmospheric conditions. Actual height above mean sea level.

Flight Level—A surface of constant atmospheric pressure related to the standard datum plane. In practice, a calibrated altitude maintained with a 29.92" Hg reference on the barometric scale.

ALTITUDE, CELESTIAL—Angular distance of a celestial body above the celestial horizon, measured along the vertical circle.

Computed Altitude (Hc)—A mathematical computation of the correct celestial altitude of a body at a specific geographic position, for a given date and time.

Observed Altitude (Ho)—The sextant altitude corrected for sextant and observation errors.

Precomputed Altitude (Hp)—Computed celestial altitude corrected for all known observational errors and adjusted to the time of the observed altitude.

Sextant Altitude (Hs)—A celestial altitude measured with a sextant; the angle measured in a vertical plane between an artificial or sea horizon and a celestial body.

ALTITUDE DELAY—A controlled delay applied to the start of the trace to eliminate the altitude hole on the PPI-type display.

ALTITUDE HOLE—The blank area in the center of the PPI, the outer edge of which represents the point on the ground immediately beneath the aircraft.

ARIES, FIRST POINT OF (♈)—The point on the equinoctial where the Sun moving along the ecliptic passes from south to north declination. Also known as vernal equinox.

ASSUMED POSITION (AP)—The geographic position upon which a celestial solution is based.

ASTRONOMICAL TRIANGLE—A triangle on the celestial sphere bounded by the observer's celestial meridian, the vertical circle, and the hour circle through the body, and having as its vertices the elevated pole, the observer's zenith, and the body.

AZIMUTH ANGLE (Z)—The interior angle of the astronomical triangle at the zenith measured from the observer's meridian to the vertical circle through the body.

AZIMUTH STABILIZATION—Orientation of the picture on a radarscope so as to place true north at the top of the scope.

AZIMUTH, TRUE (Zn)—The angle at the zenith measured clockwise from true north to the vertical circle passing through the body.

BASE LINE—The line joining the master and slave LORAN stations.

BASE LINE EXTENSION—The extension of the base line through and beyond the master and slave LORAN stations.

BEACON—A ground navigational light, radio, or radar transmitter used to provide aircraft in flight with a signal to serve as a reference for the determination of accurate bearings or positions.

BEAM WIDTH—The effective width in azimuth of radiation from an antenna.

BEAM WIDTH ERROR—An azimuth distortion of a radar beam display caused by the width of the radar beam.

BEARING—The horizontal angle at a given point, measured clockwise from a specific reference datum, to a second point. The direction of one point relative to another, as measured from a specific reference datum.

Magnetic Bearing (MB)—The horizontal angle at a given point, measured from magnetic north, clockwise, to the great circle through the object or body and the given point.

Relative Bearing (RB)—The horizontal angle at the aircraft measured clockwise from the true heading of the aircraft to the great circle containing the aircraft and the object or body.

True Bearing (TB)—The horizontal angle at a given point measured from the true north clockwise to the great circle passing through the point and the object or body.

BELLAMY DRIFT—The net drift angle of the aircraft calculated between any two pressure soundings.

BLIP—The display of a received pulse on a CRT; a spot of light representing a target; (LORAN) an upward deflection of the trace representing the received signal. Also known as pip.

BRANCH, LOWER—Half of an hour circle opposite from "upper branch," defined below.

BRANCH, UPPER—That half of an hour circle or meridian which contains the celestial body or the observer's position.

CELESTIAL EQUATOR—The great circle formed by the intersection of the plane of the Earth's equator with the celestial sphere. Also known as Equinoctial.

CELESTIAL MERIDIAN—A great circle on the celestial sphere formed by the intersection of the celestial sphere and any plane passing through the North and South Poles. Any great circle on the celestial sphere which passes through the celestial poles.

CELESTIAL NAVIGATION—See *Navigation Aids*.

CELESTIAL OBSERVATION ERRORS (Sextant)

Acceleration Error—An error caused by the deflection of the liquid in the bubble chamber due to any change in speed or direction of the aircraft.

Coriolis Error—The error introduced in a celestial observation taken in flight resulting from the deflective force on the liquid in the bubble chamber, as caused by the path of the aircraft in counteracting the Earth's rotation.

Index Error—An error caused by the misalignment of the sighting mechanism of the instrument.

Parallax Error—The difference between a body's altitude above an artificial or visible horizon and above the celestial horizon. The error is present because of the fact that the body is not at an infinite distance.

Personal Error—Errors in celestial observations caused by sighting limitations of the observer, or visual interpretation which he or she uses in collimating the body during observations.

Refraction Error—An error caused by the bending of light rays in passing through the various layers of the atmosphere.

Rhumb Line Correction—The correction applied for the bubble-acceleration error caused by the rhumb line path of the aircraft.

Wander Error—The bubble-acceleration error caused by a change of track during the celestial shooting period.

CELESTIAL POLES—The points of intersection of the extension of the Earth's axis with the celestial sphere.

CELESTIAL SPHERE—An imaginary sphere of infinite radius whose center coincides with the center of the Earth, on which all celestial bodies except Earth are imagined to be projected.

CHART—A graphic representation of a section of the Earth's surface specifically designed for navigational purposes. A chart may also be referred to as a map. Although a chart is usually specifically designed as a plotting medium for marine or aerial navigation, it may be devoid of cultural or topographical data.

CHECK POINT—A geographical reference point used for checking the position of an aircraft in flight. As generally used, it is a well-defined reference point easily discernible from the air. Its exact position is known or plotted on the navigational chart, and was selected in preflight planning for use in checking aircraft position in flight.

CIRCLES

Circle of Equal Altitude—A circle on the Earth which is the locus of all points equidistant from the subpoint of a celestial body. The altitude of a celestial body is the same measured from any point on the circle.

Diurnal Circle—The daily apparent path of a body on the celestial sphere caused by the rotation of the Earth.

Great Circle—Any circle on a sphere whose plane passes through the center of that sphere.

Hour Circle—A great circle on the celestial sphere passing through the celestial poles and a given celestial body.

Small Circle—Any circle on a sphere whose plane does not pass through the center of that sphere.

Vertical Circle—A great circle which passes through the observer's zenith, nadir, and a body on the celestial sphere.

CO-ALTITUDE (co-alt)—The small arc of a vertical circle, between the observer's position and the body (90°—altitude).

CO-DECLINATION (co-dec)—See *Polar Distance*.

CO-LATITUDE (co-lat)—The small arc of the observer's celestial meridian, between the elevated pole and the body (90° — latitude).

COLLIMATION—The correct alignment of the images of the bubble of a sextant and the object being observed.

COMPASS—An instrument which indicates direction measured clockwise from true north, or grid north.

Direct-Indicating—A magnetic compass in which the dial, scale, or index is carried on the sensing element.

Magnetic—An instrument which indicates direction measured clockwise from magnetic north.

Remote Indicating—A magnetic compass, the magnetic sensing unit of which is installed in an aircraft in a position as free as possible from causes of deviation. A transmitter system is included so that the compass indication can be read on a number of repeater dials suitably placed throughout the aircraft.

COMPASS DIRECTION—The direction measured clockwise from a particular compass needle which is more often than not displaced from the magnetic meridian by local deviating magnetic fields.

COMPASS ROSE—A graduated circle on a map or chart, marked in degrees clockwise from 0° through 360° for use as a reference in measuring bearings and courses.

CONSTELLATION—A recognizable group of stars by means of which individual stars may be identified.

CONTOUR LINES—Lines drawn on maps and charts joining points of equal elevation; also, a line connecting points of equal altitude on a constant-pressure chart.

CONTROLLED TIME OF ARRIVAL—A method of arriving at a destination at a specified time by changing direction and (or) speed of an aircraft.

CONTROL POINT—The position an aircraft must reach at a predetermined time.

COORDINATES

Celestial (1)—The equinoctial system involves the use of sidereal hour angle and declination to locate a point on the celestial sphere with reference to the first point of Aries and the equinoctial.

Celestial (2)—The horizon system involves the use of azimuth and altitude to locate a point on the celestial sphere for an instant of time from a specific geographical position on the Earth.

Celestial (3)—The Greenwich system involves the use of Greenwich hour angle and declination to locate a point on the celestial sphere with reference to the Greenwich meridian and the equinoctial for a given instant of time.

Geographical—The latitude and longitude used to locate any given point on the surface of the Earth.

Grid—A system of coordinates in which the area concerned is divided into rectangles which are in turn subdivided, and in which the subdivisions or the dividing grid lines are designated by numbers and (or) letters to serve as references in locating positions or small areas. Also a rectangular grid or fictitious chart graticule which is oriented with grid north.

Polar—A system of coordinates used in locating a point by direction and distance from an origin.

Rectangular—A system of coordinates based on a rectangular grid; sometimes referred to as grid coordinates.

CORIOLIS ERROR—See *Celestial Observation Errors*.

CORIOLIS FORCE—An apparent force due to the rotation of the Earth which causes a moving body to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

COURSE—The direction of the intended path of an aircraft over the Earth; or the direction of a line on a chart representing the intended aircraft path, expressed as the angle measured from a specific reference datum clockwise from 0° thru 360° to the line.

Great-Circle Course—The route between two points on the Earth's surface measured along the shorter segment of the circumference of the great circle between the two points. A great circle course establishes the shortest distance over the surface of the Earth between any two terrestrial points.

Grid Course—The horizontal angle measured clockwise from grid north to the course line. The course of an aircraft measured with reference to the north direction of a polar grid.

Magnetic Course—The horizontal angle measured from the direction of magnetic north clockwise to a line representing the course of the aircraft. The aircraft course measured with reference to magnetic north.

True Course (TC)—The angle measured clockwise from true north to the line representing the intended path of the aircraft.

Course Line—A line of position which is parallel or approximately parallel to the track of the aircraft. A line of position used to check aircraft position relative to intended course.

CRAB—A correction of aircraft heading into the wind to make good a given track; correction for wind drift.

CRUISE CONTROL—The operation of an aircraft to obtain the maximum efficiency on a particular mission (most miles per amount of fuel).

"D" SOUNDING—The difference between pressure altitude and true altitude as determined at a given time in flight (true altitude minus pressure altitude).

DATUM—Refers to a direction, level, or position from which angles, heights, depths, speeds, or distances are conventionally measured.

DAY

Civil Day—The interval of time between two successive lower transits of a meridian by the mean (or civil) Sun.

Sidereal Day—The interval of time between two successive upper transits of a meridian by the first point of Aries (23 hours 56 minutes).

Solar Day—The interval of time between two successive lower transits of a meridian by the true (apparent) Sun.

DEAD RECKONING—The directing of an aircraft and determining of its position by the application of direction and speed data to a previous position.

DEAD-RECKONING (DR) POSITION—The position of an aircraft determined for a given time by the application of direction and speed data only.

DECLINATION (dec)—The angular distance to a body on the celestial sphere measured north or south through 90° from the celestial equator along the hour circle of the body (comparable to latitude).

DEVIATION (dev)—Compass error caused by the magnetism within an aircraft; the angle measured from magnetic north eastward or westward to the direction of the Earth's lines of magnetic force as deflected by the aircraft's magnetism.

DEVIATION CORRECTION—The correction applied to a compass reading to correct for deviation error. The numerical equivalent of deviation with the algebraic sign added to magnetic heading to obtain compass heading.

DIP

Celestial—The angle of depression of the visible sea horizon due to the elevation of the eye of the observer above the level of the sea.

Magnetic—The vertical displacement of the compass needle from the horizontal caused by the Earth's magnetic field.

DIURNAL CIRCLE—See *Circles.*

DOG LEG—A route containing a major alteration of course (as opposed to a straight-line course.)

DOUBLE DRIFT (DD)—A method of determining the wind by observing drift on an initial true heading and two other true headings which are flown in a specific pattern. Also called multiple drift.

DRIFT—The rate of lateral displacement of the aircraft by the wind, generally expressed in degrees.

DRIFT ANGLE—The angle between true heading and track (or true course), expressed in degrees right or left according to the way the aircraft has drifted.

DRIFT CORRECTION (DC)—Correction for drift, expressed in degrees (plus or minus), and applied to true course to obtain true heading.

DRIFTMETER—An instrument used for measuring drift.

ECLIPTIC—The great circle on the celestial sphere along which the apparent Sun, by reason of the Earth's annual revolution, appears to move. The plane of the ecliptic is tilted to the plane of the equator at an angle of 23° 27′.

EFFECTIVE AIR DISTANCE (EAD)—The distance measured along the effective air path.

EFFECTIVE AIR PATH (EAP)—A straight line on a navigation chart connecting two air positions, commonly used between the air positions of two pressure soundings to determine effective true airspeed (ETAS) between the two soundings.

EFFECTIVE TRUE AIRSPEED (ETAS)—The effective air distance divided by the elapsed time between two pressure soundings.

ELEVATED POLE—That celestial pole which is on the same side of the equinoctial as the position of the observer.

EQUAL ALTITUDE—See *Circles.*

EQUATION OF TIME—The amount of time by which the mean Sun leads or lags behind the true Sun at any instant. The difference between mean and apparent times expressed in units of solar time with the algebraic sign, so that when added to mean time it gives apparent time.

EQUATOR—The great circle on the Earth's surface equidistant from the poles. Latitude is measured north and south from the equator.

EQUINOCTIAL—See *Celestial Equator.*

EQUINOX

Autumnal Equinox—The point on the equinoctial when the Sun, moving along the ecliptic, passes from north to south declination. This usually occurs on 21 September.

Vernal Equinox—The point on the equinoctial where the Sun, moving along the ecliptic, passes from south to north declination. This usally occurs on 21 March.

FIELD-ELEVATION PRESSURE—The existing atmospheric pressure in inches of mercury at the elevation of the field. Also known as station pressure.

FIX—The geographic position of an aircraft for a specified time, established by navigational aids.

FLIGHT PLAN—Predetermined information for the conduct of a flight. That portion of a flight log that is prepared before the mission.

GEOREF—An international code reference system for reporting geographic position (similar to rectangular coordinates).

GEOSTROPHIC WIND—The mathematically calculated wind which theoretically blows parallel to the contour lines, in which only pressure-gradient force and Coriolis force are considered.

GRADIENT WIND—Generally accepted as the actual wind above the friction level, influenced by Coriolis force, pressure gradient, and centrifugal force.

GRATICULE—A system of vertical and horizontal lines that is used to divide a drawing, picture, etc., into smaller sections. On a map the graticule consists of the latitude and longitude lines.

GREENWICH MERIDIAN—The prime meridian which passes through Greenwich, England, and from which longitude is measured east or west.

GRID NAVIGATION—A method of navigation using a grid overlay for direction determination.

GRIVATION (griv)—The angle between grid north and magnetic north at any point.

GROUND PLOT—A graphic representation of track and groundspeed.

GROUND RANGE—The horizontal distance from the subpoint of the aircraft to an object on the ground.

GROUND RETURN—The reflection from the terrain as displayed on a CRT.

GROUNDSPEED (GS)—The actual speed of an aircraft relative to the Earth's surface.

GROUND WAVE—A radio wave that is propagated over the surface of the Earth and tends to parallel the Earth's surface.

HEADING—The angular direction of the longitudinal axis of an aircraft measured clockwise from a reference point.

Compass Heading (CH)—The reading taken directly from the compass.

Grid Heading (GH)—The heading of an aircraft with reference to grid north.

Magnetic Heading (MH)—The heading of an aircraft with reference to magnetic north.

True Heading (TH)—The heading of an aircraft with reference to true north.

HEAT OF COMPRESSION ERROR—The error caused by the increase in the indication of the free air temperature gage, due to air compression and friction on the case around the sensitive element.

HERTZ (Hz)—The standard unit notation for measure of frequency in cycles per second; i.e., 60 cycles per second is 60 Hz.
HOMING—A technique of arriving over a destination by keeping the aircraft headed toward that point by reference to radio, LORAN, radar, or similar devices.
HORIZON

Bubble Horizon—An artificial horizon parallel to the celestial horizon, established by means of a bubble level.

Celestial Horizon—The great circle on the celestial sphere formed by the intersection of a plane passing through the center of the Earth which is parallel to the plane tangent to the Earth at the observer's position.

Visible Horizon—The circle around the observer where Earth and sky appear to meet. Also called natural horizon or sea horizon.

HOUR ANGLE

Greenwich Hour Angle (GHA)—The angular distance measured from the upper branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle passing through a body.

Local Hour Angle (LHA)—The angular distance measured from the upper branch of the observer's meridian westward through 360° to the upper branch of the hour circle passing through a body.

Sidereal Hour Angle (SHA)—The angular distance measured from the upper branch of the hour circle of the first point of Aries westward through 360° to the upper branch of the hour circle passing through a body.

HOUR CIRCLE—See *Circle*.
INDEX ERROR—See *Celestial Observation Error*.
INHERENT DISTORTION—The distortion of the display of a received radar signal caused by the design characteristics of a particular radar set.
INITIAL POINT (IP)—A preselected geographical position which is used as a reference for the beginning of a run on a target.
INTERCEPT, CELESTIAL—The difference in minutes of arc between an observed altitude of a celestial body and its computed altitude for the same time. This difference is measured as a distance in nautical miles from the plotting position along the azimuth of the body to determine the point through which to plot the line of position.
INTERNATIONAL DATE LINE—The anti-meridian of Greenwich, modified to avoid island groups and land masses; in crossing this Greenwich anti-meridian there is a change of local date.
ISOBAR—A line joining points of equal pressure.
ISOGONIC LINE (Isogonal)—A line drawn on a chart joining points of equal magnetic variation.
ISOGRIV—A line drawn on a chart joining points of equal grivation.
ISOTACH—A line drawn on a chart joining points of equal wind speed.
ISOTHERM—A line drawn on a chart joining points of equal temperature.
KNOTS (k)—Nautical miles per hour.
LANDFALL—The first point of land over which an aircraft crosses when flying from seaward; also as used in celestial navigation, the procedure in which an aircraft is flown along a celestial line of position which passes through destination.
LATERAL AXIS—An imaginary line running through the center of gravity of an aircraft, parallel to the straight line through both wing tips.
LATITUDE (lat)—Angular distance measured north or south of the equator along a meridian, 0° through 90°.
LINE OF CONSTANT BEARING—An unchanging directional relationship between two moving objects.
LINE OF POSITION (LOP)—A line containing all possible geographic positions of an observer at a given instant of time.
LOG—A written record of computed or observed flight data; generally applied to the written navigational record of a flight.
LONGITUDE (long)—The angular distance east or west of the Greenwich meridian, measured in the plane of the equator or of a parallel from 0° to 180°.
LONGITUDINAL AXIS—An imaginary line running fore and aft through the center of gravity of an aircraft, parallel to the axis of the propeller or thrust line.
LORAN—See *Navigational Aids*.
LUBBER LINE—A reference mark representing the longitudinal axis of an aircraft.
MACH NUMBER—The ratio of the velocity of a body to that of sound in the medium in which the craft is moving.
MAGNETIC DIRECTION—A direction measured clockwise from the magnetic meridian.
MAP READING—See *Navigational Aids*.
MAP SYMBOLS—Figures and designs used to represent topographical, cultural, and aeronautical features on a map or chart.
MARKER BEACONS—Radio beacons established at range stations, along airways, and at intermediate points between range stations to assist pilots and observers in fixing position.

Fan-Type—A 75-megaHertz radio transmitter usually installed at strategic points along a radio range across the on-course signal. The signal is produced in a space shaped like a thick fan immediately above the transmitter. The signal may be received visually or aurally, depending on the receiver.

M-Type—A low-powered, nondirectional radio station which transmits a characteristic signal once every few seconds. The range of the receiver is approximately 10 miles.

Z-Type—A special 75-megaHertz radio which transmits a signal within the cone of silence to enable the pilot to identify his or her position over the range station. The signal may be picked up visually or aurally depending on the receiver used. In Air Force aircraft, a marker-beacon light flashes on as the aircraft enters the cone of silence.

MASTER STATION—The primary or control transmitter station, the signal of which triggers the transmitter of one or more other stations. Also a transmitter station, the signals of which are used by other stations as a basis for synchronizing transmissions.
MEAN SEA LEVEL (MSL)—The average level of the sea, used to compute barometric pressure.

MEAN SUN—An imaginary Sun traveling around the equinoctial at the average annual rate of the true Sun.

MERIDIONAL PART—A unit of measurement equal to 1 minute of longitude at the equator.

MINIMAL FLIGHT PATH—A path which affords the shortest possible time en route, obtained by using maximum assistance from the winds.

MOST PROBABLE POSITION (MPP)—The computed position of an aircraft determined by comparing a DR position and an LOP or a fix of doubtful accuracy determined for the same time, in which relative weights are given to the estimated probable errors of each.

NADIR—The point on the celestial sphere directly beneath the observer's position.

NAUTICAL MILE (NM)—A unit of distance used in navigation, 6080 ft; the mean length of 1 minute of longitude on the equator; approximately 1 minute of latitude; 1.15 statute miles.

NAVIGATION AIDS—Any means of obtaining a fix or LOP as an aid to dead reckoning.

Celestial—The determination of position by reference to celestial bodies.

Consol/Consolan—A rotating radio-signal system used for long-range bearings.

LORAN—An electronic aid to navigation whereby a line of position may be determined by measuring electronically the time difference between the receipt of pulsating signals of radio energy received from two different synchronized transmitting stations.

Map Reading—The determination of position by identification of land marks with their representations on a map or chart.

Pressure Differential—The determination of the average drift, or the crosswind component of the wind effect on the aircraft for a given period by taking "D" soundings and applying the formula:

$$Zn = K \frac{(D_2 - D_1)}{ETAS}$$

where ZN is the cross wind component, K is the Coriolis constant, ETAS is the effective true airspeed, and D_1 and D_2 are the values of the pressure soundings.

Radar—The determination of position by obtaining information from a radar indicator.

Radio—The determination of position by the use of radio facilities.

NORTH

Compass North—The direction indicated by the north-seeking end of a compass needle.

Grid North (GN)—An arbitrarily selected direction of a rectangular grid. In grid navigation the direction of the 180° geographical meridian from the pole is almost universally used as standard grid north.

Magnetic North (MN)—The direction towards the north magnetic pole from an observer's position.

True North (TN)—The direction from an observer's position to the geographical North Pole. The north direction of any geographical meridian.

PARALLAX ERROR—See *Celestial Observation Errors.*

PERSONAL ERROR—See *Celestial Observation Errors.*

PITCH—Movement of an aircraft around the lateral axis.

PITOT—A cylindrical tube with an open end pointed upstream; used in measuring impact pressure, particularly in an airspeed indicator.

PITOT-STATIC TUBE—A parallel or coaxial combination of a pitot and static tube. The difference between the impact pressure and the static pressure is a function of the velocity of flow past the tube and may be used to indicate airspeed of an aircraft in flight.

POLAR DISTANCE—Angular distance from a celestial pole or the arc of an hour circle between the celestial pole or the arc of an hour circle between the celestial pole and a point on the celestial sphere. It is measured along an hour circle and may vary from 0° to 180°, since either pole may be used as the origin of measurement. It is usually considered the complement of declination, though it may be either 90° −declination or 90° +declination, depending upon the pole used.

PRECESSION

Apparent—The apparent deflection of the gyro axis, relative to the Earth, due to the rotating effect of the Earth and not due to any applied forces.

Induced (Real)—The movement of the axis of a spinning gyro when a force is applied. The gyro precesses 90° from the point of applied pressure in the direction of rotation.

Of the Equinox—The average yearly apparent movement of the first point of Aries to the west.

PRECOMPUTED CURVE—A graphical representation of the azimuth and (or) altitude of a celestial body plotted against time for a given assumed position (or positions), and which is computed for subsequent use for celestial observations. Used in celestial navigation for the determination of position, or to check a sextant.

PRESSURE ALTITUDE VARIATION (PAV)—The pressure difference, in feet, between mean sea level and the standard datum plane.

PRESSURE LINE OF POSITION (PLOP)—A line of position computed by the application of pressure pattern principles. Specifically, a line parallel to the effective air path and ZN distance from the air position for a given time. (See *Navigational Aids.)*

PROCEDURE TURN—A constant-rate turn of an aircraft in flight; used for computing the radius of turn and time required for its execution when very accurate navigation is required in controlling time or maintaining accurate, briefed tracks; usually associated with the turn made at the intial point of a bomb run to insure that the bombing run is made on the briefed axis of attack.

PROJECTION (CHART, MAP)—A process of mathematically constructing a representation of the surface of the Earth on a flat plane.

PULSE DURATION OR PULSE WIDTH—The duration, in microseconds, of each pulse in a radar transmission.

PULSE-LENGTH ERROR—A range distortion of a radar return caused by the duration of the pulse.

PULSE RECURRENCE RATE (PRR)—The number of pulses transmitted per second by a radar or radio transmitter. Also known as pulse recurrence frequency (PRF).

PULSE RECURRENCE TIME (PRT)—The interval of time, in microseconds, between the transmission of two successive radar or radio pulses.

QUADRANTAL ERROR—The error in a radio direction indication introduced by the bending of radio waves by electrical currents and the structural metal in the aircraft. It may also refer to magnetic-compass errors resulting from the same causes.

RADAR BEACON (RACON)—A stationary transmitter-receiver which sends out a coded signal when triggered by a radar pulse.

RADAR BEAM—A directional concentration of radio energy.

RADAR NAUTICAL MILE—The time required for a radar pulse to travel out 1 nautical mile and the echo pulse to return (12.4 ms).

RADIO COMPASS (ADF)—A radio receiver equipped with a rotatable loop antenna which is used to measure the bearing to a radio transmitter.

RADIO FREQUENCY (RF)—Any frequency of electrical energy above the audio range which is capable of being radiated into space.

RADIO NAVIGATION—See *Navigational Aids.*

RADIUS OF ACTION—The maximum distance that an aircraft can fly from its base before returning to the same or alternate base and still have a designated margin of fuel.

RADOME—A bubble-type cover for a radar antenna.

RANGE CONTROL—The operation of an aircraft to obtain the optimum flying time.

RANGE DEFINITION—The accuracy with which a radar set can measure range—usually a function of pulse shape.

RANGE, MAXIMUM—The maximum distance a given aircraft can cover under given conditions by flying at the economical speed and altitude at all stages of the flight.

REVOLUTION (of the Earth)—The Earth's elliptical path about the Sun which determines the length of the year and causes the seasons.

RHUMB LINE—A line on the surface of a sphere which makes equal oblique angles with all meridians. A loxodromic curve.

ROTATION (of the Earth)—The spinning of the Earth from the west to the east on its own axis which determines the days.

RUNNING FIX—A fix determined from a series of lines of position, based on the same object or body and resolved for a common time.

SCAN—The motion of a beam of RF energy caused by rotating or displacing the reflecting element or the antenna in relation to the reflecting element. The search pattern of an antenna.

SEMIDIAMETER (SD)—The value in minutes of arc of the radius of the Sun or the Moon.

SEXTANT—An optical instrument normally containing a two-power telescope with a 15° field of vision. It also contains a series of prisms geared to an altitude scale permitting altitude measurement of a celestial body's altitude from −10° below the horizon to 92° above the horizon.

SKY WAVES—A radio signal reflected one or more times from the ionosphere.

SLANT RANGE—Measurement of range along the line of sight.

SLAVE STATION—The station of a network which is controlled or triggered by the signal from the master station.

SOLSTICE—Those points on the ecliptic where the Sun reaches its greatest northern or southern declination. Also the times when these phenomena occur.

Summer—That point on the ecliptic where the Sun reaches its greatest declination having the same name as the latitude.

Winter—That point on the ecliptic where the Sun reaches its greatest declination having the opposite name as the latitude.

SPEED LINE—A line of position that intersects the track at an angle great enough to be used as an aid in determining groundspeed.

SPOT-SIZE ERROR—A distortion of a radar return caused by the size of the electron spot in a cathode-ray tube.

STANDARD LAPSE RATE

Temperature—A temperature decrease of approximately 2° centigrade for each 1,000 feet increase in altitude.

Pressure—A decrease in pressure of approximately 1 inch of mercury for each 1,000 feet.

STAR MAGNITUDE—A measure of the relative apparent brightness of stars.

STATUTE MILE—5,280 feet or .867 nautical miles.

SUBPOINT—That point on the Earth's surface directly beneath an object or celestial body.

SUN LINE—A line of position obtained by computation based on observation of the altitude of the Sun for a specific time.

SWEEP—The luminous line produced on the screen of a cathode ray tube by deflection of the electron beam. Also called time base line. See *Trace.*

SWEEP DELAY—The electronic delay of the start of the sweep used to select a particular segment of the total range.

TARGET-TIMING WIND—A wind determined from a series of ranges and bearings on the same target taken within a relatively short period of time.

TIME

Apparent Time—Time measured with reference to the true Sun. The interval which has elapsed since the last lower transit of a given meridian by the true Sun.

Greenwich Apparent Time (GAT)—Local time at the Greenwich meridian measured by reference to the true Sun. The angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle passing through the true (apparent) Sun.

Greenwich Mean Time (GMT)—Local time at the Greenwich meridian measured by reference to the mean Sun. It is the angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the Greenwich meridian westward through 360° to the upper branch of the hour circle through the mean Sun.

Greenwich Sidereal Time (GST)—Local sidereal time at Greenwich. It is equivalent to the Greenwich hour angle of Aries converted to time.

Local Apparent Time (LAT)—Local time at the observer's meridian measured by reference to the true Sun. The angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the observer's meridian westward through 360° to the upper branch of the hour-circle passing through the true (apparent) Sun.

Local Mean Time (LMT)—Local time at the observer's meridian measured by reference to the mean Sun. It is the angle measured at the pole or along the equator or equinoctial (and converted to time) from the lower branch of the observer's meridian westward through 360° to the upper branch of the hour circle through the mean (or average) Sun.

Local Sidereal Time (LST)—Local time at the observer's meridian measured by reference to the first point of Aries. It is equivalent to the local hour angle of Aries converted to time.

Mean Time—Time measured by reference to the mean Sun.

Sidereal Time—Time measured by reference to the upper branch of the first point of Aries.

Standard Time—An arbitrary time, usually fixed by the local mean time of the central meridian of the time zone.

Zone Time—The time used through a 15° band of longitude. The time is based on the local mean time for the center meridian of the zone.

Z or Zulu Time—An expression indicating Greenwich mean time. Usually expressed in four numerals (0001 through 2400).

TIME ZONE—A band on the Earth approximately 15° of longitude wide, the central meridian of each zone generally being 15° or a multiple removed from the Greenwich meridian so that the standard time of successive zones differs by 1 hour.

TRACK (Tr)—The actual path of an aircraft over the surface of the Earth, or its graphic representation; also called track made good.

TWILIGHT—That period of day, after sunset or before sunrise, when the observer receives sunlight reflected from the atmosphere.

Astronomical Twilight—That period which ends in the evening and begins in the morning when the Sun reaches 18° below the horizon.

Civil Twilight—That period which ends in the evening and begins in the morning when the Sun reaches 6° below the horizon.

Nautical Twilight—That period which ends in the evening and begins in the morning when the Sun reaches 12° below the horizon.

VARIABLE RANGE MARKER (VRM)—An electronic marker, variable in range, displayed on a CRT for purposes of accurate ranging; sometimes called bomb-release pip.

VARIATION (var)—The angle difference at a given point between true north and magnetic north expressed as the number of degrees which magnetic north is displaced east or west from true north. The angle to be added algebraically to true directions to obtain magnetic directions.

WIND—Moving air, especially a mass of air having a common direction or motion. The term is generally limited to air moving horizontally or nearly so; vertical streams of air are usually called currents.

WIND DIRECTION AND FORCE—The direction from which, and the rate at which, the wind blows.

WIND DIRECTION AND VELOCITY (W/V)—Wind direction and speed. Wind direction is the direction from which the wind is blowing expressed as an angle measured clockwise from true north. Wind speed is generally expressed in nautical miles or statute miles per hour.

YEAR, APPARENT SOLAR—The period of time between two successive passages of the mean Sun through the first point of Aries. It has a mean value of 365 days 05 hours 48.75 minutes. This period contains one complete cycle of the seasons and is less than the sidereal year owing to the precession of the equinoxes.

YEAR, SIDEREAL—The period of time between two successive passages of the Sun across a fixed position among the stars. Its value is constant, and equal to 366 days 06 hours 09 minutes, a true measure of the Earth's period of orbital revolution.

ZENITH—The point on the celestial sphere directly above the observer's position.

ZENITH DISTANCE (ZD)—The angular distance from the observer's position to any point on the celestial sphere measured along the vertical circle passing through the point. It is equivalent to co-altitude, but when applied to a body's subpoint and the observer's position on the Earth it is expressed in nautical miles.

ZN (Pressure Pattern Displacement)—In pressure pattern flying, the displacement in nautical miles, at right angles to the effective airpath, due to the crosswind component of the geostrophic wind.

Index

- D -

- E -

- S -

- T -

- U -

- V -

- W -

- X-Y-Z -

☆U.S. GOVERNMENT PRINTING OFFICE : 1991 - 287-462 QL 3