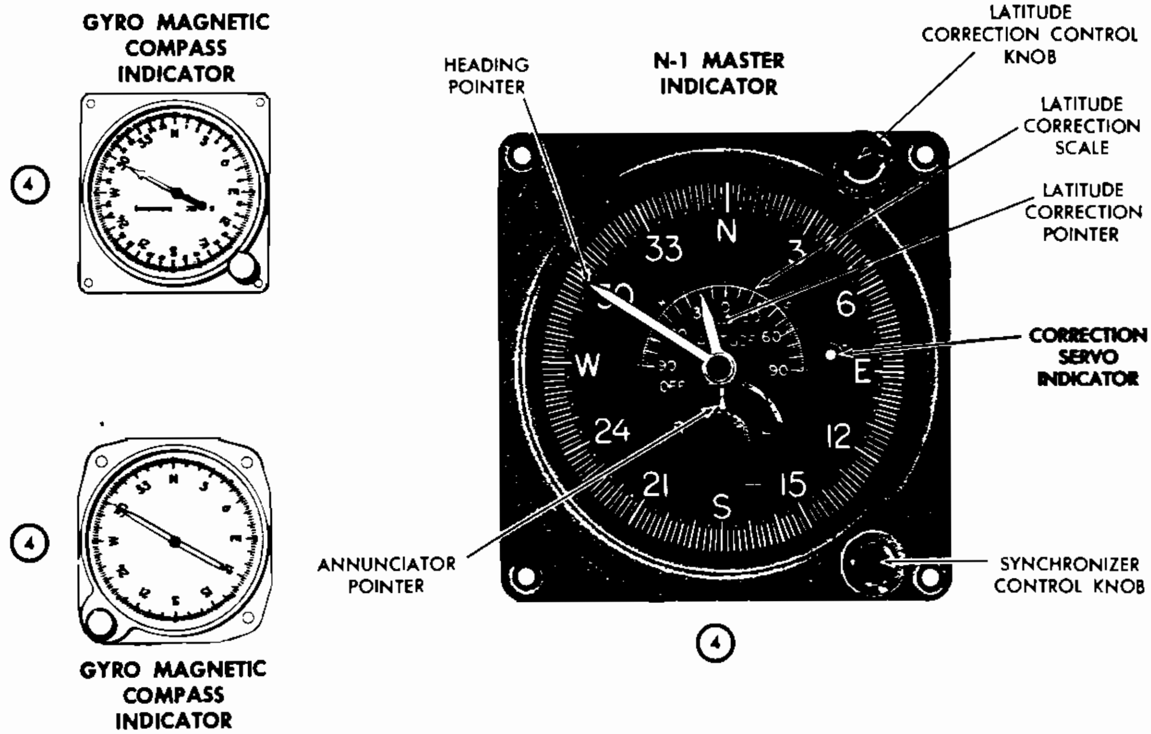


Figure 4-10. N-1 Compass System Components

netic-slaved operation or directional-gyro operation of the compass system as well as the proper latitude correction rate.

The latitude correction pointer is mechanically connected to the latitude correction control knob and indicates the latitude setting on the latitude correction scale at the center of the master indicator dial face.

The synchronizer control knob at the lower right-hand corner of the master indicator face provides a means of synchronizing the master indicator heading pointer with the correct magnetic heading when the system is in magnetic-slaved operation. It also provides a means of setting the master indicator heading pointer on the desired gyro heading reference when the system is in directional-gyro operation.

The annunicator pointer indicates the direction in which to rotate the synchronizer control knob to align the heading pointer with the correct magnetic heading.

A small hole is provided in the right side of the dial face through which the direction of rotation of a white dot, the correction servo indicator, may be observed. The rotating dot indicates that the master indicator is using information from either the latitude-correction mechanism or the remote compass transmitter. In magnetic-slaved operation, the dot will rotate slowly back and forth indicating that the system is constantly integrating information from the remote compass transmitter. In directional-gyro operation, the dot will rotate at a speed proportional to the latitude correction. It will rotate clockwise when north latitude is set and counterclockwise when south latitude is set.

Gyro Magnetic Compass Indicators. The gyro magnetic compass indicators are remote-reading, settable-dial compass indicators. They are intended for supplementary use as directional compass indicators when used with the compass system. The indicators duplicate the azimuth heading of the master indicator heading pointer. A setting knob is provided at the front of each indicator for rotating the dial 360° in either direction without changing the physical alignment of the pointer.

Slaving Control. The slaving control is a gyro-control rate switch which reduces errors in the compass system during turns. When the aircraft turns at a rate of 23° or more per minute, the slaving control prevents the remote compass transmitter signal from being transmitted to the compass system during magnetic-slaved operation. It also interrupts leveling action in the directional gyro when the system is in magnetic-slaved or directional-gyro operation.

The Gyro

Any spinning body exhibits gyroscopic properties. A wheel designed and mounted to use these properties is called a gyroscope or gyro. Basically, a gyro is a rapidly rotating mass which is free to move about one or both axes perpendicular to the axis of rotation and to each other. The three axes of a gyro, namely, spin axis, drift axis, and topple axis shown in figure 4-11 are defined as follows:

- In a directional gyro, the spin axis or axis of rotation is mounted horizontally.
- The topple axis is that axis in the horizontal plane that is 90 degrees from the spin axis.
- The drift axis is that axis 90 degrees vertically from the spin axis.

Gyroscopic drift is the horizontal rotation of the

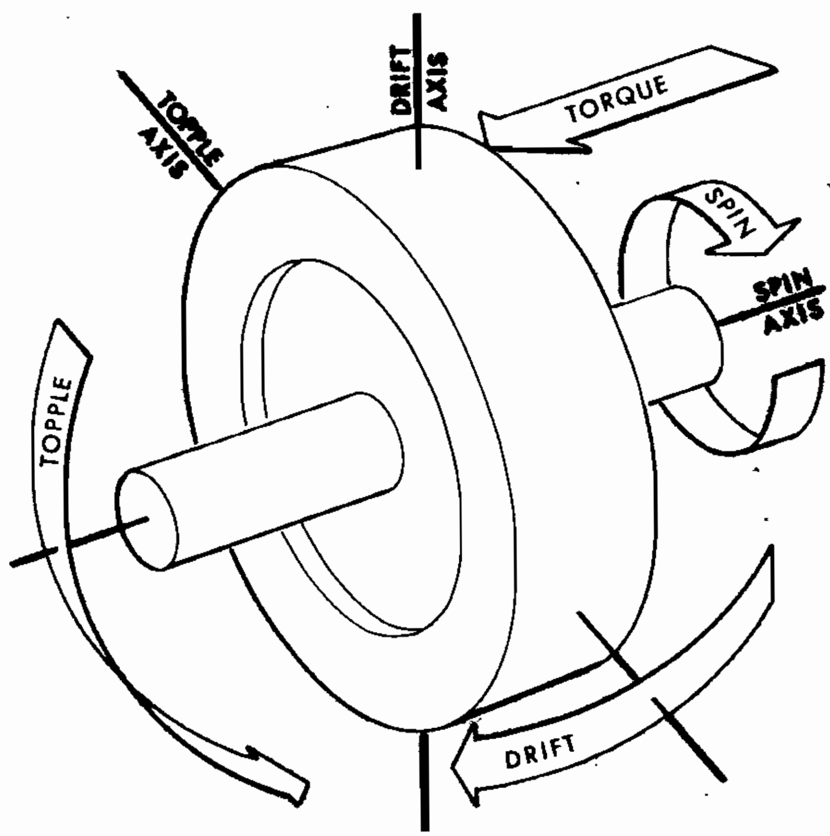


Figure 4-11. Gyroscope Axes

spin axis about the drift axis. Topple is the vertical rotation of the spin axis about the topple axis. These two component drifts result in motion of the gyro called precession.

A freely spinning gyro tends to maintain its spin axis in a constant direction in space, a property known as rigidity in space or gyroscopic inertia. Thus, if the spin axis of a gyro were pointed toward a star, it would rotate at the same rate as the star and keep pointing at the star. Actually, the gyro does not move, but the earth moving beneath it gives it an apparent motion. This apparent motion, shown in figure 4-12, is called apparent precession. The magnitude of apparent precession is dependent upon latitude. The horizontal component, drift, is equal to 15 degrees per hour times the sine of the latitude, and the vertical component, topple, is equal to 15 degrees per hour times the cosine of the latitude.

These computations assume the gyro is sta-

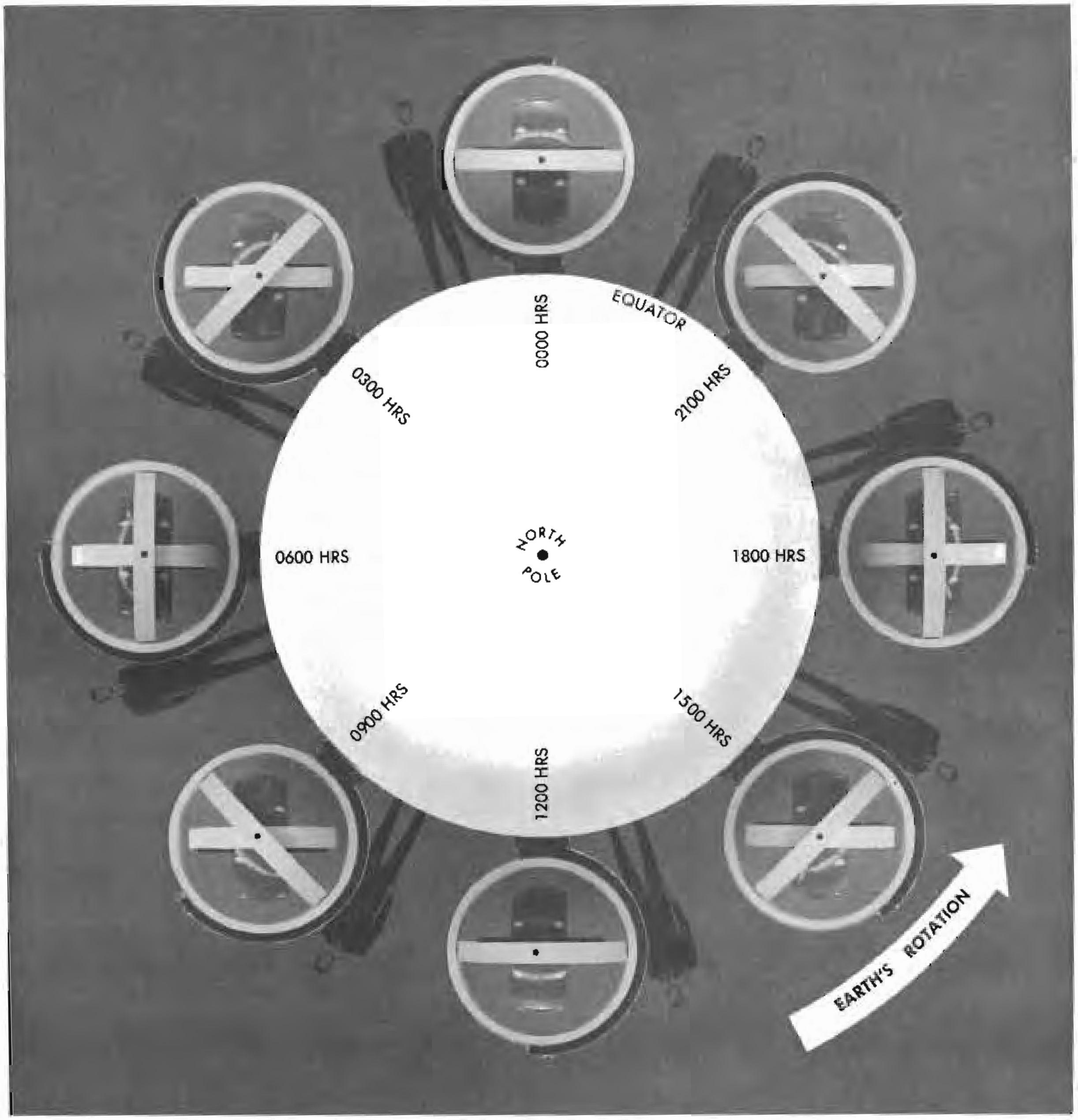


Figure 4-12. Apparent Precession

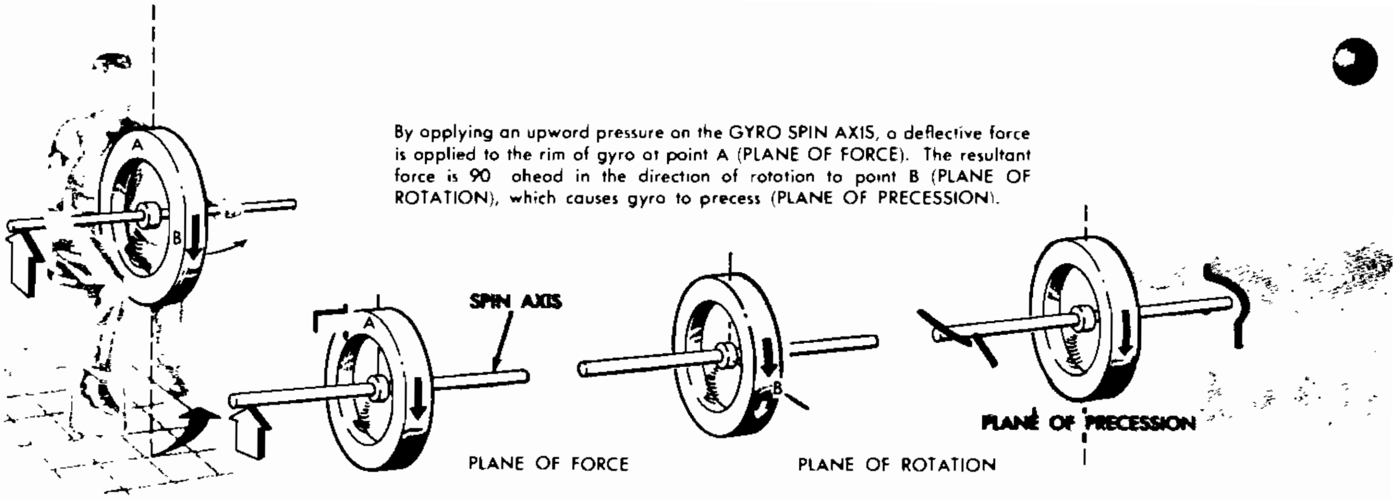


Figure 4-13. Precession of Gyroscope Resulting from Applied Deflective Force

tionary with respect to the earth. However, if the gyro is to be used in a high speed aircraft, it is readily apparent that its speed with respect to a point in space may be more or less than the speed of rotation of the earth. If the aircraft in which the gyro is mounted is moving in the same direction as the earth, the speed of the gyro with respect to space will be greater than the earth's speed. The opposite is true if the aircraft is flying in a direction opposite to that of the earth's rotation. This difference in the magnitude of apparent precession caused by transporting the gyro over the earth is called transport precession.

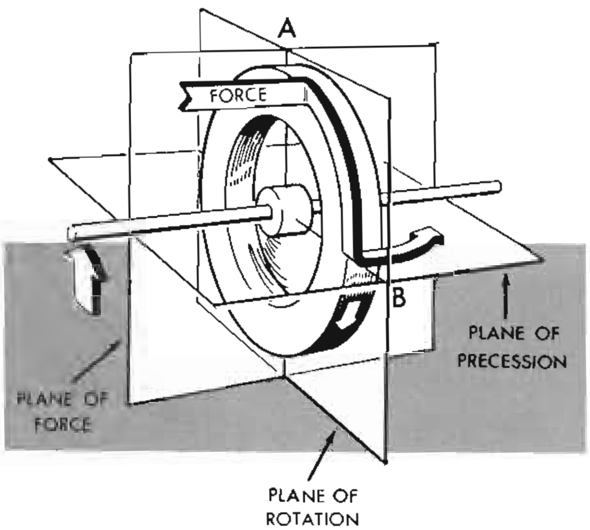
A gyro may precess because of factors other than the earth's rotation. When this occurs, the precession is labeled real precession. When a force is applied to the plane of rotation of a gyro, the plane tends to rotate, not in the direction of the applied force, but 90 degrees around the spin axis from it. This torquing action, shown in figure 4-13, may be used to control the gyro by bringing about a desired reorientation of the spin axis, and most directional gyros are equipped with some sort of device to introduce this force.

However, friction within the bearings of a gyro may have the same effect and cause a certain amount of unwanted precession. Great care is taken in the manufacture and maintenance of gyroscopes to eliminate this factor as much as possible, but, as yet, it has not been possible to eliminate it entirely. Precession caused by the mechanical limitations of the gyro is called real or induced precession. The combined effects of apparent precession, transport precession, and real precession produce the total precession of the gyro.

The properties of the gyro that most concern the navigator are rigidity and precession. By understanding these two properties, the navigator is well equipped to use the gyro as a reliable steering guide.

DIRECTIONAL GYRO. The discussion thus far has been of a universally mounted gyro, free to turn in the horizontal or vertical, or any component of these two. This type of gyro is seldom, if ever, used as a directional gyro. When the gyro is used as a steering instrument, it is restricted so that the spin axis remains parallel to the surface of the earth. Thus, the spin axis is free to turn only in the horizontal plane (assuming the aircraft normally flies in a near level attitude), and only the horizontal component (drift) will affect a steering gyro. In the terminology of gyro steering, precession always means the horizontal component of precession.

The operation of the instrument depends upon the principle of rigidity in space of the gyroscope. Fixed to the plane of the spin axis is a circular compass card, shown in figure 4-14, similar to that of the magnetic compass. Since the spin axis remains rigid in space, the points on the card hold the same position in space relative to the horizontal plane. The case, to which the lubber line is attached, simply revolves about the card.



It is important at this point to understand that the numbers on the compass card have no meaning within themselves, as on the magnetic compass. The fact that the gyro may indicate 100 degrees under the lubber line is not an indication that the instrument is actually oriented to magnetic north, or any other known point. To steer by the gyro, the navigator must first set it to a known direction or point. Usually, this is magnetic north or geographic north, though it can be at any known point. If, for example, magnetic north is set as the reference, all headings on the gyro read relative to the position of the magnetic poles.

The actual setting of the initial reference heading is done by using the principle discussed earlier of torque application to the spinning gyro. By artificially introducing precession, the navigator can set the gyro to whatever heading is desired and can reset it at any time using the same technique.

GYROCOMPASS ERRORS. The major error affecting the gyro and its use as a steering instrument is precession. Apparent precession will cause an apparent change of heading equal to 15 degrees per hour times the sine of the latitude. Real precession, caused by defects in the gyro, may occur at any rate. This type of precession has been greatly reduced by the high precision of modern manufacturing methods. Apparent precession is a known value depending upon location and can be compensated for. In some of the more complex

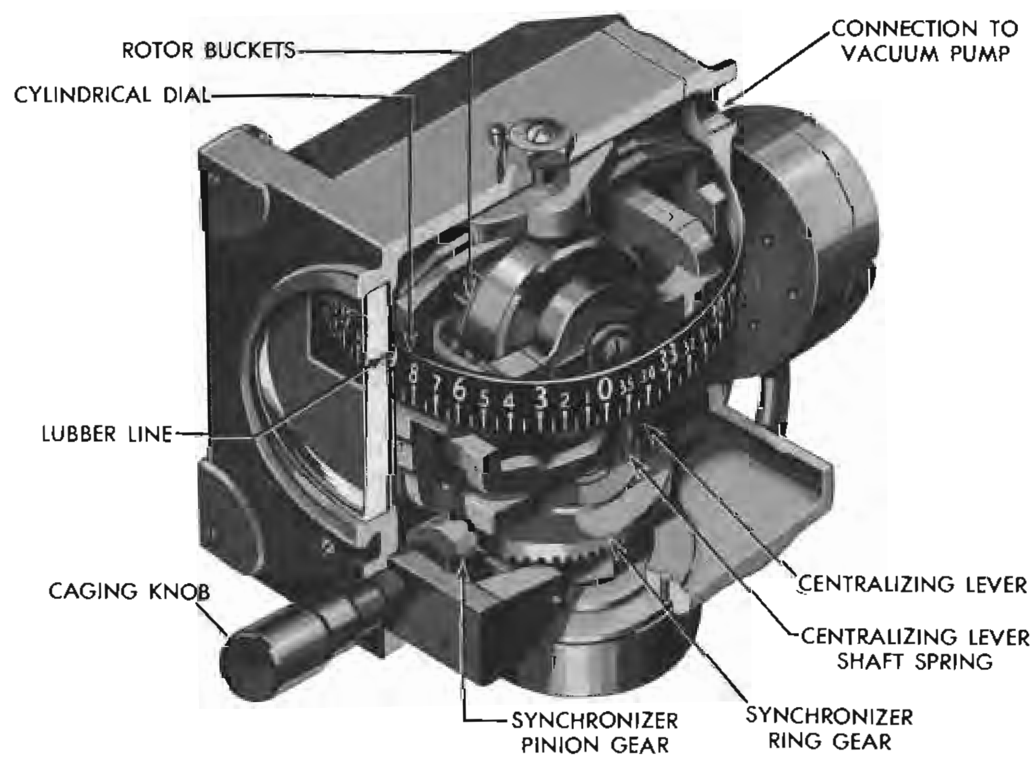


Figure 4-14. Cutaway View of a Directional Gyro

gyro systems such as the N-1 compass system, apparent precession is compensated by setting in a constant correction equal to and in the opposite direction to the precession caused by the earth's rotation.

ALTITUDE AND ALTIMETERS

Altitude may generally be defined as the height of an aircraft above the earth. Knowledge of the aircraft altitude is important for several reasons. To remain a safe distance above dangerous mountain peaks, the navigator must know the altitude of the aircraft and the elevation of the surrounding terrain at all times. This is especially important when visibility is poor and the terrain cannot be seen. Also, it is often desirable to fly a certain altitude to take advantage of favorable winds and weather conditions.

Altitude may be defined as a vertical distance above some point or plane used as a reference. There can be as many kinds of altitude as there are reference planes from which to measure them, but the navigator need concern himself only with six: *indicated altitude, calibrated altitude, pressure altitude, density altitude, true altitude, and absolute altitude.* There are two main types of altimeters; the pressure altimeter which is installed in every aircraft and the absolute or radar altimeter. To understand the pressure altimeter's principle of operation, a knowledge of the standard datum plane is essential.

Standard Datum Plane

The standard datum plane is a theoretical plane where the atmospheric pressure is 29.92 inches of mercury (Hg) and the temperature is +15°C. The standard datum plane is the zero elevation level of an imaginary atmosphere known as the standard atmosphere. In the standard atmosphere, pressure is 29.92" Hg at 0 feet and decreases upward at the standard pressure lapse rate. The temperature is +15 C at 0 feet and decreases upward at the standard temperature lapse rate. Both the pressure and temperature lapse rates are given in the table in figure 4-15.

The standard atmosphere is theoretical. It was derived by averaging the readings taken over a period of many years. The list of altitudes and their corresponding values of temperature and pressure given in the table were determined by

Altitude (feet)	Standard pressure (millibars)	Standard pressure (inches of mercury)	Standard temperature (°C)	Standard temperature (°F)
60,000	71.7	2.12	−56.5	−69.7
59,000	75.2	2.22	−56.5	−69.7
58,000	79.0	2.33	−56.5	−69.7
57,000	82.8	2.45	−56.5	−69.7
56,000	86.9	2.57	−56.5	−69.7
55,000	91.2	2.69	−56.5	−69.7
54,000	95.7	2.83	−56.5	−69.7
53,000	100.4	2.96	−56.5	−69.7
52,000	105.3	3.11	−56.5	−69.7
51,000	110.5	3.26	−56.5	−69.7
50,000	116.0	3.42	−56.5	−69.7
49,000	121.7	3.59	−56.5	−69.7
48,000	127.7	3.77	−56.5	−69.7
47,000	134.0	3.96	−56.5	−69.7
46,000	140.6	4.15	−56.5	−69.7
45,000	147.5	4.35	−56.5	−69.7
44,000	154.7	4.57	−56.5	−69.7
43,000	162.4	4.79	−56.5	−69.7
42,000	170.4	5.04	−56.5	−69.7
41,000	178.7	5.28	−56.5	−69.7
40,000	187.5	5.54	−56.5	−69.7
39,000	196.8	5.81	−56.5	−69.7
38,000	206.5	6.10	−56.5	−69.7
37,000	216.6	6.40	−56.5	−69.7
36,000	227.3	6.71	−56.3	−69.4
35,000	238.4	7.04	−54.3	−65.8
34,000	250.0	7.38	−52.4	−62.2
33,000	262.0	7.74	−50.4	−58.7
32,000	274.5	8.11	−48.4	−55.1
31,000	287.4	8.49	−46.4	−51.6
30,000	300.9	8.89	−44.4	−48.0
29,000	314.8	9.30	−42.5	−44.4
28,000	329.3	9.72	−40.5	−40.9
27,000	344.3	10.17	−38.5	−37.3
26,000	359.9	10.63	−36.5	−33.7
25,000	376.0	11.10	−34.5	−30.2
24,000	392.7	11.60	−32.5	−26.6
23,000	410.0	12.11	−30.6	−23.0
22,000	427.9	12.64	−28.6	−19.5
21,000	446.4	13.18	−26.6	−15.9
20,000	465.6	13.75	−24.6	−12.3
19,000	485.5	14.34	−22.6	−8.8
18,000	506.0	14.94	−20.7	−5.2
17,000	527.2	15.57	−18.7	−1.6
16,000	549.2	16.22	−16.7	1.9
15,000	571.8	16.89	−14.7	5.5
14,000	595.2	17.58	−12.7	9.1
13,000	619.4	18.29	−10.8	12.6
12,000	644.4	19.03	− 8.8	16.2
11,000	670.2	19.79	− 6.8	19.8
10,000	696.8	20.58	− 4.8	23.3
9,000	724.3	21.39	− 2.8	26.9
8,000	752.6	22.22	− 0.8	30.5
7,000	781.8	23.09	1.1	34.0
6,000	812.0	23.98	3.1	37.6
5,000	843.1	24.90	5.1	41.2
4,000	875.1	25.84	7.1	44.7
3,000	908.1	26.82	9.1	48.3
2,000	942 1	27.82	11.0	51.9
1,000	977.2	28.86	13.0	55.4
Sea level	1013.2	29.92	15.0	59.0

Figure 4-15. Standard Lapse Rate Table

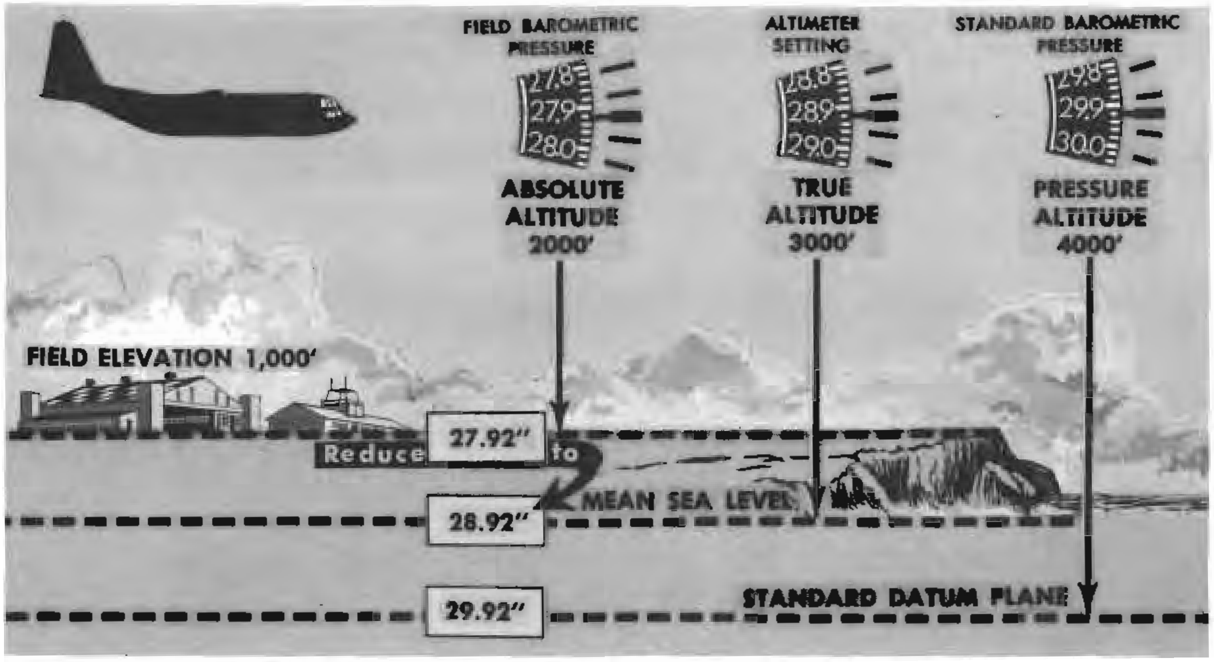


Figure 4-16. Types of Altitude

these averages. The height of the aircraft above the standard datum plane (29.92″ Hg and +15°C) is called pressure altitude as illustrated in figure 4-16.

Pressure Altimeter Principle of Operation

The pressure altimeter is an aneroid barometer calibrated to indicate feet of altitude instead of pressure. As shown in figure 4-17, the pointers are connected by a mechanical linkage to a set of aneroid cells. These aneroid cells expand or contract with changes in barometric pressure. In this manner, the cells assume a particular thickness at a given pressure level and thereby position the altitude pointers accordingly. On the face of the altimeter is a barometric scale which indicates the barometric pressure (expressed in inches of mercury) of the point or plane from which the instrument is measuring altitude. Turning the barometric pressure set knob on the altimeter manually changes this altimeter setting on the barometric scale and results in simultaneous movement of the altitude pointers to the corresponding altitude reading.

Like all measurements, an altitude reading is meaningless if the point from which it starts is unknown. The face of the pressure altimeter supplies both values. The position of the pointers indicates the altitude in feet, and the barometric pressure appearing on the barometric scale is that of the reference plane above which the measurement is made.

Altimeter Displays

THREE-POINTER ALTIMETER. The three-pointer altimeter illustrated in figure 4-17 has three concentrically mounted pointers which are coded by length and shape. The triangular-tipped pointer indicates 10,000's of feet, the small pointer indicates 1,000's of feet, and the long pointer indicates 100's of feet and parts of hundreds. The smallest graduations on the dial are 20-foot increments between hundreds of feet. The 100-foot pointer makes one complete revolution in each 1,000 feet of altitude change; the 1,000-foot pointer makes one complete revolution in each 10,000 feet of altitude change; the 10,000 foot pointer makes one complete revolution in each 100,000 feet of altitude change. A low-altitude warning symbol (hash marks) is visible at altitudes below 16,000 feet. Newer models of this altimeter include an additional 10,000-foot reference consisting of a narrow white stripe around the inner perimeter of the instrument scale. This stripe becomes visible as the 10,000-foot pointer moves clockwise. When this feature is present, the low

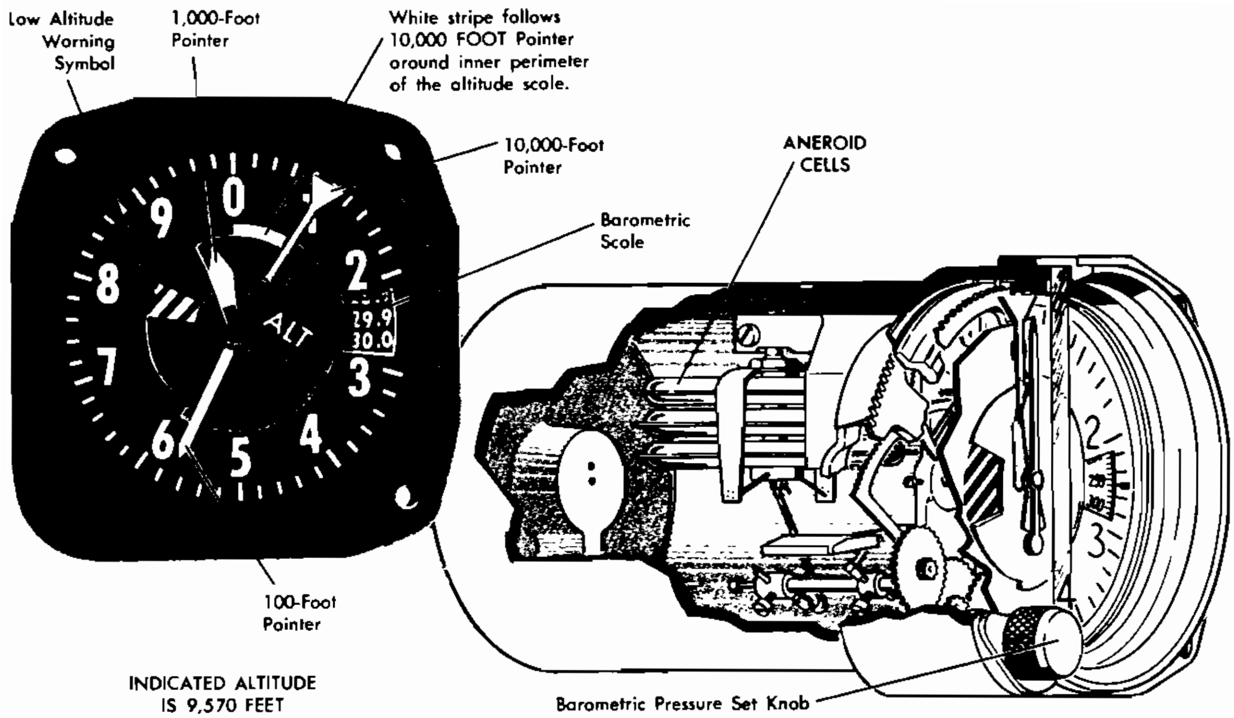


Figure 4-17. Three-Pointer Altimeter

altitude warning symbol is relocated to the nine o'clock position. To determine the indicated altitude, first read the 10,000-foot pointer, then the 1,000-foot pointer, and last, the 100-foot pointer.

COUNTER-POINTER ALTIMETER. The counter-pointer altimeter has a two-counter digital display unit located in the nine o'clock position of the dial. The counter indicates altitude in 1,000-foot increments from zero to 80,000 feet. See figure 4-18. A single conventional pointer indicates 100's of feet on the fixed circular scale. It makes one complete revolution per 1,000 feet of altitude change, and as it passes through the 900- to 1,000-foot area of the dial, the 1,000 foot counter is actuated. The shaft of the 1,000-foot counter in turn actuates the 10,000-foot counter at each 10,000 feet of altitude change. To determine the indicated altitude, first read the 1,000-foot counter and then add the 100-foot pointer indication.

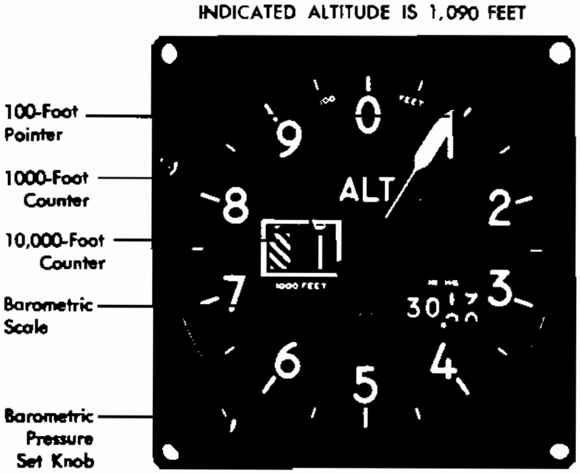


Figure 4-18. Counter-Pointer Altimeter

CAUTION

It is possible to misinterpret the counter-pointer altimeter by 1,000 feet immediately before or immediately after the 1,000-foot counter moves. This error is possible because the 1,000-foot counter changes when the 100-foot pointer is between the 900- and 1000-foot position.

COUNTER-DRUM-POINTER ALTIMETER. Aside from the familiar circular scale and 100-foot pointer, the counter-drum-pointer presentation differs somewhat in appearance from the present three-pointer altimeter. Starting at the left of the

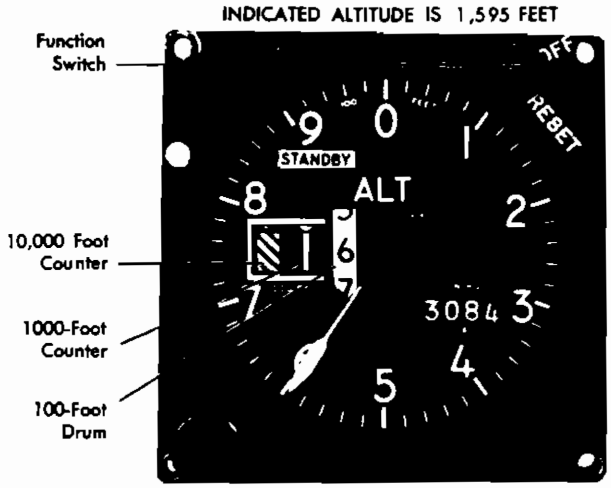


Figure 4-19. Counter-Drum-Pointer Altimeter

instrument illustrated in figure 4-19 and reading from left to right, there are two counter windows and one drum window (white). The numerals presented in the counter windows indicate 10,000's and 1,000's of feet respectively. The drum window numbers always follow the pointer number, thereby indicating 100's of feet.

Two methods may be used to read indicated pressure altitude on the counter-drum-pointer altimeter: (1) read the counter-drum window, without referring to the 100-foot pointer, as a direct digital readout of both thousands and hundreds of feet; (2) read the two counter indications, without referring to the drum, and then add the 100-foot pointer indication. The 100-foot pointer serves as a precise readout of values less than 100 feet.

The differential air pressure which is used to operate the counter-drum-pointer altimeter is processed by an altitude transducer where it is converted to electrical signals that drive the indicator. The transducer is also used to send digital signals to a transponder for purposes of automatic altitude reporting to Air Route Traffic Control Centers. A standby system is available for use should an electrical malfunction occur. In the standby system, the altimeter receives static air pressure directly from the pitot-static system. When the instrument is operating in the standby system, the word STANDBY appears on the instrument face. A switch in the upper right-hand corner of the instrument is provided to return the instrument to its normal mode of operation. This switch may also be used to manually place the instrument in the STANDBY mode.

Altimeter Errors

The pressure altimeter is subject to certain errors which fall in five general categories.

MECHANICAL ERROR. Mechanical error is caused by misalignments in gears and levers which transmit the aneroid cell expansion and contraction to the pointers of the altimeter. This error is not constant and must be checked before each flight by the setting procedure.

SCALE ERROR. Scale error is caused by irregular expansion of the aneroid cells and is recorded on a scale correction card maintained for each altimeter in the instrument maintenance shop.

INSTALLATION/POSITION ERROR. Installation position error is caused by the airflow around the static ports. This error varies with the type of aircraft, airspeed, and altitude. The magnitude and direction of this error can be determined by referring to the performance data section in the aircraft technical order.

An altimeter correction card is installed in some aircraft which combines the installation/position and scale errors. The card indicates the amount of correction required at different altitudes and airspeeds.

WARNING

Installation/position error may be considerable at high speeds and altitudes. Apply the corrections as outlined in the technical order or on the altimeter correction card.

REVERSAL ERROR. Reversal error is caused by inducing false static pressure in the static system. It normally occurs during abrupt or large pitch changes. This error appears on the altimeter as a momentary indication in the opposite direction.

HYSTERESIS ERROR. Hysteresis error is a lag in altitude indication caused by the elastic properties of the material within the altimeter. This occurs after an aircraft has maintained a constant altitude for an extended period of time and then makes a large, rapid altitude change. After a rapid descent, altimeter indications are higher than actual. This error is negligible during climbs and descents at slow rates or after maintaining a new altitude for a short period of time.

Setting the Altimeter

The barometrie scale is used to set a reference plane into the altimeter. Rotating the barometric pressure set knob increases or decreases the scale reading and the indicated altitude. Each .01 change on the barometric scale is equal to 10 feet of altitude.

The majority of altimeters have mechanical stops at or just beyond the barometric scale limits (28.10 to 31.00).

NOTE: Those altimeters not equipped with mechanical stops near the barometric scale limits can be set with a 10,000-foot error. Therefore, when setting the altimeter, insure that the 10,000-foot pointer is reading correctly.

The altimeter must be checked for accuracy before every flight. To check and set the altimeter:

1. Set the current altimeter setting on the barometric scale.
2. Check the altimeter reading at a known elevation and note the error in feet.
3. Reset the altimeter to the known elevation and apply the difference in indicated barometric pressure to all subsequent altimeter settings.

For example, the altimeter is set at 30.00 (current altimeter setting). At a known elevation of 760 feet the altimeter indicates 700 feet. The error is 60 feet. Resetting the altimeter to indicate 760 feet increases the barometric scale indication to 30.06 or a difference of *plus* .06. This difference must be applied to *all* subsequent changes in altimeter settings. The maximum altimeter error is 75 feet. Altimeters exceeding this error should be checked for proper operation before flight.

Should an altimeter setting be received which is beyond the limits of the barometric scale, the altimeter may be set using the ratio of .01 inch Hg per 10 feet of indicated altitude. For example, the altimeter indicated 500 feet at a setting of 28.10 and the current altimeter setting is 28.05. The .05 difference is equivalent to 50 feet; therefore, rotate the barometric pressure set knob until the altimeter indicates 450 feet.

Nonstandard Atmosphere Effects

The altimeter setting is a correction for nonstandard surface pressure only. Atmospheric pressure is measured at each station and the value obtained is corrected to sea level according to the surveyed field elevation. Thus, the altimeter setting is computed sea level pressure and should be considered valid only in close proximity to the station and the surface. It does not reflect nonstandard temperature nor distortion of atmospheric pressure at higher altitudes.

NOTE: Except for terrain clearance, the navigator should disregard nonstandard atmospheric effects for Air Traffic Control purposes. All altimeters within proximity of one another react to these effects in the same way, thus normal vertical separation among aircraft is provided. A complete discussion of these effects is found in AFM 105-5.

Types of Altitude

INDICATED ALTITUDE. The term, indicated altitude, means simply the value of altitude that is displayed on the pressure altimeter.

CALIBRATED ALTITUDE. Calibrated altitude is indicated altitude corrected for installation/position error.

PRESSURE ALTITUDE. The height above the standard datum plane (29.92″ Hg and +15°C) is pressure altitude (refer to figure 4-16).

DENSITY ALTITUDE. Ordinarily, the pressure lapse rate above the ground is not standard; it varies with temperature. Therefore, basic pressure altitude must be corrected for temperature variation to find density altitude. Air expands with increase in temperature. Consequently, warm air is less dense than cold air. As a result, the pressure lapse rate is less in a column of warm air than in cold air. That is, pressure decreases more rapidly with height in cold air than in warm air. Consequently, an altimeter tends to read too high in cold air and too low in warm air as shown in figure 4-20. Density altitude is of interest primarily in the control of engine performance and is of direct concern to the navigator in connection with cruise control.

TRUE ALTITUDE. True altitude is the actual vertical distance above mean sea level, measured in feet (refer to figure 4-16). It ean be determined by two methods: (1) Set the local altimeter setting on the barometric scale of the pressure altimeter to obtain the indicated true altitude. The indicated true altitude can then be resolved to true altitude by use of the DR computer. (2) Measure altitude over water with an absolute altimeter.

ABSOLUTE ALTITUDE. The height above the terrain is called absolute altitude. It is computed by subtracting terrain elevation from true altitude,

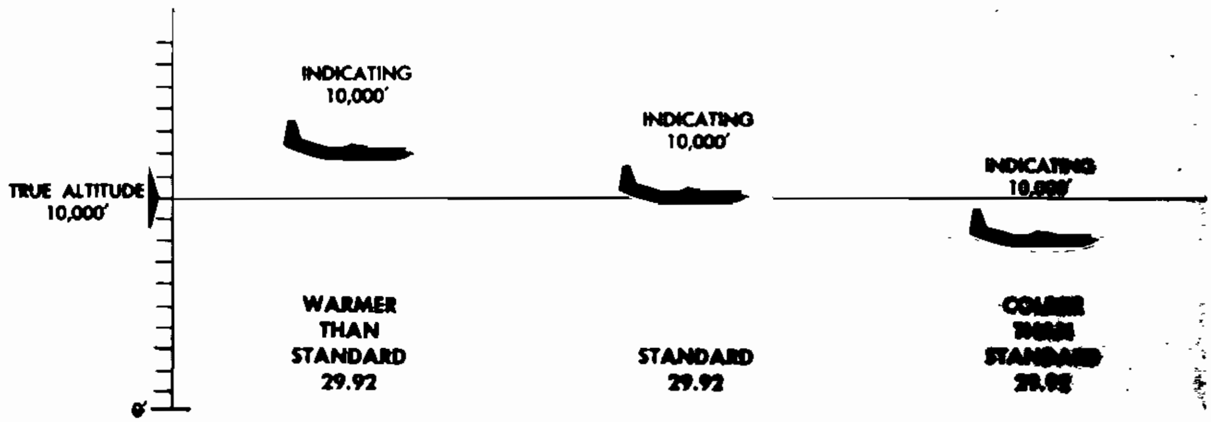


Figure 4-20. True Altitude Decreases Going Into Cold Air

or it can be read directly from an absolute altimeter.

Computer Altitude Solutions

The two altitudes most commonly accomplished on the computer are true altitude and density altitude. Nearly all DR computers have a window by which density altitude can be determined; however, be certain that the window is labeled DENSITY ALTITUDE.

TRUE ALTITUDE DETERMINATION. In the space marked FOR ALTITUDE COMPUTATIONS are two scales: (1) a centigrade scale in the window and (2) a pressure altitude scale on the upper disk. When a pressure altitude is placed opposite the temperature at that height, all values on the outer (miles) scale are equal to the corresponding values on the inner (minutes) scale increased or decreased by two percent for each 5.5°C that the actual temperature differs from the standard temperature at that pressure altitude, as set in the window.

Although the pressure altitude is set in the window, the indicated true altitude is used on the inner (minutes) scale for finding the true altitude, corrected for difference in temperature lapse rate.

Example:

Given: Pressure altitude 8,500 feet
Indicated true altitude 8,000 feet
Air Temperature (°C) −16

To Find: True altitude

Procedure: Place PA (8,500 feet) opposite the temperature (−16) on the FOR ALTITUDE COMPUTATIONS scale. Opposite the indicated true altitude (8,000 feet) on the inner scale, read the true altitude (7,600 feet) on the outer scale. The solution is illustrated in figure 4-21.

DENSITY ALTITUDE DETERMINATION. Density altitude determination on the computer is accomplished by using the window just above FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS and the small window just above that marked DENSITY ALTITUDE.

Example:

Given: Pressure altitude 9,000 feet
Air temperature (°C) −10

To Find: Density altitude

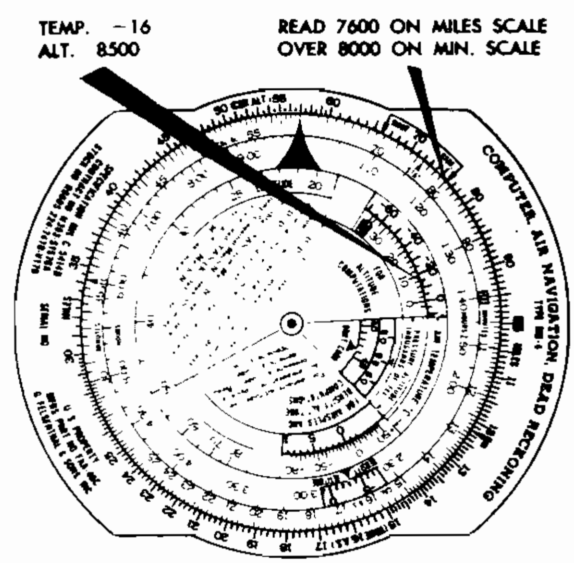


Figure 4-21. Finding True Altitude

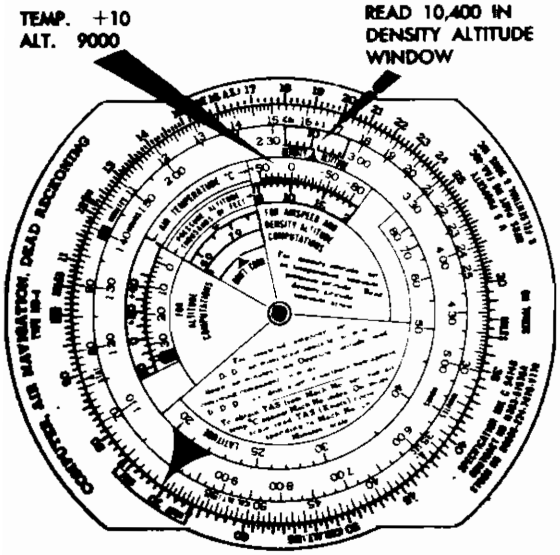


Figure 4-22. Finding Density Altitude

Procedure: Place pressure altitude (9,000 feet) opposite air temperature (+10) in window marked FOR AIRSPEED AND DENSITY ALTITUDE window, read density altitude (10,400 feet). The solution is illustrated in figure 4-22.

ABSOLUTE ALTIMETER

Accurate absolute altitude is an important requisite for navigation, photography, and bombing as well as for safe piloting. It is particularly important in pressure pattern navigation. Absolute altitude may be computed from the pressure altimeter readings if the position of the aircraft is known, but the results are often inaccurate. Under changing atmospheric conditions, corrections applied to pressure altimeter readings to obtain true altitudes are only approximate. In addition, any error made in determining the terrain elevations results in a corresponding error in the absolute altitude. Such an error in absolute altitude makes groundspeeds by timing inaccurate and precludes reasonable accuracy of soundings for pressure pattern navigation.

Electronic Altimeter Set (High Level)

A typical high level radar altimeter is designed to indicate absolute altitude of the aircraft up to 70,000 feet above the terrain, land or water. Altitude indicated is presented on the calibrated face of a cathode ray tube. This altimeter does not warn of approaching obstructions such as moun-

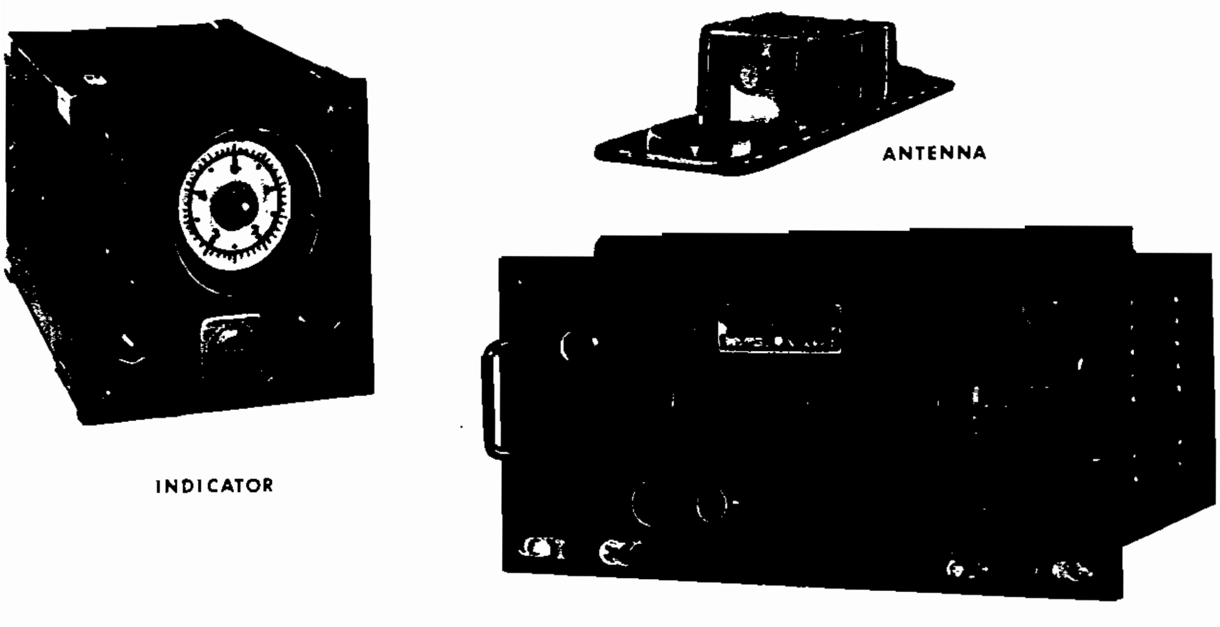


Figure 4-23. Absolute Altimeter System Components

tains because it measures altitude only to a point directly below the aircraft.

Components and Operating Principle. A typical set consists of the radar receiver-transmitter, height indicator, and antenna as shown in figure 4-23. The transmitter section of the receiver-transmitter unit develops recurring pulses of radio frequency (RF) energy which are delivered to the transmitter antenna located either flush mounted or on the underside of the aircraft. The transmitter antenna radiates the pulsed energy downward to reflect off the earth and return to the receiver antenna on the aircraft. The time consumed between transmission and reception of the RF pulse is determined only by the absolute altitude of the aircraft above the terrain since the radio wave velocity is constant. The receiver antenna delivers the returned pulse to the receiver section of the receiver-transmitter unit where it is amplified and detected for presentation on the indicator unit. On the indicator CRT a circular trace and a zero reference pulse are started coincidentially with emission of the transmitted pulse. The returned pulse, which arrives later, is displayed at a point on the circular trace determined by the aircraft absolute altitude. Calibration marks on the CRT face provide an altitude-reading scale.

Reading Altitude. The operating controls and reading scale of a typical set are located on the front panel of the indicator, shown in figure 4-24. To put such a set into operation, turn the REC GAIN knob clockwise and allow a few minutes for warmup.

The reading scale is a circular trace. One complete revolution represents either 5000 feet or 50,000 feet, depending on the position of the TIMES ONE (X-1), TIMES TEN (X-10), switch.

When the set is operating, two lobes appear on the trace. One is the zero reference lobe which can be adjusted to coincide with zero on the scale. The other lobe is the reflected or altitude lobe which moves around the scale according to the absolute altitude of the aircraft.

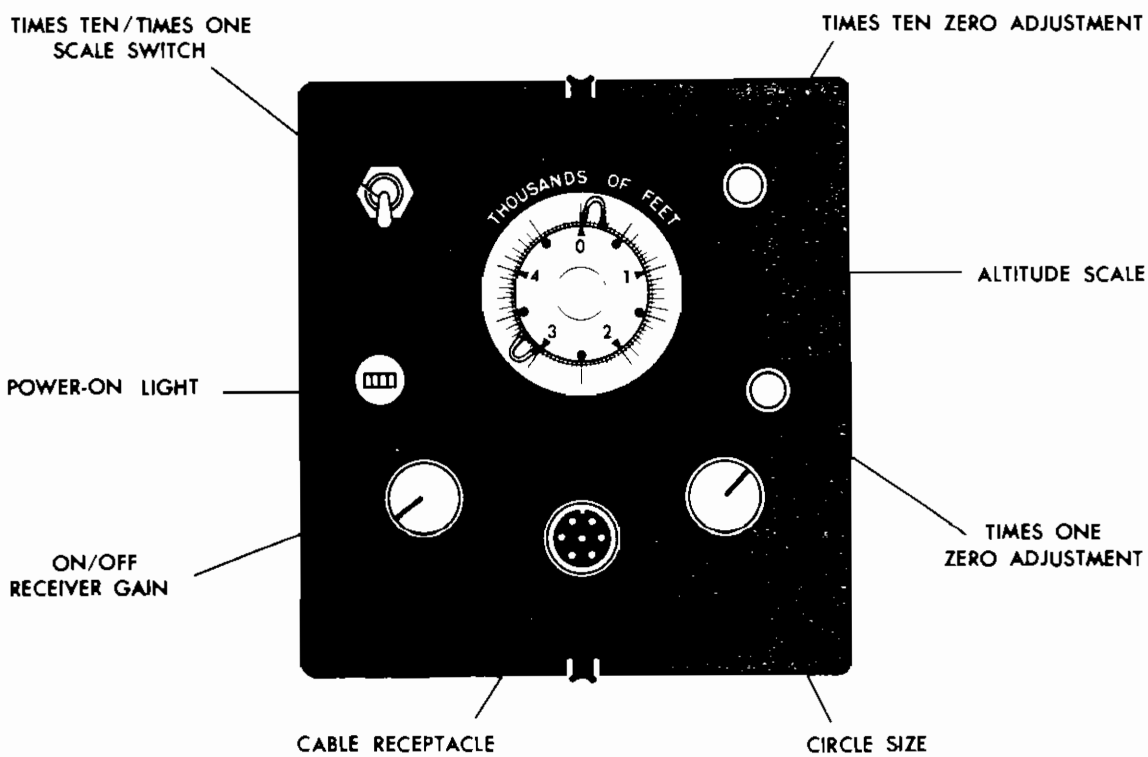


Figure 4-24. Absolute Altimeter (Indicator)

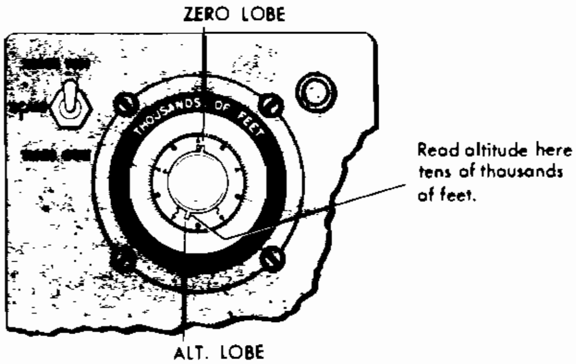


Figure 4-25. Reading Indicator, Times Ten Scale

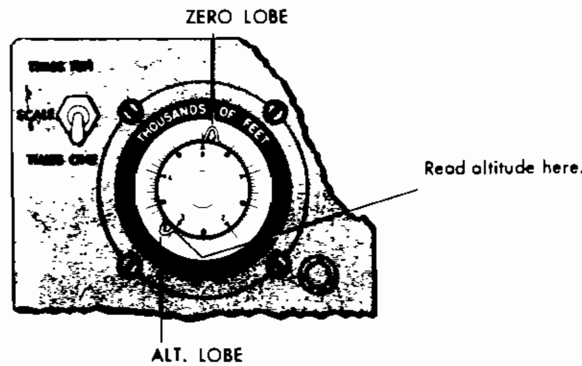


Figure 4-26. Reading Indicator, Times One Scale

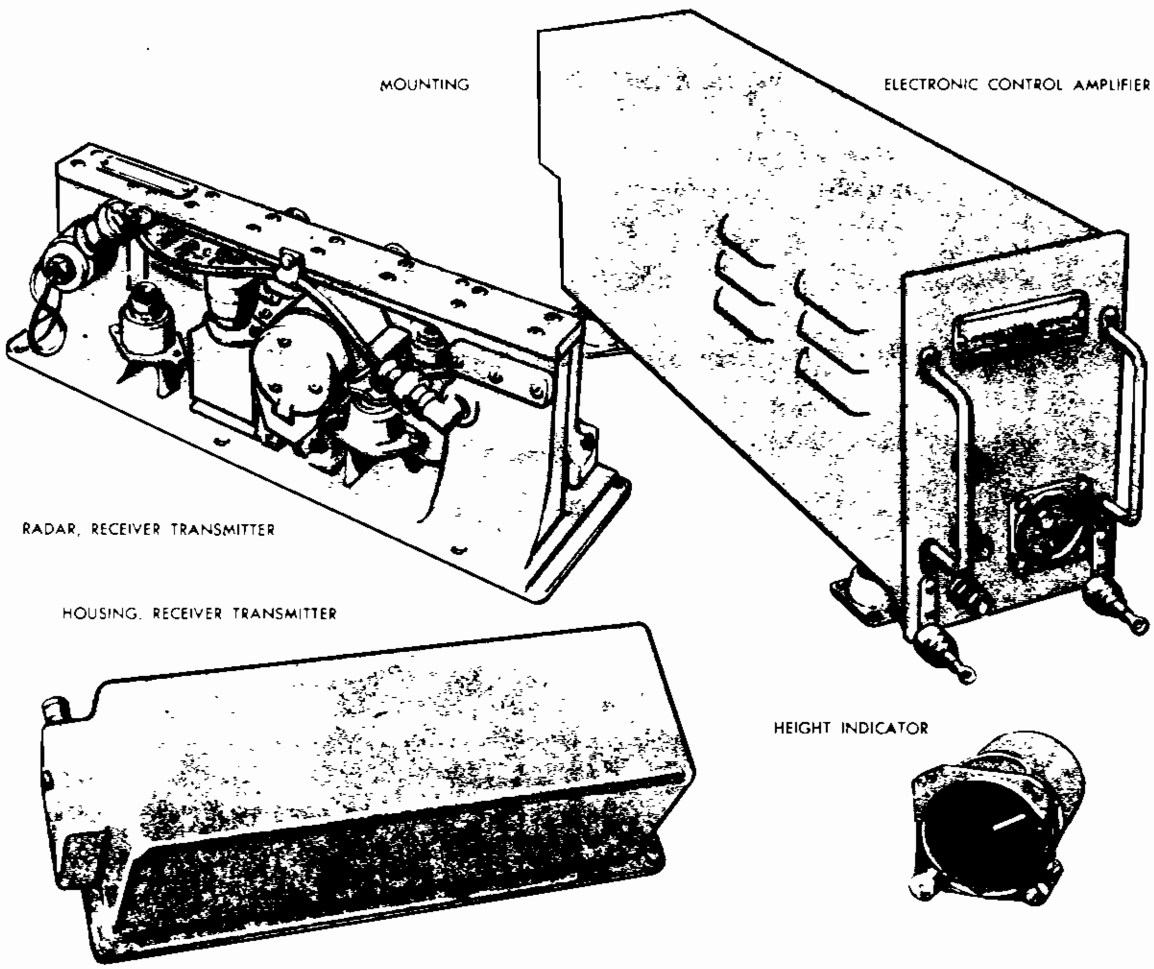


Figure 4-27. Radar Altimeter Set

Reading this type of altimeter is illustrated. In the X-10 position (figure 4-25), the indicator shows the altitude to be between 25,000 and 30,000 feet. Read the 5,000-foot marker next below the position of the lobe (25,000 feet). Next place the scale switch in the X-1 position (figure 4-26) and take the exact altitude indicated (3,000 feet). The sum of the two altitude readings (25,-000 feet plus 3,000 feet) is equal to the exact radar height of the aircraft (28,000 feet).

Radar Altimeter (Low Level)

This type altimeter provides a dial indication of the altitude of the aircraft above the terrain. It is designed to eliminate the necessity of adding antennas or any other equipment external to the surface of the aircraft. This equipment may also be used in conjunction with automatic pilot or other devices requiring altitude limit data

The components of a typical system include the receiver-transmitter, the height indicator, and the electronic control amplifier (figure 4-27). The height indicator contains the only operating control on the equipment. This instrument gives altitude readings of the aircraft up to 10,000 feet over land and up to 20,000 feet over water. The scale is logarithmic and is graduated in 10's of feet for the first 200 feet. From 200 feet to 20,000 feet, the graduations are gradually compressed. A limit indicator system is included to provide an indication of flight below a preset altitude.

To operate the equipment, turn the ON-LIMIT control to ON. After warmup, the terrain clearance of the aircraft within the range of 0-20,000 is read directly from the single printer on the indicator face. Notice the small triangular mark on the indicator in figure 4-28. This pointer can be preset to any desired altitude by the ON-LIMIT control and is used as a reference for flying at fixed altitudes. The altitude can be maintained by observing the position of the pointer with respect to the small triangular marker instead of the actual altitude scale. In addition, a red light on the front of the indicator lights up when the aircraft is at or below the preset altitude. To turn off the equipment, it is only necessary to turn off the ON-LIMIT control on the indicator.

TEMPERATURE

Determination of correct temperature is necessary for accurate computation of airspeed and altitude. Temperature, airspeed, and altitude are all closely interrelated, and the practicing navigator must be familiar with each in order to work effectively and accurately.

Temperature Gages

The temperature gage most commonly used in the Air Force employs a bimetallic element. The instrument, illustrated in figure 4-29, is a single unit consisting of a stainless steel stem which projects into the air stream and a head which contains the pointer and scale. The sensitive ele-

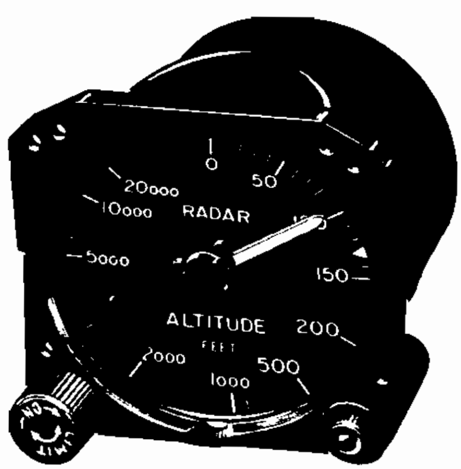


Figure 4-28. Radar Height Indicator

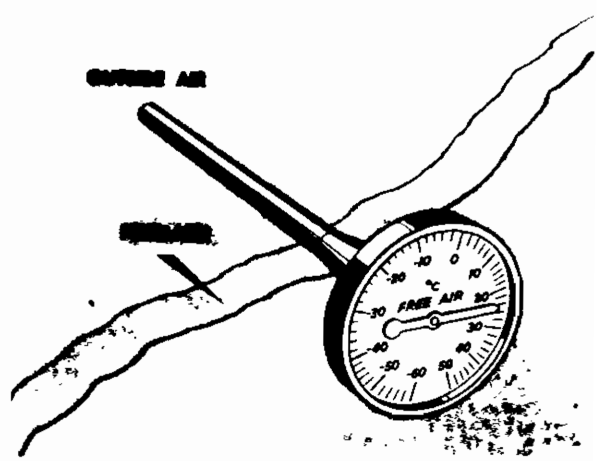


Figure 4-29. Free Air Temperature Gage

ment in the end of the stem—projected outside the aircraft—is covered by a radiation shield of brightly polished metal to cut down the amount of heat that the element might absorb by direct radiation from the sun.

The bimetallic element (called the sensitive element) is so named because it consists of two strips of different metal alloys welded together. When the element is heated, one alloy expands more rapidly than the other causing the element, which is shaped like a coil spring, to turn. This, in turn, causes the indicator needle to move on the pointer dial. Temperature between −60°C and +50°C can be measured on this type of thermometer.

Temperature Scales

In the United States, temperature is usually expressed in terms of the Fahrenheit scale (°F). In aviation, temperature is customarily measured on the centigrade, or Celsius, (°C) scale.

Although aircraft thermometers are usually calibrated in °C, it is sometimes necessary to interconvert Fahrenheit and centigrade temperatures. The following formulas may be used:

$$°F = (1.8 \times °C) + 32°$$

$$°C = \frac{°F - 32°}{1.8}$$

Temperature error is the total effect of scale error and heat of compression error. *Scale error* is simply an erroneous reading of the pointer under standard conditions. It is difficult for a crew member to evaluate this error without sensitive testing equipment. With this in mind, the reading of the indicator is considered correct and is called indicated air temperature (IAT).

The second error, *heat of compression error*, causes the instrument to read too warm. Heating occurs at high speeds from friction and the compression of air on the forward edge of the temperature probe. Thus the IAT is always corrected by a minus correction factor to produce true air temperature (TAT). Heat of compression increases with true airspeed. The TAT can be obtained from the aircraft flight manual.

AIRSPEED

Airspeed is the speed of the aircraft with relation to the air mass surrounding that aircraft.

Pitot-Static System

Accurate airspeed measurement is obtained by means of a pitot-static system. The system consists of: (1) a tube mounted parallel to the longitudinal axis of the aircraft in an area that is free of turbulent air generated by the aircraft, and (2) a static source that provides still, or undisturbed, air pressure.

Ram and static pressures may be taken from a single pitot-static tube or from completely separate sources. A pitot-static tube usually has a baffle plate, as shown in figure 4-30, to reduce turbulence and to prevent rain, ice, and dirt from entering the tube. There may be one or more drain holes in the bottom of the tube to dispose of condensed moisture. A built-in electrical heating element, controlled by a switch inside the aircraft, prevents the formation of ice in the tube.

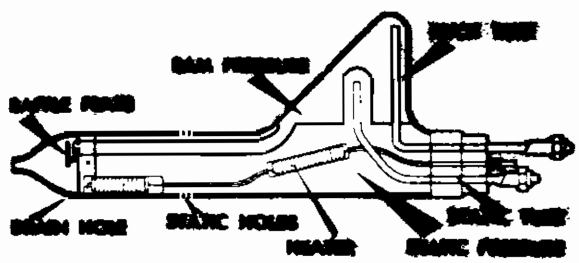


Figure 4-30. Structure of the Pitot Tube

Reasonable care should be taken with the pitot-static system to insure continuous, reliable service. The drain holes should be checked periodically to insure they are not clogged. At the completion of each flight, a cover is placed over the intake end of the tube to prevent dirt and moisture from collecting in the tube.

Principles of Operation of Airspeed Indicator

The heart of the airspeed indicator is a diaphragm which is sensitive to pressure changes. Figure 4-31 shows it located inside the indicator case and connected to the ram air source in the pitot tube. The indicator case is sealed airtight and connected to the static pressure source. The differential pressure created by the relative effects of the impact and static pressures on the diaphragm causes it to expand or contract. As the speed of the aircraft increases, the impact pressure increases, causing the diaphragm to expand. Through mechanical linkage, the expansion is displayed as an increase in airspeed. This principle is used in the indicated airspeed meter, the true airspeed meter, and the Machmeter.

Airspeed Definitions

There are many reasons for the difference between indicated airspeed and true airspeed. Some of these reasons are the error in the mechanical makeup of the instrument, the error caused by incorrect installation, and the fact that density and pressure of the atmosphere vary from standard conditions.

INDICATED AIRSPEED (IAS). Indicated airspeed is the uncorrected reading taken from the face of the indicator. It is the airspeed that the instrument shows on the dial. It can be read in miles per hour or in knots, depending upon the scale of the dial.

BASIC AIRSPEED (BAS). Basic airspeed is the indicated airspeed corrected for instrument error. Each airspeed indicator has its own characteristics which cause it to differ from any other airspeed indicator. These differences may be caused by slightly different hairspring tensions, flexibility of the diaphragm, accuracy of the scale markings, or even the effect of temperature on the different metals in the indicator mechanism. The effect of temperature introduces an instrument error due to the variance in the coefficient of expansion of the different metals comprising the working mechanism. This error can be removed by the installation of a bimetallic compensator within the mechanical linkage. This bimetallic compensator is installed and properly set at the factory, thereby eliminating the temperature error within the instrument. The accuracy of the airspeed indicator is also affected by the length and curvature of the pressure line from the pitot tube. These installation errors must be corrected mathematically. Installation, scale, and instrument errors are all combined under one title called instrument error. Instrument error is factory determined to be within specified tolerances for various airspeeds. It is considered negligible or is accounted for in TO tables and graphs.

CALIBRATED AIRSPEED (CAS). Calibrated airspeed is basic airspeed corrected for pitot-static error and or attitude of the aircraft. The pitot-static system of a moving aircraft will have some error. Minor errors will be found in the pitot section of the system. The major difficulty is encountered in the static pressure section. As the flight attitude of the aircraft changes, the pressure

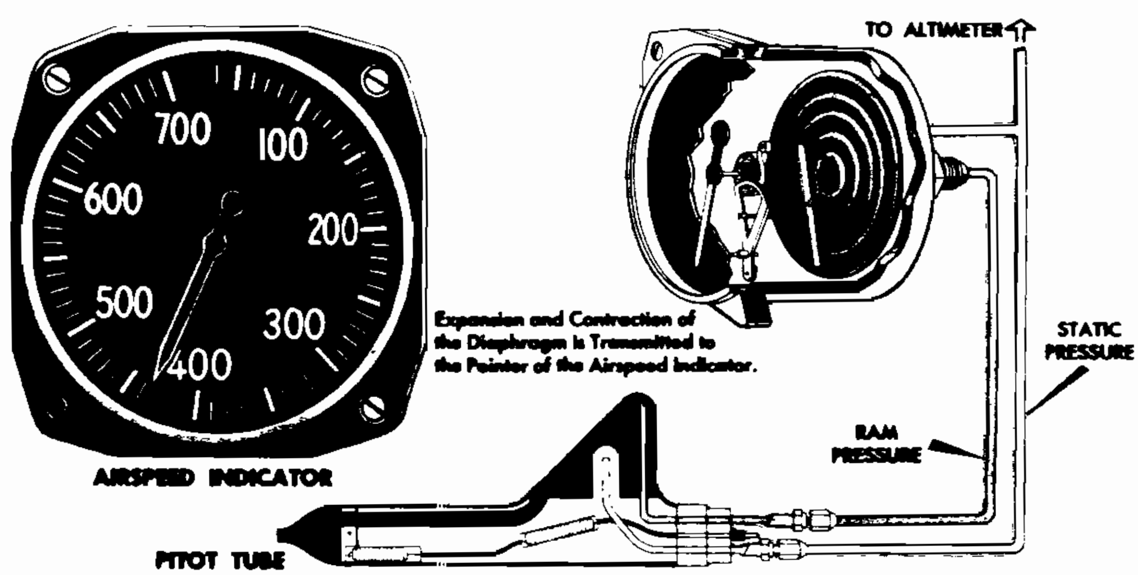


Figure 4-31. Operating Principle of the Airspeed Indicator

at the static inlets changes. This is caused by the airstream striking the inlet at an angle. Different types and locations of installations cause different errors. It is immaterial whether the static source is located in the pitot-static head or at some flush mounting on the aircraft. This error will be essentially the same for all aircraft of the same model, and a correction can be computed by referring to tables found in the appendix of the appropriate flight manual (see figure 4-32).

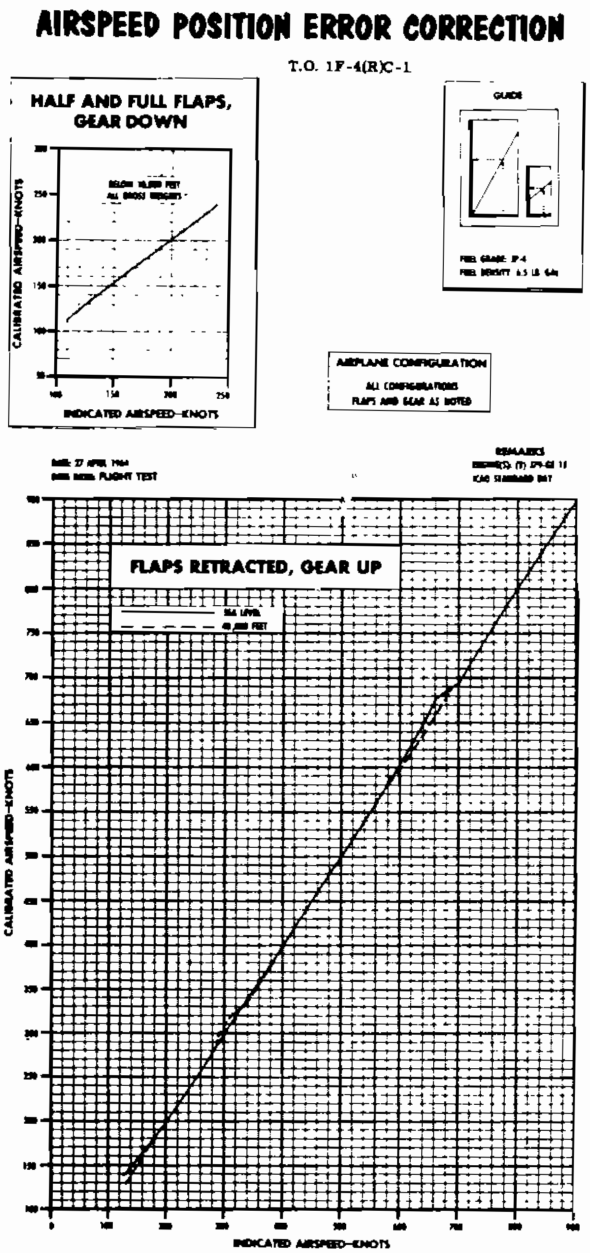


Figure 4-32. Airspeed Installation Correction

EQUIVALENT AIRSPEED (EAS). Equivalent airspeed is calibrated airspeed corrected for compressibility. Compressibility error has come into prominence with the advent of high speed aircraft. It becomes noticeable when the airspeed is great enough to create an impact pressure which causes the air molecules to be compressed within the impact chamber of the pitot tube. The amount of compression is directly proportionate to the impact pressure. As the air is compressed, it causes the dynamic pressure to be greater than it should be. Therefore, the correction is a negative value. The correction for compressibility error can be determined by referring to the performance data section of the aircraft flight manual or by using the "F" correction factor on the DR computer.

DENSITY AIRSPEED (DAS). Density airspeed is calibrated airspeed corrected for pressure altitude and true air temperature. Pitot pressure varies not only with airspeed but also with air density. As the density of the atmosphere decreases with height, pitot pressure for a given airspeed must also decrease with height. Thus, an airspeed indicator operating in a less dense medium than that for which it was calibrated will indicate an airspeed lower than true speed. The higher the aircraft flies, the greater the discrepancy. The necessary correction can be found on the DR computer. Using the window on the computer above the area marked FOR AIRSPEED DENSITY ALTITUDE COMPUTATIONS, set the pressure altitude against the True Air Temperature (TAT). Opposite the calibrated airspeed on the minutes scale, read the density airspeed on the miles scale. At lower airspeeds and altitudes, density airspeed may be taken as true airspeed with negligible error. However, at high speeds and altitudes, this is no longer true and compressibility error must be considered. (Compressibility error is explained in the equivalent airspeed section.) When density altitude is multiplied by the compressibility factor, the result is true airspeed.

TRUE AIRSPEED (TAS). True airspeed is equivalent airspeed which has been corrected for air density error. By correcting EAS for true air temperature and pressure altitude, the navigator compensates for air density error and computes an accurate value of TAS. The true airspeed increases with altitude when the indicated airspeed remains constant. When the airspeed remains

Figure 4-33. ICE-T Method

constant, the indicated airspeed decreases with altitude. Calibrated and equivalent airspeeds can be determined by referring to the performance data section of the aircraft flight manual.

Computing True Airspeed

ICE-T METHOD. To compute true airspeed (TAS) using the ICE-T method on the DR computer, solve for each type of airspeed in the order of I, C, E, and T; that is, change indicated airspeed to calibrated, change calibrated to equivalent, and change equivalent to true. This process is illustrated by the following sample problem. (Refer to definitions as necessary.)

Given: Pressure Altitude(PA): 30,000′
Temperature: —37°C
Indicated Airspeed(IAS): 253 knots
Flight Manual Correction
Factor: +2 knots

Find: Calibrated Airspeed (CAS)
Equivalent Airspeed (EAS)
True Airspeed (TAS)

Answer: CAS is determined by algebraically adding to IAS the correction factor taken from the chart in your flight manual. (This correction is insignificant at low speeds but can be higher than 10 knots near Mach 1.)

To correct CAS to EAS, use the chart on the slide of the computer entitled F CORRECTION FACTORS FOR TAS. See figure 4-33. Enter the chart with CAS and PA. The F factor is .96. This means we multiply CAS by .96 or take 96% of 255 knots. To do this, place 255 knots on the inner scale under the "10" index on the outer scale. Locate 96 on the outer scale and read EAS on the inner scale: 245 knots.

Now we need to correct EAS for temperature and altitude to get TAS. As shown in figure 4-33, in the window marked FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS place temperature over PA. Locate the EAS of 245 knots on the inner scale and read TAS on the outer scale. The TAS is 408 knots.

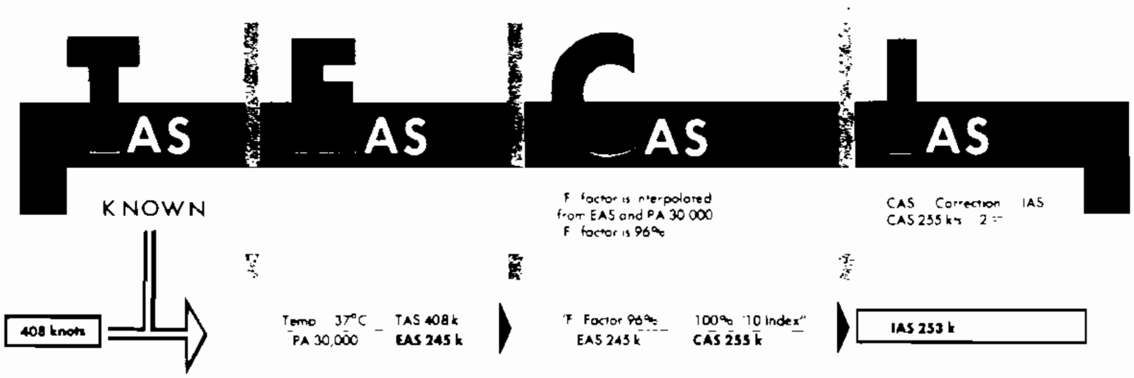


Figure 4-34. ICE-T Method in Reverse

ALTERNATE TAS METHOD. There is an alternate method of finding TAS when given CAS. The instructions for the alternate solution are printed on the computer directly below the F factor table. Mathematically, your answer should be the same regardless of the procedure you use, but the ICE-T method is used most often because the computation can be worked backwards from TAS. If you wish to maintain a constant TAS, you can determine what CAS or IAS to fly, by working the ICE-T method in reverse as illustrated in figure 4-34.

Machmeters

Machmeters indicate the ratio of aircraft speed to the speed of sound at any particular altitude and temperature during flight. It is often necessary to convert TAS to a Mach number or vice versa. Instruction are clearly written on the computer in the center portion of the circular slide rule.

Locate the window marked FOR AIRSPEED AND DENSITY ALTITUDE COMPUTATIONS and rotate the disc until the window points to the top of the computer (toward the 10 index on the outer scale). Within the window is an arrow entitled MACH NO. INDEX. See figure 4-35. To obtain TAS from a given Mach number, set air temperature over the MACH NO. INDEX, and opposite the Mach number on the MINUTES scale, read the TAS on the outer scale.

Example: If you are planning to maintain Mach 1.2 on a cross-country flight, place the air temperature at flight altitude over the MACH NO. INDEX. Read the TAS on the outer scale opposite 1.2 on the inner scale. If the temperature is —20°C, the TAS will be 742 knots.

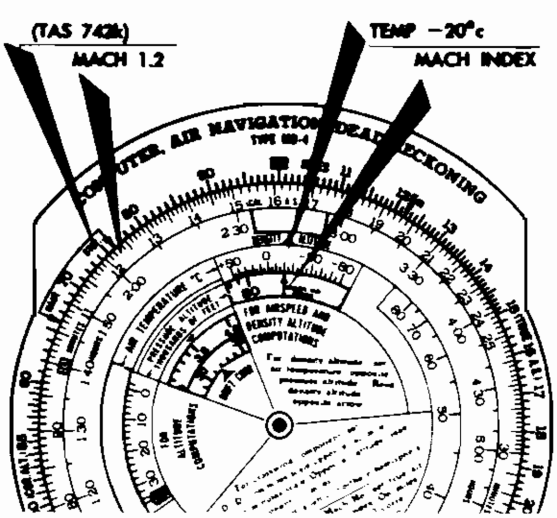


Figure 4-35. Finding TAS from Mach Number

AIRSPEED INDICATORS

True Airspeed Indicator

Most true airspeed indicators display true airspeed by a single pointer on a fixed circular scale as illustrated in figure 4-36. They employ an aneroid cell, a differential pressure diaphragm, and a temperature diaphragm to measure impact pressure, barometric pressure, and free air temperatures. The combined actions of the diaphragms mechanically compensate for air density error to provide an indication of true airspeed.

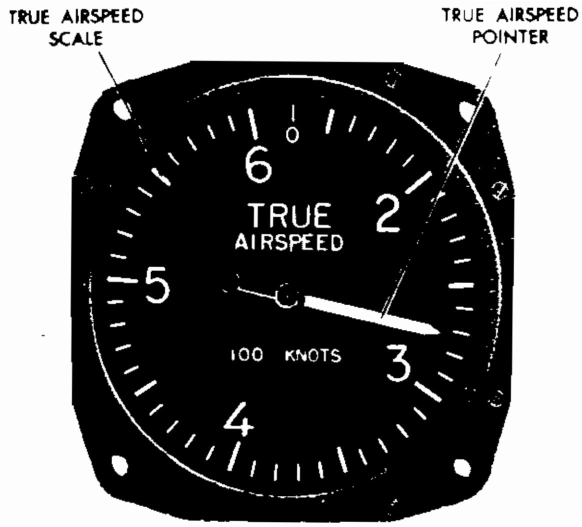


Figure 4-36. True Airspeed Indicator

Maximum Allowable Airspeed Indicator

This indicator, figure 4-37, displays indicated airspeed in 100's of knots by an indicated airspeed pointer on a fixed circular scale. It displays values less than 100 knots on a rotating scale in a readout window. A maximum allowable indicated airspeed pointer continuously indicates the maximum allowable indicated airspeed for the particular aircraft. Its indications are governed by an aneroid cell which expands as altitude increases, causing the maximum allowable indicated airspeed pointer indications to decrease. The maximum allowable Mach marker is set to the maximum allowable indicated Mach number for the aircraft.

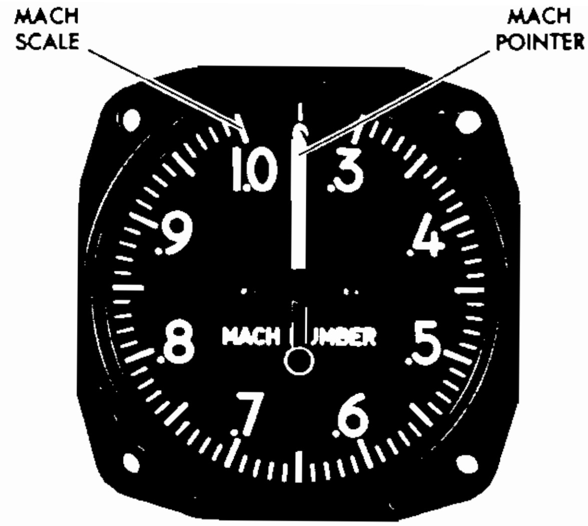


Figure 4-38. Mach Indicator

Mach Indicator

The Mach indicator, shown in figure 4-38, displays Mach number which is the ratio between the true airspeed of the aircraft and the speed of sound at flight altitude. In computing a true airspeed from indicated airspeed, air density must be taken into account. This requires that a correction for temperature and altitude be made on a DR computer. With a Mach number, these corrections are unnecessary because the existing temperature at flight level determines the speed of sound at flight level. The Mach number is determined by the speed of sound, which in turn is determined by air density; thus, Mach is always a valid index to the speed of the aircraft.

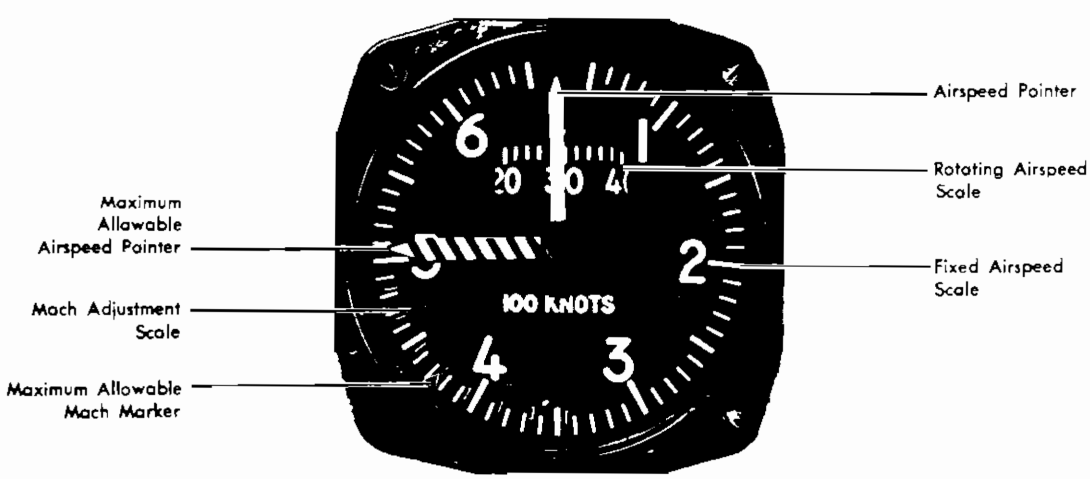


Figure 4-37. Maximum Allowable Airspeed Indicator

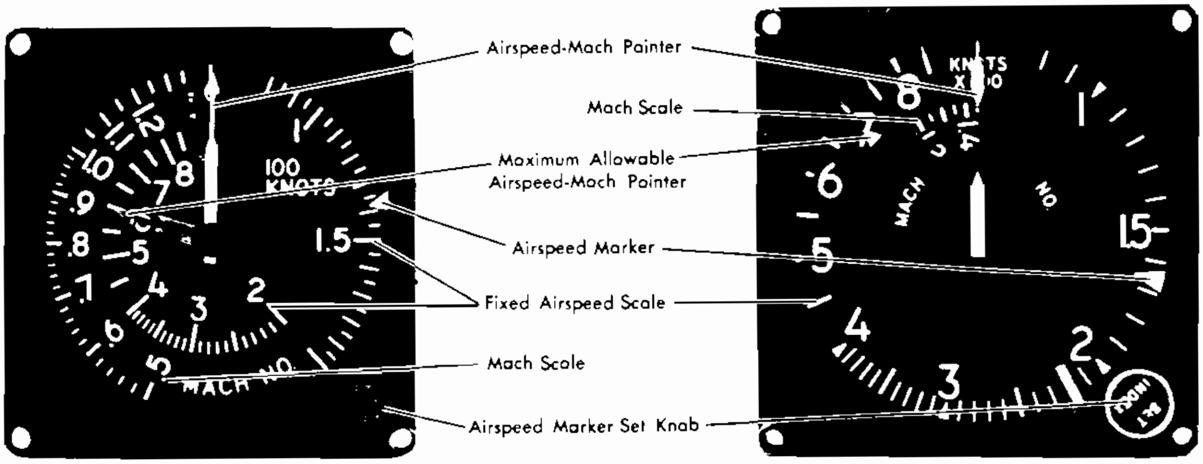


Figure 4-39. Combined Airspeed-Mach Indicators

Combined Airspeed-Mach Indicator

The combined airspeed-Mach indicator, shown in figure 4-39 is usually found in high-performance aircraft or where instrument panel space is limited. It simultaneously displays indicated airspeed, indicated Mach number, and maximum allowable airspeed. It contains a differential pressure diaphragm and two aneroid cells. The diaphragm drives the airspeed-Mach pointer. One aneroid cell rotates the Mach scale, permitting indicated airspeed and Mach number to be read simultaneously. The second aneroid cell drives the maximum allowable airspeed pointer. This pointer is preset to the aircraft's maximum indicated airspeed. Unlike the maximum indicated airspeed and unlike the maximum allowable airspeed, Mach number increases with altitude. An airspeed marker set knob positions a movable airspeed marker. This marker serves as a memory reference for desired airspeeds.

Summary of Types of Airspeed

INDICATED AIRSPEED (IAS) is the uncorrected reading taken directly from the indicator.

BASIC AIRSPEED (BAS) is the IAS corrected for instrument error.

CALIBRATED AIRSPEED (CAS) is the BAS corrected for pitot-static system error, and error induced by the attitude of the aircraft.

EQUIVALENT AIRSPEED (EAS) is CAS corrected for compressibility error.

DENSITY AIRSPEED (DAS) is the CAS corrected for pressure and temperature.

TRUE AIRSPEED (TAS) is EAS corrected for air density error (pressure and temperature). Other TAS relationships are as follows:

TAS = Density airspeed corrected for compressibility

TAS = True Mach corrected for true air temperature

INDICATED MACH NUMBER (IMN) is the Mach number displayed on the Mach indicator.

TRUE MACH NUMBER (TMN) is indicated Mach corrected for installation/position error.

Calibrated and equivalent airspeed and true Mach can be determined by referring to the performance data section of the aircraft flight manual.

CHAPTER 5

Dead Reckoning

The navigator builds his knowledge upon certain fundamentals. In navigation these basic ideas or methods are called *dead reckoning (DR) procedures*. Correct use of the plotter, dividers, computer, and charts to solve the three basic problems of navigation (position of the aircraft, direction to destination, and time of arrival) all make up dead reckoning procedures.

It is possible, using only basic instruments such as the pressure altimeter, compass, airspeed meter, and driftmeter, to navigate directly to any place in the world. But this would take conditions approaching the ideal such as good weather and perfect instruments. Therefore aids to dead reckoning or DR such as celestial, radar, loran, map reading, etc., have been developed to correct inadequacies of basic navigation. These aids are primarily known as fixing aids, and they provide information from which the fundamental skills of DR can be used to compute winds, groundspeeds, and alterations to the path of the aircraft in order to complete an assigned mission.

Thus, proficiency in DR procedures is indispensable if full use is to be made of the aids to navigation.

PLOTTING

A navigator must learn proper chart work before he can direct an aircraft from one point to another. The structure and properties of maps and charts have been covered. Now, the next step is plotting positions and directions or lines on a chart. Chart work should be an accurate and graphic picture of the progress of the aircraft from departure to destination and, with the log, should serve as a complete record of the flight. Thus it also follows that the navigator must be familiar with and use accepted standard symbols and labels on his chart as shown in figure 5-1.

Explanation of Terms

Several terms have been mentioned in earlier portions of this manual. Precise definitions of these terms must now be understood before the mechanics of chart work are learned.

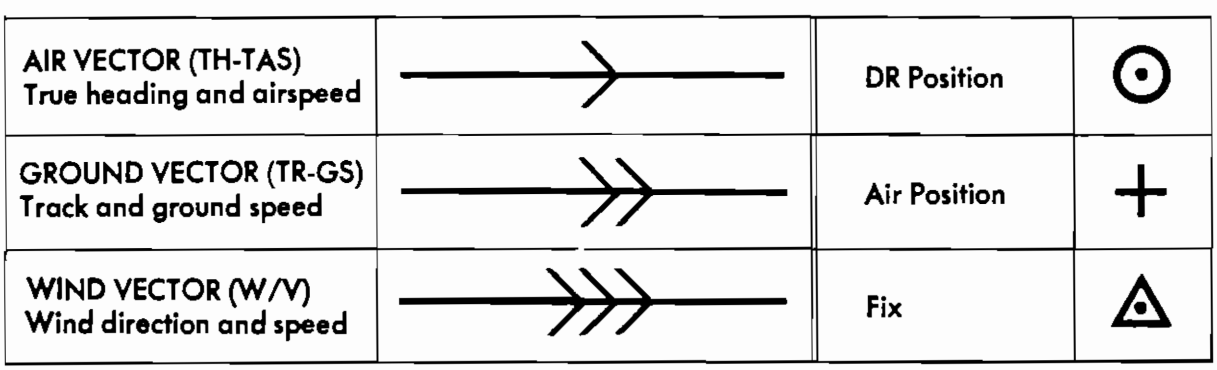


Figure 5-1. Standard Plotting Symbols

TRUE COURSE (TC) is the intended horizontal direction of travel over the surface of the earth, expressed as an angle measured clockwise from true north (000°) through 360 degrees.

COURSE LINE is the horizontal component of the intended path of the aircraft comprising both direction and magnitude or distance.

TRACK (TR) is the horizontal component of the *actual* path of the aircraft over the surface of the earth. Track may, but very seldom does, coincide with the true course or *intended* path of the aircraft. The difference between the two is caused by an inability to predict perfectly all inflight conditions.

TRUE HEADING (TH) is the horizontal direction in which an aircraft is pointed. More precisely, it is the angle measured clockwise from true north through 360 degrees to the longitudinal axis of the aircraft. The difference between track and true heading is caused by wind and is explained under wind triangles.

GROUNDSPEED (GS) is the rate of motion of the aircraft relative to the earth's surface or, in simpler terms, it is the speed of the aircraft over the ground. It may be expressed in nautical miles, statute miles, or kilometers per hour, but, as a navigator, you will use nautical miles per hour *(knots)*.

TRUE AIRSPEED (TAS) is the rate of motion of an aircraft relative to the air mass surrounding it. Since the air mass is usually in motion in relation to the ground, airspeed and groundspeed seldom are the same.

DEAD RECKONING POSITION (DR POSITION) is a point in relation to the earth established by keeping an accurate account of time, groundspeed, and track since the last known position. It may also be defined as the position obtained by applying wind effect to the true heading and true airspeed of the aircraft.

A FIX is an accurate position determined by one of the aids to DR.

AIR POSITION (AP) is the location of the aircraft in relation to the air mass surrounding it. True heading and true airspeed are the components of the vector used to establish an air position.

MOST PROBABLE POSITION (MPP) is a position determined with partial reference to a DR position and partial reference to a fixing aid.

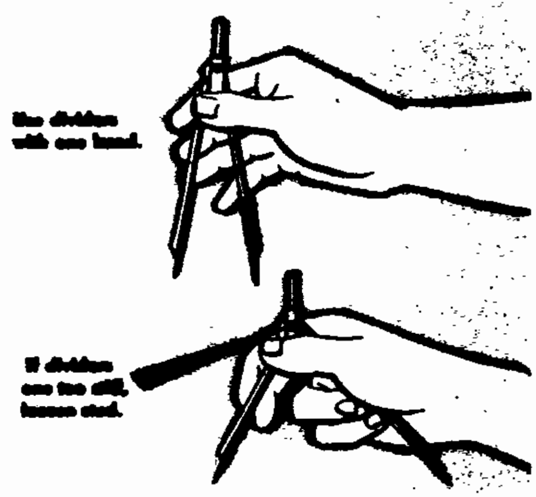


Figure 5-2. Use of Dividers

Plotting Equipment

PENCIL AND ERASER. Probably the most elementary but indispensable articles of plotting equipment are pencils and erasers. The pencil should be fairly soft and well sharpened. A hard pencil is undesirable, not only because it makes lines which are light and difficult to see, but also because it makes lines which are difficult to erase. An experienced navigator keeps his chart clean by erasing all unnecessary lines. It is good practice to carry several well-sharpened wooden pencils rather than a mechanical pencil. Mechanical pencils generally make broader, less precise lines.

Use a soft eraser which will not smudge or damage the chart. Hard, gritty erasers tend to wear away printed information as well as the paper itself. Not all erasers will remove all pencil lines, so find a pencil-eraser combination that will work satisfactorily. Nothing reflects a navigator's ability more than keeping neat, clean, and accurate charts and logs. An untidy chart, smudged and worn through in places, often causes one to conclude that the navigation performed was careless.

DIVIDERS. A pair of dividers is an instrument used for measuring distances on a chart by separating the points of the dividers to the desired distance on the proper scale (usually the latitude scale) and transferring this distance to the working area of the chart. In this way, lines of a desired length can be marked off. By reversing

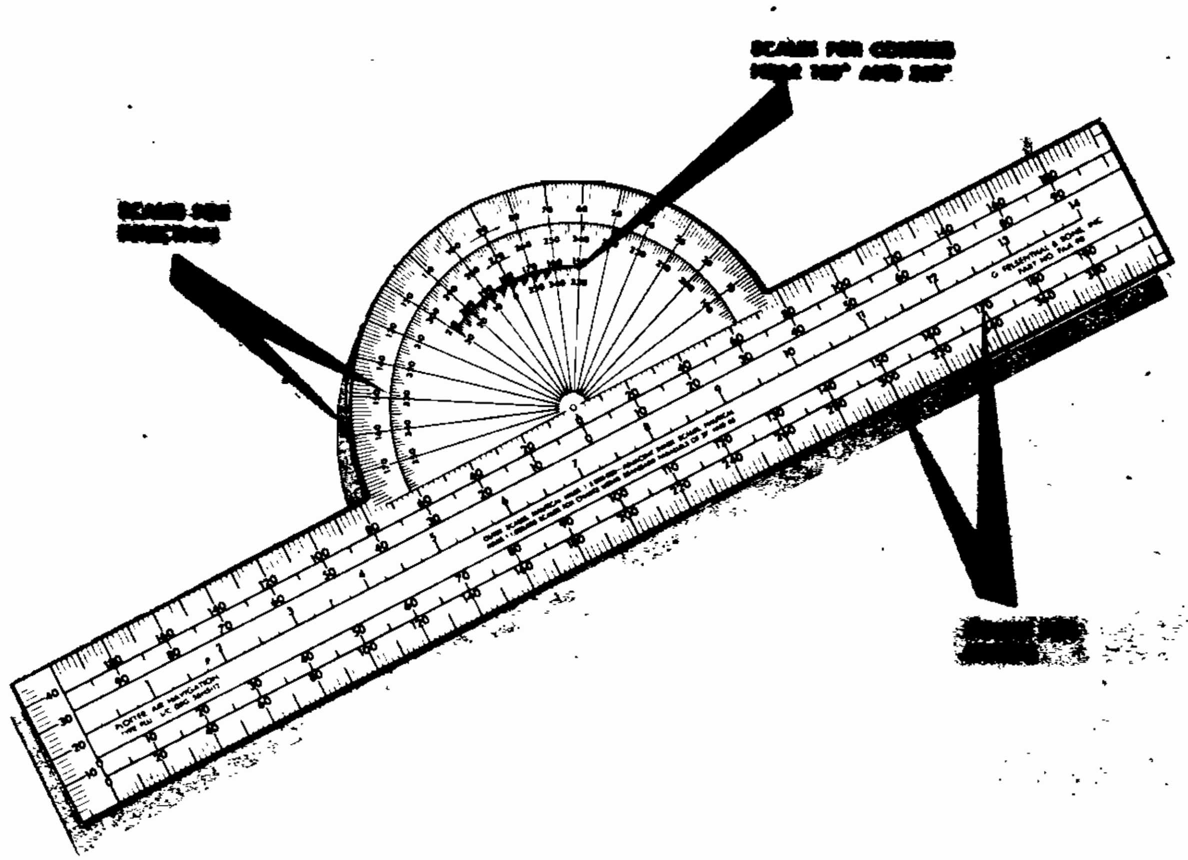


Figure 5-3. Typical Plotter

the process, unknown distances on the chart can be spanned and compared with the scale.

It is desirable to manipulate the dividers with one hand (see figure 5-2), leaving the other free to use the plotter, pencil, or chart as necessary. Most navigation dividers have a tension screw which you can adjust to prevent the dividers from becoming either too stiff or too loose for convenient use. Adjust the points of the dividers to approximately equal length. A small screw driver, required for these adjustments, should be a part of the navigator's equipment.

While making the measurement, hold the chart flat and smooth between the points of the dividers, as a wrinkle may cause an error of several miles. Mark points on a chart by applying slight pressure on the dividers so that they prick the chart. Too much pressure results in large holes in the chart and tends to spread the points of the dividers farther apart, reducing measurement accuracy. Precision navigation requires precision measurement.

PLOTTERS. A plotter is an instrument designed primarily to aid in drawing and measuring lines in desired directions. Plotters vary from complicated drafting machines and complete navigator's drafting sets to a simple plotter combining a kind of protractor and straight edge.

A common Air Force plotter is shown in figure 5-3. This plotter is a semicircular protractor with a straight edge attached to it. A small hole at the base of the protractor portion indicates the center of the arc of the angular scale. Two complete scales cover the outer edge of the protractor and are graduated in degrees. An abbreviated, inner scale measures the angle from the vertical.

The outer scale increases from 000 degrees to 180 degrees counterclockwise, and the inner

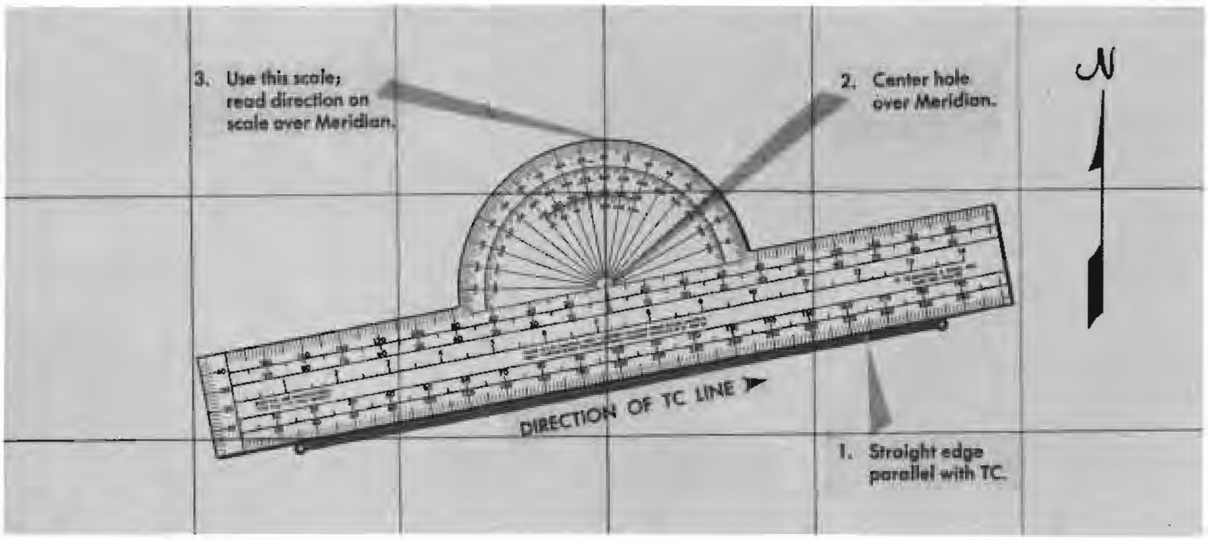


Figure 5-4. To Measure True Course

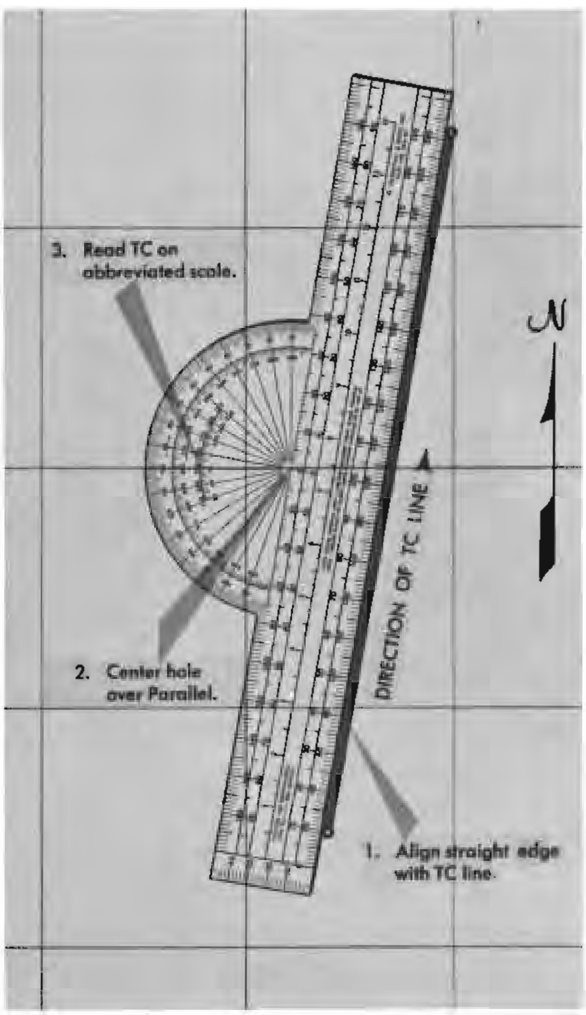


Figure 5-5. To Measure True Course Near 180° or 360°

scale increases from 180 degrees to 360 degrees counterclockwise. An angle is measured by placing the vertical line (that line containing the small hole) on a meridian, and aligning the base of the plotter with the line to be measured as shown in the illustrations measuring true course (figures 5-4 and 5-5).

The angle measured is the angle between the meridian and the straight line. The outer scale is used to read all angles between north through east to south, and the inner scale is used to read all angles between south through west to north as in figure 5-6.

Plotting Procedure, Mercator Chart

PREPARATION. A great many charts and plotting sheets are printed on the Mercator projection. When plotting work is done on a blank plotting sheet, with only the parallels of latitude and the meridians printed on it, the plotting sheet should be oriented correctly depending upon the latitude. If the chart is to be used in south latitudes, the sheet is turned upside down so that the latitude increases toward the south.

When plotting on charts which have only the parallels printed on them, the meridians should be assigned the appropriate values for the longitude of the flight. With *North* at the top of the chart, west longitude increases toward the western (left) edge and east longitude increases toward the eastern (right) edge. This is true in both

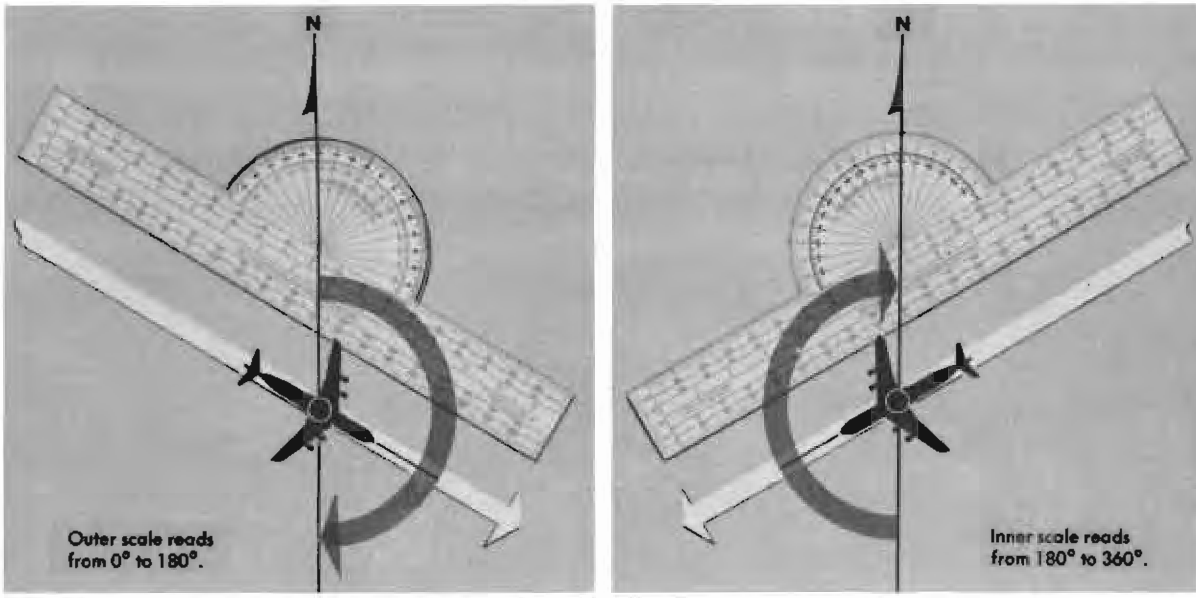


Figure 5-6. To Read Angles from Plotter

north and south latitudes. However, with *South* at the top of the chart, west longitude increases to the right and east longitude increases to the left. Once the meridians are numbered, the points of departure and destination should be plotted, along with important navigation aids.

Before starting any plot, note the scale and projection of the chart and check the date to make sure that it is the latest edition. The latitude scale is used to represent nautical miles. The longitude scale should never be used to measure distance. Some charts carry a linear scale in the margin, and, where present, it indicates that the same scale may be used anywhere on the chart.

PLOTTING POSITIONS. On some Mercator charts, the spacing between meridians and parallels is close enough to permit plotting by visual interpolation. However, on most Mercator charts, the meridians and parallels are more widely spaced, necessitating the use of dividers. There are several methods by which positions can be plotted on Mercator charts. One method is illustrated in figure 5-7. Place the straight edge of the plotter in a vertical position, at the desired longitude. Set the dividers to the desired number of minutes of latitude. Hold one point against the straight edge on the parallel of latitude corresponding to the whole degree of latitude given. Let the other point also rest against the straight edge and lightly prick the chart. This marks the desired position. In measuring the latitude and

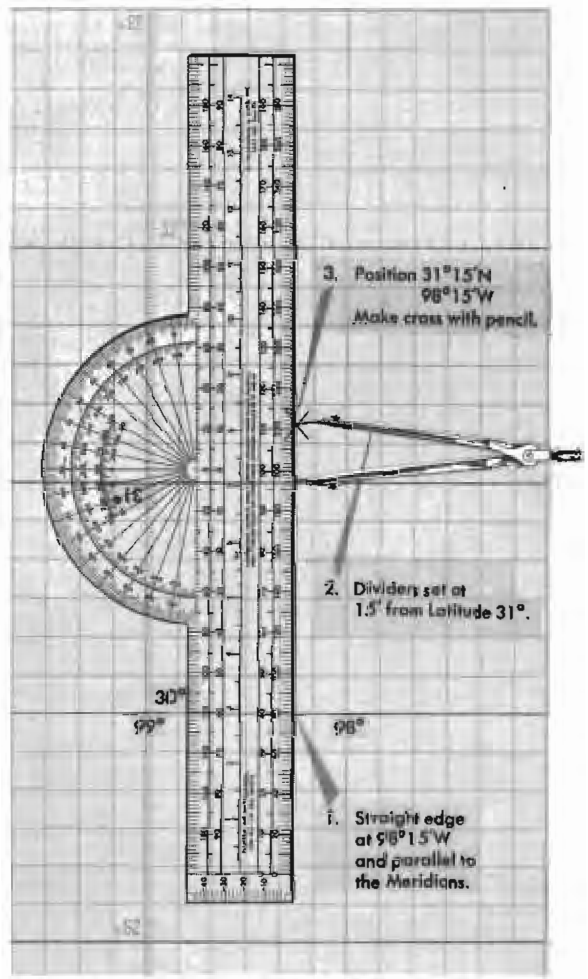


Figure 5-7. Plotting Positions on a Mercator

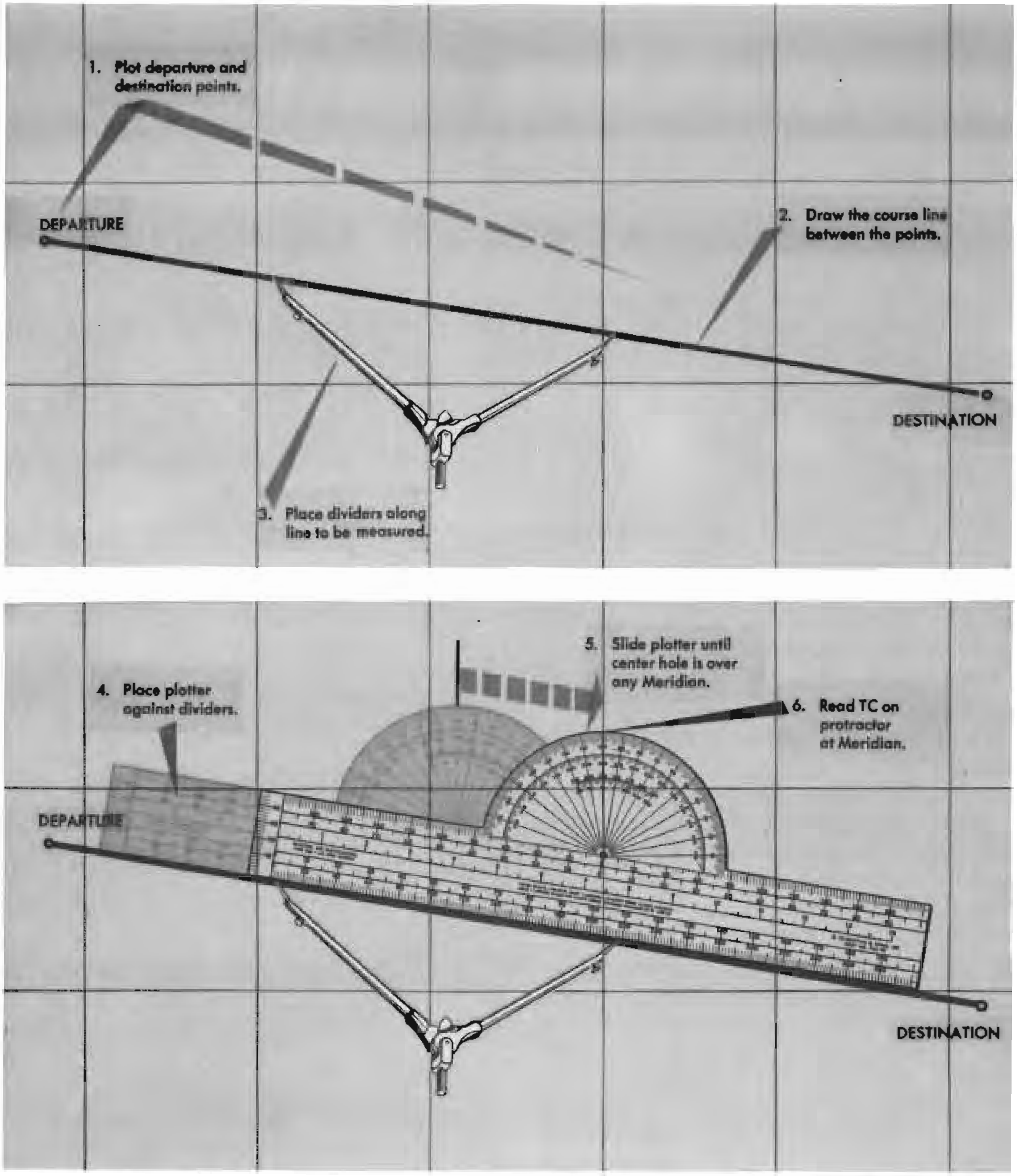


Figure 5-8. Reading Direction of Course Line

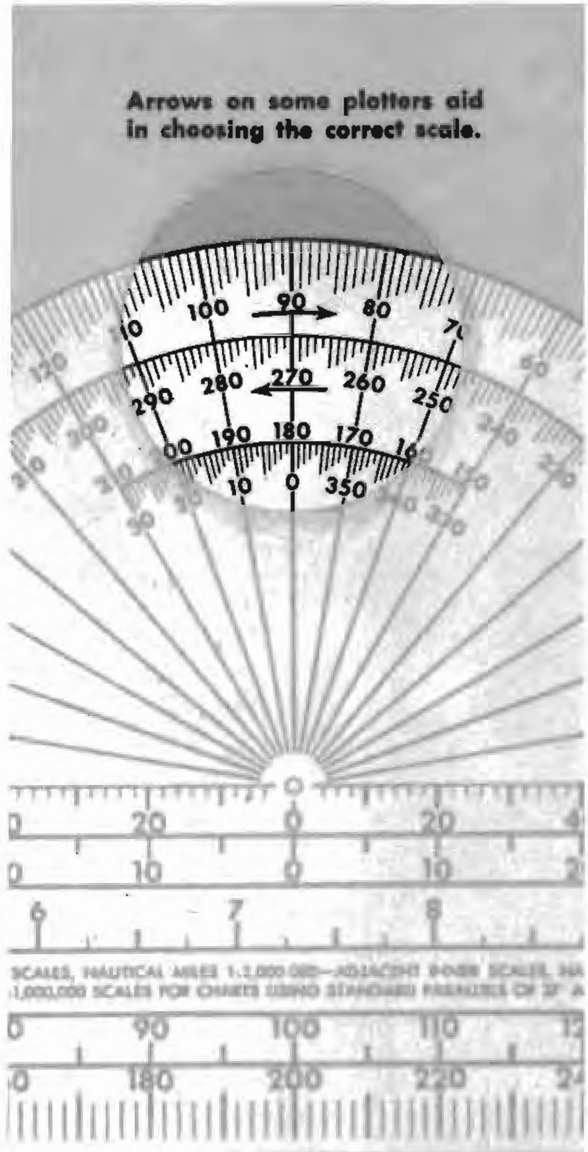
longitude of a position already plotted, reverse the procedure.

PLOTTING AND MEASURING COURSES. Plot departure and destination on the chart, as shown in figure 5-8, Step 1. Step 2 is to draw the course line between the two points. If they are close together, the straight edge of the plotter can be used. If they are far apart, two plotters can be used together, or a longer straight edge can be used. If none of these methods is adequate, fold the edge of the chart so that the fold connects the departure and destination points, and make a series of pencil marks along the edge. A plotter or straight edge can then be used to connect the points when the chart is unfolded.

After the course line has been plotted and labeled, the next step is to determine its direction. Place the points of the dividers or a pencil anywhere along the line to be measured, Step 3. Place the plotter against the dividers, Step 4. Slide the plotter until the center hole is over any meridian as shown in Step 5. Read TC on the protractor at the meridian, Step 6. Keep in mind the approximate direction of the line when reading the protractor.

A course line has two possible directions (figure 5-9): the correct one and the opposite or reciprocal. The error of plotting and measuring reciprocals is, unfortunately, all too common, and such mistakes have resulted in serious trouble for more than one navigator. By having a mental picture of the compass rose, the navigator can save himself the embarrassment of plotting or measuring reciprocal courses or bearings. Small arrows are found on some plotters near the 90°-270° marks to minimize the possibility of reading the wrong scale.

Measuring Nearly Vertical Lines. Sometimes the line whose direction is to be measured runs nearly north or south, making it difficult to align the hole in the plotter with a meridian. In this case, the easiest solution is to use a parallel of latitude as a reference instead of a meridian. Move the plotter along a line until the center hole is over any parallel of latitude. Measure the direction of the line by reading the degree scale on the same parallel and mentally adding or subtracting 90 degrees. Some plotters are provided with an abbreviated scale for measuring such angles without adding or subtracting 90 degrees.



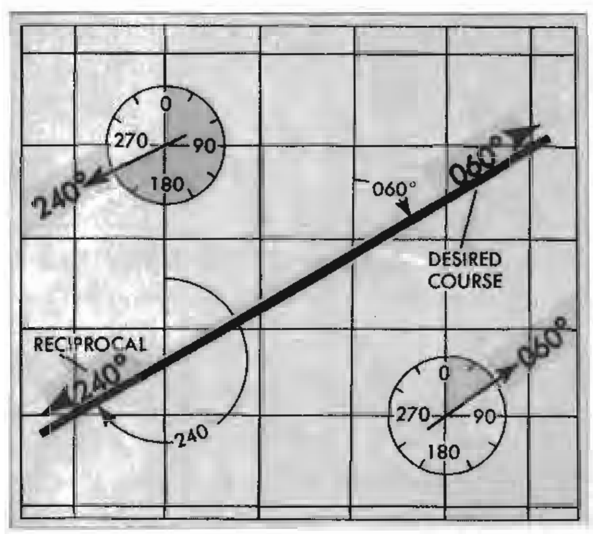


Figure 5-9. Reciprocal Directions

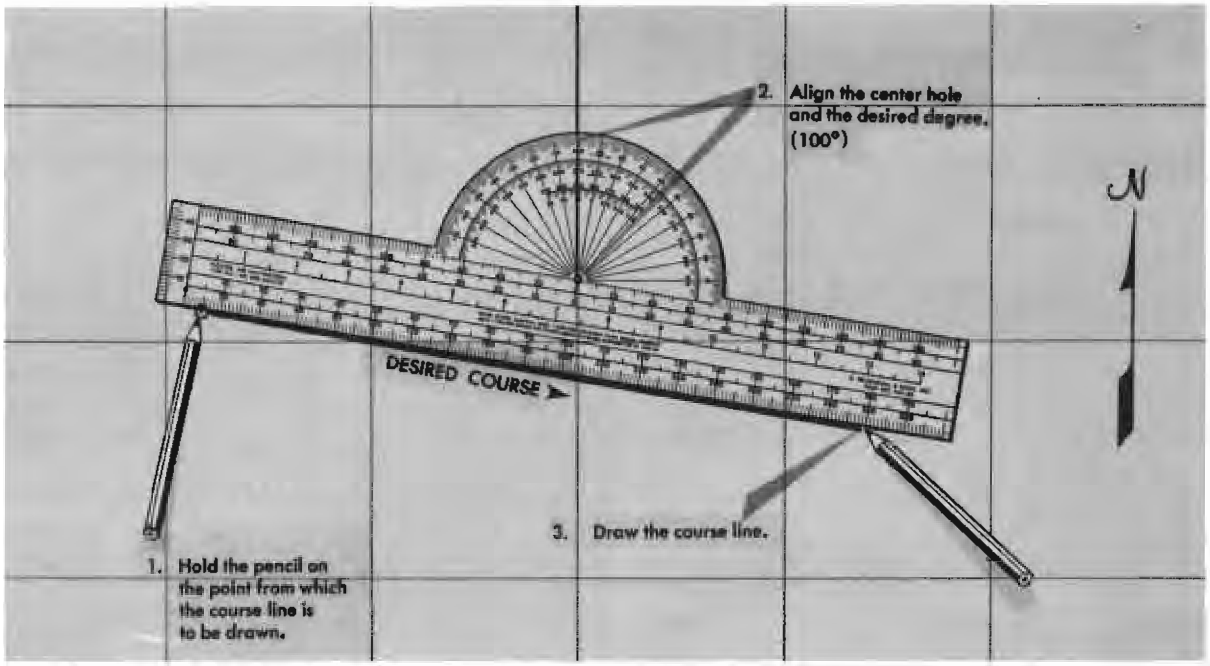


Figure 5-10. Plotting Course from Given Position

PLOTTING COURSES FROM GIVEN POSITION. A course from a given position can be plotted quickly in the following manner: Place the point of a pencil on the position and slide the plotter along this point, rotating it as necessary, until the center hole and the figure on the protractor representing the desired direction are lined up with the same meridian. Hold the plotter in place and draw the line along the straight edge (figure 5-10).

PLOTTING NEARLY VERTICAL COURSES. When a course which extends nearly north or south is to be plotted, the simplest method of orienting a plotter is to align the plotter with a parallel of latitude, as explained previously. Hold a pencil on the point from which the course is to be drawn, and then slide the plotter along the pencil until the center hole and the desired degree on the abbreviated scale of the protractor are both on the same parallel. The edge of the plotter against the pencil is now aligned with the desired course and the course line can be drawn. (figure 5-11).

MEASURING DISTANCE. One of the disadvantages of the Mercator chart is the lack of a constant scale. If the two points between which the distance is to be measured are approximately in a north-south direction and the total distance between them can be spanned, the distance can be measured on the latitude scale opposite the midpoint. However, the total distance between any two points that do not lie approximately north or south of each other should not be spanned unless the distance is short. All distances should be measured as near the midlatitude as possible.

In the measurement of long distances, select a midlatitude lying approximately half-way between the latitudes of the two points. By using dividers set to a convenient, reasonably short distance, such as 60 nautical miles picked off at the midlatitude scale, you may determine an approximate distance by marking off units along the line to be measured as shown in figure 5-12.

The scale at the midlatitude is accurate enough if the course line does not cover more than 5 degrees of latitude (somewhat less in high latitudes). If the course line exceeds this amount or if it crosses the equator, divide it into two or more legs and measure the length of each leg with the scale of its own midlatitude.

Plotting Procedure, Lambert Conformal and Gnomonic Charts

PLOTTING POSITIONS. On a Lambert conformal chart, the meridians are not parallel as on a Mercator chart. Therefore, in plotting a position

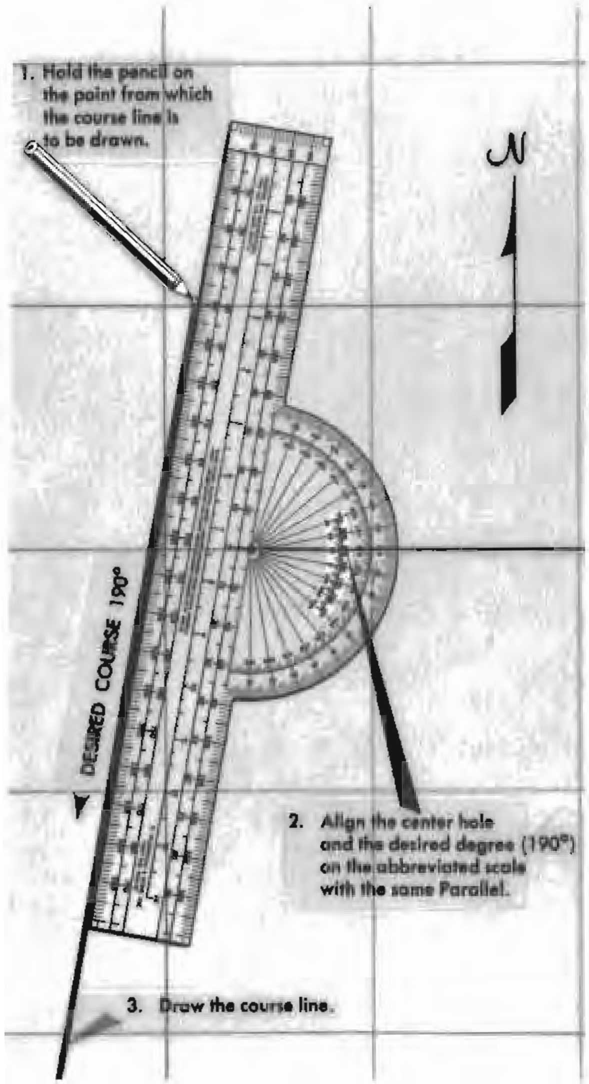


Figure 5-11. Plotting Nearly Vertical Courses

by the method described under Mercator charts, it is not accurate to allow the plotter to parallel any one printed meridian. Instead, the plotter should intersect two graduated *parallels* of *latitude* at the desired longitude. When the plotter is in this position, the dividers are set to the given minutes of latitude, and with one point resting on the given parallel of latitude against the plotter, the other point will rest on the correct position adjacent to the plotter. Follow this procedure on a small scale chart where the meridians show marked convergence. On a large scale chart, the meridians are so nearly parallel that this precaution is unnecessary.

The scale on all parts of a Lambert conformal chart is essentially constant. Therefore, it is not absolutely necessary to pick off minutes of latitude near any particular parallel except in the most precise work. Distances can be measured using any portion of the latitude scale, or by using the miles scale which is usually shown.

PLOTTING AND MEASURING COURSES. Any straight line plotted on a Lambert conformal chart is approximately an arc of a great circle. In long distance flights, this feature is advantageous since the great circle course line can be plotted as easily as a rhumb line on a Mercator chart.

However, for shorter distances where the difference between the great circle and rhumb line is negligible, the rhumb line is more desirable because a constant heading can be held. For such

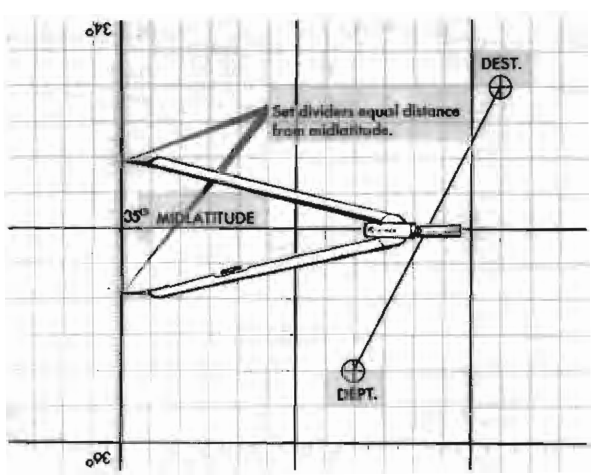


Figure 5-12. Midlatitude Scale

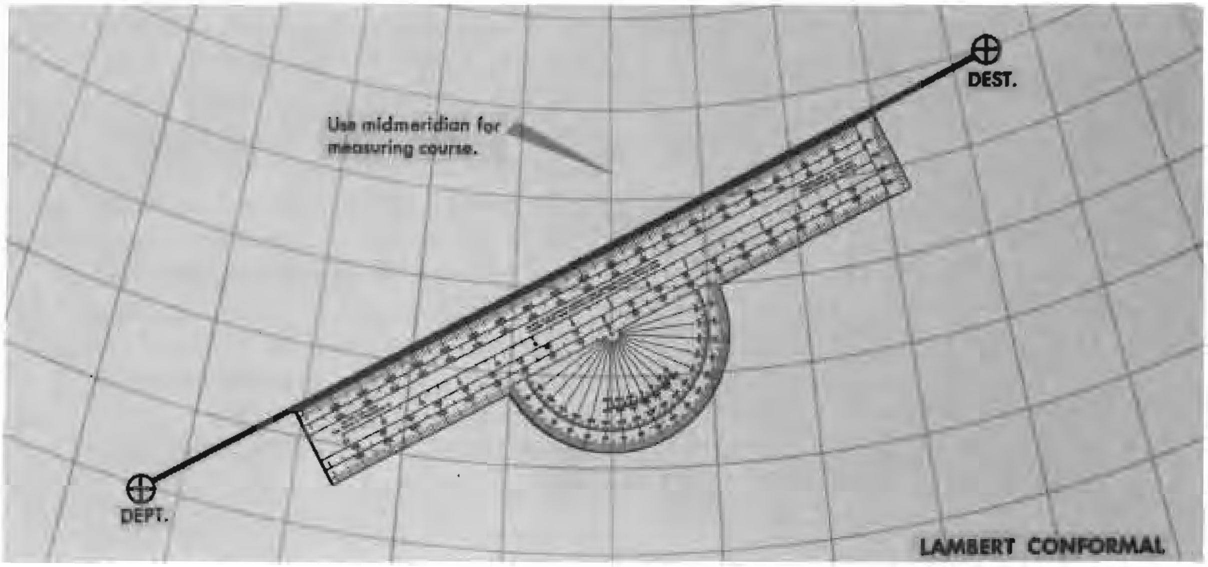


Figure 5-13. Use Midmeridian to Measure Course on a Lambert Conformal

distances, the approximate direction of the rhumb line course can be found by measuring the great circle course at midmeridian as shown in figure 5-13. In this case, the track is not quite the same as that indicated by the course line drawn on the chart, since the actual track (a rhumb line) appears as a curve convex to the equator on a Lambert conformal chart, while the course line (approximately a great circle) appears as a straight line. Near midmeridian, the two have approximately the same direction (except for very long distances) along an oblique course line as indicated in figure 5-14.

For long distances involving great circle courses, it is not feasible to change heading continually, as is necessary when following a great circle

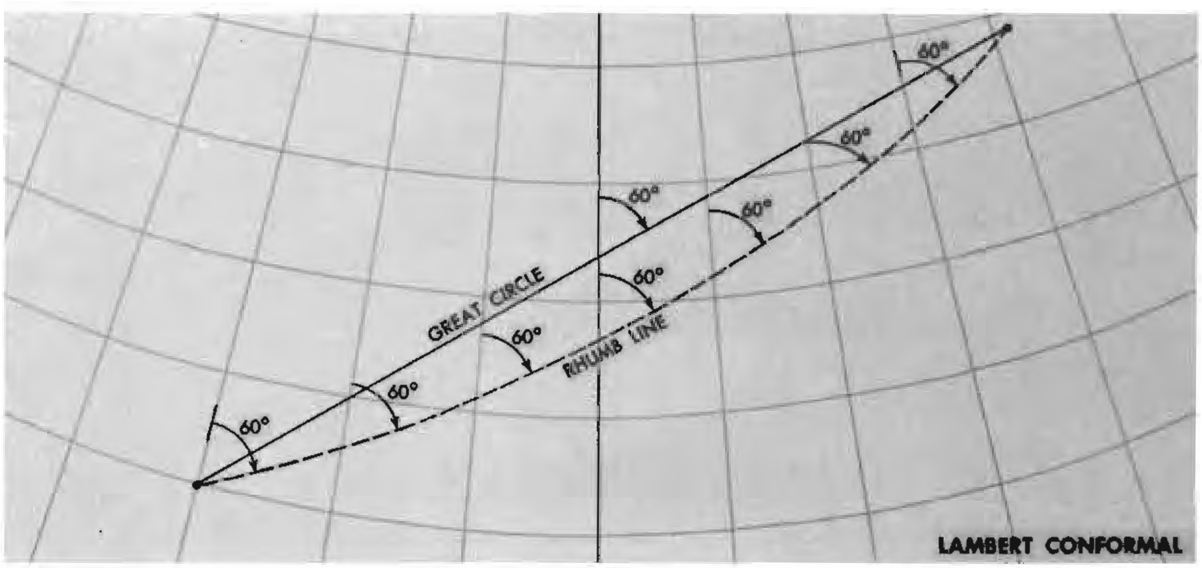


Figure 5-14. At Midmeridian, Rhumb Line and Great Circle Have Approximately the Same Direction

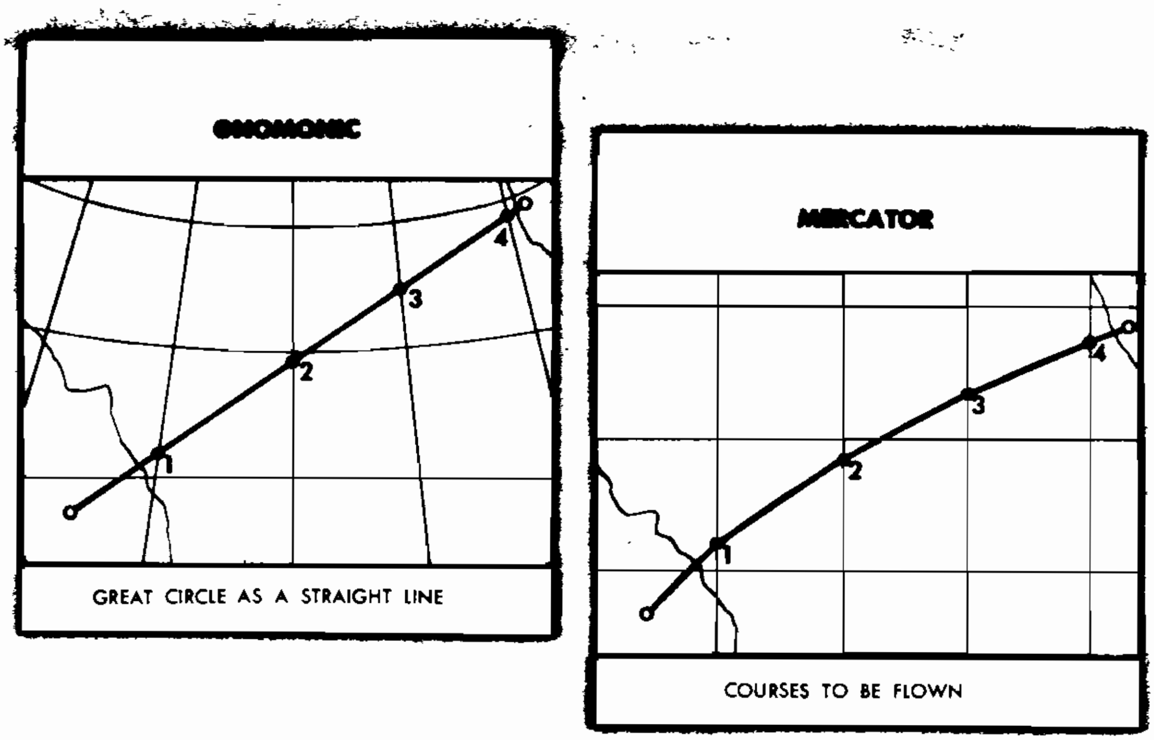


Figure 5-15. Transferring Great Circle Route from Gnomonic to Mercator Chart

exactly, and it is customary to divide the great circle into a series of legs, each covering about 5 degrees of longitude. The direction of the rhumb line connecting the ends of each leg is found at its midmeridian.

MEASURING DISTANCE. As previously stated, the scale on a Lambert conformal chart is practically constant, making possible the use of any part of a meridian graduated in minutes of latitude for measurement of nautical miles. Scales of both nautical and statute miles are shown on some Lambert conformal charts.

PLOTTING ON A GNOMONIC CHART. Gnomonic charts are used mostly for planning great circle routes. Since any straight line on a gnomonic chart is an arc of a great circle, a straight line from the point of departure to destination indicates the great circle route. This great circle route is customarily used by transferring the line in segments to a Mercator chart as shown in figure 5-15.

The latitude and longitude of a series of points along the great circle are measured and plotted on a Mercator chart. They are then connected with straight (rhumb) lines.

PLOTTING HINTS. The following suggestions should prove helpful in developing good plotting procedure:

- Measure all directions and distances carefully. Check and doublecheck all measurements, computations, and positions.
- Avoid plotting unnecessary lines. If a line serves no purpose, erase it. Do not allow lines to extend beyond their useful limits.
- Keep plotting equipment in good working order. If the plotter is broken, replace it. Keep sharp points on dividers. Use a sharp-pointed, soft pencil and an eraser that will not smudge.
- Draw light lines at first, as they may have to be erased. When the line has been checked and proven to be correct, then darken it if desired.
- Hold the pencil against the plotter at the same angle throughout the entire length of the line.
- Label lines and points immediately after they are drawn. Use standard labels and symbols. Letter the labels legibly. Be neat and exact.

DR COMPUTER

Almost any type of navigation requires the solution of simple arithmetical problems involving time, speed, distance, fuel consumption, and so forth. In addition, the effect of the wind on the aircraft must be known; therefore the wind must be computed. To solve such problems quickly and with reasonable accuracy, various types of computers have been devised of which the computer described in this manual is one. This computer is simply a combination of two devices: (1) a circular slide rule for the solution of arithmetical problems (See figure 5-16) and (2) a specially designed instrument for the graphical solution of the wind problem. (See figure 5-17.)

The slide rule is a standard device for the mechanical solution of various arithmetical problems. Slide rules operate on the basis of logarithms, but no knowledge of logarithms is necessary for the successful use of the instrument. Slide rules are either straight or circular; the one on the DR computer is circular.

The slide rule face of the computer consists of two flat metallic disks, one of which can be rotated around a common center. These disks are graduated near their edges with adjacent, logarithmic scales to form a circular slide rule approximately equivalent to a straight, 12-inch slide rule. Since the outer scale usually represents a number of miles and the inner scale, a number of minutes, they are called the *miles scale* and the *minutes or time scale,* respectively. Refer to figure 5-16.

The numbers on each scale represent the printed figure with the decimal point moved any number of places to the right or left. For example, the figure 12 on either scale can represent 1.2, 12, 120, 1200, etc.

Since speed (or fuel consumption) is expressed in miles (or gallons or pounds) *per hour* (60 minutes), a large, black arrow marked *speed index* is placed at the 60-minute mark.

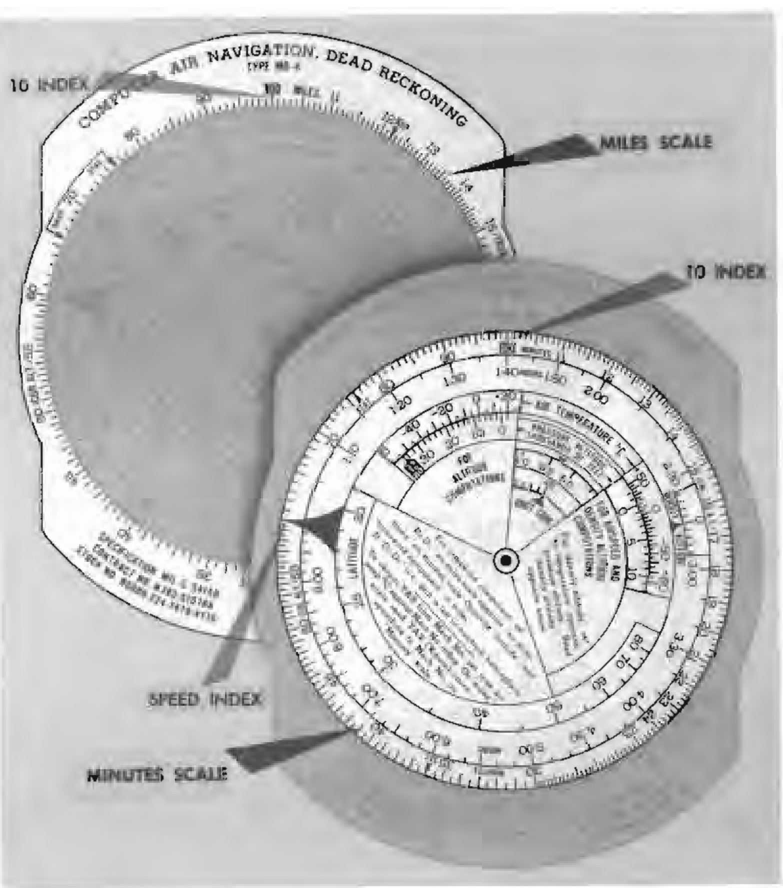


Figure 5-16. DR Computer Slide Rule Face

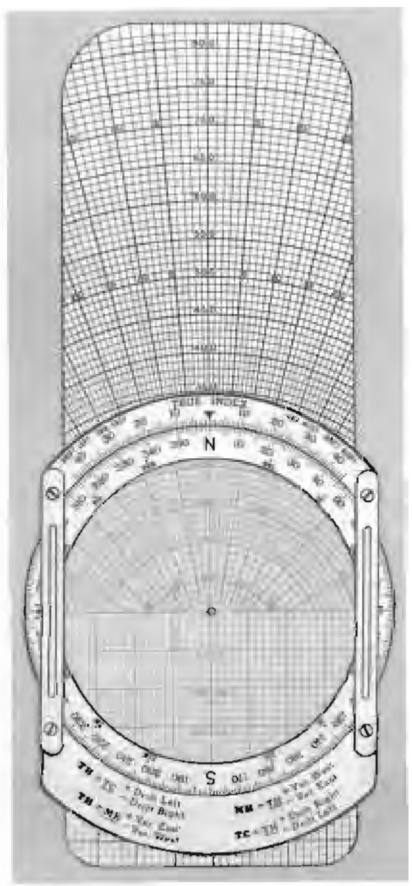


Figure 5-17. DR Computer Wind Face

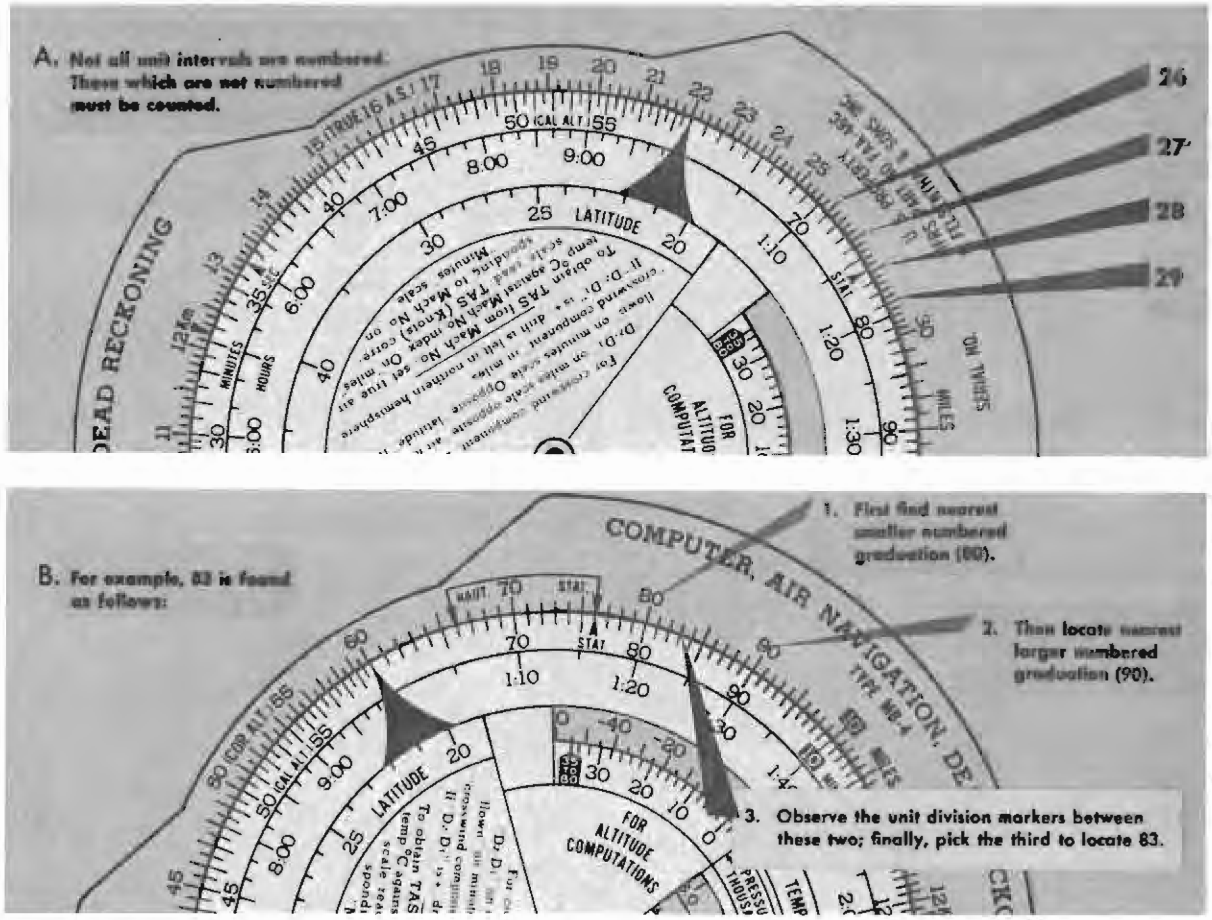


Figure 5-18. Reading the Slide Rule Face

Graduations of both scales are identical. The graduations are numbered from 10 to 100 and the unit intervals decrease in size as the numbers increase in size. Not all unit intervals are numbered. The first element of skill in using the computer is a sure knowledge of how to read the numbers.

Reading the Slide Rule Face

The unit intervals which are numbered present no difficulty. The problem lies in giving the correct values to the many small lines which come between the numbered intervals. There are no numbers given between 25 and 30 as shown in figure 5-18A, for example, but it is obvious that the larger intermediate divisions are 26, 27, 28, and 29. Between 25 and (unnumbered) 26, there are five smaller divisions, each of which would therefore be .2 of the larger unit.

To find an uneven number, such as 83, illustrated in figure 5-18B, find first the nearest smaller numbered graduation (80), then the nearest larger numbered graduation (90). After observing the value of the divisions between, select the proper division (in this case, the third) for the desired number.

For a number such as 278, first find the 27 (for 270), then the 28 (for 280), then the fourth of the intermediate divisions (for 278) since the divisions here are of two units each. Obviously, unit divisions will be found only for numbers made up of relatively few integers. For a number such as 27812, the point already chosen for 278 would be used. This same point would also be used for 27.8, 2.78, etc. There are thus several numbers for each point on the scale. The matter of the use and place of the decimal point is largely one of common sense.