AIR NAVIGATION SUPPLEMENT

PREPARED BY

BUREAU OF NAVAL PERSONNEL

CHAPTER 3

MECHANICAL PLOTTING BOARD (MK3A) AND MK8 COMPUTER

The development of the mechanical plotting board has been of special value to the Navy, particularly for the rapid solution of those navigational problems experienced in long overwater flights by single-engine aircraft. The primary disadvantages found in the board are its size and the necessity for considerable care in handling and use. It is not always as easily read as a chart would be, particularly in night operations or under other bad lighting conditions.

DESCRIPTION

The mechanical plotting board is designed as a complete navigational device, requiring nothing more than a soft lead pencil for computing any dead reckoning problem within the limits of the board. The plotting surface has a matte finish on a transparent plastic base which provides a suitable writing surface that can be easily erased. A grid disc fastened to the board by a grommet or a snap fastener rotates under the plotting surface. On each side of this disc is printed a rectangular grid and a series of concentric speed circles, equally spaced. The grid and circles are usually shown in color. A different scale is used for each side of the disc. The speed of the aircraft and the length of the mission should determine the choice of scale. Space for important data and a MK8 computer is also provided. A similarly marked disc and a transparent sheet of paper may be readily substituted for the more expensive plotting board. Templates are available for certain areas of the world, eliminating the necessity of constructing a plotting sheet on the board, and adding somewhat to the accuracy and speed of locating positions. These templates are listed in the Hydrographic Office *Catalog of Aeronautical Charts and Publications.*

CARE

Cautions.—Never place the board under extreme heat conditions such as a hot radiator. Direct summer sunlight for an extended period will warp the board.

Never leave the board in the plane. Rain and grease do not improve it. The plastic board should not be subjected to any strain that will bend the surface or the grid. It is expensive and not easily replaced.

The plotting board is not a toy; its versatility will amaze you. The disc grid should not be rotated at high speed for amusement purposes. The grommet should snugly fit the hole in the face of the board and the grid disc. When the true indices are lined up with 000, 090, 180, and 270, not more than $\frac{1}{2}°$ error should be observed. If a greater error is found, the board should be readjusted or surveyed.

Suggestions.—Always begin a problem with a clean board, using a good eraser for cleaning.

Never put a mark on the board without labeling it.

Use a sharp, soft pencil.

Most important of all, establish good working habits and be consistent in their use. When an emergency arises, much time will be saved.

The board should *never* be erased in operational use until the mission is completed. The use of subscripts is recommended. (P_1, P_2, etc.)

USE

General.—The plotting board can be worked with one hand, a desirable feature in both light planes and single-engine military aircraft. In military aircraft the board is mounted on a sliding shelf either under the instrument panel or at the side of the pilot's seat. A smaller version of the MK3 board is being considered for use in the Navy jet planes. The reduction in size was necessitated by the limited cockpit space. The need for computing speeds considerably in excess of the scale shown on the present grid compelled a revision of the speed circles on the grid disc.

Specific uses.—A plotting sheet can be constructed on the board.

Course and distance can be read directly from the board.

All directions should be read as true from the true index.

The standard vector diagram is easily reproduced on it. Interception, radius of action, point option, the vector diagram, and other navigation problems are quickly solved.

Pointers in drawing on the board.—The vector diagrams illustrated in this chapter are shown with broken lines drawn to a point indicating the (speed) length of the vector. This practice is recommended only for instruction and illustration. Indicating the dot by lettering *w*, *p*, *e*, or *s* is sufficient for operational use, or the vector may be shown by the use of arrows, or arrows and letters, as shown in figure *34*.

These practices are for the beginner. As proficiency is obtained there will be no necessity for drawing the vector or indicating the direction with the arrows. Instructors will find it helpful to their inexperienced students if they are consistent in their presentation of the vector diagram.

All geographic positions should be indicated by a circled dot, thus: ⊙. This practice has two advantages: the location of a geographic position is distinguished

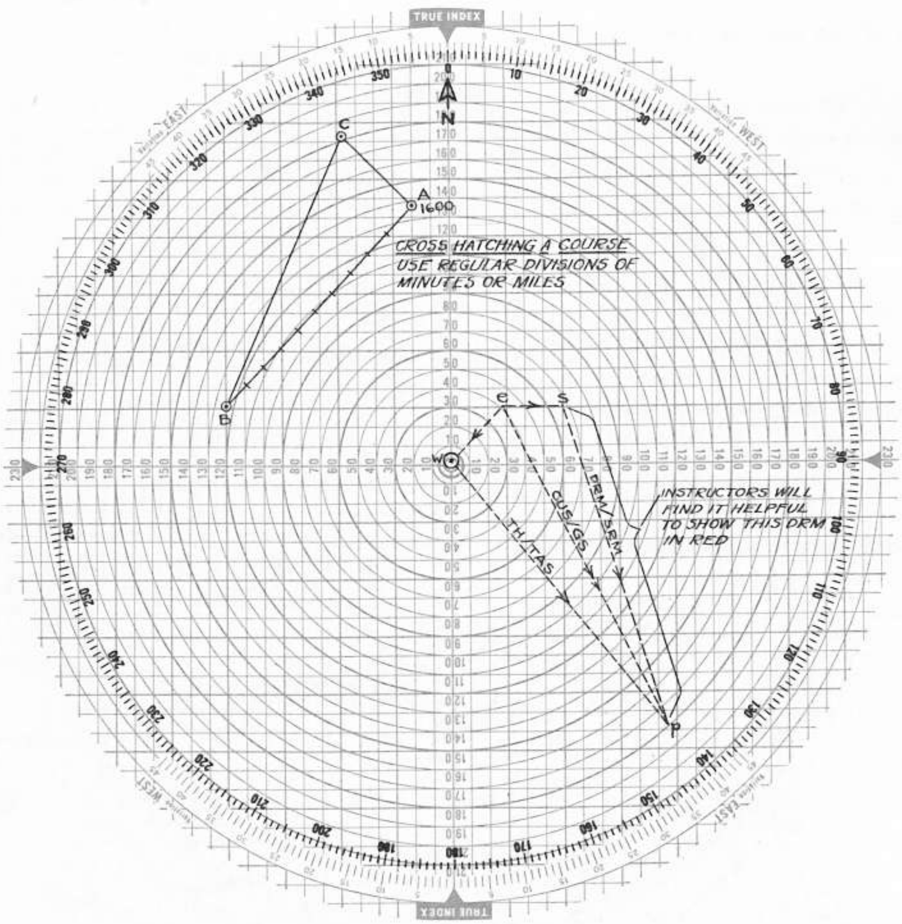


Figure 34.—Vector diagram.

A complete log may be kept on the data cards accompanying the board.

The MK8 computer, a circular slide rule, is attached to the lower right hand corner of the board and is used for solving time, speed, and distance problems, and for determining true air speed and altitude corrections.

from a portion of the vector diagram and the dot indicating the position remains clear and distinct for measuring distance, direction, or position when possible. Time should also be indicated when a geographic position is shown.

Much time can be saved if the mission or problem is studied before constructing the chart. The limited area of the MK3 board compels the navigator to select the mid-latitude and mid-longitude with care.

gardless of the amount of increases of speed valu directions and angles must *not* be changed. The si of the vector is thus reduced in all respects to the san proportions, as shown in figure 35.

In all following illustrations and problems, tl values given are true for all courses, tracks, heading airspeeds, and similar measurements, unless otherwis stated.

A velocity vector may be represented by a straigl

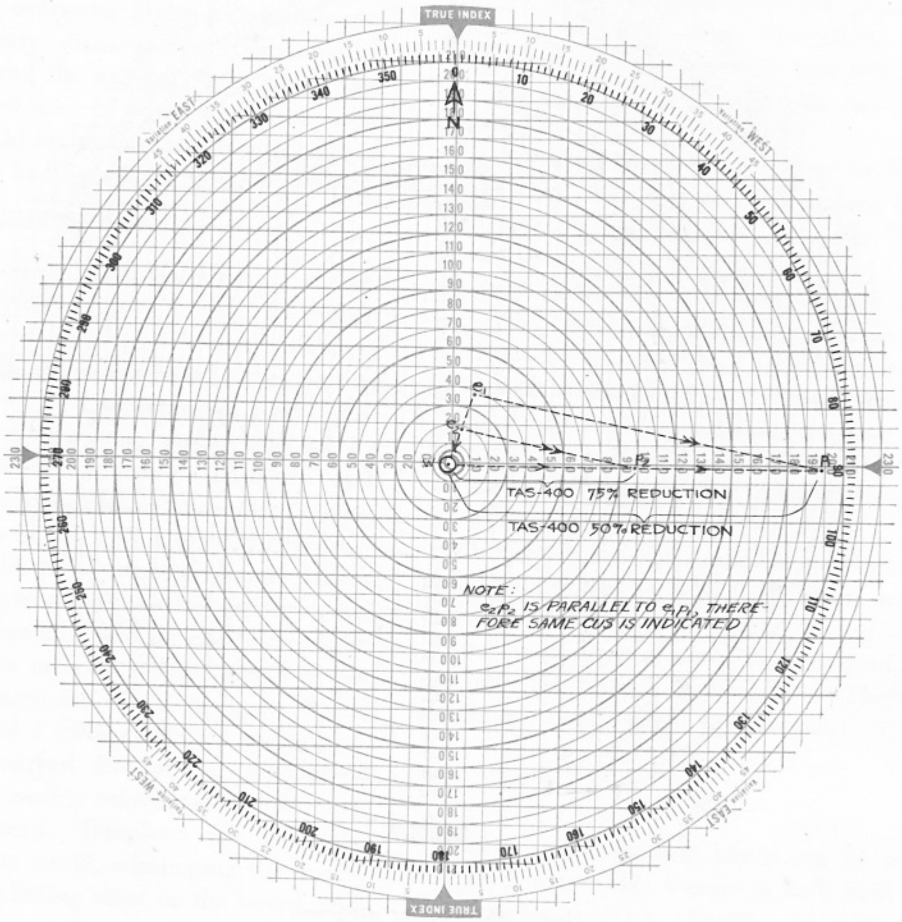


Figure 35.—Proportional reduction of a vector.

Select the side of the disc whose maximum speed circle is nearest to the true air speed of the plane. If the plane speed exceeds the maximum true air speed circle, the wind vector may be solved by increasing all speed circles proportionately. But remember, re-

line with an arrow head on one end. It indicates both direction and speed. The direction of a vector is indicated by the angle that it makes with true north while the speed is represented by the length of the vector drawn to some preselected scale.

1 HOW TO CONSTRUCT THE CHART

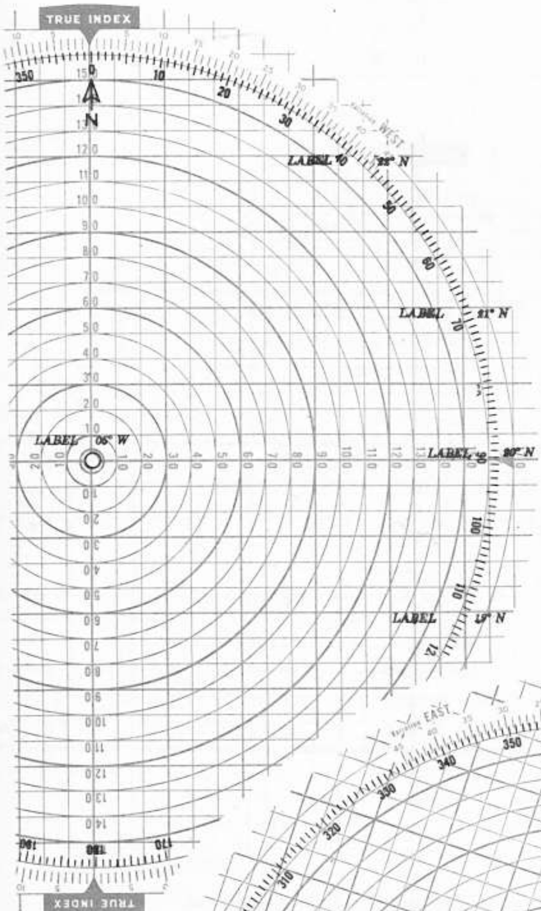
Given

Mid-latitude 20° N

Mid-longitude 05° W

Procedure

1. Set the true index directly under 0° or N.
2. Label the true index 05° W (Mid-long.).
3. Label the cross index 20° N (Mid-lat.) and every 60′ above and below with appropriate latitude.
4. Revolve the disc clockwise 20° (Mid-lat.).
5. Draw a line directly across the board coinciding with the cross index. This is the reference line for longitude.
6. Draw a short pencil line across the reference line every 60′ on each side of the grommet.
7. Label with the appropriate longitude.



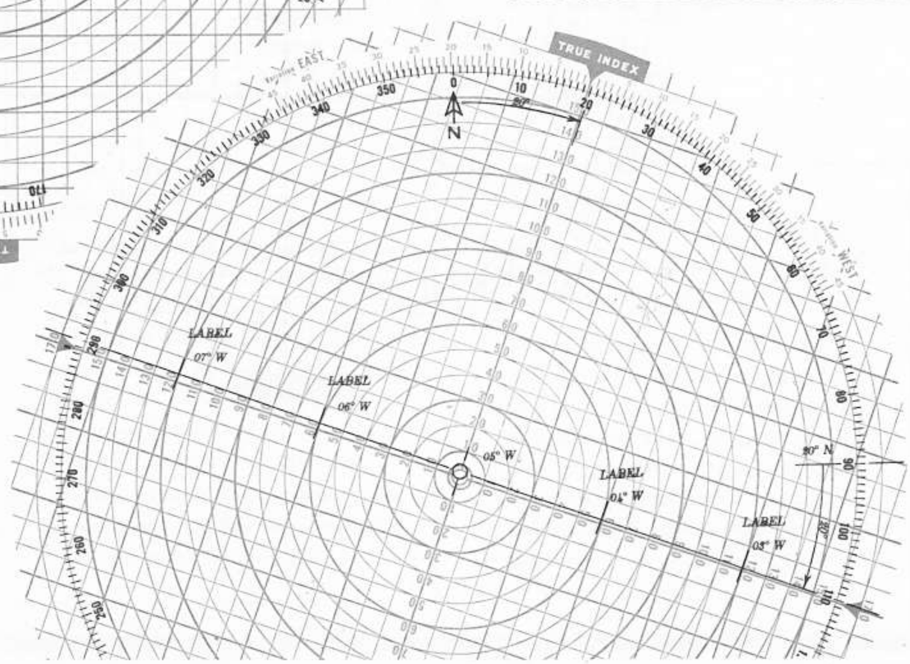


Figure 36a.

1 (CONTINUED)

8. Reorient the disc to 0°.
The illustration shows the constructed chart, which is basically a mercator projection. The horizontal grid lines represent 10′ of latitude, while the intersections of the circular grid lines with the reference line represent 10′ of longitude. The dotted lines which are here shown are for illustration purposes only. *Do not draw these lines on the board.*

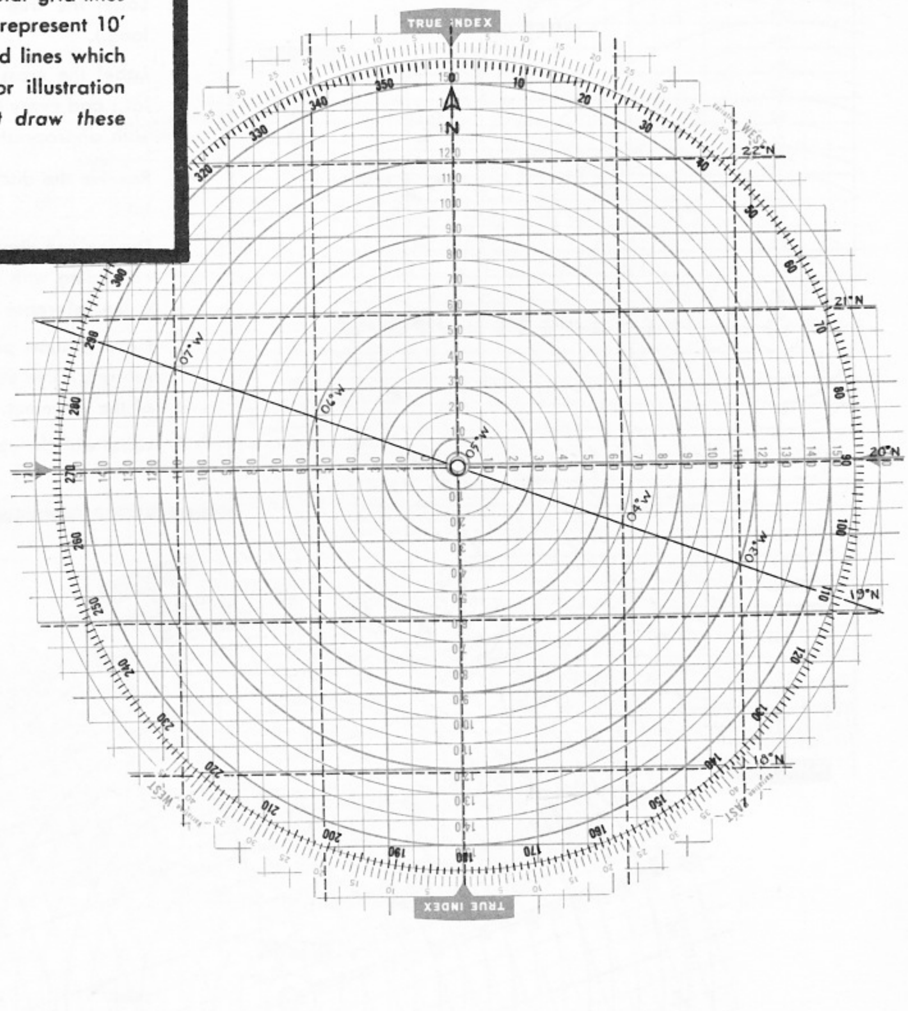
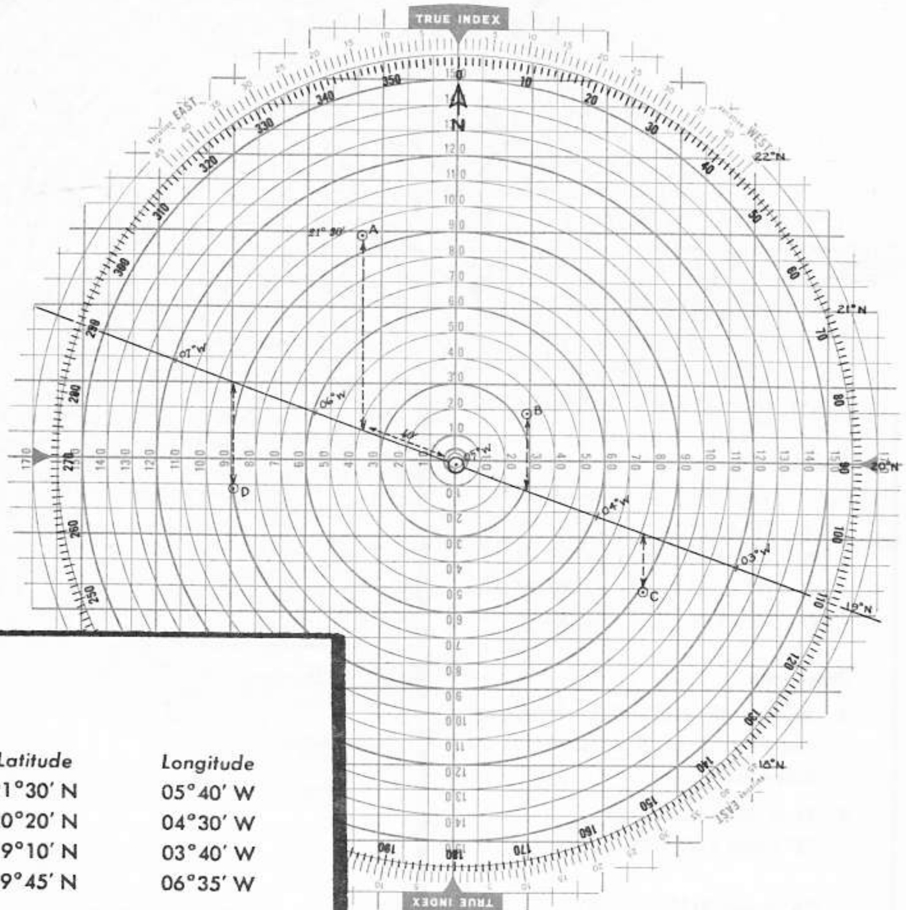


Figure 36b.

2 HOW TO LOCATE POSITIONS



Given

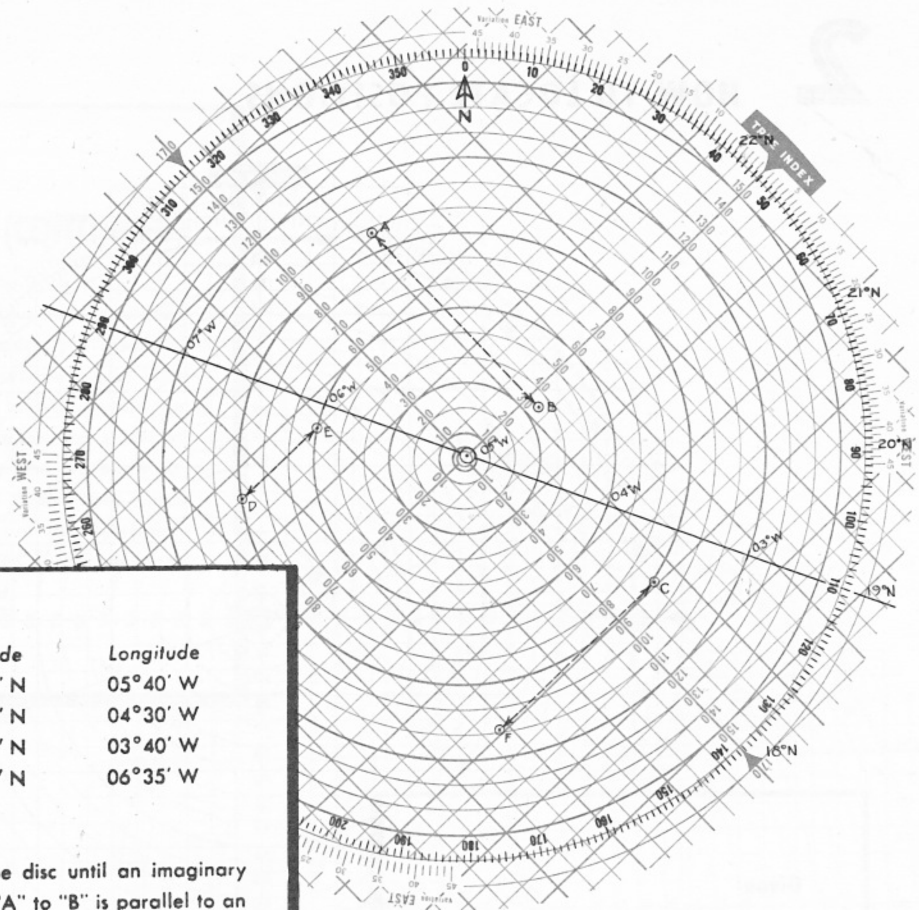
	Latitude	*Longitude*
A	21°30' N	05°40' W
B	20°20' N	04°30' W
C	19°10' N	03°40' W
D	19°45' N	06°35' W

Procedure

1. Find the longitude. The longitude of "A" is 05°40' W. From the Mid-long. (05° W) follow the reference line left (W) to the 40 circle. The intersection of the 40 circle with the reference line is 05°40' W longitude. A vertical line through this point contains all points on that meridian.
2. Find the latitude. The latitude can be determined from the horizontal grid lines above the Mid-lat. (20° N).
3. The intersection of these latitude and longitude lines gives the location of positions, as on any other chart.

In similar manner "B," "C," and "D" are located to the left or right of the Mid-long. and above or below the Mid-lat. For south latitude and/or east longitude the chart is constructed in an identical manner. *Care must be taken at all times to orient the board properly.*

Figure 37.



Given

	Latitude	Longitude
A	21°30′ N	05°40′ W
B	20°20′ N	04°30′ W
C	19°10′ N	03°40′ W
D	19°45′ N	06°35′ W

Procedure

1. Revolve the disc until an imaginary line from "A" to "B" is parallel to an index line.
2. From the compass rose
   "B" bears 137° from "A"
   or
   "A" bears 317° from "B"
3. The distance between "A" and "B" is 96 mi.
4. Find "E," bearing 047°, distance 40 miles from "D." The true index is set at 047°. From "D" in a straight line toward 047° mark off 40 mi. to locate "E."
5. In similar manner "F" bears 227°, distance 82 mi. from "C."
6. Reorient the board and locate "E" and "F."

3 DETERMINING BEARING AND DISTANCE

Figure 38.

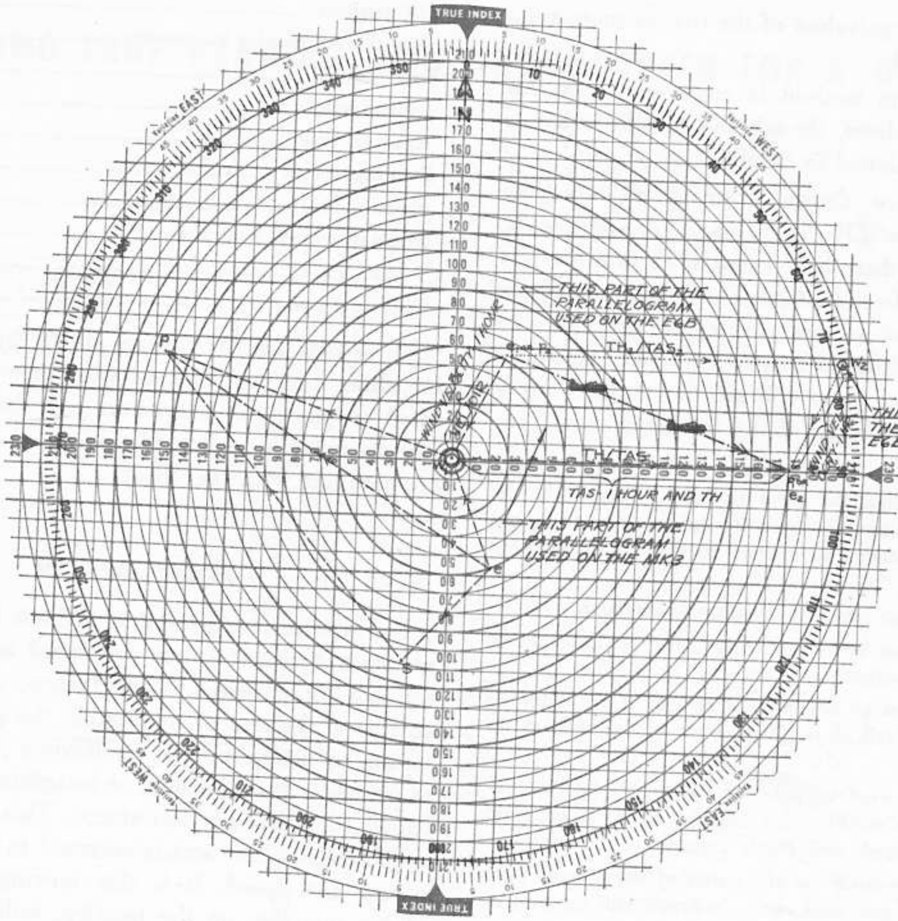


Figure 39.

Velocity vectors are used as a convenient means of determining the effect of several or a combination of velocities such as those affecting an airplane in flight. Vectors in a wind triangle may be constructed graphically or a substitution may be effected by some mechanical means, such as a computer. A diagram of a vector sum or a completed wind triangle always presents a closed figure. This vector diagram or wind triangle should not be confused with a movement plot which shows successive positions of moving objects in relation to the earth's surface.

Wind, ground speed, and airspeed have direction and magnitude, or speed, and can therefore be represented by vectors. When these vectors are combined graphically, the result is variously described as a wind triangle, a vector diagram, a wind vector diagram, a velocity vector triangle, or a triangle of velocities. For the purpose of uniformity, the term wind triangle will be used.

When the air navigator has obtained sufficient information to construct two-thirds of a wind triangle (four known quantities, two unknown), he can determine the unknown parts of the wind triangle without resorting to trigonometry.

(*Wind velocity* should not be confused with a *velocity vector,* where the former indicates only speed of wind and the latter both speed and direction of some object, as in the case of the TH and TAS of a plane.)

Remember, too, that wind direction is always given as a direction from which the wind is blowing, but plotted in the direction toward which it blows. (This is in contrast to the set of a current which is given as the direction *toward* which it flows.) Any number of velocity vectors may be added. By joining the tip of the first vector to the tail of the second vector, the *resultant* of these two velocities, or the single velocity that would be the equivalent of the two or more velocities, can be found.

The parallelogram method is commonly used for solving vector problems, though the parallelogram as such is no longer plotted in detail.

Both vectors are drawn from point E, with TH/TAS parallel to TH_2/TAS_2 and W_2P_1 parallel to wind EW_1. Where these lines cross at P_1 indicates the resultant or EP_1. See figure *39*. The completion of the parallelogram is not necessary, since the resultant can be obtained by adding the two vectors. Some consideration of the parallelogram will aid the student in visualizing any wind triangle if the following points are remembered:

1. When constructing the wind triangle it should be remembered that all directions must be indicated as true, and all force or speeds drawn to a scale common to all portions of the diagram.

2. A velocity vector has both length and direction.

3. Two vectors can be added by plotting the tail of one onto the head of another.

4. The vector sum or resultant of two or more vectors is the vector from the tail of the first vector to the head of the last vector plotted.

5. Points on the wind triangle are lettered as follows:

e—represents the earth—point from which the wind, track (course) ground speed, and ship's vectors are drawn.

w—represents the wind—at the center of the diagram; the point toward which the wind vector is drawn and from which the heading-air speed vector is drawn.

p—represents the aircraft (plane)—point toward which the heading-air speed and track (course) ground speed vectors are drawn.

If the movements of a ship are involved, an additional point is labeled:

s—representing the ship—a point toward which the ship's vector is drawn and from which the relative movement line is drawn.

Vectors are lettered as follows:

ew—wind force and direction. Drawn from the distance from which the wind is blowing, to the center of the diagram.

wp—the aircraft's true heading and true air speed.

ep—the aircraft's track (or course) and ground speed.

sp—aircraft's direction of relative movement (relative movement line) and speed of relative movement (relative speed).

The use of these abbreviations really involves the use of the wind triangle combined with the speed triangle.

The following standard abbreviations and symbols are used:

Air (no wind) position	NW
Air speed, true	TAS
Course (aircraft)	CUS
Course (ship)	C
DR position	DR
Direction of relative movement	DRM
Drift angle	DA
Ground speed	GS
Heading, true	TH
Heading, compass	CH
Speed (ship)	S
Speed of relative movement	SRM
Track	TR
Time to Turn	TTT

All sectors and/or courses should be cross-hatched for either time or distance with time or miles indicated on the plot. Instructors will find it helpful to plot the relative motion plot in red until the students are familiar with the theory.

POINT OPTION

For practical reasons it is difficult for a carrier to maintain constant course and speed while its aircraft are out on a search. Nevertheless, to intercept the carrier at the end of the search, the pilots must have means of determining a rendezvous point. Therefore, to overcome this difficulty, an imaginiary moving point called *Pt. Option* is introduced. This point is a geographical location and is assumed to have a constant course and speed. It is this moving point that the planes intercept on the last leg, unless instructed to proceed otherwise.

In peacetime operations it is the carrier's responsibility to be at Pt. Option by the time the aircraft return or to notify the planes of any change in course or speed.

When a carrier is unable to reach the original Pt. Option it will, if possible, inform the planes out on search that a new Pt. Option is to be intercepted. This point is referred to as Pt. Option No. 2, and its position is given by a bearing and distance from the original position of the *first Pt. Option* (unless otherwise designated). Similarly, Pt. Option No. 3 may be established also by direction and distance from the original position of Pt. Option No. 1.

In time of war the carrier would ordinarily maintain radio silence and therefore could not inform the aircraft of any changes in Pt. Option. Planes would probably receive visual signals from some other ship of the Fleet, or would have to find the carrier by radar in the event that the ship could not make Pt. Option at the specified time.

4 FINDING TRUE HEADING AND GROUNDSPEED FOR A GIVEN COURSE

WIND DATA		
FLIGHT LEVEL	FORCE	FROM
	25	140

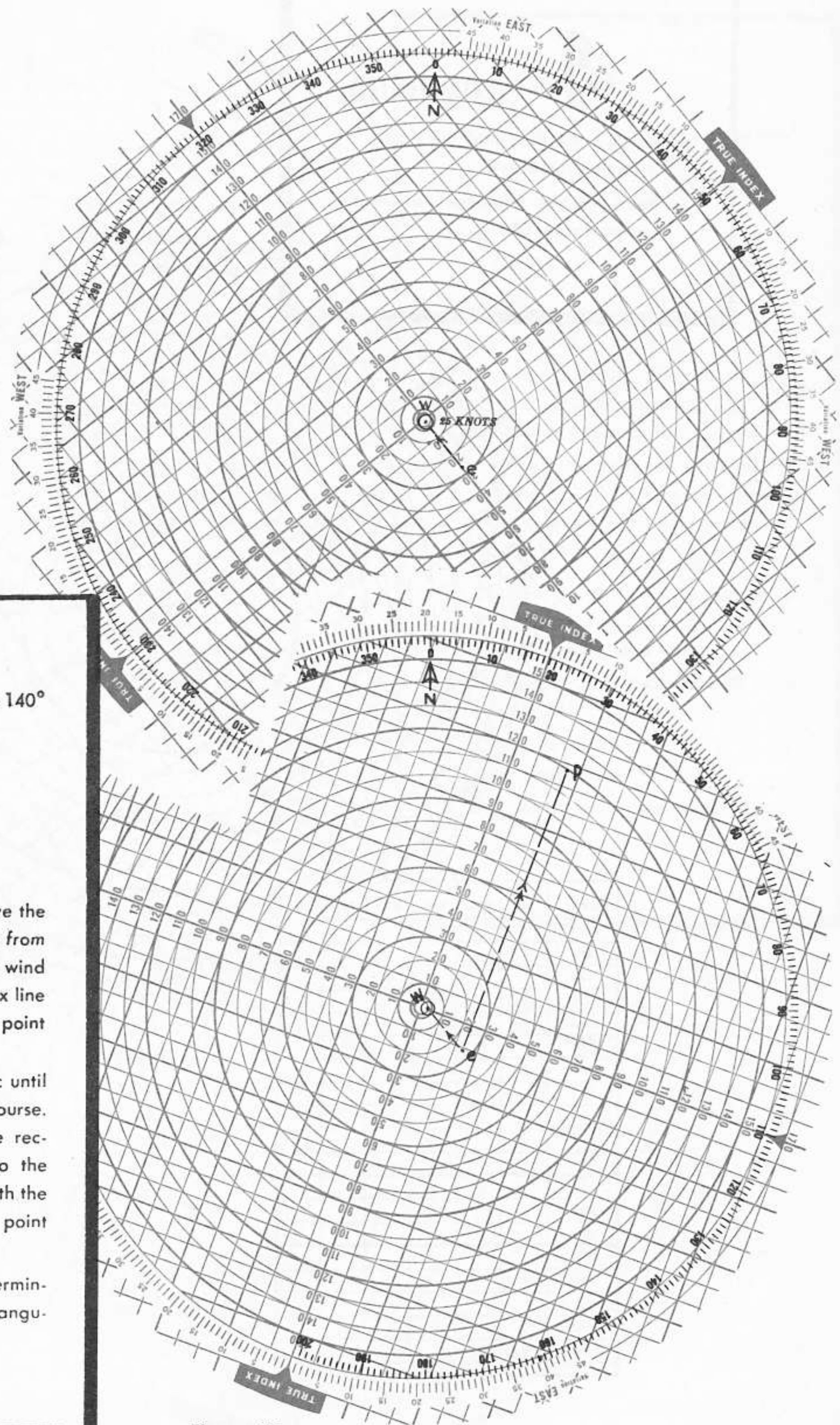


Figure 40a.

Given

Wind	25 K from 140°
Course	020°
True airspeed	120 K

Find

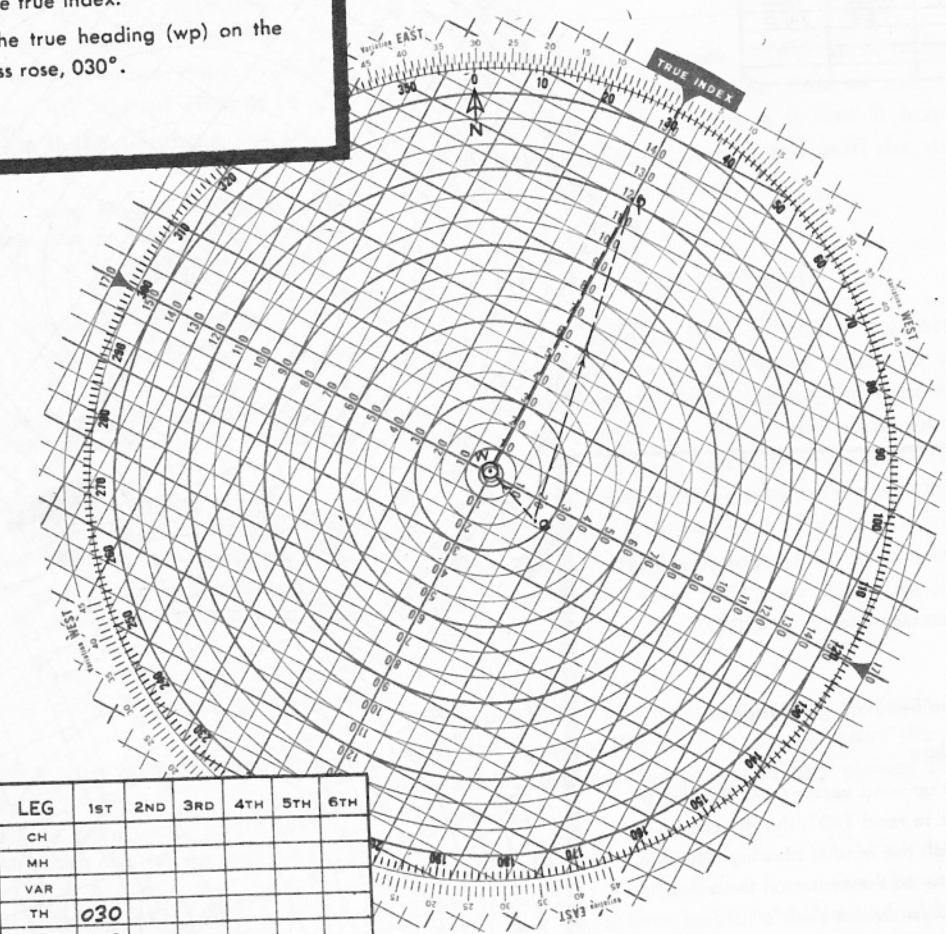
True heading; groundspeed

Procedure

1. Set up wind vector (ew). Revolve the disc to read 140°, the direction *from* which the wind is blowing. Plot wind vector to the center on the index line 25 K (a dot labeled "e" at that point will suffice).
2. Set the course. Revolve the disc until the true index reads 020°, the course. From the point "e" follow the rectangular grid lines parallel to the true index to the intersection with the 120 K TAS circle. Label this point "p."
3. Find the groundspeed by determining the distance "ep" on the rectangular grid (130 K).

4 (CONTINUED)

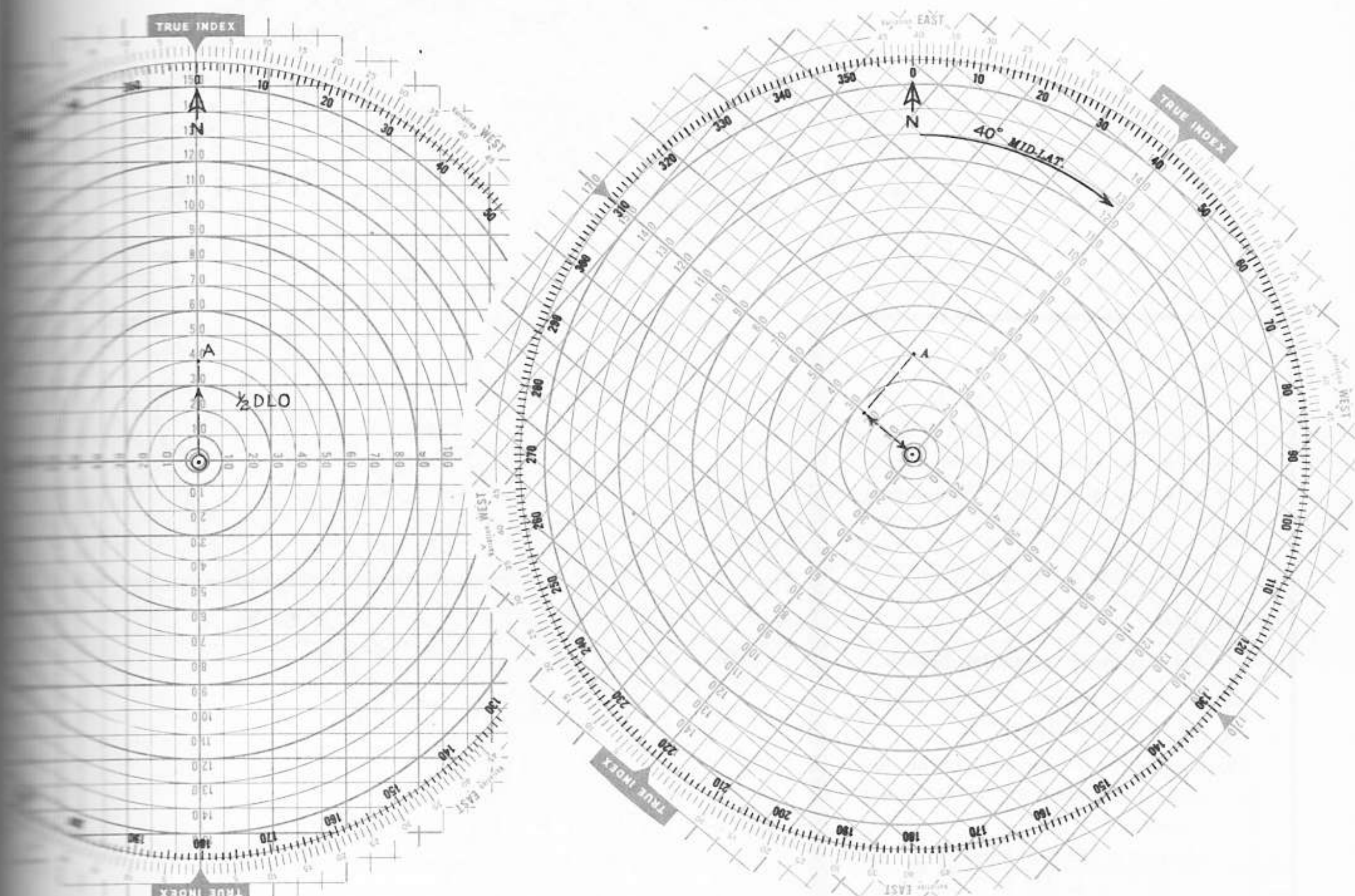
4. Revolve the disc until the point "p" is on the true index.
5. Read the true heading (wp) on the compass rose, 030°.



LEG	1ST	2ND	3RD	4TH	5TH	6TH
CH						
MH						
VAR						
TH	030					
TAS	120					
PRESS. ALT.						
TEMP.						
CAS						
IAS						
MI. SAMPLE MIN.						
DRM						
SRM						
MRM						
DRIFT ANGLE						
CUS	020					
TR						
PGS						
GS	130					

Figure 40b.

17 DETERMINING MERCATOR CORRECTION



Given

Difference of Longitude 8°

Mid-lat. 40°

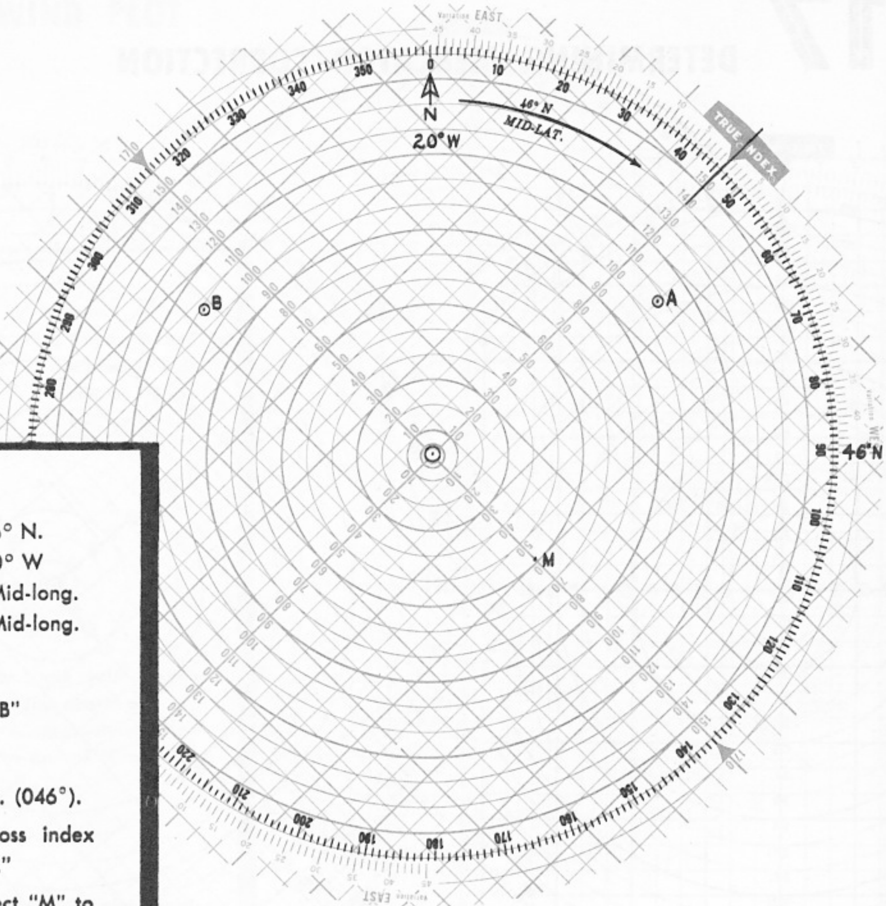
Find

Mercator Correction

Procedure

1. Set true index at 0°.
2. From grommet, mark off ½ difference of longitude (DLO) using a large scale (4° = ½ DLO with each 10 = 1°. A dot at "A").
3. Revolve disc until true index is on Mid-lat. 040°.
4. Read mercator correction in same scale (10 = 1°) on cross index (2.6°).

Figure 50.



Given

Mid-lat. 46° N.
Mid-long. 20° W
Point "A," 90 miles east of Mid-long.
Point "B," 90 miles west of Mid-long.

Find

Longitude of "A" and "B"

Procedure

1. Set true index to Mid-lat. (046°).
2. Mark intersection of cross index with 60′ circle. Label "M."
3. Reorient to 0° and project "M" to cross index (point "N" as illustrated).
   $$\frac{\text{Number of Nautical Miles}}{60' \text{ long. at } 46° \text{ N}} = 42 \text{ mi.}$$
4. On computer set 60′ on inside scale opposite 42 miles on outside scale.
5. Note that 70 on outside scale is opposite 10 on inside scale. Label 46° latitude.
6. Opposite 90 miles on outside scale read 129′ on inside scale.
7. As point "A" is 90 miles east of 20° W, subtract 129′ giving 17°51′ W as longitude of "A."
   Since point "B" is 90 miles west of 20° W, add 129′ giving 22°09′ W as longitude of "B."

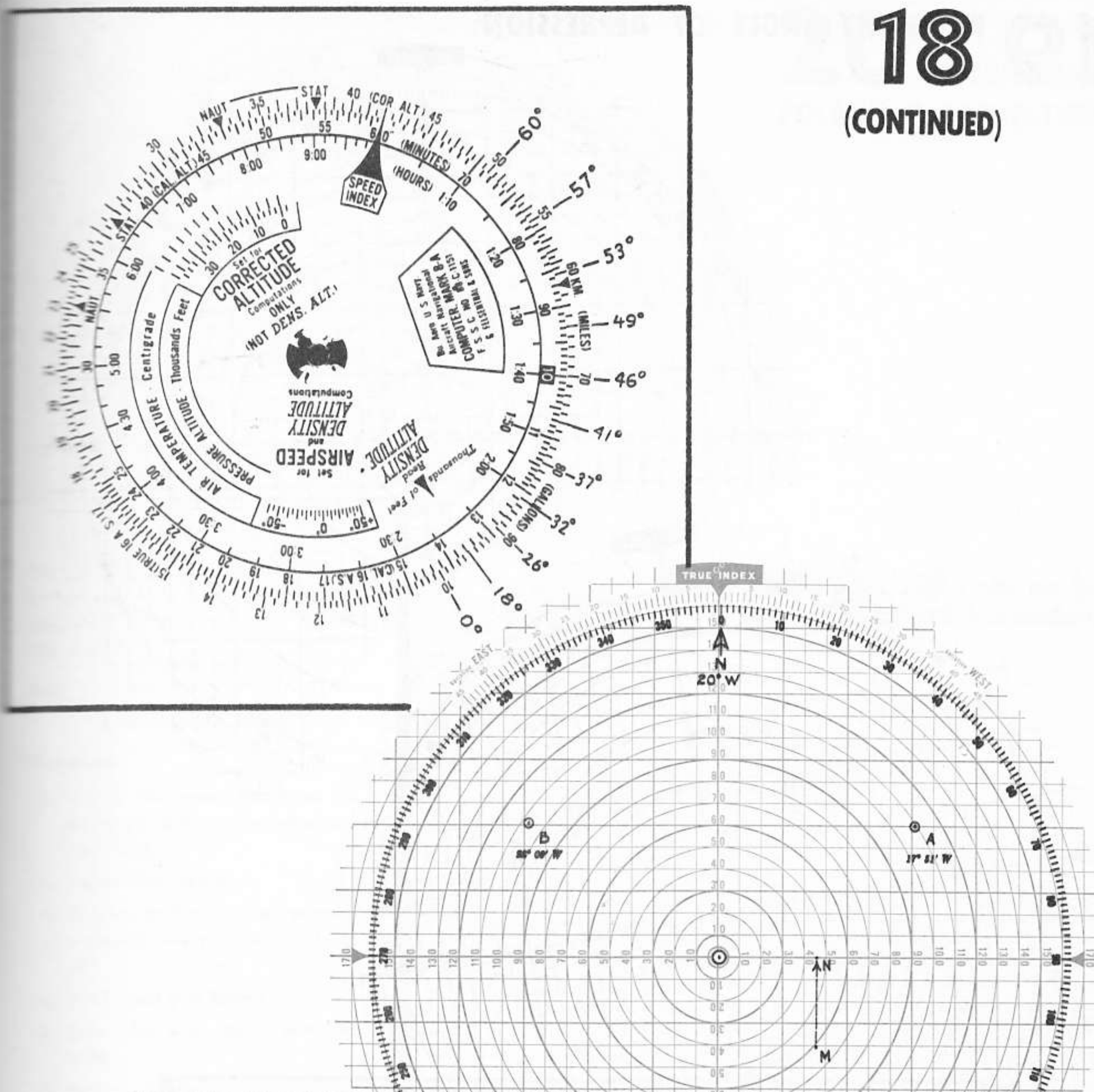
18

CONVERTING MINUTES OF LONGITUDE TO NAUTICAL MILES ACCORDING TO LATITUDE

Figure 51a.

18

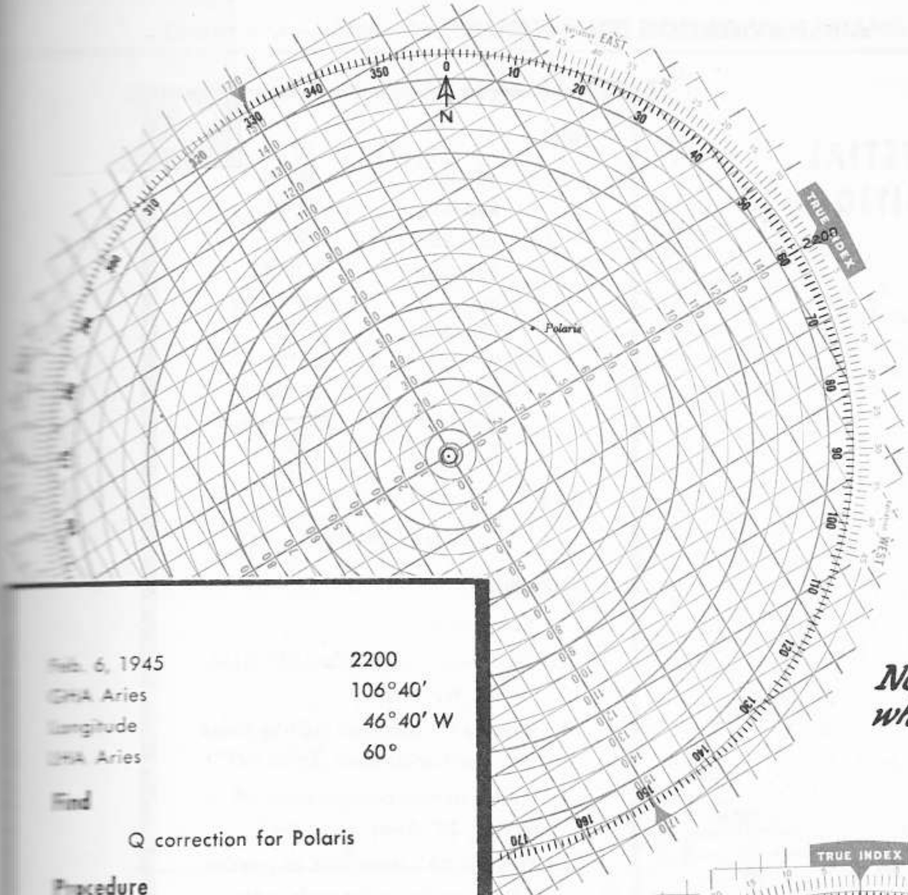
(CONTINUED)



Note: It will be noted that the relationship between the number of nautical miles to the minutes of longitude is the cosine function. A similar relationship can be set up for all latitudes. To facilitate operation, the square at 10 on the inside scale can be placed at 10 on the outside scale for 0° Lat. Mark this 0°. For 18° Lat. the square at 10 on the inside scale is opposite 95. Mark this 18°. Similarly 90 is marked 26°, 70 marked 46°, and up the scale as illustrated. Thus for rapid conversion of miles to minutes of longitude, 10 on the inside scale is placed opposite the latitude as marked on the outside scale. Opposite the number of miles on the outside scale is read the minutes of longitude on the inside scale. In this fashion longitude may be measured in terms of miles east or west of the central meridian when true index is set at 0° and converted to minutes of longitude by use of the computer.

Figure 51b.

20 DETERMINING POLARIS Q CORRECTION



Feb. 6, 1945	2200
GHA Aries	106°40′
Longitude	46°40′ W
LHA Aries	60°

Find

Q correction for Polaris

Procedure

1. On the disc locate Polaris on the 60′ circle 26½° to the left of the true index.
2. Reassemble the board.
3. Revolve the disc until the true index nearest Polaris is on the LHA Aries, 60°.
4. Mark a dot over Polaris.
5. Label LHA Aries, 060°, with time 2200.
6. Reorient the disc to 0°.
7. Read Q correction, 50, as the vertical distance from the dot to the cross index.
8. Name Q correction + if below cross index and — if above (—50).
9. Label every 5° twenty minutes later for proposed length of flight. In this manner the later use of the Almanac is eliminated in determining latitude by Polaris.

Note: Step 9 is true only when longitude is constant.

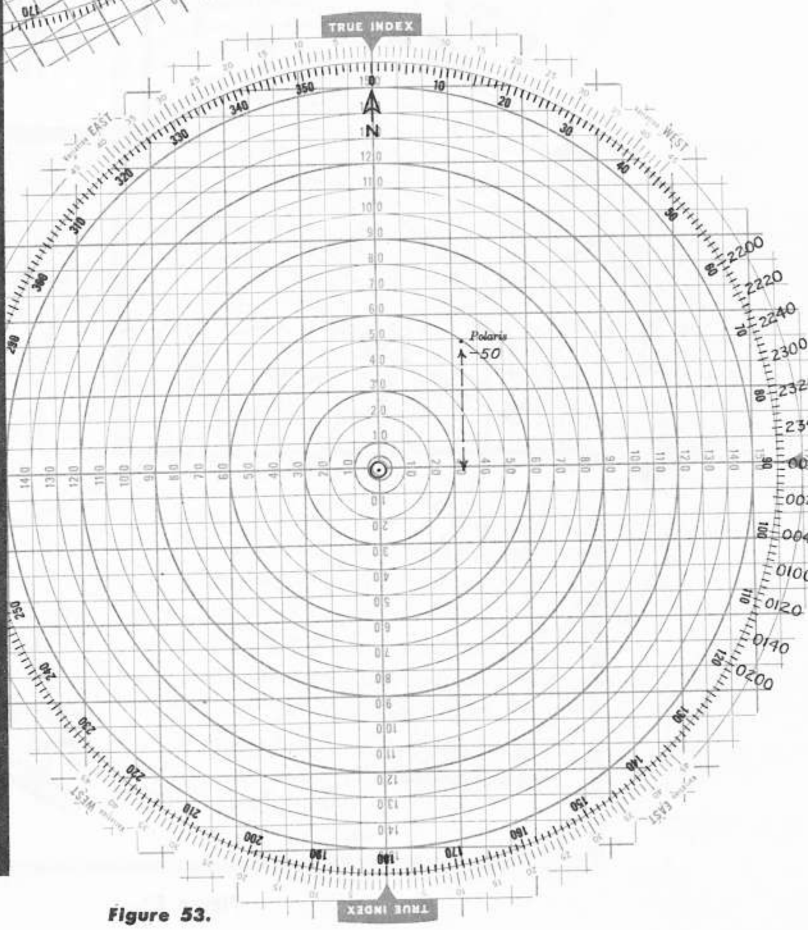


Figure 53.

21 CELESTIAL LINE OF POSITION

Given

Mid-lat.	26° N
Mid-long.	75° W
Jan. 25, 1945	1900
Sun GHA	101°53′
Long.	75°53′ W
Sun LHA	26°
H_c	38°26′
H_o	38°06′
Intercept	20′ Away
Zn	147°

Find

Line of position

Procedure

1. Set up chart.
2. Locate assumed position, 26° N Lat., 75°53′ W, Long.
3. Revolve the disc until the true index is on the true azimuth (Zn = 147°)
4. From assumed position mark off intercept, 20′ Away. Label "A."
5. Through "A" draw line of position (LOP) parallel to the cross index.

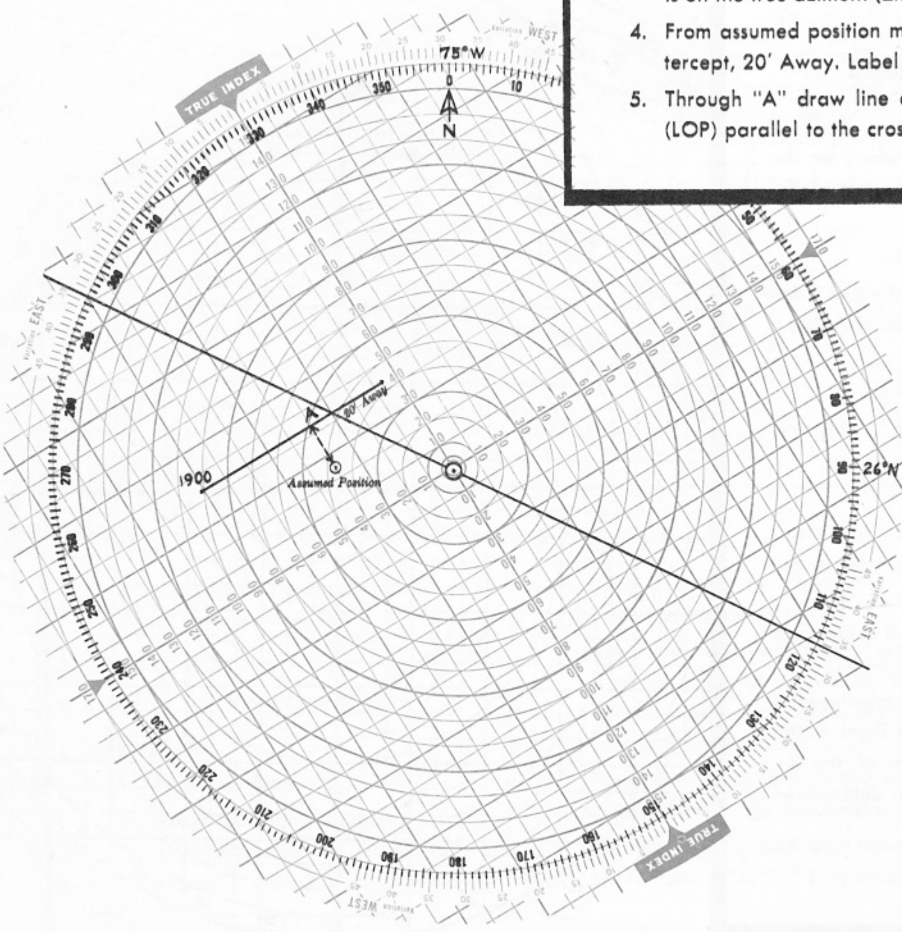


Figure 54.