If the geostrophic wind is to be an accurate approximation of the actual wind, it is essential that contours be relatively straight and parallel, and that no distortion be introduced through surface friction. A minimum of two to three thousand feet of altitude above the surface usually guarantees an accurate geostrophic wind. In the area of the equator (20° N to 20° S), Coriolis force approaches zero, thereby invalidating the geostrophic wind as a useful factor in navigation; but pressure differential navigation is reliable in midlatitudes and polar areas.

PRESSURE COMPUTATIONS AND PLOTTING

In determining position (PLOP) or drift (Bellamy drift) by pressure differential techniques, the navigator makes use of the crosswind component of the geostrophic wind over a given period of time. The determination of the crosswind component of the geostrophic wind requires specific data for use in a formula, which, when solved, will give the direction and displacement effect of the pressure system through which the aircraft has flown. This resultant is called "ZN." To solve the ZN formula, the navigator must understand how to obtain and apply such special factors as "D" soundings, effective TAS, effective air path, effective air distance, and "K" values.

"D" Soundings

The symbol "D" stands for the difference between the true altitude of the aircraft and the pressure altitude of the aircraft. It is expressed in feet as a plus or minus value. An absolute altimeter is normally used to measure true altitude on overwater flights, and the pressure altimeter is used to measure the pressure altitude. To determine the correct D sounding, assign a plus (+) to true altitude, a minus (—) to pressure altitude, and algebraically add the two. The correct sign can be applied by remembering the key word, TAMPA: True Altitude Minus Pressure Altitude.

The first D sounding is obtained at the fix when the pressure differential navigation leg is started. It is called D_1. The second D sounding, D_2, is obtained at the time of the intended pressure LOP. The value, $D_2—D_1$, is an expression of the slope (pressure gradient) experienced by the aircraft. By algebraically subtracting D_1 from D_2, the navigator determines the change in aircraft true altitude between D_1 and D_2. When this altitude change is compared with the distance flown, the resulting values becomes an expression of the slope. A large value of $D_2—D_1$ indicates a steep slope; a small value of $D_2—D_1$ indicates a gentle slope. The sign of $D_2—D_1$ indicates whether the aircraft has been flying up slope (+) or down slope (—).

The D sounding for the next position is called D_3; the slope experienced between D_2 and D_3 is expressed as $D_3—D_2$. For consecutive positions, it becomes $D_4—D_3$, $D_5—D_4$, etc. If D_2 is believed unreliable, D_3 may be compared with D_1.

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

The aircraft should maintain a constant pressure altitude to insure correct D soundings. If it becomes necessary to change altitude enroute, start a new D_1 at the new altitude.

Effective True Airspeed

In determining a pressure line of position, the navigator must compute the *effective true airspeed* (ETAS) from the last D sounding. The ETAS is the true airspeed that the aircraft would have had to make good, had it flown straight from D_1 to D_2. See figure 20-8. If the aircraft has maintained a constant true heading between D soundings, the effective true airspeed equals the average true airspeed. But if the aircraft has altered heading one or more times between the D soundings, the effective true airspeed is derived by drawing a straight line from the fix at the first D sounding to the final air position. This line is called the *effective air path* (EAP). Effective true airspeed is computed by measuring the *effective*

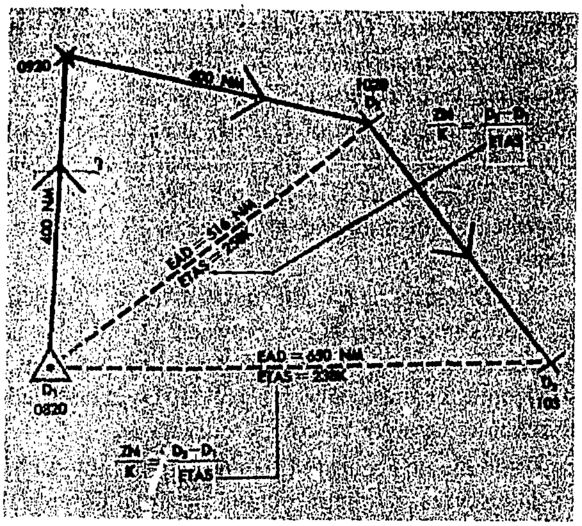


Figure 20-8. Effective True Airspeed

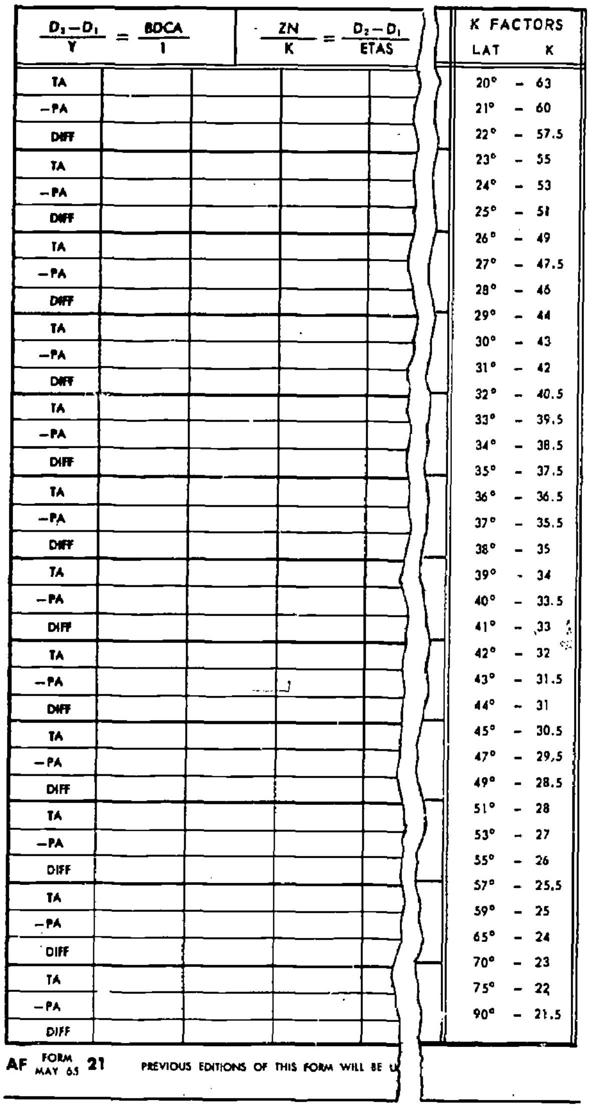
air distance (EAD) and dividing it by the elapsed time (in hours). In figure 20-8, an aircraft flew at 400 knots TAS from the 0820 fix to the 1020 air position via a dog-leg route. The effective air distance is 516 nautical miles; consequently, the effective true airspeed is 258 knots. In the illustration the navigator considered the D_2 sounding unreliable; therefore, he compared D_3 with the D_1 sounding.

K Factor

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

It is put in tabular form for the convenience of the navigator as shown in figure 20-9. In the table, this constant is plotted against latitude since Coriolis force varies with latitude. In using the ZN formula, the table is entered with midlatitude and the corresponding K is extracted.

Slope is properly expressed by vertical and horizontal displacement in the same units; however, the navigator expresses horizontal displacement in nautical miles and vertical displacement in feet. The K factor has been adjusted by a factor so that, with slope expressed in feet and distance in nautical miles, the geostrophic wind speed is computed in knots. Thus, the K factor cannot be used with statute miles to solve for the geostrophic wind in statute miles per hour.



$\frac{D_3-D_1}{Y} = \frac{BDCA}{1}$ $\frac{ZN}{K} = \frac{D_2-D_1}{ETAS}$

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K FACTORS

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

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Figure 20-9. K Factors Table from AF Form 21

Crosswind Displacement (ZN)

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

The ZN equation

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

can be rearranged for convenient solution on the DR computer as follows:

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

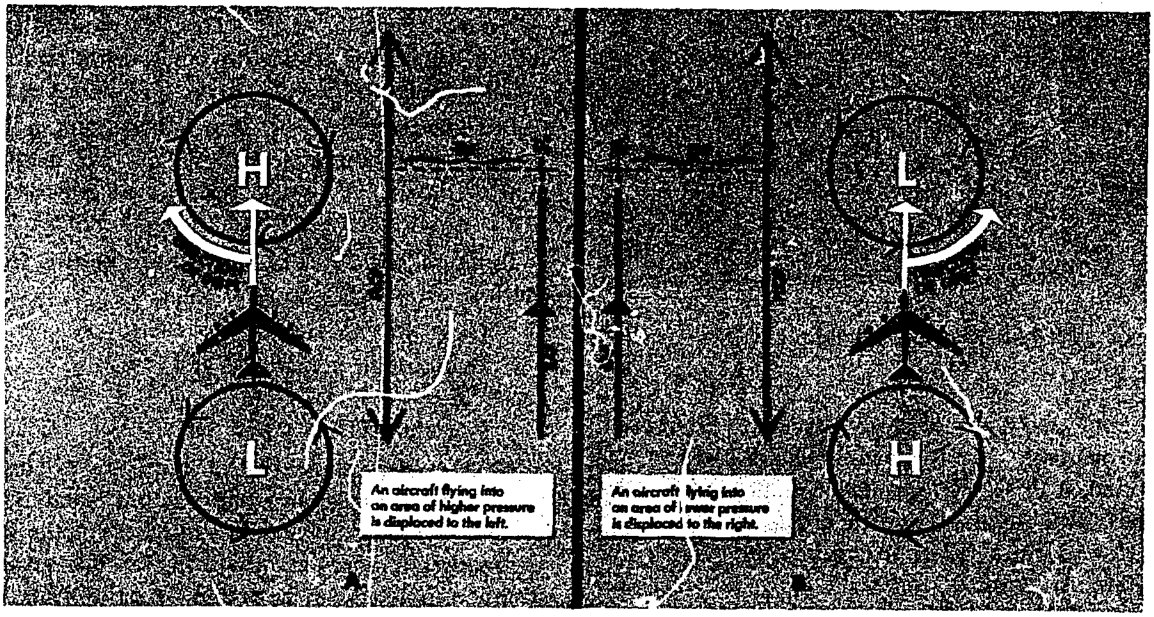

Figure 20-10. ZN Displacement in Northern Hemisphere

On newer DR computers, such as the MB-4, a subscale of latitude has been constructed opposite the values for K factors on the minutes scale. A table of K factors is not needed when these computers are used. Printed instructions on the face of these computers specify that, to compute crosswind component, set air miles flown (effective air distance) on the minutes scale opposite D_2—D_1 on the miles scale. The crosswind component (V_n) is not to be confused with crosswind displacement (ZN). The crosswind component (V_n) is crosswind velocity in knots. This component (V_n) must then be multiplied by the elapsed time between D_2 and D_1, in order to compute the crosswind displacement (ZN). If effective true airspeed is substituted for air miles flown (effective air distance) on the MB-4 computer, the ZN can be read over the K factor (or latitude on the subscale).

PRESSURE LINE OF POSITION (PLOP)

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

The direction of this displacement must also be determined; that is, the navigator must determine whether the aircraft has drifted right or left of the effective air path. Recall that wind circulation is clockwise around a high and counterclockwise around a low in the northern Hemisphere; the opposite is true in the Southern Hemisphere. Thus, in the Northern Hemisphere, when the value of D *increases* (a positive D_2—D_1), the aircraft is flying into an area of higher pressure and the drift is left (see figure 20-10A). When the value of D *decreases* (a negative D_2—D_1), the aircraft is flying into an area of lower pressure and the drift is right (see figure 20-10B).

Always plot the PLOP *parallel to the effective*

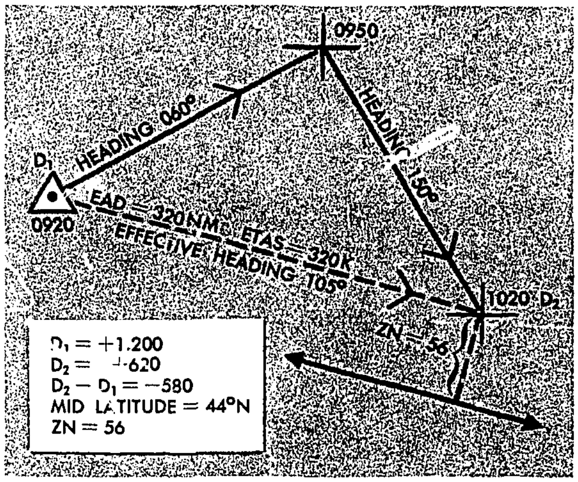

Figure 20-11. Plotting the PLOP

air path, and not necessarily parallel to the present true heading. This is shown in figure 20-11. Once plotted, a PLOP is used in the same manner that any LOP is used. It can be crossed with another LOP to form a fix or it can be used with a DR position to construct an MPP.

BELLAMY DRIFT

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

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

Bellamy drift can be determined from a ZN ground distance triangle without the intermediate step of the PLOP, but it is easier to understand if it is constructed graphically using a PLOP.

In figure 20-12, a PLOP has been plotted from the following information:

D_1 at a fix at 1000
D_2 at an air position at 1045
ZN = − 20 NM
Constant TH of 090°

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

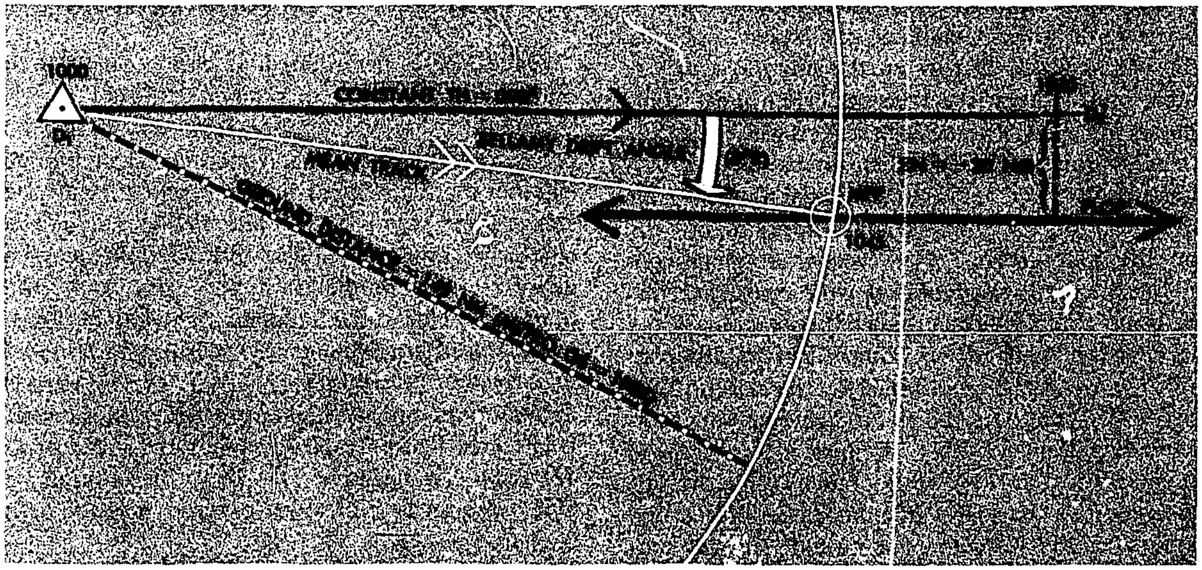

Figure 20-12. Solution of Bellamy Drift Using PLOP

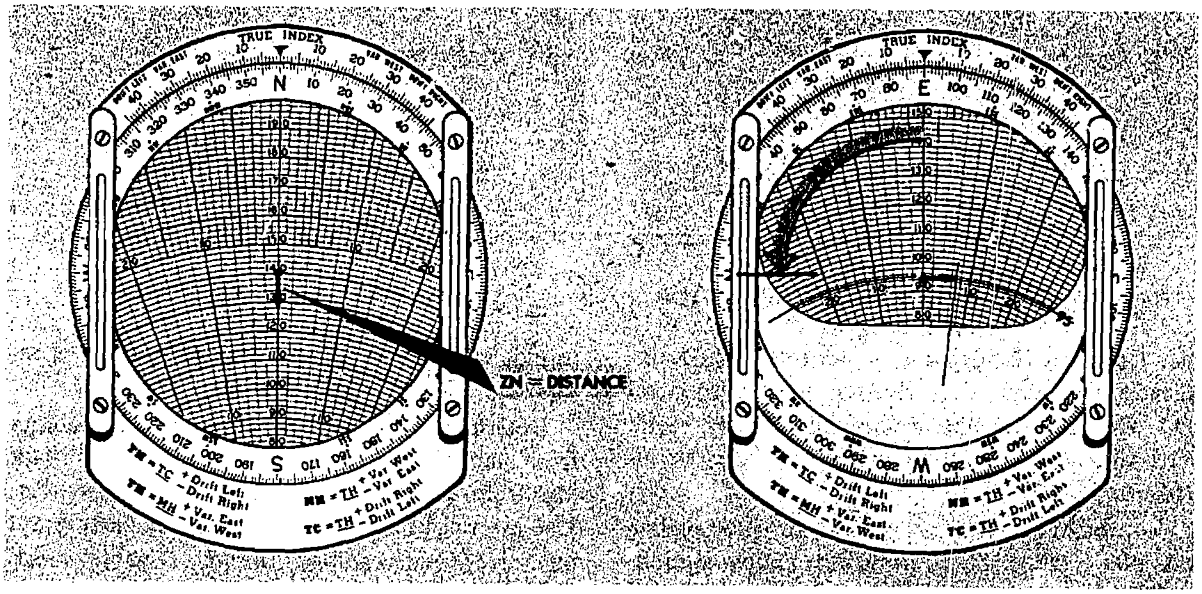

Figure 20-13. Computer Solution of Bellamy Drift

Computer Solution of Bellamy Drift

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

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

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

Example (figure 20-13)

Given: Northern Hemisphere
ZN = + 12.1
Time = 0:30
GS = 190 Knots

Find: Ground Distance = 95 NM
Drift = 7° left

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

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

The previous example would be set up as shown in figure 20-14. The answer 7.3 can be read over 57.3 on the minutes scale or under the index of the DRIFT CORR window.

The direction of Bellamy drift is determined in the same way that ZN direction is determined. In

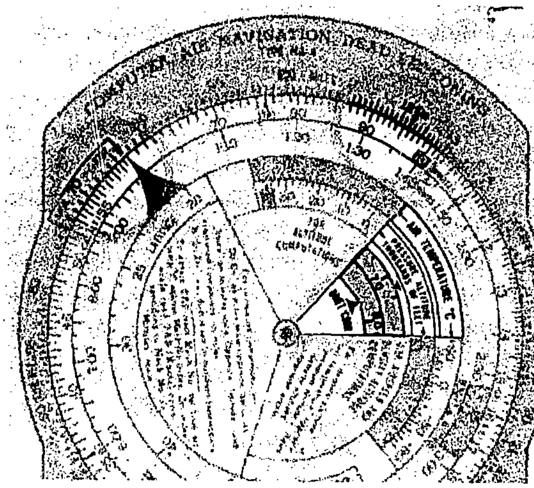

Figure 20-14. Mathematical Solution of Bellamy Drift