# DIAGRAMS FOR COMPLETION OF ARCTIC POLAR CHART No. 5965

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It is fitting that this account should begin with our paying tribute to Captain Weems, who is present among us. The system we are about to describe is based in part on the principle applied by him in his well-known Star Altitude Curves. The principle has merely been extended from the Mercator to the stereographic projection.

We should moreover mention that the particular problem of transpolar navigation has been studied and solved by Mr. Thoburn C. Lyon, under Captain Weems' supervision, concurrently with ourselves. A design for a computer we have just lately had occasion to examine has been devised by him on a basis similar to ours. A paper recently communicated to the International Hydrographic Bureau on the subject will be published in the next issue of the International Hydrographic Review.

This simultaneous research in both America and Europe, resulting in approximately similar arrangements, seems to prove that the idea has been in the wind and that a real need in transpolar navigation is being filled.

Polar Chart No 5965 is a nautical document, similar to all other marine charts, showing the whole of the Arctic Ocean and the outline of the continents bordering upon that ocean on the largest possible scale. This chart therefore makes navigation (1) possible according to standard methods that are simplified by various processes and documents taking advantage of the proximity of the Pole, such as (in so far as astronomical navigation is concerned) : American publication H.O. 214 and *Professeur en Chef d'Hydrographie* Hugon's method (No. 14-1370 of the French Navy Hydrographic Office).

Once the position has been computed it is transferred to the chart by longitude and latitude, in the usual way.

## II

The possibilities of the chart are not, however, limited to this purely documentary aspect. The chart may also be used as a navigational *instrument,* with the

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(1) In the following article the world « navigation » should be taken in the sense of a slow change of position (by ship, sled, helicopter, ordinary drift, etc...) likely to require and to permit a certain amount of accuracy in obtaining a fix. The expression « air navigation » applies to rapidly moving aircraft, whose accuracy of position is neither required nor involved in the same degree.

particular virtue of completely eliminating computation; various *tracing diagrams* need only be added, due to the following circumstances :

(a) The graphical navigation methods invented for the Mercator projection (Favé diagrams Nos. 5603, A & B) may be *transposed* on the stereographic projection, so simplified that the orthodromes, shown on the Mercator projection by rather complex curves, appear on the stereographic projection as circles that are very easy to compute and draw.

(b) As the centre of the stereographic projection is located at the North Pole, a simplified representation results for hour angles and right ascensions. This *specialization* of stereographic projection has already frequently been used for solving the spherical triangle, and is the basis for the principle of Keller's double planisphere, Kollshutter's diagram, the French National Geographic Institute's tracing diagram, etc.

It should be noted, however, that in the foregoing diagrams the hemisphere is shown in its entirety, while in the present case only the part corresponding to the area covered by the chart is used. This considerably reduces the cases where the spherical triangle is apt to be shown (we shall see that in the general case this is no major objection) ; and the degree of accuracy gained makes up for loss of range.

(c) As the projection is stereographic, circles of position are shown by circles, which can be computed and plotted with extreme ease owing to the fact that the centre of projection is the North Pole. Thus transposition of Weems' Curves (Mercator) has been considered, which can be shown with comparable accuracy on a single diagram instead of a whole atlas.

This diagram, which is adjustable to the chart, will eliminate transfer of the fix after determination of the co-ordinates.

(d) On the scale of 1 : 6.300.000, 1 mm. represents approximately 3 miles. This gives an idea of the *accuracy* capable of being supplied by this graphical method — an accuracy that corresponds with that supplied by observations in an area where horizontal refraction is not well known, and by radio observations; and which is also in harmony with the document ultimately used to determine navigational data (course and distance), since it consists of the chart itself. These considerations apply even more strongly to air navigation.

In short, the combined facts of simplicity, specialization and scale of projection have induced us to make the fullest use of the possibilities of Chart No 5965. As a matter of fact, in his article on « Mercator's Planisphere and Navigation by Radio Direction Finding » (Annales hydrographiques, 1934, p. 94), Driencourt had already foreseen — at least in connection with radio navigation — the use of such diagrams in combination with a chart in stereographic projection.

## III

We shall proceed to show how this may be attained. Let us consider the three following problems :

(a) Navigational preliminaries and navigation by dead reckoning ;

(b) Radio navigation ;

c) Astronomical navigation;

(a) *Navigational preliminaries*

These consist in plotting the orthodrome joining two points, U and V. Recourse is had for this purpose to tracing diagram No 5965 A, which is rotated on the chart, centre to centre, until the same orthodrome (black curve) passes through points U and V. The difference in the readings at U and V on the red curves shows the distance to be covered. When plotted on the chart, the orthodrome at each point supplies the course angle, measured graphically either with the meridian (in this case it may be preferable to use the blue curves) or the international meridian, if navigation is solely referred to this direction.

(b) *Radio Navigation*

($\alpha$) Measurement of $\alpha$ bearing of ship from a receiver R. Azimuth might be plotted at R, the diagram A be rotated until an orthodrome is tangent to R at the azimuth. Its rotation is preferred until the blue curve, with the value of $\alpha$ as graduation, passes through point R ; then plot the orthodrome likewise passing through R.

($\beta$) $\beta$ bearing (azimuthal with reference to the meridian) according to which transmitter E is detected from the ship. Determine point $M_1$ of the locus of points where the azimuth of E has the value of $\beta$ in the following manner : rotate the diagram until an orthodrome passes both through transmitter E and in the vicinity of the ship's position ; plot $M_1$, which is the intersection of this orthodrome and the blue curve with $\beta$ as graduation. Repeat the operation with a second orthodrome to obtain $M_2$. Join $M_1$ and $M_2$, which supplies the useful portion of the desired position.

($\gamma$) $\gamma$ bearing (computed not with reference to the North but generally with reference to the international meridian), according to which transmitter E is detected from the ship.

In the vicinity of the ship's position, plot D parallel to $\gamma$ and passing through E. Rotate the diagram until $D_1$ is tangent to an orthodrome, say $0_1$. In this position plot $0_2$, an orthodrome passing through E. If $0_2$ is close to $0_1$, $0_2$ is the desired bearing ; otherwise repeat the operation by plotting $D_2$ parallel to $D_1$ in the immediate vicinity of $0_2$.

*Note.* That such transmitters will one day gird the Arctic Ocean is no vain prophecy. One might even conceive in the distant future of radar responder beacons scattered on the pack-ice, with their positions determined according to their progressive drift and their co-ordinates supplied to mariners who could refer to them in setting their course.

(c) *Astronomical Navigation*

($\alpha$) *Fixed stars*

The method here consists in the transposition of 3 families of altitude curves for 3 stars of Weems' diagrams to a tracing diagram that is adjustable with reference to Chart No. 5965. Adjustment should be centre to centre, and the Greenwich sidereal time of each observation taken into account. The altitude curves should be plotted in the vicinity of the ship's position and then transferred for the time the position is desired. Circles of position for 1955 are shown accurately; but the intersection of the hour circle of the star with (say) the 70° parallel need only be moved along a small graduated vector for quite adequate locations of circles of position to be obtained after 1955 until a very remote date.

The diagram appeared to be of such simple construction that it seemed a natural step to construct three instead of only one, in order that 9 stars instead of 3 might be obtained, with the stars in groups of three so that with luck a single diagram would suffice for a complete fix. In this respect each of the three-star groups was so selected that they intersected properly and had declinations between 30° and 60° ; each group was moreover chosen with reference to the beginning, middle and end of the polar winter.

These are the final proposed groups :

Diagram I (beginning of winter) :
*Deneb* (α Cygni - 1.3)
*Alpherat* (α Andromedae - 2.2)
*Capella* (α Aurigae - 0.2)

Diagram II (middle of winter) :
*Mirfak* (α Persei - 1.9)
*Elnath* (β Tauri - 1.8)
*Dubhe* (α Ursae Majoris - 2.0)

Diagram III (end of winter) :
*Pollux* (β Gemini - 1.2)
*Alioth* (ε Ursae Majoris - 1.7)
*Vega* (α Lyrae - 0.1)

What size should these diagrams take ? They could not be extended to maximum coverage of Chart No. 5965, as then a larger size than double-elephant would be required. We decided that they should, extend as far as the 70° parallel, which meant a diameter of approximately 700 mm., which could be printed on double-elephant. In the case of air navigation, where larger coverage might be required, particularly over land areas, the question will again be taken up when the second polar chart, Chart No. 5966 on the scale of 1 : 12.000.000 is published, which, owing to its degree of accuracy (1 mm. = 7 miles), is likely to be of interest to air navigation.

*Practical Application*

A. Preliminary Remarks

I. The mariner will invariably prefer to use mean time for navigation purposes ; it is convenient in estimating distances covered and enables reference to be had at points of arrival and departure to times of the zones upon which these points depend.

If he returns to his point of departure, he will keep the time of the zone at that point; in the opposite case it will be to his advantage for him to set his mean-time watch upon departure for the zone of the point of arrival. It will generally be of no use to him to adopt the times of the zones he successively meets with, since ordinary living conditions in the vicinity of the Pole, which are independent of the Sun's course, require no such action.

We shall moreover assume that the navigator also takes with him a sidereal watch set at Greenwich sidereal time.

He will thus be able to regulate his navigation as of the standard time of a zone and carry out his astronomical observations on Greenwich sidereal time, without entering into tables or effecting computations.

## II. Accuracy of observations

Diagram I supplies information, with no computation, on accuracy requirements for reading watches.

Roughly speaking, less than a 3-mile shift occurs for circles of position for a rotation of

1/2 minute of time at 70°

3/4 minute of time at 75°

1 minute of time at 80°

2 minutes of time at 85°

On the other hand, up to a speed of 360 miles an hour, an error of 1/2 minute in time causes less than a 3-mile error in the transference of circles of position.

The recording of time to within half a minute is therefore amply sufficient, which justifies the use of two wrist-watches of normal quality. Every attention should be paid to maximum accuracy in determining altitudes and corrections of the latter (corrected altitudes being estimated to within 3 minutes).

## B. Exercise

A helicopter, travelling at the rate of 100 miles an hour, leaves Point-Barrow, Alaska, on Wednesday, February 20, 1952 (departure at 0400, time zone + 10), for North Cape, Norway (time zone —1). Its mean-time watch will therefore be set upon departure on time zone —1, or at 1500.

According to reckoning, at 2100, after 6 hours' flight, it should be at point $M_e$ on the chart, by $\varphi_e = 81°26'$ N, G = 157°50' W.Gr. The following observations are taken :

| | Mean time, zone —1 | Greenwich sidereal time from watch | Intervals | Corrected altitudes |
|---|---|---|---|---|
| Comparison between two watches | 21 h. 00 m. | 5 h. 59 m. | | |
| Observations | | | | |
| Pollux | | 6 h. 03 m. | + 4 m. | 19° 18' |
| Alioth | | 6 h. 07,5m. | + 8,5 m. | 54° 30' |
| Vega | | 6 h. 14 m. | + 15 m. | 47° 09' |

The exact position is requested at 2100 (zone —1)

Use of Diagram III supplies point M

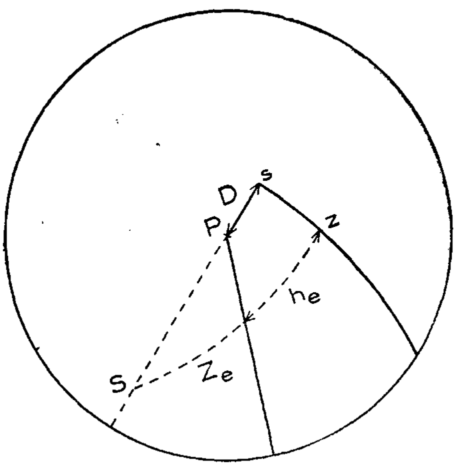
$\varphi = 81°00'$

G = 164°40' W Gr.

$\beta$) *Variable Bodies.*

During the polar summer only the Sun and occasionally the Moon are visible, with varying right ascensions and right declinations. The foregoing method is therefore inapplicable. Diagram A may nevertheless be used for the Sun in the majority of cases, and for the Moon when its declination is sufficiently slight.

This diagram enables the spherical position triangle to be solved for a star of slight declination, as follows :




Let S be the Sun and $Z_e$ the reckoned point.

Produce SP to s so as to obtain one-fourth of a great circle and S $Z_e$ to z so as to obtain one fourth of a great circle. It is clear that Ps = D and $Z_e$ z=$h_e$.

Now the spherical quadrilateral Ps z $Z_e$, which is small, is contained within the chart, and is easy to construct :

On the chart plot direction P S supplied by the right ascension of the Sun and sidereal time at the time of observation.

On the other side extend the declination to Ps; diagram A enables plotting of the orthodrome sz perpendicular at s to Ps.

It also enables the orthodrome passing through $Z_e$ and perpendicular to sz to be found. In this latter position of the diagram, the red curves supply, by taking the difference, the value z $Z_e$ = $h_e$.

Where the Sun is concerned, direct and practically continuous plotting of circles of position may even be considered as observations progress. Near the solstice, the variation in declination of this body is slight : moreover, if the voyage is not of excessive duration, it is possible to consider right ascension as being constant and equal to its value midway during the voyage.

The following tables show tolerance limits for maintaining the accuracy so far observed :

| Length of voyage less than | Extent of diagram that may be used computed from Pole | Period of utilization |
|---|---|---|
| 6 h. | Entire diagram | At all times |
| 8 h. | Entire diagram | From 2 May to 12 August |
| 10 h. | 15° | From 15 May to 30 July |
| 16 h. | 10° | From 30 May to 14 July |
| 24 h. | 7° | From 6 June to 6 July |
| 30 h. | 5° | From 10 June to 3 July |

It may be noted that the voyage of the « Aries » took place on 17-18 May 1945 ; the trip lasted 18 hours. These conditions would therefore not have been complied with ; however, four periods during June were likewise considered that would have satisfied requirements.

An appreciable extending of the limits indicated above, by making a few alterations or by decreasing the degree of accuracy required upon arrival and departure, is possible of consideration.

The method is then as follows :

*Before departure,* plot a straight line P A on the chart producing an angle GPA with the international meridian equal to the mean right ascension of the Sun. Plot s corresponding to mean declination on the diagram and plot s z.

After departure, maintain straight line PA in coincidence with the graduation corresponding to sidereal time.

At the *time of observation,* trace s z on the chart, then rotate the tracing until the two orthodromes $z_1$ $Z_1$ and $z_2$ $Z_2$ of circular graduation assume a perpendicular position with reference to s z and they enclose $Z_e$. Plot $Z_1$ and $Z_2$ on the orthodromes so that $z_1 Z_1 = z_2 Z_2 = h\ v$.

$Z_1$ $Z_2$ is the useful portion of the circle of position. Moreover the tangent to one of the orthodromes or the perpendicular to the circle of position thus plotted supplies the Sun's azimuth, which enables checking of the course with respect to the Sun.

*Application*

A helicopter travelling from Reykjavik towards the Pole on Tuesday June 10 1952, according to the estimated course plotted on the chart (and figured for time for time zone + 1) takes the following observations :

| Mean times (zone+1) read from watch | Sidereal times read from watch | Corrected altitudes |
|---|---|---|
| 10 h. 08,5 m. | 4 h. 23,5 m. | 28° 54' |
| 11 h. 10 m. | 5 h. 25 m. | 28° 18' |
| 12 h. 21,5 m. | 6 h. 37 m. | 26° 45' |
| 13 h. 02 m. | 7 h. 17,5 m. | 25° 33' |

The corresponding position lines are required to be plotted.

Before departure, right ascension and declination midway during the voyage (in the vicinity of the Pole), at 1500 (time zone + 1) have been obtained from tables.

AR = 0515 hours and D = 23°03' were obtained.

The corresponding meridian was plotted on the chart and the corresponding orthodrome on the diagram.

As observations progress, application of the method then supplies the corresponding position lines.

## IV

### *Conclusions*

Experience alone will show the advantage to be derived from the above-described methods. We repeat that they are not meant to be a total substitute for the standard methods of computation mentioned earlier ; however, they may occasionally, and perhaps then profitably, take their place. They may also complete them, particularly in navigation by dead-reckoning and by radio direction. Our final opinion is that Chart No. 5965 attains maximum efficiency through use of these improvements, and that the arduous task of navigators to the Pole may thereby be made somewhat easier.

If this be the case, we may conclude by saying that it will be possible to take similar measures in using polar charts now in the press, such as No. 5966 (Arctic Ocean), and No. 5879 (Southern Continent) on a common scale of 1 : 12.000.000, or appreciably one-half.

If the range of the area of use is not increased, it will easy to obtain these new documents through mere photographic reduction (except that diagrams for 9 bright stars in the Southern Hemisphere will have to be constructed), and they will then constitute an extremely compact instrument of definitely practical use to air navigation. If the range is slightly increased, as far as the 60° parallel, they could also be used in plotting moon circles of position, and equipment both compact and complete would be obtained.