TECHNICAL ASPECTS OF THE "ARIES" FLIGHTS

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NOTE : In May 1945 the Royal Air Force Lancaster "Aries" made a series of flights in high northern latitudes, during which the North Geographical Pole was reached and two magnetic survey flights were made in the region of the North Magnetic Pole (1).

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NAVIGATION.

Before deciding on the navigation methods we would employ, a thorough survey was made of the records of all previous Arctic flights. It is perhaps not generally realized how many successful Arctic flights were made in the twenty years or so before the late war. From the logs of these flights we obtained some useful information such as, for instance, the compasses used by Sir Hubert Wilkins in 1928, and the weather encountered by Tchukaloff in June 1937. Though designs in aircraft and navigation instruments have changed considerably since then, many of the problem of Arctic flying remain unchanged.

As was expected, the biggest navigational problem was that of measuring direction. There were several contributory reasons for this, an obvious one being the convergence of the meridians towards the Pole. It was, of course, necessary to use a polar projection instead of the usual equatorial Mercator, and of several possible projections the polar stereographic was chosen because it is conformal and the meridians are straight lines. On this projection the rhumb-line appears as a complicated curve and is therefore discarded as useless, but straight lines may still be used for plotting, as on the Mercator, and in this case approximate closely to great circles. It is awkward however to measure the direction of such lines from the local meridian, because, instead of being constant, the direction changes continually along their length. We solved this problem by using the Greenwich grid system of orientation, suggested by myself in 1941 especially for polar air navigation, and later approved by the British Commonwealth and United States Air Forces. I have since learnt that a similar method was proposed in 1928 by the Italian hydrographer, Captain L. Tonta[2], but was never widely used.

The principle of the Greenwich grid system is that local meridians are ignored, and instead all directions are measured in relation to the meridian of Greenwich. The direction of Greenwich from the pole is taken as 000° "Greenwich", or 000° "G", and whatever an aircraft's latitude and longitude, if its course when plotted is parallel to the meridian of Greenwich, it is said to be flying 000° G. If it alters course 90° to starboard, the new course is 090° G, and so forth, the normal clockwise rotation from 0° to 360° being retained. One advantage of this convention is that at the Pole the direction of any heavenly body in degrees "G" is numerically equal to its Greenwich hour angle. Even 10° or 15° from the Pole this is approximately true, which considerably simplifies the problem of orientation. Again, due to the properties of the stereographic projection, a simple formula connects the "true" system with the Greenwich system : direction in degrees "G" =, direction in degrees "T" ± long. W. (or — long. E.) ± 180°. It should be noted however that the latitude and longitude graticule is retained for expressing position., because of its use in astronomical calculations. On all three of the flights the Greenwich system worked perfectly, and we used it whenever the polar projection was needed for navigation plotting : that was, generally speaking, for all latitudes north of 70° N. So long as frequent observations of the sun were possible, we were never in doubt of the aircraft's course, even when its exact longitude was uncertain.

A second navigational problem is associated with the use of the magnetic compass. In the first place, as may be seen in figure 1, the isogonals of magnetic variation terminate at both Geographical and Magnetic Poles, with a resultant congestion of lines on the chart.

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(1) Among some previous arctic flights the following are quoted : Amundsen, 1925 ; Byrd, 1926 ; Norge, 1926 ; Wilkins, 1927 and 1928 ; Nobile, 1928 ; Graf Zeppelin, 1931 ; Lauge Koch, 1933 ; Russian Flights, 1937 ; Lauge Koch, 1938.

(2) L. TONTA : "Submarine phonotelemetry" («Hydrographic Review», Vol. V, No. 1 (1928), pages 91-125).

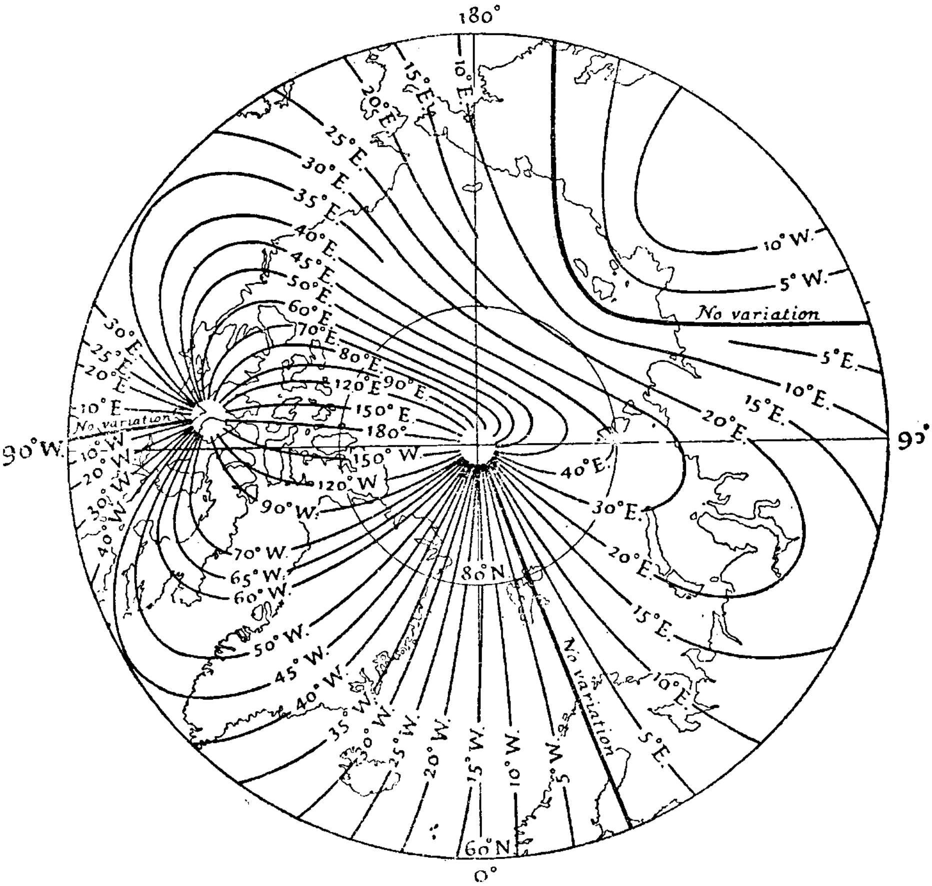

Fig. 1.—Isogonals of magnetic variation in the Arctic.

The picture can be simplified by expressing the variation in degrees " G " instead of " true " (which is logical if navigational measurements and calculations are to be made in degrees "G"), and plotting the new isogonals. Figure 2 illustrates how these new " grid variation " isogonals spread out much more evenly, the Geographical Pole no longer being a point of singularity.

A more serious problem however is the weak directive force of the magnetic compass when near the Magnetic Pole, and the comparative inaccuracy of existing magnetic surveys over a large part of the area. This can best be illustrated in a chart. In figure 3, the horizontal component of the earth's field within area A is 0.04 gauss or less (that is, less than one-quarter its value in this country), while within area B it is 0.08 gauss or less. Broadly speaking then, within area A the magnetic compass is almost useless, while within area B its indication should be treated with reserve, and checked when possible by astro or other means. The solution we adopted was to check the course by astro-compass observations of the sun at intervals of quarter or half an hour, relying, when the sky was obscured, on a specially constructed, large-size, directional gyroscope.

A third navigation problem of interest concerns the astro-observations. As we were out of range of radar-fixing aids and for the most part above cloud, not only direction but also position had to be determined from astronomical readings. It was May when the flights were made, and the Arctic day was twenty-four hours long. If astronomical fixes were to be obtained, the flights had to be made at a time when the sun and moon were approximately 60°-90° apart and the moon had a northerly declination. Such conditions existed for only five days in mid-May, and thenceforth for lessening periods, which was one of the main factors determining the date of the expedition.

Astro-navigation tables (A.P. 1618) were available to 80° N., but from there to the Pole the polar intercept method was used : that is, the Pole was taken as an assumed position,

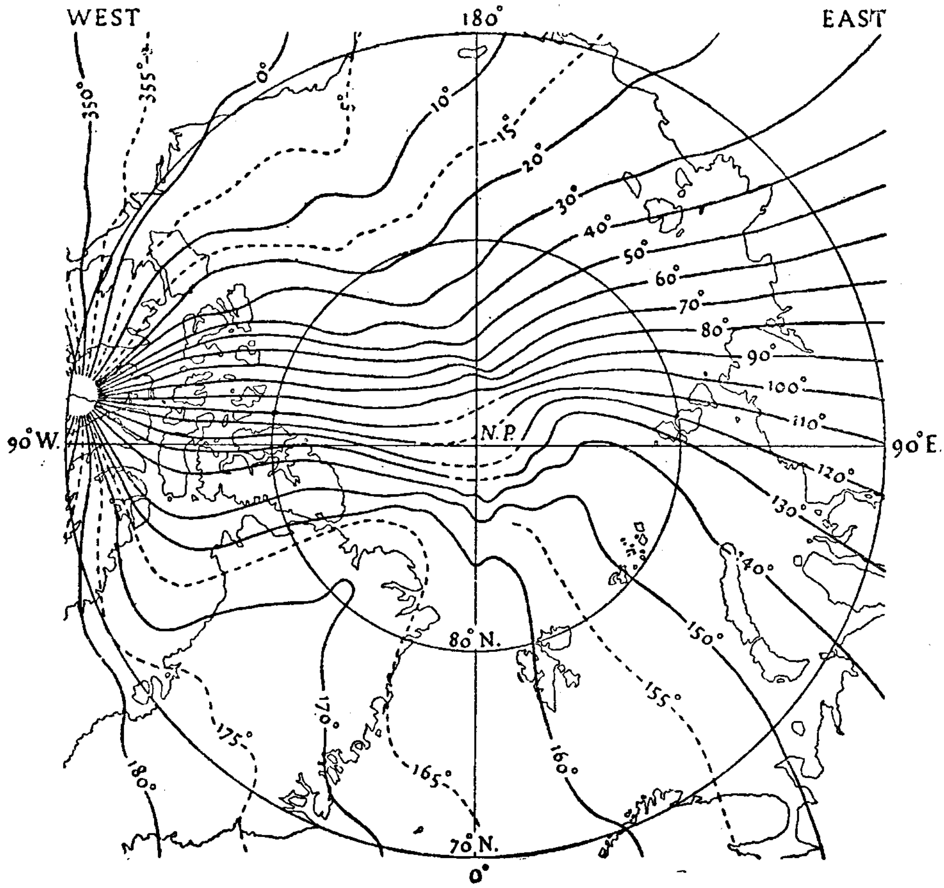

Fig. 2.—Isogonals of magnetic variation on Greenwich grid system.

the intercept being simply the difference between declination and observed altitude. To assist in plotting the rather long position lines which resulted, a special template had been constructed with the help of the Nautical Almanac Office.

The navigation instruments we carried with us were as follows : an R.A.F. type of distant-reading compass (a gyro-stabilized master unit in the tail of the aircraft, with repeaters for the navigator, pilot, and research officer) ; a non-stabilized direction-reading magnetic compass for pilot's standby ; an astro-compass ; a special directional gyroscope ; and the usual set of navigation instruments to be found at the plotting table of an R.A.F. heavy aircraft. In addition, sextant observations were taken from the rear dome, and occasionally by the second pilot from the front dome. The gyro-stabilized distant-reading compass was used as a direction indicator almost continually throughout the flights. It proved quite reliable, even in regions where the horizontal component of the earth's magnetic field was as low as 0.03 gauss, provided that it was checked at frequent intervals by astro-compass observations on the sun.

The magnetic compass linkage, and the methods of taking observations, can best be illustrated by means of a schematic diagram (fig. 9). The solid lines indicate electrical transmission lines, and the dotted lines indicate visual checks. The astro-compass is placed at the top of the diagram, because upon it all the rest depended. Although the distant-reading compass master unit fed the magnetic course to the variation-setting corrector, the latter was not set to the value of the magnetic variation on the chart, but was simply turned until the navigator's repeater agreed with the " true " course (or " Greenwich " course) as determined by an astro-compass observation of the sun. The corrected setting was then entered in the navigation log. This procedure kept the various distant-reading compass repeaters synchronized with the astro-compass readings, and enabled the pilot to steer by his repeater, even

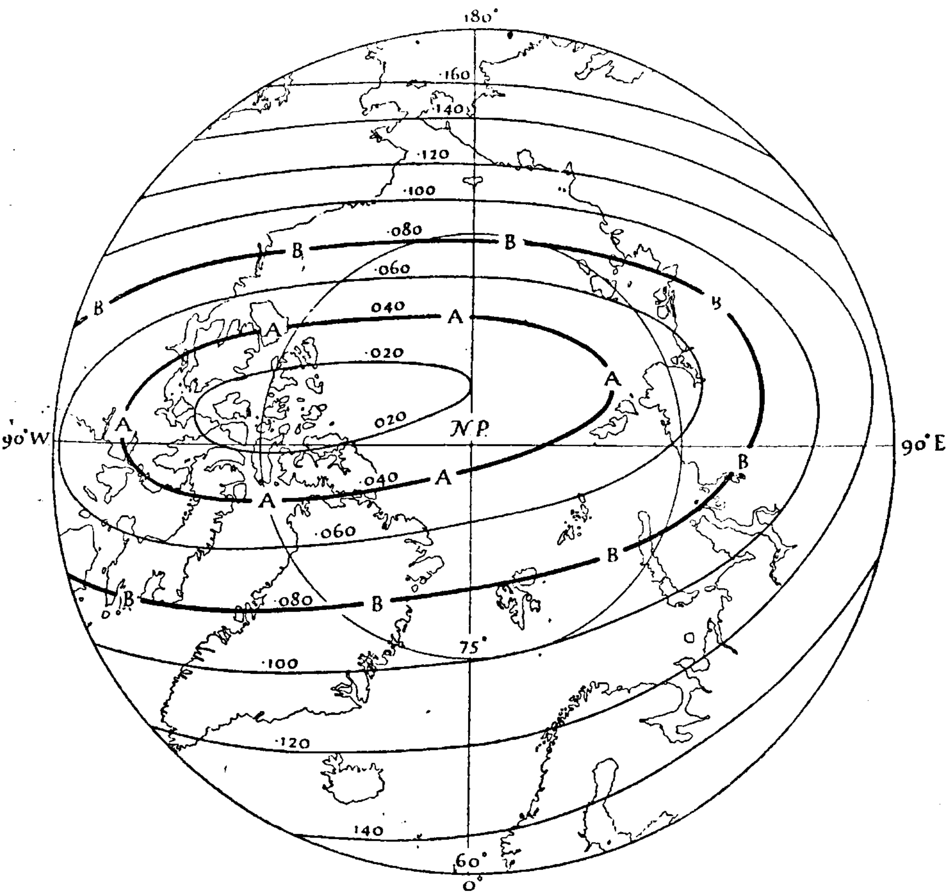

Fig. 3.—Approximate curves of equal horizontal force in Gauss.

when the master unit was not picking up the magnetic meridian but was functioning as a simple directional gyro. The special directional gyroscope was checked against the same astro-compass readings, and since it had a low and very constant precession rate it was used to check the navigator's compass repeater when clouds obscured the sun.

During the flight to the North Geographical Pole, the transfer from true course to Greenwich course was made immediately after crossing 70° N., the new course being set on the compass repeaters by turning the variation-setting corrector. The flight had been planned so that the sun would be straight ahead as we bore down on the Pole, and sextant acceleration errors would be reduced to a minimum. It was at this stage that we had the novel experience of flying due north at midnight, with the sun straight ahead and rising in the sky.

The technique outlined above, for plotting astro-position lines and checking the compass repeaters from sun observations, proved satisfactory enough, and we experienced no major difficulty. It was concluded later however that for latitudes 80° N. to 88° N. or even higher, astro-navigation tables would have been handler to use than the polar intercept method.

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COMPASSES AND MAGNETISM.

The purposes of the magnetic research were threefold : to record the performance of several standard types of aircraft compass ; to investigate the feasibility of carrying out an aerial magnetic survey in the neighbourhood of the Magnetic Pole ; and to extend the existing knowledge of the earth's magnetic field.

The magnetic compasses we carried with us (shown diagrammatically in fig. 8) were as follows : (1) R.A.F. type of distant-reading gyro-magnetic compass (1 *a*, variation-setting corrector ; 1 *b*, repeaters) ; (2) American gyro-stabilized flux-gate compass (2 *a*, variation-setting corrector ; 2 *b*, repeaters) ; (3) American magnesyn compass (3 *a*, remote indicator) ; (4) special R.A.F. type of P-10 compass, non-stabilized but with high magnetic moment ; (5) 01151-A compass, non-stabilized, with high magnetic moment, and medium damped ; (6) American type of B-16 compass, with vertical card, and lightly damped ; (7) R.A.F. type of N-1 compass, similar to the American type B-16; (8) astro-compass ; (9) special directional free gyroscope ; (10) special dipmeter (10 *a*, remote indicator) ; (11) American three-axis flux-valve magnetometer (11 *a*, remote indicator). The dipmeter was specially constructed by the Royal Aircraft Establishment at Farnborough from parts of a flux-gate compass to read dip directly in degrees. The magnetometer was a simple portable type of compass, designed for comparative rather than absolute measurements, but the best which could be installed at the time.

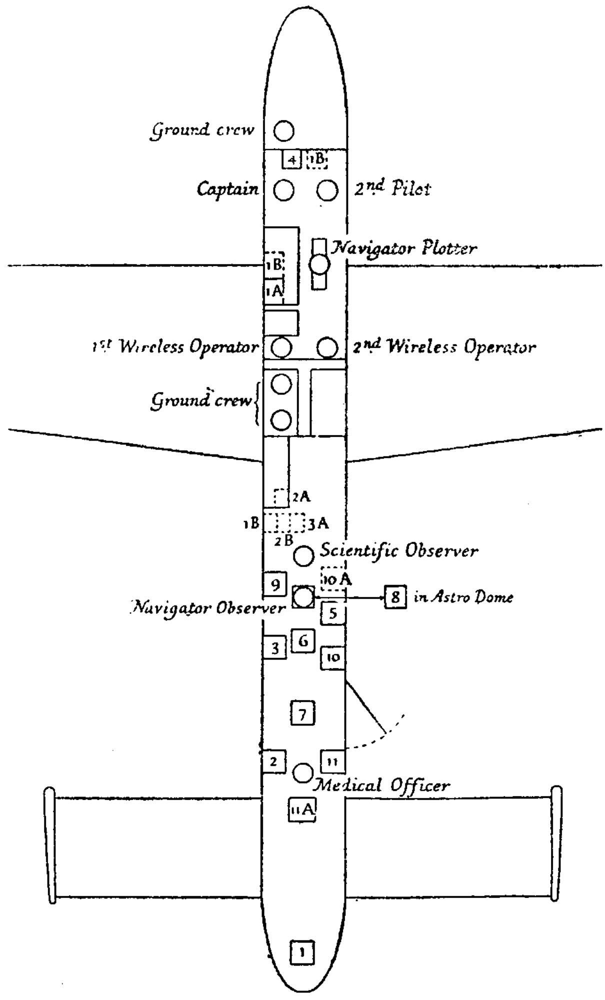

Fig. 8.—Air crew stations and siting of compasses in aircraft.

The method of taking magnetic observations will be seen by referring to figure 9. Every half-hour, and sometimes every quarter-hour, two or three readings on the sun were taken with the astro-compass. The navigator then corrected the distant-reading compass repeaters as necessary. Simultaneously, the special gyro was read and the three repeater compasses (direction-reading compass, flux-gate compass, and magnesyn) were photographed. Then, with the camera running, a series of visual observations were taken of the other magnetic gear (01151-A, B-16, N-1, and special B-10 compasses, dipmeter and magnetometer). The R.A.F. type of distant-reading compass had a triple role : as an instrument whose performance was to be tested ; as a control in the other gear by virtue of its gyro-stabilization and photographic recording ; and, above all, as a navigation instrument in almost continuous use by the navigator, whose observations had priority. Every time the navigator adjusted the variation-setting corrector, which he did very frequently, it offset all the repeaters, which necessitated extreme care in correcting the subsequent records. It was not an ideal system for a magnetic survey, but it was the best which could be devised under the circumstances.

There was some doubt as to the actual position of the North Magnetic Pole. The Astronomer Royal had calculated its mean position (apart from diurnal changes and the effects of magnetic storms) at 76° N., 102° W., in Bathurst Island, some 300 miles nort-north-west of its hitherto accepted position in Boothia peninsula. Though such a shift, or error of position, would have no bearing on navigation in areas at other latitudes which have been accurately charted magnetically, it would be of immense significance to Arctic flying.

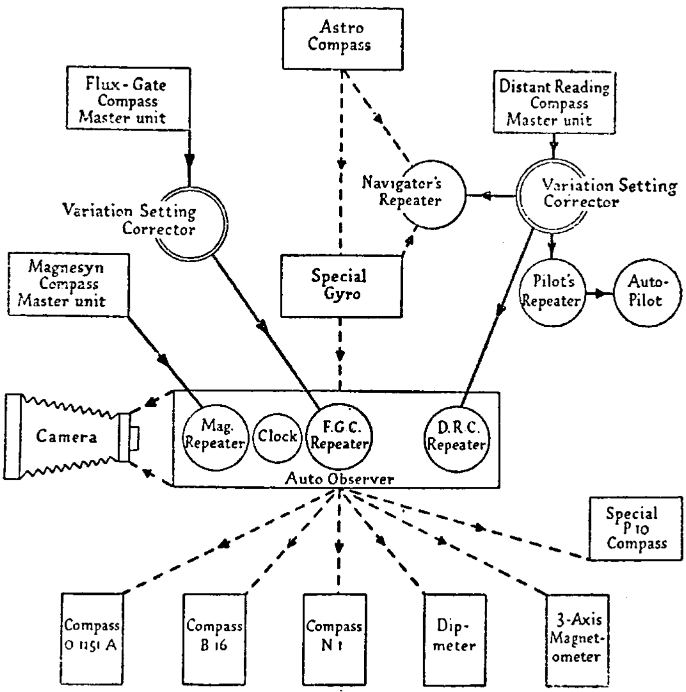

Fig. 9.—Magnetic compass linkage.

The data recorded for the compasses were obtained for the most part on the three main flights, large sections of which lay across areas of very low horizontal magnetic intensity. On the flight to the North Geographical Pole, the directive force of the compass dropped to one-fifth of its value in England. On the flight to the Magnetic Pole it almost reached zero.

The effect of the weak horizontal component on the aircraft's non-stabilized compasses was not simply to make them sluggish, but to increase amplitude of their normal oscillations. Single readings were consequently valueless, and instead the mean of a series of instantaneous readings, taken at ten-second intervals over a two-minute period, was used. The way in which the oscillations increased with decreasing directive force, can be seen in figure 10. Against the value of the horizontal component of the earth's field is plotted the average "mean deviation from the mean" for two-minute observations. Curves have been drawn for each compass, including the two gyro-stabilized instruments. To appreciate the diagram fully, it should be noted that the value of "H" in England is approximately 0.17 gauss, while at the North Geographical Pole it is 0.04 gauss, and at the North Magnetic Pole, 0.00 gauss.

Of especial interest was the performance of each of the two gyro-stabilized compasses. From figure 10 it is seen that the amplitude of their short-period random oscillations averaged much less than for the non-stabilized compasses, which was to be expected, but this did not necessarily mean that they were giving correct indications. On the contrary, as the aircraft approached the North Magnetic Pole, these compasses began to wander most erratically. Figures 11 and 12 show the relative performance of the British distant-reading compass and

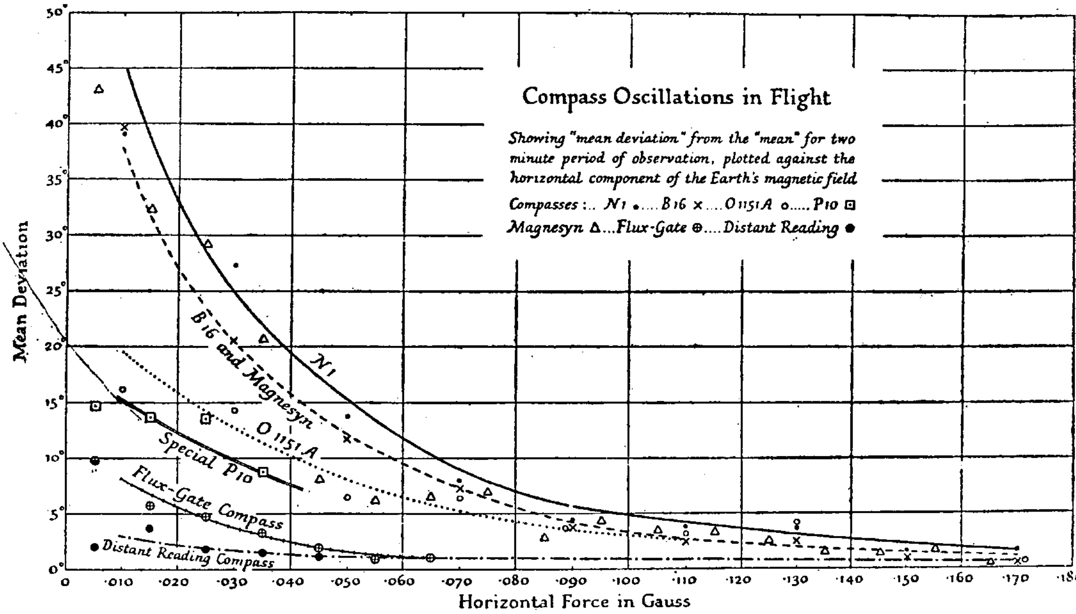

Fig. 10

the American flux-gate compass on the flight from Goose Bay to the Magnetic Pole and on the return to Dorval. The x-axis in these diagrams is a time-scale (G.M.T.), which a subsidiary scale reading in nautical miles from our turning-point at 73°40' N., 98°40' W.; the y-axis is a scale of magnetic variation. Several interesting points are brought out in the diagrams. In the first place, the aircraft flew over the charted position of the Magnetic Pole in Boothia peninsula at G.M.T. 0000 hours, and again at G.M.T. 0150 hours, while the variation shown on our standard charts (indicated as a solid line in the diagram) changed through almost 180°. Secondly, the aircraft did not reach 76° N., 102° W., the calculated position of the Magnetic Pole, but the variation indicated on the Astronomer Royal's special charts (the dotted line in the diagram) was, with little deviation, followed by the compasses. Thirdly, both compasses wandered erratically between G.M.T. 2200 hours and G.M.T. 0400 hours, when the value of " H " was 0,04 gauss or less. And lastly, when a 360° turn was made

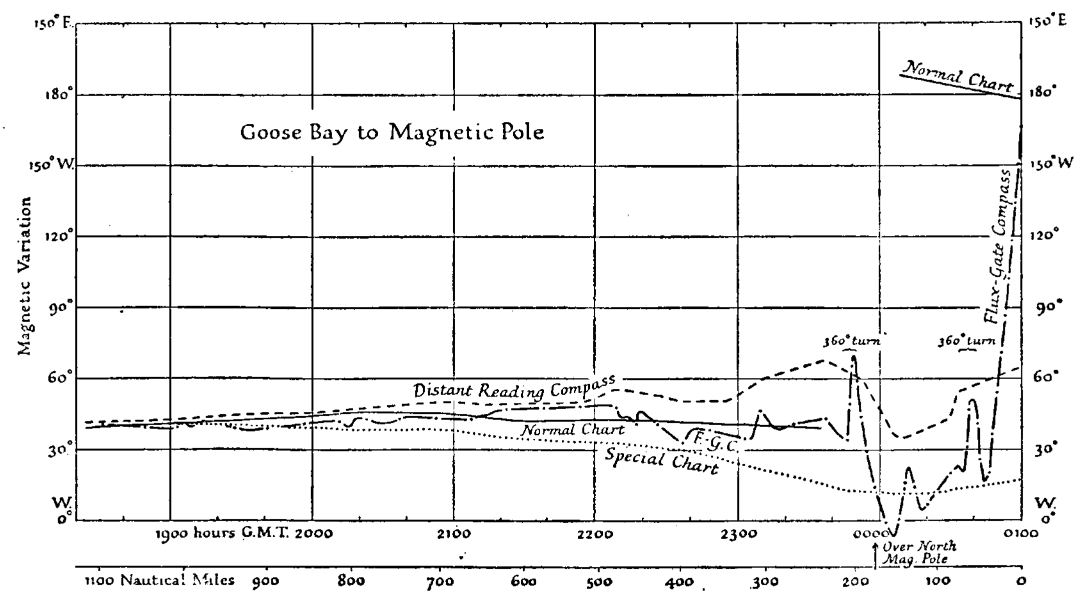

Fig. 11

at G.M.T. 2346 hours and at G.M.T. 0036 hours, the flux-gate compass picked up an error of at least 30°, but the distant-reading compass was not affected owing to its different method of stabilization.

The obvious conclusion to be drawn from this evidence is that, within areas where the value of "H" is less than 0,04 gauss (area A in fig. 3), neither type of gyro-stabilized compass can be trusted. On the other hand, provided it is well sited in the aircraft, a non-stabilized magnetic compass can still be used to detect the magnetic meridian at even lower values of "H". The amplitude of its oscillations is then large, but the mean of a series of readings taken over a period of at least two minutes may be used for steering. Figure 13 illustrates this point, since it shows the performance of two lightly-damped non-stabilized magnetic compasses on the flight from White-horse to Shawbury. The x-axis, or nautical mile scale, corresponds with the mileage shown on the track charts (fig. 15). Though the oscillations of these compasses were large when near the magnetic Pole (see fig. 10), they were of short duration, and the mean readings were remarkably reliable (fig. 13).

Figure 13 demonstrates also that the compasses tended to confirm the Astronomer Royal's deductions, since they followed the curve of calculated variation much more closely than the variation shown on the standard chart. The point at which the compasses swung towards the south on this White-horse to Shawbury track was approximately 77 1/2° N., 105° W., or roughly 240 nautical miles north-north-west of the most northerly point reached

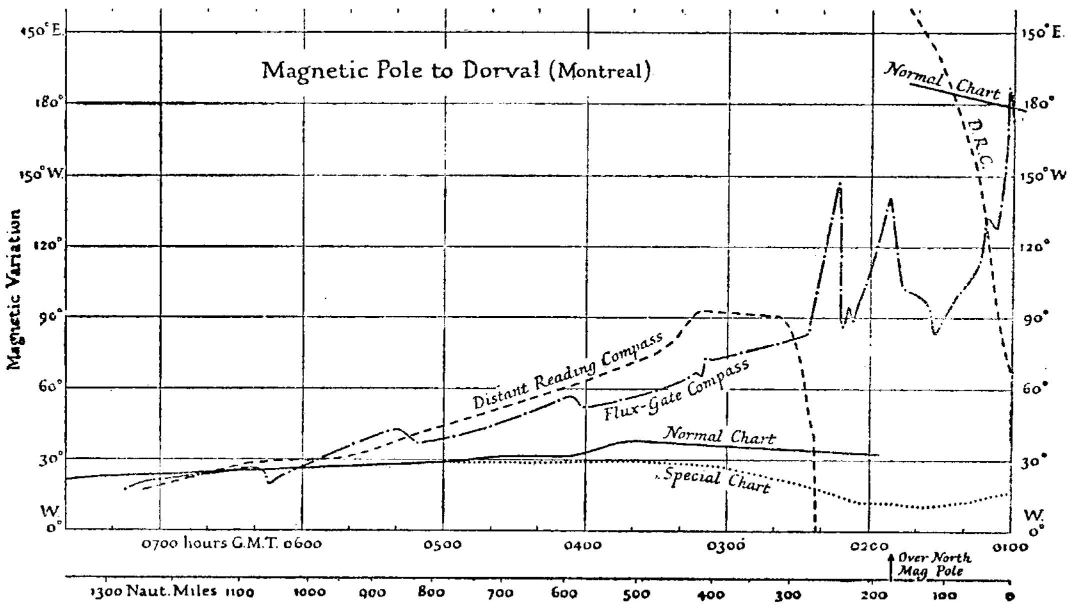

Fig. 12

on the previous flight. At both points the horizontal force measured on the aircraft's magneto-meter had dropped to 4 % of its value over London. It therefore appeared (from a height of 11,000 feet) that the Magnetic Pole lay approximately midway between these two points, which tallied closely with the position calculated by the Astronomer Royal.

It must however be emphasized that this was the first attempt at an airborne magnetic survey in the vicinity of the Magnetic Pole ; the results are herefore quite rough, and too scanty to justify any definite conclusions on the true configuration of the magnetic field. In so far as they support the theoretical shift of the Magnetic Pole, they point to the necessity for a full-scale magnetic survey of the area.

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EXTRACT OF THE DISCUSSION

Comments of the Astronomer Royal (Sir Harold Spencer Jones) :

I should like to comment on two points in Wing Commander Maclure's paper. First, in regard to the astro-navigation, as Wing Commander Maclure explained, there are special difficulties over the Polar area due to the convergence of the meridians, and the fact that the compasses become entirely unreliable, particularly when flying near the Magnetic Pole, so that it is necessary to be certain that the astro-navigation is based on sound methods. On the flight of the *Aries* the Greenwich grid method was used in practice for the first time ; it is a fine method, and will undoubtedly form the basis of future navigation over Polar regions.

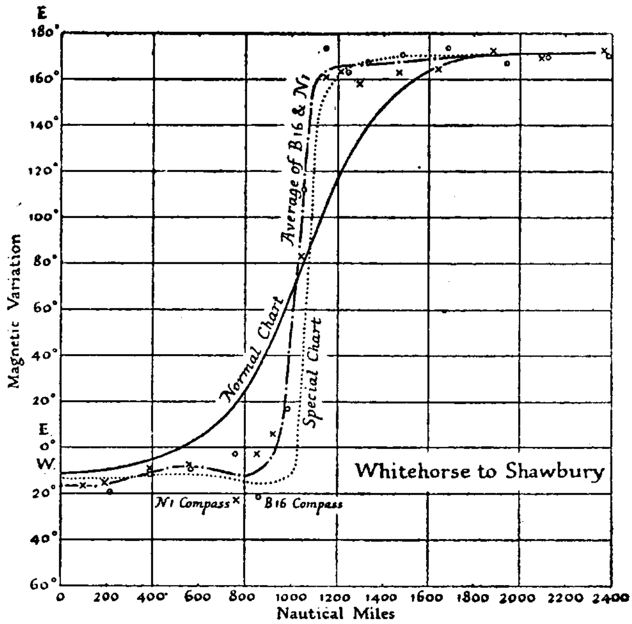

Fig. 13.—Performance of non-stabilized magnetic compasses.

Secondly, the magnetic results are not, of course, in any way conclusive, but they are of particular interest to me because there is great difficulty in drawing isogonic lines over the Polar regions. The difficulty arises in the first place because the observations which are available are extremely scanty and widely distributed in time. Moreover, there is no information whatever upon which one can rely for secular changes over the Polar area. I did make an attempt over twenty years ago, which was published in the *Geographical Journal*, to improve the accuracy of the isogonic chart over the Polar regions(1). As you have seen, the isogonals have two points of singularity, the Geographical Pole and the Magnetic Pole, and each of them has to pass through these two points. One can reduce the difficulty of drawing such complicated lines by dealing, not with the direction of the isogonals with respect to the meridian at the place of observation, but with projected lines of magnetic force. Such lines have only one point of singularity : the Magnetic Pole. The Geographical Pole is not a point of singularity, and therefore with scanty data it is very much easier to get a reasonably accurate interpolation of the projected lines of magnetic force, and then to read off the variation at different points, and from these values to construct the isogonic lines. But it did occur to me that one could get still better results, and construct iso-magnetic curves not only of equal declination or variation, but also of equal dip, of equal vertical force, and of equal horizontal force, by semi-theoretical methods. We have a fairly good knowledge of the Earth's field between about 60° N. latitude and 50° S. If one makes the assumption, and it is to some extent an assumption, that the Earth's magnetic field is due to forces which lie within the Earth and not outside it, one can analyse it by spherical harmonics, using only the data over the region of the earth where they are reasonably accurately known, and then, by using coefficients from these harmonics it is possible to compute the components of the magnetic field over other regions of the Earth.

It is possible to get a check on the assumption that the Earth's magnetic field arises entirely from forces within the Earth, since if the field was partly due to forces outside the Earth, the spherical harmonic coefficients deduced from the vertical component of the Earth's

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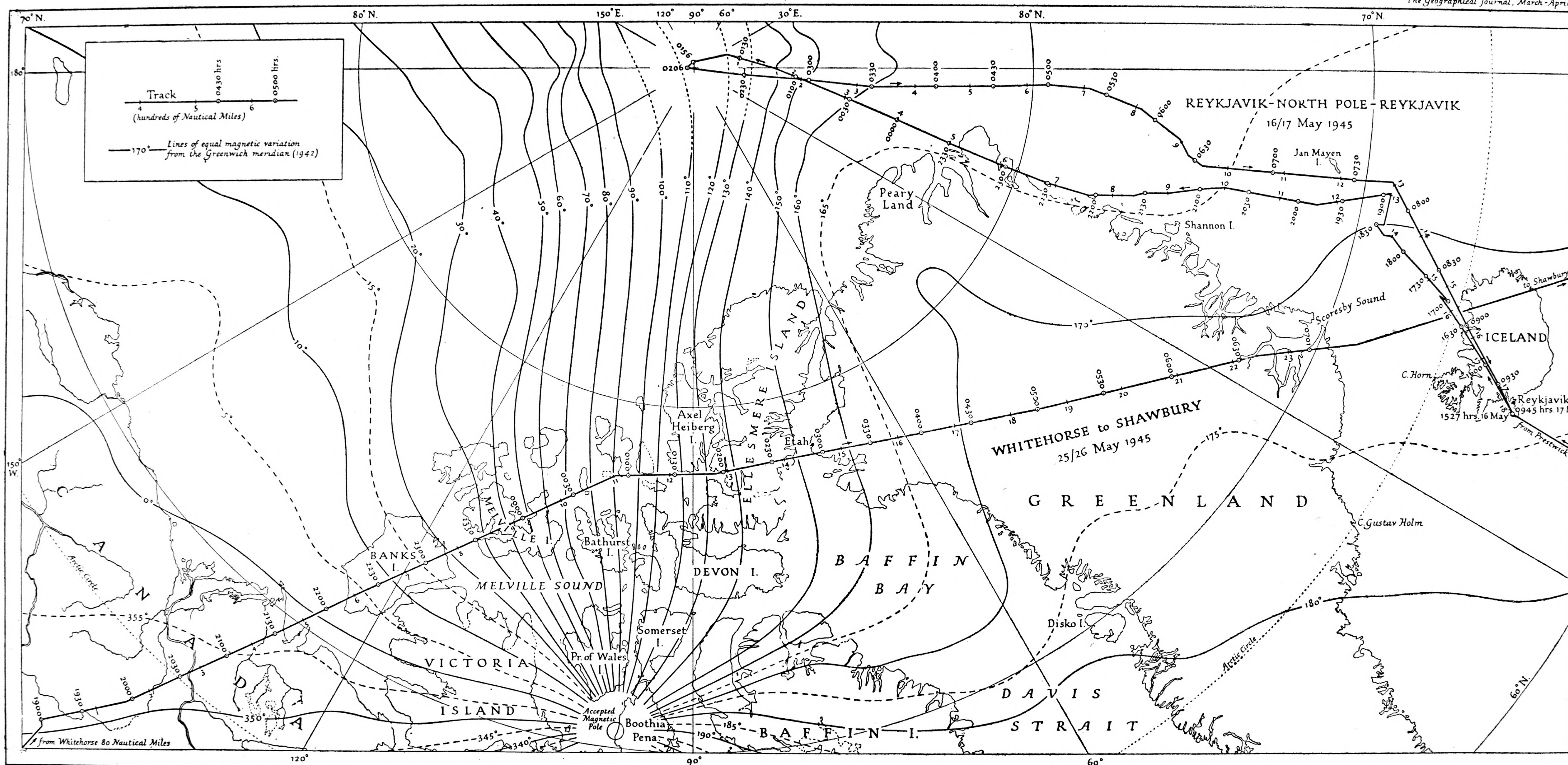
(1) " The magnetic variation in the neighbourhood of the North Pole " (" Geographical Journal ", 62 (1923), page 419).

THE ARCTIC FLIGHTS OF THE ARIES

The Geographical Journal, March-April 1946



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THE ARCTIC FLIGHTS OF THE ARIES
McKinley & Maclure

Fig. 15

field would differ from those deduced from the horizontal component and the declination. Unfortunately, the weights of the determniations in the two cases are unequal. The weight from the vertical component is very much lower than that from the other two components, but the two coefficients agree very well within the probable errors of their determinations. This supports the view that the normal field of the Earth, apart from storm disturbance which comes from outside, arises from forces within the Earth. Thus it was possible to compute the iso-magnetic lines for the various magnetic elements over the Polar regions, and to derive positions for the North and South Magnetic Poles.

The derived position for the South Magnetic Pole was in close agreement with the observed position, but there was considerable discordance in the position for the North Magnetic Pole—which leads one to ask the cause. In the first place, the adopted position, based on Amundsen's observations in 1905, is not certain. It has been used for charting because nothing better has been available, but Amundsen based his determination entirely on observations made from the south. No complete survey of the area to the nord-east or west side of his deduced position was made, and we know that in that region there are very considerable magnetic anomalies ; it is possible to obtain by observation an apparent position of the Magnetic Pole which is considerably in error, because one happened to be in a region of magnetic anomaly.

One of the advantages of making observations from the air is that the effect of such anomalies, due to deposits of magnetic material near the surface, are considerably reduced. The effect decreases with the inverse cube of the distance, so that if an aircraft is flying at 15,000 or 20,000 feet and the deposit is only half a mile or a mile below the surface, the effect is reduced to about 1 or 2 per cent. Therefore ; magnetic surveys from the air offer the possibility of getting what one really wants in navigation, that is, the smooth Earth's field freed from the effect of these troublesome magnetic anomalies.

It seems that, in so far as one can draw any definite conclusions, the preliminary results from the *Aries* flights tend to support the view that the true position of the Magnetic Pole is appreciably to the north of the position that was assigned to it by Amundsen. I do not think Wing Commander Maclure would consider that anything more definite is justified at the present moment.

The expedition has definite value in another respect, and that is that it has demonstrated that magnetic surveys can be carried out efficiently and rapidly from the air. In this case the expedition was working over the most difficult region of the Earth's surface for that purpose, but the results do, I think, justify the view that aircraft have a great part to play in charting the Earth's magnetic field. Before the war the Admiralty were constructing a non-magnetic ship for magnetic survey work at sea, because of the lack of accurate data over parts of the oceans. The non-magnetic ship will get data accurately but rather slowly, and the coöperation of aircraft, which will get data far more quickly though perhaps not quite so accurately, but with the advantage that surface anomalies are largely smoothed out, will be of the greatest value and may in time entirely replace non-magnetic ships. The crew of the *Aries* are to be congratulated on the preliminary observations obtained under very difficult conditions.

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