AIRBORNE GEOMAGNETIC SURVEYS BY THE UNITED STATES HYDROGRAPHIC OFFICE (1)

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The need for accurate world-wide geomagnetic data has long been recognized. At the present time, the magnetic information appearing on many nautical charts, especially those of the ocean areas, is based on old data which have been corrected for the long term secular change of the earth's magnetic field. Since the secular change is very irregular and its accurate prediction is impossible, the reliability of this information on some charts has depreciated to such an extent that new surveys of the affected areas are urgently needed. An additional need for geomagnetic data has been established in recent years by special defense programs such as ship degaussing, magnetic guidance, and antisubmarine and mine warfare. In order to acquire this much-needed data over the ocean areas, an airborne geomagnetic survey program, designed Project *Magnet,* was established at the Hydrographic Office in 1951.

Ocean magnetic surveys are by no means a recent development. The first such survey was made by Edmund Halley, the British astronomer, more than two and one-half centuries ago. In command of the *Paramour,* he made several voyages in the Antarctic Ocean measuring magnetic declination (variation). The results of this survey were embodied in his chart, « Lines of Equal Variation » for 1700, the first isomagnetic chart ever published which was based on observed data. By 1840, ocean magnetic surveys were successful in measuring the intensity, or strength, and the dip, or inclination, of the field in addition to the variation. In 1909, the *Carnegie,* a nonmagnetic ship especially constructed for the Carnegie Institution of Washington, started the first of her seven survey cruises. Before her destruction by fire in 1929, the *Carnegie* had sailed almost 300,000 miles in all oceans from 80° N to 60° S. The data acquired by the *Carnegie* were of inestimable value to the mariner and are still the basis upon which considerable portions of the world magnetic charts depend.

The magnetic airborne detectors developed during World War II for the detection of submerged enemy submarines made possible the first practical airborne magnetometer. Before the end of the war an AN/ASQ-3A magnetic airbone detector had been modified for geophysical prospecting by incorporating means for measuring relative values of the total intensity of the earth's magnetic field. This instrument has been widely used in prospecting for oil and mineral deposits. By 1949, an airborne magnetometer capable of measuring the direction of the field as well as intensity had been developed by the Naval Ordnance Laboratory

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under sponsorship of the Office of Naval Research and placed in service on a United States Coast and Geodetic Survey — United States Air Force cooperative survey program. This instrument the Vector Airborne Magnetometer, Type 1A, had one serious limitation. Because of its construction, it could be used only in areas where the dip of the earth's magnetic field exceeds 45 degrees, thus excluding its use over a considerable portion of the earth.

In order to make world-wide magnetic surveys possible, the Office of Naval Research and the Hydrographic Office sponsored the development of a universal magnetometer, the Vector Airborne Magnetometer, Type 2A (VAM-2A). This instrument was designed and constructed by the Naval Ordnance Laboratory, and has been used by the Hydrographic Office in the execution of its survey program. The VAM-2A, like its predecessors, is a self-orienting saturable core inductor magnetometer. By self-orienting, it is meant that the total intensity measuring inductor, which is mounted in gimbals, is continuously oriented parallel to the earth's magnetic field by a servo system. The orientation of this inductor in its gimbals is precisely measured, thus establishing the direction of the field with respect to the frame of the detector mechanism. In order to determine the true direction of the field, vertical and heading references must be established. The detector mechanism is pendulously suspended thus establishing its own vertical reference. The required heading reference is established by celestial observations. Deflection of the pendulum by Coriolis and oscillations of the aircraft introduce reference errors which must be corrected. The effect of Coriolis is offset by positioning a counterweight mounted on the pendulum, and errors due to aircraft oscillations are minimized by automatically averaging the angular data over a period of approximately two minutes.

The magnetic field of the aircraft presented an additional problem that had to be eliminated. This field was reduced considerably by removal or refabrication with nonmagnetic materials of as many magnetic parts of the aircraft as possible and by modifying the electrical system to minimize magnetic fields caused by direct currents. However, there still remained a field which either had to be measured so that mathematical corrections could be applied to the observed data, or had to be compensated for so that accurate measurements of the earth's magnetic field could be obtained directly. Since the mathematical correction is complex and time consuming, it was decided to compensate for the aircraft magnetism. This was done by creating at the inductor a magnetic field equal in magnitude and opposite in direction to the aircraft's field. The magnetic field of an aircraft actually consists of two fields — a permanent field and an induced field. A permanent field is one created by a body which has become permanently magnetized. An induced field is one produced by a body due to the influence of an external field, such as that of the earth. If the external field is removed, the induced field disappears.

The aircraft's permanent field is compensated for by passing direct currents through a Helmholtz coil system which surrounds the sensing elements of the detector. By varying the magnitude and direction of the currents through the coils, a magnetic field of any desired intensity and direction can be created. The induced fields are compensated for by placing ferrous compensators of the proper shape and size near the detector. Preliminary approximate compensation is determined from an analysis of data obtained from ground and air swings of the aircraft over points of known magnetic field, and final compensation is done during an airswing by a trial and error method. The currents through the coils and the position of the induced compensators are varied until a complete swing yields results on each heading which are constant within an acceptable range. As the aircraft's magnetic field is subject to change, the compensation is checked by periodic swings and, if necessary, the aircraft is recompensated.

Another important function of the ground and air swings is determination of the lubber's line error of the survey equipment. This error is present because the reference lines of the detectors and the sextant used to determine true heading are not precisely parallel. After the compensation has been completed, the difference between the true variation and the measured variation is the lubber's line error. Since the true variation at the swing point is known, the error can be readily determined. As the mathematical correction for this error is a simple addition or subtraction, no attempt is made at precise alignment of the two instruments involved.

The quantities measured by the VAM-2A are the total intensity and dip of the earth's magnetic field and, except for the lubber's line error, the magnetic heading of the aircraft and the bearing of a celestial body relative to the aircraft. The dip, intensity, and magnetic heading are continuously measured by the detector mechanism of the magnetometer, and the relative bearing is measured periodically with a Kollsman periscopic sextant whose mount has been modified to measure precisely the azimuth angle through which the sextant rotates. Because of the strain involved in accurately tracking a celestial body for a long period of time, relative bearing is observed over a two minute interval centered about even five minute time increments. Direct traces of all the elements measured and averaged traces of the angles are recorded on strip charts.

These recorded traces do not represent the actual values of the elements, rather they represent values relative to baselines established for each element by a control mechanism. The baseline values are observed and recorded at intervals of five minutes corresponding to the middle of the relative bearing observation period. Precise time, which is essential to accurate surveys, is kept by a 24-hour electric clock and by two electric timing devices which control the angle averaging circuits and mark time on the record charts every five minutes.

In addition, the recorders themselves keep accurate time since their chart drive mechanisms are powered by electric clock motors. In order to operate properly these timing devices must be fed alternating current whose frequency is controlled rigidly. The required frequency regulation is obtained from a frequency standard which is accurate to one part in 100,000. Translated into time, this means that the maximum error will be about 0.8 seconds in 24 hours. The clock and timers are set initially from radio time signals which are broadcast at various times by various countries throughout the world.

Reduction of the survey data is a straightforward, although time consuming process. The values of the measured elements are computed by adding the recorded trace values to the baseline values. This yields absolute values of total intensity and dip and of magnetic heading and relative bearing when lubber's line error corrections are applied. The magnetic field at a point is usually defined by five elements: declination, or variation, (D); dip, or inclination, (I); total intensity (F); horizontal intensity (H); and vertical intensity (Z). I and F have already been determined, and H and Z are computed as follows:

$$H = F \cos I$$

$$Z = F \sin I$$

The computation of D from our observed values of magnetic heading and relative bearing consists of three steps. The first of these is the computation of the true bearing of the celestial body whose relative bearing was measured. This computation is:

$$\cot TB = \frac{\cos LHA \sin \phi - \cos \phi \tan \delta}{\sin LHA}$$

where LHA = GHA — west longitude, ϕ = latitude, and δ = declination of the body. After the true bearing is computed the true heading of the aircraft is determined: TH = TB — RB. The declination can now be computed by:

$$D = TH - MH$$

It can readily be seen that the accuracy of the variation computation is dependent upon the accuracy with which the position of the aircraft is determined. Accurate positions are also required to plot all the data. These positions must be provided for each five minutes of flight by the aircraft's navigators who must also navigate the aircraft as precisely as possible along a predetermined track. In past surveys, two navigators have been assigned to the operating crew of the aircraft and both men worked full time during a survey flight. The navigators use a combination of dead reckoning, celestial fixes, loran, and radar to determine position and most of the survey flights are made at night to permit precise celestial fixes. The survey specifications called for positions to be accurate within five miles and, although no precise checks are possible, it is felt that this accuracy was attained on many of the survey flights made to date.

The first task assigned Project *Magnet* was a survey of the North Atlantic Ocean from 25° N to the Arctic Circle. In order to obtain optimum coverage of the area, a survey plan was drawn up which consisted of a system of equally spaced, parallel tracks. A track spacing of 200 miles was chosen as it was felt that this spacing would yield results which were entirely adequate for charting purposes and would allow the survey to be completed in a reasonable length of time. The maximum length of the tracks was limited by the range of the survey aircraft, a P2V, to about 2200 nautical miles. Fortunately, this was sufficient to allow excellent coverage of the area. The flights were usually made at altitudes of from 9,000 to 13,000 feet, but occasionally it was necessary to fly as high as 20,000 feet in order to top weather.

Survey specifications called for measurements of variation and dip to within 0.5 degree and of total intensity to within 0,002 oersted. During an air swing over a point where the aircraft's position and the magnetic field values were accurately known, the errors were less than 0.1 degree for the angles and 0.0002 oersted for the intensity. Although these errors will be increased by navigational errors, it is believed that the accuracies called for by the specifications were exceeded in normal survey operations.

The first survey task comprised approximately 60,000 nautical miles of track and required about a year to complete. Many delays were encountered because of weather and maintenance and repairs to the survey aircraft. Several tracks had to be reflown because of the aircraft's inability to top unforecasted weather or because of mechanical difficulties with the aircraft. Except for these delays, the survey could probably have been completed in four months.

Just after the first survey was finished, the P2V went into overhaul and another aircraft was requested. Experience had shown that the most ideally suited

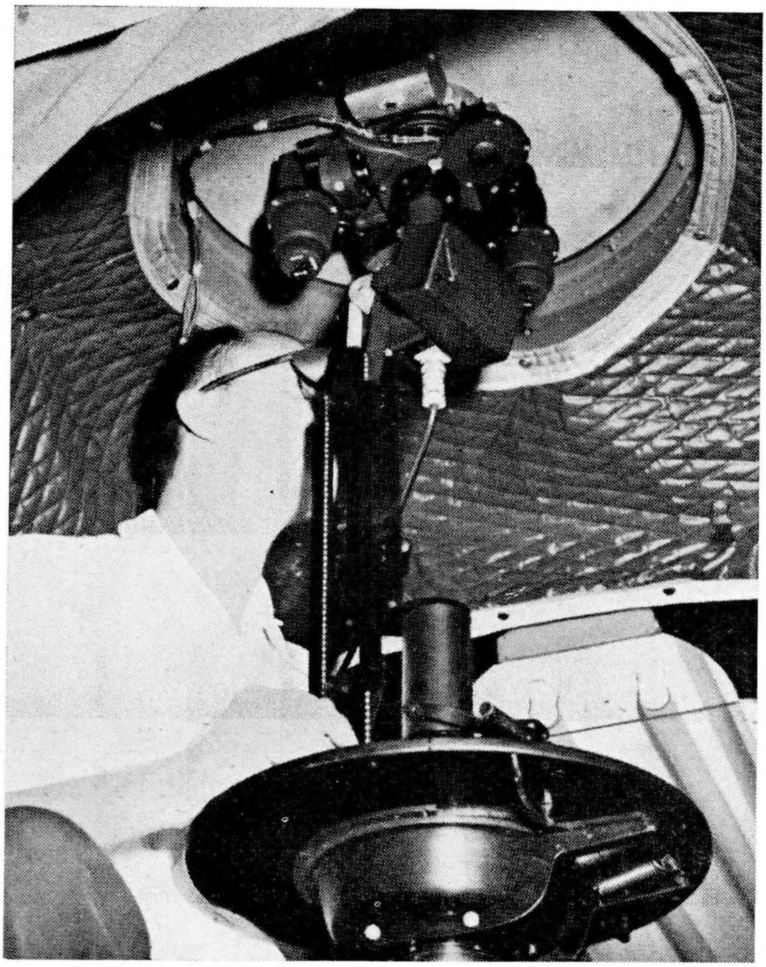

Fig. 1.

Automatically leveled periscopic sextant used to determine true heading.

aircraft for this work is a long range, pressurized, cargo type of aircraft capable of cruising at altitudes of from 20,000 to 30,000 feet. With this in mind, an R6D was recommended for future survey operations, but since an R6D could not be made available at this time, an R5D was assigned to the project. This aircraft provides more space and a greater range than the P2V, but its altitude limitations are the same.

At the present time, the R5D is being modified for magnetic surveying and the survey equipment is being installed. There are two new pieces of equipment being installed which should increase the accuracy of future surveys. One of these is a recently developed automatic navigator which should take quite a strain off the human navigators and increase position accuracy. The other device is an automatically levelled periscopic sextant which will replace the sextant used to determine relative bearing. This new sextant is basically a Kollsman sextant to which means have been added for maintaining it in a vertical position at all times.

The aircraft modification and equipment installation is expected to be completed within the next 30 days at which time the calibration and magnetic compensation flights will begin. As soon as these flights are completed, the survey program will again be underway. As soon as the first round of ocean magnetic surveys are completed, it is planned to make repeat surveys as required to maintain the accuracy of geomagnetic data throughout the world.

It is hoped and expected that as this program progresses it will make a significant contribution to man's knowledge of the earth's magnetic field and that this increased knowledge will be of great assistance to the navigator in the future.