CARTOGRAPHIC ASPECTS OF THE AIRBORNE MAGNETOMETER

Joseph E. Burch, Jr., Fairchild Aerial Surveys, Inc.

I THINK, at the outset, it is only fair to warn you that I am neither a geophysicist nor a photogrammetrist. My background has been in electronics. I have been connected with the Fairchild Airborne Magnetometer Operation since its inception some months ago, and though in that time I have acquired a fair general knowledge of the various workings of the rather complicated organization, it should be kept in mind that my experiences have been limited to the instrumental phases.

Undoubtedly you all realize that the surface being mapped by a magnetic survey is an intangible one, which usually is at some depth below the surface of the earth. Since most sedimentary rocks have little effect on the earth's magnetic field, the surface we endeavor to map magnetically is the igneous basement. There are exceptions to this general statement, however for simplicity of discussion we will neglect the exceptions. The surface which we endeavor to map bears very little relation to the actual surface of the earth.

The conventional magnetic map resembles a topographic contour map, with the contours representing lines of equal magnetic intensity. Our problem is similar to that of the topographer in that we both draw contour lines, one representing lines of equal elevation, and the other, lines of equal magnetic intensity. The topographer can see the ground surface, but in compiling a magnetic map we have to rely solely on data supplied us by the magnetometer. You can see readily that the accuracy of any contour map is dependent upon accuracy in locating the exact spot on the ground corresponding with the value of elevation for the topographic map maker, and to the value of magnetic intensity for the magnetic map maker. It is fair to say that the true accuracy of the finished map is no greater than the accuracy of the horizontal position data.

Many of you have experienced, in the past several years, the problem of obtaining control in poorly mapped areas. The astrolabe, in conjunction with trimetrogon photography, has proven quite suitable for the production of maps of large areas at reasonably small scales. When it is pointed out that the airborne magnetometer data has been proven of sufficient accuracy in itself to merit positional fixes accurate to about 100 feet, many of you will be able to visualize the magnitude of the problem we face.

It is quite easy to obtain horizontal control for magnetic maps covering areas which have been well mapped before. However, because of its speed and and relatively low cost, the airborne magnetometer is especially suitable for reconnaisance surveys in large areas which are poorly explored and therefore poorly mapped. Shoran has proven practically indispensable in obtaining horizontal control. In some cases it was the complete answer, and in others a modification of shoran has been necessary to obtain any degree of efficiency.

In considering shoran, the following should be kept in mind. Since shoran operates on relatively high frequencies, around 300 mc., the shoran range is limited almost to line of sight. The curvature of the earth limits the range of shoran. In airborne magnetometer operations the aircraft is relatively low, ranging from 1,000 feet to 2,500 feet above the ground for many petroleum surveys. Because of this relatively low aircraft height, the shoran distance from the aircraft to the ground stations becomes reasonably small. Also, a point to consider is that the shoran accuracy is at a maximum when the two stations and the aircraft form a 90° angle at the aircraft. As the airplane moves away from ideal right angle position, the shoran accuracy falls off. In the case where the two ground stations and the aircraft are in a straight line, the shoran position is indeterminate. The combination of the limited distances and the inaccuracies at bad angles of the shoran, would necessitate the shoran ground stations moving around quite a bit in order to obtain good horizontal control of a large area. When operating with the ground shoran stations in boats, or other mobile units in areas of good roads, it is not very difficult to move these stations to approach the ideal shoran positions. However, in many of the areas we have covered in South America there have been the crudest kinds of roads imaginable. Besides, a good part of the area is impassable jungle. It was neither practical

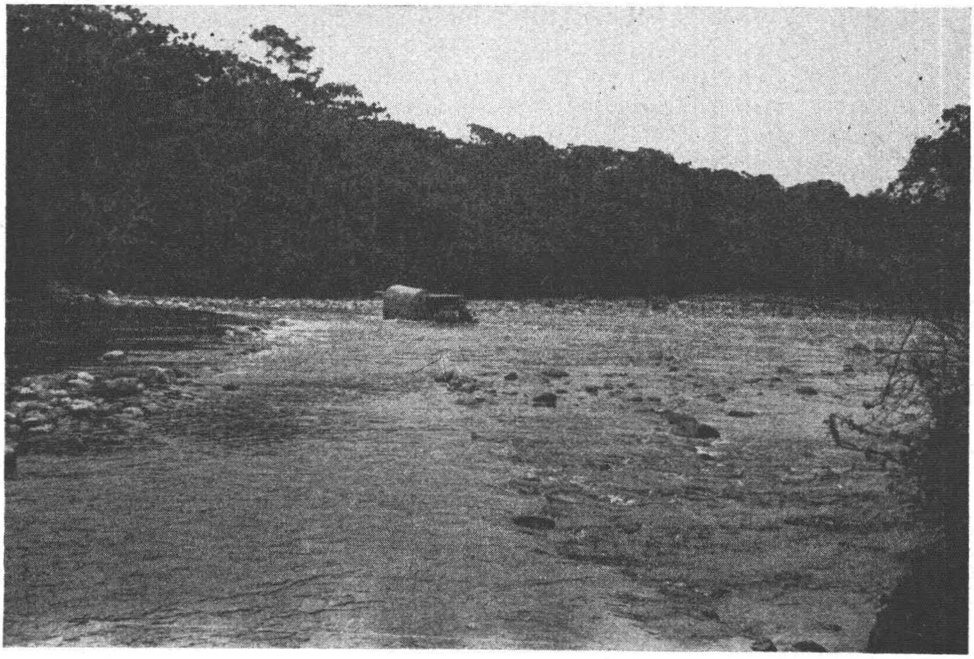

FIG. 1. Crossing rivers was one of the many obstacles in the way of the ground parties.

nor economically feasible to set up a program which required frequent moving of the ground stations. One solution we can very well apply to this problem is to make an initial mapping project of the area with shoran controlled high altitude photography. If the airplane were to fly at 25,000 feet instead of around 2,500 feet as required by the magnetometer, the shoran range would increase considerably, requiring fewer shoran sites to cover the area. High altitude photography, completely covering the area would provide the basic control. The maps produced therefrom could be used to control the lower altitude magnetometer flights. This would doubtless be our best solution if it were not for weather conditions. In some sections we have mapped, the number of perfect photographic days are approximately five a year. For this reason there are many areas where the speed and efficiency of an airborne magnetometer survey would be seriously affected if we had to await photographic weather in order to obtain the basic horizontal control. It should be pointed out that the airborne magnetometer survey, because of the relatively low flight height, can be conducted in weather conditions which would prohibit any kind of high altitude photography. We have just completed an area of over 50,000 square miles, 80% of which was accomplished on days when the normal photographic crews would go back to bed. Weather conditions rarely grounded the plane carrying the magnetometer.

Our operations have been partly over water and partly over land. In the over-water operations where photography could do us no good, we used shoran control with the magnetometer in a somewhat different manner than Aero Service Corporation, though the difference is not basic. Our over-land operations have consisted predominantly of the following procedures: For each area to be covered we set our ground shoran stations in the most logical positions considering the topographic conditions, the means of access, the shoran angles for proper accuracy, and the shoran ranges to assure complete coverage of the area

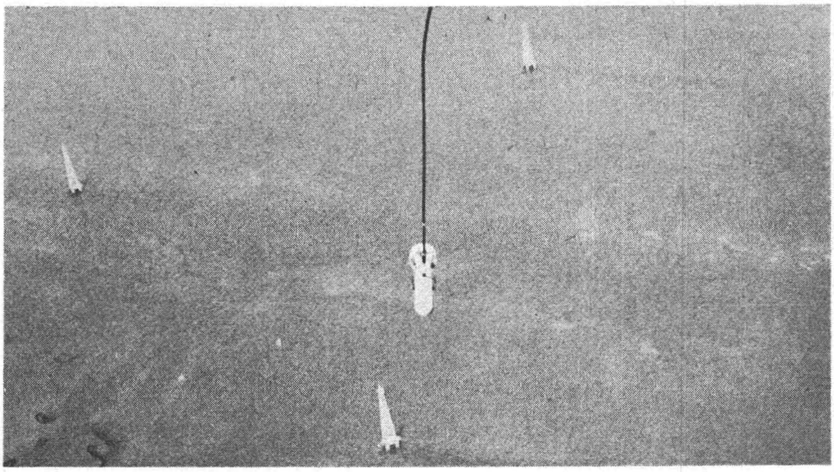

FIG. 2. This picture, taken over a developed oil field in the water, shows the "bird," or detector unit, of Gulf's magnetometer being towed by Fairchild A-26.

with the aircraft at 25,000 feet. From this altitude of 25,000 feet above sea level, we fly regular aerial photographs, using a 6″ camera, in strips at right angles to the magnetic profile flight lines, obtaining a shoran fix with each individual photo. We fly these high altitude strips approximately 30 miles apart and can accept cloud coverage up to 30%. Having obtained a skeleton framework of shoran controlled high altitude photography, we achieve all intermediate control by means of low altitude photography taken concurrent with the magnetometer flights.

As the aircraft progresses down the magnetometer flight lines, which in the present project are approximately at right angles to the control strips and are at an altitude of 2,500 feet above sea level, a small standard military type 05A Radar 35 millimeter camera photographs a complete record of the flight path on the ground. This camera had to be modified for ground photography. At an altitude of 2,500 feet above sea level, or approximately 2,200 feet above ground level on our present project, it is necessary to take six individual pictures per mile to get complete coverage with about 20% overlap when the plane is going 200 miles an hour, true ground speed, The camera is operated from an intervalometer so that the time between successive exposures is fixed.

There is another camera in the aircraft which photographs simultaneously with the ground pictures, a radar altimeter, a barometric altimeter, a thermometer, a clock, and a counter. The barometric altimeter gives us the altitude above sea level and the radar altimeter gives us the terrain clearance. These two sources of information are used as part of the interpolation for control between our shoran fixes, spaced about 30 miles apart along each flight line. If the altitude of the aircraft is known, we can get the true ground speed by using the time interval between each successive photograph and the amount of overlap. For example, if the aircraft is precisely 2,200 feet above the ground, and if the aircraft is actually making good exactly 200 miles per hour true ground speed we will achieve an overlap between the successive frames of the 35 mm. film of

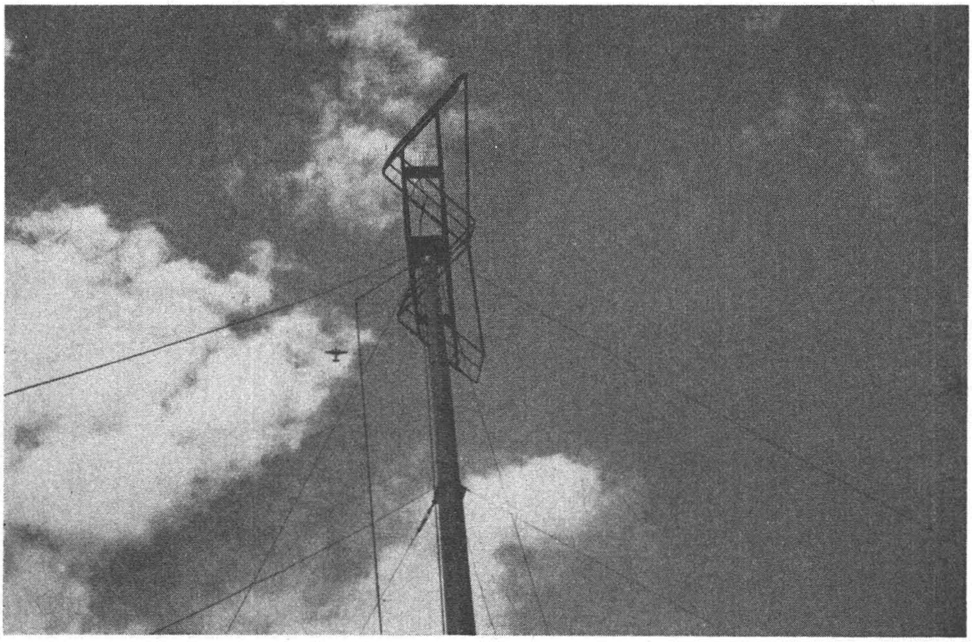

FIG. 3. Fairchild's A-26 shown making a station crossing over a shoran station in South America.

precisely 17.6%, when the intervalometer is set at exactly 3 second cycles. If, therefore, we determine that the height above ground has not changed, yet the overlap has varied from 17.6% to 20% we know that the aircraft is not making good 200 miles per hour true ground speed, but something less than that. Also, with single frame exposures, changes in the flight course due to changes in the drift or course, are immediately apparent from the angle at which two successive frames overlap each other. It is for this reason that we prefer the single frame photographs rather than the continuous strip camera. We feel that the continuous strip camera has sufficient tolerance so that it appears to give a reasonably good picture even though the camera is not synchronized with the speed of the aircraft. In addition, slight changes in drift are not very apparent on the continuous strip photography.

We have incorporated with the intervalometer, which controls the camera circuits, a special control circuit that marks the magnetometer paper tape for each sixth photograph of the ground. By this means we tie in, mechanically, the data from the continuous record of magnetic intensity to specific spots on the ground, and since we have positive shoran controlled geographic fixes at 30 mile intervals, these spots on the ground are tied to definite geographic locations.

Although this system appears quite complicated, it is reasonably simple. The principal criticism we have of it so far, is that there are a number of steps in the compilation which require precise attention to detail, since the distances involved are relatively small. We believe we are getting relative fixes within 150 feet, which seems to be the minimum requirement to balance the magnetic data. We are working on several ways to mechanize some of the steps in the

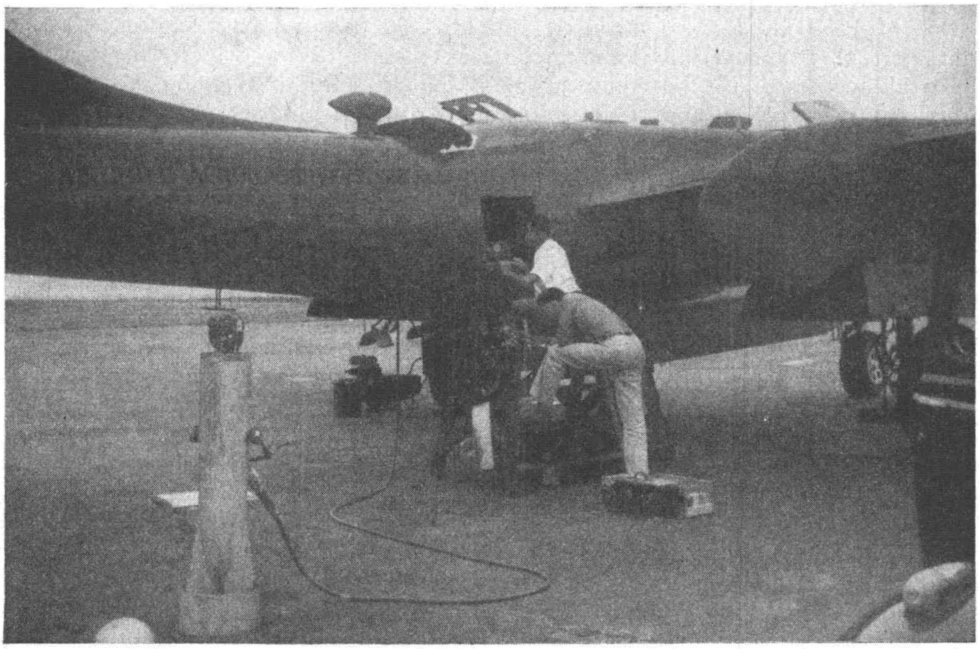

FIG. 4. Maintenance performed on the magnetometer (bird) before a day's operation.

compilation procedures which we hope will cut down the amount of drafting time involved.

It should again be stressed that the degree of accuracy necessary for horizontal fixes is solely dependent upon the accuracy of the magnetic data. In most areas of interest to petroleum companies the magnetic data should be accurate to within 5 gammas. Theoretically, the airborne magnetometer, as developed by the Gulf Research and Development Company, is capable of a greater degree of accuracy than 5 gammas. However, under operational conditions and considering the day to day variables brought up by adverse operating conditions, we think the overall accuracy is in the neighborhood of 5 gammas. For an accuracy of this kind horizontal fixes within 150 feet seem to be a requirement. Radio Corporation of America, the manufacturer of the shoran equipment, claims that individual fixes should be accurate to approximately 90 feet. We believe this is possible under the best conditions, but it is our opinion that under normal operating conditions, with some station angles necessarily weak because of topographic considerations, 150 feet average accuracy is about the best that can be expected from single shoran fixes. The system we are using in over-land areas, namely high altitude shoran control, seems to be comparable to the accuracy we would get by using shoran on all magnetometer flight lines.

The very speed at which the airborne magnetometer surveys can be run presents a rather substantial laboratory production problem. For magnetic maps of a scale of 1:50,000, we have been computing positions for points at one mile intervals down each flight line. For the past four months we have flown an average of 10,000 profile miles each month, and on a single day we have produced as much as 1,428 line miles. This means that on the average, per month, there are 10,000 map points to be computed and drafted, the magnetic values measured and balanced, and approximately 10,000 square miles at a scale of 1:50,000 to be contoured and finished. As a matter of fact, at the moment, there is a serious unbalance between the speed at which the data can be produced, and the speed at which it can be computed and drafted. Unfortunately we have found it somewhat more difficult to hire fast draftsmen and computers than to buy fast aircraft.

One point we haven't discussed is the corrections which must be made in the magnetic data to eliminate all the variable factors. The earth's magnetic field is not a constant. In fact, it is subject to several variables similar to the barometric pressure. The most serious variable, as in the case of the barometer, is the daily or diurnal variation which varies considerably and is not the same over large areas. As a rough estimate, the daily variation can be considered relatively constant within an area of about 25 mile radius, but here again this changes with each locality. In ground magnetometry, the common practice is to set up a check magnetometer in the center of the small area to be worked, and use it to correct the readings of all the rest of the magnetometers taking spot readings around that general area. Since the aircraft covers much greater distances than a base magnetometer would be accurate for, some other means had to be devised to eliminate the affect of this daily variation. The process we use is a compromise, going on the assumption that the daily variation will be linear for a period of time of 15 minutes. This seems to be a fair assumption, although it is possible to have such erratic variations that this assumption will appear rather questionable at times. This system we call "looping." A "loop" consists of a flight line flown in the form of a loop, starting at some fixed point, flying out in a loop pattern to a point seven minutes away, then returning to the original point so that we get two readings from the initial point at a time interval of not greater than 15 minutes. The difference between the two readings over the same point 15 minutes apart is measured, and the difference is distributed back over the flight course in a linear manner.

These loops are flown at right angles to the regular magnetometer profiles in such a manner that the regular magnetometer profiles intersect these corrected loops at approximately a 10 minute period. Since the magnetometer profile begins on such a loop and ends on such a loop the profile itself is corrected to this corrected control, again assuming that the daily variation is linear within a 10 minute period.

This latter is a little too complicated to describe fully in the time allotted. We point it out merely to indicate that in addition to the control problem of horizontal positions of the points on the map, we have similar control problems for all the magnetic data.

We should like to reiterate that the degree of attention necessary to detail depends upon the accuracy desired. For the most accurate work very strict attention must be paid to the small details, errors, and corrections. For instance in an oil magnetic survey, where the anomalies are small, slight variations are of great importance. In some mining surveys where the anomalies are very large, small variations, such as the daily variations in the earth's magnetic field, sometimes can be neglected.

The foregoing is a brief explanation of the basic operational procedures we are using. In conclusion I should like to pass on to you some of my experiences with shoran in the field. I spent the first three months in South America traveling around the countryside with a ground shoran party. Each party consisted of two men, two jeeps, and two trailers. One trailer carried all our supplies and spare parts and the other carried the shoran, an 80 watt communication transmitter and receiver, and test equipment. We used the power take-off in the jeep to drive a special generator to power the equipment. The electronic equipment was shock mounted in the trailer.

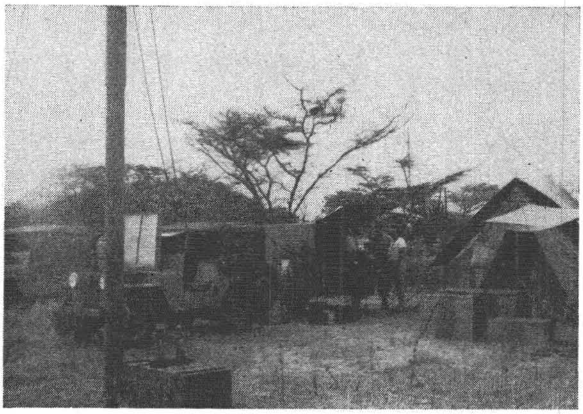

FIG. 5. A typical shoran ground party camp-site somewhere in the wilderness of South America.

If any of you are familiar with the roads of northern South America you will appreciate it when I say in general, they are about the world's worst. We travelled over roads that caused such vibration that we had to tighten the body bolts of the jeeps and trailers twice a day. I believe the electronic equipment was subjected to every type of vibration imaginable, yet not once did the shoran break down or fail to operate properly as a result of the beating it took. When we went to South America we were very skeptical about how this complicated shoran gear would hold up under the strain of constant moving. The thing that sold me on shoran's ruggedness was a little accident I had one day. We were going along a stretch of very sandy road where the only sensible way to get through was to stay in the two ruts made by trucks, that previously passed, and continue our forward momentum. One very bad feature of the jeep is its very narrow wheel base which made it impossible to stay in the truck's ruts. To make a long story short, my trailer sprang loose from the ball hitch and went rolling over on the ground. You can imagine how I felt when I saw the trailer all bashed in with that very expensive shoran gear inside it. After replacing two tubes, the shoran operation was normal. We don't recommend this treatment for all shoran sets.

In summary, we believe that the airborne magnetometer is a dependable instrument, capable of a very high degree of precision. As a matter of fact, we believe the most complicated and difficult part of airborne magnetometry is actually that of obtaining accurate geographic positions of the points for which we have the magnetic data. Shoran has proven of tremendous assistance. It can be called indispensable in areas where control is either very poor or nonexistent.