

UNITED NATIONS ECONOMIC AND SOCIAL COUNCIL



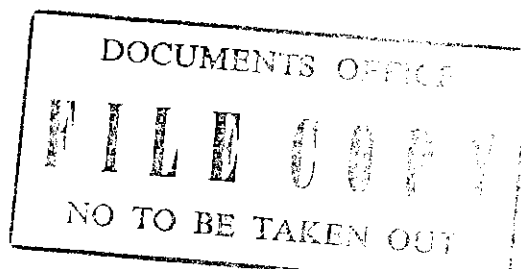
Distr.
LIMITED*

E/CN.14/CART/206
11 September 1966

Original: ENGLISH



ECONOMIC COMMISSION FOR AFRICA
Second United Nations Regional
Cartographic Conference for Africa
Tunis (Tunisia), 12-24 September 1966
Provisional agenda item 12 (b)



ELECTROMAGNETIC DISTANCE MEASUREMENT IN THE U.S. GEOLOGICAL SURVEY

Information paper^{1/} sent by the Government of the
United States of America

* participants only

^{1/} The attached document is supplied by the United States
of America

TU.43

ELECTROMAGNETIC DISTANCE MEASUREMENT
IN THE U.S. GEOLOGICAL SURVEY

By Edward A. Krahmer
U.S. Geological Survey
Washington, D.C.

International Association of Geodesy
Symposium on Electromagnetic Distance Measurement
Oxford, England
September 1965

ELECTROMAGNETIC DISTANCE MEASUREMENT*
IN THE U.S. GEOLOGICAL SURVEY

By Edward A. Krahmer
U.S. Geological Survey

Abstract

About 80 units of electromagnetic distance-measuring equipment in several makes are used by the U.S. Geological Survey for control surveys for topographic mapping, mostly in conventional traverse. For mapping in difficult terrain the AirBorne Control (ABC) Survey System has been developed, in which a hovering helicopter with a remote electromagnetic distance-measuring unit serves both as a target and as a survey platform. The unique instrumentation of this system includes a Hoversight, to enable the pilot to maintain position above a selected ground point; a height indicator, to measure the vertical distance from the ground to the helicopter; a rotating beacon, for a sighting target; and a retractable antenna. Communications between the helicopter and the ground are maintained by radio.

While in radio contact with the hovering helicopter, field parties at ground stations read both vertical and horizontal angles to the beacon, and measure the distances electromagnetically. The horizontal positions are established with at least one redundancy in angle or distance, and the elevations are based on at least two individual determinations. To establish a K factor (refraction and earth-curvature correction) for refining elevations, simultaneous reciprocal vertical angles are read hourly between ground or lower stations near the operations area.

Field tests in the States of Arizona, Maine, and Alaska have established that the system is economical in remote areas and accurate enough horizontally to control 1:24,000-scale mapping and vertically to permit a contour interval of 20 feet.

* Prepared for the Symposium on Electromagnetic Distance Measurement, International Association of Geodesy, Oxford, England, September 1965. Publication approved by the Director, U.S. Geological Survey

Introduction

Although the theme of this symposium concerns the scientific aspects of electromagnetic distance measurement, this paper is devoted mostly to applications in control surveys in the National Topographic Mapping program. The U.S. Geological Survey has about 80 units of microwave distance-measuring equipment of several makes--Tellurometers, Electrotapes, and Micro Chains.

These instruments have been used in a wide variety of terrain and under all possible conditions with generally excellent results. Our experience agrees with that of other mapping and surveying organizations. Electromagnetic distance measurement is one of the greatest single advances in surveying procedures ever made. Since the introduction of the Model MRA-1 Tellurometer some years ago, the accuracy of our basic horizontal control has improved substantially, and during the same period the cost has been reduced. We consistently obtain second-order closures with third-order methods.

For the most part our field procedures are conventional. They include long-leg traverse, control extension by radial methods and the establishment of elevations by trigonometric methods with electromagnetically measured distances. The one exceptional method, developed by the Geological Survey, is the use of airborne electromagnetic distance-measuring instruments.

The AirBorne Control (ABC) Survey System

In the ABC system, under development for the past 6 years, a hovering helicopter carries a remote electromagnetic distance-measurement unit and serves both as a target for distance and angle measurements and as a survey platform. The specialized instrumentation includes a Hoversight, to enable the pilot to maintain position above a selected ground point; a height indicator, to measure the distance from the ground to the helicopter; a rotating beacon, for a sighting target; and a retractable antenna that can be rotated in azimuth.

The Hoversight, the basic instrument on which the system depends, consists of a damped pendulum with a self-contained light source which projects a collimated light beam through a semitransparent mirror. With the aid of a second mirror the observer can see the image of the light source superimposed on the image of the ground below. The ground image is viewed stereoscopically in the same sense that the ground itself is viewed with both eyes, enabling the observer to judge the distance from the ground. The lamp-filament image projected against the ground image defines the vertical below the Hoversight. The pilot views the instrument at a depression angle of about 30 degrees, so that he retains the peripheral vision needed for maintaining aircraft stability.

The height indicator, mounted immediately above the Hoversight, consists of a weighted Dacron line which is lowered to the ground, passing over a calibrated drum geared to a counter reading in feet. A motor-driven

magnetic coupling maintains a tension of about 2 pounds on the line.

The flashing beacon is mounted above the helicopter cabin, on the vertical axis of the Hoversight to avoid eccentricities. The beacon is the target for vertical and horizontal angle measurements, and also aids observers in spotting and tracking the helicopter from ground base stations.

The electromagnetic distance-measuring equipment (DME) component is the Hydrodist, manufactured by Tellurometer, Pty., Ltd. A remote unit is carried in the helicopter, and one or more master units are at the ground stations. Instrument readings are in meters, and ambiguities are resolved in terms of 100, 1,000, and 10,000 meters. Reading patterns permit estimating distances to about 20 centimeters. A retractable, rotatable antenna is mounted on the underside of the helicopter to shield the signal from rotor interference. Fully extended, the antenna dish is entirely below the skids; retracted, it is in front of the cockpit bubble.

A vital element of the system is communication between ground parties and the helicopter. A fully duplexed frequency modulated (FM) system is provided, operating in the very high frequency (VHF) portion of the electromagnetic spectrum. The ground units each embody two transmitters and one receiver. The airborne unit functions as a repeater station having one transmitter and one receiver. With this arrangement, communications between ground stations can either be relayed through the helicopter or sent direct, depending on which transmitter is used. The repeater

transmitter can be keyed by either the pilot or the observer. Helicopter personnel hear only relayed messages and therefore are not distracted by communications pertinent only to ground crews. The repeater transmitter in the helicopter has a 1-kc beep-tone generator controlled by the pilot to indicate to the ground crews when the aircraft is in position over a point.

General Operating Procedures

When the pilot signals by radio that he is over the point to be established, horizontal and vertical angles are read to the flashing beacon on the helicopter from the ground stations, and distance measurements are made from master units on each ground station to the remote unit in the aircraft. The airborne engineer determines the hover height and photoidentifies the ground point. He is also responsible for navigation. The rate of production and the accuracy of the results depend largely on his ability. Reliable two-way communication with all party members is essential.

The system in practice has shown itself to be very flexible. Using components together or in various combinations permits positions to be computed by triangulation, trilateration, or a combination of the two. The configuration of stations, therefore, can be selected with considerable freedom. Base stations need not be situated to give strong intersection angles as in conventional triangulation.

Developing AirBorne Electromagnetic Distance Measurement

In the beginning, the most difficult problem was to obtain and maintain a readable display on the DME instruments. Model MRA-1 Tellurometers were used in the first trials. The crude prototype Hoversight, pilot inexperience, and poor antenna configuration combined to give completely negative results. If we had fully realized the extent of these problems at the time, we might have dropped the project. Fortunately, some Hydrodist instruments, designed for shipboard use, became available about this time. With the meter crystals of the Hydrodist, and a somewhat improved Hoversight, we obtained results good enough to encourage us to continue.

With hovering accuracy improved enough to be certain that horizontal movement of the helicopter was not a factor, we still experienced difficulties from rotor interference. A grassy, erratic display with a beat synchronized with the rotor revolution was produced whenever the antenna could "see" the rotor. We considered some type of shielding and tried a number of locations. The problem was solved satisfactorily when the antenna was mounted in its present position below the cabin, between the skids, and shielded completely from the rotor. In this position, the antenna must be retractable for takeoff and landing, and to reduce drag when the helicopter is traveling.

Interference from the metal skids is still troublesome at bearings near ninety degrees on either side, and measurements in these directions must be avoided. The principal problem, other than rotor chop, however, is to maintain an antenna pointing that will transmit full power. It is characteristic of helicopter hovering that the pilot can keep a constant elevation and position, but he cannot at the same time maintain a constant heading, unless atmospheric conditions are unusually stable. He must have one degree of freedom to compensate for wind changes, and a shift of heading is the most convenient.

The resultant change in antenna pointing and consequent loss of signal disrupted the tuning pattern and made it impossible to use the automatic switching for which the Hydrodist was designed. The solution, achieved after a series of modifications, consists of a feedback circuit activated by signal strength, which rotates the antenna in the direction that increases the signal level. An ideal solution would be the use of an omnidirectional antenna which would avoid pointing problems and permit two or more distances to be measured at the same time. But this would operate on an entirely different signal level, and complete redesign of the internal components would be required. The "hunting" capability based on maximum signal level operates satisfactorily.

The third major problem of airborne DME is protection against shock and vibration. The helicopter vibration quickly renders components and connections inoperable unless they are properly designed and protected.

We found no simple cure-all for this difficulty, only a gradual process of trial-and-error improvement, complicated by the limited space in the cabin. At one stage we mounted the instrument on a pillar between the pilot and the observer, but this arrangement resulted in a "whip" action that magnified vibration effects and was therefore quickly abandoned.

We found that the most effective vibration protection was the human body, and that carrying the instrument on the lap of the engineer in the helicopter gave the best results. Unfortunately, this is not practical from the standpoint of operational efficiency. In the present shock-mounting arrangement, the instrument is on the skid rack outside the cabin, supported by four Barry mounts, a type of rubber piston insulator widely used in supporting various kinds of airborne electronic instruments. In addition, the airborne components are thoroughly tested for shock and vibration resistance by the manufacturer, following standard military specifications.

ABC Survey System Operational Projects

Following a series of field tests and considerable equipment modification, the ABC System has been used on a number of operational projects. Some of these surveys with unusual features are described below.

In 1963, a densely wooded area in Maine, about 400 square miles, was surveyed with the ABC System to 1:24,000-scale map accuracy standards. Some 265 control points were established from 10 base stations on towers. Of

these, 250 vertical control points checked within 2 feet, and 15 horizontal control points checked within 3 feet. For identification of the horizontal control points, the helicopter was used as a photographic target. While the helicopter was hovering above a point, it was photographed with a 6-inch-focal-length mapping camera from about 6,000 feet. The image of the rotor blade--two small pie-shaped segments--was used to photoidentify the point on the mapping photographs.

In 1964, the ABC System was used to set and position several hundred special survey targets in the Pisgah Crater area in California, in terrain selected for its resemblance to the lunar landscape. The project was completed in a few days, and the area is being used for studies of moon landing procedures.

For several years the Bureau of Land Management has used the ABC System to establish cadastral monuments in Alaska. In this application, base stations on geodetic positions are used with precomputed angles and distances to "talk" the helicopter into the desired position. A monument is then dropped and used as a hover target while precise distances and angles are measured. From these, the distance and direction to the true position are computed, and a ground party is landed to move and set the monument. As the subdivision line is not surveyed by usual cadastral methods, the ABC System has yielded considerable economy in the rugged Alaskan terrain.

We plan to use the ABC System this fall to establish vertical control in the Okefenokee Swamp, an area in Florida of about 600 square miles which is reputed to have a general slope of less than 15 feet. The swamp is almost wholly wooded, and 80-foot towers will be required for base stations. By holding sightlines to 10 miles or less, we plan to establish a dense pattern of spot elevations to an accuracy of 1 foot. All supplementary data will be obtained by helicopter, eliminating the need for ground surveys in the swamp. Special problems in determining K-factors for curvature and refraction corrections are under study prior to the field operation.

The Aeris II Autotape System

The Aeris II Autotape, introduced recently by the Cubic Corporation, is a very accurate helicopter positioning system which will give two simultaneous slant distances, with digital readout. At the present time one system is on order for the Bureau of Land Management, and two for private firms. We are awaiting with considerable interest reports on experience with this equipment. The Autotape is compatible with the ABC Survey system.

Conclusion

The accuracy of control established by the ABC System, as demonstrated by numerous tests, has been better than expected. Horizontal accuracy is within 1 meter at any range, and vertical accuracy is within 1 foot at

ranges less than 15,000 feet. We believe that the principal reason for the surprisingly high accuracy is that the helicopter hovering motion is essentially random, both vertically and horizontally. Consequently, observing procedures designed to average out pointing errors and other random errors also average out helicopter motion. The same principle operates in distance measurements. The uncertainty of hovering, whatever it may be, apparently is never accumulative. A second factor contributing to accurate results is that the helicopter end of all lines is above the ground and therefore relatively free from refraction anomalies.

The ABC Survey System is now considered operational and is in use on mapping surveys by the Geological Survey and on cadastral surveys by the Bureau of Land Management, and certain private firms have systems available on contract. It is a practical tool for establishing horizontal and vertical control in difficult terrain.