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(6) APPLICATION OF AIRBORNE ELECTRONICS TO SURVEYING AND MAPPING.

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Abstract

A number of airborne electronic devices were developed and used during World War II for control of blind bombing and for precise navigation. Many of these devices have been tested for application to problems in surveying and mapping. The results of these tests, particularly with reference to Shoran are so promising that available equipment should be placed in operational use at once and no time should be lost in further development of instruments specifically for survey purposes.

1. INTRODUCTION

If past experience is a guide, no invention that is destined to have a profound effect on the economic life of a nation is brought forth fully developed. The radio, the airplane, and the automobile required years of gradual development before they were entirely practical. The same is true of radar and the host of radar-like devices designed to measure distances or to determine relative positions on the earth's surface. Contrary to the impression given in a flood of technical and lay articles that have appeared in newspapers and magazines, often by very reputable authors, in fact these devices are today still in the early development stage and are subject to serious and uncontrollable errors.

1.1 Electronic Survey Equipment.

If Shoran can be developed to incorporate sufficient accuracy for geodetic control surveys it will revolutionize certain phases of surveying as we know it today. It will enable the surveyor to do what he cannot do by optical instrumental means. It will make possible distance measurements between continents and it should reduce the cost and time of some field operations to a fraction of what they are today. Accurate maps and charts are important for a multitude of economic and commercial purposes, but are essential to successful military operations and are therefore a necessity in planning national defense. Electronic survey equipment today affords the only practicable means of mapping extensive enemy territory.

1.2 <u>Uses of Electronic Devices for Cartography</u>.

Electronic devices will find many applications in the field of cartography. They are now being used either operationally or experimentally in fields such as geodetic surveying, positioning of aerial photography, hydrographic surveying, determination of aircraft flying heights, and small area ground surveying.

1.3 <u>Uses of Electronics in the Field of Geodesy</u>.

One of the more important uses of electronics in this age of global warfare will be in the field of geodesy. Geodetic control is the framework of a map and can be compared with the foundation and steel frame of a large building. After the building is finished the frame is hidden from view; and similarly with a finished map or chart, the geodetic frame is not apparent, although for extensive map coverage it may be the most important feature. This geodetic framework determines the scale of the map, and its accuracy, orientation, and placement on the earth's surface. In other words, if two maps are on the same geographic datum they are correctly referenced to each other. If they are not on the same datum the maps cannot be fitted together to form a unified area coverage across the boundaries of countries and continents, and the maps do not meet the requirements for modern military purposes such as guided missiles, strategic bombing and precise navigation.

2. A BRIEF DESCRIPTION OF ELECTRONIC SYSTEMS

The electronic devices that have possibilities of application to cartographic problems generally resulted from developments for specific purposes during World War II such as blind bombing and precise navigation. These devices were all designed to accomplish one of two objectives - namely either to determine an observer's position with reference to two or more fixed points, or to measure the distance from the observer to one or more fixed points.

Electronic systems can be classified in several ways:

(1) whether they are of the pulse or phase-matching type

(2) by the frequencies used

(3) whether they are circular or hyperbolic; in the circular systems distances are measured directly, but in hyperbolic systems lines of position are obtained.

All systems mentioned in this study are of the pulse type, except Decca which is of the phase-matching type and Consol which is a directional system.

The systems considered herein are arranged below by their approximate operating frequencies:

Decca	80 - 150 kilocycles
Consol	260 - 500 kilocycles
Loran	about -1900 kilocycles
Gee G-H Shoran	20 - 80 megacycles 250 - 300 megacycles
Oboe	about 3300 megacycles

In this paper the hyperbolic-versus-circular classification has been - Loran, Gee, and Decca being hyperbolic, and Shoran, G-H, and Oboe being circular. Consol is in a class by itself inasmuch as by means of it azimuths or true directions are measured with reference to the position of the station.

2.1 Hyperbolic Systems.

The principal advantage of a hyperbolic system is that the observer requires very little equipment to determine his position. A simple lightweight radio receiver with a built-in device to measure time or phase differences electronically is all that is necessary. This equipment need not weigh over a hundred pounds. The disadvantages are that the installation at the fixed ground stations is somewhat elaborate and that the observer requires specially prepared charts or tables. The charts or tables have to be computed, drawn, and published in advance for each particular pair of ground stations.

2.1.1 Loran: Loran is a ship or air long-range navigation system, designed during the war by the Radiation Laboratory at Massachusetts Institute of Technology, Boston, Massachusetts. It is in operation today by the U.S. Coast Guard, providing coverage for the North Atlantic and North Pacific Oceans. The necessary charts are provided by the Hydrographic Office of the Navy and the Coast and Geodetic Survey of the Commerce Department. Loran ground stations are established at known geographic positions; they operate in pairs, generally called master and slave. The two stations radiate pulses of energy with a fixed-time delay between master and slave. The time difference in arrival of these pulses at the observer's receiver determines a line of position which can be readily plotted on the special Loran chart. Readings from two pairs of stations determine a fix.

Standard Loran employs a frequency of about 1900 kilocycles per second. The range over water is about 700 miles in daytime and 1,400 miles at night. Over land the groundwave range is very poor, being only about 200 miles over rough terrain.

The accuracy of Loran is undefinable, inasmuch as it depends on the observer's position with reference to the ground stations, whether the wave path is over land or water, and on the time of day. In the daytime, distances may be expected to contain errors of about one half per cent of the range, with somewhat larger errors indicated for night reception. This order of accuracy limits the use of the system to navigation or to control for field operations where only approximate positions are required.

2.1.2 Gee: The Gee system was developed in England primarily for air operations, but it was also found very useful as a navigation aid for ships taking part in the invasion of Europe.

Gee is identical with Loran in principle, but the transmitting stations are sited closer together and the transmitters employ higher frequencies, with a resulting decrease in effective range. The accuracy of Gee is similar to Loran, being about one half per cent of the range for average conditions.

2.1.3 Decca: In systems such as Loran and Gee the ground stations transmit a series of pulses of energy, and the observation made at the receiving position is a direct measurement of time differences. In the Decca system however, the transmitted signals are locked together in phase and the measurements at the receiving position are made in terms of wave length and fractions of wave lengths. Decca usually employs three ground stations, one master and two slaves. The frequency of the slaves is related to that of the master station in a simple ratio such as 4:3 or 3:2. The user, by means of a multi-channel receiver, measures the phase difference at the lowest common multiple frequency or comparison frequency of each pair. This phase difference translated into a distance difference determines a Decca line of position. A fix is determined from two or more lines of position.

Decca utilizes the frequency band of 80 to 150 kilocycles and has a practical range limit of about 300 miles. The accuracy near the base line between stations is of the order of ten meters but the probable accuracy decreases as the distance increases and as the relative position of the observer changes with reference to the stations. An average accuracy commonly mentioned for a Decca position is about $\pm$ 40 meters.

One present disadvantage of Decca is the difficulty of "lane" identification. If the user starts at a known position, Decca will continuously indicate his changing position; but Decca will not indicate the position of any otherwise unknown location. Experiments are in progress to provide some sort of "lane" identification. And, as for Loran, special overprinted "lattice" charts are necessary.

2.2 Ranging Systems.

In this category are classified the electronic devices which measure directly the distances between the aircraft and ground station. These are the only systems that have been seriously considered for geodetic control purposes. The disadvantages of these systems are that more elaborate equipment has to be carried in the aircraft and that the higher frequencies which must be employed to obtain the necessary accuracy confine the method closely to line-of-sight distances. The advantages are simplicity and flexibility in that no precomputed charts or tables are required in order to determine a position. The ground stations are also portable in the strict sense of the word.

2.2.1 Shoran: Shoran was developed during World War II by the Radio Corporation of America for use in strategic bombing. It was successfully used for blind bombing in the European Theatre. Essentially the system operates as follows: A pulse of energy is transmitted from the aircraft to a ground station. This ground station receives, amplifies, and retransmits the pulse to the aircraft where the elapsed time is measured in micro-seconds by means of an electronic clock. The dials of the clock are graduated, for convenience, in statute miles with provision for automatically subtracting the instrumental delays. One operator in the plane can match pulses to two ground stations simultaneously, thus fixing the plane's position, with respect to the ground stations. The plane's position may be determined continuously or as often as desired. The operating frequency is in the neighborhood of 250 to 300 megacycles. Inasmuch as the path of the radio waves is essentially optical, the maximum practical range from aircraft to ground station is about 300 miles. The maximum practical geodetic distances that can be measured is, therefore, about 600 miles. A proposed technique of employing airborne relay equipment in geodetic operations, however, may extend considerably the measurement of distances from aircraft to ground. The Coast and Geodetic Survey is currently using this system successfully to determine positions of a survey vessel in offshore hydrographic surveys to distances of 60 or 70 miles. Commercial aerial mapping companies are also using a very similar procedure for positioning air photographs at the time of exposure and for control of magnetic surveys. The accuracy of Shoran line measurements may be considered at present to be approximately, plus or minus, 50 feet on lines up to 280 miles in length. The probable error of positioning aerial photography for mapping and charting with current Shoran equipment is $\pm$ 50 feet.

2.2.2. <u>G-H</u>: G-H is the British counterpart of Shoran, and was developed originally for the same purpose. Its operational techniques are the same as Shoran and subject to the same errors and limiting factors. The principal differences are the operating frequency and in the method of determining the distances, which are read in the form of "G" units and subsequently converted into any standard unit of measurement desired.

2.2.3 Oboe: Oboe is similar to G-H except that control is reversed. The transmitting and recording equipment is at the ground station and the transponder station is in the aircraft. This system permits of greater theoretical accuracy in reading the ranges because of the use of a higher frequency, heavier equipment and better facilities that can be set up at a ground station. The operational difficulties, however, outweigh any possible gain in accuracy.

2.3 Directional Systems.

The measurement by electronic means of true directions or azimuths on the earth's surface has been studied and experimented with for many years. Except for standard ship navigation devices, however, most proposals have not gone beyond the paper stage and even theoretical claims hold forth little hope that directional systems will have sufficient accuracy for geodetic work in the foreseeable future.

2.3.1 Consol: Consol is a German-developed directional navigation system, originally called SONNE. German equipment captured by the Allies is now in operation at Stavanger, Norway, and at Lugo and Seville, Spain, in addition to a station recently established by the British at Bushmills, Northern Ireland.

These ground stations, or beacons, transmit dot-and-dash signals continuously and the observer determines his position with reference to two or more beacons by counting these signals during a cycle of transmission and referring to a special chart overprinted with Consol grid lines. The power output of a beacon is about 1.5 kilowatts at a frequency of 260 to 500 kilocycles per second, giving an effective range of 1,500 miles over land under favorable conditions. The only receiving equipment needed is an ordinary communications receiver, and a Direction Finder loop. The accuracy of a bearing depends on the observer's position with reference to the beacons and varies from 0.2° to as much as 3° near the edge of coverage.

Consol is probably the best of the electronic direction systems, but it still falls far short of the requirements for geodetic survey purposes. The system may have future application to navigation and to control surveys where accuracy is not a prime requirement, as in oceanography or magnetic surveys.

3. APPLICATION TO CARTOGRAPHIC PROBLEMS

The measurement of accurate distances in surveying is so fundamental that if electronic devices can be utilized for this purpose it will affect all phases of field work. To discuss all these phases is beyond the intended scope of this study, so four of the main cartographic problems have been selected for a closer examination to see what airborne electronics might accomplish when applied to the more important and fundamental operations.

3.1 Geographic Datum.

The geographic datum, also called horizontal or geodetic datum, of a map consists of the adopted position in coordinates of latitude and longitude of an initial point, to which the mapped features of a vast region are referred, the azimuth of a line from this point, and the identity of the terrestrial spheroid used. In modern mapping all latitudes are reckoned north or south of the equator and longitudes east or west of Greenwich Meridian. As it is obviously impossible for a surveyor to measure actual distances on the earth from the equator and from Greenwich to the site of his survey, he has to determine the position of a "point of origin" by astronomic observations. This would seem to be a simple matter, inasmuch as the positions of astronomic bodies are known with a relatively high degree of accuracy. Actually, however, the problem of determining accurate geodetic positions by astronomic observations has so far defied solution because of the unpredictable deflection of the vertical caused by the irregularity and variable density of the earth's crust. In the light of present knowledge it can be categorically stated that it is impossible to determine a true geodetic position by astronomic observations, or by any other independent means.

From the above statement it can be seen that all unconnected geographic datums are in error with reference to one another by varying amounts. This condition is, of course, only a minor inconvenience to one whose interest is limited to local mapping, but to the military cartographer, who must deal with global map coverage, the problem becomes very serious, and the solution he adopts is an empirical one and may incorporate errors in the maps which endanger the user. This is especially true of maps on different unconnected datums on which is superimposed a military grid.

This question of datum is also particularly acute with respect to all oceanic islands invisible from the mainland. All these islands are now positioned on the earth's surface from astronomic observations, and they are, therefore, not accurately referenced to the nearest mainland nor to one another. The obvious implication of this in connection with directed and guided missiles, used in modern warfare, is that neither bearings nor target distances can be pre-computed with sufficient accuracy; computed distances may be in error by as much as a half mile. Nautical charts compiled from unconnected datums are at best confusing and misleading but the inaccuracies in them may even lead to disastrous results in certain types of naval operations.

Airborne electronic ranging, because of its great range, gives promise of being able to solve this datum problem if sufficient accuracy can be obtained. The present usable range of 600 miles, without relay stations, may permit inter-connections between the large surveyed areas of the earth to link them together on a common datum.

A few island groups are beyond the 600-mile range, but even these may be reached by utilizing ships or aircraft as relay stations, if this method is as practicable as some preliminary experiments indicate. With datum difficulties eliminated global mapping and charting will become practical.

3.2 Geodetic Map Control.

To map an area some kind of control must first be established throughout the area; this basic control is generally a network of triangulation stations. Triangulation consists essentially in observing the angles at each end of a known base to a new station and then computing by trigonometry the distances and azimuths to the new station thereby determining its position. The establishment of control by triangulation is difficult and expensive and, from the military standpoint, is the slowest of all survey operations. Triangulation depends on the intervisibility of stations and is thus subject to the vagaries of the weather and the distance limitations imposed by the earth's curvature and man's vision. In areas of heavy jungle, extensive swamps, and Arctic wastes, triangulation is a serious bottleneck in ground survey operations.

Airborne electronic equipment can be used in establishing control by measuring the distances between stations instead of the angles, and then determining geographic positions. Inasmuch as airborne electronic systems are capable of greater ranges than optical instruments, areas of difficult terrain could be more easily spanned and fewer stations would be required. Also electronic survey systems are not dependent on visibility. In this sense they operate independently of the weather, daylight or darkness. They promise to reduce the control bottleneck in surveying, with a consequent saving in time which may be an all important element in military operations.

3.3 Air Photo Control.

There are several common instrumental methods of obtaining topographic detail, but from the standpoint of modern military mapping aerial photography is the only method worth serious consideration. An aerial photograph itself is not a map, because such photographs are subject to various distortions and errors. Present practice in topographic surveying requires that ground survey parties establish by instrumental methods the positions of a large number of identifiable photo control points, with reference to the basic triangulation control. If the country being mapped contains areas of thick jungle, swamps, or ice fields, and is therefore difficult of access for ground parties, or if the area has persistently poor visibility due to fog or rain, then the control problem is very time consuming, difficult and expensive. Even where the area is favorable for ground survey parties, the establishment of this control is still a bottleneck. This statement can be readily appreciated if one stops to realize that more than a thousand square miles can be photographed for mapping in one favorable day from one airplane. Even a small army of men on the ground could not keep up with such progress.

Experiments in the United States and England have definitely indicated the practicability of controlling aerial photographs by airborne electronic methods and thus relegating the establishment of control from a major to a minor problem of the topographer. This can be done by positioning the aerial camera every time the shutter is operated and, after some mathematical computation, arriving at the latitude, and longitude of the optical center, or principal point, of each individual photograph. If the elevation is also known and if the camera were held vertically at each exposure by means of a stabilized mount, such photographs would be usable for military mapping without further grpund control. By this method it would be possible to map up to 40,000 square miles of land area in advance of ground control or triangulation without one person setting foot on the area and possibly without the native population even realizing that the country was being mapped. Further advantage is gained by the fact that the Shoran equipment can be simultaneously used for flight line navigation and thus assure gapless photographic coverage at the first attempt.

The military advantages of this type of operations are so obvious as to require no further elaboration. From an economic standpoint it has been estimated that if this method were sufficiently perfected it would reduce the cost and time of field work to a mere fraction of what it is now.

3.4 Size and Shape of the Earth.

Airborne electronic devices such as Shoran have been prominently mentioned as a means which could be used to make geodetic connections between the continents and thus obtain data from which new and possibly more accurate values of the size and shape of the earth could be computed. This operation would require an instrument of high precision.

The International Ellipsoid of reference was adopted as the figure of the earth at the Congress of the International Union of Geodesy and Geophysics held at Madrid in October 1924. Practically all the leading nations have officially approved the International Ellipsoid as a standard of reference but only a few of the leading cartographic nations are actually using it as a basis for mapping and charting. The triangulation of Western Europe is now being readjusted on the International Ellipsoid and it is likely that future mapping and charting in this area will be based thereon.

Global mapping is of recent interest, brought about by increased speeds of aircraft and the requirements of new military weapons such as guided missiles. Up to now, each nation has been principally concerned with mapping within its own borders and many of the nations use their own individual values for the size and shape of the earth as a geodetic basis for their maps. For example, Russia has recently computed a new triaxial figure for the size and shape of the earth, based on their own transcontinental triangulation and on the North American Triangulation. The Russians state in their report on this triaxial figure that it will not be used in Russia but is the basis for their new biaxial ellipsoid, which will supersede the Bessel Spheroid in Russia. The difference between this new Russian ellipsoid and the International Ellipsoid may amount to as much as 550 feet in a geodetic line 5,000 miles in length.

While it is considered that the computed size and shape of the earth, as represented by the International Ellipsoid is adequate for practical cartographic purposes, military agencies believe that the dimensions of this spheroid are not adequate for their foreseeable needs where it will be necessary to compute azimuths and distances between distant points on the earth. Any inaccuracy of the dimensions of the ellipsoid will produce corresponding inaccuracies in the distance and azimuths between the points. Certainly maps will be required for this purpose in the future in connection with guided missiles.

4. DEVELOPMENT TO DATE

4.1 Foreign Nations.

Great Britain, the principal foreign nation engaging in extensive research and development of airborne electronics for survey purposes, has materially contributed to the eventual solution of the problem. As in the United States, devices were developed for strategic bombing and precise navigation, but the bombing accuracy tests of G-H and Oboe in September 1943 were so encouraging that the Director of Military Survey made the adaptation of these aids to surveying purposes.

and operational requirement. With the urgency of war and the availability of funds, materials, and officers of suitable background, the problem was attacked with enthusiasm. The research was mostly directed toward the ultimate aim of obtaining photo control, and a number of areas were photographed experimentally where the resulting maps could be subsequently compared with existing maps based on ground surveys. These experiments with improved and modified techniques continued until the end of the war when the economic difficulties of Great Britain curtailed further tests and development. The conclusions arrived at are ably stated in a series of Air Survey research papers, issued by the Director of Military Survey, War Office. The Directorate of Colonial Surveys has obtained electronically controlled aerial photography for mapping in the African colonies.

Recent information indicates that the British have recently developed a new model of G-H specifically for use in survey work. Another leading British development is Decca, which was developed by a commercial company as a precise navigation system but which may also be used in hydrographic surveys. Decca is now being used in England, Sweden, Denmark and Greenland to control hydrographic surveys. Decca is sold commercially, the latest quoted price being $100,000 for one complete unit delivered in New York City.

Other Western European countries are now economically unable to engage in development that does not offer immediate results and fulfill immediate needs. What, if any, research is being done with the Soviet Union is not known.

4.2 <u>Development in the United States.</u>

Research and development of airborne electronics for mapping purposes in the United States have been mostly, if not entirely, devoted to the use of Shoran. Investigations have been made with original and modified versions of bombing equipment and not with equipment specifically designed for mapping and geodetic work. It was the logical follow-up of the British experiments with G-H. On the recommendation of the Corps of Engineers, field tests of Shoran conducted by the Air Forces were divided into three phases, as follows:

PHASE I - Test of Shoran for photo control and the use of Shoran to direct a photographic plane on a straight line. The results of these tests are available in the Engineer Board report 987 "Second Interin Report, Application of Shoran to Mapping, 29 August 1946." These tests which are still in progress indicated that Shoran controlled photography, even using the presently available modified bombing equipment, could be used to compile maps very closely approaching peacetime horizontal accuracy requirements for 1:50,000 scale maps. The report recommends that the Shoran system be adopted immediately for use in mapping areas where accurate geodetic control is unavailable or where the time required for establishing geodetic control to gain increased accuracy is unwarranted.

PHASE II - Test designed to determine the possibilities of Shoran for measuring geodetic distances. In this test six distances were measured between points whose positions had been established by conventional triangulation methods. The results of this test were very promising and are reported in detail in a report from 311th Reconnaissance Wing, Interim Report "Report on Phase II, Denver Area Shoran Project" dates 20 September 1946.

PHASE III - Test to utilize Shoran for connections between Cuba, some of the Bahama Islands, and the United States. This phase, the most ambitious of the three tests, afforded a comparison of Shoran measured distances with some distances determined by Coast and Geodetic Survey first-order triangulation, with some determined by Navy second-order triangulation in Cuba, and with a distance between Florida and Walker Cay, Bahamas, determined by flare triangulation. The results of Phase III are contained in the Air Proving Ground Command report "Tactical Test of Shoran Control for Mapping and Charting" dated 15 October 1947.

As a result of the above field test a number of research and development projects were undertaken by the Air Materiel Command at Wright Field (now Wright-Patterson Air Force Base), Dayton, Ohio. The projects include studies of maximum range and optimum frequency, the employment of airborne Shoran for extension of range, the development of an automatic device for precise navigation, and two important associated projects, the development of a stabilized aerial camera mount, and a precise radio altimeter.

In addition to the above Air Force projects, the Navy, in connection with its broad basic research program, has contracts with numerous universities for the study of propagation velocities and associated problems. The Corps of Engineers is continuing with their investigations of the utilization of Shoran for mapping.

5. NEED FOR FURTHER DEVELOPMENT

The potentialities of Shoran in geodetic surveying can be developed only by a concerted research and development attack along these three lines:

(1) A redesign of Shoran equipment embodying greater accuracy. The target should be an equipment capable of measuring distances with an instrumental or electronic error no larger than five feet. (Present equipment was designed for positioning bombing aircraft over targets and not for geodetic accuracy. Competent electronic engineers are confident that a timing accuracy of ten feet or better can be achieved).

(2) A more accurate determination of the velocity of radio waves in a vacuum. The accepted value is probably correct to one part in 50,000, but recently developed engineering techniques, particularly in the measurement of extremely small time intervals, should make possible a still more accurate determination.

(3) A study to determine the effect of all sorts of atmospheric and other conditions on the propagation path and velocity of radio waves.

The remarkable results obtained with Shoran in the Phase II tests in Colorado, led many laymen and professional surveyors to believe that Shoran was already an instrument capable of first-order geodetic work. This optimism was completely dispelled by the results of Phase III. Though the tests showed that operational use of electronic survey equipment is completely feasible, the accuracy obtained proved that further development would be required to produce a first-order instrument. In this test the Shoran-measured distances in Florida were consistently short when compared with the Coast and Geodetic Survey triangulation and those in Cuba were consistently long when compared with the Navy triangulation. Shoran emerged from this test as a poor second-order instrument, with a demonstrated accuracy of less than 1:20,000. Since all the data were carefully examined by a number of qualified geodesists and electronics experts this figure probably represents the best that can be expected from the present equipment. Tests and investigations to date indicate that Shoran is sufficiently accurate for obtaining air photo control for mapping and charting and for navigation of the planes required in such work and could be immediately utilized for these purposes.

Shoran equipment suitable for geodetic surveying, however, requires further development and refinement. The development of a highly accurate instrument suitable for geodetic purposes will also result in improved accuracy for air photo control for mapping and charting.

5.1 Instrumentation.

There appears to be little hope of dealing with problems connected with velocity and propagation refinements until such time as an instrument eliminating or greatly reducing timing errors can be built. The greater part of the errors in the Phase III tests may be attributed to the instruments and, in particular, to the timing and frequency calibration errors.

A modified Shoran instrument designed to reduce some of these errors is now being produced but a completely satisfactory solution must await a basic redesign of the instrument.

5.2 Velocity and Path of Propagation.

Other factors which contribute to the errors in distances measured by electronic devices are the uncertainty in the true velocity of propagation in vacuum and the effects of the meteorological conditions along the path of propagation. The velocity of light in a vacuum is generally accepted to be accurate within about 1:50,000. One authority, [1] however, states that the "dubiety" regarding the velocity of light may be 1:30,000 which may account for some of the Phase III Shoran errors. The corrections to be applied for the meteorological conditions have been the subject of considerable study and research for many years and are known with some degree of precision. Still, since

[1] Dorsey. Transactions of the American Philosophical Society, Philadelphia, Pennsylvania. Volume 34, Part I. The Velocity of Light. 1944.

very minute quantities are involved, this field probably has many unexplored possibilities. It can be taken for granted that velocity is the one factor which will ultimately determine the practical limit of electronic survey accuracy, but there is no present indication that this limit is less than the requirements for first-order work.

A continuous program of investigation in those fields is needed, with the aim of gradually improving the basic velocity and velocity-correction formulas. No immediate results can be expected but, considering the importance of the subject, a considerable effort along this line seems justified and even necessary before electronic ranging can be used with confidence for geodetic control.

Another approach to the solution of this problem is to obtain a specially designed instrument incorporating a more accurate timing device and then to establish a Shoran test range at some convenient location in the United States. The length of this range would be determined with high precision by ground survey methods. If this range were measured with the precise Shoran every day, under a variety of atmospheric conditions and employing a variety of techniques and instrumental modifications, the pattern of errors and the allowances to be made for them might be determined.

5.3 Field and Office Technique

Electronic ranging measures the lengths of the sides of the triangle instead of its angles and requires new techniques in the field and in the subsequent mathematical treatment of the observed data. This is exceedingly important in the application of Shoran and has a very definite relation to the accuracy of the final results. The Air Force, Coast and Geodetic Survey, and the Corps of Engineers are attacking this problem. The Engineer Research and Development Laboratories are currently preparing a manual covering the field and office techniques for utilizing Shoran controlled photography for topographic mapping.

What is needed is a careful investigation and evaluation of all possible field techniques, and of computation adjustment and methods by qualified geodesists and mathematicians. The purpose of such an investigation would be to designate procedures that would provide the greatest economy of field operations with the greatest accuracy of the end product.

6. CONCLUSION

Although further development and investigation of airborne electronic survey instruments is required to produce an instrument suitable for the many geodetic applications, this should in no way prevent the immediate operational use of such equipment as is now available for controlling aerial photography for mapping and charting. It is believed that Shoran, in its present stage of development can be utilized to control aerial photography and should be put to operational use in the current mapping programs. Foreign areas to which we now have access may be inaccessible a few years hence. Operational use of such equipment will, in addition, be a very desirable aid to the research worker in development of more suitable equipment for geodetic applications. It is to be noted that the British have already developed a survey model of G-H, whereas, this country has no survey model of Shoran.

Research in electronic ranging and development of more accurate equipment for geodetic measurements is required. Global surveying and the correlation of world wide data is a prime requirement of a guided missile program. With the world political situation as it is today, and the speed of aircraft and military weapons as they will be tomorrow, the need for such equipment is urgent. Development of such equipment should be vigorously continued to a successful conclusion.