SHORAN INVESTIGATIONS FOR TRIANGULATION (*)

by

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It has long been a dream of geodesists to discover a method of mapping accurately with respect to each other, widely separated points on the earth's surface when the conventional method of ground triangulation could not be employed. For many years it has been known that this problem might be solved by the use of electronic methods, but the great expense of such research prohibited its development during peacetime. Consequently when Shoran, a precise blind-bombing instrument, was developed during the war, we immediately saw the possibility of making our dream come true and adapting it to geodetic surveying.

As a bombing instrument Shoran had an accuracy of plus or minus 50 to 100 feet. That was far from the accuracy required for geodetic measurements. We decided, therefore, first to investigate the electronic design and attempt to gain additional precision by redesign and calibration. Second, we would attempt to eliminate errors by applying all the principles of error elimination used in geodetic surveying—that is, by multiple observations properly distributed over the range of error source, the principle of reversal, and the use of Least Squares solutions.

That is what we have done and the results have surprised even ourselves. Furthermore we have only scratched the surface. I predict without hesitation that we shall in the near future be able to make first-order triangulation surveys over lines 200 to 500 miles in length, making the distance measurements by electronic means.

Description of Equipment.

First, let me give a brief description of the instrument. The Shoran equipment consists of three main units—an airborne transmitter-receiver and two ground station transponders. The airborne station transmits extremely short pulses alternately at 1/20-second intervals to the ground stations, a different frequency being used for each. The ground stations receive and retransmit the signals to the airborne station on a third frequency which is common to both. At the airborne station the returned signals are presented on the cathode ray oscilloscope as " pips " or " bumps ", together with the outgoing signal. The design of the instrument is such that when three pips—that is, the return signal pips and the outgoing signal pip—are aligned, two dials read the two distances in statute miles to the ground stations. Since we are interested in the surveying adaptation I shall not go further into detail in describing the equipment other than to say it is quite portable and quickly installed.

Procedure.

From the above it can be seen that an airplane can be positioned in the air by means of two simultaneous distances to known points and the known heights of plane and ground stations. In surveying we perform the opposite of this operation. From two known Shoran distances and known heights, the distance between the two ground stations is determined. The accuracy of that distance is dependent on two single, simultaneous readings on the distance dials. Now for geodetic operations an improved procedure is used. We cannot rely on a single pair of readings. Therefore we determine the minimum sum of a large number of pairs of readings as we *fly across the line between two ground stations.* In order to obtain these readings we

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employ a photographic recorder which records, at 2 to 3-seconds intervals on 35 mm. film, the data required to make the computations and reduce to geodetic distance. These data are the readings of the Shoran mileage counters, the barometric altimeter, air temperature indicator, clock, fluxgate compass, frame counter and data card. The equation of the relationship between the frame interval (or ground distance normal to the line) and the sum distance can be shown to be a hyperbola. In practice we substitute a hyperbola to simplify the computation. Our computation then consists of the Least Squares solution of the minimum ordinate (or sum distance) of the parabola. (See fig. 1.). By always using a fixed number of frames certain coefficients may be pre-computed to assist in quickly determining the parabolic coefficients.

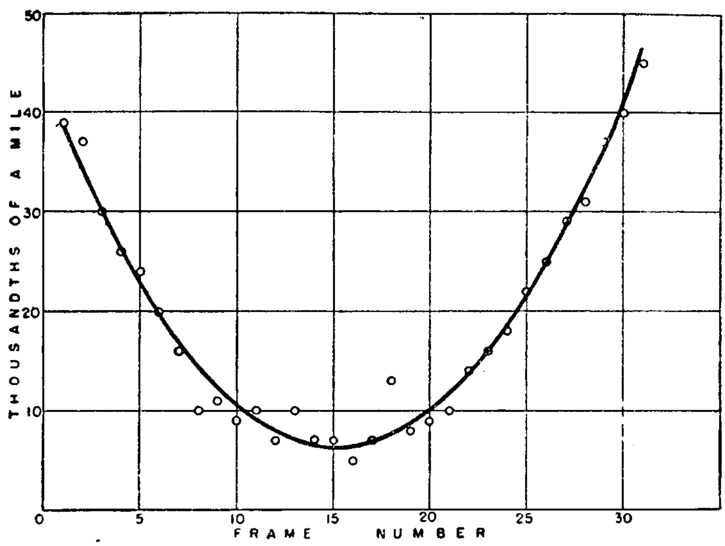

Fig. 1

Shoran line crossing minimum distance curve Cheyenne-La Junta, May 1, 1946.

Accuracy.

It is apparent then that the accuracy of the final result depends on four basic factors :—

1° The accuracy of the measured time interval between the sending and receiving of the signal pulses ;

2° The knowledge of the propagation velocity along the path of travel of the signals ;

3° The relationship between the curved or refracted propagation path and the geodetic distance between the two stations ;

4° Knowledge of the height of the airborne instrument.

These relationships indicated that the research should follow along the following four lines : (1) instrumental modification and calibration ; (2) determination of a velocity correction; (3) determination of a geometrical correction, and (4) determination of height of airplane. These are the lines we followed, but there is insufficient time in a talk of this length to describe the enormous problems involved and the methods of attack. We feel that we have gone a long way toward their solution.

Results.

The results of the adjusted Shoran triangulation conducted by the 311th Reconnaissance Wing in Colorado, Kansas, Nebraska and Wyoming are well within the accuracy required of first-order triangulation. After adjustment the worst discrepancy remaining in the comparison of the inverse geodetic distances based on the first-order triangulation of the U.S. Coast and Geodetic Survey and the adjusted Shoran distances was less than 12 feet (0.0022 mile). The worst ratio of accuracy was 1 part in 113,350. A new method of line crossing computation is now being investigated and may reduce these discrepancies still further.

The complete results are shown in Table I.

TABLE I

RESULTS OF SHORAN ACCURACY TESTS

Geodetic Line	Shoran Distance	Inverse Distance	Différence		Adjusted Shoran	Différence	
			Miles	Feet		Miles	Feet
La Junta - Garden City	148.5341	148.5395	—0.0054	—29	148.5384	—0.0011	— 6
Cheyenne - Imperial.....	173.7457	173.7471	—0.0014	— 7	173.7459	—0.0012	— 6
Imperial - Garden City...	181.3697	181.3694	—0.0003	— 2	181.3678	—0.0016	— 8
La Junta - Imperial......	198.7193	198.7099	+0.0094	+50	198.7114	+0.0015	+ 8
Cheyenne - La Junta......	227.2899	227.2868	+0.0031	+16	227.2855	—0.0013	- - 7
Cheyenne - Garden City	308.5241	308.5252	—0.0011	— 6	308.5274	+0.0022	+12

It must be remembered that the positions of the Coast and Geodetic Survey triangulation stations have an uncertainty of at least as much as these final differences.

It must be stressed that the above results were accomplished not with a surveying instrument designed for accurate electronic distance measurements but with a modified bombing instrument. A new instrument designed particularly for geodetic surveying will eventually be developed.

There are vast areas on the earth's surface, such as the island chains, where the distances involved prevents their accurate linking together by any other means. The future of electronic geodesy is wide open and we have an excellent start, but it is still only the beginning. Unquestioningly during the next few years we will see developments in electronic surveying which will revolutionize existing methods.