SHORAN CONTROLLED PHOTOGRAPHY IN CANADA, 1953.

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During four months in the summer of 1953, under the aegis of the Army Survey Establishment, Department of National Defence, Spartan Air Services Limited, with the technical support of Canadian Aero Service Limited, completed 11,000 linear miles of Shoran controlled photography in the Northwest Territories, Northern Alberta and Northern British Columbia. Eventually this photography will provide horizontal control for existing vertical photography covering 100,000 square miles of Northwestern Canada.

Much credit is due Army Survey Establishment for enlarging the effective use of this electronic method of establishing horizontal control. That the Shoran operation of 1953 was successful may be attributed in the main to the persistent efforts and foresight of Col. C.H.Smith and his associates of the Army Survey Establishment, who supplied the initiative throughout all the experimental stages and encouragement to overcome difficulties and setbacks encountered in making the application of Shoran workable. At the same time we wish to pay our respects to those members of the Royal Canadian Air Force, the National Research Council and the Geodetic Survey of Canada who played so prominent a part in developing the Shoran method of horizontal control and to thank them for their willingness to co-operate at all times

First, let us review the basic principles of Shoran. The term Shoran is a contraction of the phrase SHOrt RAnge Navigation and it is an electronic measuring system for indicating distances of an airplane or other vehicle from each of two Shoran ground stations. In operation the aircraft transmits radio signals to both ground stations. These signals are received and immediately re-transmitted to the plane. By automatic measurement of the time required for the signals to traverse each round trip path, the distance from the airborne equipment to each ground station is accurately measured. This information, together with the knowledge of the flying height, and the geodetic positions of the ground stations permits computation of the absolute airplane position.

During March 1953, personnel and equipment began to assemble at Spartan Air Services hangar in Uplands Airport, Ottawa. A Shoran detachment was organized from personnel of the two companies. Detachment organization consisted of an Administration Section, an Airborne Section, an Electronic Section, a Geodetic Section and a photo laboratory. The Administration Section included the project manager, one accountant, two cooks and two kitchen assistants. In the Airborne Section we had one chief pilot, four additional pilots two navigators, two photographers, two aircraft engineers and three engineer's aides. This section operated and maintained three Lockheed PV-1 Venturas one Anson, and one Norseman. In addition to these aircraft it also operated a Dakota during mobilization and demobilization phases of the project. The Electronics Section was composed of an electronics chief, a maintenance engineer, a communcations engineer. six ground Shoran operators four assistant ground Shoran operators and four airborne Shoran

operators. The project geodetic section consisted of one geodesist and four computers. Finally our photographic laboratory was operated by one photographic technician. In total we had forty-three men assigned to this project.

Our Shoran equipment was calibrated in Ottawa during early mobilization days. A calibration range three miles long was selected parallel to runway 14-32 at Uplands Airport Our range ran 200 feet off this runway. To insure safety we carried a radio set in our calibration truck, tuned to the control tower. We received radio instructions and a green light from the airport control tower every time we were about to enter or cross a runway.

We calibrated one airborne Shoran set against each ground Shoran set, using the same operating channel in the airborne set throughout. Two of the ground sets were again calibrated against the other airborne set, following the same procedure as during our first calibration runs. These calibration runs are necessary to establish any variation in delay among the ground sets. This delay is the "time", represented as distance, consumed during the interval when the electromagentic wave is travelling through the ground set itself.

Since we used two airborne Shoran sets, it was necessary to establish variation in delay between the two airborne sets. This variation was determined by the recalibration mentioned previously.

Our calibration runs provided us with the relative differences between ground sets when operating in combination with either airborne set. The absolute delay of the sets was not determined until our trilateration net was closed and adjusted.

In order to perform our preliminary line crossing computations, we required an approximate delay value for each ground set. To fulfill this requirement our calibration data between the one mile and three mile stakes was fitted with a parabolic curve of the type $y = Ax^2$ plus B by the method of least squares. The Y ordinate of the curve at a distance of $2\frac{1}{4}$ miles was selected arbitrarily for the delay. Any value in the empirical delay curve could have been selected; however, the chosen ordinate should be the same for all sets and should approach in magnitude the design delay value of the sets when manufactured or 0.18 miles. Selection of the delay at $2\frac{1}{4}$ miles accounted for 97% of the absolute delay as revealed later by our net adjustment.

While our Geodetic Section planned the Shoran net and computed calibration observations, our aircraft engineers were busy working on the first Shoran aeroplane. The remainder of the Airborne Section completed flight maps and photographic coverage. In addition to numerous other duties, each man who was to operate a ground Shoran station took a three day course in meterology at Rockcliffe Airport. These men later provided the Edmonton Meteorological Office of the Department of Transport with regular weather observations throughout our area of operations. These weather reports supplemented the information from existing weather stations and at times were the only local source of weather data. In return for our services, the Department of Transport gave us a weather forecast every night for the following day and predicted the probable conditions for aerial photography and geodetic measurements throughout the area. Also we received a second forecast, about three o'clock every morning, from Edmonton, which gave us additional weather information, and predicted

operating conditions again. We take this opportunity to thank the Department of Transport and to commend them on the accuracy of their predictions.

During the first week of May, an advance party departed for the Northwest Territories to prepare our base camp at the Yellowknife Airport. Relying entirely on air transportation detachment personnel and equipment left Ottawa on May 17th. By May 27th we had six ground Shoran stations installed in the field and ready for operation. The first five stations were planned for airport locations to avoid lakes during the break-up period. However, at that early date the ice was gone on Lake Bistcho in Northern Alberta, allowing us to complete installation of our first six Shoran stations. The other five stations were located at Yellowknife, Fort Smith, Fort Simpson, Hay River and Fort Vermillion. To install the five stations at landing strips our Anson airplane, loaded to the last fraction of a pound allowed by air safety regulations flew around the clock.

The weather during May was perfect for photography, but practically all the lakes were frozen and there was still some snow on the ground north of the 60th parallel. The first photo Ventura left Ottawa on June 1st, 1953, arriving at Yellowknife around 8.00 p.m. the following day, stopping briefly at Edmonton for a propellor change. With this aircraft in the field, the mobilization phase of the project was complete.

Throughout the entire project we enjoyed an unusual amount of photo weather. Daily reports from our field stations indicated that it was possible to take aerial photographs 39% of the time we were there. Most of the better photo days occurred during the months of May, June and July

For this operation we revised the photo-light tables. The time during the day when photographs could be taken was increased by two hours. During June we took acceptable photographs as early as 4.45 in the morning, and as late as 8.00 o'clock at night. Our air crews were up at three o'clock in the morning, and quite frequently they worked through until ten o'clock at night before they landed from their last mission for the day.

The Shoran equipment performance was above par. Practically a complete set of spare parts was on hand at each ground station. When these stations became unserviceable, our ground Shoran operators repaired the sets at once. On one occasion the airplane circled the area for half an hour while the station was fixed. Then, after the station was repaired, we completed, that day, a line we had been trying to do for two seasons.

Several times during the project our two photo aircraft operated out of separate bases. We based one of our planes at one time or another at Fort Nelson, Fort Simpson, Norman Wells, Sawmill Bay, Yellowknife and Fort Smith. This deployment of aircraft allowed us to reduce ferry time and to concentrate on priority areas assigned to us by the inspecting officer. We were able to fly two photo airplanes several times in the same day during the project. Our maximum production during these days exceeded 1,000 miles daily. The highest production rate was obtained when the aircraft operated in two entirely separate areas. The efficiency per airplane decreased considerably when operating in the same photo zone.

One of the most important factors in the economics of a Shoran project is the number of field stations required. The maximum efficiency of Shoran photographic coverage is

obtained by controlling the distance between stations. This distance is dependent upon two factors:

1. The horizontal angle subtended at the airplane by the ground stations as allowed by project specifications.

2. The range limitation of the equipment.

These two factors limited the distance between stations to 150 miles for maximum efficiency on our project.

During the past few years the Geodetic Survey of Canada has established a trilateration net throughout Northern Canada. We utilized stations in this geodetic net whenever possible. However, since in most cases the distances between these stations exceeded 150 miles, we found it necessary to establish a number of our own stations. During our operation we occupied a total of fifteen Shoran sites and re-occupied three of them. Of the fifteen stations occupied, eight had been established by the Geodetic Survey and the remaining seven by our crews. The combination of geodetic and photographic missions in one project allowed us to attain the greatest efficiency in the use of Shoran equipment and personnel. We concentrated on photographic work during the rare cloudless days, and we established our geodetic control during the days when photographs could not be obtained.

Last year we measured a total of fifteen lines by the method of line crossings. These lines formed two independent nets which subdivided the distance between stations established by the Geodetic Survey, allowing us to produce effective mapping control. Our contract required us to establish stations to the same order of accuracy as the geodetic stations. Our control met the specifications. In our southern net we measured eight lines and established the geodetic position of three stations. The mean length of our lines in this net was 155 miles. These lines were observed in two sets of eight measurements, each set on a different day and at a different height. The mean probable error of one observation in the lines of the net was 0.00246 miles or approximately thirteen feet. The average probable error of the most probable value of the lines in the net was 0.00062 miles or approximately three feet. The mean of the differences between two sets of eight observations in all the lines was 0.00362 miles or approximately fourteen feet. The lines were observed at a mean flying height of 10,000 feet. The adjustment of this net gave very impressive results. After adjustment was completed the largest correction applied to a line in this southern net was only four feet. This particular line was 121 miles long. At the other extreme, our smallest correction was 0.19 feet in a line 146 miles long.

Position computations of the stations produced good results. For example, in our Northern net prior to the final adjustment we computed approximate positions for the stations we had established. After the adjustment was completed we found the errors in our preliminary fixes. The largest error, 0.8 seconds, occurred in the longitude of one station. The smallest error, 0.4 seconds. occurred in the latitude of the same station. Incidentally, in this net, we found we had a systematic error per Shoran set that amounted to two meters. To give another example of the accuracy of our work, we should point out that the shortest distance between any one of the stations we established and a station of the geodetic net was 110 miles.

We introduced several time-saving methods in our data reduction processes. For instance, the rigorous computation of geodetic positions is difficult when long lines are involved. The formulas used are by nature complicated, and it is very easy for a computer to let a small error go undetected until the problem is completed. A method suggested by the United States Coast and Geodetic Survey was adopted. This method subdivides the length of any line into equal sections. We were able to divide all our lines in halves so that a direct or reverse position computation could be completed and checked in one hour. Our method employs natural functions and the calculating machine, doing away with the slow process created by logarithms.

Our nets were adjusted by the method of variable co-ordinates. First a preliminary station was obtained through a single chain of triangles. The next step consisted of computing rigid inversed distances between all points over which Shoran distances were measured. With this data, observation equations were formed and solved simultaneously by the method of least squares.

At the completion of our project we had taken 6,000 photographs. It was necessary to compute the Shoran fixes for the plumb points of each photograph. The regular reduction process of the Shoran measurement to a set of Universal Transverse Mercator co-ordinates by calculating machine is a lengthy one. First the Shoran measurements are corrected for all instrument errors. In our case our equipment had three sources of instrument errors:

1. The delay discussed previously in this report.

2. The velocity of propogation of electromagnetic waves.

3. The frequency of the timing oscillator.

The delay correction is necessary because of the basic principles of the equipment. The Shoran measures distances as a function of the time required for a pulse of electromagnetic energy to travel a round trip path. Since the pulse of energy is delayed a constant amount in passing through the ground station equipment, a considerable error is introduced in the measurement unless the airborne timing circuits are set to consider this delay. We do not pre-set our airborne timing circuits; therefore a delay correction was necessary.

Velocity correction is required because the Shoran mileage counters are so calibrated that when the timing oscillator is tuned to 93109.5 cycles per second, the distance to each ground station is read directly in miles. This calibration of the airborne counters must assume a constant velocity of propagation of electro-magnetic waves. However, the speed of radio wave depends upon atmospheric conditions and actually varies from point to point along the ray path. For this reason a velocity correction must be made to each of the Shoran readings.

The pulse travel time is measured in the airborne unit by means of a timing oscillator. The equipment design is such that true path distance is recorded, when this oscillator frequency, in cycles per second, is equal to one half the velocity of electromagnetic propagation in miles per second. Electromagnetic wave velocity, which is equivalent to the speed of light, is 186,219 miles per second at sea level under standard atmospheric conditions. As Shoran measures the loop travel, it is convenient to use the loop velocity of

93,109.5 miles per second. Correct Shoran readings will be obtained when the airborne timing oscillator is adjusted to a frequency of 93,109.5 cycles per second. Timing oscillator frequency can differ from this reference value; therefore a correction is sometimes required.

After the calibration corrections and the correction for the variations in the velocity of propagation have been applied, the Shoran distance reading gives the true distance along the curved ray path between the airplane and the ground station. In order to reduce this corrected Shoran distance to ground distance at sea level, further corrections must be applied. These corrections are necessary because of the geometric relationship between the curvature of the earth, the altitudes of airborne and ground station above sea level, and the curved path of the Shoran ray.

After all these corrections have been applied we obtain map distances to the plumb points of our photographs from the reference Shoran stations. Finally, we convert these map distances to Universal Transverse Mercator co-ordinates by means of trigonometry.

This reduction process can advance only at the rate of twenty fixes per man per day. In our efforts to speed the process of data reduction, we investigated the possibility of adopting our problem to one of the present day high speed digital computers. We solved our problem using a card programmed electronic calculator. After all the information is prepared and punched in the cards, this calculator will solve our problems at the rate of 5000 fixes per hour. We feel that we have now a short cut for our computations.

In conclusion we feel our past summer's mission has been accomplished successfully. We believe our production can be increased and we look forward to producing the third dimension in photogrammetry. In the future we should be able to provide vertical control as well as horizontal control by electronic means. Meanwhile we will continue using Shoran for:

1. Horizontal control of aerial photographs over inaccessible terrain such as jungle, swamps, muskeg and mountains.

2. Quick and efficient mapping of large areas.

3. Flight-line navigation with large savings through reduction in photo overlap, avoidance of gaps in photos, and in compilation costs.

4. Long distance trilateration with a unit area cost far lower than those of conventional methods of control.

5. Combined trilateration and aerial photographic missions, thus making use of all possible flying weather.