photographic film. Despite the risk of breakage, and the difficulties of bending glass plates to match the curvature of focal planes in certain telescopes, the temperature coefficients and hydroscopic properties of a film base would add disadvantages that could not be outweighed. Presumably a suitable flexible base will soon be found that will replace glass, but until that time comes, I expect to find the terrestrial photogrammetrist meeting the astronomers at the crossroad where glass plates become a necessity as their own work approaches more and more to the precision requirements of astrometry. I hope that this rather brief review of our problems has helped to suggest some solutions to your own problems.

SHORAN FOR THE PHOTOGRAMMETRIST*

Archer M. Wilson, Chief, Shoran Section, Engineer Research and Development Laboratories

INTRODUCTION

THE most direct application of Shoran to the compilation of photogrammetric maps is its use in controlling aerial photography. The technique employed is somewhat analogous to the well-known transit intersection method except that a distance-measuring, rather than an angle-measuring, instrument is used. Positions are established by electronically measuring the distance from a photographic aircraft to each of two ground stations at the instant of exposure of the aerial camera (see Figure 1).

These "airline" distances must first be reduced to their corresponding ground lengths before the triangle can be solved to obtain horizontal position of the airplane. It is necessary, of course, to know the distance of the "base line" between the ground stations. Normally, this is accomplished by selecting ground sites near existing triangulation stations and making the necessary ties by a short transit and tape traverse.

It is this photogrammetric application of Shoran that has received attention at the Engineer Research and Development Laboratories under a project with which the writer has been connected. The general plan of research and over-all objectives of the investigation was supplied by the Chief of Engineers, and was designed to provide results that could be utilized in fulfilling requirements of the U. S. Army mapping plan.

The first and, in fact, the only test photography available to date, has been coverage that was flown in 1946 with Shoran equipment modified very little from the original bombing model. The accuracy attained on the tests was given in a paper presented by Mr. Lorenz at the 1946 Semi-annual Meeting of the Society in Dayton. To review these results briefly, it was found that the positions contained both a constant and a random error.

The constant error, which results in a shift of the finished map sheet with respect to the ground stations, was found to be less than 40 feet with careful calibration of the equipment. In addition, the individual positions were found to contain random errors of about ± 125 feet or less on 90 per cent of the points. However, when multiplex methods were used to "average out" these individual

* This paper has been cleared for publication by both the Office, Chief of Engineers and the Department of Defense. It was read at the Sixteenth Annual Meeting of the Society, Washington, D. C., January 12, 1950.

NOTE: Comments on this paper are invited. To ensure consideration for publication in the September issue, receipt before July 15 is necessary.

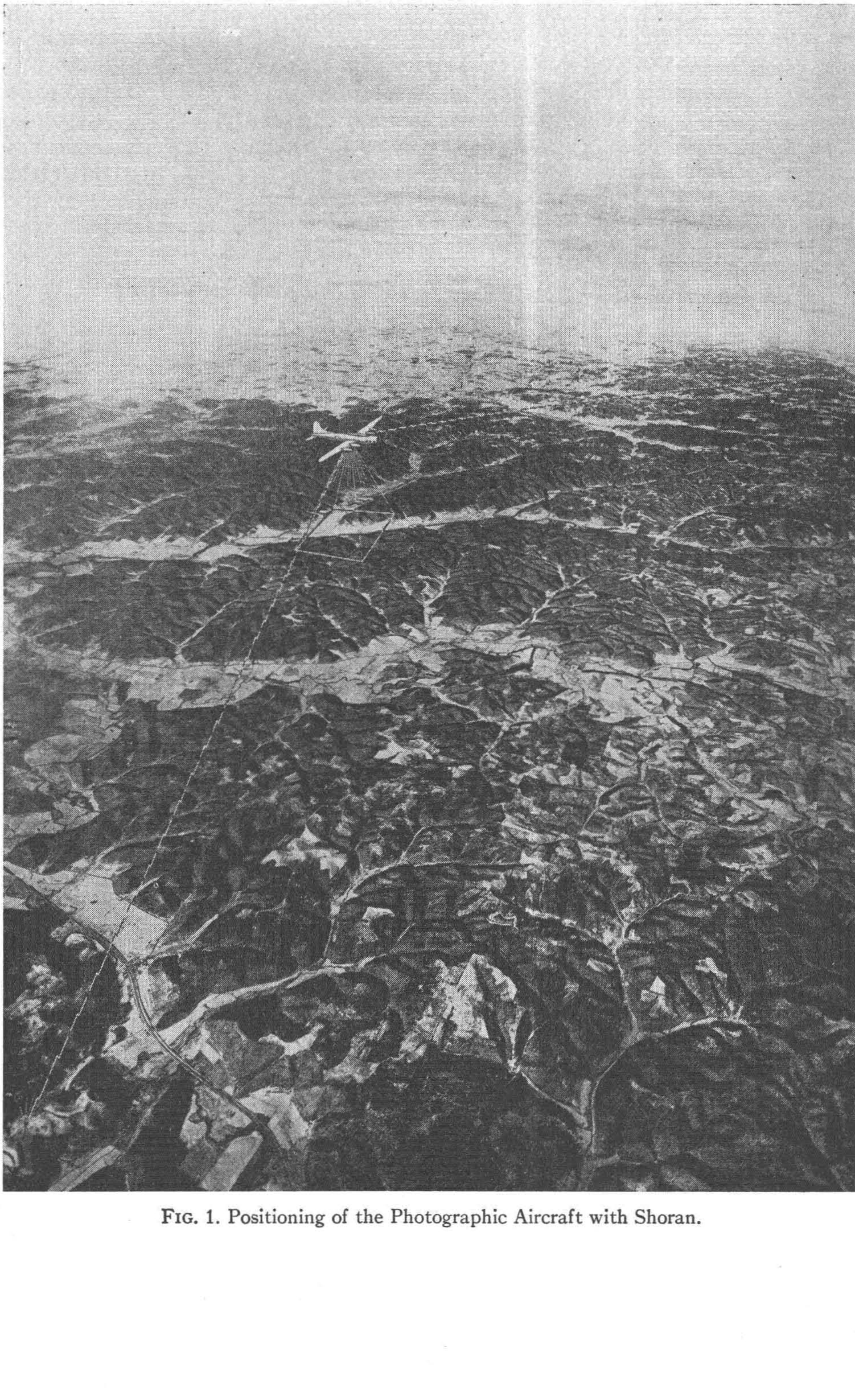

FIG. 1. Positioning of the Photographic Aircraft with Shoran.

errors, it was possible to compile maps with random errors of no more than 105 feet on 90 per cent of the well defined features, even with 20,000 foot photography. It should be remembered that these results were obtained with Shoran in 1946. There is little doubt that present day equipment will produce much better accuracy. Recent modifications to both the airborne and ground instruments make this almost certain.

The much-discussed Shoran line-crossing method, which is used to build up a triangulation network, is not a part of the ERDL investigation, though the work accomplished to date has been followed closely. Of major interest to the photogrammetrist, is the fact that points established by this method can then become controlling ground stations for Shoran photography. Furthermore, it has often been found that new computing methods, or other techniques, designed for Shoran triangulation can be applied directly, or with some slight modifications, to aerial photographic control. A third reason for following the line-crossing work is that it reveals the continuous improvement in the equipment, and thus provides a yardstick for use in predicting the accuracy to be expected from Shoran controlled photography.

STUDIES AT ERDL

After the accuracy tests had been completed at ERDL, and Shoran proved to be suitable for use, at least in some areas, our studies were directed toward the more practical objectives of developing procedures and auxiliary mapping instruments for adoption by Army operational units. Techniques were designed to vary from existing standard Army methods as little as possible, in order to minimize changes in tables of organization and equipment. Only time and experience will reveal the universality with which this type of electronic control can be employed, and the amount of specialized equipment that will be warranted.

TYPICAL SHORAN MAPPING PROBLEM

Perhaps the easiest way to summarize the development work, and to outline Shoran photogrammetric mapping as visualized by the Corps of Engineers, will be to select an imaginary area, and then briefly run through the various steps required in planning, computations, and compilation. Let us assume that we want 1:50,000 scale maps of four 30-minute quadrangles in a remote area. Photography is to be taken at 20,000 feet above mean ground elevation, for compilation by multiplex methods. The only existing horizontal control consists of an arc of triangulation running parallel to one edge of the area and about fifty miles away. Vertical control is limited to a few known elevations along a railroad which runs diagonally across the total area. An effort is to be made to delineate contours at intervals of 100 feet, though it is realized that they probably will not meet normal map accuracy requirements.

OFFICE PLANNING

Preliminary office planning by the photogrammetrist is done on the best available small scale of the area, usually a Strategic Map or Aeronautical Chart (Figure 2). The area to be covered is outlined, and all geodetic positions along the line of existing triangulation within about 200 miles are spotted for consideration as possible ground station sites. Our sample map covers only about 20 per cent of the area that can be controlled from a single pair of ground stations, and so we can limit our office study to selection of the one or two most likely pairs. A field verification of all likely sites will be required before final acceptance. Of

FIG. 2. Map Study.

first importance are the requirements that the aircraft always be within Shoran radio range, and that the "angle of cut" (that's the angle at the aircraft) from both ground stations is such as to give a strong geometric solution. With present equipment, this angle should be kept between the limits of 60 and 120 degrees. Both conditions can be verified with sufficient accuracy on a slide-rule, from approximate distances scaled from the map.

The map study also will indicate to some extent, the accessibility of the sites and the possibility of obtaining living accommodations and telephone service for the ground crews. Since installation of the ground equipment normally is an airborne operation, sites should be kept as near as possible to airfields. Still another consideration is to select points which will facilitate use of the airborne straight line indicator. This very important adjunct to the system has proved to be a valuable aid in supplying the mapper with regularly spaced, straight flight lines, devoid of gaps or excessive side laps. It operates best, however, when the Shoran base line roughly parallels the flight lines. It can be seen that careful office planning will pay good dividends during nearly all later operations.

Photographic specifications prepared by the mapping organization will be very similar to the usual type, but will incorporate provisions for specifying the needed Shoran data. A complete discussion of the calibration requirements, and many other details needed in the specifications, is beyond the scope of this paper, and is of interest only to those who are intimately connected with this phase of

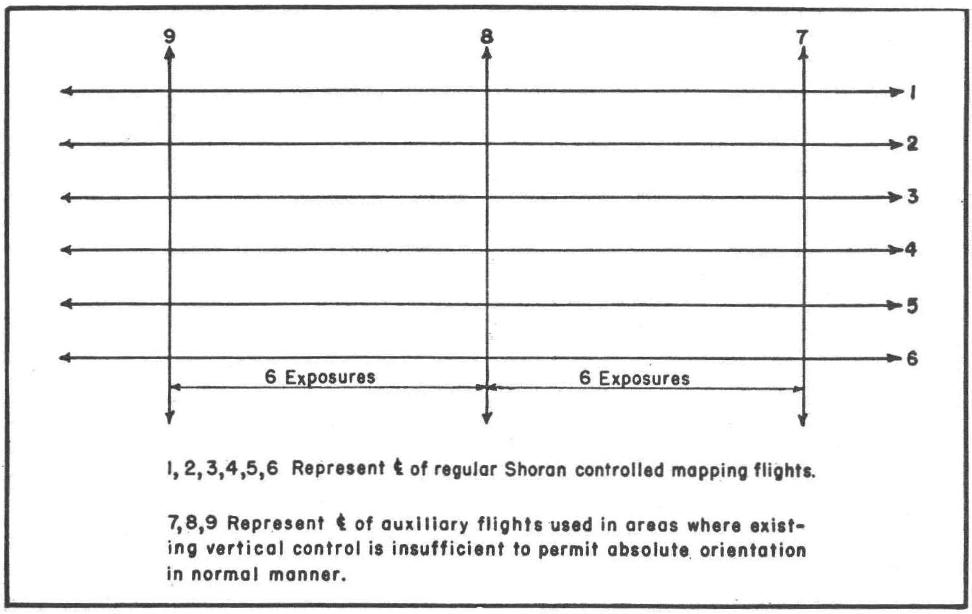

FIG. 3. Special Flight Plan for Areas of Limited Vertical Control.

the work. Mention should be made, however, of a special flight plan that will be utilized as an aid in recovering camera orientation during later multiplex operations (Figure 3). In addition to the normal type of coverage with parallel flights, we will require right-angle flights across the area, spaced at intervals of about each six exposures. This cross flight photography is not required in areas where there is sufficient vertical control to level the regular photography, but will be needed in our hypothetical example.

AIRBORNE OPERATIONS

With the submission of the specifications, the responsibility for successful execution of the photography rests with the aerial photographic unit. However, because of the newness of this type of control, it is believed that a liaison representative from the mapping organization should closely follow all later steps, commencing with the ground station reconnaissance (Figure 4) and carrying through until delivery of the photography. His duties will be varied, and will include such things as approval of the photography, authorizing changes in the flight plan, and giving assistance in assembling the necessary electronic and meteorological data. He also must be sure that exposures from all the airborne cameras have been properly correlated. Each photographic airplane, in addition to the aerial camera, carries a Shoran data recorder and an altimeter recorder. Since the exposure counters in these recorders are subject to mechanical failure, it is necessary to be constantly alert to possible errors from this source. In emergencies, recourse must be made to a comparison of the times registered on navigation watches, that appear in all exposures.

FIG. 4. Shoran Field Reconnaissance.

The airborne and ground operations involved in the execution of a successful Shoran mission is a story within itself and cannot be covered here. Nevertheless, it should be mentioned that, though exacting, procedures have been developed by the U. S. Air Force, and in particular the Second Air Force, that will practically guarantee acceptable results regardless of the area in which the equipment is put to work (Figures 5 and 6).

SHORAN COMPUTATIONS

As far as the photo-mapper is concerned, the next phase commences with receipt of the aerial photography and accompanying Shoran data. The preliminary work, as with any job, consists of examining the film, indexing and filing, and the preparation of photo indices. We can also start preparing diapositives, since multiplex compilation methods are to be employed. In the meantime, the computing team starts extracting all recorded information that will be needed in transforming from basic Shoran readings to usable map coordinates (Figure 7). Special computation forms have been designed for the entire operation, so as to permit utilization of personnel with a minimum of training.

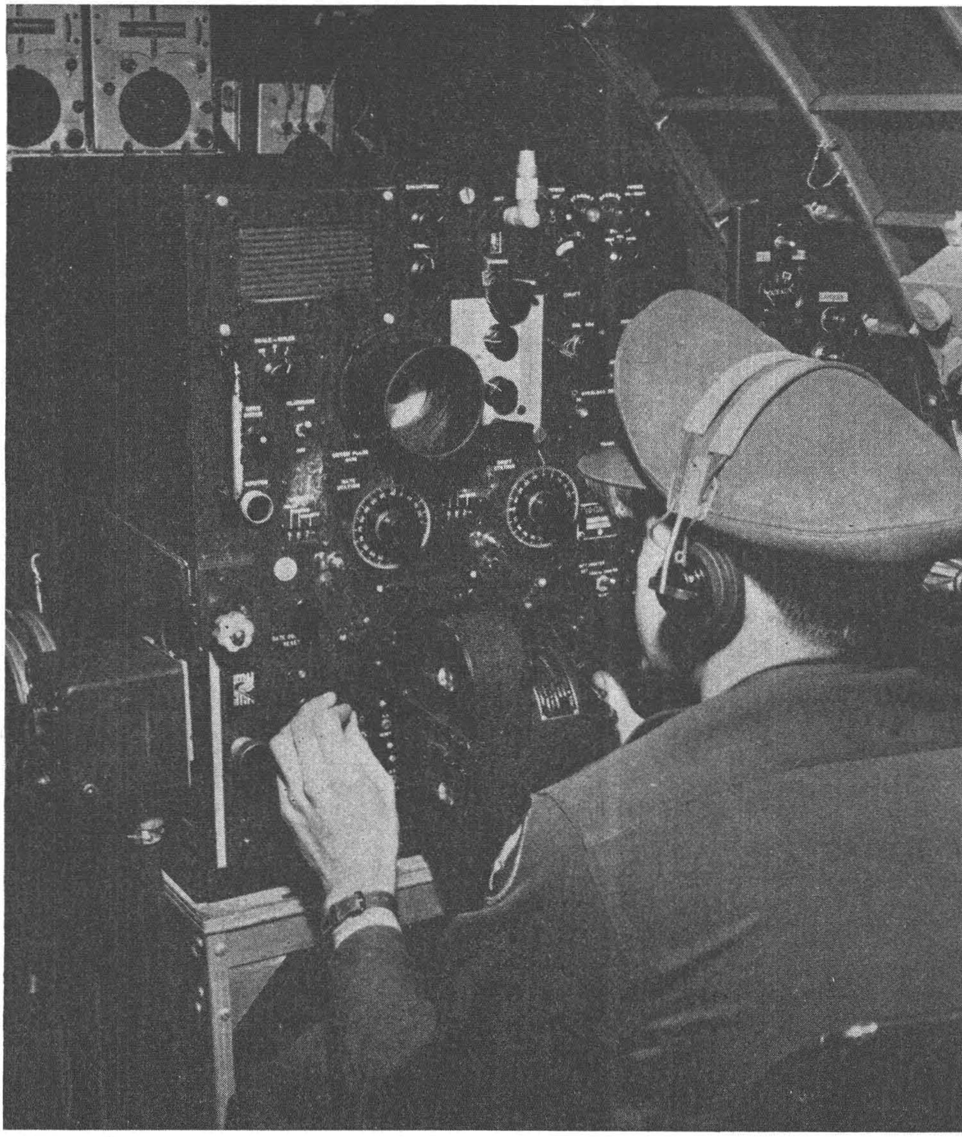

FIG. 5. Shoran Airborne Installation.

The first step will be to compute the correction needed to reduce each of the Shoran distances to its corresponding ground length. Since we probably have somewhat over 400 pictures, with each picture representing 2 measurements, this would be quite a job if each line were computed separately. Instead, the reductions from each of the ground stations are computed only for the even 5-mile intervals throughout the range of the mission, assuming that the aircraft flying height remained constant. These values can then be used to prepare a curve from which corrections for the individual readings are taken. It also is necessary to apply a small differential correction for any exposure that deviated from the assumed constant flying height by more than about 100 feet. After adding in any instrument errors that were determined during calibration, we obtain the ground distance to each base station and for each exposure.

The solution of the resulting triangles and subsequent point plotting is accomplished through a special grid based on a doubly-equidistant projection, tailored to the Shoran problem. The projection has the property that distances from any point within the map to either ground station are "true." Distances between other points are in error, but within the area covered by a single map sheet, they are inconsequential. The Shoran grid has its X-axis through the two ground stations, and uses the westernmost station as the origin of coordinates. As the projection creates a simple plane triangle, coordinates of each exposure

FIG. 6. Shoran Ground Station.

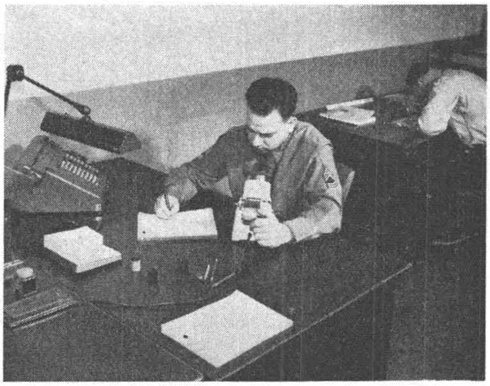

FIG. 7. Tabulation of Shoran Information.

can be computed at a rate of less than 2 minutes per point. This is only a fraction of the time that would be required to solve a spherical triangle for geographic coordinates.

MULTIPLEX OPERATIONS

Scaling of the multiplex models to the Shoran positions requires a few special procedures. It was previously noted that the Shoran points contain random errors of as much as 150 feet or more, and it is just as likely as not that two adjacent points might be in error in almost opposite directions. Thus, a relative error of as much as 300 feet could be introduced between a single pair of projectors. It becomes necessary, then, to scale a number of models as a unit to the best average fit of the control. Tests show that the best accuracy is obtained when strip units of about six models are used.

Another very important consideration in the multiplex scaling is to recover the camera orientation properly. A Shoran position represents the point directly beneath the aircraft. The corresponding position on the photograph is the nadir point, and any error in its proper recovery will be reflected as a horizontal error in the map. In our hypothetical photography from 20,000 feet, an error of 1 degree in tilt recovery would introduce a horizontal error of 350 feet. A tilt error of only 17 minutes causes a displacement of 100 feet. Unless we have a fairly reliable method for getting the models level, then, tilt errors may have a worse effect on map accuracy than does the Shoran error. It was this consideration for recovering camera orientation that governed our request for the addition of cross flights to the otherwise normal flight plan. Through their use, a multiplex procedure has been evolved which has been quite successful in establishing photo tilts. The method also provides for the addition to our map of contours, or at least form lines, since any level model plus the addition of a datum elevation is all that is needed.

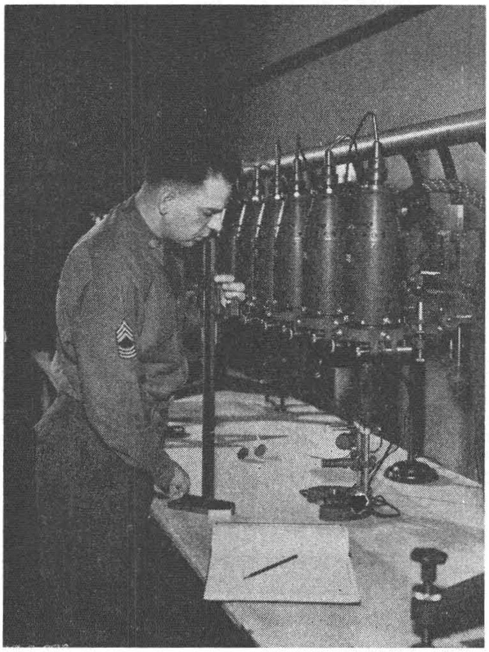

FIG. 8. Measuring Multiplex Projector Heights.

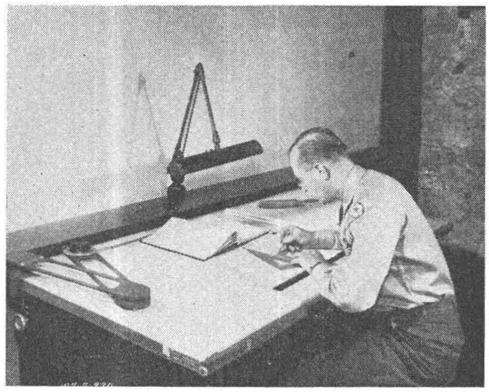

FIG. 9. Preparing Multiplex BZ Curve.

RELATIVE ELEVATIONS FROM CROSS FLIGHTS

Multiplex work is started by setting the cross flights first, and these are oriented in units of about 6 models. Great care must be exercised in establishing proper relative orientation. The terrain will often contain rivers, lakes or other features which can be relied upon for the first rough leveling of the strip. Scale accuracy, sufficient for the cross flights, is obtained by holding the principal point of each end projector to its corresponding Shoran position. Finally, the strip is carefully leveled in line of flight by assuming that difference in flying height as indicated on the altimeter is correct. In other words, if the altimeter shows the same reading for the exposure at both ends, the handwheels are adjusted until the end projectors are at the same height above the plotting table. Where the altimeter shows a difference in flying height, the end projectors are adjusted accordingly. In this orientation, we accept the strip leveling as being correct along the line of flight. Individual models, however, are still in error as a result of the fall-off, or "BZ curve" effect, that is characteristic of most stereoscopic extensions.

A BZ curve for the orientation is prepared by plotting the projector heights against distances along the center-line of the models (Figures 8 and 9). Elevations read at frequent intervals along the flight line then are corrected by an amount equal to the corresponding ordinate of the curve. Where the particular strip at hand includes one of the known elevation points along the railroad, all other elevations can be reduced to a sea level datum. Otherwise, the pass points provide relative heights only.

MULTIPLEX SCALING

The orientation of all the cross flights in a similar manner provides us with lines of relative elevations across the area, and spaced at intervals of about each six models. The regular parallel flight coverage is then oriented in the multiplex,

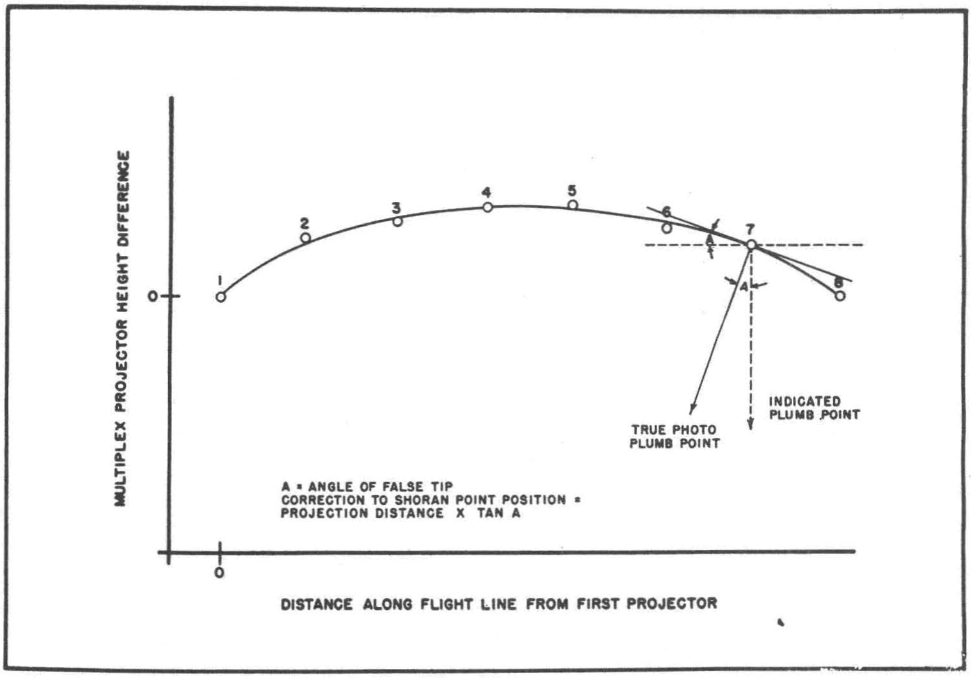

FIG. 10. "False Tip" Correction to Multiplex Nadir Points.

selecting strip units that permit bridging between our previously established lines of relative heights. Units now can be leveled in the flight direction by reference to the altimeter readings, and across the line of flight using the elevation differences of our pass points. Nadir points can be selected with confidence, and the entire unit scaled to the best mean fit of the Shoran positions. It should be noted that the true nadir point of the photo is not identical with the nadir point of the multiplex projector. Because of the fall-off effect in our strip extension, each projector contains a small amount of "false tip" which is equal to the slope of the BZ curve at the point where it passes through the projector in question. The necessary correction to the indicated nadir is obtained by multiplying the projector height by the tangent of the angle (Figure 10). When the unit has been completely oriented, enough pass points are selected so that it can be reset and the map detail drawn in.

Vertical pass-points in each model are selected at the same time as horizontal points, corrections for the BZ curve effect being taken into account as with the cross flights. A sea-level datum is picked up each time the models contain known elevations, and is carried back along the regular flights and cross flights until it reaches every model. Any written discussion of the BZ curve method appears rather involved, but actually the procedure is quite simple to apply in practice. Many of you undoubtedly applied the method to a great extent during the last war when map control was almost as much a luxury as fresh milk.

DETAIL COMPILATION

Multiplex compilation of the Shoran controlled map is no different from that of any other type. In some cases, the models will be drawn individually using sheets onto which the pass points have been traced. In other cases, the sheets used during the scaling operation will be supplied. Standard procedures also apply in all later steps of drafting and reproduction.

CONCLUSION

This discussion has attempted to outline Shoran photogrammetric mapping as envisioned at the Engineer Research and Development Laboratories. All procedures are tentative at this time since both the equipment and the mapping methods are still considered to be under development. Furthermore, as with any new tool, the techniques of application may need to undergo considerable revision, when they are integrated into the routine of an operating unit. This does not mean that we still have a long way to go. Shoran is in actual productive mapping use at the present time. Further development will only enhance its value to the geodesist and the photogrammetrist.

THE PLACE FOR VISION TESTING IN PHOTOGRAMMETRY*

M. H. Salzman, Photogrammetric Engineer,
U. S. Navy Hydrographic Office

AS a beginning of my discussion, attention is first called to the nine points on Figure 1. These nine points are clear and well defined. If asked to connect all nine points by drawing four straight lines without taking the pencil off the paper, and without retracing, how many of us could quickly find the correct solution? Take a minute, and try doing it.

Most of us, after several attempts, would wind up with a solution which would omit one point—an incorrect solution such as that on Figure 2.

In attempting to solve this problem, all of our inferences are confined to the nine points and to our instructions. If a deduction concerns the points, but does not conform to the instructions, it is rejected almost as soon as suggested. In other words, we have a mental set that pertains to the points and to the instructions. But, we may also have a set not involved in the instructions—that is, the set which makes us keep all our lines within the area encompassed by the points. As long as our thinking follows this direction we cannot solve this problem. Every inference will prove inadequate. But, if we think of the possibility that lines may go outside of the area within the points, we have the right direction. The solution may still be far off, but at least the inferences we make will be more

* Paper read at the Sixteenth Annual Meeting of the Society, Washington, D. C., January 12, 1950.