CONTROL EXTENSION BY PHOTOGRAMMETRIC METHODS

*Lewis A. Dickerson**

ABSTRACT

A résumé of photogrammetric control extension practice in the United States is given together with a brief description of the procedures for instrument work and adjustment of Multiplex and Stereoplanigraph aerial triangulation in use at the Army Map Service. Test results with control spacing of 35 miles and 6,200 ft. altitude photography show a horizontal mean square error of 16 feet and a vertical mean square error of 6 feet. With a vertical control spacing of 8 miles in the same test, the vertical mean square error was reduced to 1.8 feet. Examples of the application of aerial triangulation procedures in three mapping projects and data on costs are presented.

JOHN T. PENNINGTON

RÉSUMÉ OF UNITED STATES PRACTICE

IN COLLECTING information for this paper it was found, with one exception, that control extension by photogrammetric methods in the United States is largely confined to horizontal control. Many agencies and firms are making this use of photogrammetry. The methods used are the classic radial line methods, the slotted and mechanical templet versions of the radial line, and those stereoscopic instruments which provide a correct solution to the space problem, e.g., the Autograph, Multiplex, etc. However it was evident that the application to horizontal control has not been exploited to its full extent. It apparently has been found by the various offices that field survey work has been held down to reasonable amounts and that map accuracy requirements have been satisfied without investigating too fully the potentialities of photogrammetric methods. In some cases, other factors governing the location and amount of ground survey work have been present and these have lessened the demands on the photogrammetric methods. For example, a long and narrow route location project usually requires ground control throughout its length and may automatically result in horizontal control in every photograph. A further example is standard quadrangle mapping where National policy may dictate that ground survey markers be left on the ground at minimum intervals regardless of the needs of photogrammetric mapping methods.

In the matter of vertical control extension, practically no application of photogrammetric methods outside of the Army Map Service was found. One or two agencies stated that they would bridge two or three stereo models between vertical control upon occasion and when the areas involved were of little importance. It is suspected that others may also do this upon occasion when the going gets rough and when they expect no one to be checking in the areas involved. It is known that the U. S. Geological Survey has carried on some studies in connection with the extension of vertical control; these are still in the experimental stage and have not yet been applied in practice.

In both horizontal and vertical control extension it appears that the Army Map Service is making the largest application of photogrammetric methods in the United States. This perhaps results from the nature of the work where so many projects must be compiled from the scantiest of ground control. This

* This paper was presented at the Annual Meeting of the Canadian Institute of Surveying and Photogrammetry, Ottawa, Ontario, February 6–8, 1952. At that time the author was Chief, Photogrammetric Division, Army Map Service. He is now a consultant of surveying and mapping projects for Lockwood, Kessler & Bartlett, Inc.

resulted in the establishment of an aerial triangulation organization which is functionally devoted to this problem. With these facilities and the tremendous amount of work which it has handled, it was natural for the agency to carry on continual studies to improve the triangulation procedures. As these procedures and their application appear to be the farthest developed in the United States, it seems appropriate that the remainder of this paper be devoted to them.

Army Map Service Approach

No lengthy description will be given of the aerial triangulation procedures in use at the Army Map Service. These have been reported in considerable detail by Mr. Brandt, in a paper published in the December 1951 issue of PHOTOGRAMMETRIC ENGINEERING. A careful reading of this paper is recommended to those who wish to examine the matter in greater detail. In this paper will be given only a very brief résumé of the approach to the problem. This will be followed by some examples of the application of aerial triangulation on actual projects.

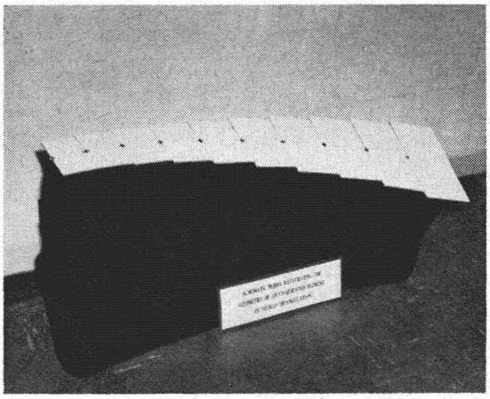

FIG. 1. Schematic model illustrating geometry of an unadjusted segment of stereo triangulation.

The aerial triangulation involves only the use of vertical aerial photography and the Multiplex and Stereoplanigraph instruments. With the instrument, the procedures followed are much the same as those used by others. The differences lay in the emphasis that A.M.S. places on a systematic method for achieving relative orientation between photographs in a strip and the relatively little emphasis it places upon the absolute orientation. It has been found that this approach produces a series of stereoscopic models which are systematically related, and any deformations which occur are accumulated in a systematic manner. During the instrumental phase there is more interest in having any deformations accumulate in this manner and in precisely recording the positions of points in the deformed models than there is in absolutely orienting the models to predetermined scales and elevations. Figure 1 serves to illustrate this approach. Suppose there is a strip of ten consecutive stereoscopic models formed by photographs taken over perfectly flat and level ground. When these photographs are oriented in the instrument it is found that the strip model takes on a deformed position as shown, of course greatly exaggerated here for illustration. The first phase of triangulation is completed when the instrumental space coordinates of points in the strip are measured and recorded. These measurements are made on all ground control points and on all photo points for which positions are desired, the

FIG. 2. Semi-graphical adjustment work.

identification of ground control points being examined, evaluated, and weighted at this stage.

The second phase of the triangulation procedure consists of the adjustment of the instrumental measurements, this work being performed after the instrument work is complete. The instrument values are adjusted in both the horizontal and vertical directions during this phase, the adjustment proceeding first with single strips and then with blocks of adjacent strips. Adjustments are based primarily on a comparison between instrumental measurements and surveyed coordinates for the ground control points, and on a knowledge of the general characteristics of deformations encountered in such work. This knowledge is the result of theory and experimentation. Adjustments may also be governed by such factors as comparison of measurements between overlapping models—both forward and side—differential shrinkage of the original aerial film negatives or recorded altitudes of aerial exposures. The adjustment methods are as varied as the projects encountered. In about all cases the adjustment is resolved to a semi-graphical approach that has been found well suited to the handling of large volumes of work. Figure 2 illustrates this approach.

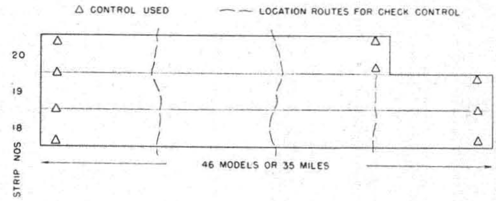

FIG. 3. Photography and control used for triangulation test for horizontal positions.

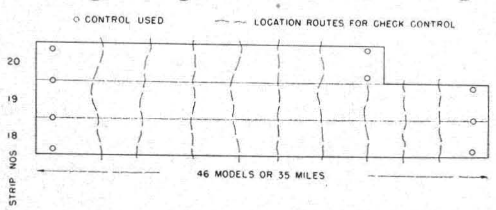

FIG. 4. Photography and control used for triangulation test for elevations—Control spacing at thirty-five miles.

TEST RESULTS

Briefly will be shown the results this triangulation approach has given on a test area. Figure 3 shows the test area, horizontal ground control used, and the location of horizontal control used for checking results. The flight height of the photography was 6,200 feet; the long dimension of the area was about 35 miles and required 46 stereoscopic models to span it. Horizontal errors in the aerial triangulation were checked on 25 horizontal control points well distributed along the routes indicated. With Stereoplanigraph triangulation, the mean square error, determined from these 25 check points, was 11 feet with a maximum error of 16 feet.

This same area and photography were also used to test Stereoplanigraph aerial triangulation for establishing elevations. The vertical ground control used and the location of elevation check points were as shown on Figure 4. By checking elevation errors on 248 points well distributed along the routes indicated, a mean square error of 6 feet was found with the maximum error of 11 feet. When vertical ground control was introduced at about 8-mile intervals along the strips of photographs as shown in Figure 5 and when errors were determined for 218 points distributed along the routes indicated, a mean square error of 1.8 feet and a maximum error of 3.8 feet were deter-

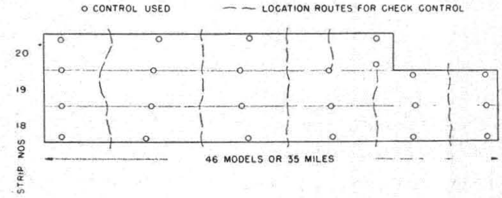

FIG. 5. Photography and control used for triangulation test for elevations—Control spacing at eight miles.

mined. The significant progress that these results indicate should be readily apparent.

SOME PROJECT EXAMPLES

There will now be discussed three actual projects and what the application of these aerial triangulation procedures means in ground control requirements. The first of these is a project known as Pikes Peak and located in the extremely rugged Rocky Mountain area of Colorado. It is a small project embracing only a 15 minute quadrangle of approximately 250 square miles and is illustrated in Figure 6. The mapping is for publication at a scale of 1:25,000 with contours at 20 feet. The maps must comply with the National Standards of accuracy

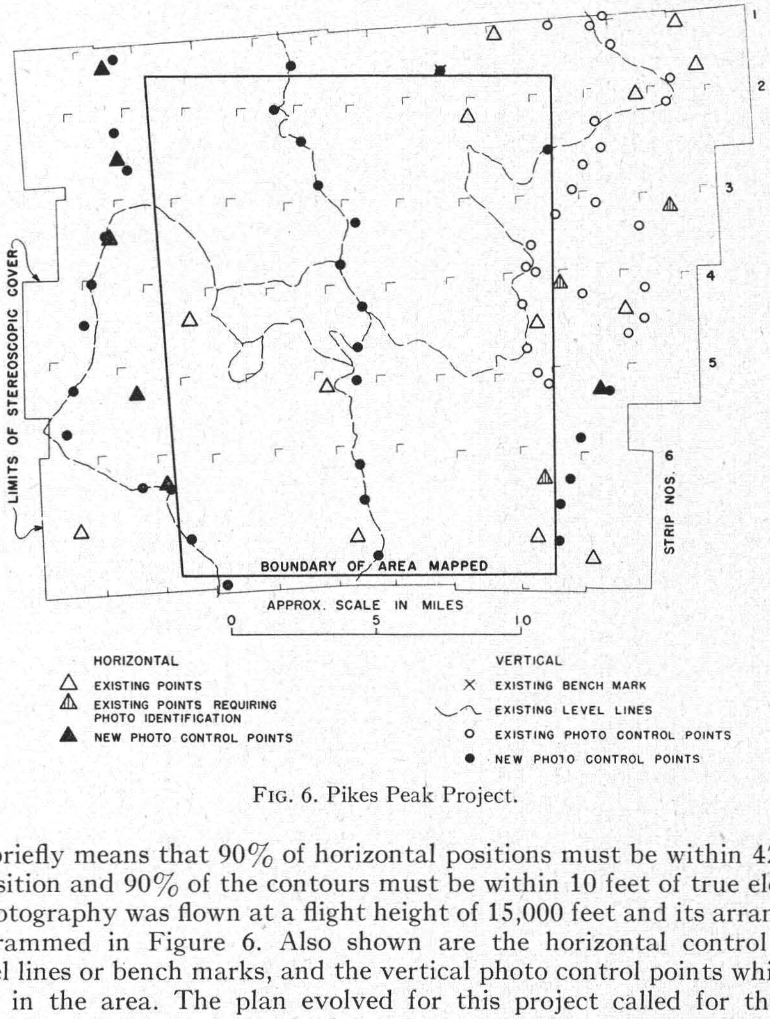

FIG. 6. Pikes Peak Project.

which briefly means that 90% of horizontal positions must be within 42 feet of true position and 90% of the contours must be within 10 feet of true elevation. The photography was flown at a flight height of 15,000 feet and its arrangement is diagrammed in Figure 6. Also shown are the horizontal control points, the level lines or bench marks, and the vertical photo control points which were already in the area. The plan evolved for this project called for the photo identification of three existing horizontal control points, the establishment of six new horizontal photo control points and 31 new vertical photo control points in the positions indicated. It is evident that with such a spacing, much latitude existed so that these points could be placed in the most readily accessible areas for ground survey work. The aerial triangulation for the project has been completed by Stereoplanigraph and map compilation is now underway by Multiplex.

The second of the projects is the Ft. Sam Houston project which best illustrates the savings that can be achieved in survey work for horizontal control. It is located at San Antonio, Texas and involves relatively low relief ranging up to about 400 feet. The area to be mapped is a 30 minute quadrangle, approximately 1,000 square miles. The mapping scale is 1:25,000 with contours at 10 feet. The National Standard accuracy requirements govern the mapping which again mean 90% within 42 feet horizontally and 90% within 5 feet vertically. Figure 7 shows the area, the existing horizontal control, in and about the area, and the arrangement of photography which was flown at a flight height of 9,000 feet. In this case, seven of the existing horizontal control points were either paneled on the ground prior to photography to make them positively

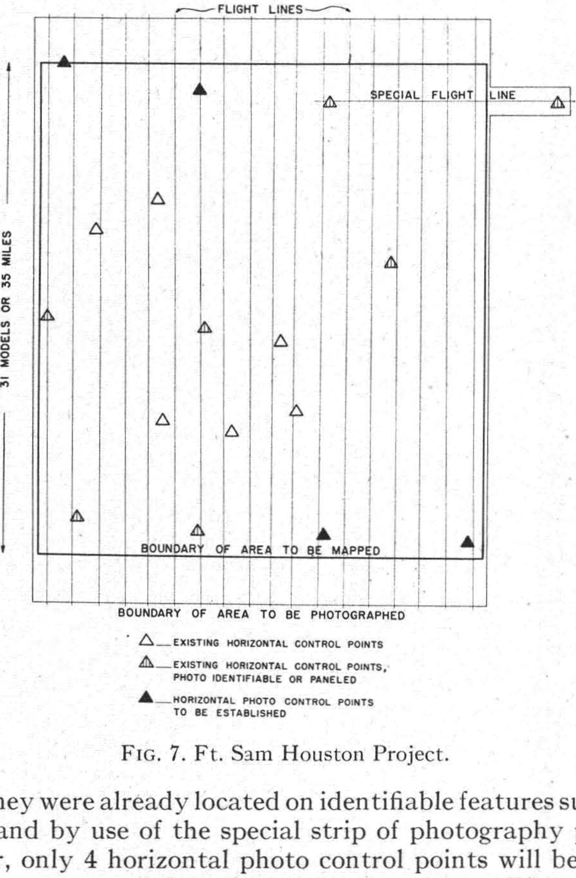

FIG. 7. Ft. Sam Houston Project.

identifiable, or they were already located on identifiable features such as tanks. By this procedure, and by use of the special strip of photography provided in the northeast corner, only 4 horizontal photo control points will be required to be established by new survey work in the indicated positions. The photography has been completed and the control phase will get underway shortly. The detailed vertical control plan has not been prepared but will present no great problem. Vertical control will be arranged along lines crossing the strips of photographs at intervals of about 5 models or 5.6 miles. The lines will be adjusted to the most easily traversed routes and this will provide quite easy going in this area. The aerial triangulation will be performed with the Stereoplanigraph and compilation of most of the area will be with the same instrument. The Multiplex may be utilized for the more rugged portions.

The third project example involves a portion of an area in Alaska. The photography was flown at a flight height of 20,000 feet and as illustrated in

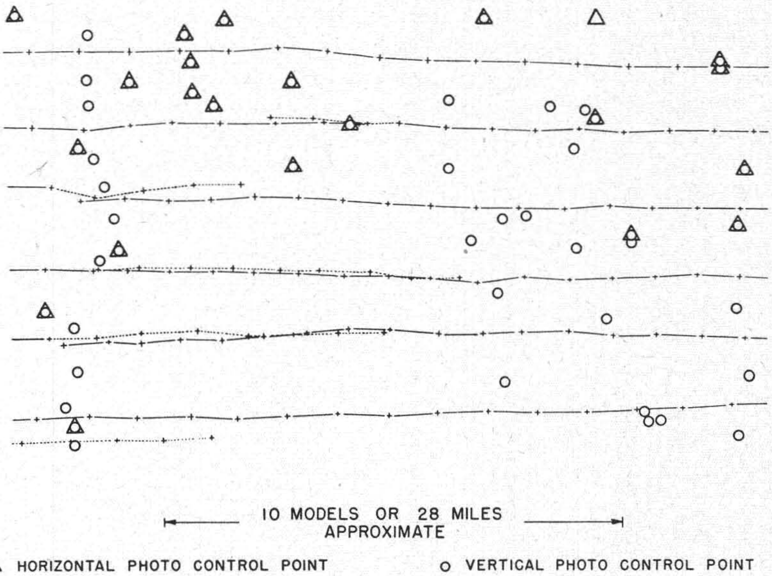

FIG. 8. Portion of Alaskan Project.

Figure 8, which also indicates the amount and distribution of the horizontal and vertical control that is being used. Although a small amount of control previously existed in the area, most of that shown was established especially for this project. The planning for this control was done some two years ago and was based only partially on the capabilities of aerial triangulation as now known.

The mapping requirement for this Alaskan area calls for a scale of 1:50,000 with contours at 50 feet. Somewhat flexible standards of mapping accuracy were established based upon an intent to conform to the National Standards. Where the remoteness of the area and the difficulties of survey work indicate, it has been recognized that these standards can be relaxed somewhat. The standards call for a horizontal accuracy of 90% within 84 feet and a vertical accuracy of 90% within 25 feet. The aerial triangulation in the area illustrated has been completed by Stereoplanigraph and the results indicate accuracy well within the requirements. As determined from the consistency in fitting to ground control and in the comparisons of elevations and positions established independently from side lapping strips, it is estimated that the triangulated horizontal positions will be accurate within 40 feet and the elevations within 10 feet, in the area illustrated. Compilation now underway in this area with the Multiplex equipment is meeting with no difficulty in complying with the National Standards of mapping when using this aerial triangulated control.

COST OF AERIAL TRIANGULATION

Information on the cost for this aerial triangulation will likely be desired. From experience gained over a large number of projects triangulated for both horizontal and vertical positions, it has been found that the direct labor cost, including direct supervision, varies from 3 to 5 man-hours per stereo model. The average is about 4 man-hours, of which about 2.5 hours is consumed in the instrument work and 1.5 hours in the adjustment. The biggest factor causing variation in the costs is the amount of ground control which is used. More time is consumed where many control points are used and hence must be measured, plotted, evaluated, and considered in the adjustment. Little variation in cost is encountered due to other factors including the type of photogrammetric equipment used. To relate the cost to square miles on any project, one needs only to divide by the area of a stereo model for the project. For example, on the sample Alaskan project, the cost is about .45 man-hour per square mile of area triangulated.

Conclusion

In spite of some significant progress, much remains to be done to speed the mapping of our vast unmapped areas at a minimum cost. Your Canadian problem in this respect seems to be even greater than that in the United States. Your solutions to this problem will be examined thoroughly for possible application in the United States.

NEWS NOTES

QUICK COPIER FOR OFFICE USE ANNOUNCED BY EASTMAN KODAK

This new office machine—the Verifax Printer for the rapid reproduction of letter-size papers, is said to be unique in that three or even more copies, costing less than 5 cents apiece, can be made from a single matrix sheet. These copies are same-size, black-on-white duplicates of the original and are immediately ready for use. One photo-exact copy can be obtained in about 50 seconds, and three copies in 60 seconds. Copies are long-lasting, have good legibility, can be referred to, written on, mailed, or filed as desired and can be produced in any office under ordinary illumination. The only service connection is a 110V outlet.

Copies can be made from practically any typed, written, drawn, or printed original through the $8\frac{1}{2}\times 11$ inch size, including pages printed on both sides. They may be produced by anyone with only a few minutes instruction.

The supply of Verifax Printers will be limited at the outset. During the forthcoming months, the company expects to be able to meet demand.

The Verifax Printer utilizes the familiar "reflex printing" method. The sensitized matrix is first placed on top of the lamp bank built into the top of the printer. The letter or document to be copied rests face down, on top of the matrix. Exposure is controlled by an electric timer build into the unit. After exposure, the matrix is slipped into an activator solution in the bottom of the unit. This simple single-solution is easily mixed and in general office operations, lasts a week. The matrix paper is left in the activator for twenty seconds. As the matrix is withdrawn, it is pulled under a roller in contact with a sheet of Verifax Print Paper. This paper is not sensitized. After the two sheets are withdrawn from the printer, they are stripped apart, and a copy of the original document is ready to use. Extra copies of the document may be made as rapidly as the matrix can be re-inserted in the activator and withdrawn in contact with another sheet of Verifax Print Paper. Copies from the matrix can often be made on regular paper or blank office forms instead of Verifax Print Paper. Whenever more copies are needed than come from one matrix, extra copies may readily be produced by repeating the procedure with a new matrix sheet.

The Verifax method greatly reduces the amount of copying normally done by hand typewriter. Savings also accrue by the elimination of copy-reading and checking normally associated with hand copying.

The price of the Verifax Printer will be $240 list. For information, contact the Industrial Sales Division, Eastman Kodak Company, 343 State Street, Rochester 4, New York.

MOVED . . . LOCK, STOCK AND BARREL

On March 1, Henry Wild Surveying Instruments Supply Co. of America, Inc. announced the removal of its executive offices, sales department and repair facilities to its new and expanded quarters at Main and Covert Streets in Port Washington, N. Y. This transfer of location to its own modern, air conditioned building will afford better service in sales and enlarged repair facilities by its factory trained specialists.