semi-skilled personnel to produce stereo-compilation to a close approximation of the accuracy of the original instrument that projected the absolutely oriented model.

Consideration is also being given to the procurement of instrument projector lenses which have a minimum depth of focus, since this requirement, which exists in plotting equipment, is not applicable to the projection of the stereo model onto a plane. Freeing the lens designer of this restriction would enable him to concentrate on the attainment of other desirable lens characteristics, such as resolution and reduction of illumination fall-off.

Conclusion

These preliminary investigations indicate that the photogrammetric anaglyph in both resolution and vertical accuracy, approaches the instrument used to project the original stereo-model. It is believed then, that any increase of these qualities in the projecting instrument will also be reflected in the anaglyph.

In the process of exploring the potentials of the photogrammetric anaglyph, we have run into problems, and undoubtedly there will be many more which we do not even foresee at this time. It has been said that if only the problems of a certain situation are considered, no progress will ever be made. So exploration will be continued. A preliminary comparison of the anticipated problems against the potential advantages indicates the feasibility of the turtle sticking its neck out in order to move forward.

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*How Aerotriangulation Can Reduce Ground Control Costs**

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ABSTRACT: *The practical application of modern aerotriangulation methods by a professional user is discussed. The considerations of planning the project with available equipment, the accuracies involved, and a comparison of costs between methods is undertaken. An actual project is used to present the problems involved and the solutions obtained. The saving in time and money by use of carefully planned aerotriangulation is illustrated.*

AEROTRIANGULATION, or photogrammetric bridging, has been employed for a number of years to reduce ground surveying costs in connection with establishing ground control for high-order accuracy aerial mapping. Yet surprisingly little has ever been published on the subject from the viewpoint of the practicing professional user of the technique. Aspects such as project procedures, balancing the accuracy of photogrammetric equipment with the needs of the specific assignment, and, most important of all, *cost*, have hardly ever been discussed in public.

It is time that the mantle of secrecy, veil-

* Paper presented at the Fall Technical Meeting of the Ohio Region of the American Society of Photogrammetry, held in Columbus, Ohio, October 10, 1958.

ing this valuable tool be shed. Perhaps the actual job experiences cited in this paper will encourage more public exchange of information.

In the highway engineering field, perhaps the most valuable source of data in route location is the 1 inch = 200 feet topographic map with 5 foot contours, accurate to within a contour interval. Today, probably a large majority of such maps are compiled from aerial photography exposed at 1 inch = 1,000 feet. The stereoplotters used to compile these maps require for ground-control, to align the stereo models, a minimum of two known horizontal points and three known vertical points for each stereo pair of photographs in the flight strip.

The problem confronting my firm recently was how best to obtain this ground control for a 90 mile section of the Keystone Shortway, an authorized Interstate Route in Western Pennsylvania. We had been engaged by a consulting engineer to perform an engineering location study.

For comparison's sake, we calculated the cost of establishing ground control by the usual ground-survey techniques of traverse and leveling. The accuracy for this type of survey is usually no better than plus or minus 4 feet, horizontally, and plus or minus 1 foot vertically.

As a rule, a horizontal traversing crew can cover approximately $2\frac{1}{2}$ miles a day while the level crew may cover 5 miles. A survey of the project in question would require 103 horizontal-control miles and 207 vertical-control miles to properly control 212 photographs at 1 inch = 1,000 feet. Assuming surveying costs at a rate of $60 per mile, the cost of the ground work would amount to about $18,600.

Next we calculated the cost of obtaining ground-control by aerotriangulation using the 1 inch = 1,000 feet photography. We employ a Wild A-7 Universal Plotter to accomplish this extension of control points through stereo-pairs in a flight strip. Due to inherent machine errors, we normally do not attempt to bridge more than 16 model intervals. Since the aerotriangulation technique requires known points in the middle of a flight strip to serve as a check, we require known points every 8 model intervals. Thus, aerotriangulation 1 inch = 1,000 feet photography of the 90 mile section would still require 81 horizontal control miles and 108 vertical control miles of ground surveying, assuming the availability of suitable U.S.G.S. and U.S.C. and G.S. data.

Based on the rate of $60 per mile, this ground survey would have cost about $11,000 The aerotriangulation itself would have required another $7,400.

About the only benefit of photogrammetric bridging, using the compilation photography, would have been the time saved.

The technical justification for high-level photography for control is derived from a comparison of the accuracy of the A-7 used for aerotriangulation, with that of the Kelsh plotter used in compilation.

Basically, the A-7 is $1\frac{1}{2}$ times more accurate than the Kelsh. But aerotriangulation involves reading spot elevations, which are about twice as accurate as plotted contour lines. Thus, the A-7 with sufficient accuracy should be able to bridge from photography at twice the compilation photography scale.

The Kelsh plotter's contour interval ability, using 1 inch = 1,000 feet photography, is no greater than $\pm 2\frac{1}{2}$ feet. Its horizontal accuracy at 1 inch = 200 feet mapping scale is 0.015 to 0.02 inches, or 3 to 4 feet at ground scale.

Using 1 inch = 2,000 feet photography, the machine scale of the A-7 is 1 inch = 833 feet. Its horizontal accuracy of 0.1 mm. represents 3.2 feet on the ground. The vertical accuracy at this scale is 3.3 feet. These values are very close to standard accuracy for 1 inch = 200 feet.

The 1 inch = 2,000 feet photography used on the Keystone Shortway job took in a number of very helpful government control points that were not available in the narrower band of compilation photography. The big advantage, of course, is that much less ground surveying is required since fewer models had to be bridged.

Since there were 72 exposures, known points had to be obtained by ground surveying in only 10 areas, or at an interval of eight models. This new control was supplemented by at least two U.S.G.S. or U.S.C. and G.S. points that appeared in the photography in every 10 model interval.

Ground surveying amounted to $5,500, while aerotriangulation with the A-7, at $35 per model, cost $2,520. This totals $8,020, as against the $18,600 required to establish conventional ground-control.

We were fortunate in being able to obtain several checks on the accuracy of the 1 inch = 200 feet topo maps subsequently produced by the Kelsh plotter.

One of the best checks occurred when the highway alignment selected from the 1 inch = 200 feet maps was staked in the field prior to starting final design. A profile of the eastbound half of the highway was run on the ground by the client's field crew, plotted, and then compared with the plotted profile from the 1 inch = 200 feet map. The maximum discrepancy between the two sets of data was 4 feet, while 90% of the compared points differed by less than 1 foot.

A similar check was made on the horizontal scale of the 1 inch = 200 feet map when the field crew staking the line referenced their line to certain building corners which appeared in the mapping. No discrepancies, within the limitation of scaling, were found by comparing these chained distances with values scaled from the 1 inch = 200 feet map.

A third check was made when the terrain data for roadway cross sections were read from 1 inch = 250 feet photography in the Kelsh plotter. A ground profile for the westbound lanes was obtained. This profile was compared with that obtained from the 1 inch = 200 feet mapping with resulting accuracies comparable to those of aforementioned field check on the eastbound lanes.

For the benefit of those who have not had the experience of using the A-7, I shall run through the operational procedures. The instrument is first set to the calibrated focal-length of the camera. Optical arrangements are provided in the instrument so that the operator will always see the stereo-model in its proper orientation. A convenient "base distance" is set in the instrument so that the stereo-model scale will be two to three times the photo scale.

The process of relative orientation is then carried out by one of the usual methods. There are formulas based on measured y parallaxes for numerical relative orientations. However, we used the empirical method which is faster and is believed by many operators to be just as accurate. Whatever method is employed, the A-7 operation should be done with extreme care.

After relatively orienting the initial model, it is absolutely oriented to scale and elevation.

For the 1 inch = 2,000 feet photography we assumed a machine scale of 1 inch = 833 feet. We then adjusted the base using the known ground distance between two points. This is very easy using the machine x and y counters, first converting the ground distance to millimeters at the machine scale. At the completion of scaling, leveling is performed. This we accomplish by using four known points. In general three points are sufficient, but I believe that for the little extra field costs, obtaining a fourth point is a wise move.

Having absolutely oriented the first pair, we now set our counters. The setting of these gives an imaginary grid system to the series of plates to be triangulated. The counter supplied with the Wild A-7 gives complete freedom of movement and therefore can be set at pre-determined readings. The z counter was set during the absolute orientation and requires no special consideration during the x and y set-up stage.

The work of triangulating from this point on runs fairly smoothly. The optical mechanical arrangement, called the "Zeiss-Parallelogram," permits formation of the second pair with the "base-out" setting of the instrument. The relative orientation of the second model is than accomplished by a single projector relative orientation. This model is scaled by returning to the pass point near the principal point of photo number 2. The x motion is adjusted until the reading coincides with the reading in the previous model. The counters are then adjusted, tying the first model to the second. In this manner the operator passes through the entire strip of photographs alternating "base in" and "base out."

At the conclusion of the machine work, the co-ordinates are recorded in list form and punched out on regular I.B.M. electronic computer cards.

As yet our horizontal transformation is linear. The linear equation is

$$X(g \cdot c \cdot) = ax + by + C,$$

and

$$Y(g \cdot c \cdot) = -bx + ay + C_2.$$

Once the passpoints have been transformed from machine values to ground values, we endeavor to increase the accuracy by adjusting graphically errors created by the by curve. Because of the initial transformation, this graphical adjustment takes very little time.

The vertical transformation presents a different problem. The influence of systematic and unsystematic errors force using an equation of a much higher order. The general formula used for this transformation is a third order polynomial

$$Z - z = ax + by + cz + dxy + ex^2y + fx^2 + gxz + hx^3 + K$$

(constant). In some cases one or more of the terms need not be used. The terms are generally not used in cases of short strips or level terrain.

The vertical transformation adjustment, which makes use of a general least squares curve fitting routine, should be accomplished on an electronic computer. The control point data are first read in and the co-efficients of the polynomial are determined using the curve fitting program. The pass-points are then read in and the adjustment for the elevations computed. Generally the control points are included with the pass-points in order to compare the computed elevations with the given data.

As a check on the electronic computer output, we utilize an automatic line plotter that operates directly from the output cards of the computer. The line plotter constructs the Z-z values in respect to a "zero datum" of the x distance. As the points are being plotted the operator numbers each point. A parabola is then constructed using a spline. This determines a point or points which might appear to be out of balance with other points in the strip.

In summary, in producing the Keystone Shortway topo maps, the use of aerotriangulation to extend ground-control to all stereo pairs of the compilation photography proved to be as accurate as conventional ground surveying methods of establishing control, and much faster and less costly.

*A Photogrammetric Cadastral Survey in Utah**

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ABSTRACT: *The rugged topography of lands remaining to be surveyed and the difficulty of access increases the need for finding methods to cut costs of making cadastral surveys. The Bureau of Land Management has completed the survey described in this paper, using a combination of field and stereophotogrammetric methods. Original surveys were made covering ten townships. Five of these had been surveyed by conventional methods the year before. The comparison of positions obtained independently was used in appraising the reliability of the new procedure and as a criterion in the acceptance of the work on the other five. Attempt was made to take maximum advantage of maps, photography, and control done by other Government agencies.*

IN THE spring of 1957, the Bureau of Land Management decided to carry out an experiment in the use of photogrammetry for cadastral surveys. The primary purpose was to determine the specifications for photogrammetric procedures necessary to make original cadastral surveys within the degree of accuracy required by the Bureau of Land Management in extending the rectangular system of surveys over the public lands.

It is evident that with low-level photography and numerous control points, a high degree of accuracy can be obtained in the identification and determination of points on the ground. This was proved by the work done in the Tahoe test area of California by the U. S. Forest Service, with the Bureau of Land management assisting.[1] Careful position checks were made by parties of the U. S. Coast and Geodetic Survey. However, the problem was to determine whether the accuracy required in extending the rectangular network could be obtained by 1:20,000 photography and, if not, what scale of photography would be required. Also, the Bureau wished to know how the cost would compare with cadastral surveys made by ground methods, and whether manpower and time would be reduced in completing an assignment. Such a saving is especially critical at this time as the Alaska Statehood Bill provides for survey by the

[1] PHOTOGRAMMETRIC ENGINEERING, XXIII, 3, 493.

* Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C. March 8 to 11, 1959.