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Bridging with Independent Horizontal Control

Analytical aerial triangulation performed with distances and azimuths proved to be less costly than that performed with conventional ground control.

Abstract: *The concept of using distances and azimuths to control aerial triangulation has been long established, but examples of practical implementation in commercial mapping have not been widely publicized. The underlying principles of one method of bridging with independent horizontal control are described. A block of four sidelapping flight lines containing 67 photographs at a scale of 1 in. = 500 ft was initially controlled for and bridged by conventional aerial triangulation procedures. The same project also was controlled and bridged according to the method of independent horizontal control. Comparison of coordinates of passpoints from the two methods of bridging showed rms differences of 0.58 and 0.60 ft in* X *and* Y, *reflecting good relative accuracy. Overall savings in producing mapping control amounted to 33 percent when the method of independent horizontal control was used as an alternate to the conventional method. Greater savings are anticipated for other projects.*

Introduction

Justification for Independent Horizontal Control

Traditionally, aerial triangulation as practiced in the commercial mapping community is controlled by horizontal and vertical control points. In the case of horizontal control points, these are most often established by traverse surveys. In mapping projects, where permanent ground surveys are not required, such traverse work is merely an expense item relative to producing the maps. That is, results of the field work are not generally reusable. When the field effort is viewed in this way one must necessarily ask whether this cost can be reduced but yet allow production of the maps in accordance with the project specifications. In many cases the answer to this question is a definite yes, and a means by which this may be accomplished is by utilizing independent horizontal control instead of traverse control.

The Basic Concept

Horizontal control for aerial triangulation and mapping simply serves three fundamental purposes:

- to provide scale,
- to provide azimuth orientation, and

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- to provide absolute reference to some adopted X-Y coordinate system.

Note that none of these dictate that X-Y horizontal control points are an absolute necessity. For example, scale can be provided simply by surveying horizontal distances between a few pairs of points scattered throughout the project. Azimuth orientation can be provided by astronomic observations of azimuth over lines between the same or separate pairs of points. Absolute reference may be established simply by assigning assumed coordinates to one point, in which case the coordinate system is a local or arbitrary one. Alternately, one or more *existing* points of known position in, say, a state plane coordinate system may be used. Thus, all of the fundamental functions of horizontal control may be satisfied by new surveys which do not establish positions of control points. Moreover, the only necessity for intervisibility is along lines over which distances and/or azimuths are observed. Since these lines need only be scattered throughout the project, they are totally independent of one another, that is, not tied together as in a traverse or triangulation network. Hence, the designation "independent horizontal control."

It is well to make clear that the concept of independent horizontal control does not originate with the authors. In fact, the technique has heretofore been described in the literature by others (e.g., Brandenberger, 1959; Colcord, 1961; Ghosh, 1962; and Wong, 1972). Also, the method has been used on some commercial mapping projects over the past several years, but these applications have not been widely publicized. Moreover, to the knowledge of the authors, there have never been documented studies of the accuracy and cost-effectiveness of the method based upon production experience.

COMPUTATIONAL METHODS

There are two basic methods for incorporating independent horizontal control into the aerial triangulation. The most rigorous method is to introduce such data directly into the aerial triangulation adjustment, such as described by Wong (1972). This is done by introducing condition equations which mathematically impose additional constraints within which the adjustment must be solved. As an example, an equation may be set up which states that the computed coordinates of a pair of passpoints must be such that the inversed distance agrees with the surveyed distance (in the least squares sense). Likewise, an equation can be set up to express that a calculated azimuth must agree with the surveyed value. Other condition equations may be set up, including the very basic one that the computed coordinates of a point must agree with known X-Y values. This particular equation, however, is not unique to the method of independent horizontal control; it is a basic equation of all aerial triangulation adjustments.

The second method is to impose the independent horizontal control condition equations in a separate adjustment computation. This adjustment would be preceded by a normal aerial triangulation computation, but one which employs only two X-Y horizontal control points or approximated X-Y horizontal control points. Results of this aerial triangulation are, of course, only provisional and will be "warped" to some extent. The function of the second adjustment, then, is to remove these deformations by using the independent horizontal control data. This two-step approach is the one employed by the authors.

MATHEMATICAL FORMULATION

In the two-step approach to the use of independent horizontal control, the first step (i.e., aerial triangulation) is not affected in any way programming-wise. There is only a minor procedural difference owing to the sparse and/or approximated X-Y horizontal control used in the aerial triangulation computations. Hence, it is necessary to consider only the mathematical nature of the second step wherein the independent horizontal control are used to "readjust" results of the first step.

BASIC MATH MODEL

It is a basic assumption that the result of the first step is systematically warped such that the deformations are representable by the conformal equations:

$$\begin{bmatrix} X \\ Y \end{bmatrix}_2 = \boldsymbol{P}_1 \cdot \boldsymbol{C} \tag{1}$$

in which,

X_2, Y_2 = coordinates of a point after the second-step adjustment

$\boldsymbol{P}_1$ = the coefficient matrix of the conformal equations evaluated using coordinates of the same point resulting from the first-step adjustment

$$= \begin{bmatrix} 1,0,X,-Y,(X^2-Y^2),-2XY,(X^3-3XY^2),(-3X^2Y+Y^3) \\ 0,1,Y,X,2XY,(X^2-Y^2),(3X^2Y-Y^3),(X^3-3XY^2) \end{bmatrix}_1$$

$\boldsymbol{C}$ = the vector of conformal transformation constants whose values must be determined in the second-step adjustment
$= [c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8]^T$

POSITION CONDITION EQUATION

For any point whose final coordinates are known in advance, Equations 1 are simply rearranged to form the position condition equation:

$$\begin{bmatrix} X \\ Y \end{bmatrix}_2 - \boldsymbol{P}_1 \cdot \boldsymbol{C} = 0 \qquad (2)$$

in which the known coordinates are substituted for X_2 and Y_2, since we desire the final values to be equal to the known values.

As a minimum there must be one such condition equation. Otherwise, the solution will float around in the X-Y plane. That is, we must tie the solution down at least at one point. This point may be arbitrarily chosen and assigned artificial coordinates such as 0, 0; or 1 000 000, 500 000; or the point may be one for which state plane coordinates are known. If more than one point has known coordinates in the same coordinate system, all of these points may be used simply by writing as many condition equations of the form of Equation 2.

DISTANCE CONDITION EQUATION

For any pair of points, between which the horizontal distance is known, Equations 1 give rise to the condition equation:

$$d - \left[(\Delta\boldsymbol{P}_1 \cdot \boldsymbol{C})^T (\Delta\boldsymbol{P}_1 \cdot \boldsymbol{C})\right]^{1/2} = 0 \qquad (3)$$

in which,

d = the surveyed distance reduced to horizontal (and grid if applicable)

$\Delta\boldsymbol{P}_1$ = the difference between the $\boldsymbol{P}_1$ coefficient matrices generated by the two endpoints of the line

Typically, measured distances are scattered throughout the project just as X-Y horizontal control points are in conventional aerial triangulation.

AZIMUTH CONDITION EQUATION

For any pair of points between which the azimuth is known, Equations 1 give rise to the condition equation:

$$\alpha - \text{Tan}^{-1}\left[(\Delta\boldsymbol{P}_X \cdot \boldsymbol{C})/(\Delta\boldsymbol{P}_Y \cdot \boldsymbol{C})\right] = 0 \qquad (4)$$

in which

α = the azimuth (reduced to grid, if applicable) from one point to the other

$\Delta\boldsymbol{P}_X$ = the difference between the first rows of the P_1 coefficient matricies generated by the two endpoints of the line

$\Delta\boldsymbol{P}_Y$ = the difference between the second rows of the $\boldsymbol{P}_1$ coefficient matricies generated by the two endpoints of the line

Azimuths are also typically scattered throughout the project and these are an absolute necessity as the basis for removing systematic distortions which remain at the end of the first-step adjustment. Except for very short strips, it is incorrect to assume that azimuths can be dispensed with. Azimuths are determined preferably through observations on Polaris, but careful solar observations aided with a Roelof's prism may also be used.

SOLUTION OF THE SYSTEM

The condition equations (Equations 2, 3, and 4) are linearized, evaluated, and accumulated into the normal equations in accordance with standard procedure for any least squares adjustment. The program used by the authors allows individual weighting of known coordinates and distances in ground feet (or meters) and azimuths in seconds of arc. The coefficient matrix of the normal equations is of rank 8, so the inverse and calculation of the solution vector is very fast. The solution vector is added to the previous values of the unknowns $c_1, c_2, \ldots, c_8$ and the entire process is repeated. This iterative procedure continues until the solution vector goes to zero.

Cooperative Investigation

BACKGROUND

Up until 1970, General Development Corporation (GDC) did not make use of aerial triangulation of any kind. All stereomodels were fully controlled by conventional horizontal and vertical ground surveys. At this time, with the adoption of fully analytical aerial triangulation via contracted services, GDC never again reverted to controlling stereomodels completely on the ground.

At first, aerial triangulation control was established by GDC according to traditional schemes, but it was not long before the firm tried the concept of perimeter control (horizontally) which had recently been investigated by Kunji (1968) and Gyer and Kenefick (1970). Actual field checks made by GDC through the interior of a 13-strip block controlled horizontally only about the perimiter verified that the technique was suitable for production work. Thereafter, GDC's policy was to run perimeter horizontal control only. In many instances, the boundary survey of a tract also served as the horizontal control survey for the aerial triangulation. In these cases the horizontal control for aerial triangulation was obtained without any added field costs except for targetting of selected turning points on the traverse.

There are situations, however, when GDC desires to map an area where a boundary survey is not required. Heretofore, GDC would nonetheless run a perimeter traverse solely for the purpose of controlling the aerial triangulation. It is this "special survey" situation that GDC preferred to avoid or, at least, reduce in terms of time and cost. It is precisely at this point at which GDC was introduced to the concept of independent horizontal control.

ORGANIZATION OF PILOT PROJECT

As is evident from authorship of this article, four firms worked together to execute a pilot project. Brief descriptions of their responsibilities are given here. It is well to mention, however, that this was an actual production mapping project being done for the first time.

GDC assumed the responsibility for execution of all field surveys. Also, time and cost figures for the field work were closely monitored and compiled by GDC. Miami Aerial Photogrammetric Services (MAPS), who is responsible for all of GDC's photogrammetric mapping, not only produced the maps but also coordinated the field survey requirements between Analytic Photo Control (APC), their aerial triangulation specialist firm, and GDC.

APC performs all of MAPS aerial triangulation work. APC planned the field control scheme and then performed the point transfer work on their Wild PUG4, mensuration on their Kern MK2, and data processing on their NOVA 3/12. APC's aerial triangulation software is the JFK-developed RABATS system which incorporates the adjustment to independent horizontal control according to the technique described earlier.*

JFK's participation was primarily concerned with analyses and reporting of results. This included a number of experimental aerial triangulation "runs" and transformations between sets of resulting coordinates.

* RABATS is the acronym for Rapid Analytical Block Aerial Triangulation. The adjustment to independent horizontal control capability is an optional "plug-in" module which can easily be interfaced to any other aerial triangulation system.

GROUND SURVEYS

The pilot project is located in south Florida where GDC desired to map approximately 8 400 acres at a scale of 1 in. = 100 ft from aerial photographs of scale 1 in. = 500 ft. Horizontal control was established in two separate ways. First, a perimeter traverse was run even though a boundary survey was not required by GDC. This survey was executed solely to provide horizontal control for conventional aerial triangulation. Selected turning points on the traverse were targetted for this purpose (see Figure 1). Distance observations were made with an HP 3800 distance meter and angles were observed with a Wild T2.

The second horizontal survey consisted of measuring independent distances and azimuths as indicated in Figure 2. Preliminary selection of these lines was based upon the desire to scatter the independent horizontal control throughout the project and upon a study of accessability as best as this could be determined from 1:24 000 U.S. Geological Survey quadrangle sheets. The same field equipment was used for these measurements as was used in the traverse work. Astronomic observations were on Polaris with time being kept by means of an accurate stopwatch synchronized (at the office) with WWV prior to and upon completion of the field work.

Calculation of both surveys was performed on the Florida State plane coordinate system. However, the project did not require that a tie be made to the State plane system. The traverse closure amounted to 1:57 000 in position after adjustment of each angle by 0.7 sec of arc.

Inasmuch as the mapping project required contours, elevation control was established by differential leveling. Selected turning points were targetted to control the aerial triangulation (see Figure 1). The same elevation control was used for the conventional aerial triangulation and for aerial triangulation with independent horizontal control.

STRIP ADJUSTMENTS

In production, block aerial triangulation normally would be performed without intermediate adjustment of individual strips. It was desired, however, to evaluate the effectiveness of independent horizontal control on a single strip as well as on the entire block. Hence, flight line 1 was computed by itself in two ways. In the first calculation the strip was bridged in the usual way using the 12 X-Y horizontal control points which fell within the strip (Figure 1). The resultant

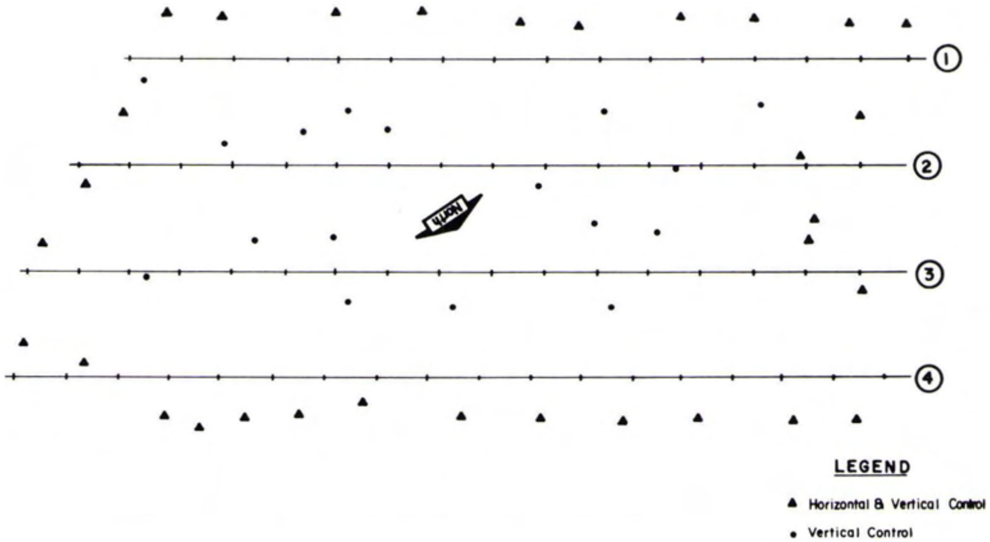

FIG. 1. Layout of the pilot project showing flight lines and horizontal and vertical control for conventional aerial triangulation.

RMS "fit" to the control was 0.30, 0.29, and 0.23 ft in X, Y, and Z, respectively. Maximum misfits amounted to 0.57, 0.53, and 0.51 ft.

In the second calculation the strip was rebridged and initially adjusted to only two X-Y control points. These two control points were actually the endpoints of the independently measured distance near the center of the strip (Figure 2); they were not traverse stations. Assigned coordinates of the end points were artificial except for the fact that their inverse produced the measured distance (reduced to the State plane grid). This calculation of the strip is that which was referred to earlier as the "first-step adjustment".

Before proceeding with the second-step adjustment to the independent horizontal control, results from the first-step adjustment were mathematically translated and rotated (but not scaled) to the results from the conventionally controlled aerial triangulation. RMS differences existing between the two sets of data were found to be 1.04 and 1.72 ft in X and Y, with maximum differences amounting to 2.79 and 4.54 ft. This transformation was performed using all points to obtain the overall best-fit in the least squares sense. Moreover, the pattern of these differences was markedly systematic owing to yet uncorrected varying scale and azimuth drift in the strip. But, by rescaling

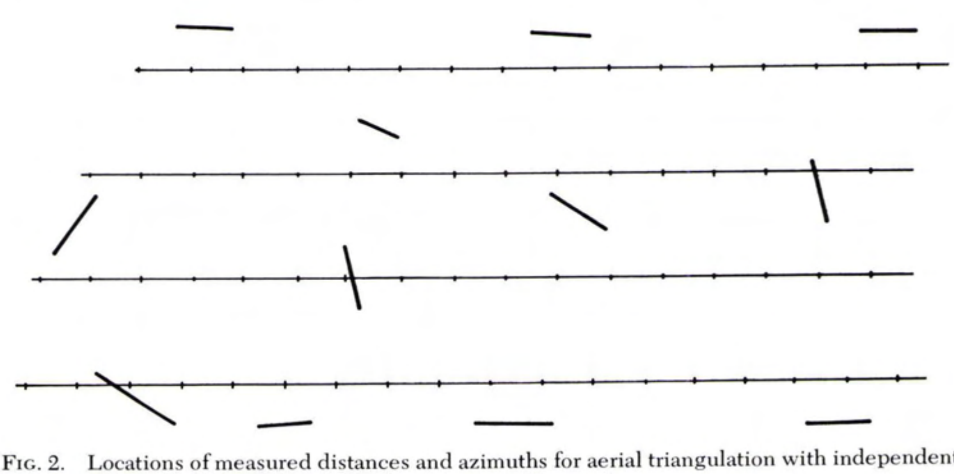

FIG. 2. Locations of measured distances and azimuths for aerial triangulation with independent horizontal control. Vertical control is the same as in Figure 1.

using an average scale based on all three distances, it was possible to reduce the RMS values to 0.89 and 1.40 ft with maximum differences of 2.14 and 3.20 ft.

The next step was to perform the second-step adjustment to the three distances and three azimuths which fell within the strip. One endpoint of one distance was also assigned artificial *X-Y* coordinates to prevent the strip from "floating" in the *X-Y* plane. These control data generated eight condition equations, which theoretically would allow a determination of the eight transformation constants ($c_1, c_2, \ldots, c_8$) of Equations 1. But, recognizing that this represented a unique solution, the program automatically truncated the two cubic terms, leaving only six transformation constants to be solved for. Nevertheless, the "fit" to all three distances and azimuths was essentially perfect (i.e., zero residuals).

The above step normally would be the last performed in production inasmuch as it produces the final *X-Y* ground coordinates. For comparison purposes, though, these results were further translated and rotated to the results from the conventionally controlled strip adjustment. RMS differences between the two sets of data now amounted to 0.52 and 0.30 ft in *X* and *Y* with maximum differences of 1.32 and 0.68 ft.

BLOCK ADJUSTMENTS

The entire block was also computed in two ways. In the first calculation the block was bridged in the usual fashion using the *X-Y* horizontal control points about the perimeter of the block (Figure 1). The resultant RMS "fit" to the control was 0.37, 0.28, and 0.31 ft in *X*, *Y*, and *Z*, with maximum differences of 0.89, 0.71, and 0.70 ft. At tie points between the strips the RMS of the "half residuals" was 0.30, 0.23, and 0.29 ft, with maximum half-values of 0.68, 0.67, and 0.66 ft.

In the second calculation the block was rebridged and initially adjusted to six "approximate" *X-Y* horizontal control points. Three of these were across the top of the block and three were across the bottom such that each strip contained two such approximate control points. All of these points were photo identities in the sense that they could be located on the 1:24 000 USGS quadrangle sheets, from which the *X-Y* coordinates were scaled. Hence, the designation "approximate" horizontal control.

It is well to mention here that this procedure of using approximate horizontal control is deemed desirable for bridging blocks with programs which use polynomial smoothing functions. In order to obtain a good fit at tie points between longer strips it is necessary to allow the polynomial functions to go into the second and third degree. If only two *X-Y* horizontal control points are used to initially control the block (as is done with single strips) it is conceivable that the block may be very severly deformed in the absence of *X-Y* horizontal control within each or, at least, within every other strip.

As expected, the "fit" at the approximate horizontal control was poor by ordinary standards. RMS misfits amounted to 27 and 14 ft in *X* and *Y*, respectively. But, bear in mind that this is only what was referred to earlier as the "first-step adjustment." The goal up to this point was to obtain a provisional solution with remaining errors of such systematic nature that they may be removed in the second-step adjustment to the independent horizontal control.

Before proceeding with the second-step adjustment, results of the provisional solution was translated and rotated to the results obtained from the conventionally controlled aerial triangulation. RMS differences between the two sets of data were found to be 5.83 and 9.01 ft, respectively, in *X* and *Y*. But, by rescaling the provisional solution based on the 12 independent distances, the RMS values were reduced to 1.15 and 1.01 ft in *X* and *Y*, respectively, with maximum differences of 3.15 and 2.72 ft. This was actually an unexpected result. Other experiments have indicated that such small values cannot always be expected after a simple scaling.

The next step was to perform the second-step adjustment using the 12 azimuths and 12 distances (Figure 2) as the independent horizontal control. One endpoint of one horizontal distance was also assigned artificial *X-Y* coordinates to prevent the block from "floating" in the *X-Y* plane. Together, these control data generated 26 condition equations which allowed all eight transformation constants of Equations 1 to be determined. Upon conclusion of this adjustment, the residuals at the control were as shown in Figure 3. However, the large residual at azimuth 127-126 is misleading. Because a blunder occurred in this particular azimuth, its assigned accuracy (standard deviation) was set at 9 999 sec of arc whereas all other azimuths were assigned accuracies of 3 sec of arc. In essence, then, azimuth 127-126 contributed nothing to the solution (i.e., had no effect on the solution) but its residual was nonetheless computed.

FINAL RESIDUALS

ABS. CONTROL PTS. (ADJUSTED VALUES)

POINT	X	Y	VX	VY
363	734617.60	1076311.57	0.00	0.00

HORIZ. DISTANCES (ADJUSTED VALUES)

PT.	TO PT.	DIST.	VD
110	109	2074.08	-0.36
106	105	1922.22	-0.15
102	101	2001.70	0.54
127	126	3216.43	0.87
124	154	2810.14	0.02
155	122	2064.01	0.46
120	119	2818.61	-0.43
113	112	1972.02	0.25
363	336	2245.29	-0.47
334	368	1774.59	-0.05
333	343	2459.96	-0.23
115	116	2407.03	-0.59

PLANE AZIMUTHS (ADJUSTED VALUES)

PT.	TO PT.	AZIMUTH	VAZ	
110	109	152 16 34.42	0 0 -5.42	
106	105	152 5 21.91	0 0 27.09	
102	101	153 37 16.48	0 0-37.48	
127	126	91 15 11.60	0 -2-52.60	*
124	154	0 2 12.82	0 0 25.18	
155	122	336 4 10.19	0 0 -7.19	
120	119	337 14 42.26	0 0 -4.26	
113	112	224 11 11.56	0 0 -8.56	
363	336	179 44 25.41	0 0-49.41	
334	368	53 9 47.87	0 0 15.13	
333	343	182 45 10.25	0 0 17.75	
115	116	155 33 38.84	0 0 27.16	

* azimuth relaxed

FIG. 3. Computer output of final residuals at independent horizontal control.

Magnitudes of the distance residuals shown in Figure 3 are in line with those which should be expected from aerial triangulation with 1 in. = 500 ft photographs. For production work with the RABATS aerial triangulation programs it is usually estimated that the passpoints will be determined with an RMS accuracy (standard deviation) of 1 part in 1,850 of the negative scale, as expressed in feet per inch, in X and in Y, provided, of course, that the ground control is of good quality and well distributed. For 1 in. = 500 ft negatives, then, the expected RMS passpoint accuracy (standard deviation) is 0.27 ft in X and in Y. Statistically it can be shown that the distance calculated between any two passpoints, regardless of their distance apart, should have a standard deviation of $\sqrt{2} \times 0.27$ or 0.38 ft. As a practical matter the maximum expected error would be approximately 2.5 times the standard deviation or 0.95 ft. These values compare very nicely to the distance residuals "VD" shown in Figure 3.

With regard to the azimuth residuals, these too are within expectations. Statistically it can be shown that the standard deviation of an azimuth computed between two passpoints is equal to the standard deviation of the distance divided by the distance itself. It was shown in the preceding paragraph that the expected standard deviation between any two passpoints is 0.38 ft. Since the lengths of the lines over which azimuths were observed range between 2,000 and 3,000 ft, it should be expected that the standard deviations of the azimuths will lie in the range of 26 to 39 sec of arc with maximum expected errors on the order of 65 to 98 sec of arc. From Figure 3 it can be seen that the results were actually better than statistical estimates would indicate.

Two practical points should be mentioned here. The first is that misfits on the horizontal distances and on the azimuths are attributable almost entirely to error in the aerial triangulation. Survey errors in measuring the distances and azimuths are small relative to the errors in the aerial triangulation. This is the basis for the earlier statement that careful solar observations can be employed in lieu of observations on Polaris.

The second point is relative to elevations computed in the aerial triangulation. Inasmuch as the pilot project covered rather flat terrain, elevations computed in the first-step adjustment were correct and were used for the mapping. If a project is in rough terrain, however, these elevations will suffer from incorrect scaling at this stage. To obtain correct elevations it is necessary, therefore, to repeat the aerial triangulation in a con-

TABLE 1. DIFFERENCES BETWEEN BRIDGING WITH CONVENTIONAL CONTROL AND INDEPENDENT HORIZONTAL CONTROL

Point of Comparison \ Differences in feet	STRIP RMS-X	STRIP RMS-Y	STRIP MAX-X	STRIP MAX-Y	BLOCK RMS-X	BLOCK RMS-Y	BLOCK MAX-X	BLOCK MAX-Y
After First-Step Adjustment	1.04	1.72	2.79	4.54	5.83	9.01	14.12	17.40
After Rescaling[1]	0.89	1.40	2.14	3.20	1.15	1.01	3.15	2.72
After Adjustment to Independent Control	0.52	0.30	1.32	0.68	0.58	0.60	1.74	1.66

[1] Step not done in practice. The adjustment to independent horizontal control immediately follows the first-step adjustment.

ventional sense using a few pass points as horizontal control points, X-Y values for which would be taken from the results of the adjustment to independent horizontal control.

In order to further evaluate results obtained with the block adjustment to independent horizontal control, the final X-Y coordinates were translated and rotated (but not scaled) to the corresponding values from the block adjustment with perimeter X-Y horizontal control. RMS differences were 0.58 and 0.60 ft in X and Y, with maximum differences of 1.74 and 1.66 ft.

SUMMARY OF DATA ANALYSIS

Inasmuch as the preceding discussions were necessarily complicated by numerous explanations, it is well to summarize the results before proceeding. It must be borne in mind, however, that all of the comparisons described earlier were against the result of the conventionally controlled aerial triangulation. Hence, all differences reported really reflect differences between data produced by conventional aerial triangulation and data produced by the adjustment to independent horizontal control method, both of which contain errors of their own. Table 1 summarizes only relative accuracy since the adjustments to independent horizontal control were not done on the State plane coordinate system (but, the program can do so if State plane coordinates are known for one or more points).

ECONOMIC ANALYSES

Costs involved in performing both types of horizontal surveys were carefully monitored. Final costs to produce the mapping control for the block are given in Table 2.

From Table 2 it is clear that savings in field work alone amounted to 50 percent. Overall savings, however, amounted to 33 percent owing to the increased cost of the aerial triangulation work. Of course, these percentages apply only to this particular project. It is the opinion of the authors, however, that this pilot project is actually a poor example insofar as savings are concerned. This is because it was possible to run the perimeter traverse on hard surfaces along three sides of the project with only the fourth side (and one of the shortest) being cross-country. Also, access to the interior of the project was difficult owing to the

TABLE 2. COSTS TO PRODUCE MAPPING CONTROL FOR THE BLOCK

CONVENTIONAL BRIDGING			
1. Perimeter horizontal survey[1]	420 hrs.	@ $15.00	$ 6,300
2. Elevation survey[1]	180 hrs.	@ $15.00	2,700
3. Aerial triangulation	67 frames	@ $37.00	2,479
			$11,479
BRIDGING WITH INDEPENDENT HORIZONTAL CONTROL			
1. Measure distances and azimuths[1]	120 hrs.	@ $15.00	$ 1,800
2. Elevation survey[1]	180 hrs.	@ $15.00	2,700
3. Aerial triangulation	67 frames	@ $47.00	3,149
			$ 7,649

[1] Includes targetting and computations.

swampy nature of the land. Finally, the job-site was so close to home base that transportation and per diem expenses were not experienced. Surely all of these conditions will be just the reverse on many projects, thereby making the use of independent horizontal control even more attractive.

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