Production Mapping With Computational Photogrammetry

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The interdependence of precise ground surveying, aerial targeting, aerial photography, analytical aerial triangulation, and map compilation are depicted in reporting the results of an 83-mile, continuous, large-scale mapping project. This project would have been considered impossible without the implementation of aerial photogrammetry and specifically without the aid of aerial triangulation. The paper describes the operations performed from project inception to the completed map manuscript with discussion on surveying procedures, targeting, comparator operations, and map compilation. It should be emphasized that the work was performed on a production basis and not as a research project.

•ON October 3, 1966, the National Park Service asked Region 15, Bureau of Public Roads, to make an aerial survey and prepare large-scale topographic maps of an 83.5-mile section of the Blue Ridge Parkway. Detailed land-use maps encompassing the existing Parkway right-of-way at a scale of 100 ft = 1 in. with a 5-ft contour interval were specified. These maps were intended to serve as an aid in the administration of management programs, including:

1. Determining land-use patterns to expedite the year-to-year management of agricultural programs.
2. Simplifying the study of adjacent public roads for the purpose of minimizing nonconforming use of the Parkway and for eliminating private crossings and accesses where feasible.
3. Providing an invaluable aid to the landscape architects in location, planning, and design of roads, campgrounds, picnic grounds, and other facilities.
4. Providing an accurate reference for fire-fighting and other protection purposes, because these maps would show all roads, public and private, even little-used woods roads or trails, and other vital features.
5. Furnishing, in many instances, the only accurate location of electric and telephone lines, roads, and other features valuable in the day-to-day administration of the Blue Ridge Parkway.

This section of the Parkway extends from milepost 136 at Adney Gap to milepost 218 just beyond the Virginia-North Carolina State Line (Fig. 1). Throughout this area the Parkway meanders southwesterly along the crest of the Blue Ridge front. The terrain adjacent to the Parkway and to the west is in a series of rolling hills displaying the natural beauty of rural landscapes enlivened by the highland farms, campgrounds, trails, and wayside exhibits of the hill culture of the area. To the east lies the Blue Ridge escarpment, which affords numerous overlooks and vistas along the Parkway. Approximately 50 percent of the area has a cover of hardwood trees with intermittent

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BLUE RIDGE PARKWAY

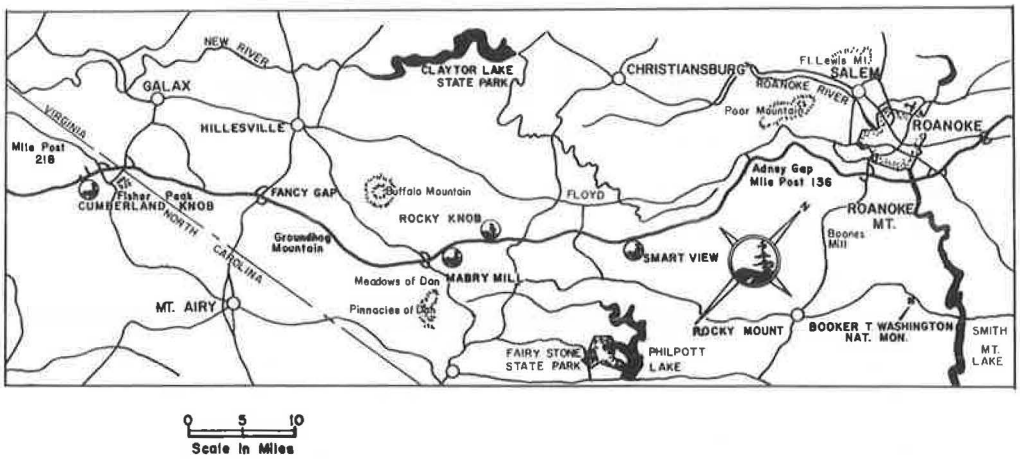


Figure 1. Location map.

stands of white pine and rhododendron, and the remaining 50 percent is cultivated farms and pasture land.

BASIC CONTROL REQUIREMENTS

To insure the development of an accurate and usable topographic map at a reasonable cost, the following basic control requirements were established:

1. The control survey should be connected to the Virginia South Zone State Plane Coordinate System.
2. The basic plane coordinate grid for the mapping should be established on an adjusted datum corresponding to the average elevation of the area.
3. The basic control traverse should be of second-order accuracy or better.
4. Semipermanent control monuments should be established along the Parkway in areas where future surveys and construction are contemplated.
5. Supplemental control should be obtained by photogrammetric aerial triangulation techniques to reduce the cost of field surveys.
6. Existing right-of-way monuments should be recovered and targeted to determine their coordinate positions by photogrammetric methods.

PRELIMINARY PREPARATIONS

To expedite the project the Park Service requested that late fall photography be obtained. Timing was critical due to the length of the project. A maximum of 8 weeks was available in which to prepare and negotiate a contract for aerial photography, obtain supplies, establish a control traverse throughout the project, and place photographic targets on all required horizontal and vertical control points.

All existing control for the area was obtained from the U.S. Coast and Geodetic Survey and the U.S. Geological Survey. Fifteen-minute quadrangle sheets were then assembled into a single map of the area. The geodetic control data received were reviewed and all second- and third-order geodetic control convenient to this section of the Blue Ridge Parkway was identified on the map.

A contract was negotiated with a local aerial photographer to obtain high-altitude photography (approximately 1:24000 scale). The area of coverage was specified by delineating five flight lines on the assembled quadrangle sheets. As soon as this photography was received, a base map (flight map) was constructed. The high-altitude vertical photographs were assembled into five strip mosaics using alternate photographs.

Each strip was fitted and sized by using identified image points and distances scaled from the 15-minute quadrangle sheets. By correlating the mosaics to the same area on the quadrangle sheets, their average scale was determined to be 2100 feet to 1 inch. The mosaics were then studied closely to determine a minimum number of flight lines required to obtain 1:6000 scale photographic coverage of the area to be mapped.

Due to the curvilinear alignment of the Parkway, the most efficient flight line arrangement proved to be a series of single flight strips overlapping at each change in direction. A line, indicating the path and direction that the aircraft should follow when obtaining the large-scale mapping photography, was plotted on the mosaics. The width of photographic coverage was also drawn on them, delineating the area each flight strip should cover. The exact number of stereoscopic models was determined for each flight strip and their photocenters marked along each flight line. The average elevation for the terrain in each flight strip was determined by studying the same area on the quadrangle sheets. Utilizing this information, the flying height for each flight line was written on the flight map. The positions of required horizontal and vertical control points were then selected and marked in the prescribed models of each flight line while making a stereoscopic examination of the photography. The final product was a detailed flight map containing 31 flight lines varying in length from 5 to 15 models comprising 260 photographs. Twenty-seven of the flight lines were controlled and four were uncontrolled. Figure 2 illustrates the first three flight lines for the project.

The density and spacing of the basic control delineated on the flight map were patterned after specifications for analog bridging of supplemental control on a universal type photogrammetric instrument. The first model in each flight strip was fully controlled with two horizontal and four vertical targeted points. Thereafter, one horizontal and two vertical control points were placed in every fourth model and the last model in each strip. Additional horizontal control points were placed in each flight strip to meet Region 15 requirements for spacing semipermanent control stations along the Parkway. The total number of targeted control points delineated on the flight map came to 170 traverse points and 170 elevation pass points.

A second contract was negotiated with the local aerial photographer for taking the 1:6000 scale photography. A copy of the flight map was furnished with instructions concerning its use. Emphasis was placed on the importance of exposing the first photograph in each flight strip precisely as shown by its marked center on the flight map. This precaution was necessary to insure that all targeted ground control would occur in the prescribed model as shown on the flight map. This requirement was not unreasonable since the aerial photographer would be able to identify actual ground objects for precisely orienting the aircraft while exposing the film. Another requirement concerning the photography was that it be taken between the hours of 10:30 a.m. and 1 p.m. to keep excessive ground shadows, which occur during the late fall months, to a minimum.

On October 17, 1966, a meeting was held with representatives of the National Park Service in Roanoke, Virginia, to discuss a timetable for accomplishing the field work. An agreement was made that while the Region 15 control survey party was laying out the basic control traverse and placing the required aerial targets, the Park Service would furnish additional personnel to locate and target as many right-of-way monuments as possible before the mapping photography was taken. Public Roads agreed to supply the necessary target material along with instructions for placing the targets.

FIELD SURVEYS

Actual field work began on October 18, 1966. The first activity was to fabricate the photographic targets. Three types of targets were used (Fig. 3): target 1 was used for right-of-way monuments; target 2 was used for traverse points (horizontal and vertical); and target 3 was used for vertical control points only. Target types 2 and 3 were symmetrical with black centers and white outer legs. The black centers were omitted for the type 1 target and its overall dimension increased to 16 feet. This was done in an effort to increase photographic identity, because many of the right-of-way monuments were in wooded areas.

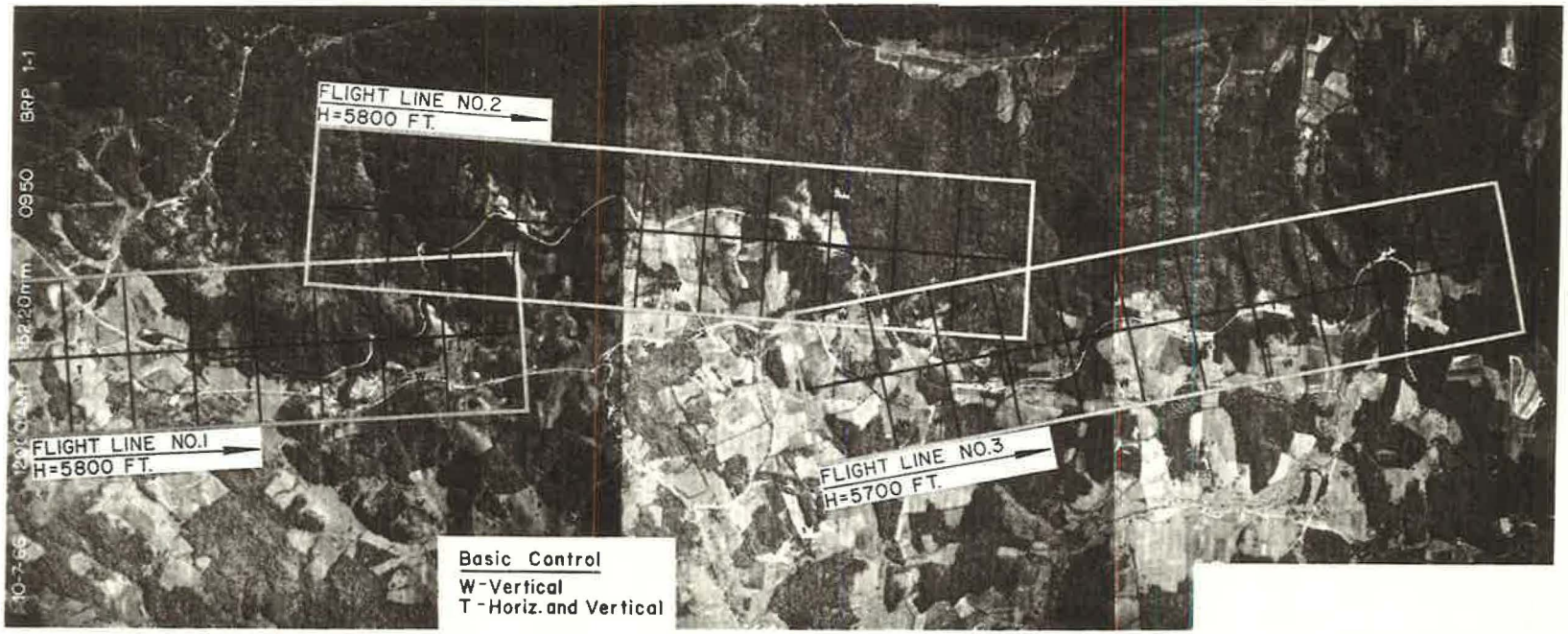


Figure 2. Flight map.

The targets were made of a vapor barrier material produced by the American Sisalkraft Corporation. It has a polyethelene facing laminated to a treated paper base with a tar-like binder and is available in black and white. The material came in rolls 8 feet wide containing 125 linear feet and had to be cut into rolls 9 inches wide with a bandsaw. The material has several characteristics which make it excellent target material:

1. The paper side of the material has a matte-type surface that is non-reflective.
2. It is inexpensive; the cost for each target was approximately 60 cents.
3. It is very durable; i.e., it is resistant to moisture and does not separate or ravel from exposure.
4. It has sufficient weight to adhere to the ground when fastened at 4-foot intervals along its edges.
5. Livestock and other animals will not eat this material. It is conjectured that the tar binder makes if offensive to animals.

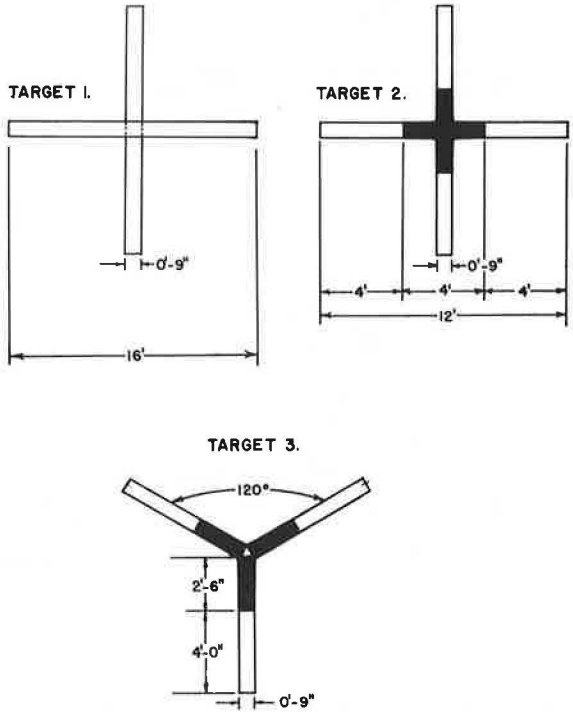


Figure 3. Design for photographic targets.

In certain areas where horizontal control was required, the Parkway was the only open area where aerial targets could be placed. In these instances a white cross with a gap in the center was formed with Scotch Lane Striping Tape on the asphalt surface.

A total of 170 type 2 targets and 170 type 3 targets were fabricated and placed within a 7-day period by six engineering technicians. This work was expedited by use of the flight map described previously. Target placement on right-of-way monuments required 4 weeks due to difficulty in locating these points. Many of the recorded right-of-way monuments could not be found and, as a result, were not targeted.

While the targets were being placed, the basic control traverse was established along the Parkway. The targeted horizontal control points were interconnected with a minimum number of auxiliary stations to form a continuous traverse. Considerable effort was made to keep the distances as long as possible, but many short distances resulted due to the curvalinear alignment of the Parkway. The decision to establish the basic control traverse along the Parkway was influenced by two factors: the cutting of trees was prohibited, and portable survey towers were not available.

The total length of the resulting traverse was 514,006 feet (97.35 miles) with 424 individual stations. The bulk of the basic control survey work was accomplished during the 6-week period from November 1 to December 17, 1966. Three 3-man level parties established elevations for traverse and wing points, while three 2-man Electrotape units measured distances. Following these operations, two 4-man instrument parties equipped with Wild T-2 Theodolites measured the angles.

Differential levels were first run through all traverse stations along the Parkway. USGS bench marks were recovered at frequent enough intervals to maintain third-order level closure throughout the traverse. Wing point elevations were then established by running closed level loops through each point from the nearest traverse station. In all, approximately 200 miles of differential levels were run on this project.

All distances were measured with Electrotapes operated in a leap-frog sequence. While two units were measuring the distance between adjacent stations, the third unit

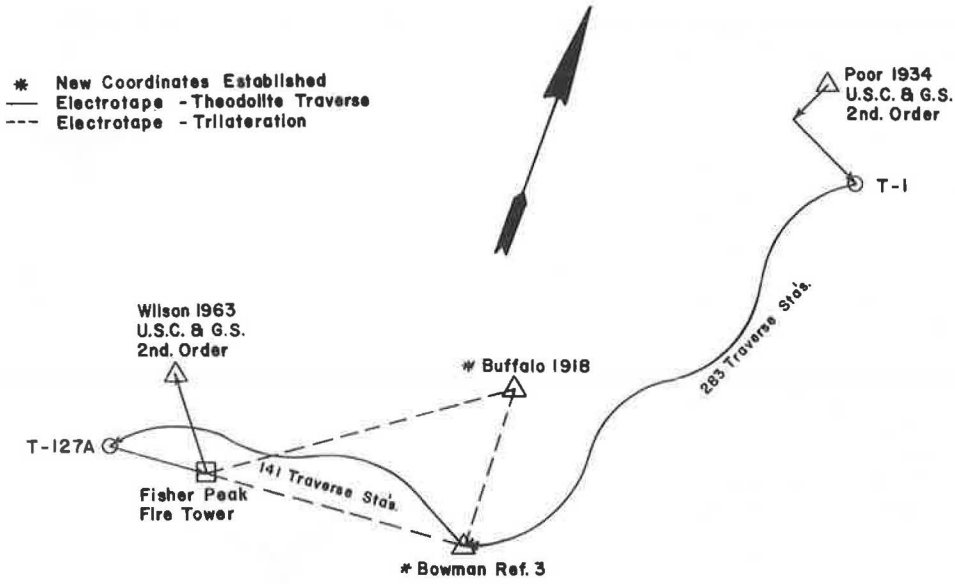


Figure 4. Basic control traverse diagram.

moved ahead to the next station. With this procedure, an average of 25 lines were measured each day. The Electrotapes were operated during all kinds of weather including rain, light snow, and fog, with temperatures ranging from 14 to 73 F. A special umbrella was used to shield the instrument and operator during inclement weather.

All angles were measured using Wild T-2 Theodolites and sighting tripod-mounted targets. Special targets used consisted of a section of range pole (point up) held by an adapter mounted on a Wild tribrack. The optical plumb in the tribrack insured accurate centering of the target over the station marker. Once the tripod was in place, a 16-oz plumb bob was extended from the tribrack. For short distances the instrument man sighted on the plumb bob string; on intermediate distances he sighted on the tip of the range pole; and on long distances he sighted on the shaft of the range pole.

The control traverse (Fig. 4) began at a second-order USC&GS triangulation station (Poor 1934), and was closed on another second-order station (Wilson 1963). At Groundhog Mountain (Milepost 189), a third-order control station (Bowman), plotted on the quadrangle sheets during the reconnaissance stage, was not recovered. However, reference mark No. 3 for this station was recovered and this point was incorporated into the basic control as a traverse station. New coordinates (second order) were determined for this point by electronic traverse and trilateration methods. This point was used as a closing station and the overall traverse was computed and adjusted for a closure in two segments. A least squares adjustment program developed by Kenngott (1) was used to compute traverse closures on the IBM 1401 computer. Before survey closure the plane coordinates were adjusted using a Datum Adjustment Factor (DAF = 1.000156).

The first section from Poor to Bowman reference No. 3 contained 283 stations and the adjusted distance was 312,496 feet. Angle closure before adjustment was 170 seconds, approximately 0.6 second per station. The error of closure after azimuth adjustment was 2.82 feet (one part in 110,830). The second section from Bowman reference No. 3 to Wilson contained 141 stations and the adjusted length was 201,510 feet. Angle closure before adjustment was 128 seconds, approximately 0.9 second per station. The error of closure after azimuth adjustment was 11.05 feet (one part in 18,233). Polaris observations were made on the first leg of the traverse at station Poor and on

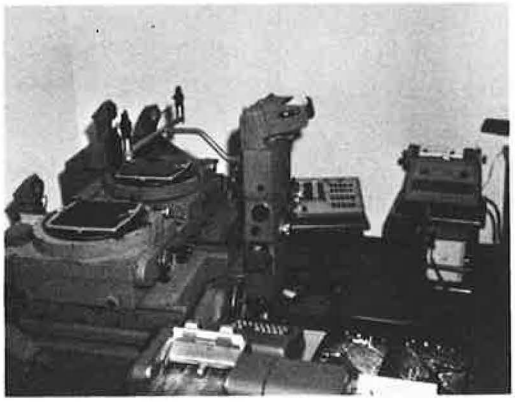
the traverse leg terminating at Bowman reference No. 3 for azimuth control. An established azimuth mark was recovered and used for azimuth control at the end of the traverse at station Wilson.

An early snowstorm, preceded by 2 or 3 days of freezing temperatures, moved through the area the weekend of November 12 and 13. It was accompanied by high winds, and leaves on the deciduous trees were 95 percent removed over the 2-day period. The aerial photographer was given notice by telephone to proceed on the morning of November 15. Three days were required to photograph the entire 83.5 miles due to the flying time required to reach the project, the restricted hours for taking photography, and the length of the project. A Wild RC-8 aerial camera was used to obtain the 1:6000 scale mapping photography.

Considerable effort was expended in an attempt to complete all field work before the end of the year, but due to snow and freezing temperatures, work had to be suspended on December 17. The field work was about 85 percent complete. Emphasis was placed on completing the level work since it was realized that wing point targets would not remain in place through the winter.

Field work was resumed the first week in March and was completed by April 1, 1967. Approximately 200 traverse stations were referenced throughout the project. Semipermanent survey markers (metal T-bars with $1\frac{1}{16}$-inch diameter nickel-plated brass caps) were used at these locations. These points are intended to preserve coordinate position and azimuth control in all areas where future surveys and construction are contemplated. Also, approximately 60 test profiles were measured between control points at random throughout the project for future use when checking the contour plotting accuracy of the mapping contractor.

Wild PUG-3 point transfer device used for marking points on the diapositives.



Wild STK-1 stereocomparator used to measure image coordinates on diapositives.

Figure 5. Analytical bridging equipment.

PHOTOGRAMMETRY

The analog bridging of supplemental control was delayed due to unexpected complications. Because of the magnitude of the project, and the time element involved, other means were investigated for accomplishing the bridging work. Jesse R. Chaves, Engineering Systems Division, Office of Research and Development, Bureau of Public Roads, recommended that the analytical method be used. Through arrangements made by Mr. Chaves, the USC&GS offered the use of their bridging equipment located at the Washington Science Center, Rockville, Maryland, after regular working hours.

The analytical aerial triangulation work was performed with two Wild STK-1 stereocomparators and a Wild PUG-3 point transfer device (Fig. 5). The STK-1 comparators were equipped with digital readout.

Measurements were made by two operators. One operator, on loan from the Aerial Surveys Branch, Highway Standards and Design Division, Bureau of Public Roads, had 5 months' prior operating experience with the Wild STK-1 comparator. The other operator, a graduate civil engineer, was trained by the "experienced" operator for one week. At the end of this training period, the new operator began measuring a strip consisting of six models. Four days were required to measure the flight line. As experience and confidence in his measurements were developed, the new operator's speed increased from one model per 6-hr shift to a maximum of four models.

The drilling of the pass points was performed by the two comparator operators and a technician. The technician had been training on the Kelsh plotter for 8 months before he was trained to use the PUG-3. After several days of experience with the PUG-3, the technician was able to drill the glass plates satisfactorily.

Contact prints for each flight line were examined to locate the targeted ground control points. Each identified point was circled on the photograph and its identification

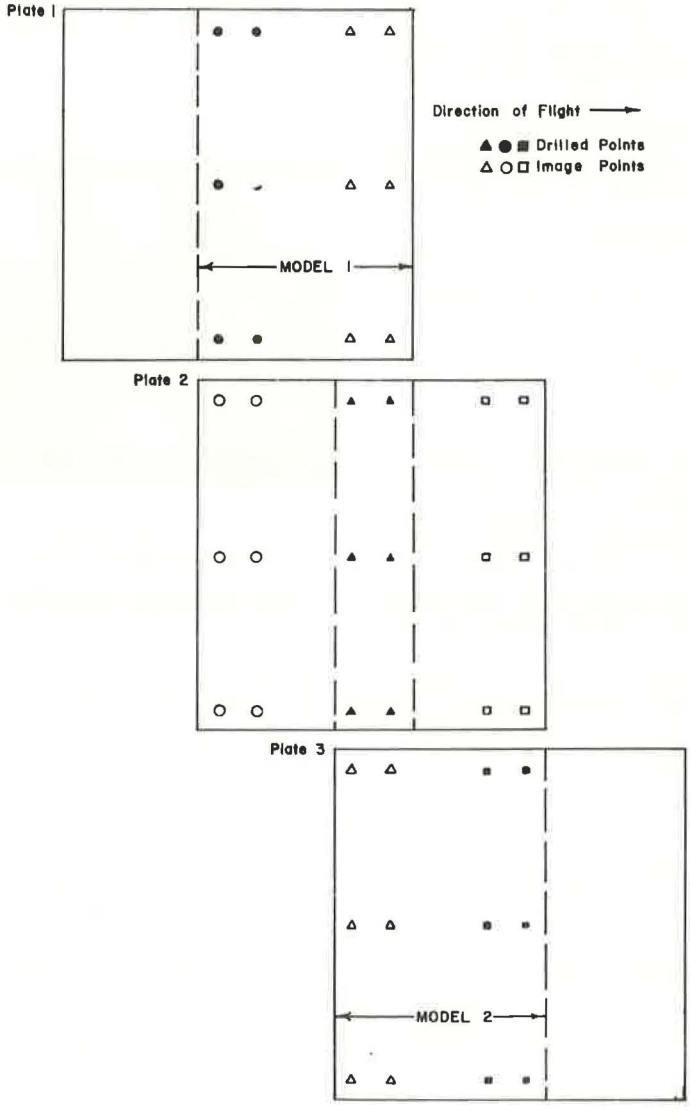


Figure 6. Pass point distribution.

number written beside it. Right-of-way points had to be located and marked on the photographs since their position was to be determined analytically.

Pass point distribution used on this project consisted of three sets of two points each, placed in the triple overlap area of each photographic plate. Each point was placed on the plate by drilling through the plate's emulsion with the Wild PUG-3. Since the measurements were to be made stereoscopically, it was necessary to drill only the triple overlap area of each plate (Fig. 6). Pass point areas were examined stereoscopically before the points were drilled. This procedure insured that the drilled points were in the triple overlap area and would appear in adjacent models.

Originally, effort was made to place one set of points near the photocenter with the other sets placed within 1½ inches of the plate edge (perpendicular to the flight axis). This placement gave the best theoretical geometry for the analytical computations and was followed on the first eight flight lines. Difficulty was encountered, however, in measuring the points placed in wooded areas because of bare limbs and shadows. After repeated attempts to measure points in wooded areas, it was decided to sacrifice

FLIGHT LINE 26 MODEL 3

PROJECT BLUE RIDGE PARKWAY DATE 10-30-67

STATE Va. DISTRICT SECTION Adney Gap to N.C. Line

PLATES COMPRISING MODEL 2-38 AND 2-37

SCALE 1:6000 FLIGHT HEIGHT 3,000 FOCAL LENGTH 152.30 m.m.

POINT		ID NUMBER	NORTH Y	EAST X	ELEV. Z	REMARKS
PASS POINTS	PLATE 2-38	030403 310	116,433.11	4,345,364.10	2936.023	
		030403 311	116,451.68	4,345,352.60	2936.968	
		030403 330	117,504.89	4,344,979.30	3022.174	
		030403 331	117,472.14	4,344,988.90	3022.029	
		030403 320	119,276.49	4,344,280.10	2931.544	
		030403 321	119,227.97	4,344,292.90	2926.365	
PASS POINTS	PLATE 2-37	030404 310	115,500.78	4,344,170.30	2924.232	
		030404 311	115,467.36	4,344,031.00	2929.491	
		030404 330	116,892.81	4,343,386.40	2996.878	
		030404 331	116,867.73	4,343,324.50	2999.978	
		030404 320	118,149.62	4,342,520.60	2840.840	
		030404 321	118,169.88	4,342,534.10	2848.306	
TARGET POINTS	R-5	030403405	117,358.28	1,344,819.50	3020.950	
	R-6	030403406	117,471.34	1,344,210.50	3000.618	TARGET CENTER OBSCURED
	T-103	030403104	117,225.73	1,344,259.10	3005.402	
	W-127A	030403203	119,263.78	1,343,104.60	2936.513	FENCE CORNER

Figure 7. Control data form.

geometry when necessary to insure measurable points. This was accomplished by selecting areas closer to the center of the photograph and outside the area to be mapped. This arrangement seemed to work satisfactorily insofar as analytical calculations were concerned.

One-hundred-and-fifty-micron diameter drills were used in drilling the pass points. After the pass points were drilled, their locations were marked and the identification numbers written on the emulsion with a felt-tip ink pen. When the entire flight line was drilled, control points were marked on every other plate with a grease pencil. The grease marks were made on the non-emulsion side so they could be erased if desired at a later date.

To help the comparator operator, data sheets were made up for each model listing all of the points to be measured (Fig. 7). In instances where the control points were photo-identified ground features, descriptions of the points were also included. The comparator operator noted any problems he encountered while measuring the points. These notes were reviewed when setting up the data for the final computer program. The Kelsh operator could also refer to them when setting up his model.

The general measuring procedure required three independent readings on each pass point and all targeted points. If the three measurements fell within a spread of 8 microns, they were considered good. (The least count of the Wild STK-1 stereocomparator is 1 micron.) The 8-micron limit was selected as desirable after each operator had measured several strips, determined his ability to repeat, and analyzed computed results of these measurements. In a few instances the targeted points were so badly washed out, hidden in shadows, or otherwise indistinguishable, that it was impossible to fall within the 8-micron limitation. In these cases, a determination was made by the operator, based on the target type (right-of-way, T-point, wing point), as to what spread could be allowed. When this was done, notations was made on the comparator sheets describing the difficulty and operator's judgment whether to use the point as control in the final adjustment.

After measuring all targeted points and pass points, the operator measured the fiducial marks. These plates had corner fiducials. The operator measured each fiducial leg three times with a total of 12 measurements recorded for each fiducial.

Contrast of the plates varied considerably throughout the project. Some flight lines had high contrast plates and some had very little contrast. Both operators experienced difficulty with the low contrast or "washed out" plates. The degree of operator difficulty was directly related to the degree of contrast and operator experience. It was generally agreed that the desirable comparator plate should have enough contrast to help distinguish targets in light areas.

COMPUTATION PROCEDURES

After each flight line was measured, a listing of the raw comparator punch data was made. The listings were checked to see that each model had 48 fiducial readings and 12 sets of pass point readings, and that all of the cards appeared to be punched correctly.

After review, the raw data were arranged for the first computer program (program 35) (2). This program took the three measurements for each fiducial leg and constructed a set of equations representing the fiducial legs.

These equations, when solved simultaneously, gave the center of each fiducial. The center of each plate was then determined from the fiducial equations. Once this calculation was performed, the program averaged the three readings for each measured point in the model and computed plate coordinates for each point with the plate center as the origin. The program also eliminates the inherent mechanical errors of the STK-1 comparator.

When review of program 35 output was completed, the data were arranged for the Three-Photo Aerotriangulation Program (3). This program computes strip coordinates for a strip of ". . . aerial photographs through an analysis of three photographs simultaneously, advancing one photograph at a time. Corrections are included for lens distortion, film distortion, atmospheric refraction, and earth curvature (if desired).

Blunders in the input data are detected and eliminated, and the rejection level is controlled by the user. The data is analyzed without reference to the ground control." (3)

Precisions for targeted points that were to be used for control in the next program were checked. When the precision for a control point exceeded 15 microns, its use as a control point was questioned. If another point could be used, the questionable point was used as a test point.

TABLE 1

REQUIRED CONTROL POINTS FOR AEROTRIANGULATION STRIP ADJUSTMENT

Degree of Adjustment	Minimum Points Required	
	Horizontal	Vertical
1	2	4
2	3	5
3	4	7

The final program, Aerotriangulation Strip Adjustment (4), transformed and adjusted the strip coordinates of the measured points to fit the ground control data. This program contains a variable degree provision that allows the selection of either third-, second-, or first-degree polynomial correction in the horizontal direction and also in the vertical direction independent of the horizontal choice. The minimum number of control points required for each degree adjustment is given in Table 1.

Control placement throughout each strip (as explained earlier) was placed for the analog bridging method. Therefore the control distribution, although more than adequate for analog bridging, was not the most desirable arrangement for analytical bridging. If the specifications had been followed stringently, flight lines containing six models would have had four horizontal control points, and flight lines containing three, four, or five models would have had three horizontal control points. Due to the flight line arrangement, control for the first model of each strip also appeared in the last model of the preceding strip. This, in all but two cases, resulted in at least five horizontal control points in each flight line.

In an effort to get the most stringent and best solution, all strips were run on a third-degree adjustment. Two strips contained only four horizontal points and, as a result, no horizontal control was available to use as test points. In these instances the amount of deviation from the control value used was examined. There was little deviation between the ground control value inserted and the computed control value; therefore, it was assumed that the analytic triangulation was adequate. Here, inexperience probably hindered judgment and a second-degree adjustment should have been made on these two strips.

The control distribution for each flight line was studied by examining the photographs and the three-photo output data. After some study, the ground control to be used in the strip adjustment was chosen. Targeted points not used for control were used as test points in the adjustment. Except for the instances referred to previously, at least one horizontal and two vertical test points were used in each strip.

MAPPING

The contract for the actual mapping work was negotiated with a local firm on September 1, 1967. The contract called for mapping a corridor averaging 1,000 feet in width along the 83.5-mile section, plotting referenced traverse points, and plotting all of the right-of-way points. The mapper was furnished the comparator sheets, a list of the right-of-way points and traverse points to be plotted, the glass plates, and a set of photographs with the area to be mapped outlined on them.

The completed maps were furnished on standard size 24- by 36-inch plan sheets. As the mapping progressed, blueline prints of each sheet were submitted for checking. When errors were found, they were noted and given to the mapper for correction. The completed project contained 131 sheets. Figure 8 illustrates one of the map sheets.

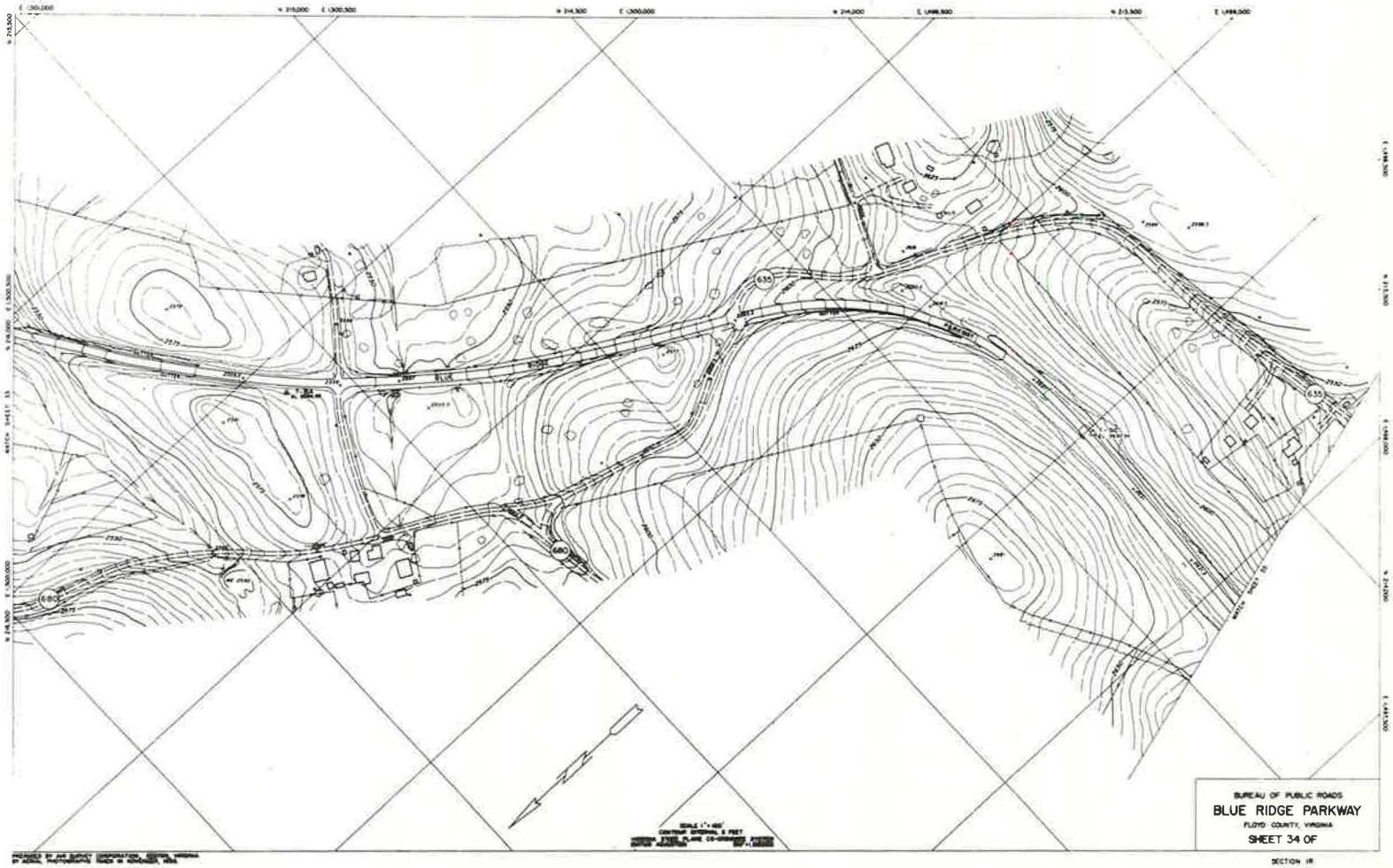


Figure 8. Typical map sheet—final manuscript.

DISCUSSION

Surveys

The length of the project created a tremendous amount of book work. In all, 22 field books were used on the project. All data for each traverse point were entered into a master book in order to facilitate the use of the data. Here, again, even with double checking, occasional copying errors were found.

Targeting

A 3-week time lapse occurred between the placement of basic control targets and obtaining the aerial photography. When the prints were available, they were checked to see if all targeted points appeared on them. Where the targets were missing, the photographs were studied for ground features that could be used in lieu of the missing targets. Road intersections, bases of telephone poles, ends of headwalls, and tips of islands were used when necessary as photo-identified points. Once the photo identification was made, these points were included in the control survey. The points used were circled and described on the back of the applicable photograph. The description of each point was very important as the comparator operator used the field description to identify and measure each point.

Analytical Aerial Triangulation

Three-legged targets (Type 3, Fig. 3) were used for wing points to eliminate any confusion as to the type of target. Finding the center of this target, however, did prove to be difficult when one of the legs was missing or the ground on which it was placed sloped sharply away from the camera exposure station. With one leg missing, it was extremely hard to repeat the comparator measurements for position within the 8-micron limit. In most instances the operator picked his center with the aid of land features and the two remaining legs.

Few problems were experienced in measuring the traverse control targets. Although in some low-contrast plates the white legs of the target distorted badly, it was still possible to find the center of the target within the measuring limit of 8 microns. Photo-identified points, in some instances, were difficult for the comparator operator to measure. Although they could be seen when using the comparator, many were not well enough defined for the operator to be certain that the point he was measuring was the same point the field party had measured.

Several blunders were found in the vertical ground control during the final strip adjustment program. In one case, an error of 100 feet was found through analyzing the output data. An examination of the level notes revealed a transcribing error of 100 feet. In another case, an error of 10 feet was found in a wing point used as a test point. A check of the field notes found a 10-foot error in the bench mark used to establish the wing elevation.

The horizontal control seemed to be good and very few problems were encountered. As indicated previously, the control traverse had been adjusted by the least squares method prior to using it for control in the strip adjustment.

Computation

Program 35 was processed on the IBM 360 computer. Average run time for a flight line of seven models was 3 minutes. The program was also revised to fit the IBM 1401 computer. Average run time for a flight line of seven models was 10 minutes.

The Three-Photo Aerotriangulation Program was processed on the IBM 7030 (STRETCH) computer of the Naval Weapons Laboratory at Dahlgren, Virginia. Average run time for a flight line of seven models (6 triplets) was 30 seconds.

The Aerotriangulation Strip Adjustment Program was performed on the IBM 1620 computer. Average run time for a flight line of seven models was 12 minutes.

TABLE 2

STANDARD DEVIATIONS FOR CONTROL DATA

Flight Line	No. Model	No. Control H	No. Control V	3 Photo RMSE (fl. li. avg.)	Final Adjustment—Control Used STDX (micron)	STDY (micron)	STDX & STDY (micron)	STDZ (micron)
1*	6	5	9	1.7408	2.988	2.062	3.630	3.392
2	8	7	12	2.7109	5.836	8.369	10.203	8.313
3	9	5	10	3.4794	2.347	3.722	4.401	6.653
4	13	7	14	3.3879	5.378	8.920	10.416	23.077
5	6	5	11	3.3745	12.674	9.786	16.013	17.857
6	15	9	16	3.625	11.585	12.171	16.803	17.374
8	8	5	11	2.8027	4.102	4.958	6.435	12.573
9	15	6	15	3.5386	39.476	43.635	58.842	27.771
10	7	6	11	2.9973	10.515	10.456	14.829	17.688
11	6	5	9	2.5941	3.654	3.300	4.924	7.808
14	9	6	13	3.2901	13.913	21.338	25.473	12.291
15	7	4	8	5.0042	12.632	13.271	18.322	5.552
16	4	4	8	2.6254	10.338	3.436	10.894	2.517
17	8	7	12	2.3073	7.890	10.438	13.085	8.944
18	8	4	10	2.8230	4.084	4.737	6.255	12.162
19	8	5	13	2.4863	2.170	5.907	6.293	22.441
20	7	6	9	2.4395	40.994	46.074	61.671	6.754
21	4	4	7	5.1624	2.241	4.047	4.627	.0000
22	5	4	7	2.0432	10.405	29.441	31.226	.0000
23	7	4	9	2.5342	3.782	6.709	7.702	15.748
24	16	10	19	2.5110	20.711	9.546	22.805	19.728
25	8	7	10	3.9626	7.944	17.099	18.854	9.332
26	12	9	13	2.3234	19.013	27.824	33.699	21.895
27*	7	4	10	3.9623	0.097	3.075	3.076	9.742
28	8	5	10	2.5961	3.341	9.740	10.297	34.358
29	9	6	13	2.9733	9.051	6.097	10.914	7.795
30	5	5	9	3.3040	0.748	2.087	2.217	3.829
Project avg. (microns)				3.059	9.922	12.157	16.070	12.429
Project avg. (ft)					0.20	0.24	0.32	0.25

*No horizontal test points in this strip.

Mapping

Frequent liaison with the mapper was maintained to monitor progress of the work. The mapper experienced very few problems in setting up the models or in compilation. A few transcribing errors in the coordinate data for isolated points caused momentary problems, but these were easily corrected.

RESULTS

The overall results from the analytical triangulation were well within the accuracy required for this project. It should be emphasized that the work was performed on a production basis and not as a research project.

Table 2 gives the results of the three-photo aerotriangulation and final aerotriangulation strip adjustment. Definitions for abbreviations used in Table 2 follow:

1. RMSE—This is the strip average root-mean-square value of all residual parallaxes for all the pass points of the triplet expressed in microns at negative scale.
2. STDX & STDY—Standard deviation (root-mean-square-deviation) of all the horizontal control used in strip adjustment in microns at negative scale.
3. STDXY—Standard deviation vector (position) of horizontal control used in strip adjustment in microns at negative scale.
4. STDZ—Standard deviation (root-mean-square) of all vertical control used in strip adjustment in microns at negative scale.

The RMSE from the three-photo program gives an indication of how well the pass points in the strip were measured. In only one instance did the pass point measurements exceed the 25-micron rejection limit. This, in turn, did not affect the analysis of the strip because the other pass point of the set was substituted for the rejected point and used twice in the computations.

TABLE 3

PROJECT TEST POINT RESULTS

	Horizontal Control			Vertical Control	
	No. Points	X (ft)	Y (ft)	No. Points	Z (ft)
Project RMSE	49	0.41	0.88	77	0.49
Algebraic mean	49	-0.015	+0.059	77	-0.011

TABLE 4

QUESTIONABLE TEST POINT RESULTS

	T-67F	T-67
X	-0.46 ft	-0.60 ft
Y	-3.81 ft	+2.52 ft

The standard deviations are a confidence criteria relative to the validity of the strip adjustment. Since 1 micron at photo scale represents approximately 0.02 foot on the ground, the project average STDXY and STDZ for the control points were 0.32 foot and 0.25 foot, respectively.

Test points were regular targeted traverse and wing points with known field position. These points were measured with the other field control and selected as test points when setting up the data for the final strip adjustment. Many points that were noted on the comparator sheets as being difficult to measure, partially destroyed, or having poor precision were withheld from the control and were used as test points. The remaining targeted points not used for control were also used for test points.

In some cases test points were not uniformly distributed through the strips. The computed ground coordinates and elevations of the test points were compared with the field values and the RMSE for X, Y, and Z computed. Table 3 indicates the overall project accuracy obtained based on test point values. It should be noted that each flight line was drilled, measured, and computed independently from the other flight lines.

The RMSE for Y in Table 3 contains two test points from flight line 18 that are questionable. Their deviations from the traverse values are given in Table 4.

A recheck of the photographs did not indicate poor target visibility or a large amount of target distortion. With discrepancies this large, they should be classed as blunders. Two hypotheses can be suggested for these deviations: (a) operator difficulty in pointing during comparator measurement of these targets, and (b) error in original field survey data.

Additional computer work (a first- or second-degree adjustment) and varying the control points would probably give a better indication of the cause of these blunders. By withholding these blunders from the RMSE computation for Y, this value would have been 0.59 foot instead of 0.88 foot. This would make the RMSE for Y more compatible with the RMSE for X. Since X and Y are interrelated, it seems reasonable to assume their RMSE's should be near the same magnitude.

CONCLUSIONS

The USC&GS system of analytical aerial triangulation proved to be a satisfactory method for obtaining supplemental control for large-scale mapping. The cost to obtain these data by ground survey methods would have made this project economically unfeasible.

Based on the experience gained on this project the following conclusions are presented:

1. An 80-mile project is too long. Future projects will be limited to a maximum length of 50 miles with traverse closures every 25 miles. This will improve survey procedure and will reduce the tremendous amount of data handling.

2. Target design and placement is critical to precise comparator measurements. Major problems occur when sufficient contrast is not maintained between the target

and its photographic background. When using photo-identified control points, special care should be exercised to select finite points that can be readily identified by the comparator operator.

3. High-contrast glass plates are recommended for use in a stereocomparator to accentuate the targeted points.

4. Pass points should be of sufficient diameter to be easily recognized during map compilation. A 150-micron diameter hole is recommended when using a Kelsh instrument.

5. Results from the analytic aerial triangulation can be improved by more effective control placement during the basic control survey.

6. High-speed computers with large storage capacity must be used to perform analytic computations efficiently and economically. Small-capacity computers require considerable segmentation of the programs resulting in excessive card handling.

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