Forest Service Procedure for Stereotriangulation Adjustment by Electronic Computer

PART I

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IN MARCH 1957 a new Stereoplanigraph C-8 was installed in the Regional Office of the Intermountain Region of the U. S. Forest Service. It was required specifically for use in road location and design surveys through the medium of photogrammetry. With the Stereoplanigraph came the problems of relating the bridged positions of selected photo points, recorded by the Stereoplanigraph counter in the form of *x*, *y* and *z* coordinates, to true ground coordinates. The graphic or stereotemplet method for locating ground positions from aerial photos was no longer applicable or adequate.

In order to develop new methods and procedures that would be applicable to using the Stereoplanigraph as a road survey tool, it became necessary for Forest Service personnel to become familiar with a new and highly complex phase of photogrammetry and photogrammetric equipment.

Arrangements were made with the U. S. Coast and Geodetic Survey in Washington, D.C. to provide the initial pre-delivery training and orientation on stereoplanigraph equipment and procedures. This opportunity is taken to express sincere appreciation for their fine cooperation.

The photogrammetric unit of that agency, under the direction of G. C. Tewinkel, had developed a combination graphical and mathematical system for correcting and transformation machine coordinate data to ground equivalents, irrespective of direction of flight lines.[1]

After becoming familiar with the Coast Survey's method of coordinate rotation and correction, the merits and weaknesses of the system, as applied to our use, were analyzed. The adaptability to non-cardinal flight direction was of extreme importance since the majority of the photographic strips are governed by the general alignment of roads rather than by cardinal directions. The graphic part of the solution, however, left many opportunities for human error and was time-consuming. The Coast Survey itself considered the graphic step as an interim method necessary only until the whole procedure could be carried through mathematically.

As soon as the stereoplanigraph had been assembled, Mr. Herbert Trager—representative of Zeiss Aereotopograph, Munich—came to Ogden in order to provide a period of intensive training in calibration, operation, and bridging techniques. At the end of this training, Mr. Trager demonstrated the two following methods, these being those most frequently used in Europe for coordinate rotation and correction.

METHOD NO. 1:

This is the classic method of coordinate transformation and correction. Dr. Schwidefsky of Zeiss Aereotopograph is the author of the book of Photogrammetry used as text during the explanation. This method employs separate independent normal quadratic condition equations which are solved simultaneously for unknown constants for each of the three curves of error. The three major curves of error that the quadratic equation represents are scale, direction and *z*.

METHOD NO. 2:

The Helmert transformation in which all coordinates are reckoned from the gravicenter of all points under consideration. No attempt will be made to explain this method since it was not used in our final answer.

With the completion of these training periods, the staff of photogrammetrists in Ogden, with Mr. Trager acting as adviser, analyzed all of the methods under consideration and set up the following list of system requirements that our final method of coordinate correction must possess:

1. Entirely mathematical.
2. Accommodate non-cardinal photographic flights.

[1] The method consists of an adaptation of the general method developed by the Army Map Service and described by Robert S. Brandt, in PHOTOGRAMMETRIC ENGINEERING: Vol. XVII, No. 5, p. 806 (1951); and by Charles W. Price, Vol. XIX, No. 4, p. 627 (1953).

3. Adaptable to electronic computer processing.
4. Not lose any accuracy of the first-order Stereoplanigraph in the process of translating and relating stereoplanigraph coordinates to ground coordinates.

It was the belief that a system with such features would largely eliminate the introduction of human error in handling the coordinate data and, at the same time, erase the great time gap between actual machine operation and development of useable answers. Attendant with these would be a considerable reduction of man hours of labor and cost.

Work was initiated on the development of formulae and flow diagrams to accommodate the program. The contribution of Mr. Trager in this effort was excellent and extensive. After much research and revision, the flow diagram shown in Figure No. 1 was accepted as adequate.

It will be noted that the system utilizes the U. S. Coast and Geodetic Survey method of transforming and rotating field control coordinates into the system of stereoplanigraph coordinates for determination of ordinates of error. It then makes use of the classic mathematical condition equations, as taught by Mr. Trager, to solve for unknown constants simultaneously, and thus to determine the best least square fit for the correction curve. It then applies these constants in the final formulae to all measured points, correcting and transforming the machine coordinate data to state grid coordinates.

Following the development of this system, various electronic computer concerns were contacted in an effort to obtain assistance in the actual programming of the problem for the most appropriate computer equipment. The Los Angeles Applied Science Division of IBM, under the direction of Mr. Lloyd Hubbard, immediately scheduled the work in his unit. Within a few short weeks the program (see Part II) had been written by Mr. Bob Perry for the IBM 650.

The Forest Service then selected the project—designated the "Davis Mountain Road"—on the Wasatch National Forest, Utah, as the pilot project. It consists of 15 stereomodels of photography obtained at 1:8,000 scale. The model scale selected for machine operation was 1:4,000, and the plotting scale on the coordinatograph was 1:2,400. Approximately nine miles of road location are involved within the stereo-bridge. Field control was established by Wild T-2 theodolite and Zeiss self-leveling level.

The project had been corrected by the U. S. Coast and Geodetic Survey graphic curve system, prior to presenting it to IBM Corporation; hence, the possibility for comparison of the two systems was presented. This comparison of coordinate values is shown in Figure No. 2. It must be borne in mind in studying these values that the graphic curve procedure has no position correction dependent on the Z; hence, a small variation is expected. This motion is accounted for in the flow diagram by the BXZ term in equation #20. Furthermore, it is realized that the answers obtained by the graphic solution are based on human judgment, and probably should not be considered as reliable as those obtained mathematically.

The first answer obtained by the IBM 650 varied considerably from the graphic curve solution, and a rewrite of the program was required. Through the continued cooperation of the U. S. Coast and Geodetic Survey, Mr. Tewinkel joined IBM and U. S. Forest Service personnel in Los Angeles to assist in this last effort. At this meeting Mr. Tewinkel explained the difference between the mathematical formula the Coast and Geodetic Survey had developed and that of the Forest Service. He also said that the Coast and Geodetic Survey was in the process of publishing this information programmed for the IBM 650, at which time it would be available for direct comparison. No attempt will be made here to explain the difference of approach except that Mr. Tewinkel's formulae were dependent on one another, and might in this manner more closely control the secondary or first derivative effects of errors.

After Mr. Tewinkel had left this meeting a search was made through original IBM program with hopes of finding an error that would explain the large differences between the graphic and mathematical approaches. An error in sense of rotation was found; the program was adjusted, and rerun. The tabulated answers shown in Figure No. 2 were taken from the adjusted IBM 650 program whose origin is the U. S. Forest Service flow chart as originally submitted.[2] Computer time for

[2] *Note:* The corrected stereoplanigraph coordinates resulting from 7H of the flow diagram are not exactly at the selected model-scale. This is true because the ground coordinates were equated to the stereoplanigraph bridged coordinates in step 2H of the flow diagram. In order to arrive at exact model-scale coordinates the model-scale factor should be applied to the state grid metric coordinates resulting in step 9 and printed out. In addition, a print out of state grid coordinates in units of feet should be made.

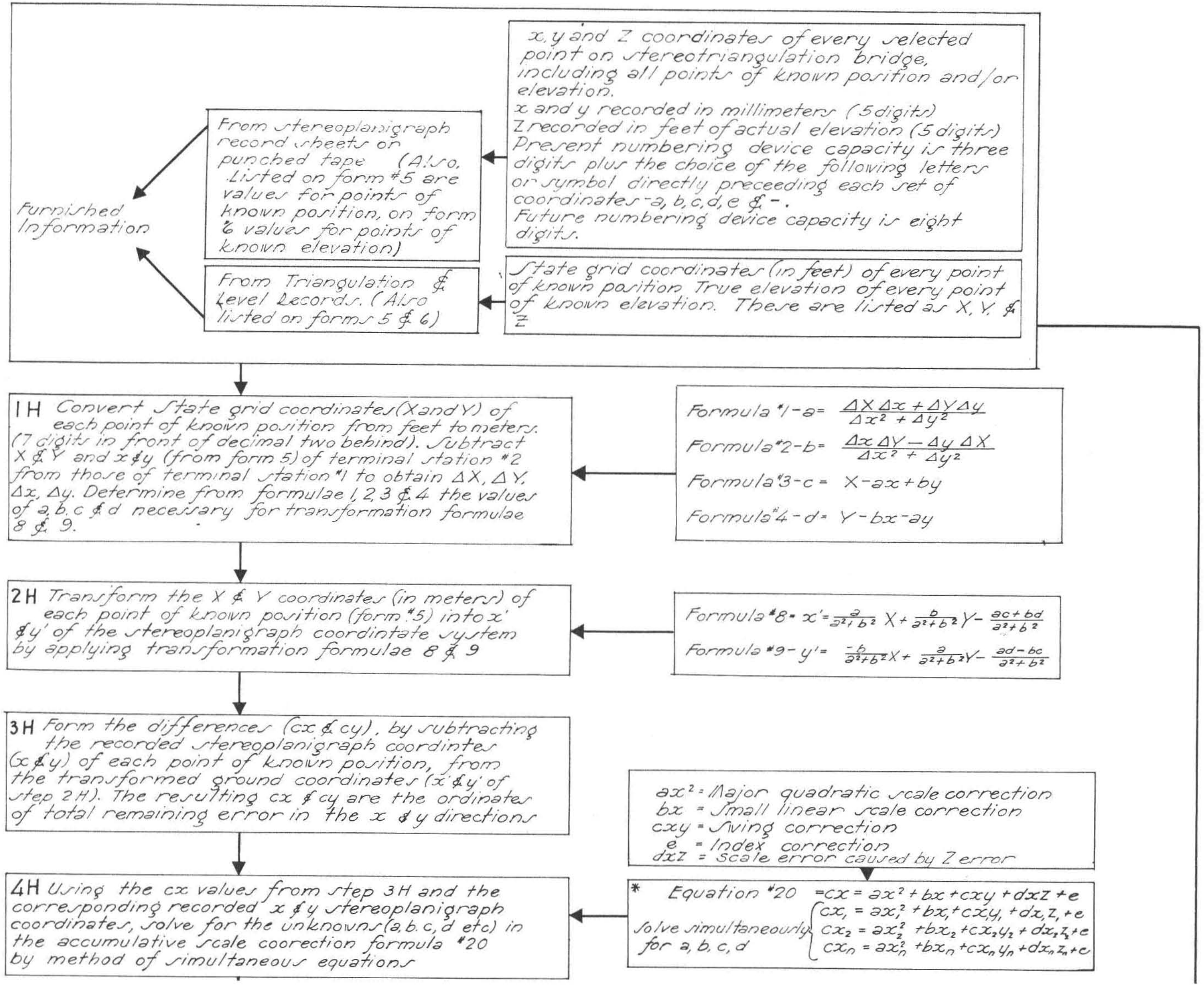
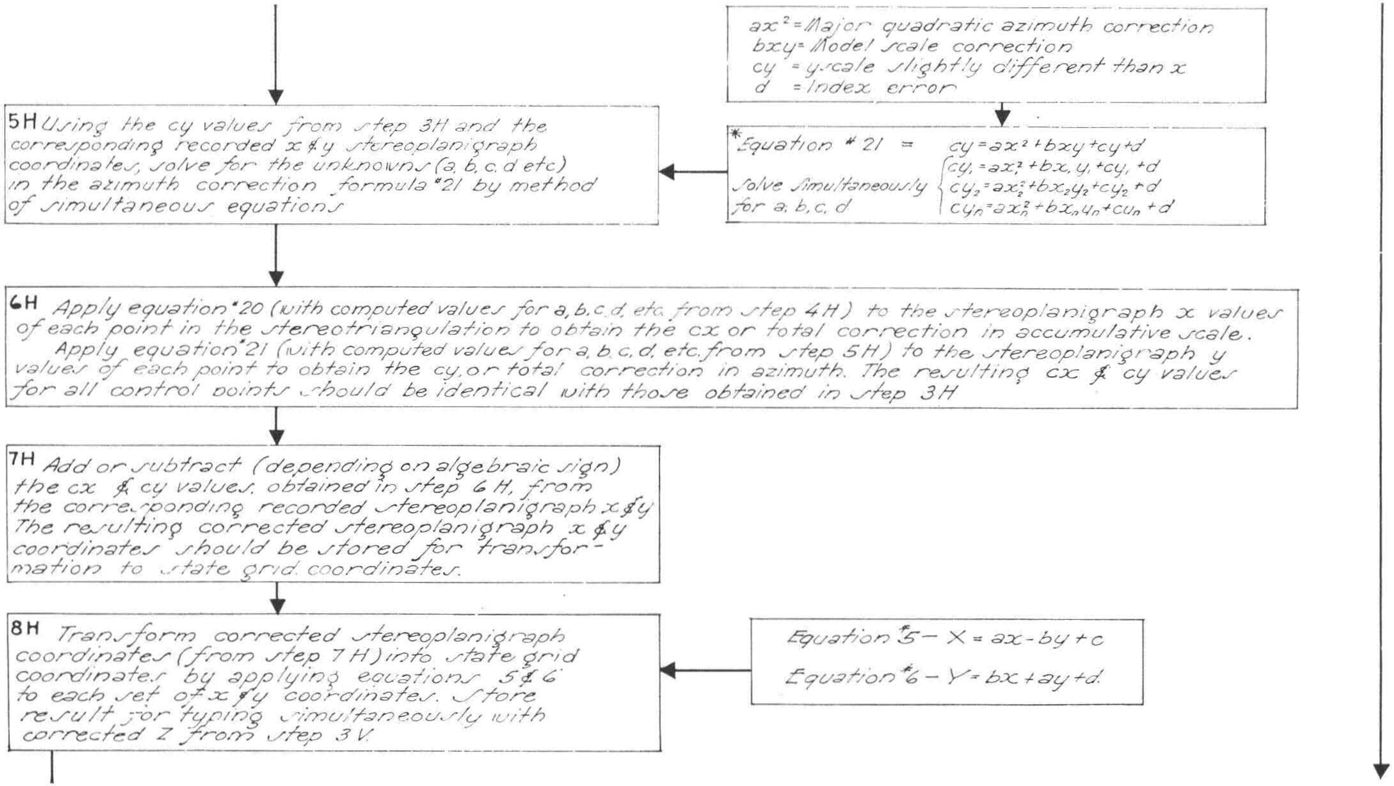
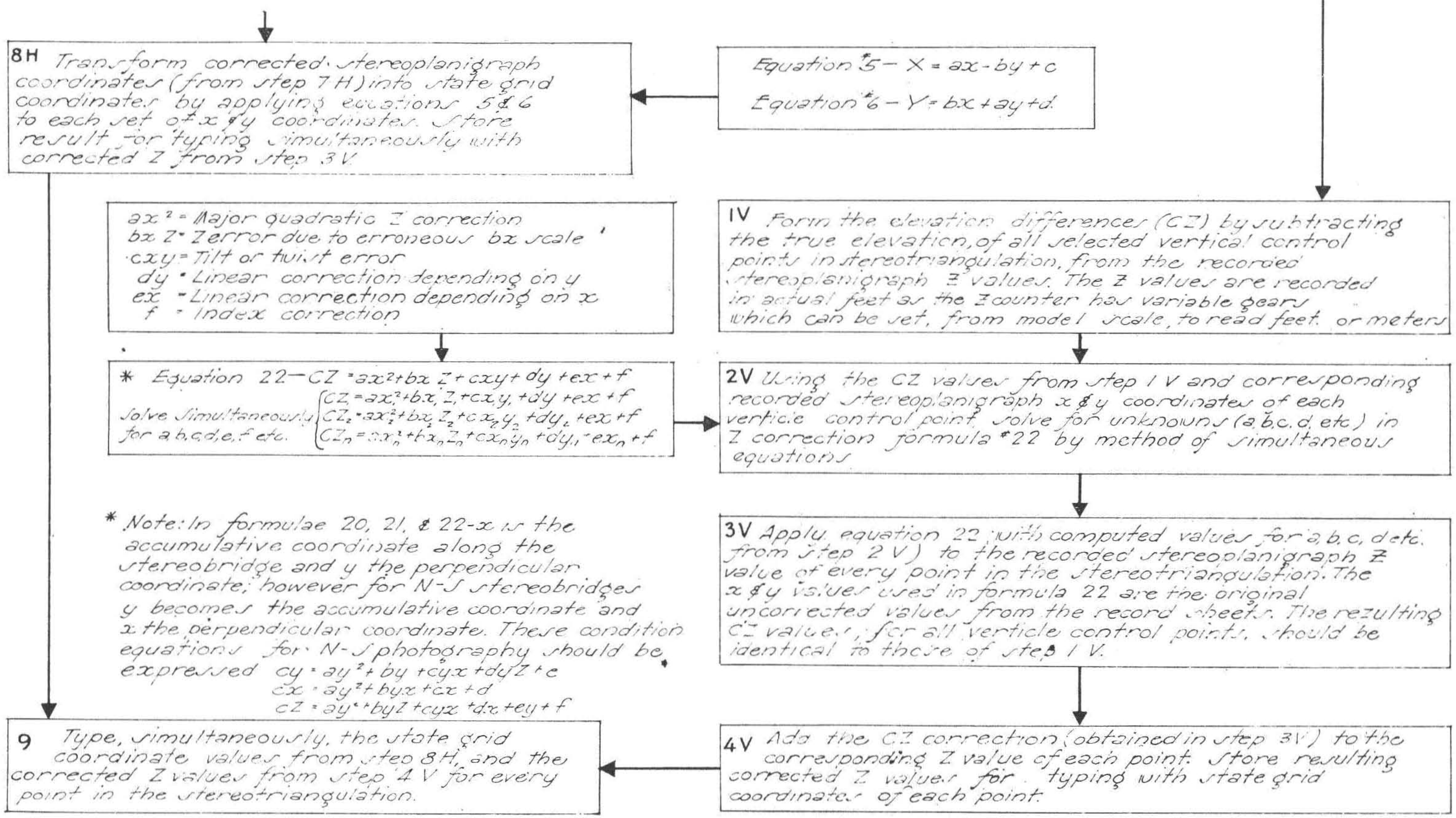


FIG. 1. Stereotriangulation Adjustment Flow Diagram, United States Forest Service, Region 4, Ogden, Utah

(*Continued on following pages*)



Flow Diagram Continued



Flow Diagram Concluded

FIG. 2

DAVIS MOUNTAIN STEREOTRIANGULATION RESULTS

Comparison of Corrected Values

WASATCH NATIONAL FOREST—REGION 4

	Point No. & Designation Control Designation	Point No.	Least Squares error of fit X (M)	Y (M)	Z(Ft)	Graphic X(M)	Mathematic X(M)
•	None	141	--	--	--	584233.377	584233.268
	"	142	--	--	---	584934.589	584934.700
	"	143	--	--	--	585673.451	585673.708
△	JEEP (USGS) (8650)	145	0.094-	0.030-	1.138	584914.246	584914.340
△	BUSH (USFS)	146	0.021-	0.036-	--	584906.152	584906.173
	None	151	--	--	--	584249.160	584249.081
	"	152	--	--	--	584930.120	584930.141
	"	153	--	--	--	585549.009	585549.129
□	USGS LEVELS (7496)	154	--	--	--	584405.108	584405.041
	None	155	--	--	--	584453.406	584453.363
	"	156	--	--	--	584983.196	584983.216
	"	157	--	--	--	585585.048	585585.218
	"	161	--	--	--	584267.818	584267.772
	"	162	--	--	--	584938.511	584938.535
	"	163	--	--	--	585681.592	585681.653
	"	171	--	--	--	584246.868	584246.860
	"	172	--	--	--	584937.672	584937.634
	"	173	--	--	--	585512.788	585512.890
□	USGS LEVELS (8114)	174	--	--	2.046-	584916.137	584916.124
△	2H USFS (8096.66)	175	0.168	0.165	1.837	585170.614	585170.446
	None	181	--	--	--	584291.736	584291.734
	"	182	--	--	--	584909.540	584909.538
	"	183	--	--	--	585712.917	585712.917
□	USGS LEVELS (8180)	184	--	--	0.540-	584414.514	584414.544
	None	191	--	--	--	584278.730	584278.820
	"	192	--	--	--	584921.900	584921.937
	"	193	--	--	--	585516.087	585516.071
∠	USFS VA (7530.03)	194	--	--	1.462	585406.345	585406.343
∠	USFS VA (8170.97)	195	--	--	4,077	584458.930	585459.092
	None	201	--	--	--	584274.726	584274.900
	"	202	--	--	--	584759.306	584759.445
	"	203	--	--	--	585583.038	585583.008
	"	211	--	--	--	584241.711	584241.988
	"	212	--	--	--	584826.370	584826.549
	"	213	--	--	--	585474.666	585474.722
△	3H USFS (8001.1)	214	0.154	0.048-	0.492-	584717.946	584717.792
	None	221	--	--	--	584160.193	584160.677
	"	222	--	--	--	584813.836	584814.122
	"	223	--	--	--	585537.194	585537.261

(Continued on following pages)

EXPLANATORY NOTE: The following completes the data for points 141 to 223, given on preceding page—*Ed*

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▲X	Graphic Y(M)	Mathematic Y(M)	▲Y	Graphic Z(Ft)	Mathematic Z(Ft)	▲Z
.109	64500.003	64500.427	-.424	7822.16	7820.420	1.74
-.111	64518.271	64518.271	-.000	8606.92	8605.251	1,67
-.257	64512.441	64512.175	.266	8004.40	8003.663	0.77
-.094	64744.017	64744.041	-.030	8649.90	8648.862	1.03
-.021	64730.374	64730.410	-.036	8647.32	8645.942	1.38
.079	65071.204	65071.684	-.480	8088.85	8087.383	1.47
-.021	65104.996	65105.113	-.117	8522.55	8521.946	0.604
-.120	65151.294	65151.141	.153	8009.32	8010.101	-0.781
.067	65305.851	65306.287	-.436	7947.07	7948.591	-1.521
.043	65081.000	65081.367	-.367	8258.35	8257.392	0.958
-.020	65240.729	65240.815	-.086	8539.12	8538.922	0.198
-.170	65203.130	65202.996	.134	8003.50	8004.740	-1.24
.046	65652.734	65653.350	-.616	7642.37	7642.967	-0.597
-.024	65669.470	65669.605	-.135	8443.61	8443.896	-0.286
-.061	65605.364	65605.249	.115	7777.24	7777.762	-0.522
.008	66176.085	66176.846	-.761	7409.92	7410.919	-0.999
.038	66251.608	66252.911	-.303	8128.76	*4131.264	ER
-.102	65995.864	65995.786	.078	7772.92	7771.554	1.366
.013	66227.721	66227.904	-.183	8114.82	8116.046	-1.226
.168	66843.569	66843.404	.165	8096.66	8097.437	-0.777
.002	66780.226	66780.839	-.608	8108.92	8110.045	-1.125
.002	66886.470	66886.718	-.248	8125.75	8126.306	-0.556
.000	66804.328	66804.328	.000	7269.08	7270.245	-1.165
-.030	66705.984	66706.497	-.513	8179.90	8180.540	-0.640
-.090	67360.354	67360.808	-.454	8705.69	8705.077	0.613
-.037	67457.201	67457.561	-.360	7902.29	7901.686	0.604
.016	67397.826	67397.929	-.103	7588.15	7587.400	0.750
.002	67817.913	67818.143	-.230	7530.57	7528.538	2.032
-.162	68021.040	68021.604	-.564	8168.82	8166.923	1.895
-.174	67891.189	*67898.569	- 7.380	8448.62	8447.503	1.117
-.139	68035.000	68035.500	-.500	7836.03	7835.001	1.029
.030	68066.922	68067.250	-.328	7062.87	7061.917	0.953
-.277	68472.730	68473.458	-.728	8093,63	8092.691	0.939
-.179	68595.492	68596.046	-.554	7649.32	7648.692	0.628
-.056	68675.911	68675.853	.058	7835.51	7833.879	1.631
.154	68399.341	68399.389	-.048	8001.75	8001.592	0.158
-.484	69171.119	69171.902	-.783	7966.86	7967.568	-0.708
-.286	69166.255	69166.818	-.563	7548.91	7548.934	-0.024
-.067	69252.570	69252.477	.093	7734.46	7733.271	1.189

* Obvious error in mathematical result.

FIG. 2—(*Continued*)

FIG. 2—(*Continued*)

Point No. & Designation Control Designation	*Point No.*	*Least squares error of fit* X (M)	Y (M)	Z (Pt)	*Graphic X(M)*	*Mathematic X(M)*
USFS VA (8021.78)	224	--	--	2.157-	584149.612	584150.124
" " (7723.17)	226	--	--	1.215	585027.110	585027.372
" " (7746.7)	227	--	--	1.348	584958.290	584958.580
None	231	--	--	--	584139.913	584140.534
"	232	--	--	--	584784.330	584784.686
"	233	--	--	--	585534.916	585534.987
4H USFS (7812.05)	234	0.220-	0.086-	0.802-	585121.227	585121.447
USFS LEVELS (7587.32)	235	--	--	0.039-	584944.160	584944.419
None	241	--	--	--	584139.080	584138.892
"	242	--	--	--	584734.272	584734.643
"	243	--	--	--	585474.075	585474.069
"	244	--	--	--	584254.371	584254.961
USFS LEVELS (7644.49)	246	--	--	0.151-	584710.619	584710.970
" " (7519.2)	247	--	--	0.801-	585244.072	585244.173
None	251	--	--	--	584053.000	584053.699
"	252	--	--	--	584713.470	584713.823
"	253	--	--	--	585404.249	585404.220
USFS LEVELS (7539.85)	254	--	--	0.447	585212.965	585213.042
" " (7586.88)	255	--	--	1.173	584324.177	584324.697
" " (7626.5)	256	--	--	2.736-	584436.210	584436.696
None	261	--	--	--	583958.930	583959.613
"	262	--	--	--	584640.454	584640.760
"	263	--	--	--	585353.862	585353.836
USFS LEVELS (7637.34)	266	--	--	0.131-	585035.244	585035.236
" " (7584.81)	267	--	--	0.849-	584986.218	584986.245
None	271	--	--	--	583831.576	583832.053
"	272	--	--	--	584597.439	584597.581
"	273	--	--	--	585292.451	585292.340
USFS LEVELS (7541.58)	275	--	--	0.882	584229.956	584230.366
" " (7453.85)	276	--	--	0.066-	584019.197	584019.612
5H USFS (7671.28)	277	0.187-	0.012	1.565	584558.801	584558.951
None	281	--	--	--	583776.838	583776.529
"	282	--	--	--	584565.499	584565.260
"	283	--	--	--	585300.681	585300.432
6H USFS (7637.7)	284	0.201	0.019	0.429-	584720.091	584719.890
USGS LEVELS (7229.6)	285	--	--	0.129-	584448.985	584448.875
" " (7367.9)	286	--	--	0.126-	584271.761	584271.920
None	287	--	--	--	583798.818	583798.686
"	288	--	--	--	584818.938	584818.791

(*Concluded on next page*)

EXPLANATORY NOTE: The above completes the data for points 224 to 288 on preceding page—*Ed.*

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▲X	Graphic Y(M)	Mathematic Y(M)	▲Y	Graphic Z(Ft)	Mathematic Z(Ft)	▲Z
-.512	69347.532	69348.276	-.744	8022.78	8023.957	-1.177
-.262	69907.101	69907.256	-.155	7722.59	7721.958	0.632
-.290	69704.315	69704.560	-.245	7745.86	7745.316	0.544
-.621	69759.102	69759.767	-.665	8078.43	8080.209	-1.771
-.356	69794.558	69794.916	-.363	7753.87	7754.737	-0.867
-.071	69830.489	69830.304	.185	7650.58	7649.829	0.751
-.220	69723.377	69723.463	-.086	7812.79	7812.802	0.488
-.259	70336.276	70336.474	-.198	7586.76	7587.339	-0.579
.188	70373.838	70374.333	-.495	7965.22	7966.877	-1.657
-.371	70428.085	70428.401	-.316	7640.69	7641.642	-0.952
.006	70432.088	70431.876	.212	7624.94	7624.383	0.557
-.590	70371.511	70371.991	-.480	7901.58	7903.122	-1.542
-.351	70517.001	70517.304	-.303	7643.64	7644.651	-1.011
-.101	70520.645	70520.644	.001	7519.95	7520.001	-0.050
-.699	70950.174	70950.647	-.473	7822.55	7824.830	-2.28
-.358	70983.105	70983.330	-.231	7580.20	7581.367	-1.167
.029	71070.217	71069.774	.443	7778.05	7777.173	0.877
-.077	71034.296	71034.168	.128	7539.37	7539.353	0.017
-.520	71356.965	71357.336	-.371	7585.51	7585.727	-0.217
-.486	70932.815	70933.205	-.390	7627.41	7629.236	-1.826
-.683	71532.409	71532.925	-.516	7668.99	7670.450	-1.460
-.306	71498.094	71498.273	-.179	7542.86	7543.680	-0.820
.026	71576.509	71575.799	.710	7994.29	7993.619	0.671
.008	72207.146	72206.852	.294	7636.88	7637.431	-0.551
-.027	72135.866	72135.582	-.284	7585.26	7585.649	-0.389
-.477	72123.406	72124.052	-.646	7500.90	7500.774	0.126
-.142	72206.607	72206.588	.019	7638.52	7638.660	-0.140
.111	72263.472	72263.009	.463	7608.61	7609.734	-1.124
-.380	71815.262	71815.633	-.371	7541.15	7540.718	0.432
-.415	72083.701	72084.246	.545	7453.77	7453.866	-0.096
-.150	72257.196	72257.159	.037	7670.72	7669.735	0.985
.309	72870.610	72871.400	-.790	7547.45	7546.190	1.26
.239	72867.822	72867.954	-.132	7620.11	7620.780	-0.670
.249	72967.628	72967.643	-.015	7204.72	7207.479	-2.759
.201	72810.837	72810.818	.019	7637.40	7638.129	-0.729
.110	72680.075	72680.641	-.566	7229.98	7229.729	0.251
-.159	72317.635	72318.090	-.455	7368.09	7368.026	0.064
.132	72734.164	72734.844	-.680	7606.56	7604.903	-1.637
.147	72745.826	72745.682	.144	7662.79	7663.221	-0.431

FIG. 2—(*Concluded*)

the entire flow chart was 15 minutes as compared to 15 man days for the graphic solution.

Additional projects are now being prepared for correction and adjustment. One consists of a flight line 80 stereo-models in length on which field control has been established in excess of requirements. It is planned to complete the adjustment of this stereo-bridge with the IBM 650 at least three times, and varying the intensity and location of field control in each case. In this way we hope to learn much about minimum control requirements for road location purposes.

This program has answered our needs as of this writing. It may be that further refinements and adjustments will be required in uses other than for National Forest road locations. Continued efforts to improve the program are anticipated. Any comments or suggestions by others who may choose to use it will be welcomed.

PART II*

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ABSTRACT: PURPOSE.—*This program for the IBM Type 650 has been set up to accomplish the horizontal and vertical adjustment of a stereobridge for a single strip of aerial photographs.*

METHOD.—*On the basis of known horizontal and vertical "control" points, the stereo-bridge is adjusted both horizontally and vertically to give a best least squares fit to the known points. There are no limits to the numbers of horizontal, vertical and pass-points. A strip consisting of 80 points of which 25 are vertical points and 7 are horizontal control-points can be adjusted in 12 minutes. Computations are performed in a floating decimal mode. However, the optional floating point hardware on the computer is not used. Thus, the program can be used on any 2,000 word Type 650 presently in the field.*

650 PROGRAM WRITE-UP

A. *Title:* Aerial Survey Triangulation; Single Strip.

B. *Author and Date:* O. R. Perry, November 22, 1957.

C. *Installation:* Applied Science, Santa Monica Branch Office.

D. *Purpose*: Determine the ground-coordinates of points read stereometrically from film.

E. *Justification:* This type of routine was not previously available.

F. *Detailed Statement of Problem:*

1. *Origin of Data*

A strip of terrain to be mapped is photographed from the air. The photographs are so taken that each ground point appears on two consecutive photographs. Following processing, the film plates are mounted in a Stereoplanigraph and all "interesting points" are "read" giving rise to horizontal and vertical "instrument-coordinates." The stereoplanigraph is so adjusted that the vertical reading is recorded directly in the units of feet or meters as desired. Horizontal units are simply millimeters or "instrument units." In addition to instrument data, a variable amount of "control data" is required. These latter data consist of actual ground-coordinates of several points in the strip.

Computation consists of determining a series of transformations which transform the instrument-coordinates of control-points into the actual ground-coordinates of these points. These transformations are then applied to all instrument readings furnished,

* Distributed by IBM Applied Science, Western Region (c/o District 17) Los Angeles, 1958.

thereby determining ground-coordinates for all points.

2. *Notation*

a. Coordinates

X: Ground-coordinate; accumulative (any units)[1]
Y: Ground-coordinate; lateral (units same as for X)[1]
Z: Ground-coordinate; elevation (any units)
x: Instrument-coordinate; accumulative (any units)
y: Instrument-coordinate; lateral (any units)
z: Instrument-coordinate; elevation (same coordinates as Z)
X_0: Ground-coordinate; accumulative reference[2]
Y_0: Ground-coordinate; lateral reference[2]

b. Coefficients

These quantities are defined by the equations in which they occur. Subscripts are used to denote transformation number.

3. *Transformation Computations*

The following steps must be accomplished in computing the transformations:

a. Determine A_1, B_1, C_1, and D_1 for the following transformation.

$$\left.\begin{aligned} x' &= A_1(X - X_0) + B_1(Y - Y_0) + C_1 \\ y' &= A_1(Y - Y_0) - B_1(X - X_0) + D_1 \end{aligned}\right\} \quad \text{Trans. \#1.}$$

The computation is performed in such a way that the ground coordinates of terminal points 1 and 2 are transformed to the instrument coordinates of terminal points 1 and 2 exactly. ("Terminal points" are specified by the customer.)

b. Determine A_2, B_2, C_2, and D_2 for the following transformation.

$$\left.\begin{aligned} X - X_0 &= A_2x' - B_2y' + C_1 \\ Y - Y_0 &= A_2y' + B_2x' + D_2 \end{aligned}\right\} \quad \text{Trans. \#2.}$$

The computation is so performed that the instrument-coordinates of terminal points 1 and 2 are transformed to the ground-coordinates of terminal points 1 and 2 exactly. It will be noted that trans. #2 is the inverse of trans. #1.

c. Apply transformation #1 to all horizontal control points thereby computing x' and y' for all such points.

d. Compute cx and cy for all horizontal control points as follows:

$$cx' = x' - x$$
$$cy' = y' - y$$

e. Determine A_3, B_3, C_3, D_3, E_3 for the following transformation.

$$cx = A_3x^2 + B_3x + C_3xy + D_3xz + E_3 \quad \text{Trans. \#3.}$$

The computations to be performed in such a way that $\sum(cx_i - cx_i')^2$ is minimal (where i denotes the ith horizontal control point).

f. Determine A_4, B_4, C_4, D_4 for the following transformation.

$$cy = A_4x^2 + B_4xy + C_4y + D_4 \quad \text{Trans. \#4.}$$

The computations to be performed in such a way that $\sum(cy_i - cy_i)$ is minimal (where i denotes the ith horizontal control point).

g. Determine A_5, B_5, C_5, D_5, F_5 for the following transformation.

$$Z' = A_5x^2 + B_5xz + C_5xy + D_5Y + E_5x + F_5 + z \quad \text{Trans. \#5.}$$

The computations to be performed in such a way that $\sum(Z_i' - Z_i)^2$ is minimal (where i denotes the ith elevation control point).

4. *Ground Coordinate Computations*

The following steps are performed for all points in the strip.

a. Apply transformations #3 and #4 (computing cx and cy).

b. Compute

$$x' = cx - x$$
$$y' = cy - y$$

c. Apply trans. #2 (computing $X - X_0$ and $Y - Y_0$)

d. Add X_0 and Y_0 to get computed ground coordinates X and Y.

e. Apply transformation #5 thereby computing Z', the computed ground coordinate.

G. *Derivation or Reference:* Stereotriangulation Adjustment Flow Diagram; U. S. Forest Service; Region 4; Ogden, Utah.

H. *Accuracy and Range:* There are no limitations of the number of points involved. Since computations are performed in floating-point,

[1] For flights which are not strictly north-south or east-west, the terms "accumulative" and "lateral" as applied to X and Y may be ambiguous. In this case, if a rotation of A degrees will rotate the positive x axis into the positive y axis; X and Y must be designated so that a rotation of A degrees will rotate the positive X axis into the positive Y axis.

[2] These numbers are arbitrary but are actually chosen as the ground-coordinates of terminal point #2. They remain fixed throughout the computation.

accuracy of computation is well above the accuracy of the data. The method used is not an elaborate one; accuracy could be improved by further complication of the method.

I. *Type of Routine:* Self-contained engineering procedure.

J. *Calling Sequence:*

Console Settings:

Storage entry switches
70 1951 9900
(If program is already on drum, set to
00 0000 0350).

Programmed: Stop
Half Cycle: Run
Address selection: Any
Control: Run
Display: Program register
Overflow: Sense
Error: Stop
Loading of the program automatically transfers control to start processing.

K. *Symbol Definition in Calling Sequence:* Not applicable.

L. *Input Format:*

Data cards have the format given below.

The order of the cards during processing is very important. The prescribed order is as follows:

Terminal #2 card
Terminal #1 card
All horizontal control cards
Spacer card (blank except for zeros in cols. 1–10)
All vertical control cards
Spacer card (as above)
All points

In order to achieve this ordering, some of the cards must be duplicated; possibly as many as three times. For example, a card may appear as a terminal card, a horizontal-control card, a vertical-control card, and (of course) in the "all cards" portion of the deck. The card code can be used to advantage in achieving this ordering.

It should be noted that the Type 533 panel to be used may require 12 punches for plus signs.

M. *Output Format:* Two types of cards will be punched: Coefficient cards and results cards.

FORMAT OF THE DATA CARDS

Card Col.	*Item*	*Units*	*Decimal Point Location*
1	"9"	—	—
2	card code*	—	—
3–10	identification	numeric**	—
11–20	x***	any	No figures to right of dec. pt.
21–30	y***	same as for x	No figures to right of dec. pt.
31–40	z	any	3 figures to right of dec. pt.
41–50	X***	any	3 figures to right of dec. pt.
51–60	Y****	same as for X	3 figures to right of dec. pt.
61–70	Z****	same as for z	3 figures to right of dec. pt.
71–80	strip identification*****	—	—

* The card code is defined as follows:

Code	*Definition*
1	horizontal-control pt. but not vertical-control point
2	horizontal and vertical-control point
3	vertical-control pt. but not horizontal-control point
4	pass point-(no vertical or horizontal-control).

** Identification should ordinarily be numeric. However, if the alphabetic feature is available, alphabetic identification can be used by making the following changes:

cc 1–5	blank
cc 6	card code
cc 7–10	alphabetic identification

*** Since any units can be used for x and y, the decimal point location is actually arbitrary. However, the transformation coefficients will be computed as if the decimal point were at the right. This remark holds for other items as well.

**** These fields should be left blank when data are not available.

***** The strip identification is any arbitrary coding. It should be identical for all data cards from any one strip.

Coefficient cards are punched as follows:

Card Col.	Item
1–9	837961759†
10	Transformation #
11–20	Coefficient *A* for this transformation
21–30	Coefficient *B* for this transformation
31–40	Coefficient *C* for this transformation
41–50	Coefficient *D* for this transformation
51–60	Coefficient *E* for this transformation
61–70	Coefficient *F* for this transformation
71–80	Strip identification (in the same form as on input cards)

All coefficients are punched in floating decimal form as follows:

$$x_1x_2x_3x_4x_5x_6x_7x_8x_9x_{10}\pm$$

should be interpreted as

$$(\pm x_1 \cdot x_2x_3x_4x_5x_6x_7x_8)10^{x_9x_{10}-50}$$

Thus, for example,

1234567842+ represents $(1.2345678)10^{-8}$.

Result cards are punched as follows:

Card Col.	Item
1–10	Identification, same as input card
11–20	*X* as computed
21–30	*Y* as computed
31–40	*Z* as computed
41–50	delta *X* } difference between computed
51–60	delta *Y* } and actual values (zero if
61–70	delta *Z* } "actual" is not available).
71–80	Strip identification

All data quantities on the result cards have three figures to the right of the decimal point.

N. *Status on Exit:* Computer stops with a "Read Card" command.

O. *Stops Explicitly Stated:* None.

P. *Error Return and Error Code:* All error stops should indicate overflow during pseudo-floating-point operations. These will always be "storage selection errors" with addresses "99XX." In addition, faulty arrangement of cards can cause a "distributor error" consisting of blanks. This latter type of indication cannot be assured since this type of error cannot always be detected by the program.

Computation should be restarted from the beginning of the deck: the program begins at location 0350.

Q. *Overflow and Underflow Technique:* No general rule can be stated. If cards have been punched and sorted properly, no overflow should occur.

† If the alphabetic device is used, cols. 1–5 will be blank and cols. 6–9 will contain the word "TRAN," an abbreviation of "transformation."

R. *Special Coding Information:* None.

S. *Amount of Storage Required and Amount of Erasable Required:*

Approximately 1,700 cells are utilized. Of this amount,

approx. 300 are erasable.
approx. 500 are floating point routines.
approx. 900 are programming.

The remaining cells are not in one block but are scattered. If modifications to the program are required, it is suggested that the drum be cleared, the program loaded, and a print-out be accomplished. Any blank cells between 800 and 1,500 are available.

T. *Timing:* Timing depends on the amount of data involved. As a typical figure, a strip containing 80 points of which 25 are vertical-control points and 7 are horizontal-control points can be adjusted in 12 minutes.

U. *Other Subroutines or Systems Required:* None.

The program deck furnished contains the required floating point routines (package 4 of FORTRANSIT)

V. *Components:* Standard 2,000 word type 650. If the alphabetic device is available, it can be used as described elsewhere.

W. *Name of Board Required:* Standard "80-80 Read and 80-80 Punch." Col. 1 is wired to "Load." If the alphabetic feature is used, word 1 should be wired for alphabetic from cols. 6–10 on both read and punch: the remainder of the panel being identical to the 80-80 panel.

X. *Description of Test Problem:* A complete set of data and results for a typical strip are contained in Appendix V. In addition to this, sample data and result cards will be furnished with the program deck.

Y. *Status:* Debugged for test data.

Appendix III: Process Chart

The entire problem has been programmed in 4 "phases" and 2 subroutines.

Phase I: Compute trans 1 and trans 2 (Figure 3).

Phase II: Compute trans 3 and trans 4 (Figure 4).

Phase III: Compute trans 5 (Figure 4).

Phase IV: Apply all transformations (Figure 5).

Subroutine #1: "Float" input data (Figure 3).

Subroutine #2: Solve "n" simultaneous linear equations (Figure 1).

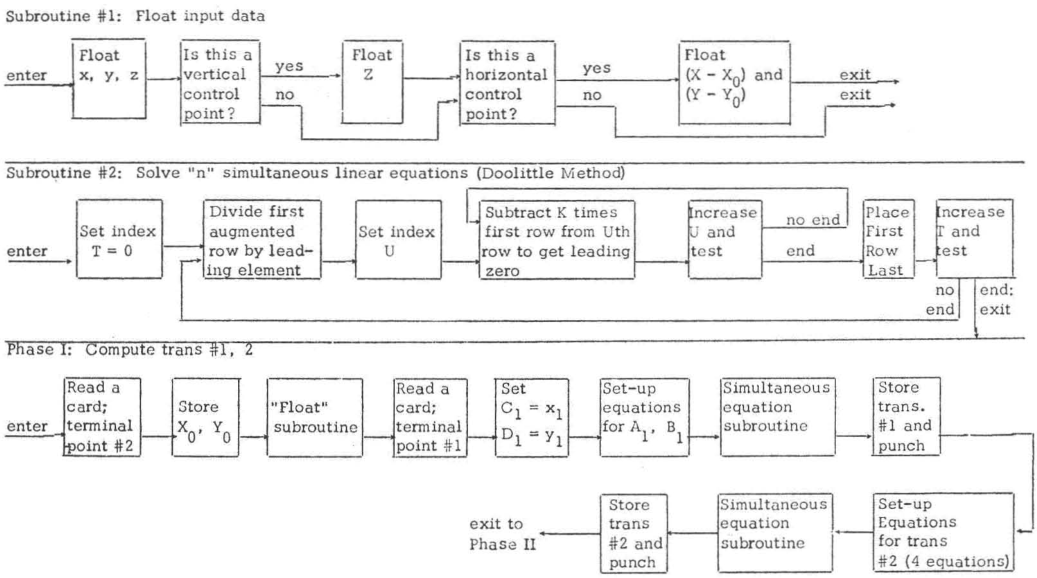

FIG. 3. Subroutine No. 1. Float Input Data.
Subroutine No. 2. Solve n simultaneous linear equations.
Phase I. Compute Trans 1 and Trans 2.

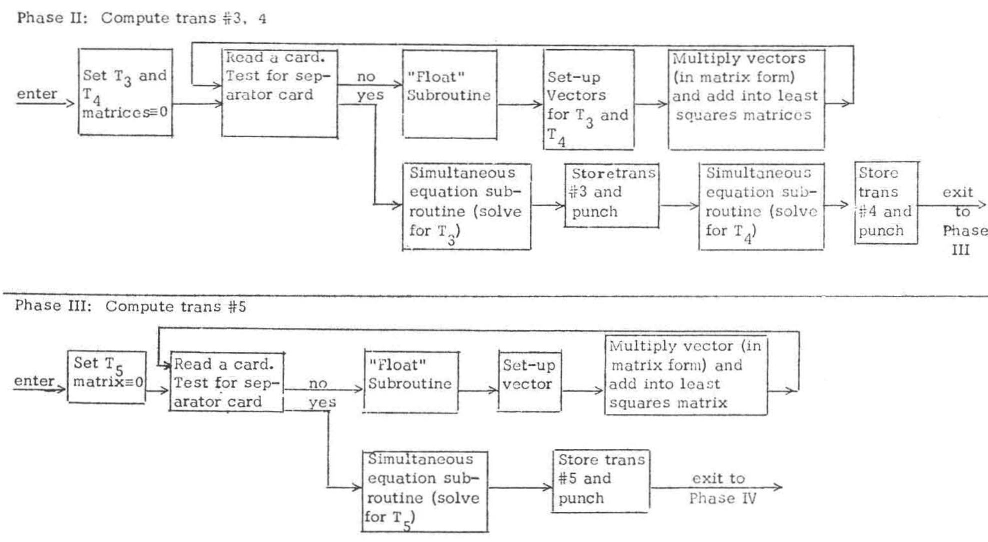

FIG. 4. Phase II. Compute Trans 3 and Trans 4.
Phase III. Compute Trans 5.

Phase IV: Apply all transformations

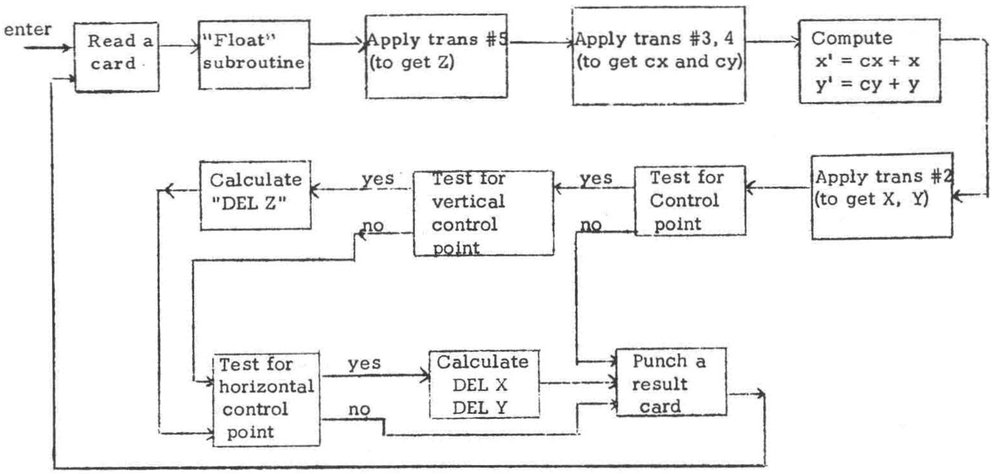

FIG. 5. Phase IV. Apply all Transformations.

APPENDIX V: CHECK PROBLEM

I. *Data*

North-South Photography
Terminal point #1: Stereo #146
Terminal point #2: Stereo #284
Strip identification: 64

Stereo No.	y(mm.)	x(mm.)	z(ft.)	Y(ft.)	X(ft.)	Z(ft.)
145	447.49	231.89	8,678.9	584,914.246	64,744.011	8,650.0
146	445.19	228.70	8,676.0	584,906.152	64,730.374	
175	554.79	744.19	8,111.8	585,170.614	66,843.569	8,095.6
214	475.81	1,137.41	8,002.5	584,717.946	68,399.341	8,001.1
234	603.20	1,455.65	7,813.6	585,121.127	69,723.377	7,812.0
241	374.34	1,636.69	7,960.8			
251	365.37	1,780.64	7,819.1			
253	701.25	1,782.01	7,779.1			
261	354.32	1,926.25	7,665.8			
277	517.45	2,092.58	7,670.4	584,558.764	72,257.171	7,671.3
284	568.78	2,225.91	7,641.8	584,720.091	72,810.837	7,637.7
286	447.85	2,113.49	7,367.4			7,367.9

II. *Results*

Results appear on Table A. Headings were inserted manually before listing for the purpose of clarification.

TABLE A

AERIAL SURVEY SAMPLE

STRIP 64

FLTG PT	A	B	C	D	E	F
TRAN 1	2466823251	2097503150–	2225910055	5687800054		
TRAN 2	4024698948	3422142247–	9153262053–	1527430353–		
TRAN 3	3053645041–	1924217247	5323737341–	1154699343–	1325147751–	
TRAN 4	1640740841	8212895141–	7728129146	2628994151–		
TRAN 5	1699996541–	6991376041	3061298541	8639890746–	3698850946	2785798050–
PT ID	*X*	*Y*	*Z*	DEL *X*	DEL *Y*	DEL *Z*
145	64744.041	584914.340	8649.698	.030–	.094–	.302
146	64730.410	584906.173	8646.824	.036–	.021–	
175	66843.404	585170.466	8096.052	.165	.168	.452–
214	68399.389	584717.792	8001.614	.048–	.154	.514–
234	69723.463	585121.447	7811.350	.086–	.220–	.650
241	70374.333	584138.892	7968.536			
251	70950.647	584053.699	7826.359			
253	71069.774	585404.220	7775.603			
261	71532.925	583959.613	7671.790			
277	72257.159	584558.951	7670.237	.012	.187–	1.063
284	72810.818	584719.890	7638.626	.019	.201	.926–
286	72318.090	584271.920	7368.021			.121–

Sociogrammetry

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THE PROBLEM

SOME time ago 172 Kenya Africans were killed when tribesmen from across the border made three successive raids; two battalions of King's African Rifles were rushed to the scene. A series of enquiries into the causes of this, the largest of frontier disturbances, was instituted. Following a long period of calm, both of the two old tribal enemies had moved into the neutral zone which had been planned to be a separation area. This movement no doubt was due to urgent need for grazing land and by growing numbers. Control had become lax. The fighting not only caused a heavy loss of life, but it created new enmities with cries for vengeance, and with fears that in this already disturbed continent, new problems are to be added.

The raids came as a surprise. The Kenya Police is large and mobile and has an air wing. It also has made several studies using air photography. What appears to have escaped the observation of the local authorities is that these air photographs could be used in tribal administration. This is perhaps less curious than it at first appears, because information is deficient in the general area of cooperation between the photo interpreter and the administrator, or of even greater significance, between air surveyors and social surveyors.

It is the purpose of this paper to examine what the social scientist might be able to contribute to the kind of aerial survey that so often is commissioned by governments in the hungry parts of the world; where human needs are crying out for more man-power research, census work, urbanization studies, information on migration patterns, that is in