TABLE 1. WORLD AIR PHOTO COVERAGE DATA—PART VI (*Continued*)

S P E C I F I C					
PHOTO YEAR	PHOTO SIZE	COST PER PHOTO	AVAIL-ABLE TO NON-NATION-ALS	SAMPLES AT U.W. M.& A.P. LIBRARY	MAIN HOLDING AGENCY
1940	9 x 9 in.		Yes	Yes	Servicio Geografico del Ejercito or Cia. Mexicana Aerofoto, Mexico City, D.F.; Photographic Records & Services Div.,U.S.A.F.Aeronautical Chart & Information Center,Wash.D.C.
				No	
				No	
				No	Servicio Aerofotografico Nacional, Lima, Peru
				No	C.B.A.S., Paramaribo, Surinam
1938				No	
	9 x 9 in.			Yes	Ministerio de Obras Publicas, Caracas, Venezuela

office in the country concerned.

Much remains to be done in the assembly of information about world air photo coverage. It must be recognized that any tendency to conceal data about air photos should be modified. Much old coverage is valuable for current research and historical characteristics and has lost its military significance. Further, many detailed maps and documentary source materials already available negate a large part of the possible military use of air photos. To deny availability of data on air photos, or of the photography itself, is to stifle research. To supply such information is to guarantee the increased use of air photos for interpretation, photogrammetry, and in field mapping and, thereby, to improve research techniques and results.

*Photographic Image Identification Errors and Their Effect on Determination of Tilt and Resection**

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(*Abstract is on following page*)

THIS paper is a report of an investigation

1) to determine the magnitude of discrepancies resulting from image misidentification during measurement of photographic coordinates;
2) to ascertain the effects of these discrepancies on orientation and resection computations using a modified form of the Church "Post-card" Method; and
3) to determine whether the results of the computations involving coordi-

* Portions of a thesis submitted in partial fulfillment of the requirements for the Master of Science Degree at the State Univ., College of Forestry at Syracuse Univ.

nate measurement errors were governed in part, by the magnitude of the flying height, tilt, swing, and the area of the triangle formed by the images of the three ground-control points.

This study is a portion of an investigation being conducted at Syracuse University to determine and to evaluate error sources in analytical photogrammetry. While analytical photogrammetry is an exact science, its full potential will not be realized until sources of error in the input data are evaluated and significant errors are eliminated or reduced.

One of the significant sources of error in analytical photogrammetry is the inability to obtain correct coordinate values for photographic images. There are many contributing factors such as residual lens distortions and film shrinkage, but at least some of the error may be attributed to the inability of the comparator operator to identify the exact portion of the photographic image to be used for the measurement.

Generally, when the coordinates of photographic images are measured in a comparator, a relatively short time elapses before the observer returns to any one image for check measurements. This procedure permits the observer, consciously or unconsciously, to retain a mental picture of the image originally selected for measurement, and he is able to return to that point each time a check measurement is made. It is not surprising then, that subsequent pointings frequently agree with the original values to within one or two microns. The question remains, however, "Was the observer's original identification of the image valid?" If not, the coordinate values are worthless regardless of the consistency of repeated measurements.

This study reported upon herein was designed to determine the consistency with which coordinate values may be determined when a sufficient time period has elapsed for the observer to forget completely his original identification of the photographic images. In this manner, a measure of the precision of point identification can be established by comparing sets of readings taken at different times.

Many types of images appear on any photograph, and it was suspected that the reproduction of coordinate readings would vary for each type. Accordingly three classes of 30 points each were selected for the study. The first class contained the sharpest and clearest points on the photograph. For the most part these points were building corners and would seldom be used as ground-survey control points. The second class of points consisted principally of sidewalk and road intersections. In the majority of cases these points would be used as ground-survey control stations. The third class of points comprised objects that are occasionally used for photogrammetric-control. Included here were trees, bushes, erosion gullies, stream intersections, and field corners.

The 90 points were selected on a single near-vertical photograph taken with a T-11 camera and having a mean scale of approximately 1:40,000. Selection of the images was made independently of the actual measurements, and the image positions on the photograph were chosen at random. A careful sketch, similar to the usual field sketch of each image was made at the time of selection.

With a sketch of each point before him, the operator identified each image on a contact glass-plate positive made from the original negative, and measured its coordinates in a Mann Coordinate Comparator, Type 422C.

ABSTRACT: *This paper describes a study to determine the discrepancies involved in image identification on a photographic plate, and to determine the effects of these discrepancies on the orientation and resection solutions for a single aerial photograph. The photographic coordinates of a number of images were determined twice using a Mann Comparator, Type 422C. The standard deviations of the discrepancies ranged from ±4 microns to ±12 microns, depending on image type and quality. Computations were performed on an IBM 650 electronic computer using the Church "Post-card" Method. The errors in the values computed for the tilt and resection, resulting from image misidentification, were determined, and it was noted that the errors changed when the magnitude of the initial flying height, swing, tilt, or area of the control triangle was altered.*

In each case repeated measurements were made until three sets of x and y values agreeing within five microns were obtained. All 90 points were measured in this manner on two separate occasions about two weeks apart. This time period, together with the large number of points involved, was considered sufficient to eliminate all chance of the operator returning to the original image because of memory. During both periods of measurement, temperatures remained constant to within plus or minus one degree centigrade. It should be noted that the plate was not removed from the instrument between the two sets of readings, so as to preclude the introduction of discrepancies because of differences in plate orientation. This was verified by check readings on the fiducial marks before making the second set of measurements.

In a further attempt to eliminate operator bias, all computations were postponed until both sets of measurements had been completed. Then, the average of the three coordinate values for each image was calculated for each set of measurements. These average values were rounded to the nearest micron and were used for the set comparions. Discrepancies between corresponding coordinate values in the two sets of measurements are shown in Table 1. The maximum difference and the standard deviation for each coordinate value in each class of points are shown in Table 2.

Tests have shown that the accuracy of the Mann Comparator is nearly equivalent to its least reading. Consequently, considering the manner in which image coordinate measurement was accomplished, it may be assumed that the discrepancies shown in Tables 1 and 2 result primarily from misidentification of the photographic images.

Professor Church's Bulletin 19 served as the primary reference for all the following analytical computations.[1] Since his theory is well known and Bulletin 19 has been widely distributed, specific computational methods have not been included in this paper.

In order to determine the effect of errors in point identification on the orientation and resection computation of a single photograph, seven fictitious photographs were prepared. The image positions of the control stations on five of these fictitious photographs were identical, and their locations formed a control triangle which covered 46.8% of the entire photograph. As shown in Table 3 the first five photographs differed only in flying-height, tilt, and swing. The last two fictitious photographs listed in Table 3 varied only in the size of the control triangle.

Since image identification errors are random in nature, a table of Gaussian Deviates was used in conjunction with the standard deviations of the second class points to assign an accidental error to each photographic coordinate.[3] The orientation and resection computations were performed 30 times for each

TABLE 1

DIFFERENCES IN COORDINATE VALUES IN MICRONS

No.	*x Coordinate Differences*			*y Coordinate Differences*		
	Class 1	*Class 2*	*Class 3*	*Class 1*	*Class 2*	*Class 3*
1	−2	+2	0	−4	+3	+2
2	+3	0	−13	−6	+7	+1
3	−1	+14	0	−3	+12	+9
4	−5	+7	+1	0	+20	−8
5	+1	+8	−1	−5	+9	+1
6	−5	+6	−9	−3	+3	+1
7	+4	−3	−45	−1	+6	−13
8	+2	0	−21	+4	+5	−7
9	−5	−4	−4	+3	−4	+6
10	+3	−4	−1	−1	0	+2
11	+1	+2	−21	+2	+3	+17
12	+3	+5	+5	+6	−4	+13
13	+4	+1	+9	+15	−6	+10
14	+4	−5	+7	+7	−7	+14
15	+5	+4	+11	+1	−10	+3
16	+1	+4	+7	+5	+2	+3
17	0	+2	+10	+5	+2	−3
18	+6	−6	−7	+6	+17	−6
19	−5	−1	+8	+4	+1	−8
20	+6	+2	+6	+2	0	+3
21	+2	+3	+4	+5	+1	+16
22	+3	+2	+9	−2	+5	−2
23	0	0	−1	+4	−6	+42
24	0	+6	+4	+10	+7	+2
25	−2	+4	+4	0	+6	+6
26	−6	−11	+9	0	+7	+4
27	−4	+3	+3	0	−5	+5
28	+3	+7	0	−4	+5	+5
29	0	+3	−1	+6	+7	+10
30	+5	0	−3	+3	0	−4

TABLE 2

A SUMMARY OF COORDINATE MEASUREMENT DIFFERENCES IN MICRONS

Class	*x*		*y*	
	Maximum Difference	*Standard Deviation*	*Maximum Difference*	*Standard Deviation*
1	+6	+3.6	+15	±4.7
2	+14	±4.8	+20	±6.7
3	−45	±11.7	+42	±10.2

TABLE 3

FICTITIOUS PHOTOGRAPHS

No.	*Flying Height in Feet*	*Tilt*	*Swing*	*Control Triangle Size*
1	10,000	0°30′	0°	Large Triangle
2	10,000	0°30′	90°	Large Triangle
3	10,000	3°00′	0°	Large Triangle
4	20,000	0°30′	0°	Large Triangle
5	40,000	0°30′	0°	Large Triangle
6	20,000	0°30′	0°	Small Triangle
7	20,000	0°30′	0°	Smallest Triangle

fictitious photograph, employing a new set of adjustments to the correct coordinates at the beginning of each computation.

The results of the 30 solutions were compared with the correct values, and the final errors were statistically established. The results of the computations are summarized in Tables 4 and 5.

In observing the general effects of the erroneous photographic coordinate values on the eight components that were computed, the first impression is that the errors are small. For the solution of a single photograph, this tends to be true. However, when the solution of entire strips or blocks of photography are considered, these errors will be greatly magnified. A recent aerial triangulation report by Faulds verifies this fact.[2]

As would be expected the errors in swing and azimuth of the principal plane directly affect the errors in the x and y coordinates of the nadir-point.

The errors in tilt are relatively constant regardless of the range of basic data.

The first, fourth, and fifth fictitious photographs in Table 3 differ only in flying-height. A comparison of the results based on these three photographs gives the effect of scale on the errors introduced by point misidentification. The findings are illustrated in Figure 1.

As would be expected the errors introduced into the coordinates of the exposure station by photographic coordinate errors are directly proportional to the flying-height (see Figure 1a).

The effect of coordinate errors on swing, the azimuth of the principal plane, tilt, and the x and y coordinates of the nadir-point is constant regardless of scale as shown by Figure 1-b, c, and d.

Fictitious photographs 1 and 2 compare the results obtained when the swing-angle changes from 0° to 90°. Among the several interesting trends which occur, the computed tilt-angle appears to be somewhat more accurate at a swing of 90°. The difference is 3.6 seconds and is apparently due to the interaction of the sine and cosine values in the orientation matrix. With the tilt remaining constant at 0°30′ and the swing-angle being changed directly from 0° to 90° there is opportunity for the sine and cosine values, inherently different in rates of change, to generate this discrepancy in the tilt determination. (Refer to the middle section of Table 4.)

The angle of swing has very little effect on the values computed for the exposure station coordinates.

The accuracy of swing, the azimuth of the principal plane, and the x and y coordinates of the nadir-point are all affected by the magnitude of swing.

Errors in the nadir-point coordinates seem to be correlated with the magnitude of tx and ty. When a swing angle of 90° is considered and virtually all the tilt value is thrown into the ty component, the errors in the x coordinate of the nadir-point correspondingly become larger.

Since in this case the nadir-point displacement ov is only 1.333 millimeters, it is then conceivable that a difference of a few microns will change both the swing and the azimuth of the principal plane considerably.

At the present time, it is not possible to control the swing-angle in near-vertical photographs; therefore, the preceding find-

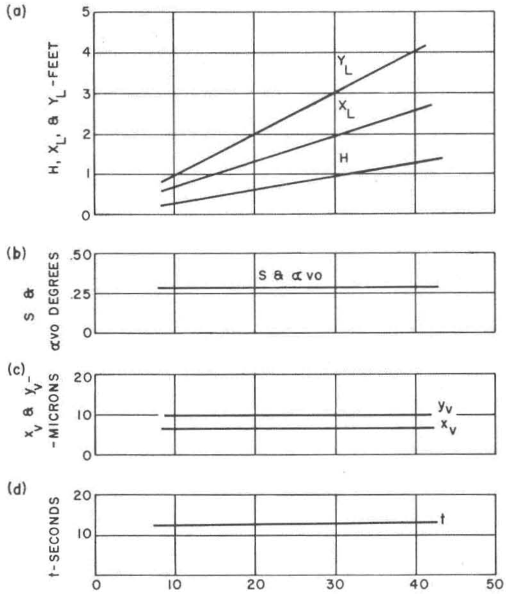

FIG. 1. Effect of flying height variation when using incorrect photographic coordinates for the tilt and resection solution.

TABLE 4

ERROR ANALYSIS OF FLYING HEIGHT, SWING, AND TILT COMPARISONS

Components	Unit	Error Maximum	Error Mean	±Standard Deviation	Error Maximum	Error Mean	±Standard Deviation
		S−0° t−0°30' H−10,000			*Large Control Triangle H−40,000*		
S	(00'–00")	−(32–31)	−(03–22)	(17–08)	−(32–47)	−(03–25)	(17–02)
αvo	(00'–00")	−(32–30)	−(03–23)	(17–04)	−(32–46)	−(03–25)	(17–01)
t	seconds	+28.44	.00	12.60	+28.44	.00	12.96
H	feet	− .70	+ .03	.29	− 2.97	+ .11	1.24
X_L	feet	− 1.35	− .11	.65	− 5.58	− .34	2.56
Y_L	feet	+ 2.03	+ .01	1.00	+ 8.53	− .14	4.05
x_v	microns	−12.50	−1.37	6.74	+12.60	−1.38	6.74
y_v	microns	+20.90	.00	9.42	+20.90	.00	9.50
		H−10,000 t−0°30' S−0°			*Large Control Triangle S−90°*		
S	(00'–00")	−(32.31)	−(03–22)	(17–08)	−(54–51)	−(00–00)	(24–20)
αvo	(00'–00")	−(32–30)	−(03–23)	(17–04)	−(54–48)	−(00–00)	(24–16)
t	seconds	+28.44	.00	12.60	−16.56	−1.80	9.00
H	feet	− .70	+ .03	.29	− .69	+ .03	.29
X_L	feet	− 1.35	− .11	.65	− 1.29	− .08	.60
Y_L	feet	+ 2.03	+ .01	1.00	+ 2.03	− .03	.94
x_v	microns	−12.50	−1.37	6.74	−19.00	−1.90	7.78
y_v	microns	+20.90	.00	9.42	+16.80	.00	6.49
		H−10,000 S−0° t−0°30'			*Large Control Triangle t−3°00'*		
S	(00'–00")	−(32–31)	−(03.22)	(17–08)	−(05–21)	−(00–34)	(02–46)
αvo	(00'–00")	−(32–30)	−(03–23)	(17–04)	−(05–20)	−(00–34)	(02–43)
t	seconds	+28.44	.00	12.60	+29.16	+0.36	12.96
H	feet	− .70	+ .03	.29	− .85	− .03	.35
X_L	feet	− 1.35	− .11	.65	− 1.34	− .08	.61
Y_L	feet	+ 2.03	+ .01	1.00	+ 2.09	− .02	1.01
x_v	microns	−12.50	−1.37	6.74	−12.40	− .67	5.83
y_v	microns	+20.90	.00	9.42	+21.60	.00	9.97

ings can be used only to contribute a partial explanation of errors that develop in analytical procedures. In special cases such as convergent photography, where swing angles are controlled, the above results may very well have special significance.

Referring to the last section of Table 4, which compares fictitious photographs 1 and 3, it can be seen that the coordinates of the exposure station were not affected by the change in the degree of tilt.

The errors in the computed tilt-angles tended to increase slightly as the magnitude of the tilt-angle increases. Perhaps this inclination would be more pronounced when considering solutions involving convergent photography where the normal tilt of each photograph is 20°.

Tilt values have very little effect on the nadir-point coordinates which account for the increased accuracy of the swing and the azimuth of the principal plane at the greater degree of tilt.

In view of the above computations it would seem that small tilt-angles should be avoided in aerial triangulation strips computed with the Church Method.

Figure 2 and Table 5 show the importance of the control triangle size in the tilt and resection solution of an aerial photograph. This portion of the study compares the results of fictitious photographs 4, 6, and 7.

The relative sizes and positions of the control triangles used in this study may be seen in Figure 3.

It is interesting to note the crossing of the x and y nadir-point error curves in Figure 2-c. It seems that the absolute extent of the x photographic coordinate range plays a part in the nadir-point errors in the x direction.

TABLE 5

ERROR ANALYSIS OF CONTROL TRIANGLE SIZE

$H-20{,}000'$ $S-0°$ $t-0°30'$

Components	*Units*	*Maximum Error*	*Mean Error*	± *Standard Deviation*
		LARGE TRIANGLE		
S	(00°-00′-00″)	−(00-32-41)	−(00-03-26)	(00-17-10)
αvo	(00°-00′-00″)	−(00-32-41)	−(00-03-24)	(00-17-02)
t	seconds	+28.44	.00	12.60
H	feet	− 1.46	+ .05	.61
X_L	feet	− 2.73	− .17	1.27
Y_L	feet	+ 4.20	− .07	1.99
x_v	microns	−12.60	−1.60	6.53
y_v	microns	+20.90	.00	9.47
		SMALL TRIANGLE		
S	(00°-00′-00″)	−(01-26-27)	−(00-08-06)	(00-44-03)
αvo	(00°-00′-00″)	−(01-26-43)	−(00-08-09)	(00-44-04)
t	seconds	−37.44	.00	19.08
H	feet	+ 3.06	− .08	1.33
X_L	feet	− 5.21	− .39	2.51
Y_L	feet	− 6.10	− .20	3.05
x_v	microns	+31.90	.00	17.13
x_v	microns	−27.20	− .60	14.04
		SMALLEST TRIANGLE		
S	(00°-00′-00″)	−(02-10-17)	−(00-06-03)	(01-05-12)
αvo	(00°-00′-00″)	−(02-10-42)	−(00-06-01)	(01-06-15)
t	seconds	−52.92	−1.44	25.20
H	feet	+ 4.66	− .26	2.04
X_L	feet	− 7.17	− .56	3.59
Y_L	feet	− 9.76	− .06	4.80
x_v	microns	+51.00	−4.53	25.74
y_v	microns	−40.00	−1.20	18.80

Thus, because the range of the y coordinates has remained constant, it can be seen that the rate of change in the y coordinate error curve of the nadir point is less than that of the x coordinate error curve.

The rapidity with which exposure station coordinates decrease in accuracy as the control triangle size decreases is illustrated in Figure 2-a.

During the course of this study, it was found that accurate tilt and resection solutions cannot be obtained through the use of approximate flying-height values. In order for the proper tilt and swing-angles to be computed, the flying-height must be modified directly following the verification step of the first approximation.

The following conclusions have been drawn from this study:

1. The discrepancies in x and y coordinate measurements due to image-point misidentification are from five to seven microns for the type of point normally used for survey control.
2. The errors introduced into the three coordinates of the exposure station by image-point misidentification are directly proportional to the flying-height; however errors in S, αvo, t, x_v, and y_v are constant regardless of the flying-height.
3. The magnitude of the swing-angle appears to have no effect on the accuracy with which exposure station coordinates are established.
4. The swing-angle seems to affect, to a minor degree, the accuracy of S, αvo, x_v, and y_v.
5. Tilt-angle magnitudes appear to have little effect on the accuracy of the exposure station coordinates.
6. The errors in x_v and y_v remain relatively constant at higher tilt-angles, thereby

increasing the accuracy of S and αvo determinations.

7. The error in the computed tilt-angle seems to increase slightly with larger tilts.
8. The control triangle should cover at least 35% of the photograph. Any area smaller than this will introduce substantial errors into the tilt and resection computations.

It must be kept in mind that all computations leading to the results referred to in conclusions 3 through 8 were carried out with the image-point misidentification errors present. Image-point misidentification discrepancies are but a small segment of the errors that exist in photographic coordinate measurements. Studies to determine the effect of errors originating from lens distortions, resolution, earth curvature, refraction, and differential film shrinkage are necessary in order that a complete analysis be made. The ultimate success of analytical photogrammetry will depend a great deal on the degree to which these errors are isolated and subsequently corrected.

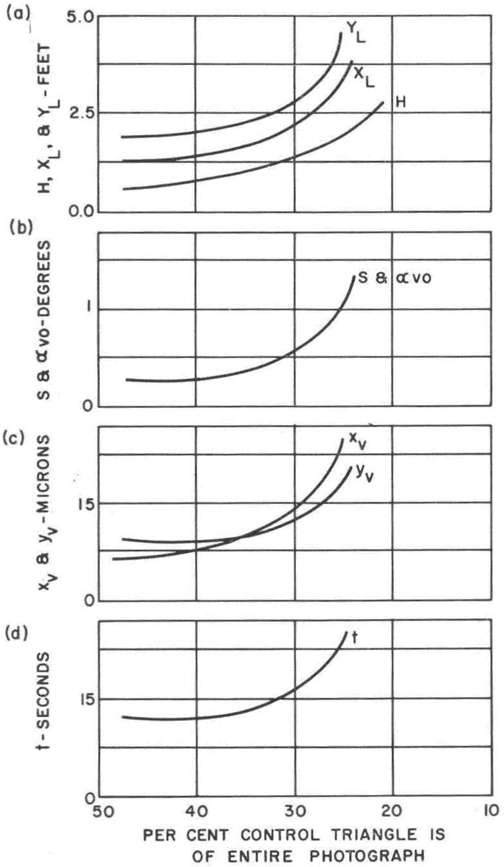

FIG. 2. Effect of control triangle size variation when using incorrect photographic coordinates for tilt and resection solution.

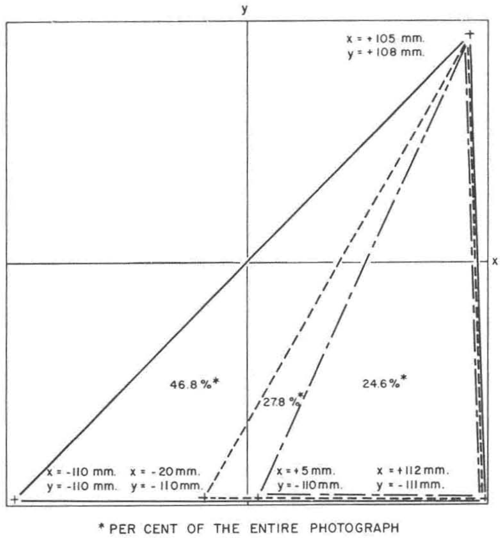

FIG. 3. Position and size of the control triangles.

ACKNOWLEDGMENTS

The author thanks Professor Arthur H. Faulds, Associate Professor of Civil Engineering at Syracuse University, and Professor Bruce T. Stanton, Associate Professor of Forest Management at the State University College of Forestry at Syracuse University, for their assistance in this study.

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