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ABSTRACT

The operator of the Army Analytical Photogrammetric Positioning System (APPS) must perform a critical step in the coordinate determination procedure by the subjective comparison of dissimilar images. He must correlate reconnaissance mission imagery with aerotriangulated photographic stereoscopic pairs, known as data base imagery, and visually identify the image position on the data base of a target detected on the mission image. Results obtained from 40 image interpreters performing this task using vertical, oblique, and panoramic mission imagery are given. Two levels of target position difficulty were established: A-points located at terrain or man-made features mutually identifiable on both mission and data base imagery, and B-points remote from terrain or man-made features mutually identifiable on mission and data base imagery. (Author)

Technical Paper 346

THE EFFECTS OF PHOTO CHARACTERISTICS UPON LOCATION DETERMINATION IN A PHOTOGRAMMETRIC FACILITY

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FOREWORD

The Hum Factors Technical Area is concerned with the demands of the future battlefields for increased man-machine complexi to acquire, transm process, disseminate and utilize information. The research is focused on the interface problems and interactions within command and control centers and is concerned with such areas as topographic produ and procedures, tactical symbology, user-oriented systems, inform management, staff operations and procedures, and sensor systems egration and utilization.

One ical aspect of intelligence information from aerial sensor is the accurate location of targets. Recently, the Army has developed the Analytical Photogrammetric Positioning System (APPS) which provides an improved capability for target positioning. However, there are several unknown factors in this system associated with the human interface. present publication deals with the determination of the speed and accuracy with which operators can transfer terrain positions from relatively large-scale mission photographs to small-scale database vertic photographs and the dependence of such performance on the characteristics of the photographs used. This is a critical factor of the performed by the operator of the APPS. Results indicate that the most important variables were how close the target is to an identifiable terrain detail; whether the target is in the foreground or background of a non-vertical image and the resolution of the mission imagery

Research in the area of sensor systems integration and utilization is conducted as an in-house effort augmented through contracts with organizations selected for their unique capabilities and facilities for research on sensor systems. The present study was conducted by personnel from Raytheon Company/Autometric and Human Factors Research Inc. under contract DAHC19-73-C-0031 with program direction from Abraham H. Birnbaum. This effort is responsive to requirements of Army Project 2Q162106A722, the U.S. Army Engineer Topographic Laboratory, Ft. Belvoir, Va. and the Assistant Chief of Staff for Intelligence. Special requirements are contained in Human Resource Needs 73-65.

JOSEPH ZEIDNER
Technical Director

THE EFFECTS OF PHOTO CHARACTERISTICS UPON LOCATION DETERMINATION IN A PHOTOGRAMMETRIC FACILITY

BRIEF

Requirement:

To determine how well an image interpreter can transfer image points from reconnaissance (stimulus) photography to a small-scale photographic data base, using photography from vertical frame, oblique frame, and panoramic cameras as stimulus imagery.

Procedure:

Points selected for transferring were: Type A points appearing on identifiable ground objects and Type B points more than 200 meters from identifiable ground objects. These were marked on negatives of high- and low-altitude vertical photograms, high- and low-altitude panoramic photographs, and an oblique photograph, using varying scales. Transparent prints and paper prints were made from each negative. A photogrammetric data base at a scale of 1:100,000 was obtained for each area covered by the stimulus imagery.

After a short pretest training period, 40 Army image interpreters were required to transfer 30 points from each of the four different types of stimulus photography to the appropriate data base by marking the selected points. Time required to transfer each point was recorded. Coordinates of the marked points were compared to the true coordinates, and error vectors listed. The effects of resolution, scale, and position on location accuracy were statistically tested and described.

Findings:

Point-transfer accuracy was affected most by the relationship of a point to identifiable detail imaged on both the stimulus and data base photography. Type A points were located more accurately than Type B points by ratios of 3:1 to 6:1.

Accuracy was also affected by the position of a point in the Near or Far portion of a non-vertical photograph. (Near is defined as the half of the photograph closest to the vertical. Far is the horizon-half of the photograph.) Points in the Near portion were located more accurately than points in the Far portion. Examples of error magnitudes at the 75th percentile are:

Oblique,	B-Points	Near-	54 meters	Far-	229 meters
High Pan,	A-Points	Near-	14 meters	Far-	32 meters

The difference in ground resolution (paper print vs. transparency) was most significant for Type A points on the Low Pan imagery. The transfer error for the transparent print was 25 meters compared to 165 meters for the paper prints. For other mission imagery the resolution difference was of no practical consequence.

Under the conditions of these tests, transfer errors of less than 20 meters can be met 50% of the time for Type A points on all imagery and 75% of the time for Vertical and Near High and Near Low Pan photos. Only the Vertical imagery is adequate for keeping Type B point transfer errors to 20 meters.

Test subjects preferred transparencies to paper prints for the stimulus imagery and they preferred transmitted light (light table) to reflected light (high-intensity lamp) even for paper prints.

Utilization of Findings:

This study showed clearly that large errors may result in the point transfer process. Targets appearing on identifiable features visible on both the mission and data base imagery (Type A points) can generally be transferred to within 30 meters at 75th percentile. However, even for Type A points, when the resolution of the mission imagery falls too low because of scale and position, the accuracy deteriorates rapidly. For this case an acceptable level of resolution can be maintained by using transparent prints instead of paper prints. Transfer accuracy improves overall when transparent prints are used. This strongly suggests the use of equipment on which transparencies can be viewed and the operational use of transparencies instead of paper prints.

Type B points cannot be transferred visually to acceptable accuracies with any consistency. Since most target points are likely to be Type B points, a way must be found for improving the transferring of these points.

The difference in transfer error between scales for vertical mis-sion imagery was not operationally significant. This does not mean that scale is not an important factor. Rather, it indicates that the ground resolution of all vertical mission imagery used in the test was higher than the corresponding data base ground resolution. It follows that higher quality data base photography might permit better utilization of vertical mission imagery in the transferring process. Higher ground resolution can be obtained by better cameras (lens-film combinations) or by larger scale data bases.

THE EFFECTS OF PHOTO CHARACTERISTICS UPON LOCATION DETERMINATION IN A PHOTOGRAMMETRIC FACILITY

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THE EFFECTS OF PHOTO CHARACTERISTICS UPON LOCATION DETERMINATION IN A PHOTOGRAMMETRIC FACILITY

INTRODUCTION

Many photogrammetric applications require the locating and marking of the images of the same ground point on one or more sensor records. In aerial triangulation, pass points and control points are transferred stereoscopically from one photograph to one or more overlapping photographs. In terrestrial photogrammetry, identical image points on two photographs must be measured. Target images found on reconnaissance imagery are often transferred to a map or some other type of data base so their ground positions can be found. The accuracy with which a point can be transferred from one sensor record to another is a function of many factors, such as resolution, scale, relative attitudes, target/environs relations and technique and equipment used. Also, the intended application dictates, to some extent, the care that is given to such transfers.

There is a continuing need for more accurate and faster means of acquiring aiming data for the artillery. This is especially true in areas where adequate maps are not available. The United States Army Engineer Topographic Laboratory, Ft. Belvoir, Va. has developed an instrument which, together with a precision photographic data base, provides a new capability for target positioning. This instrument is called the Analytical Photogrammetric Positioning System (APPS)[1/]. It consists essentially of a mirror stereoscope mounted over a coordinate measuring system whose outputs are fed to an interface unit and then to a programmable desk calculator. Two overlapping data base photographs are mounted on the two stages of the mirror stereoscope. After preliminary indexing and checking, index marks are placed over a point of interest and the attached calculator computes the X, Y, and Z ground coordinates of the point of interest. The inherent accuracy of the APPS has been found to be adequate for locating the artillery field piece and the target and for some other types of ground surveying. The unknown factor in this positioning system is the error associated with the transferring of points to a data base from several types of photographic imagery of different scales and resolutions, and the relationships of the target to features in the scene (target/environs).

[1/] A more detailed description of the APPS is given in Appendix A.

Transferring of image points from one photograph to another seems straightforward and quite exact. This may be true under some circumstances but not under others. It has been shown in precision photogrammetric applications that when a reasonably good stereo model can be formed with two photographs, conjugate images can be marked on the photographs with very high accuracy--ten (10) micrometers or less. But when the two photographs differ in scale, resolution, attitude, etc., the problem becomes one of trying to match two dissimilar types of photographs. Some of the differences that must be considered are discussed below.

Scale of the Data Base

The scale of the photo data bases now being used with the APPS is 1:100,000. Data base scales as small as 1:160,000 are being considered for adoption. At a scale of 1:100,000, ten micrometers on the data base represents one meter on the ground. A maximum of 20 meters per coordinate dimension has been projected in the APPS error budget for the transfer accuracy of points located in friendly terrain, while 50 meters per dimension for transfer accuracy of points located in enemy terrain has been allocated. This means that a target point must be transferred to the data base with an accuracy of 1/5 millimeter (200 micrometers). This leaves very little margin for error, and in areas with few or no prominent scene features it may be extremely difficult to transfer a point "by association" to this accuracy.

Scale and Geometry of Reconnaissance Photography

Targets can be imaged by any one of a variety of reconnaissance cameras. Panoramic and oblique cameras produce photographic imagery that has geometry different from that produced by vertical frame cameras. The farther the target is from the vertical, the greater the difference in geometry. As the horizon is approached it becomes difficult even to locate the general area in which the target is located, one reason being that the scale becomes smaller as one moves from the nadir towards the horizon, and ground features become masked by higher elevations on the camera side of the scene. These conditions, plus the fact that, usually, there is a large scale difference between the mission imagery and the photo data base, are important factors when trying to correlate two dissimilar types of imagery to the required accuracy. Of course the scale of the data base can be enlarged optically so it will be closer to the mission imagery scale. The optics of the APPS are fixed at 6X so that was the maximum enlargement permitted for this study. Even if zoom optics are permitted, very little additional useful information can be expected unless the data base photography is of unusually fine quality.

Other Factors

Some of the other factors that can cause problems in transferring points are:

- Seasonal differences in the time of exposure of the data base photography and the mission imagery.
- Different acquisition times of the data base and the mission photography. New roads, railroads, and housing developments, different water levels of rivers and lakes, different crop patterns, etc. may be on one photograph and not the other. This may cause confusion in transferring points.

OBJECTIVE

The objective of this study was to determine how well an image interpreter could transfer image points from a reconnaissance photograph to a small scale photographic data base. Tests were designed to determine both the accuracy and the speed of transfer. Mission (reconnaissance) photographs used in the tests were selected frames from oblique, panoramic and vertical frame cameras at various scales and resolutions. The data bases were vertical mapping photographs at 1:100,000 scale.

SCOPE

This study was limited to the one act of transferring points from one type of photography (mission imagery) to another type of photography (data base). The transferring was done visually, i.e., no instrumental aids, other than small tube-type or linen tester magnifiers, were allowed. APPS operations were approximated by using, in this study, the same type of photographic material used in APPS, by limiting the magnification of the data base to 6X, and by using the same scale data base. The tests were designed to provide information on the accuracy and speed of transferring points from mission imagery for combinations of the following variables:

- Types of imagery (vertical, panoramic, oblique)
- Scale
- Resolution (positive transparency vs. paper print)
- Point/environs relationship.

METHOD

Experimental Design

The experimental design for the vertical mission photos was a 2x2 factorial. The effects of Print Type, Scale, and the interaction between the two variables were between groups. The experimental design for each of the non-vertical photos was also a 2x2 factorial. The effect of Print Type was between groups, but the effects of

Position and the interaction between the two variables were within groups. As can be seen in Table 1, each group of subjects transferred the points from four mission photos--one vertical photo and three non-vertical photos.

Table 2 shows the order in which the four mission photos were presented to each of the groups. Within each group, half of the subjects were given one sequence of the four photos and the other half another sequence. The photo sequences were varied across groups to control for the effects of time-correlated variables, such as boredom, fatigue, and learning. An equal number of subjects were presented with each non-vertical photo, first, second, third, and fourth. For example, five subjects worked with B_1 the oblique transparency first, a different five subjects with it second, etc. An equal number of subjects were presented with each vertical photo either first and second, or third and fourth.

For each photo, half of the subjects transferred the points in one sequence and the remaining half in the reverse sequence. In the case of the non-vertical photos, half of the subjects transferred the points starting at the horizon and working toward the nadir, and the other half transferred the points in reverse sequence. This was done to minimize any bias in performance on the Near and Far points and on the A and B points due to the potential effects of any time-correlated variables.

Subjects

Forty enlisted image interpreters from the 1st Military Intelligence Battalion, Aerial Reconnaissance Support (1st MIBARS), Ft. Bragg, North Carolina served as subjects. The experience of the image interpreters ranged from one year to over twenty years. The forty subjects were assigned randomly in equal numbers to one of four groups. A given combination of Print Type and Scale for the vertical photographs was assigned to each group. Thus no subject viewed the same scene more than once. Transparencies of each of the non-vertical photos were assigned to two groups and Paper Prints to the two remaining groups. Here, again, no subject viewed the same scene more than once. The experimental condition by groups is shown in Table 1.

Variables

Independent Variables. There were two independent variables for the vertical mission photos and two for the oblique, the high pan, and the low pan mission photos. The independent variables for the vertical photos were scale and ground resolution. Scale change was achieved by selecting different flight altitudes and resolution difference was achieved by the use of paper prints and transparencies of the mission photos. Hereafter these two variables will be referred to as Scale and Print Type. The independent variables for each of the non-vertical photos were Print Type and Position of the point (Far vs. Near). Near points are defined as those located in the half of the photo which is

Table 1

EXPERIMENTAL CONDITIONS BY GROUPS

MISSION PHOTO	SCALE	PRINT TYPE: Paper	PRINT TYPE: Transparency
Vertical	Large	Gp 1[a]	Gp 2
	Small	Gp 4	Gp 3

MISSION PHOTO	POSITION	PRINT TYPE: Paper	PRINT TYPE: Transparency
Oblique	Far	Gp 3 + Gp 4	Gp 1 + Gp 2
	Near		

MISSION PHOTO	POSITION	PRINT TYPE: Paper	PRINT TYPE: Transparency
High Pan	Far	Gp 3 + Gp 4	Gp 1 + Gp 2
	Near		

MISSION PHOTO	POSITION	PRINT TYPE: Paper	PRINT TYPE: Transparency
Low Pan	Far	Gp 1 + Gp 2	Gp 3 + Gp 4
	Near		

[a] 10 subjects in a group (Gp). Each cell represents a photo.

Table 2

ORDER OF MISSION PHOTOS BY GROUPS

GROUP	N	ORDER 1st	2nd	3rd	4th
Gp 1	5	A_4	B_1	D_2	C_1
	5	D_2	C_1	A_4	B_1
Gp 2	5	B_1	D_2	C_1	A_3
	5	C_1	A_3	B_1	D_2
Gp 3	5	A_2	B_2	D_1	C_2
	5	D_1	C_2	A_2	B_2
Gp 4	5	B_2	D_1	C_2	A_1
	5	C_2	A_1	B_2	D_1

NOTE: A = Vertical Photos
- 1 = Small Scale/Transparency
- 2 = Small Scale/Paper Print
- 3 = Large Scale/Transparency
- 4 = Large Scale/Paper Print

B = Oblique Photos

C = High Pan Photos

D = Low Pan Photos

For B, C, and D
- 1 = Transparency
- 2 = Paper Print

closest to the vertical. Far points are defined as those located in the horizon-half of the photograph.

Dependent Variables. The dependent variables for these tests were the location error (in micrometers), and the time (in seconds) required to transfer a point.

Control Variables - The control variables were the two types of points, A and B. The points were selected in terms of significant background detail, i.e., point/environs.

Development of Experimental Materials

Stimulus Imagery. Mission imagery was chosen that was representative of Army reconnaissance photography as to type, quality and scale. Further, the test materials issued to the subjects were printed on two types of emulsion bases--paper and transparent(film). Preliminary tests confirmed that more of the available resolution in the negatives was retained by transparent prints than by paper prints. (A 40 lines/mm photo negative contacted onto standard photographic paper produces paper prints having a ground resolution of about 22 lines/mm. The same negative contact printed onto copy film produces transparencies having a ground resolution of about 32 lines/mm. An 80 lines/mm negative yields 30 lines/mm paper prints and 55 lines/mm transparencies). One portion of the experiment was designed to compare transfer performance when using paper prints ("low" resolution) with performance using transparent prints ("high" resolution). The characteristics of the mission and data base imagery are shown in Table 3.

Point Selection. Transfer points were selected by examining the mission and the data base photographs using 6X magnifiers. The points were selected carefully so they could be classified logically in terms of their proximity to features. Although three levels of proximity were considered originally, it was found that a two-level classification, Type A and Type B, was more meaningful. The two types of points are defined as:

Type A - Points on a feature identifiable on both the mission and the data base photographs. (For example, a point on a road intersection, a building corner, a bridge, or a drainage pattern.)

Type B - Points which are more than 200 meters from a point identifiable on both the mission and data base photographs.

Test Materials. Test material produced for each subject consisted of four frames of mission imagery and their associated data bases. Two frames were paper prints and two were transparent prints. The data bases were printed on a pigmented film base.

Table 3

CHARACTERISTICS OF THE MISSION AND THE DATA BASE PHOTOGRAPHY

Mission Photography

Code	Location	Type of Photography	Scale	Photo Base
A1	Ft.Belvoir,Va.	High Alt.Vertical	1:20,000	Transparency
A2	Ft.Belvoir,Va.	High Alt.Vertical[a]	1:20,000	Paper
A3	Ft.Belvoir,Va.	Low Alt.Vertical	1:5,000	Transparency
A4	Ft.Belvoir,Va.	Low Alt.Vertical	1:5,000	Paper
B1	Ft.Sill,Okla.	Low Oblique	1:10,000 (at nadir)	Transparency
B2	Ft.Sill,Okla.	Low Oblique	1:10,000	Paper
C1	Alexandria,Va.	High Alt.Panoramic[b]	1:30,000 (at nadir)	Transparency
C2	Alexandria,Va.	High Alt.Panoramic	1:30,000	Paper
D1	Syracuse,N.Y.	Low Alt.Panoramic	1:30,000 (at nadir)	Transparency
D2	Syracuse,N.Y.	Low Alt.Panoramic	1:30,000	Paper

Data Base Photography

Code	Location	Scale	Photo Base
A	Ft.Belvoir,Va.[a]	1:100,000	Cronapaque[d]
B	Ft.Sill,Okla.	1:100,000	Cronapaque
C	Alexandria,Va.[c]	1:100,000	Cronapaque
D	Syracuse,N.Y.	1:100,000	Cronapaque

a/ See Figure 1
b/ See Figure 2
c/ See Figure 3
d/ Cronapaque is the trade name for a translucent, low-shrink film used for the APPS data base. Commercial or trade names are given only in the interest of precision in reporting experimental procedures. Use of the names does not constitute official endorsement by the Army or by the U.S. Army Research Institute for the Behavioral and Social Sciences.

Pilot Tests

Pilot tests were conducted prior to the principal tests. The purpose of these tests was to provide a realistic assessment of the test materials, test equipment, test procedures, mensuration, and data processing. Also, these tests provided useful data on the time that would be required to conduct the principal tests. Personnel from the Army Research Institute, the Engineer Topographic Laboratories, and the contractor participated in the tests. All pilot test data were measured, graded and analyzed.

Subject Training

Test equipment, consisting of a light table, two six-power magnifiers, a point marker, an electrical timer, and a high intensity gooseneck lamp, was issued to each subject (See Figure 4). Photographs of the APPS equipment were shown, the equipment was described and the subjects were told the purpose of the tests. They were instructed on use of the test equipment and on techniques for making point transfers. Sample mission and data base photographs were issued and the subjects were asked to practice transferring points from a mission photo to the data base. Instructor personnel observed the subjects to ensure that each one was adequately prepared for the tests.

Data Collection (Principal Tests)

A packet of test material containing all mission photos, data base photos, and sheets for recording the time taken for each transfer was issued to each subject. The subjects were told that, even though time was being recorded, there was no time limitation and that accuracy, not speed, was of paramount importance. Each subject was required to transfer 30 points on each of four[2] mission photographs by marking the location of each point on a data base and recording the time taken to transfer each point.

It required from 1 to 1½ hours to transfer the 30 points from a single mission photograph. After each session, a critique was held to get the views of the test subjects concerning the tests and the test equipment. All tests were completed in seven working days.

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[2] Five mission photos were used in the tests but the two verticals covered the same ground area. Only one vertical mission photo was assigned to a subject.

Statistical Computations

Preliminary Screening of Data. Inspection of the location error data revealed that 3 of the 40 subjects did not follow the procedures adequately, so these subjects' data were not used. In addition, one subject's data for the high pan photo Paper A points were not used. It was apparent that on half of the Far points, he had misidentified the appropriate features in the data base.

The data from three points in the low pan photos were also eliminated from the analyses. One point was a Far A point, one a Near A point, and one a Far B point. One of the points was eliminated because a valid solution could not be obtained for its true location. The other two points were eliminated because over half of the subjects did not attempt to transfer them. Thus for the low pan photos, there remained a total of 7 Far A points, 6 Near A points, 7 Far B points, and 7 Near B points.

About 2½ percent of the required transfers were either missing or could not be scored for the following reasons: the subject made a long scratch or the pinprick was so large that the intended location of the point could not be determined; he selected the wrong point; or, by far the most common reason, no pinprick could be found on the data base, or the subject noted that he could not find the point on the data base photo.

After the study was completed, it was discovered that, due to a clerical error, half of the subjects assigned to the oblique photos were not given the point numbers appropriate for these photos. Instead, they were given the 30 point numbers appropriate for the vertical photos. As a consequence, these subjects transferred 14 A points and 16 B points instead of 15 of each type. Ten A points and 7 B points were in common with the points transferred by the other half of the subjects. This did not seriously affect the data analyses.

Preparation of the Data for Statistical Analysis. The measure of each subject's location error performance for a particular experimental condition was the median of the errors he made on the points for that condition. The median rather than the mean error was used because, for many of the subjects, the distribution of errors across points was generally positively skewed; that is, many subjects made a large error on one or two of the points. If a subject was missing an error score for a particular point, he was assigned an artificial score which was the median of the other subjects' errors for that point.

For the vertical photos, two median errors were computed for each subject--one based on 15 A points and one based on 15 B points. For the non-vertical photos, four medians were computed for each subject; for the high pan photos, the medians were based on 8 A and 8 B Far points, and 7 A and 7 B Near points; for the low pan photos the medians were based on 7 A and 7 B Far points, and 6 A and 7 B Near points; for the oblique photos, the medians for half of the subjects were based [illegible] 8 A and 8 B Far points and 7 A and 7 B Near points; and for the other half of the subjects, the medians were based on 8 A and 8 B Far [illegible] and [illegible] A and 8 B Near points.

Mean[illegible]e subject's median errors were used in testing the statistical [illegible]ficance of the effects of the various independent variables. The [illegible]istical tests (analysis of variance and t tests) were used to te[illegible] only the significance, but to determine whether or not levels of the independent variables should be combined for descriptive purposes.

Scoring

Point Location Standards. Point location standards (school solutions) were established for each frame of mission imagery.

The A points on the mission photo were located visually on the data base and the location of each point was marked with a pin prick. The B points could not be transferred accurately in this way. A series of tests showed that sufficient accuracy could be attained by analytically transferring the B points from the mission to the data base photographs. To perform this, an eight-parameter projective transformation was chosen and programmed on a CDC 6600 digital computer.

The true locations of the points were determined in the following manner. Each mission photo, which had been marked with A and B points, was placed in a precision comparator and the coordinates of all points were measured and recorded on punched cards. The corresponding data base photo was placed in the comparator and the fiducial markers and all A points were measured and recorded on punched cards. A series of local transformations was set up. A local transformation was made up of B points surrounded by A points. (Additional "control" points were added in areas where there were not enough A points to effect a strong transformation.) Since the A points were measured on both the mission and the data base photographs, transformation parameters could be computed. Using these transformation parameters, the B points (measured on the mission imagery only) were transformed into the data base coordinate system. The computer program printed out the X and Y residuals of the A points. The size of the residuals was a good indication of how well the B points had been transformed. A typical layout of A and B points for an oblique local transformation is shown in Figure 5. The computer printout for this is shown in Figure 6.

The true locations, then, are the data base comparator coordinates of the A points and the transformed locations of the B points, in the data base coordinate system.

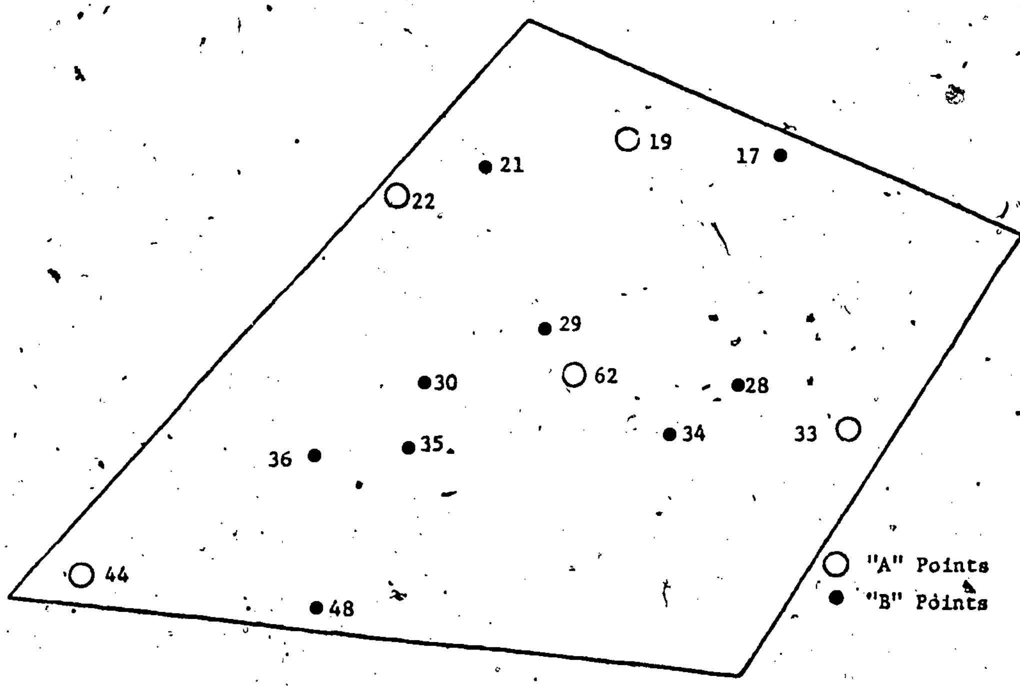

Figure 5. - Typical Layout For A Local Transformation

FORT SILL

C A L I B R A T E D   V A L U E S

ID	X	Y
2019	15274[illegible].000	487639.000
2022	157725.000	482578.000
2033	173332.000	491456.000
2044	180742.000	48105[illegible].000
2062	171355.000	487576.000

M E A S U R E D   V A L U E S

ID	X	Y
2019	578344.000	569778.000
2022	547513.000	561322.000
2033	610876.000	53[illegible]060.000
2044	535126.000	509201.000
2062	57157[illegible].000	537272.000

Note; All values in micrometers

ID	CAL X	CAL Y	TRAN X	TRAN Y	RES X	RES Y
2019	152747.000	487639.000	152749.796	487637.344	-2.736	1.156
2022	157725.000	482576.000	157714.251	482578.165	10.749	-.165
2033	173332.000	491456.000	173825.75-	491457.031	6.246	-1.031
2044	180742.000	481[illegible].000	180740.940	481055.611	1.060	.389
2062	171355.000	487276.000	171368.655	487077.333	-13.655	.167

RMS X 8.366129 RMS Y = .722108

A N S F O R M E D   V A L U E S

ID	X	Y
2017	152707.369	491339.597
2021	154054.990	484200.717
2028	171414.231	489833.205
2029	158070.651	486477.193
20[illegible]	172[illegible].902	484566.295
2034	174081.544	488019.331
2035	175125.954	484711.880
2036	17564[illegible].151	483440.401
2048	181280.047	484256.698

Figure 6. - Typical Printout For A Local Transformation

Mensuration and Error Vector Computation. Each of the forty (40) test subjects transferred thirty (30) points to each of four data base photographs. Each data base was placed in a precision comparator and the coordinates of the four fiducial marks and the 30 points were measured. The output of these measurements was a punched card for each transferred point showing the Subject Number, the Mission Photo Code (B_1, B_2, C_1, etc.) and the x and y coordinates of the point.

Programs were written for the CDC 6600 computer to process the measurement data. A transformation program was used to place the subject's measurements into the appropriate data base coordinate system. Thus, the coordinates of all points on the subject's data base could be compared directly with the true coordinates of their conjugate points. The computer printout contained the errors in x and y and the error vector (location error) for each point, in micrometers (See Figure 7). At the scale of the data base (1:100,000), ten micrometers equals one meter on the ground.

RESULTS

Marking Error

One factor that has a direct bearing on transfer accuracy is the accuracy with which a person can mark a pre-selected point. Tests made with six subjects showed that, at a scale of 1:100,000, the error in marking was less than two meters on the ground.

Location Errors

The location errors for each type of mission photo are described in the following four sections. Within each section, the results for the A points are presented first, and those for the B points second. For each type of point, there is a table of error means by levels of the independent variables, statistical tests of the effects of the independent variables, and a description (or descriptions) of the location error in the form of cumulative percentage distributions. Descriptive statistics based on the cumulative percentage of error in meters were considered more appropriate than those based on the normal distribution assumption because the distribution of errors was positively skewed.

A cumulative percentage distribution was presented for each level of the independent variables if the effects of that variable were statistically significant ($p < .05$). If the effects of a variable were not statistically significant, the data were combined into a composite cumulative percentage distribution. Artificial error scores are not included in these distributions.

Vertical Mission Photos. Table 4 shows the error means for the vertical photo A points. It is apparent from the table that there were only small and negligible differences among the means for the different combinations of Print Type and Scale.

SUBJECT 3 HI-RES FT. SILL.

CALIBRATED VALUES

ID	X	Y
11111111	100000.000	500000.000
11111111	107476.000	475999.000
11111111	205062.000	471263.000
11111111	202976.000	516695.000

MEASURED VALUES

ID	X	Y
1001	500000.000	500000.000
1002	507277.000	475936.000
1003	604532.000	470444.000
1004	603110.000	515888.000

ID	CAL X	CAL Y	TRAN X	TRAN Y	RES X	RES Y	ERR VECTOR
1001	100000.000	500000.000	100000.000	500000.000	-.000	-.000	0
1002	107476.000	475999.000	107476.000	475999.000	-.000	0.000	0
1003	205062.000	471268.000	205062.000	471263.000	-.000	-.000	0
1004	202976.000	516695.000	202976.000	516695.000	.000	-.000	0

RMS X = .000000 RMS Y = .000000

TRANSFORMED VALUES

ID	CAL X	CAL Y	TRAN X	TRAN Y	RES X	RES Y	ERR VECTOR
2001	105204.000	489600.000	104786.702	489526.981	417.298	73.019	424
2002	103794.000	486814.000	103840.030	486887.125	-46.030	-73.125	86
2004	113711.000	481299.000	113744.580	481335.549	-33.580	-36.549	50
2005	129069.000	478212.000	129077.342	478036.839	-8.342	173.161	173
2007	123177.000	473931.000	122766.323	474169.619	410.677	-238.619	475
2009	134245.000	488598.000	134289.319	488633.531	-44.319	-35.531	57
2011	142444.000	483412.000	144041.969	483227.505	-1597.969	184.495	1609
2013	144126.000	479919.000	144170.899	479946.103	-44.899	-27.103	52
2014	127486.000	473049.000	127276.152	475059.403	209.848	-2010.403	2021
2016	148773.000	475729.000	148193.592	474207.645	579.408	1521.355	1628
2017	152762.000	491306.000	152472.368	491175.225	289.632	130.775	318
2020	161551.000	485472.000	161547.597	485465.191	3.403	-13.191	14
2021	154365.000	484201.000	154278.228	484214.207	86.772	-13.207	88
2024	159948.000	479230.000	159963.839	479207.359	-15.839	22.641	28
2025	163468.000	477382.000	164742.803	477466.915	-1274.803	-84.915	1278
2026	157045.000	474772.000	157220.189	474773.838	-175.189	-1.838	175
2027	168379.000	490120.000	168372.070	490090.426	6.930	29.574	30
2029	168535.000	486480.000	168496.770	486435.650	38.230	44.350	59
2030	171982.000	484593.000	172078.916	484571.044	-96.916	21.956	99
2031	167213.000	481285.000	167477.477	481306.598	-264.477	-21.599	265
2033	173332.000	491456.000	173339.366	491422.116	-7.366	33.884	35
2034	174074.000	486606.000	174531.985	486634.755	-457.985	-28.755	459
2035	175123.000	484722.000	175254.327	484769.796	-131.327	-47.796	140
2037	175917.000	480386.000	176069.769	480026.460	-152.769	359.540	391
2039	177867.000	490606.000	177974.475	490068.516	-107.475	537.484	548
2040	179008.000	489320.000	178808.500	489575.069	199.500	-255.069	324
2041	179502.000	486453.000	179734.761	486580.565	-232.761	-127.565	265
2043	179656.000	484692.000	179751.765	484725.892	-95.765	-33.892	102
2046	182514.000	486685.000	182617.291	486651.056	-103.291	33.944	109
2045	181296.000	484245.000	181837.422	484404.200	-541.422	-159.200	564

Figure 7. - A Typical Printout Showing The Comparison Of A Subject's Location Of Points To The True Locations

Table 4

VERTICAL MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR A POINTS

SCALE	PRINT TYPE: Paper	PRINT TYPE: Trans-parency	Mean Total
Large	7.6 (10)[a]	5.9 (8)	6.8
Small	8.7 (10)	7.1 (10)	7.9
Mean Total	8.2	6.5	7.4

[a]Number of subjects.

An analysis of variance of the data (Table 5) indicated that the effects of Scale, Print Type, and the interaction between the variables were not statistically significant. The data from all levels of the independent variables were combined.

Table 5

VERTICAL MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR A POINTS

Source	df	MS	F
Scale (A)	1	12.28	1.48
Prints (B)	1	24.52	2.96
A x B	1	.01	<1.00
Error	33	8.27	

Figure 8 shows the cumulative percentage of location error (in meters) for the A points. The figure may be interpreted as follows: if the interest is in the typical or average error on these points, select 50% (the median) on the ordinate and read the value on the abscissa (location error) that corresponds to the point where 50% intersects the

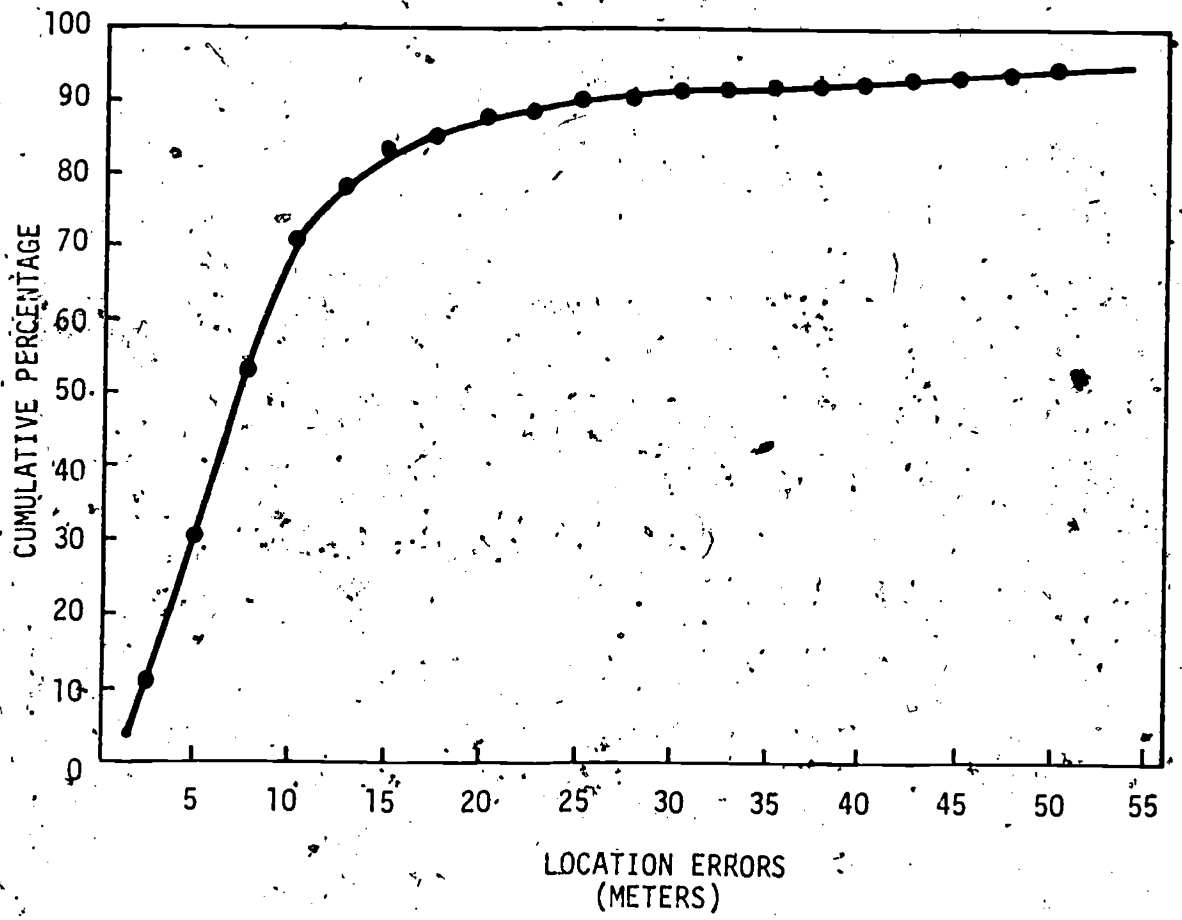

Figure 8. Cumulative percentage of location errors: vertical mission photos/A points (N=542).

function. In Figure 8 that value is 8 meters. This means that half of the errors were less than 8 meters and half were greater than 8 meters. If the interest is not in typical performance, but rather in some point below, say 75% of the errors fall, select 75% on the ordinate and determine the corresponding error value on the abscissa. In Figure 8 that value is 11 meters. In other words, 75% of the errors were less than 11 meters and 25% were greater than 11 meters. Interpretations may be made in the same way for other percentages.

Table 6 shows the error means for the vertical photo B points. Though the mean errors for the Paper Prints were slightly larger than they were for the Transparencies, an analysis of variance (Table 7) showed that the effects of Print Type, Scale, and the interaction between the variables were not statistically significant. The data from all levels of the independent variables were combined.

Table 6

VERTICAL MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR B POINTS

SCALE	PRINT TYPE Paper	PRINT TYPE Trans-parency	Mean Total
Large	23.9 (10)[a]	20.0 (8)	22.0
Small	27.1 (10)	20.7 (9)	23.9
Mean Total	25.5	20.4	23.0

[a] Number of subjects.

Table 7

VERTICAL MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR B POINTS

Source	df	MS	F
Scale (A)	1	34.59	<1
Print (B)	1	242.61	3.73
A x B	1	13.83	<1
Error	33	64.98	

Figure 9 shows the cumulative percentage of location errors for the vertical photo B points. The median error was about 20 meters.

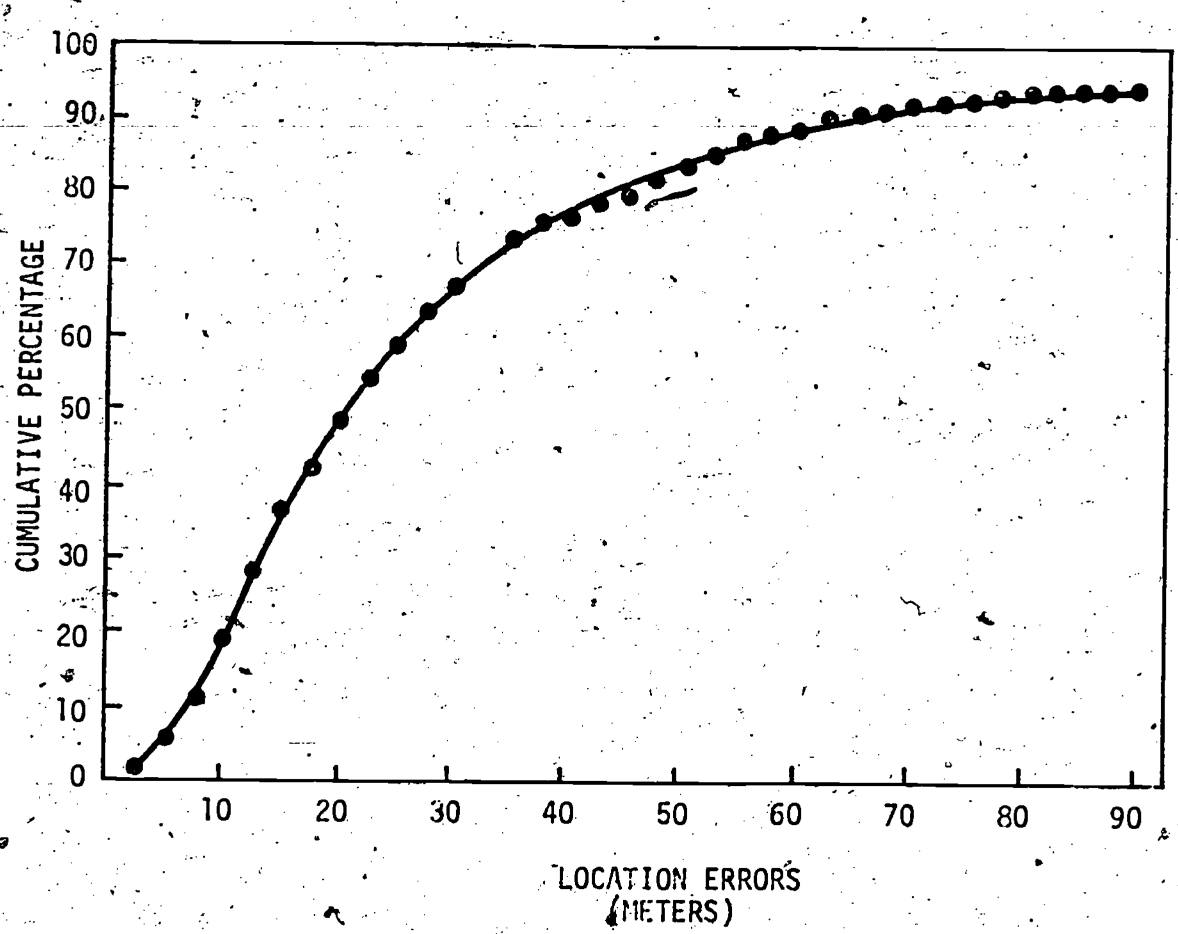

Figure 9. Cumulative percentage of location errors: vertical mission photos/B points (N=550).

Oblique Mission Photos. Table 8 shows the error means for the oblique photo A points. (The means are based on the performance of two subgroups of subjects. As pointed out earlier, the two subgroups did not transfer all of the same points.) The error means were larger for the Far points than for the Near points and larger for the Paper than for the Transparency.

Table 8

OBLIQUE MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR A POINTS

POSITION OF POINTS	PRINT TYPE		Mean Total
	Paper	Trans-parency	
Far	24.6 (19)	20.8 (18)	22.7
Near	16.6 (19)	9.3 (18)	13.0
Mean Total	20.6	15.0	17.8

But an analysis of variance (Table 9) indicated that the effects of Position, Print Type, and the interaction between the variables were not statistically significant. The data from all levels of the independent variables were combined.

Table 9

OBLIQUE MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR A POINTS

Source	df	MS	F
Between Subjects	36		
Prints (A)	1	1,915	3.57
Groups	1	1,080	2.01
Error	34	537	
Within Subjects	37		
Position (B)	1	505	2.28
A x B	1	152	<1.00
Error	35	221	

Figure 10 shows the cumulative percentage of location error for the oblique photo A points. The median error was about 11 meters.

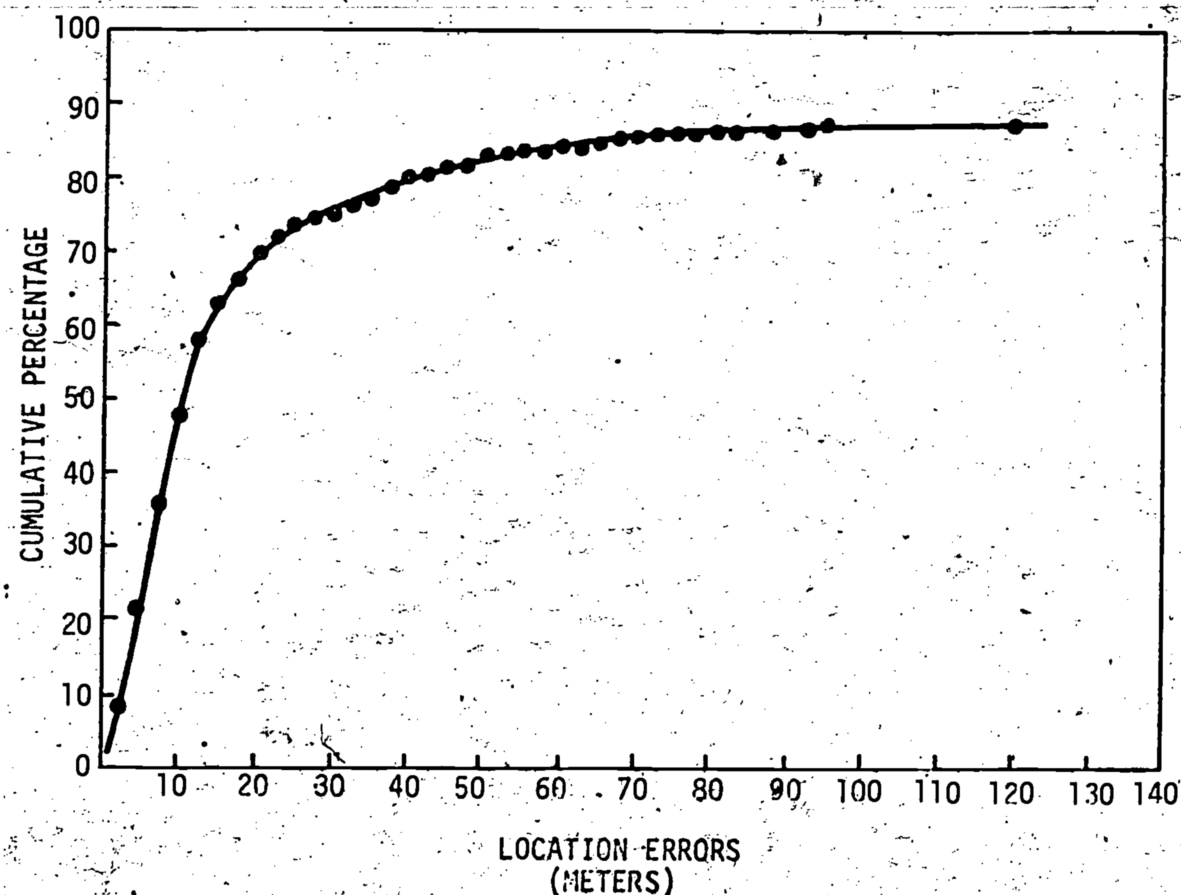

Figure 10. Cumulative percentage of location errors: oblique mission photos/A points (N=529).

Note that the median error is somewhat smaller than the mean total of 17.8 meters shown in Table 8. This difference is due to the positive skew of the error distribution. If a distribution of measures is positively skewed, the mean will be larger than the median, and the magnitude of the difference between the mean and the median will depend upon the amount of skew. Differences between the means and medians will be evident in the remaining results and will not be commented on further.

Table 10 shows the error means for the oblique photo B points. (As with the A points, the means are based on the performance of two subgroups.) The error means were larger for the Far points than for the Near points for both Print Types, but there was no substantial, consistent difference between the means for Print Types.

Table 10

OBLIQUE MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR B POINTS

POSITION OF POINTS	PRINT TYPE Paper	PRINT TYPE Trans-parency	Mean Total
Far	132.2 (19)	138.3 (18)	135.0
Near	35.5 (19)	34.4 (18)	35.0
Mean Total	83.8	86.3	85.0

An analysis of variance (Table 11) indicated that only the effect of Position was statistically significant ($p < .01$). The data from the two Print Types were combined for the Near and for the Far points.

Table 11

OBLIQUE MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR B POINTS

Source	df	MS	F
Between Subjects	36		
Prints (A)	1	114	<1.0
Groups	1	556	<1.0
Error	34	4,150	
Within Subjects	37		
Position (B)	1	185,626	58.24**
A x B	1	237	<1.0
Error	35	3,187	

**$p < .01$

Figure 11 shows the cumulative percentage of error for the Near and for the Far B points. The median error for the Near points was 29 meters and for the Far points 104 meters.

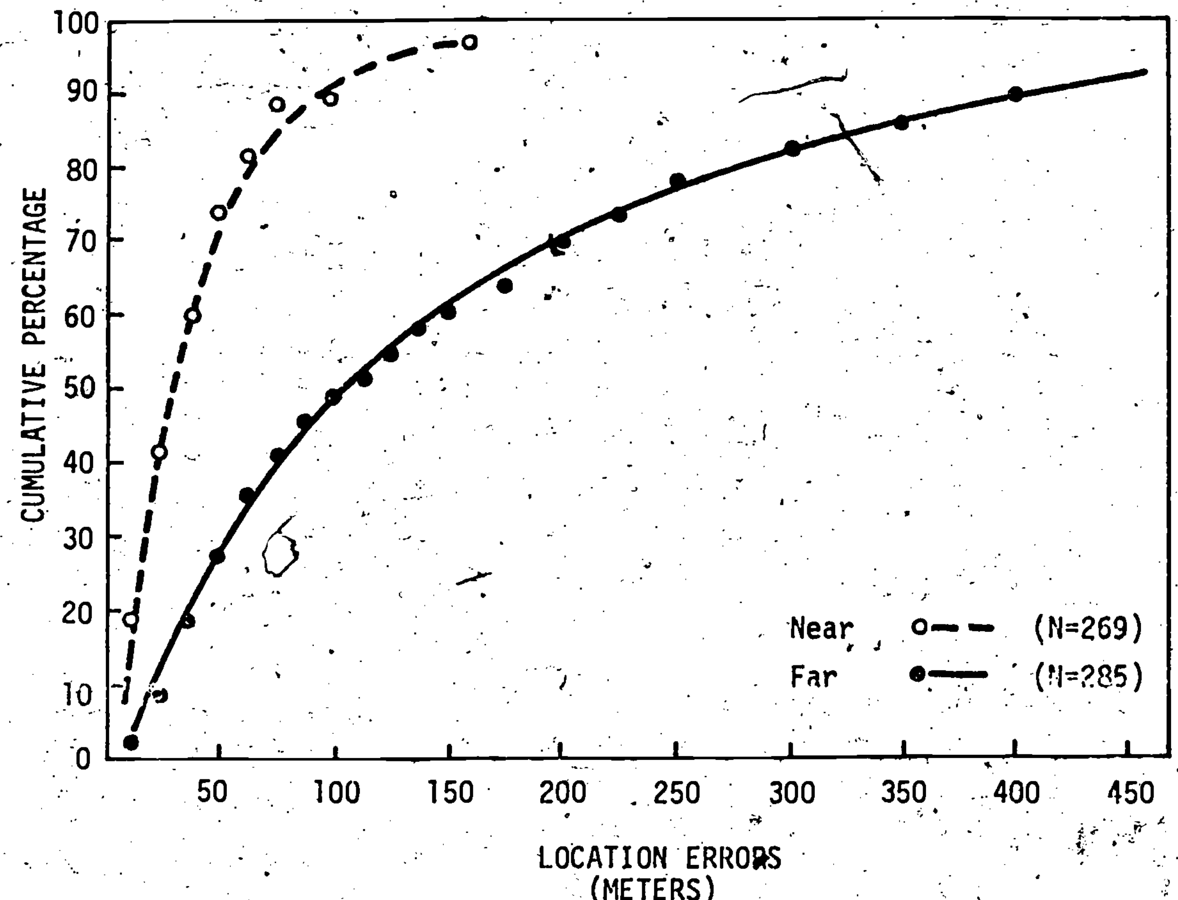

Figure 11. Cumulative percentage of location errors: oblique mission photos/B points.

High Pan Mission Photos. Table 12 shows the error means for the high pan photo A points. The error means were larger for the Far points than for the Near points for both Print Types, larger for the Paper than for the Transparency for both Positions.

Table 12

HIGH PAN MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR A POINTS

POSITION OF POINTS	PRINT TYPE		Mean Total
	Paper	Trans-parency	
Far	20.6 (18)	11.8 (18)	16.2
Near	10.9 (18)	6.2 (18)	8.6
Mean Total	15.8	9.0	12.4

An analysis of variance (Table 13) indicated that the effects of both Print Type and Position were statistically significant ($p < .01$), but the interaction between the two variables was not. The data from the two Positions were combined for the Paper and for the Transparency, and, similarly, the data from the two Print Types were combined for the Near and for the Far points.

Table 13

HIGH PAN MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR A POINTS

Source	df	MS	F
Between Subjects	35		
Prints (A)	1	832	9.04**
Error	34	92	
Within Subjects	36		
Position (B)	1	1,039	20.78**
A x B	1	77	1.54
Error	34	50	

**$p < .01$

Figures 12 and 13 show the cumulative percentage of errors for the Paper and Transparency and for the Near and Far points. The median error for the Paper was 12 meters and for the Transparency 8 meters. The median error for the Far points was 12 meters and for the Near points 7 meters.

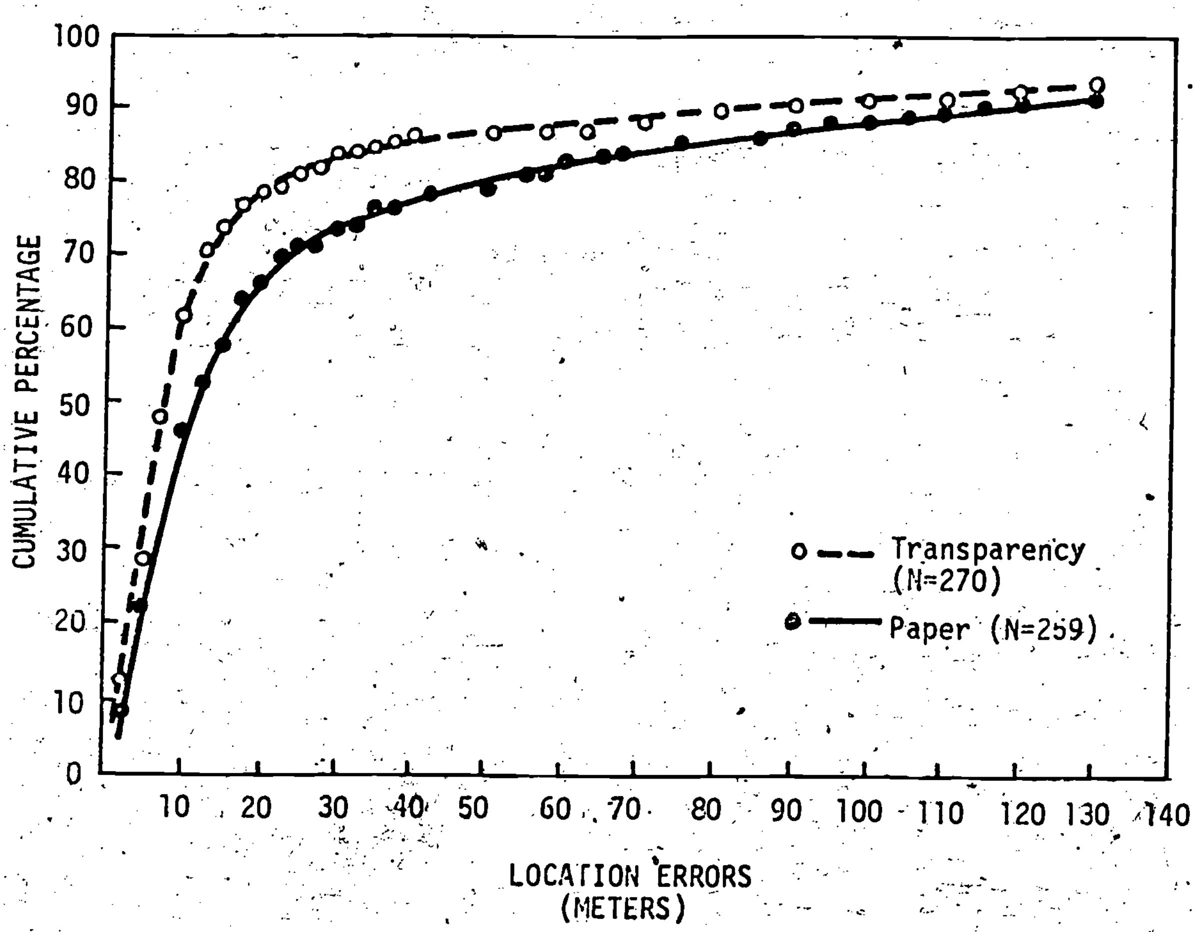

Figure 12. Cumulative percentage of location errors. High pan mission photos/A points; Print Type.

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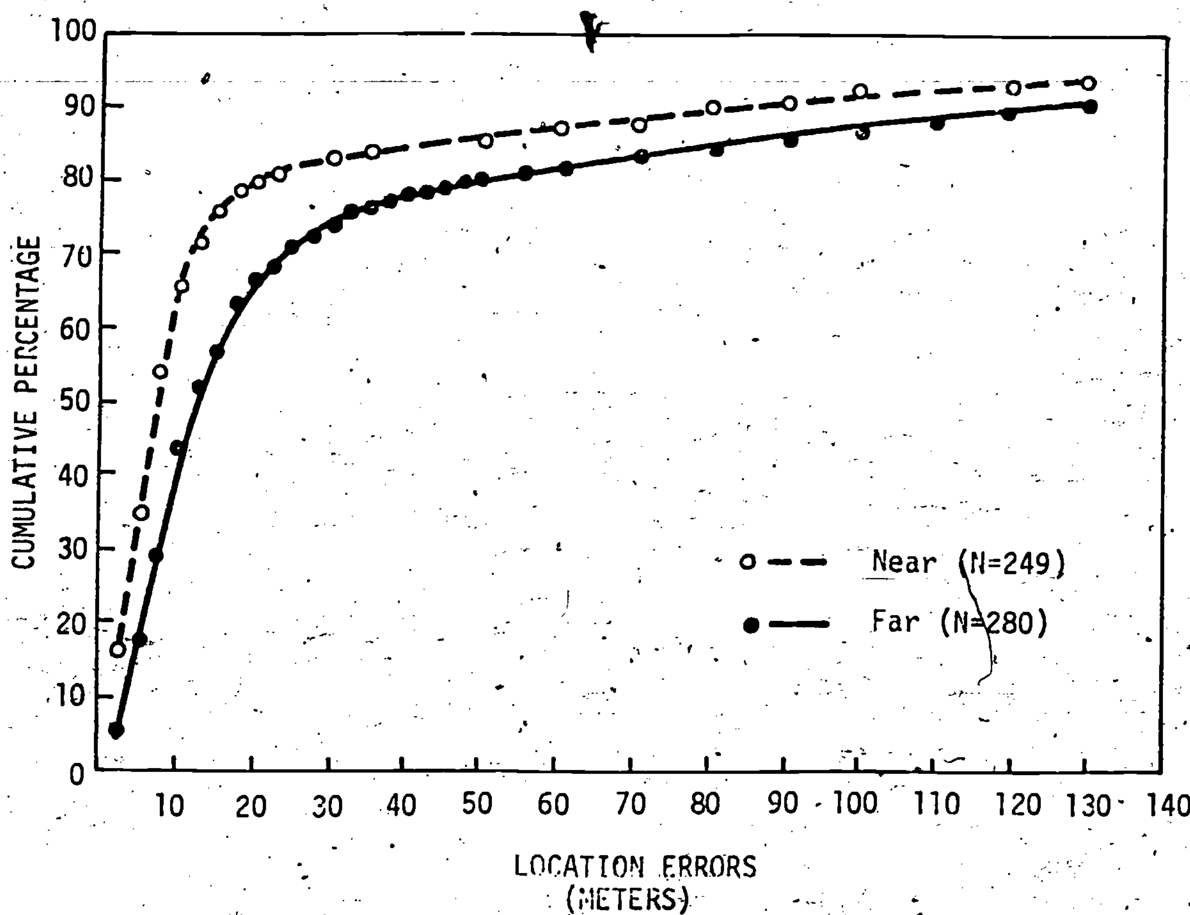

Figure 13. Cumulative percentage of location errors: high pan mission photos/A points; Position.

Table 14 shows the error means for the high pan photo B points. The error means were larger for the Far points than for the Near points for both Print Types, but there was essentially no difference between the means for the Paper and Transparency.

Table 14

HIGH PAN MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR B POINTS

POSITION OF POINTS	PRINT TYPE Paper	Transparency	Mean Total
Far	57.1 (19)	56.0 (18)	56.6
Near	38.2 (19)	35.3 (18)	36.7
Mean Total	47.6	45.7	46.7

An analysis of variance (Table 15) indicated that only the effect of Position was statistically significant ($p < .01$). The data from the Paper and Transparency were combined for the Near and for the Far points.

Table 15

HIGH PAN MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR B POINTS

Source	df	MS	F
Between Subjects	36		
Print (A)	1	76	<1.0
Error	35	749	
Within Subjects	37		
Position (B)	1	7,255	20.8**
A x B	1	15	<1.0
Error	35	348	

$^{**}p < .01$

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Figure 14 shows the cumulative percentage of location error for the high pan mission photo Near and Far B points. The median error for the Far points was 48 meters, and for the Near points 34 meters.

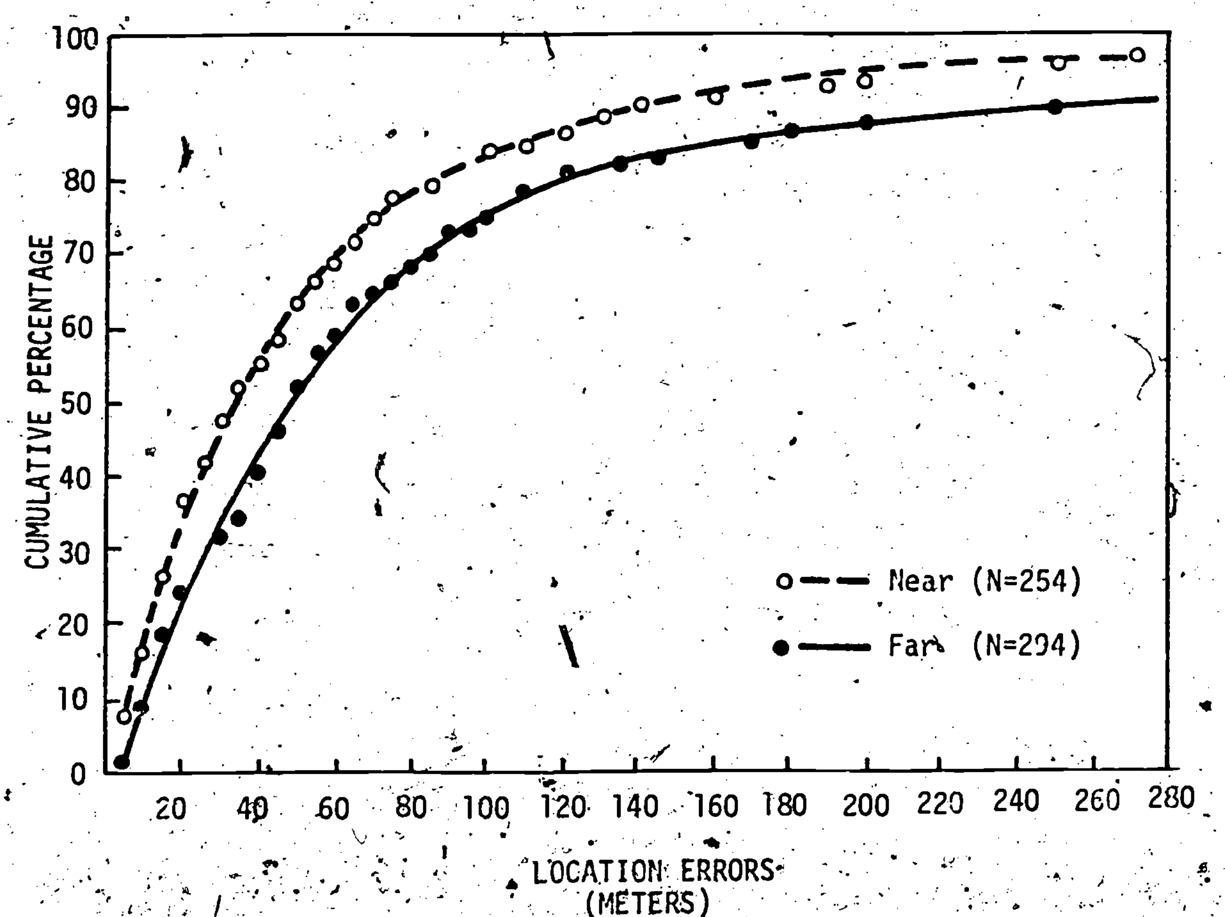

Figure 14. Cumulative percentage of location errors: high pan mission photos/B points.

Low Pan Mission Photos. Table 16 shows the error means for the low pan photo A points. The mean error for the Paper/Far points was considerably larger than for any of the other three combinations of Print Type and Position, and the error mean for the Transparency/Far point was somewhat larger than that for the Transparency/Near point.

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Table 16

LOW PAN MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR A POINTS

POSITION OF POINTS	PRINT TYPE: Paper	PRINT TYPE: Transparency	Mean Total
Far	59.1 (18)	15.6 (19)	37.4
Near	6.3 (18)	7.1 (19)	6.7
Mean Total	32.7	11.4	22.0

An analysis of variance (Table 17) indicated that the effects of Print Type and Position were statistically significant ($p < .05$ and .01, respectively) as well as the interaction between the two variables ($p < .01$).

Table 17

LOW PAN MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR A POINTS

Source	df	MS	F
Between Subjects	36		
Prints (A)	1	8,410	4.09*
Error	35	2,054	
Within Subjects	37		
Position (B)	1	16,743	8.61**
A x B	1	9,031	4.61**
Error	35	1,944	

*$p < .05$
**$p < .01$

It is apparent from inspection of Table 16 that the statistical significance of the two variables is due almost entirely to the large error on the Paper/Far point combination. A t test for correlated observations indicated that for the Paper the difference between the means for the Far and Near points was statistically significant ($t = 2.59$, $p < .02$ df 1 and 17); but, for the Transparency, the difference between the means for the Far and Near Points was not statistically significant ($t = 1.67$). Consequently, only the data from Paper and Transparency Near points were combined.

Figure 15 shows the cumulative percentage of error for the low pan photo A points. Three cumulative percentage distributions are shown: one for the Near points, one for the Transparency/Far points, and one for the Paper/Far points. The median error for the Near points and the Transparency/Far points was about 8 meters, and for the Paper/Far points about 19 meters.

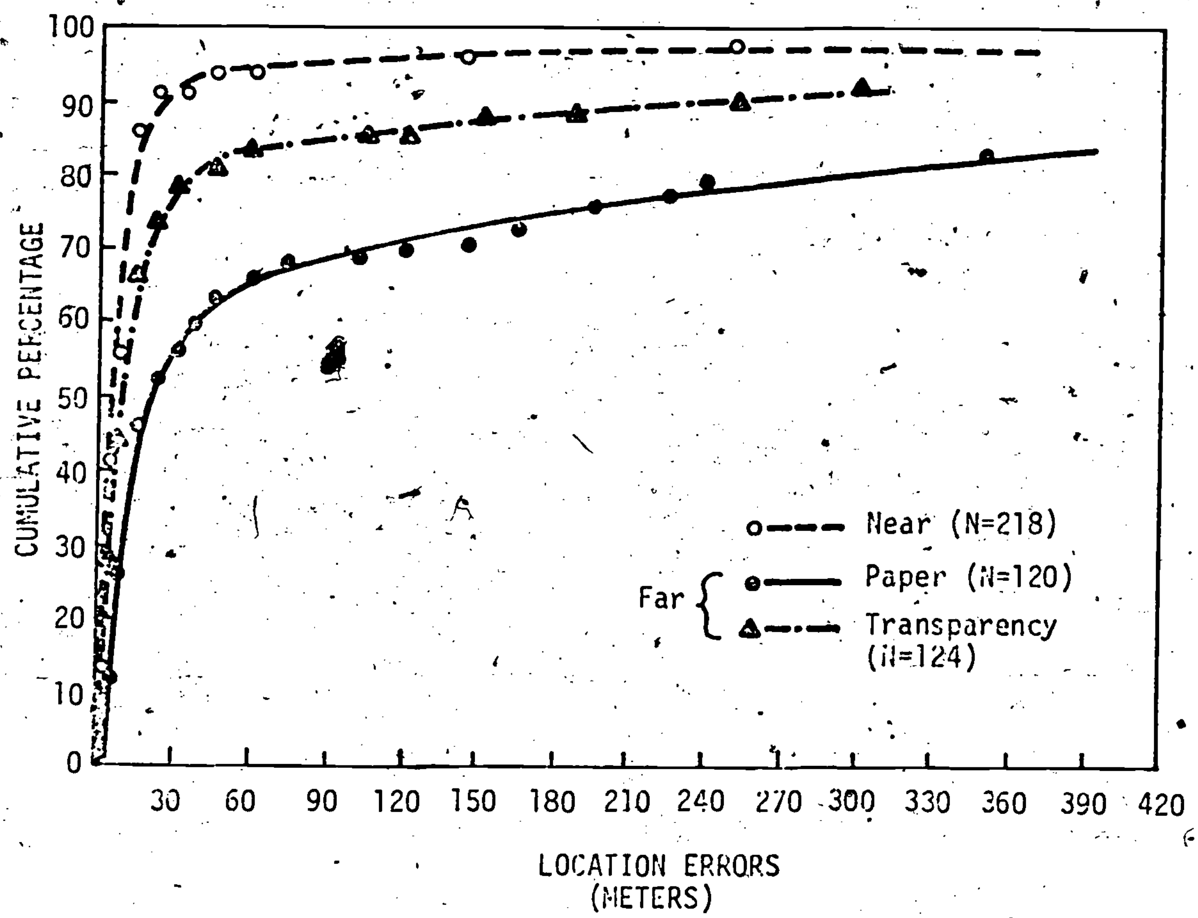

Figure 15. Cumulative percentage of location errors: low pan mission photos/A points.

Table 18 shows the error means for the low pan photo B points. The error means for the Far points were considerably larger than those for the Near points for both the Paper and Transparency. The difference between means for the Paper Near and Far points was considerably larger than the difference between the means for the Transparency Near and Far points. There was little difference between the means for the Paper and Transparency Near points.

Table 18

LOW PAN MISSION PHOTOS
MEAN LOCATION ERROR (METERS) FOR B POINTS

POSITION OF POINTS	PRINT TYPE		Mean Total
	Paper	Transparency	
Far	225.1 (18)	117.8 (19)	171.4
Near	42.5 (18)	48.3 (19)	45.4
Mean Total	133.8	83.0	108.4

An analysis of variance (Table 19) indicated that effects of Print Type, Position, and the interaction between the two variables were statistically significant ($p < .05$, $.01$, $.01$, respectively).

Table 19

LOW PAN MISSION PHOTOS
ANALYSIS OF VARIANCE OF
LOCATION ERRORS (METERS) FOR B POINTS

Source	df	MS	F
Between Subjects	36		
Prints (A)	1	47,568	7.12*
Error	35	6,677	
Within Subjects	37		
Location (B)	1	286,792	53.76**
A x B	1	59,112	11.08**
Error	35	5,335	

*$p < .05$
**$p < .01$

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A t test for correlated observations indicated that the difference between means for the Paper Near and Far points and for the Transparency Far and Near points was statistically significant: the values for t were 5.44 ($p < .01$, df 1 and 18) and 5.97 ($p < .01$, df 1 and 17). A t test for uncorrelated observations indicated that the difference between means for the Paper and Transparency Far points was also statistically significant ($t = 3.02$, $p < .01$, df 1 and 21)[3]. The difference between means for the Paper and Transparency Near points was not statistically significant. Consequently, only the data from the Paper and Transparency Near points were combined.

Figure 16 shows the cumulative percentage of error for the low pan photo B points. Three cumulative percentage distributions are shown: one for the Near points, one for the Paper/Far points, and one for the Transparency/Far points. The median error for the Near points was 39 meters; for the Paper/Far points, about 183 meters; and for the Transparency/Far points, about 100 meters.

Point Transfer Times

Visual inspection of the times taken to transfer the points revealed no practical differences between the levels of independent variables of Scale, Print Type, or Position. The differences among the levels of the variable were on the order of fractions of a minute. Generally speaking, the mean time taken to transfer points was about 30 seconds on the vertical photos and about 50 seconds on the non-vertical photos.

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[3] df is 21 instead of 36 because the variance of the two samples was not homogeneous. This technique of testing hypothesis about the difference between two means when the population variances are not equal is described by Welch, B. L. (1947). In Winer, J. B., *Statistical Principles in Experimental Design*, p. 37. New York: McGraw-Hill, 1962.

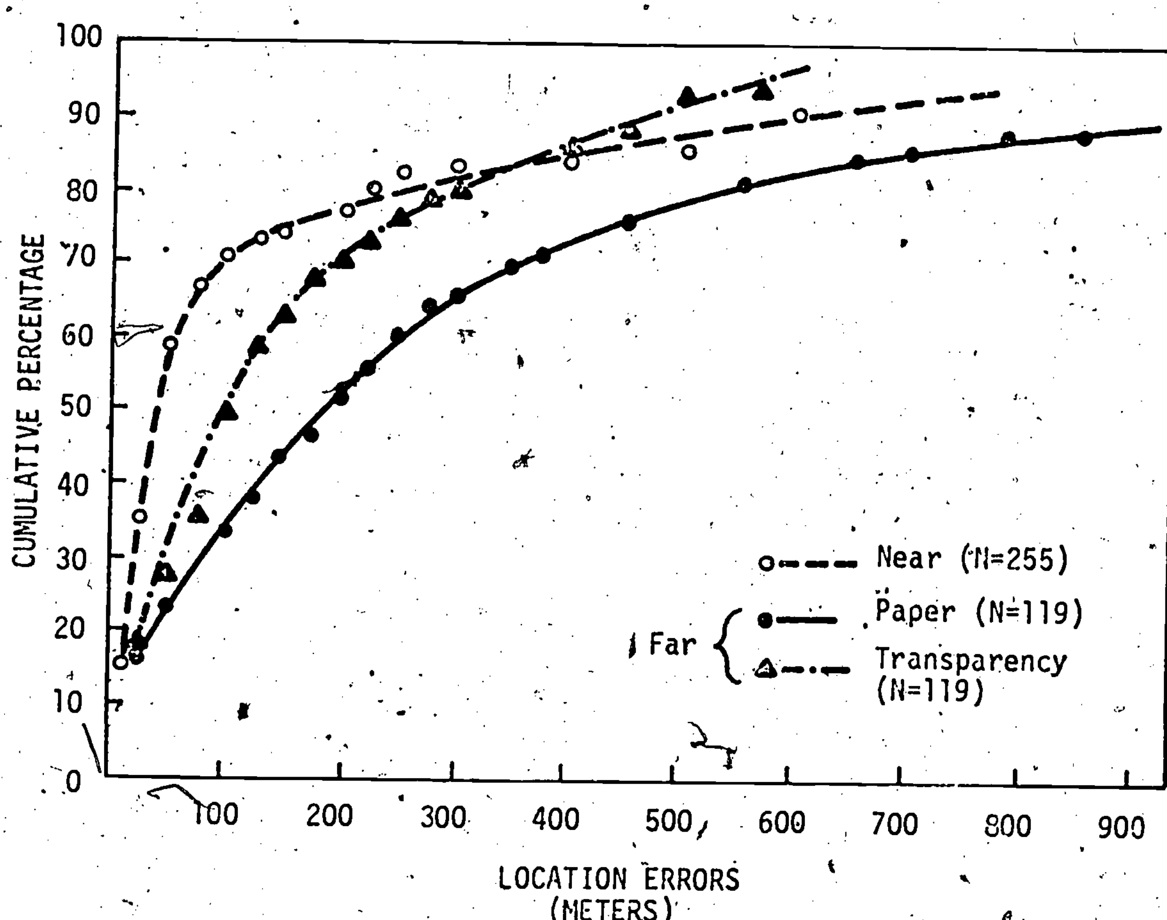

Figure 16. Cumulative percentage of location errors: low pan mission photos/B points.

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SUMMARY AND DISCUSSION

Because of the large number of independent variables and types of mission photos, a summary of the location error results is provided in Table 20.

Table 20

SUMMARY OF RESULTS FOR LOCATION ERRORS

MISSION PHOTO	POINTS	INDEPENDENT VARIABLE	STATISTICALLY SIGNIFICANT	LEVELS OF VARIABLE	ERROR (METERS) 25%	50%	75%
Vertical	A	Scale Print	No No	All levels combined	4	7	11
	B	Scale Print	No No	All levels combined	12	20	36
Oblique	A	Print Position	No No	All levels combined	6	11	28
	B	Print Position	No Yes	Far[a]	44	104	229
				Near[a]	14	29	54
High Pan	A	Print	Yes	Paper	6	12	35
				Trans-parency	4	8	16
		Position	Yes	Far	6	12	32
				Near	3	7	14
	B	Print Position	No Yes	Far[a]	22	48	97
				Near[a]	15	34	72
Low Pan	A	Print	Yes	Far-Paper	8	19	165
				Far-Trans-parency	5	8	25
		Position	Yes	Near[a]	4	8	10
	B	Print	Yes	Far-Paper	60	183	433
				Far-Trans-parency	38	100	233
		Position	Yes	Near[a]	18	39	150

[a]Data from Print Types combined.

The table shows for each mission photo and for the A and B points separately whether or not the independent variables were statistically significant; the levels of the independent variables for which accumulative percentage distribution was computed; and the error corresponding to each of three selected cumulative percentages. Each percentage and associated error may be interpreted as follows: for example, consider the vertical mission photo A points; 25% of the location errors were less than 4 meters, 50% were less than 7 meters, and 75% were less than 11 meters.

The location error for the three percentages is shown to allow the reader to assess the skew of the error distributions. The direction and the amount of skew may be computed by comparing $(75\%_e - 50\%_e)$ to $(50\%_e - 25\%_e)$ where e is the location error. If the first term is larger than the second, the distribution is positively skewed; if the first term is smaller than the second term, the distribution is negatively skewed; and if the two terms are equal, the distribution is symmetrical. The magnitude of the difference in these two terms indicates the amount of skew.

It is evident from inspection of Table 20 that nearly all of the distributions were positively skewed, with the exception of that for the vertical photo A points[4] and for the low pan photo Near A points. The positive skew is attributable to two factors: for most of the mission photos, a few of the points were far more difficult to locate accurately than the remaining points and this was particularly true for the B points and for the Far points; on some points, a few subjects made errors considerably larger than those made by the remaining subjects.

Now to consider the effects of independent variables of Scale, Print Type (Resolution), and Position (Near, Far). The scale of the vertical mission photos did not affect the magnitude of error. This was true for the A points, points that were on easily identifiable features, and for the B points--points that were not close to such features. Scale did not affect the error magnitude possibly because the two scales provided sufficient detail for locating the points on the data base.

The variable of Print Type did not affect location error for the vertical or oblique mission photos. It did have a statistically significant but small effect for the high pan photo. A points (Paper = 12 meter median error; Transparency = 8 meter median error); a slightly larger effect for the low pan photo Far A points (Paper = 19 meters; Transparency = 8 meters); and a pronounced effect for the low pan photo Far B points (Paper = 183 meters; Transparency = 100 meters).

Performance with the transparencies was considerably better than it was with the Paper prints only on the Far portion of the low pan photos. This seems to indicate that the ground resolution in the Far portion of the mission negative was close to a level where even a

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[4] This has a slight positive skew but is neglible compared to the others.

small degradation would cause a significant loss of the detail useful for accurate point transfer. Apparently the transparency preserved more of this useful detail than the Paper print. Generally, the small degradation caused by the Paper print was not as harmful for the other mission photos because the overall quality of the negatives was sufficiently high so that a small loss in ground resolution did not cause a significant loss of detail useful in point transferring.

As expected, the variable of Position significantly affected location error. The error for the Far points was usually larger than for the Near points and the difference in the magnitude of the error was larger for the B points than for the A points. The probable explanation of the larger error for the Far points is that they were in the portion of the mission photo in which the distances between scene features are not linearly proportional to their corresponding features on the data base, whereas the Near points were in the portion of the photo in which the distances were closer to linear. It was undoubtedly more difficult to locate points where the distances were non-linear. The effects of Position were larger for the B points than for the A points because, by definition, the A points were located on identifiable features while the B points were relatively far removed from such features.

The location error for the non-vertical photo Near A points was not much larger than that for the vertical photo A points. For the vertical photos, the 50% (median) and 75% location errors were 7 and 11 meters; for the non-vertical photos, the 50% error ranged from 7 to 11 meters and the 75% error ranged from 10 to 28 meters. But the error for the Near B points was considerably larger than that for the vertical photo B points. For the vertical photo, the 50% and 75% errors were 20 and 36 meters; for the Near B points, the 50% error ranged from 29 to 39 meters, and the 75% error ranged from 54 to 150 meters.

These results indicate that the location error for the vertical mission photos and for the near portion of the non-vertical mission photos are comparable for only specific kinds of points--those located on or very close to identifiable features in the scene.

For the B points, the location errors for the vertical mission photos and for the Far portion of the non-vertical photos were not comparable: the 50% error for the Far points ranged from 48 meters for the high pan photos to about 140 meters (mean of 183 and 100 meters) for the low pan photos; the 75% error ranged from 97 meters (high pan photos) to about 335 meters (mean of 433 and 233 meters) for the low pan photos.

The results of this study, as summarized in Table 20 should be useful in assessing the operational capabilities of the APPS for targets appearing on various types of reconnaissance photography. It is apparent that B-type targets usually cannot be transferred visually to acceptable accuracies except from vertical mission imagery. This indicates that other means for transferring B-type targets should be found.

Overall improvement in point transfer accuracy might be achieved by judicious selection of operators plus specialized training.

This report should be useful to G-2 air officers and reconnaissance aircraft pilots because it shows clearly the value of acquiring targets in a near vertical mode. Of course, operationally, this is sometimes not possible but at least the operational personnel will know the loss of transfer accuracy that will result when targets are imaged in the Far portion of a panoramic or oblique frame.

There may be some advantage in viewing the data base or the mission photography in a stereo mode and still further advantage if both are viewed in stereo. Stereo was not used in this study but, based on past related experience, the use of stereo might improve both A point and B point accuracy, but the greatest improvement would be to B points.

During the main tests it required an average of less than one minute per point to effect a transfer. However, there are two steps in the transfer process. The first is finding on the data base the area covered by the mission photo. In some preliminary tests this was found to be so time consuming (up to 30 minutes) that transparent templates were furnished each test subject so he could quickly locate the areas on the data bases. In areas having limited cultural and prominent natural features, the location of the general area of the mission photo could become a major problem. The training of interpreters to more quickly relate one photo to another, when there is a large disparity in scale and geometry, seems essential for efficient operation of the APPS. The second step is the finding and marking of the point of interest on the data base.

CONCLUSIONS

Based on the results of this study and on general observations made during the testing phase it is concluded that:

- The tests were conducted according to the test plan and were successful in fulfilling the stated objectives.
- The following variables were found to be practically significant:

  Position (Far or Near portion of the format of non-vertical imagery)

  Point/Environs (Relationship of point to identifiable detail)

  Resolution (Transparency vs. Paper Print) - significant only for some combinations of conditions

- The variable found to be not practically significant is:

  Scale (within operational ranges - vertical photography)

- Under the conditions of the experiment, transfer CEP of less than 20 meters was obtained for 50 percent of the A points transferred from all mission types and 75 percent of the transfers were within a CEP of 20 meters for Vertical missions, for the Near portion of High and Low Panoramic missions, and for film transparencies for the High Panoramic mission irrespective of target position on the image. Only the Vertical mission imagery was adequate for the purpose of providing a CEP or 20 meters for the transfer of 50 percent of the B points.

- Test subjects preferred transparencies to paper prints for mission imagery and they preferred transmitted light (light table) to reflected light (high intensity lamp), even for paper prints.

- The cumulative percentage curves are useful in estimating transfer errors for different kinds of mission imagery.

APPENDIX A

ANALYTICAL PHOTOGRAMMETRIC POSITIONING SYSTEM (APPS)

The Analytical Photogrammetric Positioning System (APPS) is a point positioning system developed at the US Army Engineer Topographic Laboratories (USAETL), Fort Belvoir, Virginia. The APPS has evolved as a solution to the problem of determining X, Y, Z coordinates of points of interest anywhere in or forward of a Corps-size area in a matter of minutes.

Photogrammetric theory and techniques have been combined with the capabilities of a desk top programmable calculator to provide for utilization of the analytical methods of determining position, unlike the more classical analog methods found in photogrammetric map compilation instruments. The problem is treated as an intersection problem for which universally accepted solution techniques are available. Numerical data are accepted for certain known parameters, and measured photo coordinates are treated as the observed parameters, thereby solving for the unknown X, Y, Z coordinates of a point.

There are two parts to the APPS; (1) a Data Base (DB) consisting of mapping quality aerial photography and its associated numerical data, and (2) an assemblage of mensuration and data processing equipment with associated software.

The DB is the key element of the APPS. It is rigorously prepared as part of the normal mapping process and only then extracted from that process for application to the APPS. The DB is mathematically adjusted by an analytical procedure known as aerial block triangulation which is based upon the method of least squares. Given two points of known horizontal positions (X,Y) and three points of known elevation (Z), one can determine the six orientation parameters of a photograph, whether dealing with one overlapping pair of photographs or overlapping coverage of entire countries. Use is made of redundant control data whenever possible to reduce accumulation of small uncorrected systematic errors and random errors. The adjustment is held to ground control.

The DB photograph requires no special processing such as rectification. It is annotated with orientation points called index points and with check points. Its associated numerical data includes interior and exterior orientation parameters, photo coordinates of the index points, and geocentric coordinates of the check points. APPS equipment calibration parameters are also incorporated in the numerical data.

The other portion of the APPS, the hardware, is primarily an assemblage of commercial, off-the-shelf items that will accept the DB and perform the necessary measurements and computations for X, Y, Z coordinates. The current package represents first generation components. Modifications and add-ons have been envisioned to increase the flexibility of the system.

There are five major component items of equipment to include: (1) a modified Zeiss Stereotope,[1] (2) an operator control box, (3) an interface unit, (4) a Hewlett-Packard[1] (HP) 9810A programmable calculator,[1] and (5) an HP cassette memory.[1] See Figure A1.

The Stereotope provides the capability for stereoscopic viewing and parallax measurement by the X, Y and X-parallax motions it possesses. To extract these measurements, a Bendix X, Y digitized data grid[1] is installed under the Stereotope baseplate and a signal cursor is connected to the moveable photocarriage. Also, a shaft angle encoder is connected to the X-parallax motion drive.

The operator control box provides a simple means of selecting a particular operation for the APPS to perform, i.e., zero the baseplate data grid datum, or index the DB stereomodel, etc.

The interface unit converts cursor signals to the HP language and subsequently HP language to a desired output language.

The HP 9810A programmable calculator and the HP cassette memory function together. The memory holds the software programming and DB files on tape covering a Corps size area for sequential access by the calculator. The calculator uses the program and one numerical DB file at a time together with the input from the Stereotope through the interface to compute the X, Y, Z coordinates of a point.

In practice, the operator uses a photo index overlay to determine which DB stereo pair of photographs to place on the Stereotope. He inserts the magnetic tape cassette containing the program and DB numerical data files for that model into the cassette memory. He then activates the cassette memory to load the program by use of a magnetic card. The card also contains the Stereotope calibration parameters mentioned earlier. He then calls in the DB file for the model being used by keyboard commands. Each photo of the model is oriented independently using the index points mentioned earlier. The photo coordinates of four index points are measured and a transformation computation made to relate the measured photo coordinates to the adjusted photo coordinates. The operator then observes and measures a check point, this time in stereo, to ascertain that he correctly oriented the model. He must agree with the known coordinates of the check point within established tolerances before he can proceed. Once he is signalled to proceed he then observes the point of interest, measures and computes the X, Y, Z coordinates of the point and obtains a printout on paper tape of the UTM Zone, Easting, Northing and elevation in meters.

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[1] Commerical or trade names are given only in the interest of precision in reporting experimental procedures. Use of the names does not constitute official endorsement by the Army or by the U.S. Army Research Institute for the Behavorial and Social Sciences.

Test results conclude that horizontal position locations determined with the APPS are approximately equivalent to third-order ground surveys. This is readily achieved by personnel having previous training in the interpretation of aerial photographs and additional 16-40 hours instruction on the APPS.

The APPS is packaged for transport in three militarized carrying cases for a total weight of 478 pounds and a volume of 27.42 cubic feet. It requires 600 watts of power at 110v, 60 Hz.

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