Technical Paper 348

LEVEL

AD

TOTAL SYSTEM ACCURACY FOR APPS

(The Analytical Photogrammetric Positioning System)

E. Sewell
Raytheon Company/Autometric
A. Harabedian
Human Factors Research, Inc.

and

Thomas E. Jeffrey
U.S. Army Research Institute

HUMAN FACTORS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

October 1978

U. S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

Research accomplished under contract to
the Department of the Army

Raytheon Company
Human Factors Research, Inc.

NOTICES

DISTRIBUTION: Primary distribution of this report has been made by ARI. Please address correspondence concerning distribution of reports to: U. S. Army Research Institute for the Behavioral and Social Sciences, ATTN: PERI-P, 5001 Eisenhower Avenue, Alexandria, Virginia 22333.

FINAL DISPOSITION: This report may be destroyed when it is no longer needed. Please do not return it to the U. S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Paper 348

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
TOTAL SYSTEM ACCURACY FOR APPS (The Analytical Photogrammetric Positioning System)

5. TYPE OF REPORT & PERIOD COVERED
Final Report, 10 June 1974 thru 9 June 1975

6. PERFORMING ORG. REPORT NUMBER
FR 75-1516

7. AUTHOR(s)
E. Sewell, Raytheon Company/Autometric;
A. Harabedian, Human Factors Research, Inc.; and
T. Jeffrey, ARI

8. CONTRACT OR GRANT NUMBER(s)
DAHC19-74-C-0063

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Raytheon Company, Equipment Division, Autometric
Boston Post Road
Wayland, Massachusetts 01778

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
62717A, 2Q762717A721
00, 018

11. CONTROLLING OFFICE NAME AND ADDRESS
Department of the Army
Office of the Assistant Chief of Staff for Intelligence (DAMI), Washington, DC 20310

12. REPORT DATE
October 1978

13. NUMBER OF PAGES
58

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Army Research Institute for the Behavioral and Social Sciences (PERI-OS)
5001 Eisenhower Avenue
Alexandria, VA 22333

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
--

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

--

18. SUPPLEMENTARY NOTES

--

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Coordinate determination
Analytical transformation
Imagery correlation
Analytical Photogrammetric Positioning System

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The accuracy and speed with which experienced APPS operators can obtain UTM coordinates and the elevation above the datum plane for points of interest designated on various reconnaissance imagery types were determined. These points of interest were transferred by an analytical method from representative operational imagery--panoramic photography, infrared, and radar--to 1:100,000 scale data base photography and their UTM coordinates and

(continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

79 01 17 033

20. (continued)

elevation above the datum plane determined. Results were compared with known values and error magnitudes and performance time requirements obtained. Results indicate that experienced APPS operators are very consistent in their placement of points of interest under the reference dot (monocular pointing). (NOTE: All distances are reported at ground scale and not at the distance measured on the data base image.) The median variability error was 1.6 meters in the XY-plane. Time required per point for monocular pointing was about .18 minutes. On the average, stereoscopic pointing--the placement of the point of interest in the three-dimensional data base model in apparent contact with the floating reference dot--was accomplished with a median elevation error of 3 meters, a median XY-plane error of 6 meters, and a median total error of 7.5 meters. Median time required per point for stereoscopic pointing was .8 minutes. Finally, the transfer of a point of interest from a reconnaissance to data base image combined with stereoscopic pointing gave results that varied with the type of reconnaissance imagery used. For infrared imagery, median elevation error was 5.7 meters, median XY-plane error was 9.5 meters, and median total error was 12.3 meters. The median time per point to transfer and obtain coordinate data was about 7 minutes. Similar but somewhat larger median errors were obtained for panoramic and radar reconnaissance missions. The speed and accuracy with which these experienced APPS operators determined coordinate and elevation data are well within the initially stipulated requirements.

Technical Paper 348

TOTAL SYSTEM ACCURACY FOR APPS

(The Analytical Photogrammetric Positioning System)

E. Sewell
Raytheon Company/Autometric
A. Harabedian
Human Factors Research, Inc.

and

Thomas E. Jeffrey
U.S. Army Research Institute

HUMAN FACTORS TECHNICAL AREA

Submitted as complete and technically accurate, by:
Edgar M. Johnson
Technical Area Chief

Approved By:

Frank J. Harris, Acting Director
ORGANIZATIONS AND SYSTEMS RESEARCH LABORATORY

Joseph Zeidner
TECHNICAL DIRECTOR

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

October 1978

Army Project Number
2Q762717A721

Contract DAHC19-74-C-0063
Surveillance Systems

ARI Research Reports and Technical Papers are intended for sponsors of R&D tasks and other research and military agencies. Any findings ready for implementation at the time of publication are presented in the latter part of the Brief. Upon completion of a major phase of the task, formal recommendations for official action normally are conveyed to appropriate military agencies by briefing or Disposition Form.

FOREWORD

The Human Factors Technical Area is concerned with the demands of the future battlefield for increased man-machine complexity to acquire, transmit, 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 products and procedures, tactical symbology, user-oriented systems, information management, staff operations and procedures, and sensor systems integration and utilization.

One critical 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. The present publication is primarily concerned with the identification of the sources and magnitude of errors made by trained APPS operators as they determine the ground coordinates for targets detected on a variety of aerial surveillance/reconnaissance displays. The precision with which the APPS equipment/operator can determine the coordinates of a specified target on repeated trials was obtained for monoscopic and stereoscopic measurements. A list of the skills, traits, and physical characteristics required in an APPS operator candidate was generated for use in future selection research. A step-by-step instruction manual was prepared for the self-teaching of APPS operators in alternative transfer techniques for enhancing the speed and accuracy of performance.

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 DAHC19-74-C-0063 with program direction from Dr. Abraham H. Birnbaum. The effort is responsive to requirements of Army Project 2Q762717A721, the U.S. Army Engineer Topographical Laboratory, Fort Belvoir, Va., and the Assistant Chief of Staff for Intelligence. Special requirements are contained in Human Resource Needs 74-20 and 74-22.

JOSEPH ZEIDNER
Technical Director

TOTAL SYSTEM ACCURACY FOR APPS

BRIEF

Requirement:

By total task and subtask determine error contribution and performance time requirements of experienced Analytical Photogrammetric Positioning System (APPS) operators transferring points of interest from selected types of operational reconnaissance imagery to APPS data base imagery and obtaining UTM coordinates and the elevation with respect to the datum plane for these points. In addition, refine the previously developed analytical transformation technique and prepare a manual for use in instructing APPS operators and trainees in its use. Also, investigate the utility of selected aids and procedures as means for reducing error and/or response time.

Procedure:

Two of the three photo data bases used in the tests were developed under this program. Comparator measurements were made on index marks, pass points, control points and target points and an aerotriangulation least squares adjustment was performed. Digital data tapes were prepared by Defense Mapping Agency Topographic Center (DMATC), based on data provided by Autometric. Panoramic, infrared, and radar mission imagery were used. Target points were marked on these image records. Their true ground positions were found during the triangulation phase. Ten subjects participated in three experiments: Experiment I--Monoscopic measurement of index marks; Experiment II--Stereoscopic measurement of points marked on the data base; Expertiment III--Indirect transferring of points from infrared, panoramic, and radar mission imagery to a data base and solving for ground coordinates of the points.

Findings:

Ground coordinates of points, whose images appear on infrared, panoramic, and radar reconnaissance records, can be determined to stated accuracy requirements using the APPS equipment and the techniques described in this report. The average median time for finding the coordinates of one point was under 7 minutes. The 25th, 50th, and 75th centile total errors for the infrared targets were 8.3, 12.3, and 17.9 meters (total error $\sqrt{X^2+Y^2+H^2}$). For the panoramic targets the total errors were 9.7, 14.4, 20.3 meters (average for targets within and beyond 45° from nadir).

For the radar targets the total errors were 12.2, 17.0, and 24.7 meters. All errors at the 75th centile level are less than the requirements stated in a report entitled Photogrammetric Applications to Field Artillery, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, March 1970, viz., "However, the most stringent Field Artillery positional accuracy requirement is roughly 25 meters CPE, i.e., 50% assurance, or about 46 meters (90% assurance)." Desired positional accuracy has been upgraded by letter, HQ TRADOC dated 12 June 1975, subject: APPS, Advanced (APPS-2) in which the positional accuracy requirement for terrain locations beyond the FEBA are to fall within 15-25 meters CPE while for positions to the FEBA they are to fall within 5-10 meters CPE. Acceptable error for height above or below the datum plane is specified as 5-15 meters PE (Probable Error) beyond the FEBA and 3-8 meters PE to the FEBA. Median Height and Plane errors for this research fall within the bounds specified in these more stringent requirements.

Utilization of Findings:

The techniques described in this report can be used with the APPS-1 equipment with only minor equipment and software modifications. Operators, trained in these techniques, will be able to get better positional accuracy for isolated target points and will have greater confidence in their work for two reasons: The transformation residuals provide a measure of the transfer accuracy; and the coordinates determined for a given target point can be verified by using another set of control points and repeating the transfer procedure. The four investigations contained in the Appendices provide information of immediate use with APPS-1 as well as suggestions for consideration in the development of future APPS generations.

TOTAL SYSTEM ACCURACY FOR APPS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

General

Modern reconnaissance systems are capable of recording at high resolution, terrain features and man-made objects from distances up to fifteen miles, under good or inclement weather conditions and under all lighting conditions. Even photographs from satellite altitudes (Nimbus, Apollo, ERTS) contain information useful to the intelligence community. Even though new and better sensors are being developed, it can safely be said that, today, we have the capability of providing valuable tactical and strategic intelligence about any area which we can overfly. The value of some intelligence data decreases rapidly with time, so means have been developed for transmitting data from the sensor platform to one or more ground receivers in real or near-real time. Intelligence data, acquired by any means, often has only limited value without some knowledge of the location associated with the data. Positional requirements vary considerably from several thousand meters for certain kinds of intelligence to 25 meters or less for tactical targets.

In 1971, the U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia addressed the tactical target location requirement and developed the Analytical Photogrammetric Positioning System (APPS)[1] to meet this requirement. According to an ETL report[2] "the most stringent Field Artillery positional accuracy requirement is roughly 25 meters CPE, i.e., 50% assurance, or about 46 meters (90% assurance)".

In a report published by the U.S. Army Field Artillery School, Ft. Sill, Oklahoma[3], it is stated "APPS-1 maximum potential accuracies at point location approach 9.13, 13.62 and 15.21 meters for (X, Y, and Z) coordinates, linear error at 95% around control values for the 1:106,000 scale data base tested; . . . . Circular Probable Error for 1:106,000 scale data base approached 7 meters";

1/ Described in Appendix F

2/ Griffin, Eugene P.,Donald R. Barnes, and James E. Stilwell, Photogrammetric applications to field artillery. U.S. Army Topographic Laboratories. March 1970.

3/ Testing, evaluation, and development of the analytical photogrammetric positioning system. U.S. Army Field Artillery School. July 1974.

Tests conducted by the Defense Mapping School of DMA demonstrated that accuracies of 5.6, 5.6, and 2.8 meters (Composite Standard Deviations in Eastings, Northings, and Elevations) could be attained with the APPS, using a 1:100,000 scale data base. Converting these accuracy measures to the 95% level of confidence used by Ft. Sill yields estimates of 10.98, 10.98, and 5.49 meters for (X, Y, and Z) coordinates respectively.

The above tests, plus tests made by Raytheon and others, show clearly that the APPS equipment is capable of accuracies considerably better than the Field Artillery positional accuracy requirements of 25 meters, CPE. However, previous studies by Raytheon,[4/],[5/] have shown that large errors can result when making direct point transfers from panoramic and oblique reconnaissance photography and from infrared and radar reconnaissance imagery.

Background

In the previous ARI studies, points were transferred to photographic data bases from various types of photographic, infrared and side-looking radar imagery. Two general classes of points were transferred; those located on a feature identifiable on both the mission and data base photography (Type A); those which are more than 200 meters distance on the ground from a point identifiable on both mission and data base photography (Type B). Two transfer techniques were used: the Direct technique in which the subject related the point of interest on the mission imagery to the data base by association with background detail surrounding the point; the Indirect technique in which coordinate measurements made on the reconnaissance and data base imagery were used to locate the point of interest in the data base coordinate system. Ground coordinates were not determined during these tests.

It was found that, using the Direct transfer method, Type A points on vertical, oblique or panoramic photography did not present any serious transfer problems except when images on the oblique and panoramic photos approached the horizon. Transfer errors for A points on all three side-looking radars tested were, in general, larger than can be tolerated ... while errors for Type A points on the IR imagery were similar to the errors on photographic imagery. Direct transfer of Type B points, even at the 50th centile level, resulted in excessive transfer errors for all types of photographic, radar and IR imagery. These errors, combined with the APPS positioning error, will reduce the total effectiveness of the APPS unless the transfer errors can be reduced substantially.

4/ Sewell, E., R. Bradie, A. Harabedian, and T.E. Jeffrey. The effects of photo characteristics upon location determination in a photogrammetric facility. ARI Technical Paper 346, October 1978.

5/ Sewell, E., A. Harabedian, and T.E. Jeffrey. Mission/data-base imagery correlation techniques (M/DICT). ARI Technical Paper 347, October 1978.

Much of the reconnaissance imagery used in previous APPS tests was of areas containing an abundance of background detail, such as cultural development. This makes point transferring easier and more accurate. In unfamiliar areas, having limited man-made detail for reference, the transfer errors will be even larger, especially for direct transfers.

One of the conclusions from the report on the second ARI study[5/] stated that "Indirect as well as Direct transfer techniques are needed by the APPS operator for transferring points from a variety of records from remote reconnaissance sensors".

OBJECTIVE

The primary objective of this program was to determine the accuracy and speed with which trained APPS operators can find ground coordinate locations for targets detected on a variety of aerial surveillance/reconnaissance displays. A secondary objective was to measure the repeatability of the APPS equipment/operator for both monoscopic and stereoscopic measurements. Another objective was to identify the important psychological and physical traits that should be considered when selecting APPS operator candidate. A general objective was to explore ways to improve operator performance and to speed up APPS operations.

METHOD

General

The work performed under this contract has been divided into two parts in order to simplify the reporting. One part is the main experiment and the other part consists of several miscellaneous research efforts. The main body of the report is concerned only with the main experiment. The secondary research efforts including an operation manual are described in the appendices.

The part referred to as the main experiment was the total effort expended in the developing and testing of techniques and software for getting ground positions of points whose images appeared on various types of remote sensor imagery. After procedures, software and preliminary test materials had been developed and subjected to a pilot test, the modified test materials for the main test were assembled. The main tests were performed by experienced personnel, using APPS equipment provided by the U.S. Army Research Institute for the Behavioral and Social Sciences.

The miscellaneous research efforts included: investigations for improving accuracy of Indirect transfers in mountainous areas;

5/ Ibid.

use of locating studs for rapid positioning of data base photographs; investigation of 8-parameter transformation program as a possible replacement of the 6-parameter transformation program; use of a quick-print process for making records of areas of interest found on original reconnaissance negatives; and an investigation of the psychological and physical traits to be considered when selecting APPS operator candidates.

Development of Experimental Materials

Three separate data bases were used for these tests. The White Sands Proving Grounds data base, used for Experiments I and II, was developed by the Topographic Center of the Defense Mapping Agency (DMATC). Two data bases were developed under this contract: a three-photo base of Phoenix, Arizona and a four-photc base of the Northeast Test Range. Information concerning the data base imagery and the reconnaissance imagery is shown in Table 1.

Table 1
DATA BASE IMAGERY

AREA	ALTITUDE	SENSOR
White Sands Proving Grounds	50,000 ft.	6" f.1. 9"x9" format camera
Phoenix, Arizona	50,000 ft.	6" f.1. 9"x9" format camera
Northeast Test Range, N.Y.	50,000 ft.	6" f.1. 9"x9" format camera

RECONNAISSANCE IMAGERY

AREA	ALTITUDE	SENSOR
Phoenix, Arizona	2500 ft.	AAS-24 Infrared
Northeast Test Range, N.Y.	3000 ft.	6" f.1. KA-77 Pan vertical
Northeast Test Range, N.Y.	2800 ft.	3" f.1. KA-78 Pan vertical
Northeast Test Range, N.Y.	29000 ft.	APD-10 Side looking radar

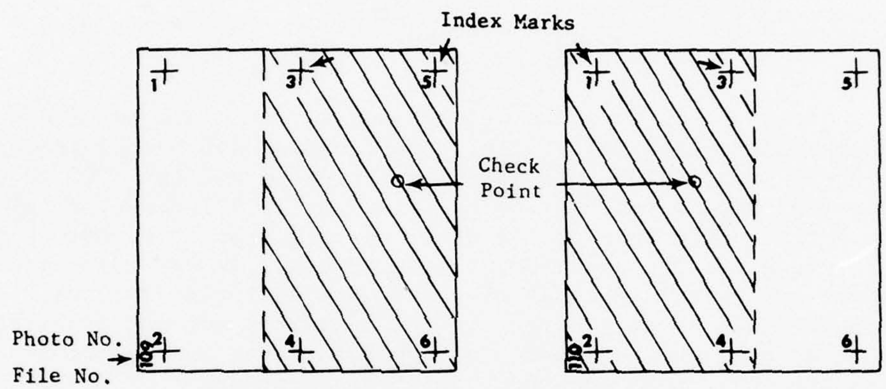
All data base imagery was printed on a very stable pigmented film base. All reconnaissance imagery was printed on the photographic paper most suitable for the available negatives.

A program was written for the APPS programmable calculator so the complete operation--from the Indirect transfer to computing the Easting (E), Northing (N), and elevation above sea level (H) of the test point--could be performed without having to remeasure index and check points for each test point.

Experimental Tasks

The main experiment involved the performance of three distinct experimental tasks.

Experiment I--Monoscopic Measuring. The purpose of Experiment I was to determine the speed and the repeatability (precision) of measuring the data base index marks. Each data base photo has six index marks and one or more check points as shown below:



In this illustration, Photos 109 and 110 have a forward overlap of about 60% so the stereo model covers only the area marked by cross-hatching. Index marks are made by drilling the emulsion, except when the photo is covered by a reseau, then reseau intersections are often used for index marks. Index mark coordinates are measured during the mensuration phase of the data base preparation and all subsequent APPS photogrammetric operations are referenced to these marks. Thus, the importance of precise index measuring can be seen.

The measuring operation was very simple. Points 3,4,5 and 6 were measured monoscopically on the left photo using the left reference dot of the APPS. Points 1,2,3 and 4 were measured on the right photo using the right reference dot. The APPS calculator was programmed so the coordinates of each index mark could be recorded by pressing the foot switch so manual recording was unnecessary. The time was recorded for each set of eight measurements. Each subject measured the eight marks four times.

Experiment II--Stereoscopic Measuring. The purpose of Experiment II was to determine the accuracy with which points can be measured stereoscopically on the data base. For this experiment a data base of the White Sands Proving Ground, prepared by DMATC, was used. The total experiment consisted of:

1. Measuring index marks
2. Measuring the check point
3. Stereoscopically measuring eight ground points
4. Recording the time required for each stereoscopic measurement
5. Repeating steps 1 through 4 three times for a total of four replications.

After the index marks were measured, the check point was measured stereoscopically, i.e., the floating dot was placed on the check point. The foot switch was pressed and the APPS calculator performed a computation to determine if all measurements were sufficiently accurate to meet the criterion of 10 meters in X, Y, and H for the check point coordinates. If the criterion was met the calculator indicated that the equipment was ready for making further measurements. If the criterion was not met (because of one or more bad measurements) the calculator instructed the operator to repeat index mark and check point measurements.

The coordinates of each of the eight points were found by placing the floating dot on a point of interest, entering the point ID in the calculator keyboard and pressing the foot switch. The E(X), N(Y), and H values were printed on paper tape. The time for each subject's measurements of a point was recorded.

Experiment III--Point Transfer and Stereoscopic Measuring. The purpose of Experiment III was to determine the accuracy and speed of transferring target points from panoramic, radar and infrared imagery to a photo data base and then determine the ground positions of these points. All transfers were made using the Indirect technique. The total experiment consisted of:

1. Measuring index and check points
2. Making Indirect transfer for
   - 10 points on infrared imagery
   - 20 points on panoramic imagery
   - 10 points on radar imagery.

3. Determining UTM ground coordinates (E,N,H) of all points
4. Recording time for each operation.

[A special piece of equipment was needed for this experiment. It is a display unit that plugs into the APPS Interface unit. This unit presents a continuous digital display (in inches to three decimal places) of Datagrid coordinates. It is zeroed when the APPS equipment is zeroed. Plus (+) and minus (-) symbols are displayed as appropriate. The Indirect transfer produces Datagrid coordinates of the target point in the left data base photo. In order to place the left reference dot at this exact point it was necessary to observe the Display unit while the photo carriage was moved in X and Y.]

The step-by-step procedure for this entire operation is given in Appendix A.

Point Location Standards

Three data base stereo models were used for these tests. A data base of the White Sands Proving Ground (1:100,000 scale), prepared by DMATC, was used in Experiments I and II; a Phoenix data base and a Northeast data base were used in Experiment III. No data bases existed for the Phoenix area and the Northeast Test Range so they were generated under this contract. A four-photo strip of 1:100,000 scale 6" focal length imagery was selected for the N.E. Test Range data base. Only the two center photos were to be used in the tests so all test points had to be in the overlap area of those photos. Index marks were scribed only on the two center frames. The panoramic, infrared and radar reconnaissance records were compared with data base imagery and test points were selected. In addition, pass points and ground control points were identified. Positive transparencies of the selected frames were placed in a precision comparator one at a time and all index, pass, target and control points were measured on every frame on which they appeared. The next step was to perform a photogrammetric least squares adjustment of the measured data from the four photos. The output of the triangulation program was: position and attitude of the camera for each exposure; the ground position of all points (except index points); the adjusted plate coordinates of the index points, and the plate residuals for all points included in the adjustment. Selected data from these computations was sent to DMATC personnel who prepared an APPS data tape. Similarly, a three-photo data base of the Phoenix area was developed.

Location Error Computation

Using the Indirect technique, each subject transferred to the data base 20 points from the panoramic imagery and 10 points from the infrared and from the side looking radar imagery.

The location error in three dimensions (X,Y,H) was determined for each point by taking the absolute difference between the school solution and the observed (subjects) solution.

Pilot Experiment

A pilot experiment was conducted to determine the suitability of the test material and the planned test procedures. The modified calculator programs were used operationally and time trials were run to provide data useful in planning the main tests. A few of the selected test points were found to be unsatisfactory so new points were selected and school solutions were computed for them. In general, the test material, calculator software and the APPS equipment were found to be satisfactory.

Main Experiment

Subject and Subject Training. Ten subjects participated in the main experiment - nine contractor personnel and one enlisted man (a stereo instrument instructor) from the Defense Mapping School. All but two subjects had previous APPS experience and those two had experience with other photogrammetric instruments. Each subject had experience in image interpretation although some had very limited experience in infrared and radar interpretation. Each subject was given time to work with the APPS before beginning the tests. During this period the subjects became familiar with the different calculator programs that were needed for the tests. The overall instructions were sufficiently detailed to permit the subject to turn on the equipment, load the calculator programs, zero the equipment and make appropriate data base checks, perform analytical transfers and determine ground coordinates of test points.

Dependent Measures. There were five conditions for which error and time measures were gathered: data base index marks (Experiment I), data base points (Experiment II), transfer of target points from Infrared (Experiment IIIA), Panoramic (Experiment IIIB), and Radar mission imagery (Experiment IIIC).

One type of error and time measure was computed in Experiment I. Four error measures were calculated for each subject for each of 8 index marks or a total of 32 measurement errors for a subject (8 marks x 4 repetitions). The measurement error was the absolute difference in millimeters between each measurement (XY positioning) and the mean of the four measurements of an index mark. The error was then multiplied by 100,000, the scale of the data base photograph, converting it to distance on the ground.

Four time measures were recorded for each subject, one for each repetition of 8 index marks. Each measure, then, was the total time taken to measure one set of 8 index marks.

In Experiment II, selected points on the data base were measured in three dimensions. Consequently, three meaningful types of error measures were derived from each subject's measurement of each point. The three types of error were the absolute difference in millimeters between the true location (School solution) and the subject's location of each point in XY (Plane error), H (Height error), and XYH (Total error). Each error was multiplied by 100,000, converting it to distance on the ground. There were 80 measurement errors of each type for each repetition of the 8 points (10 subjects x 8 points), or a total of 320 of each type for all four repetitions combined.

The time taken to measure the points was recorded separately for each point; consequently there was a total of 320 time measures (8 points x 4 repetitions x 10 subjects).

Three types of location error measures and time measures were computed for the Infrared (Experiment IIIA), Panoramic (Experiment IIIB), and Radar mission imagery (Experiment IIIC) in the same way described in Experiment II. There were 100 of each error type and 100 time measures for the Infrared and for the Radar imagery (10 points x 10 subjects). The points in the Panoramic mission photographs were grouped according to whether they were within or beyond 45° from the nadir. Thirteen points were beyond 45° and 7 points were within 45°. Thus there were 130 of each error type and 130 time scores for those points beyond 45° from nadir (13 points x 10 subjects) and 70 of each error type and 70 time scores for those points within 45° from nadir (7 points x 10 subjects).

RESULTS

The results of the analyses of error and time measures are described for each experiment separately. The error is described graphically as a cumulative percentage. Only Plane (XY) error is presented for Experiment I since the index marks were not measured stereoscopically. Plane (XY), Height (H), and Total (XYH) errors are presented for Experiments II and III in which the points were measured stereoscopically. The time measures for each experiment are described numerically in terms of the 25^{th}, 50^{th} (median), and 75^{th} centiles--points below which lie 25%, 50%, and 75% of the measures.

Experiment I. Measurement of Data Base Index Marks

Figure 1 shows the cumulative percentage of ground measurement error for the data base index marks. The figure may be interpreted as follows: if the interest is in the average error, select 50% (the median) on the ordinate and read the value of the abscissa (measurement error) that corresponds to the point where 50% intersects the function. In Figure 1, that value is 1.6 meters. This means that half of the errors were less than 1.6 meters and half were greater than 1.6 meters. If the interest is not in average performance, but rather in a more stringent criterion, for example, 75%, select 75% on the ordinate and determine the corresponding error on the abscissa. In Figure 1, that error is 2.4 meters. In other words, 75% of the errors were less than 2.4 meters and 25% were greater than 2.4 meters. Similarly, if a less restrictive criterion than the average is used, say, 25%, the figure shows that 25% of the errors were less than 1 meter and 75% greater than 1 meters. Summarizing, then, measurements of index points are repeatable within 1 meter 25% of the time, 1.6 meters 50% of the time, and 2.4 meters 75% of the time. Interpretations may be made in the same way for other percentages in this figure and like figures for Experiments and II and III.

The median time taken to measure all 8 index marks was about 1.5 minutes, and the 25^{th} and 75^{th} centiles were 1.3 minutes and 2.5 minutes.

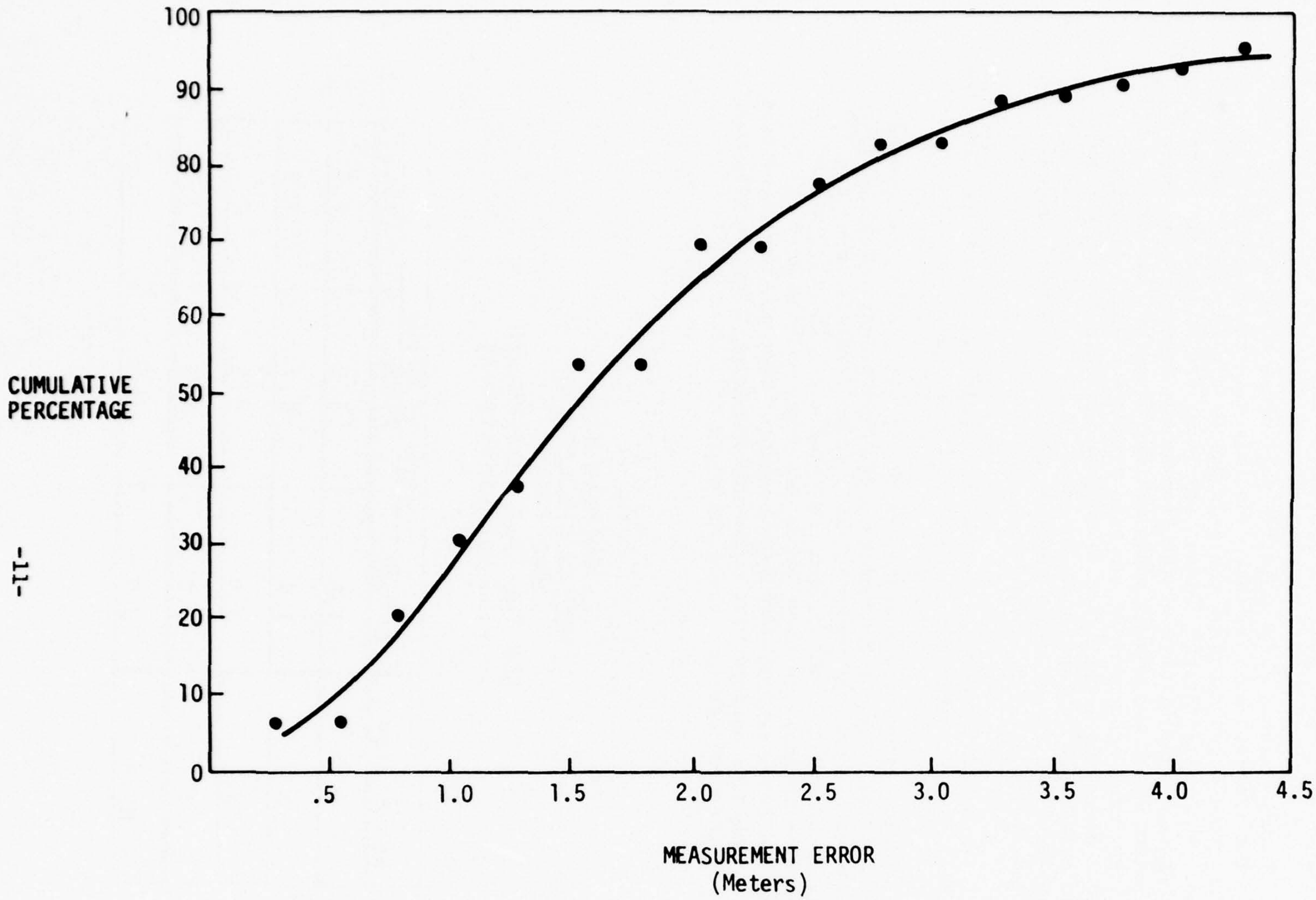


Figure 1. Cumulative percentage of measurement error for the data base index points (N = 320).

Experiment II. Measurement of Data Base Points

Figure 2 shows the cumulative percentage of measurement error for the data base points. The figure is based on the data for the four repetitions of the 8 points or a total of 320 measurements. The median Height, Plane, and Total errors were 3, 6 and 7.5 meters, respectively. Inspection of the figures shows that the Height error was consistently smaller than the Plane error and that the Total error was larger than either the Plane or Height error. Since the Total error is composed of both the Height and Plane errors, by definition it cannot be less than either the Height or Plane error. This applied also to the error measures in Experiments IIIA, B, and C.

The median time taken to measure a point was .8 minute, and .6 and 1.3 minutes for the 25th and 75th centiles.

Table 2 shows the medians for the three types of measurement error for the 4 repetitions of the data base points. The Height error showed a maximum variation of 1 meter from the mean, the Plane error about .5 meter, and the Total error about .2 meter. These results indicate these error measures, particularly the Plane and Total errors, were very reliable; that is, the magnitudes of the subjects' errors were quite stable, going from one measurement of the data base points to the next.

Table 2

EXPERIMENT II:
MEDIAN MEASUREMENT
ERROR (Meters)
FOR THE DATA BASE POINTS
(N = 80 Per Repetition)

Repetition	Type of Error		
	Height	Plane	Total
1	3.0	5.5	7.3
2	3.9	6.1	7.3
3	3.0	6.3	7.7
4	2.0	6.2	7.5
Mean	3.0	6.0	7.5

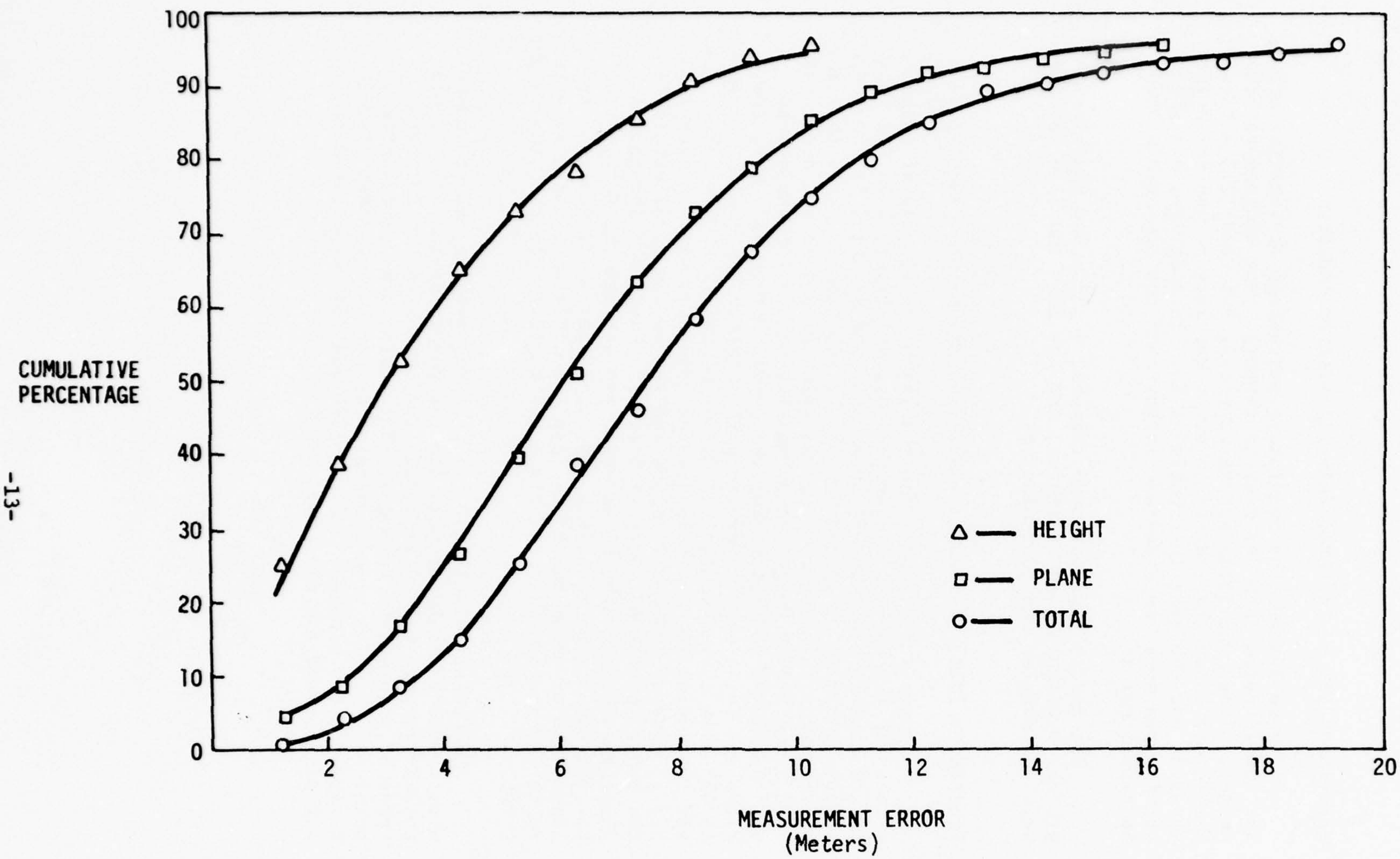


Figure 2. Cumulative percentage of measurement errors for the data base points (N = 320).

Experiment IIIA. Infrared (AAS-24) Mission Imagery

Figure 3 shows the cumulative percentage of location errors for the Infrared (AAS-24) mission imagery. The medians for the Height, Plane, and Total errors were 5.7, 9.5, and 12.3 meters. The figure shows that the Plane error was larger than the Height error as was the case in Experiment II. In addition, all three error types were, as expected, larger than the comparable ones in Experiment II.

The median time taken to transfer a point and find its ground coordinates was 7 minutes, and the 25^{th} and 75^{th} centiles were 4.6 minutes and 10.2 minutes.

Experiment IIIB. Panoramic (KA-77, KA-78) Mission Imagery

Figures 4 and 5 show the cumulative percentage of location errors for the Panoramic mission imagery. Figure 4 is for those points that were within 45° from nadir and Figure 5 is for those points beyond 45°. Inspection of the two figures shows that the Height error function for the two types of points was about the same. The median Height error was 5.6 meters for the points within 45° and 5.8 meters for the points beyond 45°; but, the Plane and Total errors were somewhat smaller for the points within 45° than they were for the points beyond 45°. The median Plane and the median Total errors for the points within 45° were 10.1 and 13 meters; the median Plane and the median Total errors for the points beyond 45° were 12.5 and 15.8 meters. Though the difference between the Plane error and between the Total error for the two types of points was not large, it is apparent from inspection of error functions that the difference was consistent. As in Experiment IIIA, the Plane error was larger than the Height error.

The points within 45° took, on the average, about one-half minute less to transfer than did the points beyond 45°. Since this difference was quite small, the time measures for both types of points were combined. The median time to transfer a point and find its ground coordinates for the combined distribution was 6.5 minutes, and the 25^{th} and 75^{th} centiles were 4.8 minutes and 8.9 minutes.

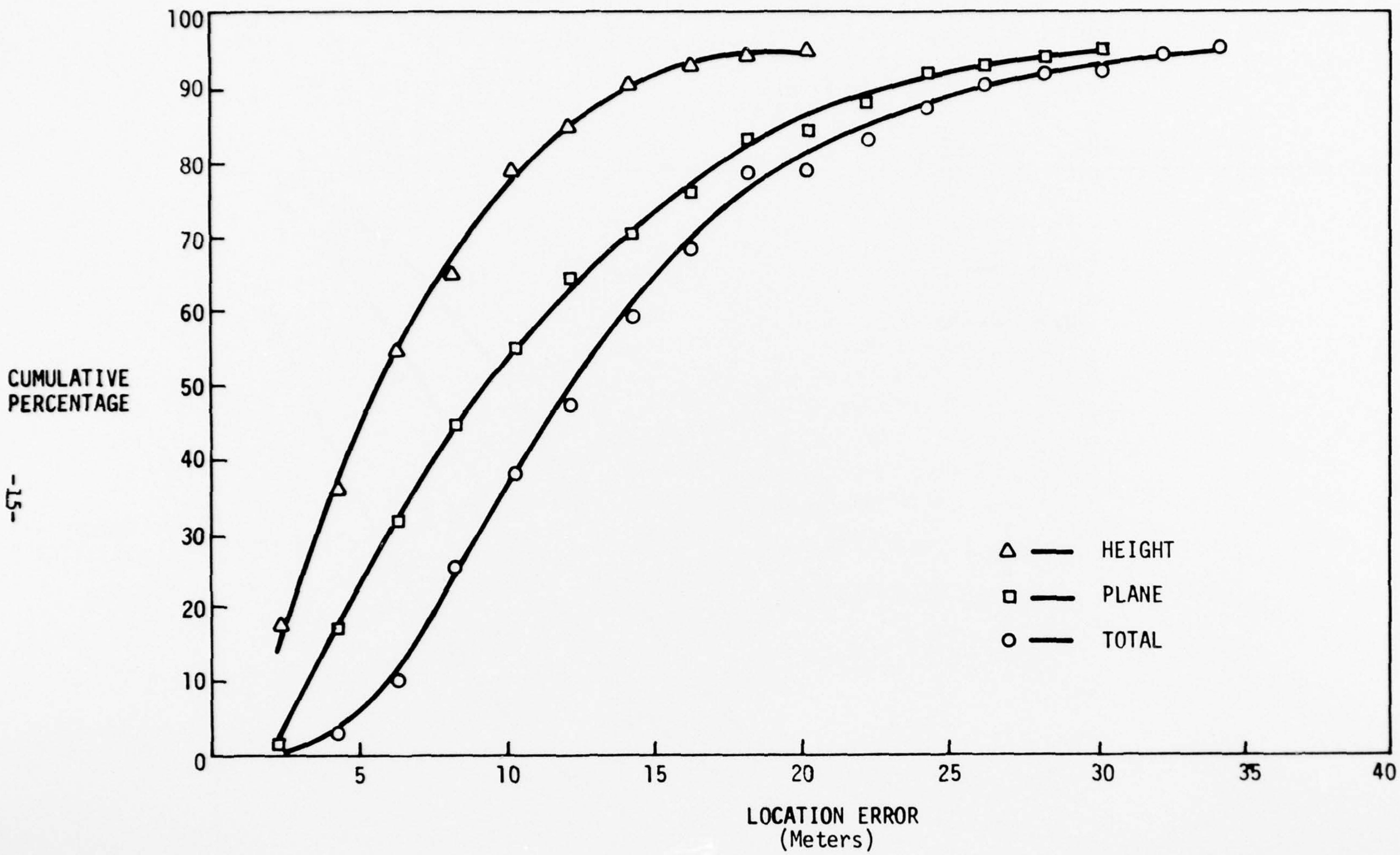


Figure 3. Cumulative percentage of location errors for the infrared (AAS-24) mission imagery (N = 100).

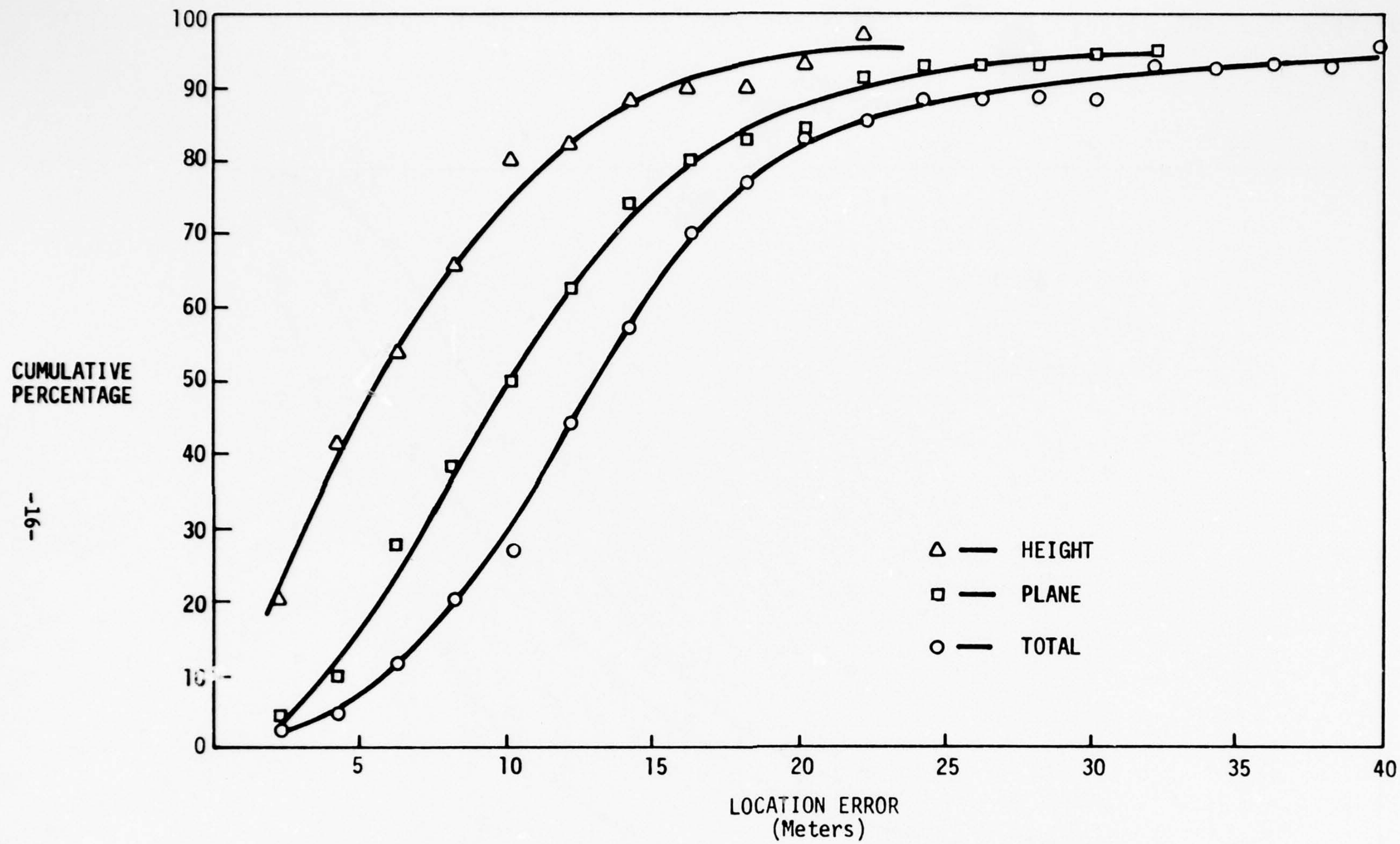


Figure 4. Cumulative percentage of location errors for the panoramic mission imagery. The points transferred were within 45° from nadir (N = 70).

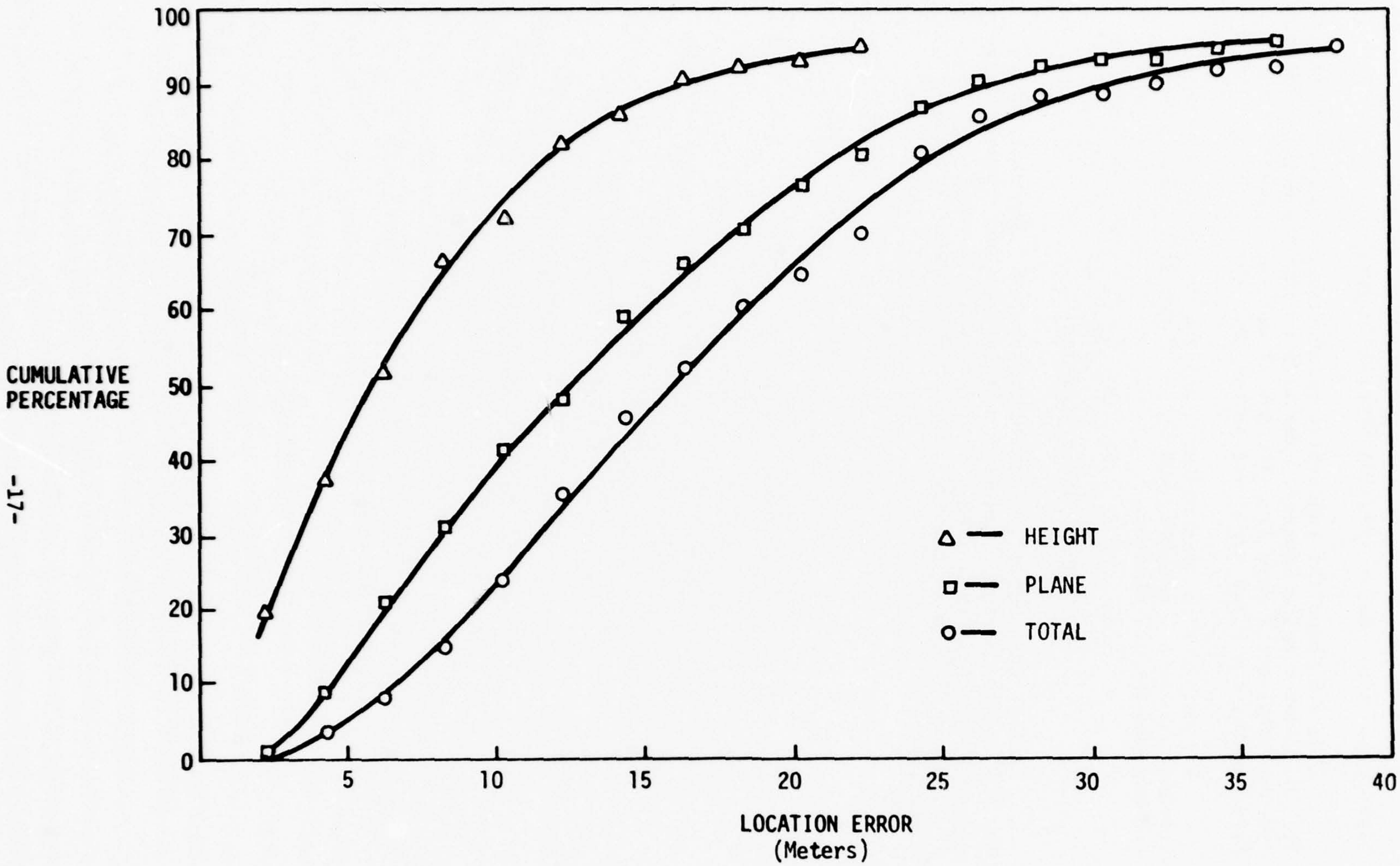


Figure 5. Cumulative percentage of location errors for the panoramic mission imagery. The points transferred were beyond 45° from nadir (N = 130).

Experiment IIIC. Radar (APD-10) Mission Imagery

Figure 6 shows the cumulative percentage of location errors for the Radar mission imagery. The medians for the Height, Plane, and the Total error were 6.2, 14, and 17 meters, respectively. Here, again, the Plane error was larger than the Height error.

The median time to transfer a point and find its ground coordinates was 6.5 minutes, and the 25^{th} and 75^{th} centiles were 4.8 minutes and 9.1 minutes.

SUMMARY AND DISCUSSION

Table 3 is a summary of the error scores. The table shows the 25^{th}, 50^{th} (median), and 75^{th} centiles for each type of imagery and each type of error. Table 4 is a summary of time measures, showing the 25^{th}, 50^{th} (median), and 75^{th} centiles for each experiment.

Table 3

SUMMARY OF ERROR MEASURES
(Meters)

Imagery		Type of Error	Centile 25th	50th	75th
Data Base Index Marks		Plane	1.0	1.6	2.4
Data Base		Height	1.4	3.0	5.5
		Plane	4.0	6.0	8.6
		Total	5.3	7.5	10.1
Infrared (AAS-24)		Height	3.2	5.7	9.7
		Plane	5.2	9.5	15.5
		Total	8.3	12.3	17.9
Panoramic (KA-77, KA-78)	Within 45°	Height	2.5	5.6	10.1
		Plane	6.2	10.1	15.0
		Total	9.2	13.0	17.8
	Beyond 45°	Height	2.8	5.8	10.3
		Plane	7.2	12.5	19.5
		Total	10.3	15.8	22.7
Radar (APD-10)		Height	2.8	6.2	11.3
		Plane	9.7	14.0	20.5
		Total	12.2	17.0	24.7

Table 4

SUMMARY OF TIME MEASURES
(Minutes)

Imagery	Number of Observations	Centile 25th	50th	75th
Mono White Sands DB	8 index marks	1.3	1.5	2.5
Stereo White Sands DB	per point	.6	.8	1.3
AN/AAS-24	per point	4.6	7.0	10.2
KA-77 and KA-78	per point	4.8	6.5	8.9
APD-10	per point	4.8	6.5	9.1

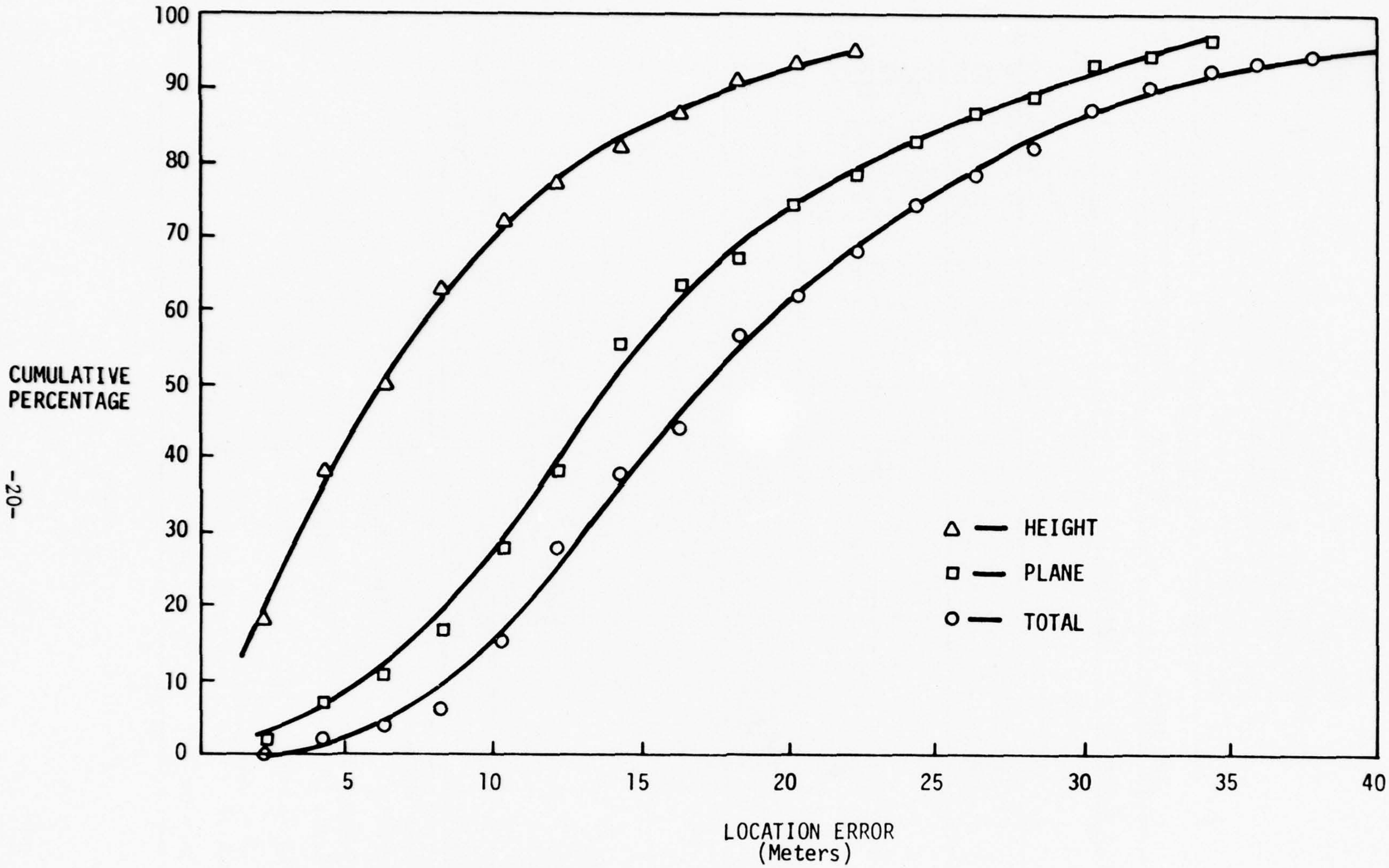


Figure 6. Cumulative percentage of location errors for the radar (ADP-10) mission imagery (N = 100).

The median measurement error for the data base index marks was quite small, 1.6 meters, and 75% of the errors were 2.4 meters or less. Errors of 2 to 3 meters for the index marks, if random, would cause virtually no ground errors in transferring points from mission imagery to the data base. These results define the accuracy limits of the APPS/operator system.

As it was pointed out in the introduction, the DMA Defense Mapping School demonstrated that accuracies of 5.6 meters in X and in Y, and 2.8 meters in H (Height) could be attained with the APPS using a 1:100,000 data base. In that investigation, the dispersions of error were reported as standard deviations and the X and the Y standard deviations were reported separately; in the present investigation, the dispersions of error were reported as centiles and the X and Y error were reported an XY vector error (Plane error)--the length of the XY vector.

To determine whether or not DMA's results were similar to those obtained in this research effort, their X and Y errors were converted to a Plane error by the formula $\sqrt{X^2 + Y^2}$, yielding a plane error standard deviation of 7.9 meters. This standard deviation and that for Height error of 2.8 meters were each converted to median error (probable error) by the relationship that in a normal distribution the probable error equals $.6745\sigma$. Based on this computation, the median Plane and the median Height error were 5.3 and 1.9 meters. These values are quite similar to the 6 and 3 meters obtained in the present effort. The slight discrepancy may be due to the fact that the measurement errors were not normally distributed in the present effort.

The results of that investigation, together with those of the present investigation, indicate that using a 1:100,000 data base, the APPS system is capable of average accuracies of about 5-6 meters in XY and about 2-3 meters in height.

A comparison of the errors for measuring the data base points with the errors for measuring the mission imagery points indicates the amount of error inherent in measuring points on the data base and the amount of error associated with transferring the points from the mission imagery to the data base and then measuring these newly determined data base points. For example, the median Height error for the data base points was 3 meters (Experiment II); while the median Height error for transferring points from the mission imagery to the data base and then measuring the newly determined point locations was about 6 meters. These results might lead one to conclude that the 3-meter difference in Height error was attributable to the transfer process. Some of it might be, in rugged terrain, but most of it in this case was due to other things, such as, differences in data base quality. It is interesting to note that the Height location error was much the same for all three types of mission imagery.

In contrast, the other component of the Total error, Plane error, was the same--about 10 meters--for the Infrared and for the Panoramic points within 45°, but was slightly larger, 12.5 meters, for the Panoramic points beyond 45°, and larger still, 14 meters, for the Radar points. Similarly, the medians of the Total error increased going from the Infrared (12.3 meters), to the Panoramic (13.0 and 15.8 meters), to the Radar mission imagery (17.0 meters). Since the Height error was essentially constant for the different types of mission imagery, this increase in the Total error is attributable to the Plane error component of the Total error. It is not surprising that the results for the IR tests are better than those for the panoramic tests. The IR imagery was of excellent quality, of large scale and the scale was essentially the same for the entire format. The quality of the panoramic imagery was good but the scale and geometric variations across the format were quite severe. Also, height errors in the three parts of Experiment III should be essentially the same since height measurements depend on the judgment of the subject and are only indirectly related to transfer errors (Plane errors) except in steep terrain.

Cited in the introduction was an ETL report in which it was stated that a stringent positional accuracy requirement for Field Artillery was 25 meters CPE with 50% assurance and about 46 meters with 90% assurance. It is clear from inspection of Table 3 that the 25 meter, 50% assurance criterion was easily met for all three types of mission imagery, both in terms of Plane and Total error. Further, the 46 meter, 90% assurance criterion was met also. For the Radar, the mission imagery that showed the largest location error, the 90^{th} centiles for the Plane and for the Total error were 29 and 32 meters. These results indicate that experienced operators using the APPS equipment and an indirect transfer technique can transfer points from Infrared (AAS-24), Panoramic (KA-77, KA-78), and Radar (APD-10) to the data base with highly acceptable accuracy.

The desired positional accuracy of a second generation APPS was set forth by letter, HQ TRADOC dated 12 June 1975, subject: APPS, Advanced (APPS-2) which specified the error bounds by coordinate dimension as shown below:

	Type of Error	
Terrain Location	Height Error (PE)	Plane Error (CEP)
To FEBA	3- 8 meters	5-10 meters
Beyond FEBA	5-15 meters	15-25 meters

The median Height error--similar to the Probable Error (PE) statistic--for the experiments reported here is less than the upper bound (8 meters) shown above for the allowable error for objects of interest located in friendly held territory for all types of mission imagery tested. Median Plane error--similar to Circular Error Probable (CEP)--exceeds the specified upper bound (10 meters) for objects of interest in friendly held terrain for the radar mission and that portion of the panoramic missions that fell 45° and beyond from the ground track.

Assuming that aerial surveillance beyond the FEBA by manned aircraft will be accomplished in a standoff mode, the panoramic cameras (KA-77 & KA-78) and the side-looking radar (APD-10) would be the remote sensors used in these experiments to acquire coverage of enemy held terrain. The median Plane error for these sensors falls well within the bounds specified above (15-25 meters) for objects of interest located beyond the FEBA. Table 3 shows that Panoramic coverage 45° and beyond from the ground track was associated with a median Plane error of 12.5 meters and the Radar coverage with a median Plane error of 14.0 meters. These results strongly suggest that APPS-1, as presently configured, can provide the accuracy stipulated for the Advanced APPS (APPS-2).

CONCLUSIONS

As the result of the investigations and tests performed under this contract, it is concluded that:

- Monocular measurements (of index marks) can be made with the APPS equipment with sufficient accuracy so the overall accuracy of ground point determination is not appreciably lowered.

- The Indirect technique and associated software, described in this report, provide a practical and an accurate means for determining the ground coordinates of target points in areas of sparse background detail whose images appear on photo, IR and radar records.

- Isolated target points can be transferred by the Indirect technique to a photo data base and ground coordinates determined well within the 15-minute per point suggested performance rate, including the time for measuring the index marks and check point.

- Target points in mountainous areas generally can be transferred to a photo data base to acceptable accuracies using techniques described in this report.

- The 8-parameter transformation program offers advantages not available in the 6-parameter program (Appendix C).

- The use of quick prints of areas of interest, made during the interpretation phase, will allow point transfers to be made with greater speed and accuracy (Appendix D).

- A digital display unit is a necessary item for the APPS-1 instrument if Indirect trasnfers are to be made (Appendix A, page 36).

- An effort should be made to screen APPS operator candidates by tests and eye examinations prior to any extensive training program (Appendix B).

- Equipment and software diagnostics are needed for the APPS.

RECOMMENDATIONS

It is recommended that:

- Training schools for APPS operators be urged to teach the Indirect transfer technique.

- Diagnostic techniques be developed for the APPS-1.

- The possibility of identifying candidates with the most potential for becoming proficient APPS operators be explored, by means of physical testing and consideration of human factors.

- Further tests with the 8-parameter transformation program be encouraged by making it available to DOD operational units.

- The Instruction Manual be tested for utility in training and in operational application (Appendix A).

APPENDIX A

Instruction Manual: Point Transfer Techniques

INTRODUCTION

Empirical research efforts[1/,2/,3/] have demonstrated that the APPS equipment has the inherent precision required for an operator to make measurements on a 1:100,000 scale photographic data base and to compute ground position to an accuracy of less than 10 meters in X, Y and h. However, to attain this accuracy of positioning, the point of interest (target point) must be clearly defined on the data base photography. Prior research[4/,5/] has shown that sizable errors can result when the operator views a point of interest on reconnaissance imagery acquired by certain sensor systems--panoramic or oblique photographic, infrared, and radar--and must then transfer the point of interest to its corresponding location on the data base photograph by direct visual comparison.

PURPOSE

The purpose of this manual is to describe several techniques for transferring points from various types of reconnaissance imagery to a photographic data base.

1/ Sewell, E., A. Harabedian, and T.E. Jeffrey. Total system accuracy for APPS. ARI Technical Paper 348, October 1978.

2/ Testing, evaluation and deployment of the analytical photogrammetric positioning system. USAFAS Report. July 1974.

3/ McIntosh, LTC B.W. Adaption of the analytical photogrammetric positioning system (APPS) to geodetic survey. Paper presented to the International Federation of Surveyors (FIG). September 1974.

4/ Sewell, E., R. Bradie, A. Harabedian, and T.E. Jeffrey. The effects of photo characteristics upon location determination in a photogrammetric facility. ARI Technical Paper 346, October 1978.

5/ Sewell, E., A. Harabedian, and T.E. Jeffrey. Mission/data-base imagery correlation techniques (M/DICT). ARI Technical Paper 347, October 1978.

TRANSFER TECHNIQUES

Definitions

Transfer techniques can be divided into two general categories: Direct and Indirect. A Direct transfer is made by viewing, alternately, the reconnaissance imagery (containing the point of interest) and the corresponding area of the data base. The operator selects the location based on the relationship of the point to image patterns that appear on both the reconnaissance and data base imagery. It is likely that in military operations most target points will be transferred by the Direct technique because it requires less time and is often adequate.

An Indirect transfer is used when the target point is isolated from terrain patterns that would permit a useable Direct transfer. It is accomplished by utilizing points, surrounding the target point, whose images can be seen on both the reconnaissance and data base photography.

Description of Equipment and Calculator Programs

Figure A1 shows a schematic diagram of the APPS photocarriage and Datagrid. The left photoholder is mounted securely to the photocarriage. The right photoholder is mounted on the photocarriage but can be moved relative to the left photoholder by means of the X- and Y-parallax micrometer screws. Mounted on the underside of the photocarriage is the Datagrid sensor that senses and measures the X and Y movements of the photocarriage. Mounted directly over the two photoholders are two glass discs with a reference dot in the center of each. These discs are stationary, that is, the photoholders can move under them. The dots are on the bottom of the discs and about ½ mm above the surface of the mounted photos.

Three calculator programs are used for making an Indirect transfer and for getting the ground position of the target point. The first is the standard APPS-1 program. This program is designed to perform interior orientation of the two data base photos and to determine the X, Y and H of any point whose photo coordinates have been measured stereoscopically. Model data is stored on magnetic tape and can be entered into the calculator by entering the model storage file number in the calculator X-register.

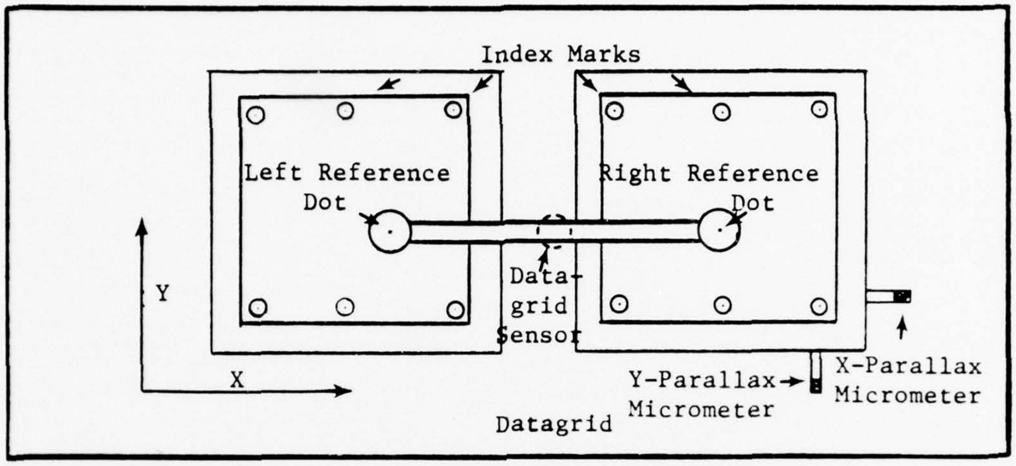


Figure A1. APPS Photoholders Over Datagrid

The second important program used is the 6-parameter transformation program. This program performs a least squares adjustment of points measured on the reconnaissance photo and the corresponding points on the data base imagery. In addition, it prints the residuals for each point. After the transformation parameters have been computed, the left data base photo coordinates of the target point, in the Datagrid coordinate system, are computed.

The third program is designed to store on the data tape the index and check point measurements and to recall them and the APPS-1 and transformation programs as needed.

The two latter programs were developed under ARI contracts.

Procedures

The U.S. Army Engineer Topographic Laboratories' Operator's Manual for Analytical Photogrammetric Positioning System describes the APPS components and gives detailed instruction for its use. Table A1 is a reprint from this manual. It shows the steps required to activate the equipment and to perform necessary indexing and checking.

Table A1

APPS-1 Equipment Operation

STEP	OPERATOR ACTION	APPS RESPONSE	OPTIONAL/CORRECTIVE ACTION
1	SWITCH POWER ON FOR THE INTERFACE, CALCULATOR, CASSETTE MEMORY, LIGHTING FIXTURE.		
2	PRESS THE "OPEN" LEVER ON THE CASSETTE MEMORY AND INSERT THE MAGNETIC TAPE CASSETTE. CLOSE THE RECEPTACLE AND PUSH THE "REWIND" BUTTON.	THE MAGNETIC TAPE CASSETTE WILL REWIND TO ITS STARTING POSITION.	
3	PRESS [STOP] [END] [FIX ( )] [1] [LOAD]	PRESSING "1" CAUSES ALL DISPLAYED NUMBERS TO CONTAIN ONLY ONE DIGIT AFTER THE DECIMAL POINT. "LOAD" WILL ACTIVATE THE MAGNETIC CARD READER.	
4	FEED THE MAGNETIC CARD INTO THE TOP SLOT OF THE CALCULATOR. ONLY ONE SIDE OF THE CARD NEEDS TO BE ENTERED. WHEN THE CARD STOPS MOVING, PULL IT OUT OF THE LOWER SLOT AND RETURN IT TO STORAGE.	THE MAGNETIC CARD ENTERS PRELIMINARY DATA AND PROGRAM INFORMATION INTO THE CALCULATOR.	
5	PRESS [STOP] [END] [CONTINUE]	THE APPS-1 PROGRAM IS ENTERED INTO THE CALCULATOR FROM THE CASSETTE MEMORY TAPE. THE FOLLOWING INFORMATION IS PRINTED OUT DATAGRID DATA LOADED LOADING PROGRAM APPS-1 STARTS 0.0	
6	POSITION THE PHOTOCARRIAGE AGAINST THE LOWER LEFT HAND CORNER OF THE BASE PLATE. PRESS [ZERO]	AN ORIGIN OF REFERENCE IS ASSIGNED TO THE DATAGRID FOR ALL FOLLOWING PHOTO MEASUREMENTS.	THIS ACTION MAY BE TAKEN JUST PRIOR TO ANY PROCEDURE CALLING FOR THE "INDEX" ACTION.
7	PLACE THE TWO SELECTED PHOTOGRAPHS IN THE PHOTO HOLDERS. THE LOWER NUMBERED PHOTOGRAPH SHOULD BE IN THE LEFT HOLDER. SECURE THE PHOTOGRAPHS WITH THE MAGNETS PROVIDED. PRESS [INDEX]	THE PRINTED OUTPUT: FILE IS ASKING THE OPERATOR TO ENTER THE FILE NUMBER OF THE SELECTED MODEL. NOTE: THE DISPLAY PANEL WILL LIGHT UP ONLY WHEN A KEYBOARD ENTRY IS REQUIRED.	
8	ENTER THE FILE NUMBER OF THE LEFT PHOTOGRAPH INTO THE DISPLAY PANEL BY PRESSING THE APPROPRIATE DIGITS OF THE KEYBOARD.	THE FILE NUMBER IS DISPLAYED IN THE X-DISPLAY REGISTER.	IF AN INCORRECT NUMBER IS ENTERED, PRESS [CLEAR] AND ENTER THE CORRECT NUMBER. THIS CORRECTIVE ACTION IS VALID ANY TIME A WRONG NUMBER IS ENTERED ON THE KEYBOARD BUT MUST BE PERFORMED BEFORE THE "CONTINUE" BUTTON IS PRESSED.
9	PRESS [CONTINUE]	THE FILE NUMBER AS DISPLAYED IN THE X-REGISTER IS PRINTED OUT NN.0* THE CASSETTE MEMORY IS SEARCHED FOR THAT FILE AND WHEN FOUND, THE FILE DATA IS STORED IN THE CALCULATOR MEMORY. THE FOLLOWING OUTPUT THEN PRINTS PHOTO NN.0 INDEX POINTS #	
10	IN TURN, POSITION THE LEFT DOT ON EACH OF THE MODEL INDEX POINTS IN THE LEFT PHOTOGRAPH AND PRESS [MEAS CONT] AT EACH POINT, HOLD THE POSITION OF THE CARRIAGE AT EACH INDEX POINT UNTIL THE PRINTER RESPONDS TO THE BUTTON. THE INDEX POINTS ON THE LEFT PHOTOGRAPH ARE NUMBERED 3, 4, 5, AND 6.	THE CALCULATOR WILL DETERMINE THE NUMBER OF THE INDEX POINT MEASURED AND PRINT IT FOLLOWING THE # SYMBOL IN THE FOLLOWING FORMAT. N.0 # N.0 # N.0 # N.0 # N.0 • #	IF THE OPERATOR IS NOT SATISFIED WITH AN INDIVIDUAL INDEX ACTION, PRESS [REJECT] AND REINDEX THE POINT BEFORE MOVING TO THE NEXT INDEX POSITION. IF, AFTER THE • AND = ARE PRINTED OUT, THE OPERATOR IS NOT SATISFIED WITH THE INDEXING THEN RETURN TO STEP 6 OR STEP 7. THE FOOTSWITCH MAY BE USED IN PLACE OF ANY REQUIRED "MEAS/CONT" BUTTON. THIS PERMITS THE OPERATOR TO HOLD THE CARRIAGE IN PLACE WITH BOTH HANDS AND TO VIEW THE REFERENCE DOTS WHILE MEASURING OCCURS.
11	PRESS [MEAS CONT] OR FOOTSWITCH	THIS TERMINATES OPERATIONS ON THE LEFT PHOTOGRAPH. THE FOLLOWING OUTPUT IS PRINTED CONCERNING THE RIGHT PHOTOGRAPH PHOTO NN.0 INDEX POINTS #	
12	IN TURN, POSITION THE RIGHT DOT ON EACH OF THE MODEL INDEX POINTS IN THE RIGHT PHOTOGRAPH AND PRESS [MEAS CONT] AT EACH POINT, HOLD THE POSITION OF THE CARRIAGE AT EACH INDEX POINT UNTIL THE PRINT RESPONDS TO THE BUTTON. THE INDEX POINTS ON THE RIGHT PHOTOGRAPH ARE NUMBERED 1, 2, 3, AND 4.	THE CALCULATOR WILL DETERMINE THE NUMBER OF THE INDEX POINT MEASURED AND PRINT IT FOLLOWING THE # SYMBOL IN THE FOLLOWING FORMAT N.0 # N.0 # N.0 # N.0 # N.0 • #	
13	PRESS [MEAS CONT]	THIS TERMINATES OPERATIONS ON THE RIGHT PHOTOGRAPH. THE FOLLOWING OUTPUT IS PRINTED FOR THE VALIDATION OF THE INDEXING PROCEDURE AND SYSTEM OPERATION CK #	
14	MOVE THE PHOTO CARRIAGE SO THAT THE CHECKPOINT MAY BE VIEWED IN STEREO. POSITION THE PHOTO CARRIAGE AND REMOVE THE X-PARALLAX AND Y-PARALLAX SO THAT THE FLOATING DOT APPEARS TO BE POSITIONED ON THE GROUND AT THE INDICATED CHECKPOINT. PRESS [MEAS CONT]	IF A COMPUTED VALUE FOR THE CHECKPOINT COMPARES FAVORABLY TO A STORED VALUE IN THE CALCULATOR, THE PRINTER WILL ADVANCE THE PAPER AND PRINT POINT, ZONE, E, N, H THE OPERATOR MAY NOW MEASURE THE COORDINATES OF ANY POINTS WITHIN THE MODEL.	IF A COMPUTED VALUE FOR THE CHECKPOINT DOES NOT COMPARE FAVORABLY TO A STORED VALUE THE CALCULATOR WILL PRINT OUT NINE LINES OF USELESS NUMBERS THEN PRINT FILE THE OPERATOR SHOULD CHECK THAT THE CORRECT PHOTOGRAPHS AND TAPE CASSETTE ARE BEING USED AND THAT THEY ARE MOUNTED PROPERLY. RETURN TO STEP 8.

As soon as Step 14 is completed the equipment is ready to determine the ground coordinates of any point within the overlap area of the data base stereo pair. All that is required is for the operator to enter an ID number, place the "floating" dot on the point of interest and press the foot switch. If the point of interest is found on a reconnaissance record it first must be transferred to the photo data base. Procedures for both Direct and Indirect transfers are shown below.

Direct Transfer - Point transfers are made with the data base stereo pair in position on the APPS and with the indexing and checking completed as shown in Table A1. The reconnaissance imagery can be a positive or negative transparency, a positive or negative paper print or a CRT display. The general approach to Direct transferring is to view the area surrounding the target point alternately on the reconnaissance record and the data base. If the reconnaissance imagery is a transparency it is viewed over a light table using suitable optics. The recommended way to transfer a point from a reconnaissance photo paper print is to place the print on top of the right data base photo. The left reference dot is placed at the approximate location of the target point. Without moving the APPS' carriage, the reconnaissance photo is positioned beneath the right dot and oriented, approximately, with the data base photo. Now, by looking through the APPS optics the operator can view the data base photo and the reconnaissance photo by, alternately, opening and closing each eye. The carriage is moved until the left dot is directly over the point on the data base judged by the operator to correspond to the image of the target point on the reconnaissance photo. The reconnaissance photo is removed and the photocarriage locked. The right dot is made to fuse with the left dot by moving the right photoholder using the X-parallax and Y-parallax micrometer screws. The X-parallax screw is now moved until the "floating" dot appears to be on the ground. The point ID is entered through the calculator and the foot switch is pressed to enter the Datagrid and X-parallax measurements of the target point into the calculator which, in turn, performs an analytical space intersection to compute the X, Y, and H of the point in UTM coordinates.

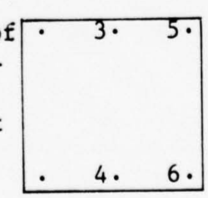
Indirect Transfer

Flat Areas - A transfer technique for target points in relatively flat areas will first be described. Following this will be the description of a technique to be used for points in rolling or mountainous terrain.

Since the image of the point of interest does not appear on the data base it is necessary to make use of nearby points whose images are identifiable on both the reconnaissance and data base imagery. By making coordinate measurements on these surrounding points, on both the reconnaissance and data base imagery, it is possible to determine the transformation parameters between the two image records for the area within these points. Then by measuring the coordinates of the target point on the reconnaissance record and applying the transformation parameters to them, the coordinates of the target point, in the Datagrid coordinate system, can be found.

A detailed description of the Indirect transfer technique, including the use of the calculator programs, is given below. An abbreviated form of APPS set-up and checking instructions, shown in Table A1, is given here for ready reference:

(a) Mount appropriate data base photos.
(b) Insert appropriate Tape Cassette in cassette holder.
(c) Zero the photocarriage by moving it to the stops in the lower left corner of the base plate and pressing ZERO.
(d) Load APPS-1A program by pressing
    STOP
    END
    FIX()
    1
    LOAD
    Now insert APPS-1A magnetic card in slot.
(e) Press
    STOP
    END
    CONTINUE
(f) After the tape winding stops, press
    INDEX
    The word FILE will be printed on tape.
(g) Enter File Number (from left photo) and press
    CONTINUE
    The tape output will be INDEX POINTS.
(h) Measure the left photo Datagrid coordinates of Index Marks 3,4,5 and 6. (Move entire photocarriage until Point 3 is under the left reference dot and press foot switch. Repeat this procedure for Points 4,5 and 6.) The Index Mark numbers will be printed on the tape after each measurement.



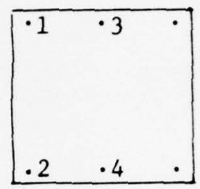
CAUTION: • *The coordinate data is entered into the* calculator when the foot is raised and not when it is pressed against the foot switch.

• Do not move the photocarriage until the paper tape has moved to its new position.

• Do not turn parallax screws during the indexing of the two photos.

(i) Now <u>press</u> the foot switch once more.

(j) <u>Measure</u> the right photo Datagrid coordinates of Index Marks 1,2,3 and 4 in the same manner as described in (h), using the right reference dot.



(k) <u>Press</u> foot switch once more.

(l) The tape will print CK (check).

(m) <u>Place</u> floating dot on Check Point. <u>Press</u> foot switch.

(n) If the Index and Check Point measurements are within the built-in criteria[6] the tape will advance and print:

POINT, ZONE, E, N, H

(o) The equipment is ready for measuring any point within the overlap area of the data base photos.

[*The coordinates of points selected* by the Direct transfer technique can now be computed.

•Enter on the keyboard the identification number (ID) of the point of interest.

•<u>Press</u> CONTINUE

•Set floating dot on point of interest

•<u>Press</u> foot switch

The UTM zone number, the UTM grid Easting and Northing, and the elevation in meters of the target point will be printed in the following format:

```
     00.0  (Zone)
 000000.0  (Easting)
0000000.0  (Northing)
   0000.0  (Elevation)
```

•<u>Press</u> foot switch. This will advance paper tape

•Enter ID of next point and repeat (o) above. If the new point of interest falls on another data base stereo pair, repeat (a) through (o).

---

[6] If not within criteria, data will be printed on tape and useless data on the *display board will flash on and off.* The word FILE will then be printed on the tape. Press STOP END CONTINUE CHECK CASS and repeat (m) and (n). The Check Point setting can thus be repeated without remeasuring the index points. However, if the flashing lights persist, the index points should be remeasured.

(p) Make an Indirect point transfer:

After par n above, the tape will read POINT, ZONE, E,N,H

Enter •GO TO 1900[7] CONTINUE (The index and check point measurements will be read onto the data tape and the 6-parameter transformation program will be loaded in the calculator.)

•Perform Indirect transfer.

To make an Indirect transfer (analytical transformation) the reconnaissance photo is now placed over the right data base photo and oriented as described under "Direct Transfer" above. The operator searches for 4 to 6 points surrounding the target point, whose images appear on both the reconnaissance and data base imagery. Points as close as possible to the target point should be selected. Corresponding points are found by alternately viewing the reconnaissance imagery through the right eyepiece and the data base photo through the left eyepiece. The images are not physically marked on either record. As each suitable "control" point is selected, the operator measures its coordinates by moving the photocarriage (not the parallax screws). First on the reconnaissance imagery by placing the right dot on the image and activating the foot switch and then on the data base by placing the left dot on the image and activating the foot switch. After accepting the Datagrid coordinates of the data base, the calculator will advance and print the number of the next control point to be measured and the operation is repeated until four points have been measured.

For the fifth and sixth control point measurements the calculator will print the point's number and will stop to allow the operator either to continue with the measurement of the control point coordinates (press CONTINUE and measure as before) or to process those control points already measured (press SET FLAG, CONTINUE), if he is unable to identify another control

---

[7] This tape location applies only to the Phoenix and N.E. Test Range data tapes which have been modified by creating files for index and check point data; 6-parameter transformation program; and the APPS-1A program.

point with confidence.

After all measurements have been made the calculator performs a 6-parameter transformation and prints the X- and Y- residuals for each control point. The calculator will then print the message "SET FLAG TO REMEASURE PTS, GO TO 0368 TO ADD NEW POINT". If the operator is satisfied with the results of the transformation as represented by the residuals, he places the right dot over the point of interest, enters the point's ID, presses CONTINUE and presses the foot switch. The left photo coordinates of the target point in the Datagrid coordinate system are printed on paper tape. (Residual criteria of 0.005 inches for photo and IR reconnaissance records and 0.010 inches for SLAR records were used in the tests performed under this contract, but different criteria can be established to meet stated accuracy requirements.) If the operator is not satisfied with the residuals, he has several options.

- To remeasure or substitute control points:
  Press SET FLAG, CONTINUE. The calculator will respond by printing "PT # TO REMEASURE".
  Enter the control point number to be changed and
  Press CONTINUE.
  Measure the imaged points as before, first on the reconnaissance imagery and then on the data base imagery. After the measurement is completed the calculator will respond: "IF MORE SET FLAG".

- If it is desired to remeasure another control point the operator will press SET FLAG, CONTINUE and proceed as before. If no further measurements are to be repeated press CONTINUE and the 6-parameter transformation is performed, as described previously.

- If, for some reason, less than six points were measured previously and the operator now feel confident that another control point can be adequately identified and measured:
  Press GO TO 0368, CONTINUE
  Proceed as before (If six points were measured previously, a seventh cannot be added.)

•Remove the reconnaissance photo from the right photoholder.

[The next operation requires a piece of equipment not standard to the APPS-1. It is a digital display unit that connects into the APPS Interface Unit. It presents a continuous digital display of Datagrid coordinates (in inches to three decimal places). It is zeroed when the APPS equipment is zeroed. Plus (+) and minus (-) symbols are displayed, appropriately.]

•Move the APPS photocarriage so the readings on the digital display unit are the same as the coordinates found by the Indirect transfer process, above. This places the left reference dot over the target position on the left data base photo.

•Lock the photocarriage by lowering the APPS' brake.

•Move the right photo in X and Y, using the parallax micrometers, until the reference dots come together and appear as a single "floating" dot, resting on the point of interest.
GO TO 1100[7] CONTINUE.

This recalls the index and check point data.
After data tape has stopped winding:

•Press TTY. This enters the APPS-1 program into the calculator. Ground positions can now be found for the target point. (The floating dot was previously placed on the target point.)

•Enter target point ID CONTINUE.

•Press foot switch (The calculator performs a space intersection and prints out the UTM coordinates of the target point, including the UTM zone number.

•Press foot switch--This advances the tape and prepares the calculator for the next point.
For the next Indirect transfer
GO TO 1900[7] (repeat from (p) above).

•For a Direct measurement
Enter point ID CONTINUE.
Set floating dot on point.
Press foot switch.

---

[7] Ibid.

Procedures for Indirect Transfers Using Unmodified Data Tapes

The Indirect transfer technique can be used without modifying the data tape. Under some circumstances it will require the re-measuring of index marks and the check point. A digital display unit still must be attached to the APPS in order for the Indirect technique to have practical application.

The 6-parameter transformation program is recorded on a magnetic card. An Indirect transformation can be made at any time after the data base stereo pair has been mounted and the Datagrid has been zeroed. To make an Indirect transfer:

- Press STOP, END, FIX(), 3, LOAD
- Load Side 1 of 6-parameter transformation magnetic card
- GO TO 0500, LOAD
- Load Side 2 of magnetic card
- Press STOP, END, CONTINUE (The calculator display will read X=24 Y=42 Z=41)

  The program is now loaded. Instructions for making the transfer are the same as found in Par. (p), above, beginning at: "•Perform Indirect Transfer" and ending after: "•Remove the reconnaissance photo from the right photoholder."

  Note: More than one Indirect transfer can be made at this time and the Datagrid coordinates of the points of interest saved until the APPS-1A program has been loaded into the calculator.
- Perform Steps 1-14, Table A1.

  [The next operation requires the use of a digital display unit as described earlier.]
- Move the APPS photocarriage so the readings on the digital display unit are the same as the coordinates found by the Indirect transfer process, above. This places the left reference dot over the target position on the left data base photo.
- Lock the photocarriage by lowering the APPS' brake.
- Move the right photo in X and Y, using the parallax micrometers, until the reference dots come together and appear as a single "floating" dot, resting on the point of interest.
- Enter target point ID, CONTINUE.
- Press foot switch (The calculator performs a space intersection and prints out the UTM coordinates of the target point, including the UTM zone number.
- Press foot switch--This advances the tape and prepares the calculator for the next point.

  Ground coordinates can now be found for all other points whose Datagrid coordinates were determined previously.

- For a Direct Measurement

  Enter point ID, CONTINUE.

  Set floating dot on point.

  Press foot switch.

Mountainous Areas - The six-parameter transformation program used for making indirect transfers is valid, theoretically, only if the "control" points and the target point are in a flat plane. The amount that one or more of these points can deviate from this plane is related directly to the accuracy required for the point transfer. Also, it is related to the location of the target point in the data base stereo model. Generally, control points can be found close enough to the target point so there will be no excessive elevation differences.

For targets in mountainous areas, the transfer error due to elevation differences can be greatly reduced by using the techniques described below:

a. Locate on the data base the approximate position of the target point.
b. Set the floating reference dot on this point and measure its elevation using the normal APPS operation.
c. View the area stereoscopically, using the APPS, and select candidate control points surrounding the area.
d. Measure their elevations by setting the floating reference dots on the ground and by using the APPS-1 intersection program.
e. Select control points from those points whose elevations are close to the elevation of the target point area and proceed as in f through p. (see section of Flat Areas).

If a target is on an isolated peak or butte it will not be possible to find nearby control points at the same elevation so the Indirect technique will not be fully effective. Often targets of this nature can be transferred by the Direct technique with high accuracy by viewing the reconnaissance imagery in stereo using an off-line stereoscope. Then by viewing the target area on the data base in stereo the third dimension on the two stereo models will give added clues to the target position on the data base.

Miscellaneous - An APPS operator is likely to encounter target transfer problems that are unique and that cannot be solved by standard techniques. If a target is of sufficient importance the APPS operator must be able to develop one or more approaches to find the best location possible. For example, if the target is on an isolated peak or in a deep ravine, the operator can use the APPS to measure the height of the hill or the depth of the ravine above or below the surrounding area. He can then compute or determine graphically the amount of image displacement caused by elevation differences. The displacement can be measured on the reconnaissance photograph along the line from the photo center to the target image. Now this point can be transferred by the Indirect technique using control points surrounding the target point. As shown in Figure A2, on a photo the corrected image point is towards the photo center for an elevated point and away from the photo center for a point lower than the surrounding terrain. Elevated points are displaced inward on radar imagery so the target image would have to be moved outward for a more exact image position; for depressed points, the correction would be made inward (toward the flight path).

For high priority targets, both Direct and Indirect transfers can be made for the same target to give the operator more confidence in his final position. Also, two or more Indirect transfers can be made using different control points for each transfer. The average of the target positions should be better than a single position.

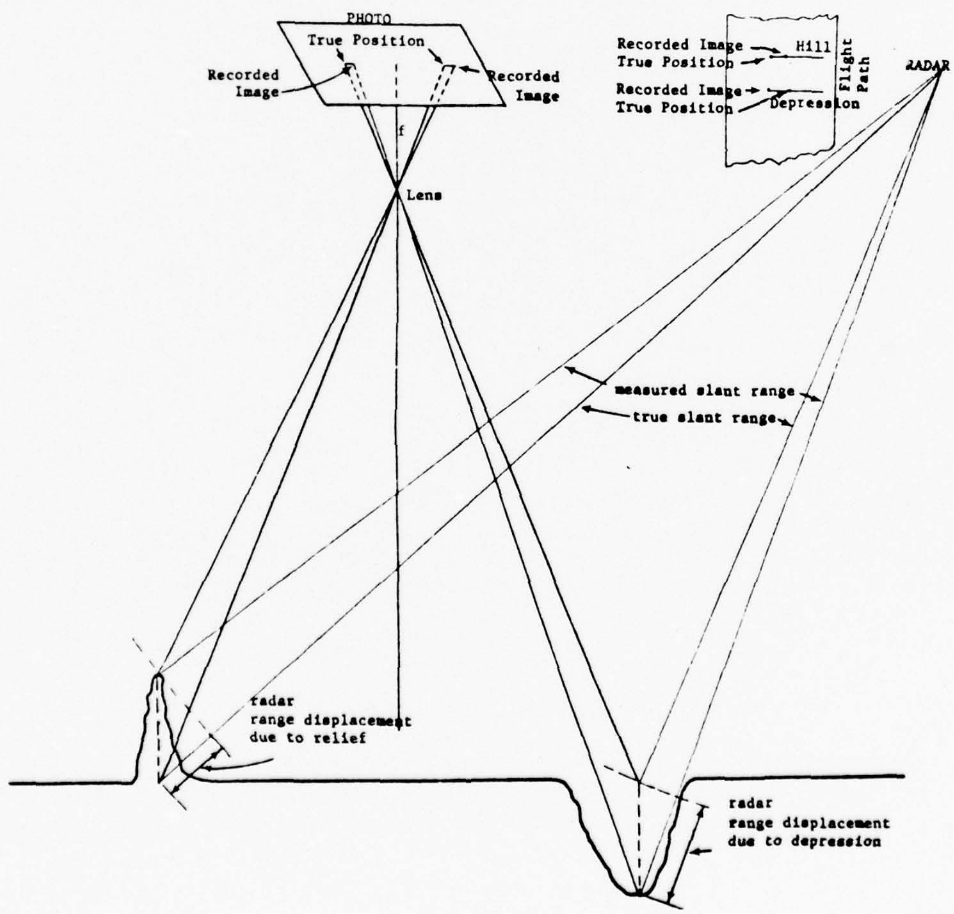


Figure A2. Relief Displacement For Photo And Radar Imagery

All APPS operators should be urged to:

- learn the functions of the basic APPS components, including the type of data stored on the cassette tape;
- practice with the APPS until all operations become natural;
- learn to recognize equipment irregularities and unlikely answers;
- master the Indirect technique and develop variations of it for handling special cases; and
- document newly discovered techniques and pass them upward so they can be incorporated in future training courses.

APPENDIX B

Selection of APPS Operator Candidates

The APPS equipment is capable of performing two basic functions, measuring and computing. The accuracy and efficiency of computing are related directly to the APPS calculator and to calculator software. Calculator programs normally are not the responsibility of APPS operators so, for this study, we will assume that the calculator program for the APPS are satisfactory.

Tests have shown that the APPS Datagrid is reliable and will measure consistently to within 0.001 inch. Other tests have shown that an operator can place a single reference dot on a selected point with a precision (repeatability) of 0.001 to 0.002 inch. The only other basic measuring demand on an operator is to be able to place a "floating" dot (two fused reference dots) on a target point with high accuracy. Since an operator's primary function is to make measurements it seems that it would be relatively straightforward to find candidates who will become good APPS operators.

There are two general approaches one can take in a search for operators. The first is to train X-number of persons and, after the training period and some operational experience, to retain only those who seem to be doing a good job. The second approach is to subject the candidates to physical and psychological tests and to select the ones with the best scores to receive the detailed APPS training.

The second approach would undoubtedly be preferred if it could be shown that the test results are valid for selection and deletion of candidates.

It is not within the scope of this study to prepare such a test but an effort will be made to identify the critical items that a test should address. The observations and suggestions given below are entirely subjective and are not based on the analysis of empirical data gathered during controlled tests for APPS operator candidates. They are based on: the experience of the author in training and observing stereo-instrument operators, including APPS operators; studying the results and analyses of tests given to photo interpreter candidates by others; and discussions with experienced stereo-instrument operators and instructors.

The skills and aptitudes of any good stereo instrument operator would be desirable for an APPS operator. These are listed below together with a fourth desirable trait especially important to APPS operators.

- Good stereo vision
- No serious eye defects
- Good human traits
- Good orientation instincts

Stereoscopic Vision

Stereoscopic vision is defined as that application of binocular vision which enables the observer to view an object simultaneously from two different perspectives (as two photographs taken from different camera stations) to obtain the mental impression of a three dimensional model. Since the elevation (or height) accuracy is related directly to the ability of the APPS operator to correctly position a reference dot in a three dimensional model, it is imperative that the operator has good stereoscopic acuity (depth perception). Even though some individuals are unable to perceive the third dimension, other persons have good stereoscopic vision in varying degrees. It is by no means an all-or-none matter. Even those who display a somewhat low level of stereo acuity can improve their acuity by proper training.

True binocular perception of depth requires that the observer make two observations simultaneously. Although parallax can be measured by means of two separate observations, it can be directly perceived only by fusion of two images received simultaneously by the two eyes. The two images seen by the two eyes must be similar in size, brightness, shape and orientation or the brain will reject all or part of one of the images or else the images may fuse erratically, or the observer may see double.

Eye Defects

A stereo instrument operator does not require perfect vision to see stereoscopically but he should have equal or nearly equal vision in his two eyes. The reason for this may not be too apparent to an infrequent stereo instrument operator. Most normal eyes have one or more slight defects, and many persons have significant visual deficiencies, not all of which can be corrected. Stereoscopic viewing makes special demands on the visual apparatus, and a flaw that would be insignificant for normal viewing, may disqualify a stereo instrument operator.

There are several types of eye defects that become harmful to persons who operate stereo instruments for several hours a day. It would be impractical to eliminate all candidates who have any kinds of eye defects. However, one major test for a candidate should be a thorough eye examination so those with serious (for stereo viewing) eye defects will be eliminated from strenuous stereoscopic work.

Some of the eye defects that could limit an operator's performance are listed below but they will not be described since any capable optometrist will be acquainted with them and the means for testing for them. The most common defects of vision have to do with refraction, or the ways the eyes are focused; defects caused by disease are not considered here.

a. Defects of focus
   - Myopia (short sightedness)
   - Hyperopia (far sightedness)
   - Astigmia (2 focal planes for each object)
   - Presbyoria (inability to focus for near vision)
   - Anisometropia (unequal refractive power in the two eyes)

b. Defects of coordination
   - Heterophoria (tendency toward incoordination of the visual axes).
   - Subnormal fusional reserve [(weakened ability to maintain binocular (fused) vision.]

c. Defects in depth perception

d. Defects in color perception (at present not applicable to APPS operations).

Persons with one or more of the eye defects described above might be unaware of such defects and might actually be engaged in stereo instrument operations. Also, they could be unaware of why they experience certain physical discomforts such as blurring of vision, drowsiness, itching, burning or stinging of the eyes, headaches, nervous irritibility, sties, watering and bloodshot eyes, poor stereoscopic acuity, fatigue, and progressive loss of visual efficiency. Eye discomforts, caused by eye defects, will lead to loss of efficiency and accuracy and shortened careers for APPS operators. The levels of acceptable eye defects should be established by qualified medical and instrument operator teams.

Human Factors

Tests have been available for years for testing stereo acuity and for detecting eye defects. A more difficult problem is to examine a person for those human traits that are essential if he is to become a good APPS operator. Only three are listed here as essential although others such as imagination, patience and good judgment are important. Those considered essential are:

- Proper attitude
  - Can the candidate be motivated sufficiently?
  - Does the candidate want to be an APPS operator?
  - Does he want to master the equipment and techniques?
  - Does he fully appreciate the importance of his role?
- Honest
  - Will honest evaluations and reports be made even though they might reflect adversly on on the operator's judgment or ability?
- Tenacious
  - Will the candidate (operator) search for alternate ways of getting a target position as long as there is any doubt concerning his initial attempts?

Too often candidates for a job are selected because they show an initial enthusiasm or a "natural" skill. Some people like to try new things and they seem to catch on quickly. However, the ones who were slower in the beginning might very well be better equipped, both physically and psychologically, to perform the demanding work of an APPS operator. Tests are needed to select those most psychologically suited for the work.

Orientation Instincts

This requirement is somewhat difficult to define. It is for an intuition not unlike that possessed by most good aircraft navigators. It is the ability to look at a map or aerial photo and a ground scene and quickly orient oneself. In the APPS application it is the ability to look at two sensor records of the same area and quickly orient one to the other in spite of scale, geometry and resolution difference. More specifically, it is the ability to visually match one small area on one sensor with the same area recorded by the other sensor, even one small image with its corresponding image.

When using the APPS for determining the positions of tactical targets, the reconnaissance imagery is usually at a scale many times (20 to 1 is not uncommon) larger than the data base scale. The entire reconnaissance frame will cover only a small portion of the data base frame. A 5"x5" vertical photo at a scale of 1:5,000 would cover an area only ¼"x¼" on the 1:100,000 scale data base photo. Unless this area contained a prominent land mark it would be difficult for any operator to find it on the data base without additional clues. Recent tests have shown that some subjects were able to use very subtle clues that were meaningless to other subjects. The same was true during Indirect transfers. Some subjects could quickly and accurately relate corresponding images appearing on two different sensor records while other subjects were either unable to do so at all unless the relationships were obvious or they were very slow in finding corresponding images. Some of those who were able to quickly relate two scenes were relatively inexperienced in photogrammetry and instrument operation while some of the slower ones were experienced in both photogrammetry and stereo equipment operation. This has led to the opinion that this orientation ability is a natural instinct found more strongly in some than in others. Perhaps this can be developed by training and experience but if candidate operators can be found with natural orientation instincts the development of good APPS operators can, undoubtedly, be accelerated. Tests must be designed to discover this natural trait.

Discussion

Care must be taken in all test designs to be sure the tests are both valid and reliable. A valid test measures just those abilities and traits it is supposed to measure; a reliable test measures an ability or trait with consistent accuracy in repeated testing.

The prerequisites for an APPS operator should be considered carefully. A distinction should be made between what is really needed and what someone might assume is important. A college degree, math through calculus, training and experience as an image interpreter, and experience as a stereo instrument operator all might seem like important prerequisites but they are probably less important than a proper attitude or good stereo acuity. Of course, a candidate with an impressive background might be selected for APPS training as a part of his overall career development program. He might be a future APPS instructor or a coordinator of an operation involving several disciplines.

After the best candidates have been selected for training in the operation of the APPS, it is important that they be thoroughly trained so they can utilize the APPS to its true potential. Operators must have confidence in their work. One way this can be built is by teaching more than one way to arrive at a solution. Being able to do self-checking is important in building confidence. For instance, a point can be transferred by the Direct technique and the ground position found in the usual manner. The same point can then be transferred using the Indirect techniques and the ground position found. Also, another Indirect transfer can be made using a new set of control points and the ground position found. An analysis of the three positions should indicate whether more work is required or if an acceptable answer has been found.

The operator must know what can and cannot be done with the APPS. He must recognize situations where special techniques must be used in order to get acceptable results, in mountainous areas for instance. After the training period, the operator must be able to spend many hours with the APPS. He needs to transfer many points from different types of remote sensor records to the data base, using Direct and Indirect techniques. He needs to stereoscopically place the floating dot on target points whose ground positions are known. Operating the APPS equipment must become natural to him. As experience is gained, he will learn to recognize when things are going right and when he is having instrument or technique problems. When he suspects trouble he must have simple equipment checks to help pinpoint the problem so corrective action can be taken or to restore his confidence in him measurements.

APPENDIX C

EIGHT PARAMETER TRANSFORMATION PROGRAM

One of the Work Statement requirements was to investigate the possible use of an 8-parameter transformation for Indirect transfers instead of the 6-parameter transformation used in previous tests. An 8-parameter transformation program, written by DMA's Defense Mapping School personnel for the APPS calculator was made available to Raytheon and some limited tests were conducted using it.

Several sets of fictitious data were generated representing vertical, panoramic and oblique photography. These digital data were used to check the 8-parameter transformation program and to compare the 8-parameter results with the results obtained with the 6-parameter transformation program. Time did not allow for extensive tests so definite conclusions cannot be made. However, several things became evident during the investigation. For most transfers, where control points could be selected close to the point of interest, the 6-parameter program seems to work as well as the 8-parameter program. As control points were selected farther from the point of interest, the 8-parameter transformation provides a better fit between the two sets of points. This is to be expected since an 8-parameter nonconformal transformation is capable of mapping planar surfaces into other planar surfaces. Specifically, a non-vertical photograph from the air may be transformed point by point into a true map of the same area. Also, a linearly distorted and scaled network or grid may be correlated to a reference grid by this transformation program. The need for such a program becomes more evident in areas near the horizon on oblique or panoramic imagery.

Figure C1 is a plot, at 2/3 reduction, of panoramic digital data used in some of the tests. This plot represents the geometry of a 3-inch panoramic camera flown at 2500 feet with all panoramic, sweep positional and image motion compensation effects being considered. Each rectangle represents an area of 500 feet by 500 feet on the ground. It is evident from this plot that the transformation becomes more complex as the area of interest changes from the nadir towards the horizon. Theoretically, the 8-parameter transformation program is able to handle this changing geometry better than the 6-parameter program and preliminary tests show that it does.

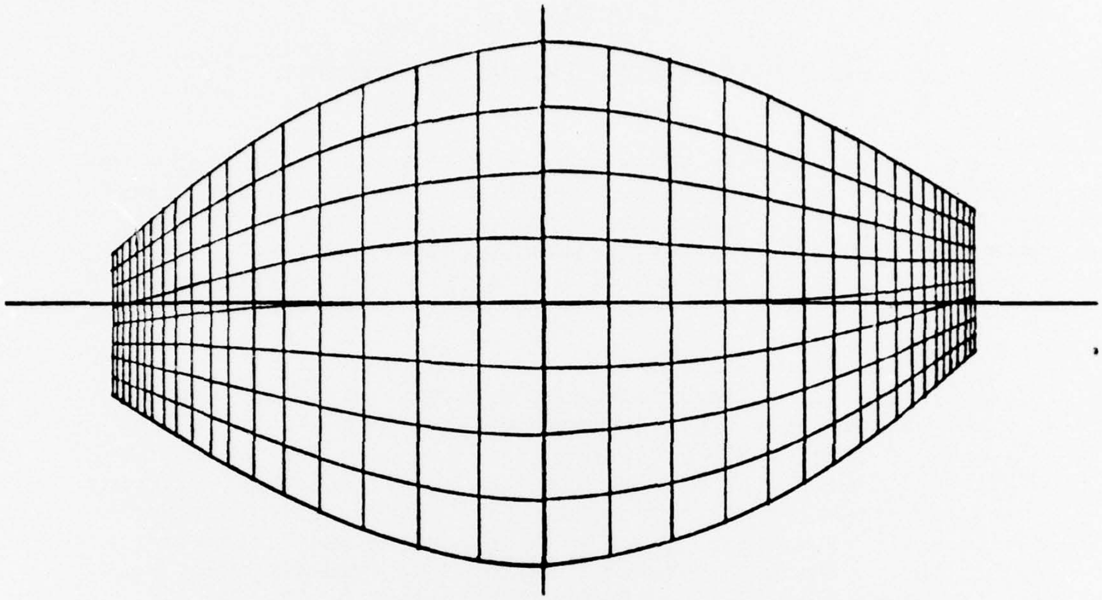


Figure C1. Geometry Of A Short Focal Length Panoramic Camera

The obvious solution seems to be to use the 8-parameter program for all transformations. This conclusion should not be reached before further tests are made, for several reasons. One reason is that the 8-parameter is bigger and requires 16-17 seconds more computing time. This should not be a stumbling block to its use if future studies show that the program is needed. Only four control points are needed for the 6-parameter program while five are needed for the 8-parameter program (this assumes that at least one more point is measured beyond that required for a unique solution). Often it is difficult to find good control points and, under these circumstances, four will be easier to find than five. Both programs, as now written, can handle up to 6 control points.

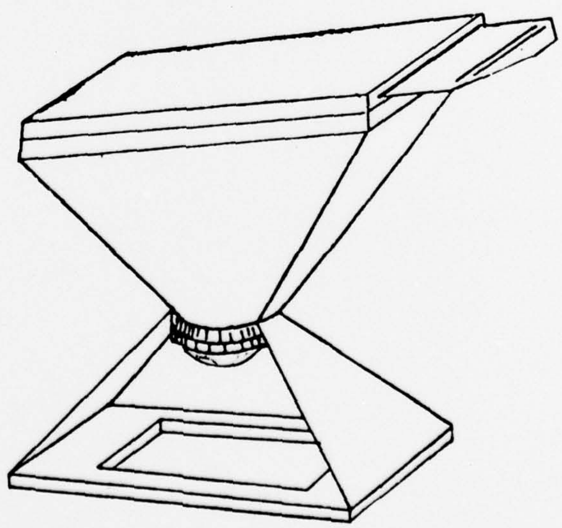
In summary, both programs are available but a strong recommendation for one or the other cannot be made until further tests are made or until they are both used operationally for an extended period.

APPENDIX D

Quick Prints From Reconnaissance Negatives

When reconnaissance imagery is first received after a mission, it is processed and, often, the initial interpretation is performed by viewing the original negatives. When a target is identified the next step is to find its location. When using the APPS for this locating function, the usual procedure is to use the Direct transfer technique as described in Appendix A under Direct Transfers. The portion of the negative containing the target is viewed (over a light table) and then the data base is viewed through the APPS' optics. This is awkward, time consuming and generally unsatisfactory. During this process the entire roll or negatives is being held up and the interpretation is being delayed. Further it provides no way for performing an Indirect transfer.

One possibility as an alternative to the above procedure was demonstrated during this contract effort. A Polaroid[1/] camera, mounted on a special stand, as shown below, was placed on the negative over the area of interest, and exposed. In ten seconds a 3½" x 4½" photo print of the area was available. This print could then be placed on the right photoholder of the APPS and either Direct or Indirect transfers could be made. The interpreter was able to continue scanning the roll of negatives while the operator was finding the position of the target point.



[1/] 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.

If the standard Polaroid film is used for photographing a negative then a negative print is produced. This might not be acceptable to some APPS operators but is would be preferred to viewing the negative transparency over a light table. If a positive transparency is being viewed by the interpreter then a positive print could be made in the same manner. There are available several quick processing methods that could be used with high-speed photographic paper for producing positive paper prints from reconnaissance negatives, in a very short time.

APPENDIX E

Data Base Locating Pins

Each time a new stereo pair is selected from the data base files and mounted on the APPS it is necessary to measure the eight index points and the check point. It the points are not measured with sufficient care the calculator will void all measurement and will indicate that a new set of measurements must be made. Even though a complete set of measurements can be made in about three minutes, if repeat measurements had to be made the delays encountered might be serious under some operational circumstances.

One possible way of speeding this initial indexing would be to mount locating studs on the APPS' mounting surfaces and punch holes in the data base photos to fit the studs when the photos were in the nominal positions and orientations. Thus, the photos could be quickly and accurately repositioned after having been removed. In order for this method of mounting to be of any value it would be necessary for each stereo pair of the data base to be mounted, each index and check point to be measured and for appropriate parameters to be stored on the data tape prior to the time of operational use. In theory, a stereo pair could then be selected from the data base file, positioned by the locating studs, and be ready for measuring ground positions.

A series of tests was made to determine the practicality of using locating studs on the APPS. Two studs, 6 millimeters in diameter, were mounted on the outside edge of each stage plate as shown in Figure E1.

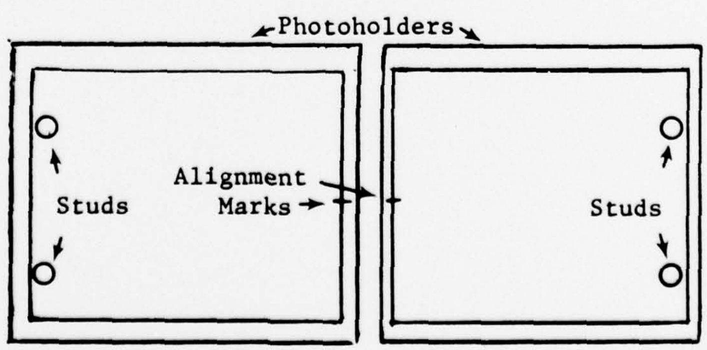


Figure E1. Location of Alignment Studs

Holes were punched in the data base prints to fit the studs. Alignment marks were drawn on the photos to correspond to lines on the mounting surface. In subsequent mountings a photo was placed as shown and, after the alignment marks were made collinear, a piece of transparent tape was used to hold the print securely.

It was found that a photo could be re-positioned to an accuracy of .001 to .002 inches. This is within the measuring accuracy of the APPS.

Discussion

Even though the tests seemed to show the feasibility of relocating photos by use of locating studs, they were not extensive enough to demonstrate operational advantages. Rather than consider using locating studs on the APPS-1's, currently in the field or on order, it is something that could be considered in future APPS design.

APPENDIX F

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 F1.

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

---

[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.

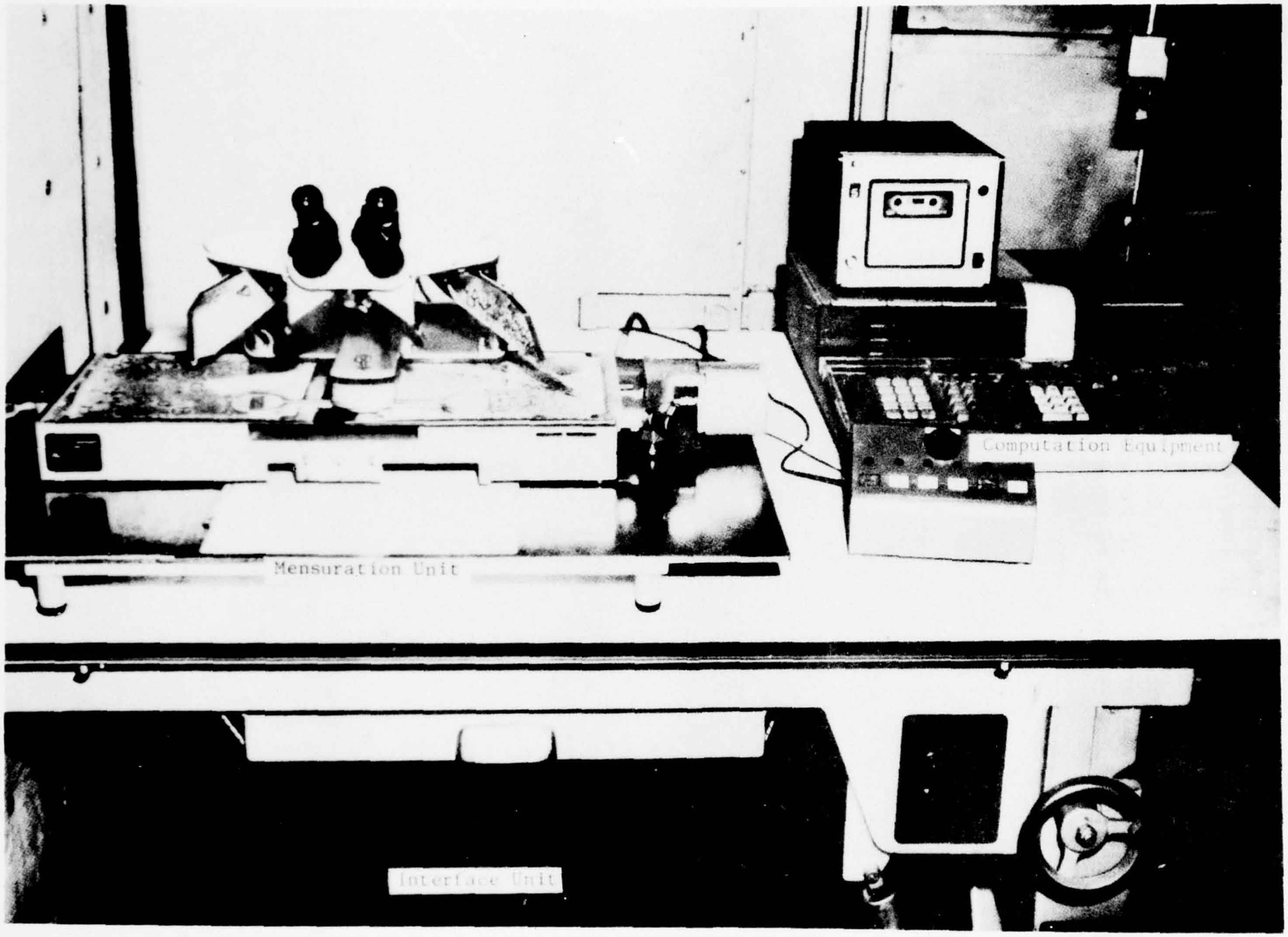


Figure F1 - Analytical Photogrammetric Positioning System (APPS) Equipment signalled to proceed he then observes the point of interest, measures and computes the X, Y, Z coordinates of the point and obtains a print-out on paper tape of the UTM Zone, Easting, Northing and elevation in meters.

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.

DISTRIBUTION

ARI Distribution List

4 OASD (M&RA)
2 HQDA (DAMI-CSZ)
1 HQDA (DAPE-PBR
1 HQDA (DAMA-AR)
1 HQDA (DAPE-HRE-PO)
1 HQDA (SGRD-ID)
1 HQDA (DAMI-DOT-C)
1 HQDA (DAPC-PMZ-A)
1 HQDA (DACH-PPZ-A)
1 HQDA (DAPE-HRE)
1 HQDA (DAPE-MPO-C)
1 HQDA (DAPE-DW)
1 HQDA (DAPE-HRL)
1 HQDA (DAPE-CPS)
1 HQDA (DAFD-MFA)
1 HQDA (DARD-ARS-P)
1 HQDA (DAPC-PAS-A)
1 HQDA (DUSA-OR)
1 HQDA (DAMO-RQR)
1 HQDA (DASG)
1 HQDA (DA10-PI)
1 Chief, Consult Div (DA-OTSG), Adelphi, MD
1 Mil Asst. Hum Res, ODDR&E, OAD (E&LS)
1 HQ USARAL, APO Seattle, ATTN: ARAGP-R
1 HQ First Army, ATTN: AFKA-OI-TI
2 HQ Fifth Army, Ft Sam Houston
1 Dir, Army Stf Studies Ofc, ATTN: OAVCSA (DSP)
1 Ofc Chief of Stf, Studies Ofc
1 DCSPER, ATTN: CPS/OCP
1 The Army Lib, Pentagon, ATTN: RSB Chief
1 The Army Lib, Pentagon, ATTN: ANRAL
1 Ofc, Asst Sect of the Army (R&D)
1 Tech Support Ofc, OJCS
1 USASA, Arlington, ATTN: IARD-T
1 USA Rsch Ofc, Durham, ATTN: Life Sciences Dir
2 USARIEM, Natick, ATTN: SGRD-UE-CA
1 USATTC, Ft Clayton, ATTN: STETC-MO-A
1 USAIMA, Ft Bragg, ATTN: ATSU-CTD-OM
1 USAIMA, Ft Bragg, ATTN: Marquat Lib
1 US WAC Ctr & Sch, Ft McClellan, ATTN: Lib
1 US WAC Ctr & Sch, Ft McClellan, ATTN: Tng Dir
1 USA Quartermaster Sch, Ft Lee, ATTN: ATSM-TE
1 Intelligence Material Dev Ofc, EWL, Ft Holabird
1 USA SE Signal Sch, Ft Gordon, ATTN: ATSO-EA
1 USA Chaplain Ctr & Sch, Ft Hamilton, ATTN: ATSC-TE-RD
1 USATSCH, Ft Eustis, ATTN: Educ Advisor
1 USA War College, Carlisle Barracks, ATTN: Lib
2 WRAIR, Neuropsychiatry Div
1 DLI, SDA, Monterey
1 USA Concept Anal Agcy, Bethesda, ATTN: MOCA-WGC
1 USA Concept Anal Agcy, Bethesda, ATTN: MOCA-MR
1 USA Concept Anal Agcy, Bethesda, ATTN: MOCA-JF
1 USA Artic Test Ctr, APO Seattle, ATTN: STEAC-MO-ASL
1 USA Artic Test Ctr, APO Seattle, ATTN: AMSTE-PL-TS
1 USA Armament Cmd, Redstone Arsenal, ATTN: ATSK-TEM
1 USA Armament Cmd, Rock Island, ATTN: AMSAR-TDC
1 FAA-NAFEC, Atlantic City, ATTN: Library
1 FAA-NAFEC, Atlantic City, ATTN: Hum Engr Br
1 FAA Aeronautical Ctr, Oklahoma City, ATTN: AAC-44D
2 USA Fld Arty Sch, Ft Sill, ATTN: Library
1 USA Armor Sch, Ft Knox, ATTN: Library
1 USA Armor Sch, Ft Knox, ATTN: ATSB-DI-E
1 USA Armor Sch, Ft Knox, ATTN: ATSB-DT-TP
1 USA Armor Sch, Ft Knox, ATTN: ATSB-CD-AD
2 HQUSACDEC, Ft Ord, ATTN: Library
1 HQUSACDEC, Ft Ord, ATTN: ATEC–EX–E–Hum Factors
2 USAEEC, Ft Benjamin Harrison, ATTN: Library
1 USAPACDC, Ft Benjamin Harrison, ATTN: ATCP–HR
1 USA Comm–Elect Sch, Ft Monmouth, ATTN: ATSN–EA
1 USAEC, Ft Monmouth, ATTN: AMSEL–CT–HDP
1 USAEC, Ft Monmouth, ATTN: AMSEL–PA–P
1 USAEC, Ft Monmouth, ATTN: AMSEL–SI–CB
1 USAEC, Ft Monmouth, ATTN: C, Facl Dev Br
1 USA Materials Sys Anal Agcy, Aberdeen, ATTN: AMXSY–P
1 Edgewood Arsenal, Aberdeen, ATTN: SAREA–BL–H
1 USA Ord Ctr & Sch, Aberdeen, ATTN: ATSL–TEM–C
2 USA Hum Engr Lab, Aberdeen, ATTN: Library/Dir
1 USA Combat Arms Tng Bd, Ft Benning, ATTN: Ad Supervisor
1 USA Infantry Hum Rsch Unit, Ft Benning, ATTN: Chief
1 USA Infantry Bd, Ft Benning, ATTN: STEBC–TE–T
1 USASMA, Ft Bliss, ATTN: ATSS–LRC
1 USA Air Def Sch, Ft Bliss, ATTN: ATSA–CTD–ME
1 USA Air Def Sch, Ft Bliss, ATTN: Tech Lib
1 USA Air Def Bd, Ft Bliss, ATTN: FILES
1 USA Air Def Bd, Ft Bliss, ATTN: STEBD–PO
1 USA Cmd & General Stf College, Ft Leavenworth, ATTN: Lib
1 USA Cmd & General Stf College, Ft Leavenworth, ATTN: ATSW–SE–L
1 USA Cmd & General Stf College, Ft Leavenworth, ATTN: Ed Advisor
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: DepCdr
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: CCS
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: ATCASA
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: ATCACO–E
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: ATCACC–CI
1 USAECOM, Night Vision Lab, Ft Belvoir, ATTN: AMSEL–NV–SD
3 USA Computer Sys Cmd, Ft Belvoir, ATTN: Tech Library
1 USAMERDC, Ft Belvoir, ATTN: STSFB–DQ
1 USA Eng Sch, Ft Belvoir, ATTN: Library
1 USA Topographic Lab, Ft Belvoir, ATTN: ETL–TD–S
1 USA Topographic Lab, Ft Belvoir, ATTN: STINFO Center
1 USA Topographic Lab, Ft Belvoir, ATTN: ETL–GSL
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: CTD–MS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATS–CTD–MS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI–TE
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI–TEX–GS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI–CTS–OR
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI–CTD–DT
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI–CTD–CS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: DAS/SRD
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI–TEM
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: Library
1 CDR, HQ Ft Huachuca, ATTN: Tech Ref Div
2 CDR, USA Electronic Prvg Grd, ATTN: STEEP–MT–S
1 CDR, Project MASSTER, ATTN: Tech Info Center
1 Hq MASSTER, USATRADOC, LNO
1 Research Institute, HQ MASSTER, Ft Hood
1 USA Recruiting Cmd, Ft Sherdian, ATTN: USARCPM–P
1 Senior Army Adv., USAFAGOD/TAC, Elgin AF Aux Fld No. 9
1 HQ USARPAC, DCSPER, APO SF 96558, ATTN: GPPE–SE
1 Stimson Lib, Academy of Health Sciences, Ft Sam Houston
1 Marine Corps Inst., ATTN: Dean–MCI
1 HQUSMC, Commandant, ATTN: Code MTMT 51
1 HQUSMC, Commandant, ATTN: Code MPI–20
2 USCG Academy, New London, ATTN: Admission
2 USCG Academy, New London, ATTN: Library
1 USCG Training Ctr, NY, ATTN: CO
1 USCG Training Ctr, NY, ATTN: Educ Svc Ofc
1 USCG, Psychol Res Br, DC, ATTN: GP 1/62
1 HQ Mid–Range Br, MC Det, Quantico, ATTN: P&S Div

1 US Marine Corps Liaision Ofc, AMC, Alexandria, ATTN: AMCGS–F
1 USATRADOC, Ft Monroe, ATTN: ATRO–ED
6 USATRADOC, Ft Monroe, ATTN: ATPR–AD
1 USATRADOC, Ft Monroe, ATTN: ATTS–EA
1 USA Forces Cmd, Ft McPherson, ATTN: Library
2 USA Aviation Test Bd, Ft Rucker, ATTN: STEBG–PO
1 USA Agcy for Aviation Safety, Ft Rucker, ATTN: Library
1 USA Agcy for Aviation Safety, Ft Rucker, ATTN: Educ Advisor
1 USA Aviation Sch, Ft Rucker, ATTN: PO Drawer O
1 HQUSA Aviation Sys Cmd, St Louis, ATTN: AMSAV–ZDR
2 USA Aviation Sys Test Act., Edwards AFB, ATTN: SAVTE–T
1 USA Air Def Sch, Ft Bliss, ATTN: ATSA TEM
1 USA Air Mobility Rsch & Dev Lab, Moffett Fld, ATTN: SAVDL–AS
1 USA Aviation Sch, Res Tng Mgt, Ft Rucker, ATTN: ATST–T–RTM
1 USA Aviation Sch, CO, Ft Rucker, ATTN: ATST–D–A
1 HQ, DARCOM, Alexandria, ATTN: AMXCD–TL
1 HQ, DARCOM, Alexandria, ATTN: CDR
1 US Military Academy, West Point, ATTN: Serials Unit
1 US Military Academy, West Point, ATTN: Ofc of Milt Ldrshp
1 US Military Academy, West Point, ATTN: MAOR
1 USA Standardization Gp, UK, FPO NY, ATTN: MASE–GC
1 Ofc of Naval Rsch, Arlington, ATTN: Code 452
3 Ofc of Naval Rsch, Arlington, ATTN: Code 458
1 Ofc of Naval Rsch, Arlington, ATTN: Code 450
1 Ofc of Naval Rsch, Arlington, ATTN: Code 441
1 Naval Aerospc Med Res Lab, Pensacola, ATTN: Acous Sch Div
1 Naval Aerospc Med Res Lab, Pensacola, ATTN: Code L51
1 Naval Aerospc Med Res Lab, Pensacola, ATTN: Code L5
1 Chief of NavPers, ATTN: Pers-OR
1 NAVAIRSTA, Norfolk, ATTN: Safety Ctr
1 Nav Oceanographic, DC, ATTN: Code 6251, Charts & Tech
1 Center of Naval Anal, ATTN: Doc Ctr
1 NavAirSysCom, ATTN: AIR–5313C
1 Nav BuMed, ATTN: 713
1 NavHelicopterSubSqua 2, FPO SF 96601
1 AFHRL (FT) William AFB
1 AFHRL (TT) Lowry AFB
1 AFHRL (AS) WPAFB, OH
2 AFHRL (DOJZ) Brooks AFB
1 AFHRL (DOJN) Lackland AFB
1 HQUSAF (INYSD)
1 HQUSAF (DPXXA)
1 AFVTG (RD) Randolph AFB
3 AMRL (HE) WPAFB, OH
2 AF Inst of Tech, WPAFB, OH, ATTN: ENE/SL
1 ATC (XPTD) Randolph AFB
1 USAF AeroMed Lib, Brooks AFB (SUL–4), ATTN: DOC SEC
1 AFOSR (NL), Arlington
1 AF Log Cmd, McClellan AFB, ATTN: ALC/DPCRB
1 Air Force Academy, CO, ATTN: Dept of Bel Scn
5 NavPers & Dev Ctr, San Diego
2 Navy Med Neuropsychiatric Rsch Unit, San Diego
1 Nav Electronic Lab, San Diego, ATTN: Res Lab
1 Nav TrngCen, San Diego, ATTN: Code 9000–Lib
1 NavPostGraSch, Monterey, ATTN: Code 55Aa
1 NavPostGraSch, Monterey, ATTN: Code 2124
1 NavTrngEquipCtr, Orlando, ATTN: Tech Lib
1 US Dept of Labor, DC, ATTN: Manpower Admin
1 US Dept of Justice, DC, ATTN: Drug Enforce Admin
1 Nat Bur of Standards, DC, ATTN: Computer Info Section
1 Nat Clearing House for MH–Info, Rockville
1 Denver Federal Ctr, Lakewood, ATTN: BLM
12 Defense Documentation Center
4 Dir Psych, Army Hq, Russell Ofcs, Canberra
1 Scientific Advsr, Mil Bd, Army Hq, Russell Ofcs, Canberra
1 Mil and Air Attache, Austrian Embassy
1 Centre de Recherche Des Facteurs, Humaine de la Defense Nationale, Brussels
2 Canadian Joint Staff Washington
1 C/Air Staff, Royal Canadian AF, ATTN: Pers Std Anal Br
3 Chief, Canadian Def Rsch Staff, ATTN: C/CRDS(W)
4 British Def Staff, British Embassy, Washington
1 Def & Civil Inst of Enviro Medicine, Canada
1 AIR CRESS, Kensington, ATTN: Info Sys Br
1 Militaerpsykologisk Tjeneste, Copehagen
1 Military Attache, French Embassy, ATTN: Doc Sec
1 Medecin Chef, C.E.R.P.A.–Arsenal, Toulon/Naval France
1 Prin Scientific Off, Appl Hum Engr Rsch Div, Ministry of Defense, New Delhi
1 Pers Rsch Ofc Library, AKA, Israel Defense Forces
1 Ministeris van Defensie, DOOP/KL Afd Sociaal Psychologische Zaken, The Hague, Netherlands