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ANALYTICAL STEREOPLOTTERS IN THE USGS

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Introduction

The President's Office of Management and Budget established a special task force in 1972 to study mapping problems within the civilian mapping organization shortly after the Department of Defense mapping was consolidated into one agency - the Defense Mapping Agency. One of the many recommendations of this task force addressed the consolidation of mapping and associated activities and the upgrading of mapping equipment and procedures. The U.S. Geological Survey, as the civilian agency charged with national mapping, began modernizing equipment, procedures, and products even before the Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy, and Surveying, July 1973, was published.

One of the areas ready for modernization was the equipment used on the photogrammetric processes of map compilation. While these equipments have undergone significant changes from the days of direct-optical projection type plotters, they had not kept pace with the development of precision aerial cameras. Certainly the developments in the marking of image points on aerial emulsions, the development of high production output precision coordinate measuring comparators and the contributions of the application of computers as interactive devices to the positioning of stereoplotter stages have been significant steps in the evolution of equipment to support the mapmaking process.

The USGS, responsible for the National Mapping Program of the United States, agreed to accept this challenge of modernization and began equipping itself with the most modern stereoplotting equipment available. There was much to be proven about the cost effectiveness of the new technology so it was approached with advisable caution and the initial decision to implement the utilization of analytical stereoplotters was with the loan of two such devices from the Defense Mapping Agency, followed immediately by the initial purchase of four additional systems.

Other factors effecting this decision were associated with the attendant problems of aerial photography acquisition in air space that was continuously being restricted to access for low altitude photography missions (3000 to 8000 meters flying height) and, more importantly, by the fact that a very successful program was well underway for the production of orthophotoquads, using as input, 1:80 000-scale, 153 mm focal length aerial photography. This data base was single purpose and it was evident that, if the full advantages of the treatment of this photography in analytical stereoplotters could be exploited that definite advantages could be realized. Experiments, referred to later in this report, support this utilization. Because of the initial success of the utilization of this high altitude data base in analytical stereoplotters, the Geological Survey is in the process of acquiring three additional analytical stereoplotter systems. The description of analytical systems in use in the Survey, their utilization, and the use of associated peripheral equipments follows.

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OMI ANALYTICAL STEREOPLOTTER AS-11A

Acquisition

Procurement of new analytical stereoplotters is a rather lengthy process, but through the cooperation of the Defense Mapping Agency, the Geological Survey was able to acquire an AS-11A from the Defense Mapping Agency Aerospace Center, St. Louis, Mo., in July 1973, the same month that the Federal Mapping Task Force published their report. A second AS-11A was acquired shortly thereafter from the Defense Mapping Agency Hydrographic/Topographic Center and both of these Centers trained GS operators and maintenance technicians.

In October 1973 the first test of the AS-11A for 1:24 000-scale compilation was completed in the 20-ft contour-interval compilation of an area in the vicinity of Gillette, Wyoming. This area had been compiled previously in a conventional stereoplotter using color photographs taken at a nominal altitude of 40 000 ft, but the conventional compilation did not meet National Map Accuracy Standards; only 89 percent of the contours tested were accurate to within 1/2 the contour interval. The AS-11A compilation did meet National Map Accuracy Standards, with 93 percent of the contours tested being accurate to within 1/2 the contour interval.

These two AS-11A stereoplotters had delay-line-memory computers, and although the existing software was suited for most GS frame photographs, modifications to the software were needed for correcting those stereomodels having complex vertical errors. Preparing computer programs for the delay-line computers was a lost art, so it was decided to upgrade the AS-11A stereoplotters with more powerful computers that would accept higher-level computer languages. The Defense Mapping Agency was in the process of upgrading their analytical stereoplotters so the GS acquired two central (Modcomp II/45) computers and four controller-type (Modcomp II/25) computers under the DMA procurement. A fifth (Modcomp II/25) controller computer was acquired under a separate Geological Survey contract.

One of the Modcomp II/45 computers serves as a central computer or master to the controllers, and the other Modcomp II/45 is serving as a controller for a correlation system being developed. They both have 64 Kwords of memory, with each word being 16 bits in length. Peripheral equipment for the central computer includes three nine-track magnetic tape units, a paper tape read/write unit, two disk cartridge drives, two disk-pack units, a line printer, a card reader, a card punch, a CRT terminal, and a typewriter/paper tape punch and reader unit (Fig. 1).

For convenience in the retrofitting of controllers the two AS-11A stereoplotters were exchanged for two AS-11A/B stereoplotters. These latter instruments were originally designated AS-11A stereoplotters, then redesignated AS-11B stereoplotters after being fitted with correlators. The correlators were removed before transfer to the Geological Survey, and consequently the stereoplotters have been redesignated AS-11A/B since they do not fit the criteria of either an AS-11A or AS-11B but have characteristics of both. The controller for each stereoplotter is a Modcomp II/25 computer having 40 Kwords of memory, each word being 16 bits in length. Each has as peripherals two disk cartridge drives and a typewriter/paper tape punch and reader unit. One of the disk cartridges is for the computer programs (operating system and program library), and the other cartridge is for storing collected digital data. At the present time, each analytical plotter is a stand-alone instrument, but hardware links are available for eventually linking all five of the controller computers to the Modcomp II/45 central computer (Fig. 2 and Fig. 3).

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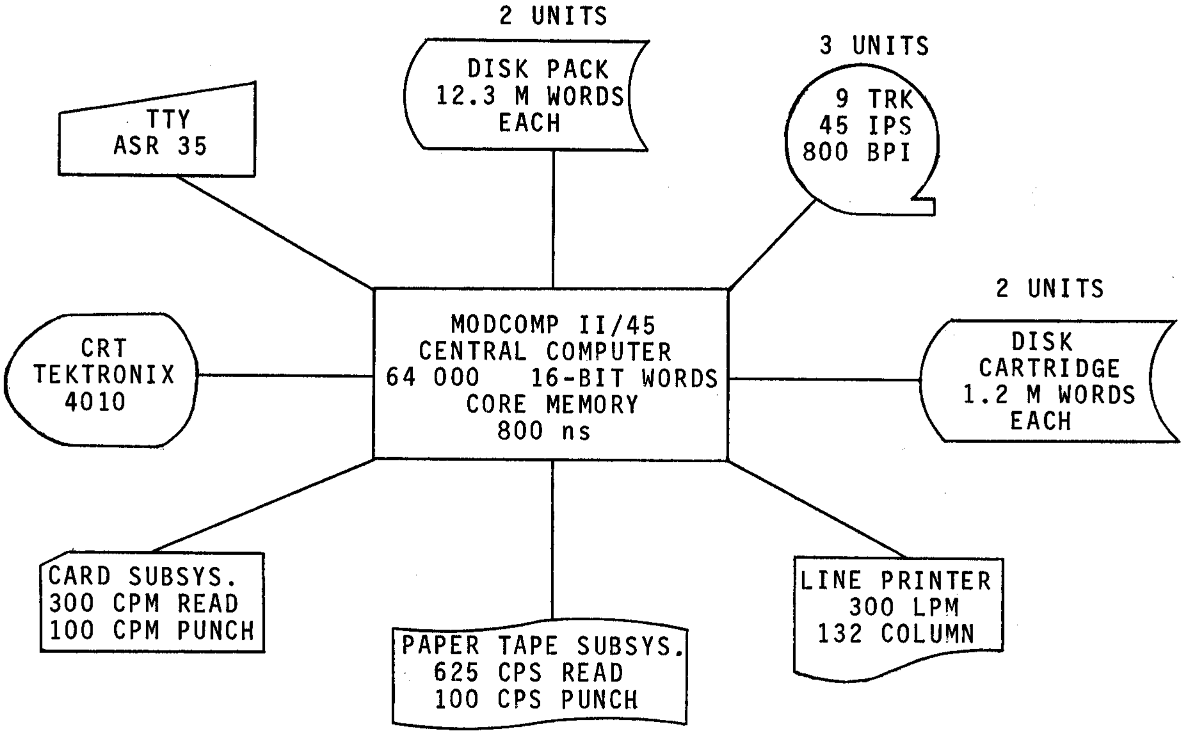

Fig. 1 Modcomp II/45

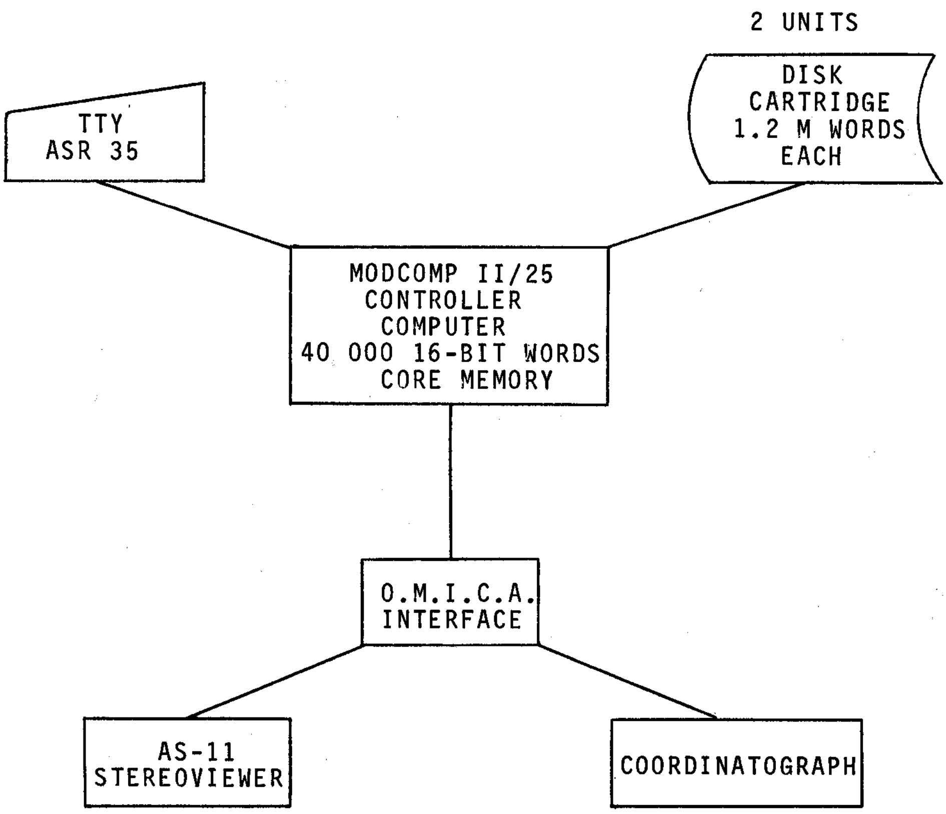

Fig. 2 Modcomp II/25 with AS-11 Stereoplotter System

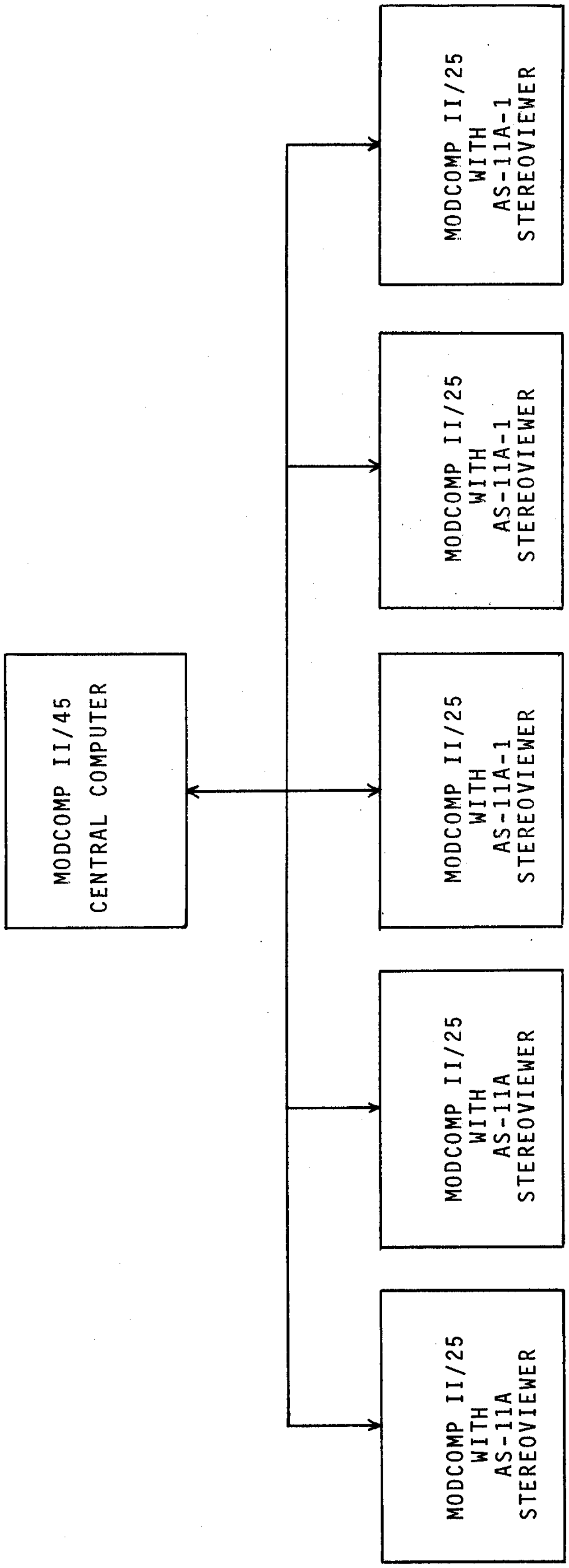

Fig. 3 Configuration of Modcomp computers and AS-11 stereoplotters

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The links will permit transferring stereomodel data and digital terrain data between the central computer and the control computers. The digital data will be collected and stored on a disk cartridge of the controller, and when digitizing is complete, the digital data will be sent over the link to the central computer. The data will then be stored on one of the two large disk packs, and eventually transferred by the central computer to a nine-track magnetic tape for further off-line processing.

The communication link between the Modcomp II/45 and the controllers is disconnected to simplify computer program debugging, and data is being transferred between the Modcomps via the disk cartridges. That is, photo and model information is transferred from the Modcomp II/45 data base by writing the information on a disk cartridge and manually transferring the cartridge to the appropriate Modcomp II/25. Similarly, information can be transferred from the Modcomp II/25 to the Modcomp II/45.

Software

Preparation of software for the Modcomp computers of the AS-11 stereoplotters was done by a Defense Mapping Agency Aerospace Center software team organized specifically for the task. As preparation of each software package was completed, a copy was given to the GS for tailoring to the GS configuration of plotters and computers.

The software presently in use at GS for frame photographs is divided into three categories: interface software, realtime software, and application software (Fig. 4). These computer programs reside on the "primary" disk cartridge of each controller.

Interface software The interface software comprises 20 subroutines written to provide communication between the application programs and the stereoplotter operator. This software, prepared by the manufacturer, can be called on by the application programs to receive input from or send output to the stereoplotter servo motors, limit switches, handwheels, footwheel, dove-prism motors, lens magnification control, panel pushbuttons, panel lights, stage lights, keyboard, and the digital display.

Realtime software The realtime software performs two functions: continuous update of model position and communication with the viewer and coordinatograph. The main program, prepared by the manufacturer, oversees the input and output of the interface, controls the timing, and, every 20 milliseconds, calls on a subroutine that transforms model coordinates to photocoordinates. This model-to-photo coordinate transformation subroutine reads the handwheel and footwheel counts; applies corrections for earth curvature, lens distortion, and film shrinkage; and outputs stage coordinates for use by the interface software.

Application software Most of the application software was prepared by the Defense Mapping Agency. The routines in this software monitor the panel buttons, control the panel lights, operate the digital displays, automatically drive the stages from point to point in making reseau measurements, automatically handle input and output data in setting up or shutting down a stereomodel, compute interior, relative, and absolute orientation parameters, and provides means for digital and graphical output. In interior orientation, parameters for transforming stage coordinates to photocoordinates are computed by fitting measured stage coordinates of fiducial marks to their calibrated photocoordinates. The transformation involved is based on translations in x and y, an overall rotation, and an overall scale change.

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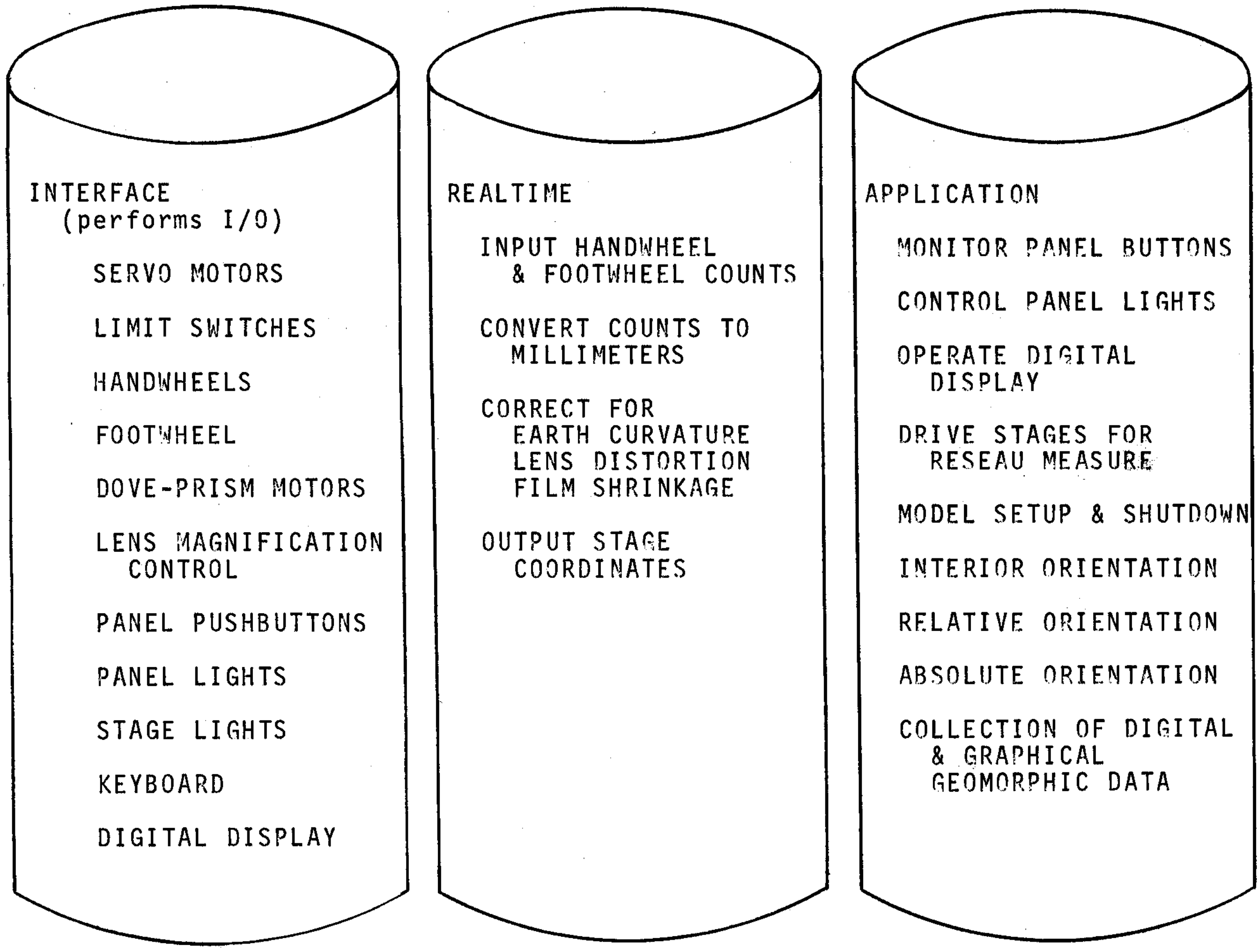

Fig. 4 AS-11 Software

OMI ANALYTICAL STEREOPLOTTER AS-11A-1

Hardware

In mid 1975, contracts were awarded for the acquisition of three AS-11A-1 stereoplotters, an AS-11B-1 stereoplotter, and a TA3/P1 analytical comparator. The AS-11A-1 stereoplotters with Modcomp II/25 computers are similar to the AS-11A/B stereoplotters except that the stage plates will accommodate 9- by 18-inch photos and they do not have split optics for simultaneously viewing and correlating. Like the AS-11A/B stereoplotters, they are equipped with rotary encoders, and they have computer-stereoplotter interfaces compatible with that of the AS-11A/B (Fig. 5).

Software

The same computer programs are used for the AS-11A-1 stereoplotters as for the AS-11A/B and when the links are connected between the Modcomp II/25 controller computers and the Modcomp II/45 central computer, the AS-11A-1 and AS-11A/B will all be in the same network. The computer programs do make checks at appropriate operations to ascertain whether the AS-11A/B (9 x 9-inch stages) or AS-11A-1 (9 x 18-inch stages) is involved.

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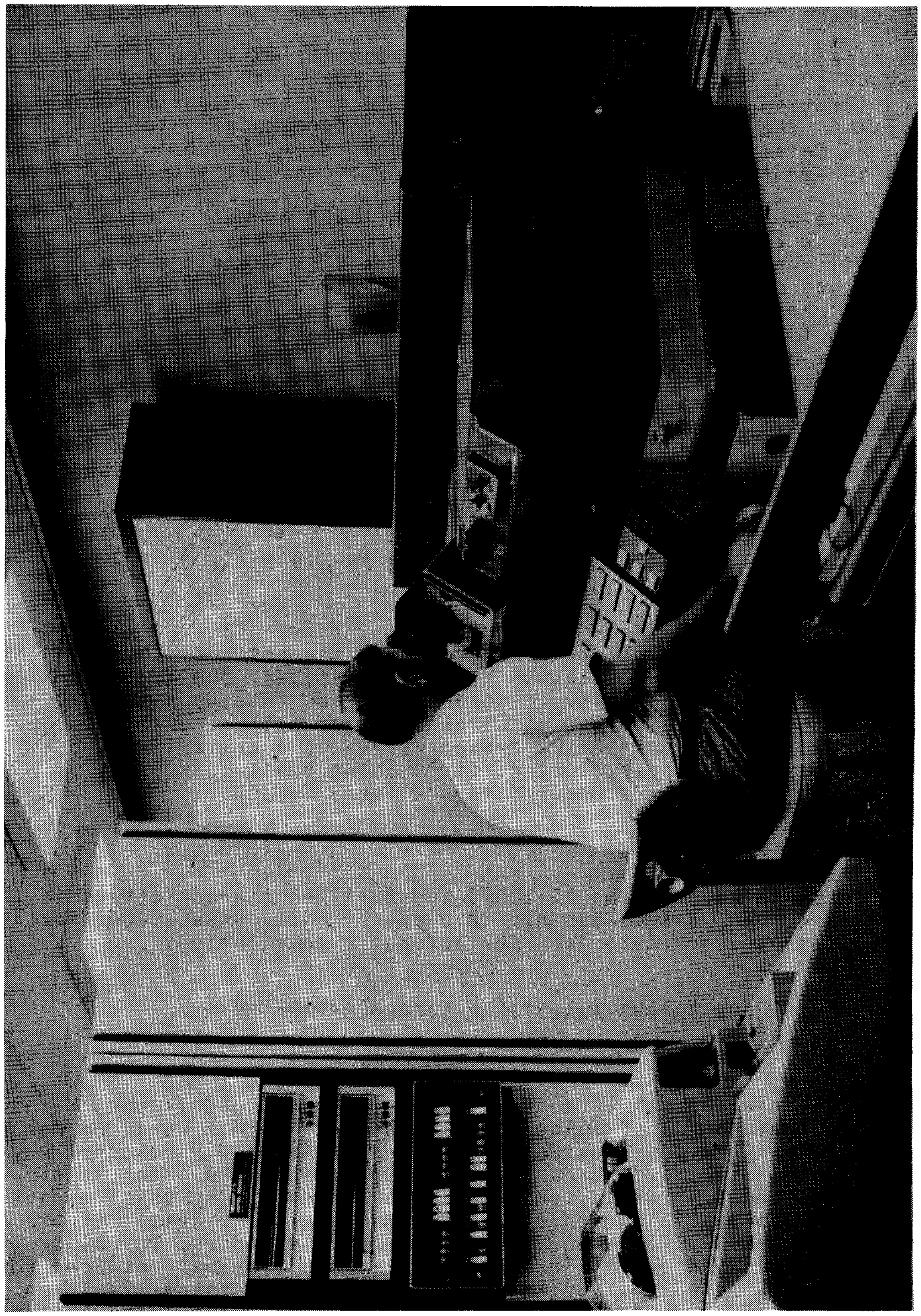

Fig. 5 AS-11A-1 analytical stereoplotter

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The prime objective in equipping the analytical stereoplotters with modern computers was to update the software. In January of this year (1979), a contract was let to Autometric, Inc., for preparing computer routines for correcting complex error patterns in stereomodels. As the computer programming progressed, it became evident that the scope of the effort needed to be changed to make the stereoplotter operations much more efficient.

Two data bases will be established for the Modcomp II/45 large disk pack under the Autometric contract. One data base will be for photo data including camera calibration and exposure station data taken from magnetic tape or punched cards. The other data base will be for stereomodel data so that a model can be relatively and absolutely oriented after the photo data have been used in aerotriangulation or after a stereomodel has once been formed.

When a project begins, pertinent data will be taken from the two data bases and a user-disk cartridge containing camera ground survey and aerotriangulation data will be prepared for the project. The disk cartridge can be accessed by any of the Modcomp II/25 computers via the wired linkage or by manually transferring the disk cartridge from the drive unit of the Modcomp II/45 to the drive unit appropriate of the Modcomp II/25.

Such a network of central and control computers would be prone to costly accumulations of down time if all of the Modcomp II/25 computers could not operate independent of each other and of the central Modcomp II/45. To minimize the amounts of this downtime, one of the Modcomp II/25 controllers is being equipped with a magnetic tape unit so that it can prepare user-disk cartridges from the tape if the Modcomp II/45 is down.

ANALYTICAL STEREOPLOTTER AS-11B-1

Hardware

When the AS-11A-1 stereoplotters were acquired, the contract included the delivery of four viewers with the 9- by 18-inch stages. One of these viewers was delivered to DBA Systems for its transformation into an AS-11B-1, that is, a 9- by 18-inch stage analytical stereoplotter with automatic image correlation. This instrument has a Modcomp II/45 as a controller and a linear array scanner for correlation. It is being built in support of a research effort and is now scheduled for delivery in 1980.

Software

The basic software used on the AS-11A/B and AS-11A-1 stereoplotters is used on the AS-11B-1. DBA Systems has had to prepare additions and modifications for controlling the correlator and for automatic compilation.

OMI TA3P-1 ANALYTICAL STEREOCOMPARATOR

Hardware

The TA3/P1 in operation has three 9- by 18-inch stages and is controlled by a PDP 15 computer (Fig. 6). The computer has 32K 18-bit words of memory, and as peripherals, it has a cathode ray tube terminal; a hard-copy, keyboard-type terminal; a card reader; a card punch; a line printer; a paper-tape reader and punch; a disk storage unit; a standard nine-track magnetic tape unit; and two special-purpose magnetic tape units. Like all of the AS-11 stereoplotters, the TA3/P1 is equipped with rotary encoders. It has only recently been placed in operation so its full capability has not been realized. However, its potential for throughput is very promising. It is an ideal instrument for transferring pass points and control between photos without the need for marking imagery. This point-transfer capability is not only useful for transferring points between photos from the same film, but it is also useful for transferring points from high-resolution imagery to lower-resolution photos. Ground control identified on large-scale photos can be transferred to aerotriangulation and compilation photos of smaller scale by using the zoom optics to bring the two photos to a common scale

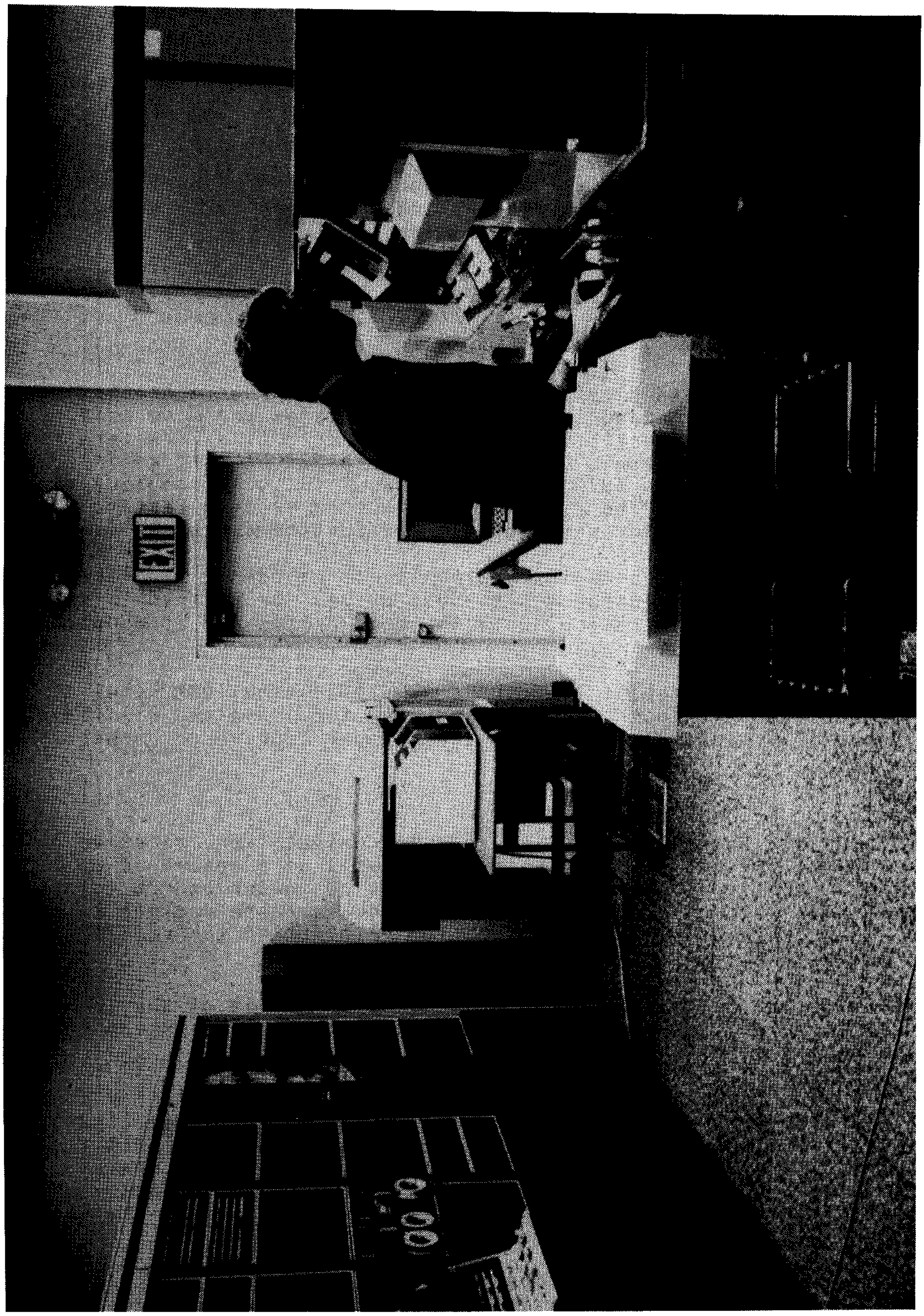

Fig. 6 TA3/P1 analytical stereo comparator

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and viewing them stereoscopically. Photo and camera parameters determined on the TA3/P1 can be stored and used later for setting stereomodels in AS-11 compilation.

A technique is being tested for performing aerotriangulation on the analytical stereocomparator and compilation on the analytical stereoplotter using specified photocoordinates as pass points rather than discrete images or premarked points. Orientation parameters determined on the stereocomparator and refined during compilation will be used in the analytical stereoplotters.

Software

Enough software was acquired with the stereocomparator for basic or routine operations. Special-purpose software is planned to more fully exploit the capability and flexibility of the comparator.

SYSTEMHOUSE AUTOPLOT

Hardware

The AS-11 analytical stereoplotters and the TA3/P1 stereocomparator are all located in the Reston area and late in 1978 a decision was made to expand the use of analytical stereoplotters into the other regional centers of the Geological Survey's Topographic Division. As a result of that decision a contract was let in January 1979, to Systemhouse, Inc., to manufacture three analytical stereoplotters, one each for the Western Mapping Center, the Rocky Mountain Mapping Center, and for the Mid-Continent Mapping Center.

These stereoplotters will be equipped with linear encoders, and like the OMI instruments, they will be equipped with dove prisms for anamorphic viewing and zoom optics for magnification. Both the dove prisms and zoom optics will be under computer control.

The computer for each Autoplot is to be a PDP-11/34 with 192K bytes of memory. It will be equipped with both CRT and hard-copy terminals and will have a disk drive unit, a magnetic tape unit, and a paper tape reader-punch (Fig. 7).

Software

Software for basic operations such as interior orientation, relative orientation, absolute orientation, and compilation will be prepared as part of the contract. Additional software is being acquired under contract for compilation with panoramic photographs. A second software package to be acquired under contract will be designed for eliminating the need for marking pass points.

The accuracy of the Autoplot should be comparable to that of the stereocomparator. Therefore, we plan to use the Autoplot as both a stereocomparator and compilation instrument.

In conventional procedures of map compilation, pass points are marked on the photos in the approximate locations of those illustrated in figure 8. The coordinates of these points as well as those of the fiducial marks and any photoidentified ground control points are measured with a precise comparator. These coordinates, along with camera calibration data, are input into an offline aerotriangulation program which computes the ground coordinates of the pass points.

The marking of pass points on the photos is time consuming and sometimes is a large source of error because points must be transferred from photo to photo and from strip to strip. When transferring a point from a photo in which the point is marked, to a photo in which the point is not marked, precise correlation is difficult and the transfer errors can be large, especially when transfers are made between strips. An alternative to physically marking the pass points is to locate and recover them by prespecified photocoordinates.

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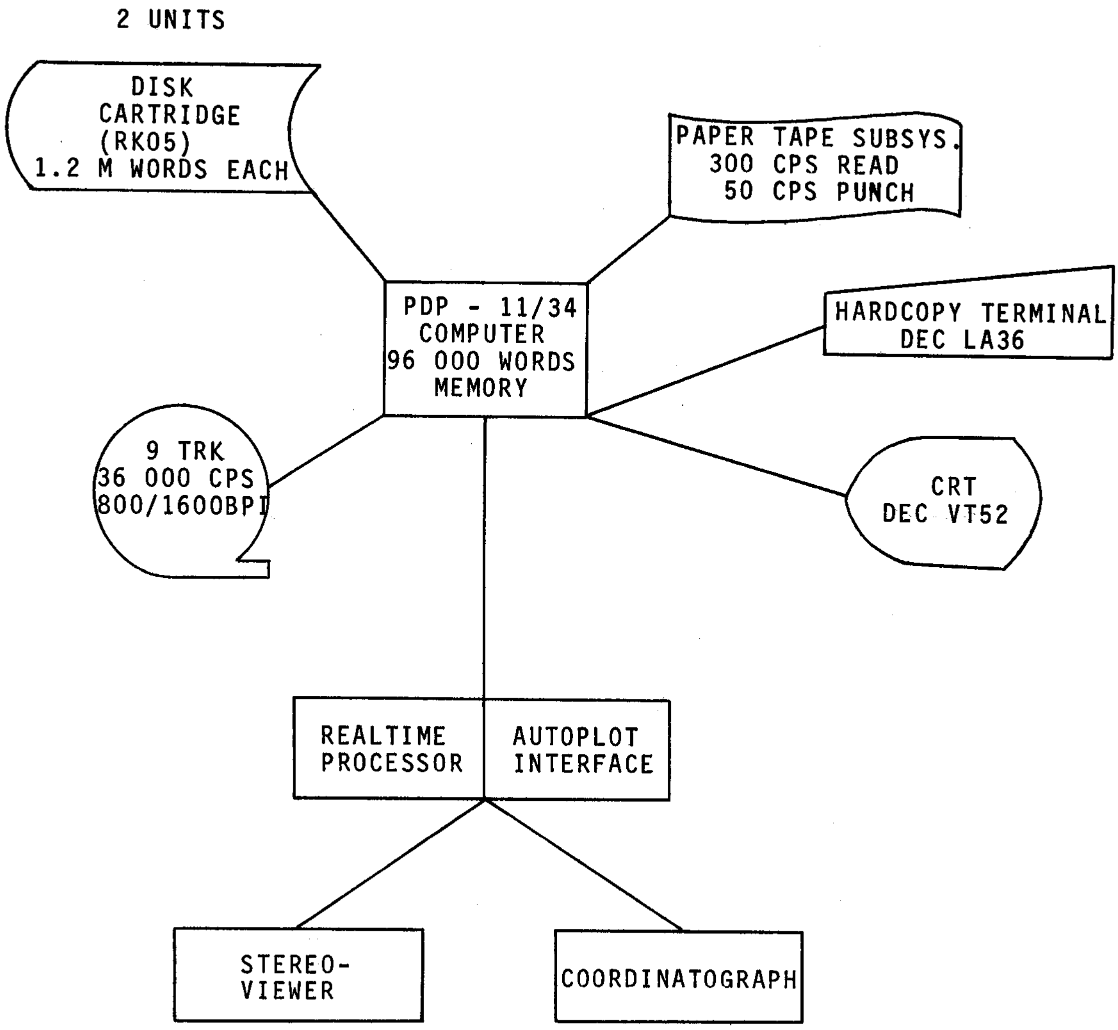

Fig. 7 Systemhouse Autoplot configuration

Furthermore, it is desired to retain pass point data, such as photo and ground coordinates, in a recently established pass-point data bank. If photos must be physically marked, provisions must be made for retaining the marked diapositives. If pass points can be located by precise photo-coordinates, the storage of all marked diapositives will not be necessary. Instead a diapositive will be prepared only on request, and afterwards the pass points will be marked automatically on an x-y plotter. The USGS has prepared a statement of work to obtain software so that the Autoplot can be used as both an aerotriangulation and map compilation instrument. All operations are to be performed with the Autoplot, with the exception that the aerotriangulation computation will be done with an offline aero-triangulation program.

The first step as specified in the statement of work is to perform interior orientation for the first stereopair by measuring and recording the coordinates of each fiducial mark on each of the two photos. Based on these measurements, the photocoordinate systems will be constructed for each of the photos with the origin of each system being at the point of autocollimation.

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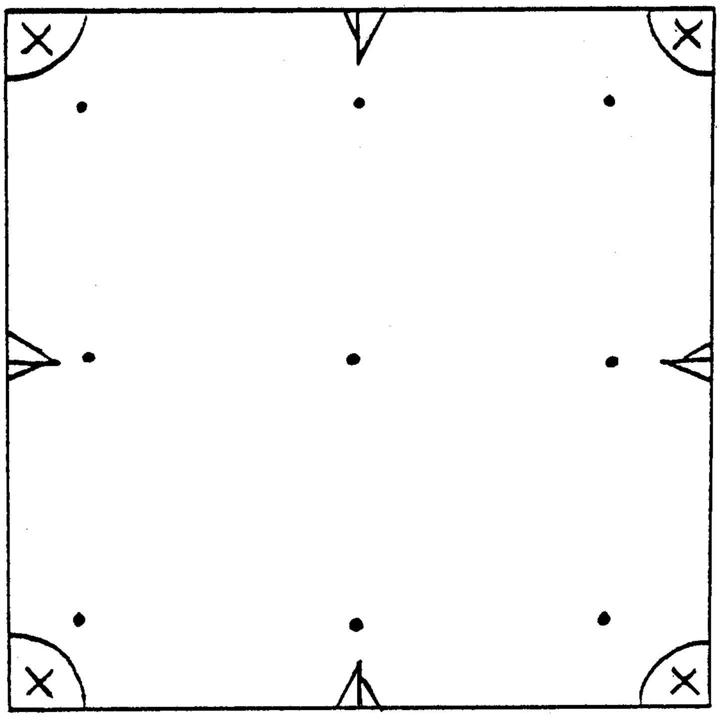
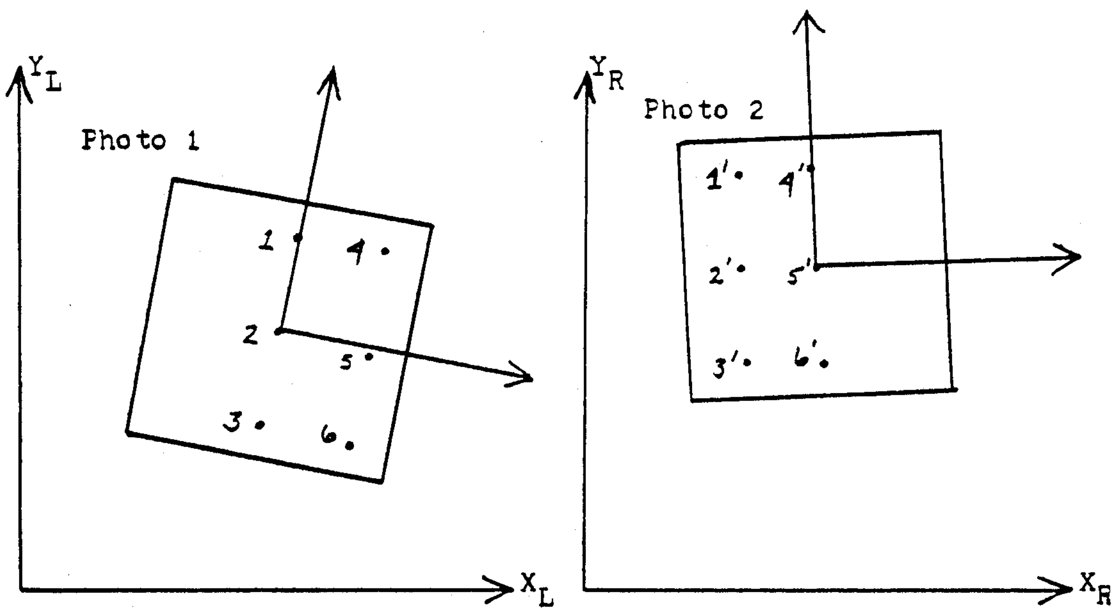


● - Approximate Pass Point Location

FIGURE 8



PLOTTER LEFT STAGE

PLOTTER RIGHT STAGE

FIGURE 9

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In order to perform a relative orientation, pass points will be required in the vicinity of the positions shown in figure 8. This method will not use marked pass points, so none will be identified or marked on the photos. Instead, the left stage of the plotter, designated the master stage, will be automatically driven to a standard set of coordinates assigned to point 1 on photo 1, and the right stage will be automatically driven to the vicinity of point 1' on photo 2 as shown in figure 9. The operator will manually clear parallax at this point by moving the photo 2 stage. If for some reason the operator would like to specify another point as a replacement he will be able to do so. The photocoordinates of the two corresponding image points will be recorded in their respective photocoordinate systems. In a like manner, parallax will be cleared at points (2, 2') and 3, 3'). The right stage of the plotter will then be designated the "master" stage and automatically driven to the assigned coordinates of point 4' on photo 2, while the left stage will be driven to the vicinity of point 4 on photo 1. Parallax will be cleared manually and the coordinates recorded. The operator proceeds, clearing parallax and recording coordinates in a like manner at point (5, 5') and (6, 6'). After measuring the pass points, any control points which appear in a model will also be measured for later use in aerotriangulation. As parallax is cleared from point to point, relative orientation parameters will be updated so that after all points in a stereopair have been measured, the stereopairs will be relatively oriented.

After the points on photo 1 have been measured, photo 1 will be replaced by photo 3. The operator will measure points on the photo 2 - photo 3 stereopair, and continue in the same manner down the strip.

A similar procedure will be used between strips. After the measuring process is completed for a block, the data will be processed with the offline aerotriangulation program, and the ground coordinates of the pass points will be added to the pass-point data bank. The orientation parameters of the photos will be refined in the aerotriangulation computations and these refined parameters will be used as input for the compilation.

In map compilation using an analytical stereoplotter, an interior orientation will be done from fiducial-mark measurements, and then, using the refined photo parameters from aerotriangulation, relative orientation will be done. Further parallax refinement will be done if needed. The plotter will drive automatically to the pass point locations, absolute orientation will be performed using the aerotriangulation results, and the model will be compiled.

If a conventional stereoplotter is to be used in the compilation, then the pass points will be drilled automatically on an x-y plotter being designed specially for the task. The drilling will take place after photomeasurements for the aerotriangulation have been done so that any errors introduced in the drilling will have no effect on the aerotriangulation results and minimal effect in absolutely orienting a stereomodel for compilation.

The data for each pass point and ground control point will be stored in the pass point data bank so that it can be recovered by name, photo, x and y photocoordinates, x and y ground coordinates, or by quadrangle designation. When a customer requests a set of pass points or control points, the data for each point will be furnished on any desired media such as punched cards of magnetic tape and the points will be marked on appropriate imagery using the special x-y plotter.

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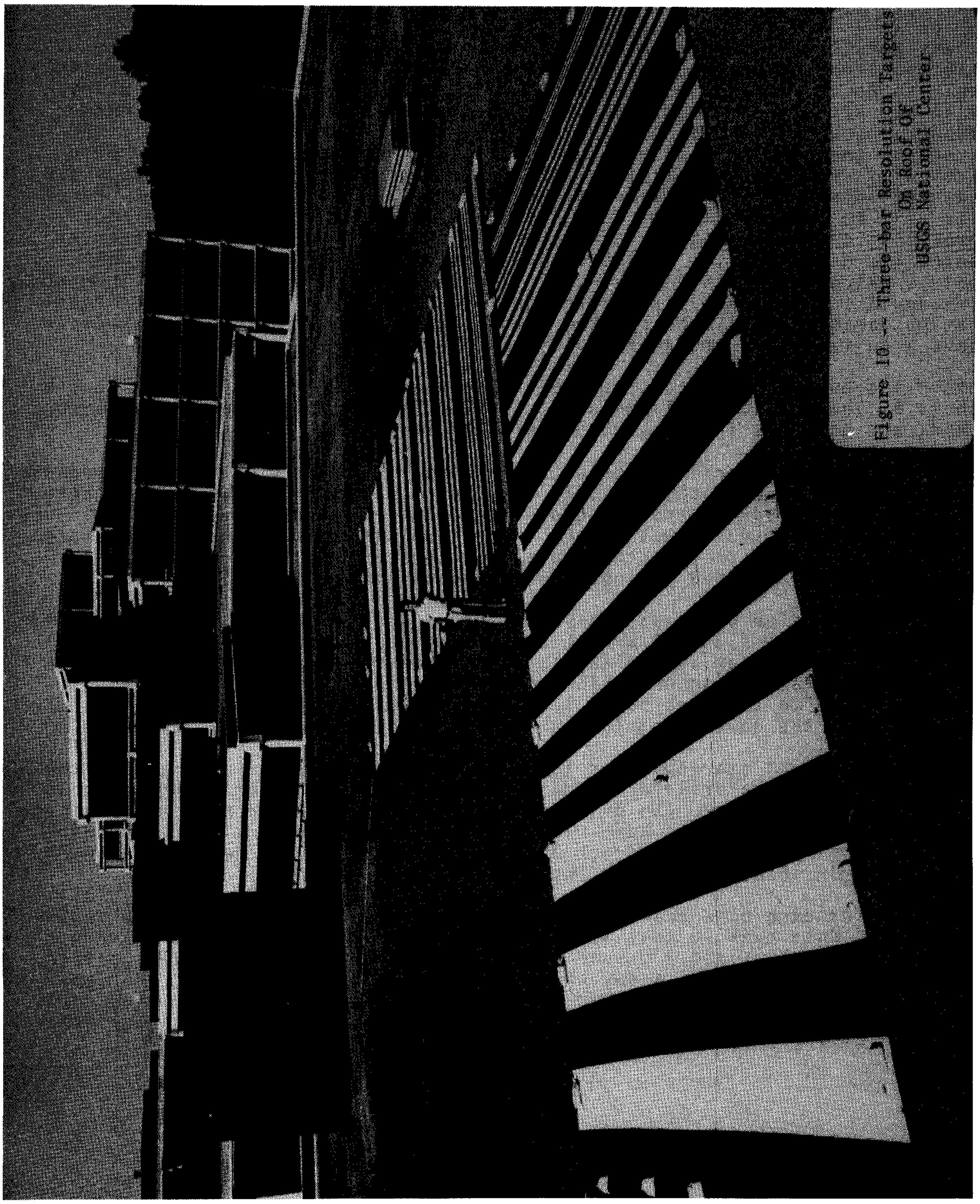

Figure 10 -- Three-bar Resolution Targets On Roof Of USGS National Center

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PHOTORESOLUTION EXPERIMENTS

The angle of intersection of corresponding rays in a stereomodel remains constant for all flight heights provided the ratio of the air base to the flight height remains constant. However, ground resolution does decrease with flight height and the effects of each micrometer of image displacement (film shrinkage, lens distortion, instrument errors) becomes more damaging in terms of feet on the ground. The high inherent precision of the analytical stereoplotter coupled with the ability to mathematically correct the stereomodel allow for image displacements to be corrected and photoresolution retained to a large extent. The missing ingredient is high ground resolution in the original negatives.

GS experiments over the past five years have shown that the resolution of original aerial negatives using standard 153 mm focal length cameras averages about 30 lines per millimeter, and the use of high-resolution film does not appear to improve ground resolution significantly. For 40 000-foot-flying-height photos taken with conventional cartographic cameras, we have found that ground resolution measured along the flight path is about the same as ground resolution measured perpendicular to the flight path, indicating that image motion compensation devices in standard 6-inch focal length frame cameras contribute little toward improving ground resolution. This was further supported in a later experiment in which resolution targets (Fig. 10) were photographed at a 12 000-foot flight height with a 153 mm focal length camera having an image motion compensation device.

CONCLUCION

As we view the situation, stereoplotter and film-emulsion developments have out-paced aerial camera developments. For photogrammetrists to take full advantage of analytical stereoplotters they must now await these camera developments. We hope that the manufacturers of precision cameras will take the challenge that the analytical stereoplotter has posed and that cameras having the capability of taking photos from about 12 000 meters (40 000 feet) with a ground resolution of 1 or 2 feet will be developed.

Abstract

As an outgrowth of recommendations made by a special high-level task force, in 1973 the U.S. Geological Survey began an accelerated program for modernizing mapping instruments and streamlining procedures. Two analytical stereoplotters were acquired from the Defense Mapping Agency, four new stereoplotters were purchased, and three more are on order for delivery in 1979. Attention is now focused on improving software and photograph resolution.

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