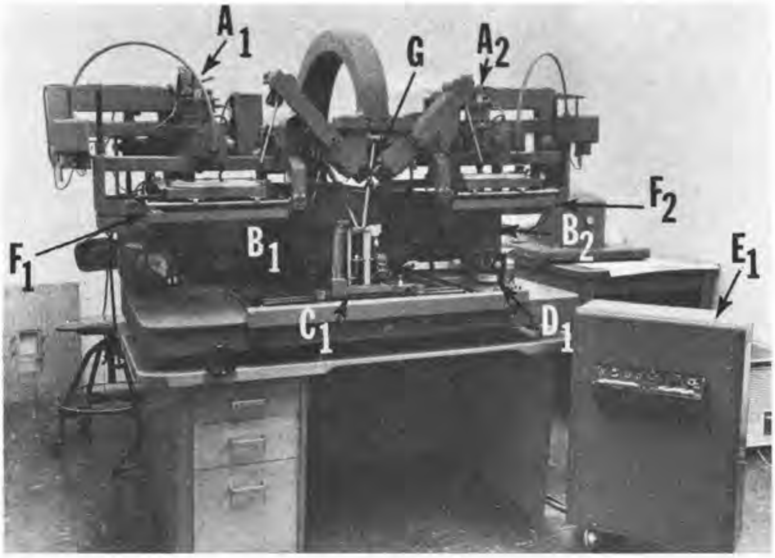

FRONTISPIECE. Stereomat IV. (See text, page 396.)

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Stereomat IV, Automatic Plotter

Automation through electron correlation of photographic imagery is now a reality.

INTRODUCTION

DURING THE EARLY and middle 1950s, many rumors circulated concerning the automation of the stereophotogrammetric compilation process. In fact, before it was commonly known that this could be accomplished, the electronic possibility had been discussed by Army Map Service (AMS) compilers. There was little time for this possibility to be ridiculed, for within a few years the mapping community became aware that the development of electronic correlation of photographic imagery was a reality.

Many papers have been written, published, and presented, describing the design of the several Stereomat systems.[1–5] This paper will concentrate on an operational test which was designed to determine the accuracy, reliability, speed of operation, and limitations of the Stereomat IV, as incorporated in the Wild Aviograph B8.

This presentation will be divided into three phases. Phase I will describe the background and previous investigation. Phase II will describe the equipment, modifications, test procedures, and the test results. Phase III will be an analysis of the test results, the electronic engineers contribution to the overall operation; and the present use of the Stereomat IV in the production of orthophotographs. The paper will conclude by showing how this automatic process has the promise of easing and speeding the task of map compilation.

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ABSTRACT: *The Stereomat IV (Stereomated Wild B8) is one instrument which can accomplish the electronic correlation of the imagery from overlapping photographs. The instrument is a further development of the system demonstrated by Mr. G. L. Hobrough in 1958. Relative orientation is accomplished automatically, semi-automatically, or manually, whereas the interior and absolute orientations are done manually. Profiling and contouring modes are both provided, together with a manual override possibility. The average vertical* rms *accuracy in a grid test was 1/10,032 of the flight height* (H) *for the optimum principal distance, where the corresponding manual value was 1/7,585. Terrain model accuracy was 1/5,648 of* H *automatically and 1/4,946 manually. Orthophotos were produced at an average rate of 2.2 hours per model. This is considered to be a successful step toward automating the photogrammetric compilation process.*

PHASE I

BACKGROUND AND PREVIOUS INVESTIGATION

The system of electronic correlation of similar photographic images was first demonstrated by G. L. Hobrough of Canada in 1958. This method was referred to as the "Auscor." The first photogrammetric compilation instrument to accommodate this new system was the Nistri Photomapper, and this combination was designated as the Stereomat II. This instrument was designed with a single cathode ray tube (*CRT*) for scanning and two photomultipliers for the production of the electrical signals. This instrument was delivered to the United States Army Geodesy, Intelligence, Mapping Research and Development Agency (GIMRADA) for test and evaluation in April 1960. Upon completion of the acceptance testing, AMS personnel were given the opportunity to familarize themselves and operationally evaluate the instrument.

The next development, the Stereomat III, was delivered to the AMS in March 1961 for test and evaluation (Figure 1). This instrument was basically the same as the Stereomat II, except for the addition of another *CRT* as a source of light for scanning. Instead of viewing the platen to check the instrument's floating mark, the operator viewed the stereomodel on the two *CRT* surfaces through a set of binoculars. Upon completion of the testing and evaluation of the Stereomat III in early 1964 it was concluded that: the speed of automatic contouring is three times that of manual contouring with some reduction in accuracy; the unit could contour slopes from 2 to 40 degrees and profile slopes up to 42 degrees. It was further concluded from the evaluation that the Stereomat III would have to produce more than contours automatically before it would be suitable as a production instrument.

The Stereomat III was considered the forerunner of the Stereomat IV. The use of the two *CRT*s was necessary because of the proposal, at that time, to mount the Stereomat system on a mechanical-projection-type plotting instrument. The two-tube system also permitted changes in the shape of the scanning rasters for better correlation of slope detail.

As the Stereomat II did not possess this feature, it would only contour slopes up to 20 degrees.

The mechanical projection instruments were considered because of their inherent superior precision over the anaglyphic projection equipment, and because they could be easily modified for the additional capability of the orthophotoscope. Instrument designers were of the opinion that the system could be mounted on the first-order instruments; however, further study revealed that the mass to be moved on this equipment was too great for rapid operation by the existing electronic circuitry. A lighter, more compact instrument was chosen, the Wild Aviograph B8. The new Stereomat was designed to produce an orthophotograph of the stereomodel. All other mapping detail, excluding contours, would be extracted from the orthophotograph. The Stereomat IV was delivered to the AMS for evaluation in March 1964.

PHASE II

SYSTEM DESCRIPTION

The instrument is composed of two basic

FIG. 1. Stereomat III.

portions, the Wild B8 and the Orthophotoscope (Frontispiece). This figure is a front view of the instrument. The important parts of the basic instrument marked on this figure, A_1 and A_2, are the cathode ray tubes; B_1 and B_2 are the photomultipliers; C_1 is the tracing unit; D_1 is the Z-counter system and the Y-parallax indicator. E_1 contains the correlation circuitry with the instrument control panel. F_1 and F_2 are the plate holders, with G being the viewing binoculars. Figure 2 shows the Orthophotoscope, which is located directly to the rear of the B8. It is mechanically linked to the B8 through wire banding with X- and Y-bars. These bars insure that the *CRT* of the Orthophotoscope is moving simultaneously with the tracing unit. A_1 shows the vacuum bell with the film cassette

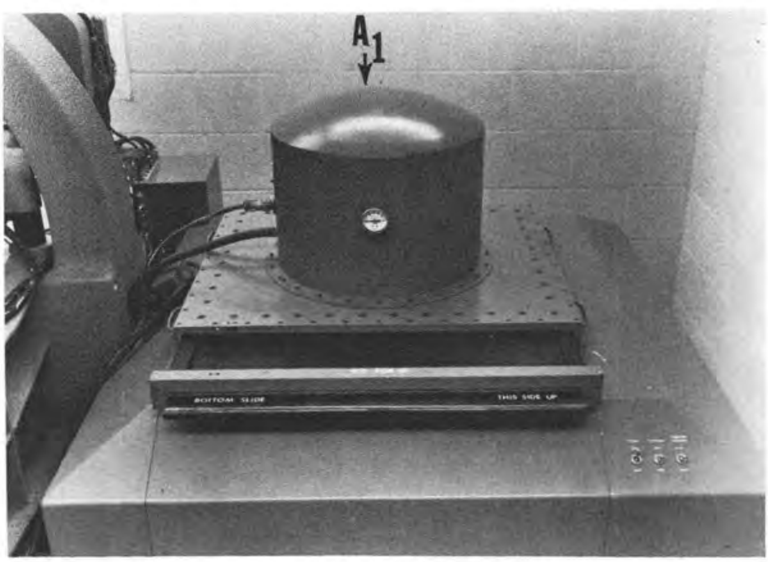

FIG. 2. Orthophotoscope.

FIG. 3. Orthophotoscope *CRT*.

pulled forward ready to accept the film. The three switches visible in this slide are left to right: (1) the pump, (2) vacuum, and (3) vacuum release. The film is held in place by a vacuum for the exposure of the orthophotograph. Figure 3 shows the vacuum bell removed with the *CRT* and the exposing lens system. This is a brief description of the main portions of the instrument. Other figures and descriptions follow.

In the Frontispiece, the tracing unit was shown. Figure 4 is a close-up of this unit. The tracing pencil (A_1) only operates when the correlation is within 20 microns. The X- and Y-bars can be seen (B_1, B_2). The Y-bar is 74 inches long and runs from the front of the B8 to the end of the slate of the Orthophotoscope. It controls the X-motion of the tracing unit and the *CRT* of the Orthophotoscope. The X-bar shown is duplicated on the Orthophotoscope slate. These bars are 31 inches long. The steel drive tapes are driven by X-Y servo motors which are contained in the Orthophotoscope unit. The servo motor for the control of the Z is mounted on the tracing unit. This unit is the heart of the Stereomat IV operation.

At this point, it would be appropriate to discuss the inputs and outputs of the system. The inputs to the instrument are: (a) over-

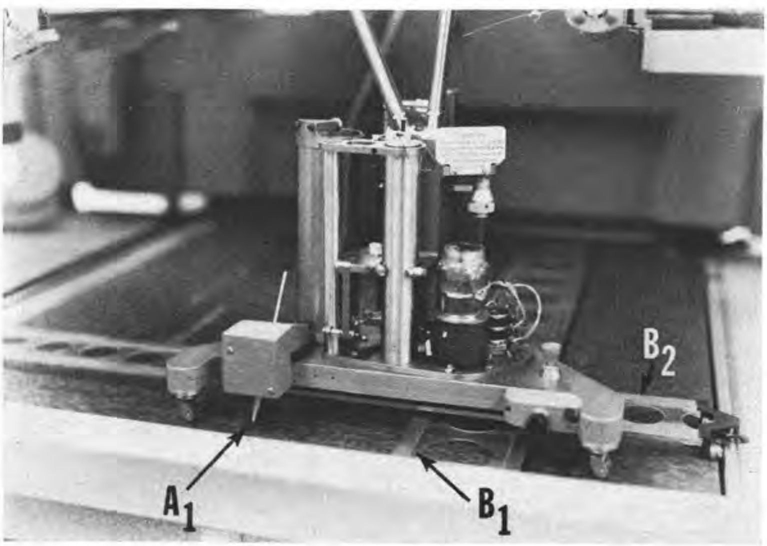

FIG. 4. Tracing Unit.

lapping distortion-free glass positives; (b) ground coordinates of three or more photo-identifiable points. The glass positives are preferred because when using these types of plates the viewing system is correct and the production of the orthophotograph negative is proper. The outputs of the system are the contoured manuscripts and orthophotographs.

The instrument can be used both in the profiling and contouring modes. Briefly, the operation is as follows: (a) interior orientation has to be accomplished manually; (b) relative orientation is automatic, semi-automatic or manual; and (c) absolute orientation is manual. Once the orientation process is complete, the instrument is used automatically in either the contouring or the profiling mode, with a provision for manual override.

In both the profiling and contouring modes, the operation is described as the translation of correlated photographic imagery to electrical signals. This is accomplished by scanning the images with rapidly moving, interrelated spots of light produced on the face of each *CRT*. As this light passes through the over-lapping photographic-imagery input photoelectric cells detect the changes of light intensity resulting from the image densities of the areas scanned. These changes of light intensities cause a variance of the electrical output of the photoelectric cells. When this operation is properly correlated, electrical signals are generated to drive the rotational and translational servos within the system.

The orthophotograph is produced by reproducing the signal from the right photoelectric cell (facing the instrument) on the *CRT* in the orthophoto unit. The signals produce an image which has been completely corrected for scale and relief displacements through the profiling operation. As stated earlier, the *CRT* of the Orthophotoscope is tied mechanically to the *X*- and *Y*-position of the tracing unit. The Orthophotoscope exposes the same area being scanned and viewed in the instrument proper.

INVESTIGATION

The pre-testing difficulties were numerous. The output of the *CRT*s appeared weak, so improved *CRT*s were installed in the system. This required different designs of electronic circuits, and some overhauling of the system for the acceptance of those new tubes. The metal bands controlling the *X*- and *Y*-bars broke quite frequently, causing further loss of time before the test proper could be initiated. As can be expected with any prototype instrumentation, these were the major problems.

However, there were many other difficulties which caused numerous false starts of the project. Often it required considerable time to correct the operation of the instrument. This can be readily understood as 90 per cent of the failures were with the electronics, and the AMS electronics personnel were not familiar with the prototype electronic designs. Furthermore, an adequate maintenance manual for their guidance did not exist. The AMS personnel did not start the actual evaluation until June 1965. Although the instrument operated fairly well during the testing, failures still plagued the operation and caused the original plan of test to be altered considerably.

The testing was accomplished in three parts. The first part consisted of the reading of grid models at the optimum, minimum, and maximum projection distances (*PD*). Single terrain model orientations were planned for part two of the evaluation. Reading difficulties and poor correlation confined the terrain model observations to the optimum *PD*. As part three, four terrain models of varying terrain slopes and density were to be contoured and orthophotographed. The contoured manuscripts were to be compared with published maps of the area. The orthophotographs were to be carefully checked for positioning of map detail as well as the photographic quality of the exposures.

Before the initiation of the test, AMS testing personnel were faced with the problem of determining the proper *f*-stop settings for different exposures in the production of orthophotographs. Originally it had been planned to use the entire Orthophotoscope unit and make a series of different *f*-stop settings on a piece of test film. However, after the exposure was completed, the film processing followed, and it was found that the processing required the minimum of eight hours. This was a serious time delay before orthophotographs could be exposed.

Figure 5 shows the top portion of the Orthophotoscope unit with the vacuum bell removed and a plywood board platform A_1 holding a polaroid back B_1. This platform was leveled and the surface of the polaroid face was set the same distance from the exposing lens as the vacuum frame. When the polaroid orthophoto unit was exposing, the black cloth *C* was pulled over the platform. This solved the processing time delay. Trial exposures could be made on the polaroid film to de-

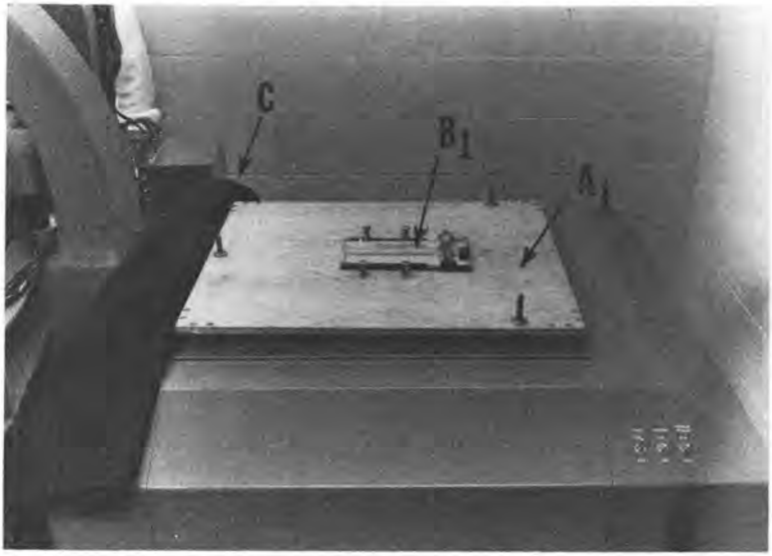

FIG. 5. Polaroid attachment to the orthophotoscope.

termine the best setting for the commercial sheet film. The minimum time delay of eight hours was reduced to a matter of minutes.

The vertical accuracy of the Stereomat IV was tested with a stereoscopic grid model. The grids used were Wild precision 240×240 mm. with a 20-mm. interval. The 23-point grid model was measured at the optimum (262 mm.), maximum (311 mm.) and minimum (213 mm.) projection distances. The grids were absolutely oriented at a base-height ratio of 0.6. The orientations required 10 to 15 minutes to accomplish; also they were repeated three consecutive times in both the manual and the automatic modes.

The instrument failed to correlate in the automatic mode at the minimum *PD*, therefore no test data exist for this mode. The test results are shown in Table I. The average Root Mean Square Error (*RMSE*) accuracies manually were as follows: minimum-*PD* 1/11,210; optimum-*PD* 1/11,909; maximum-*PD* 1/7,585. The average *RMSE*s in the automatic mode were as follows: optimum-*PD* 1/20,154 and maximum-*PD* 1/10,032.

The revised plan of test specified that the

TABLE I. GRID ACCURACY (MM.)

Projection Distance	*RMSE*		*RMSE/Projection Distance*	
	Manual	*Automatic*	*Manual*	*Automatic*
213	±0.020	No Correlation	1/16,650	No Correlation
	±0.018	No Correlation	1/11,833	No Correlation
	±0.020	No Correlation	1/10,650	No Correlation
Average	±0.019		1/11,210	
262	±0.022	±0.012	1/11,909	1/21,833
	±0.023	±0.013	1/11,391	1/20,154
	±0.021	±0.013	1/12,476	1/20,154
Average	±0.022	±0.013	1/11,909	1/20,154
311	±0.048	±0.025	1/6,479	1/12,440
	±0.039	±0.034	1/7,974	1/9,147
	±0.037	±0.033	1/8,405	1/9,424
Average	±0.041	±0.031	1/7,585	1/10,032

TABLE II. TERRAIN MODEL ACCURACY

RMSE/Altitude		
Orientation	*Manual*	*Automatic*
1	1/5,917	1/5,626
2	1/3,030	1/6,015
3	1/5,891	1/5,305
Average	1/4,946	1/5,648

terrain model flatness was to proceed in the same manner as the grid check. At the minimum *PD*, however, no correlation could be achieved, and at the maximum *PD*, correlation was difficult. The plan of test was further revised so that the terrain flatness tests were conducted at the optimum *PD* only. The first model was absolutely oriented to five control points, and 50 points within the model were read for elevation. The scale (1/13,500) was compatible with the optimum *PD* of 262 mm. When the first model was finished, it was disturbed and reoriented. All points within the model were read again. Each point was read three consecutive times in the manual mode. This operation was repeated for three successive orientations in both the manual and automatic modes. (This same photography had been used on the evaluation of the Stereomat III.)

Because every model was absolutely oriented, a post-adjustment was not considered necessary. The differences between the mean instrument elevations and the elevations of the panel points were recorded. These differences were used to determine the *RMSE* flatness in both the manual and automatic modes of operation. Table II shows these results. It should be noted that the manual operation recorded slightly lower accuracy than the automatic; the manual *RMSE* was 1/4,946 of the altitude, compared to the 1/5,648 for the automatic.

The contour comparison test was conducted immediately following the terrain model flatness. There were a total of four models, absolutely oriented, contoured, and then profiled for the exposure of the orthophotographs. The models had a wide variety of terrain conditions as well as an acceptable production density range. The contour manuscripts of the models were compared with completed maps of the area. The Stereomat manuscripts were reduced to the scale of the map for comparison purposes. Six arbitrary profiles were drawn through each contoured manuscript and the finished map sheet and comparisons were made wherever the contours of the manuscript crossed the profile. The number of points for comparison ranged from 352 to 481. The results of the contouring phase were not in agreement with the Stereomat IV's ability to profile or read individual points. All of the *RMSE*s, upon completion of the comparisons, were quite large.

The Orthophotoscope testing was conducted to determine the production speed, as well as the quality of an orthophotograph. As stated previously, the polaroid back was used to determine the proper speed and *f*-stop setting for the orthophotograph production. The average acceptable speed was determined to be 6 mm./sec for a satisfactory exposure. The *f*-stop setting depended on the density of the plates. It was determined, through a series of test exposures with the polaroid and commercial film, that a conversion factor of 2 had to be applied to the *f*-stop when transferring from the polaroid to the 18-$\times$22-inch film used for the orthophoto negative. This size is specified in order to have a precise fit in the vacuum frame. If this size film is not used, the vacuum pressure decreases and a faulty orthophotograph is produced.

The time required to produce the test orthophotographs ranged from 1.7 to 2.6 hours with the average of 2.2 hours. The *f*-stop settings for the best exposures were from *f*-5.6 to *f*-11, with the majority of exposures at *f*-8. Random checks for comparison were made between the original photography and the orthophotograph. The deterioration of image quality of these models was determined to be a maximum of approximately 20 per cent. The photography used for this test had a maximum resolution of 26 lines/mm., and the loss of resolution reduced this to 21 lines/mm.

Even with this degradation all of the orthophotographs were of suitable quality, so that planimetric detail could be extracted without any difficulty. At the present time a separate project is being conducted involving the Stereomat IV's capability for production of orthophotographs. Additional information will be available when this task is complete.

The *Y*-parallax indicator of the Stereomats III and IV had never been correlated. In fact, the relationship of the scale of the meter and the actual amount of *Y*-parallax in the model had not been determined. This was a phase incorporated in the final plan of test. A precision guage was positioned on the drafting surface and placed in contact with the plate holders. Minute changes were introduced in the tilt direction of an absolutely oriented model. These changes were recorded on both the gauge and the Y-parallax indicator. This was repeated for positions throughout the model and it was determined that the value of each interval of the Y-parallax indicator is 2 microns. These determinations concluded the formal testing for this evaluation.

Phase III

ANALYSIS

During the evaluation, a great deal was learned concerning the operation of the Stereomat IV. The grid testing indicated that the best performance could be expected from the optimum projection distance. At the minimum *PD*, the operation of the instrument was so erratic that vertical readings could not be made. Operation was somewhat improved at maximum *PD*, but the constant oscillation made readings very difficult. The instrument operated properly at the optimum *PD*. It should be explained at this point that these operational problems at both the maximum and minimum *PD* were mechanical. The counterweight was at the extreme lower and upper position of the Z-column. In these positions it is difficult to operate the instrument manually, and the electronics are not capable of moving parts of the system that bind in any manner. This indicates that the instrument will operate efficiently at the optimum *PD* with approximately ± 40 mm. from the optimum of 262 mm. Because of the results of the grid test, an optimum acceptable plotting scale is 1.7 times the photographic scale. This test further indicated that at the optimum *PD*, with grids, one could realize approximately a superior vertical accuracy of two times using the automatic mode over the manual.

This superior accuracy factor was not reflected in the terrain flatness portion of the investigation. Although the average *RMSE* flatness (Table II) indicates that the automatic mode is superior to the manual mode, this difference is small compared to the spread between individual orientations. It could thus be concluded that the accuracies of the automatic and manual modes on the reading of individual Z-observations in a single model are approximately equal. The vertical accuracy results of the Stereomat IV are superior to the Stereomat III by a factor of 2.3. The Stereomat III read the same model used in the Stereomat IV model-flatness test. The automatic mode of the Stereomat IV is comparable to the AMS M-2 Plotter which produced an *RMSE* flatness of $h/6{,}024$ with the same model used in the Stereomats III and IV evaluations. This task has shown that the Wild B8 is a very fine compilation instrument and its modification to accommodate the Stereomat system has not appreciably deteriorated its over-all accuracy.

The Stereomat IV was a disappointment in the contouring mode. In fact, on a comparative basis, the Stereomat III had a considerably smaller standard deviation when compared to maps, than the IV. Also, with the III, the speed of contouring was faster and the necessity for human intervention was much less. The exact reasons for this superiority are not known. Two facts are known: (a) the scan (size and shape) was optimized in Stereomat III for the contouring mode, (b) in the Stereomat IV, the scan pattern served several purposes: the contouring, profiling, as well as part of the image transfer for the production of orthophotographs. If the same optimization could be designed for the IV in contouring as exists in the III, there is the possibility that the IV could out-perform or at least equal the III in the contouring mode. This has been suggested to the manufacturers of this system as a modification for the next prototype Stereomat.

What position does the electronic engineer maintain in a mapping system composed of Stereomats? He becomes an important individual because his knowledge and skills are needed to produce a cartographic product. The experienced cartographer is quite familiar with mechanical adjustment of photogrammetric equipment; however, the addition of the electronic circuitry is a recent innovation, which requires the specialities of an electronic engineer. Therefore, the operation, adjustment, and maintenance of a system, such as the Stereomat IV, depends on the combined efforts of the electronics engineer and the cartographer. The cartographer describes to the electronic engineer what is desirable in the operation of the equipment for the production of the final product; and the electronic engineer, in turn, either repairs, adjusts, or redesigns the circuits to produce satisfactory results.

Modern technology has dictated to the cartographer that part of the map production which will be automated. The electronic correlation of photographic imagery is one step toward automating the compilation process. As a result, the Stereomat IV investigation has produced a working partnership between the electronic engineer and the cartographer

As noted earlier in this paper, many months passed after the installation of equipment before the evaluation was started. A very high percentage of this period was spent in electronic repair and redesign of the circuitry. Even after the equipment was placed in operational condition, 20 per cent of the evaluation time was spent in electronic adjustments. The electronics engineers with their oscilloscopes, various testing meters, and other adjustment and repair gear, became familiar personalities to the cartographers; without the services of these specialists the evaluation would have been impossible to conduct.

It should be further noted that electronics engineers are working in cooperation with the cartographer for the improvement of the Stereomat System. The future is quite promising. AMS testing personnel are working closely with other government agencies and private industry to develop a more sophisticated Stereomat System. The Stereomat V, with many mechanical and electronic improvements, is now in existence. The Stereomat VI is in the design stages. What the AMS has learned from the evaluation and present use of the instrument has been passed on to the designers. AMS has also recommended that certain features be included in the new designs. The later instruments can be constructed in such a manner that the cartographer could make certain electronic checks on the system as well as the necessary adjustments which follow these checks. Although this would decrease our present dependence on the electronic engineer for adjustments and calibration, he would continue to be a necessity for maintenance purposes.

The Stereomat IV is presently producing orthophotographs for the AMS study, "Use of Orthophotographs in Topographical Mapping." When the analysis of the results of the AMS evaluation of the Stereomat IV was completed, the basic conclusion was that the instrument operated more efficiently in the profiling than in the contouring mode. Orthophotographs are produced in the profiling mode. It should be noted that all of the orthophotos of this evaluation were of acceptable quality. Therefore, the Stereomat IV was chosen to produce the orthophotos for the latest AMS orthophotography study whose objectives are to determine techniques of combining compilation and scribing of planimetric detail directly from orthophotos, and to investigate the use of orthophotos in map accuracy evaluation and photo revision of existing maps. This project will increase our knowledge as to the techniques, procedures, and materials to be used for the compilation of map detail from orthophotography.

The Stereomat IV is being modified by AMS testing personnel to produce a line-drop manuscript while operating in the profiling mode. This is the same type of device that had been attached to the AMS Integrated Mapping System.[b] A line would be drawn for every other contour interval along an individual profile. This would be repeated for every profile, which would produce a line-drop manuscript. Contour information would be sketched by manually connecting the ends of these contour interval lines. The average production time for the profiling and production of the orthophotographs with the Stereomat IV was 2½ hours. This means that the contoured manuscript and the orthophotograph can be produced simultaneously in this period of time, thereby saving many man-hours and substantially reducing the cost of map production.

This paper has presented the background and previous investigation, difficulties encountered, and a description of the equipment, test procedures and results. In conclusion, these results have been analyzed, a present production test has been mentioned, and a modification to the instrument has been described with a prediction of a future use of the equipment. Automation through electronic correlation of photographic imagery is now a reality. This is accomplished with the Stereomat IV, a successful step toward automating the photogrammetric compilation process.

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