DISCUSSION OF SPATIAL TRIANGULATION WITH THE ZEISS STEREOPLANIGRAPH

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Synopsis: This article deals with preliminary tests of the Zeiss Stereoplanigraph at the Army Map Service and should be of special interest to those groups now possessing the instrument. Multiplex people will also be interested for comparison purposes, since the two instruments are so similar in principle. It will be worthwhile for the reader to note the potential value of the Stereoplanigraph for bridging operations in connection with Multiplex production. The author concludes that the accidental error in operation of Stereoplanigraph should be very slight and secondly that the Stereoplanigraph will plot as accurately as present photographic processes permit.—*Publications Committee.*

1. Purpose

THIS article is presented (1) to acquaint all concerned with the characteristics of the Stereoplanigraph; (2) to make available factual data on bridging experiments performed at the Army Map Service; (3) to discuss the results of these experiments; and (4) to present some of the economic factors to be considered in using this instrument for stereoscopic plotting. While realizing that only qualified conclusions are warranted, both from the limited experiments and the limited experience, it is believed that this article should assist in the over-all planning of Stereophotogrammetric operations in those agencies which utilize the instrument.

2. General

Although the Zeiss Stereoplanigraph is not a new stereoscopic plotting instrument, experience with its use has been very limited in the United States. Prior to 1946, the only instrument of this type used for production mapping, was being operated by the Fairchild Aerial Surveys, Los Angeles, California. In spite of the known fact that the Fairchild instrument had been performing with satisfactory results for over ten years, it was important to determine whether or not the newly-acquired Stereoplanigraphs could equal the Fairchild results. Moreover, the nature of the Corps of Engineers, War Department mapping program was such that exploitation of the spatial-triangulation potentialities of these instruments seemed desirable. Also since the Fairchild Company had rarely used this aspect in their production jobs, much experimental work was still necessary.

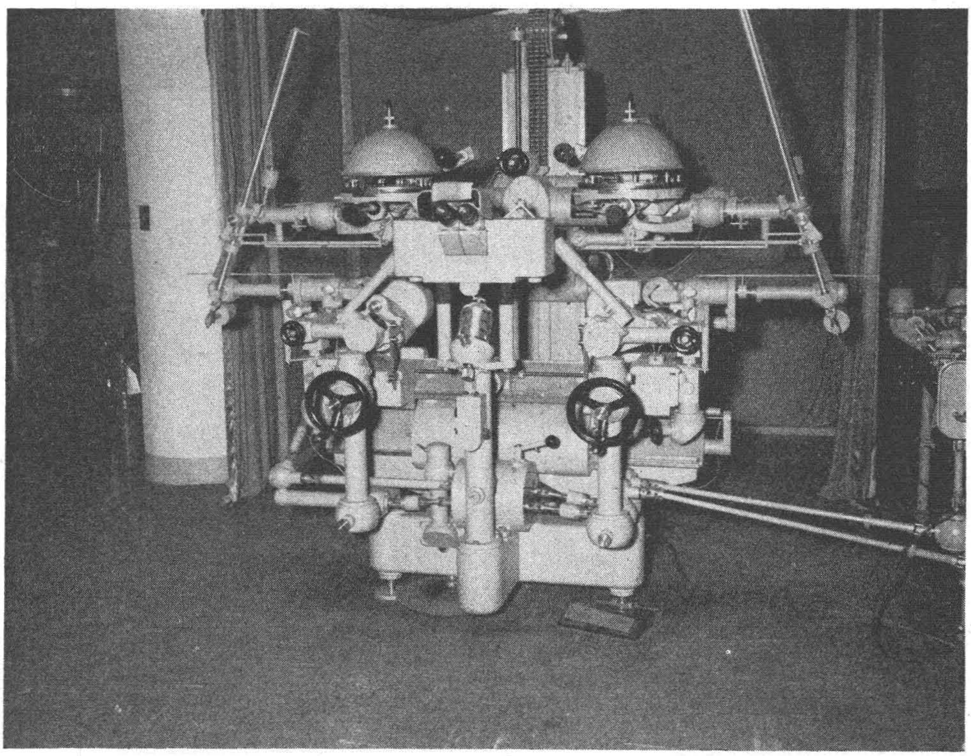
Basically the instruments used in the Army Map Service experiments are the same as the Stereoplanigraph owned by the Fairchild Aerial Surveys. The Fairchild instrument is of the series C/4 which were manufactured from 1930 to 1936. This instrument has the same general shape adhered to in all succeeding series, namely, vertically-mounted plotting cameras. The instruments at the Army Map Service, which were used in the experiments under discussion, are all of the C/5 series manufactured from 1937 to 1943. While a great many minor changes were introduced in the C/5 series, it appears that no significant effect was intended with regard to improving the potential accuracy of the instruments. For a more detailed description of the optico-mechanical principles involved, the reader is referred to *Photogrametrie* by Otto von Gruber.

3. Description of the Stereoplanigraph

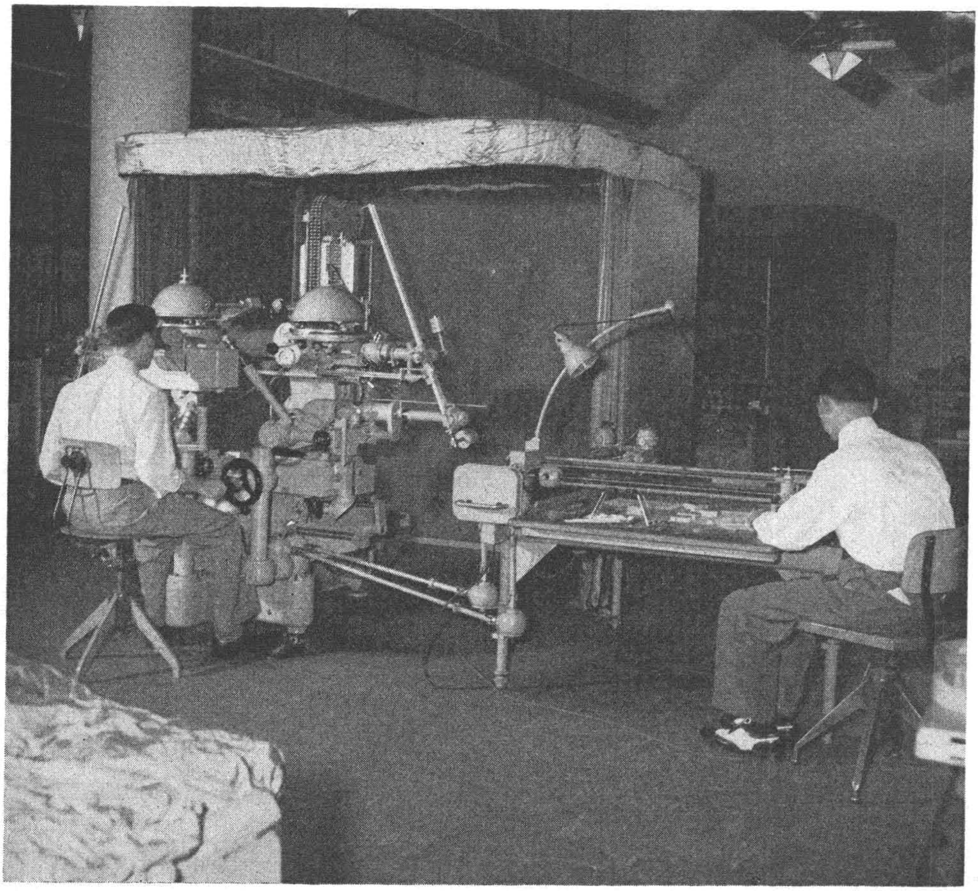
a. *General*

(1) The Stereoplanigraph is a stereoscopic plotting instrument which semi-automatically produces topographic maps from overlapping pairs of aerial photographs. In addition to compilation from pairs of photographs, the instrument can be used for spatial triangulation with a strip of over-lapping photographs. Basically, the principle of optical design is the same as in the Multiplex where the photographic process is inverted in such a manner that rays of light which were reflected from a landscape when photographed, are projected in a reverse direction into space, by projectors which correspond to the taking cameras. If the projectors are in the same relative position as the photographing camera at the moment of exposure, then homologous rays of light from overlapping photos will intersect, and these points of intersection in their entirety will yield an optical model of the terrain.

(2) The principle of optical design is quite simple. For photogrammetric work, however, one must consider the means of creating a precise three-dimensional model, the precision used in measuring it, and the means by which a graphical representation is made. First among the precision considerations is the negative of the photograph from which the three dimensional model will be created. For purposes of this discussion of the Stereoplanigraph, it is assumed that the negative will have been made with a precision mapping camera of the Zeiss P-10 type on topographic base film, carefully processed for photogrammetric usage. From this negative, a contact print diapositive is made on a specially



Zeiss Stereoplanigraph. C/5 Series.



OPERATION OF ZEISS STEREOPLANIGRAPH. C/5 SERIES WITH COORDINATOGRAPH.

selected glass plate. This provides a Stereoplanigraph diapositive with the shrinkage present at negative size. Another factor which must be considered is the means by which these diapositives are projected to form a precise spatial model. The Stereoplanigraph is equipped with two plotting cameras, or projectors which are physical likenesses of the Zeiss P-10 camera. The only difference between the plotting camera and the taking camera is the stop opening. Most of the Zeiss P-10 cameras have a topogon f/6.3 lens which can be stopped down to f/12. The plotting cameras have topogon lenses with fixed f/10 stops. These plotting camera lenses were stopped down in order to improve the average definition and thereby to attain more consistent elimination of parallaxes in the model.

(3) A further consideration with regard to creating a true stereoscopic picture of the terrain, is the inner orientation of each diapositive within each plotting camera. In the format of the plotting camera, are four fiducial markers which are set ninety degrees to each other and are used to locate the principal point of the camera. These markers consist of an etched cross on glass, the lines of the cross being approximately .05 mm. wide. Setting the diapositive fiducial marks onto the plotting camera fiducial ticks, with the aid of a special light-table and magnifier, locates the diapositive principal point on a radius of less

than 0.5 mm. from its true position. Another inner orientation feature is the principal distance adjustment which allows for the lowering of the format or stage to compensate for the average film shrinkage. This compensation maintains a precise angular relation between rays which entered the taking camera, and their homologous counterparts in the plotting camera projection. Under these conditions of interior orientation, it can be seen that the projected image will very closely approximate the hypothetical condition of reprojecting through the taking camera itself, and thus the model should represent a very accurate facsimile of the terrain.

(4) The outer orientations, relative and absolute, are accomplished by means of the six degrees of freedom present in the machine. The three rotational degrees of freedom—tip, tilt, and swing—are present in the mount of the plotting cameras and the linear components—BX, BY, and BZ—are accomplished by differential movements of the reference planes. These reference planes are two first surface mirrors: one mirror reflects the image from air station number one to one eye; the other mirror reflects the image from air station number two to the other eye. When differential movement of these mirrors is performed, an image point projected from air station number one can be aligned optically with its corresponding image point projected from air station number two, thus enabling the operator to view two identical points simultaneously. On each mirror is a small black dot, 0.1 mm. in diameter, which acts as the measuring or floating mark when fused in the model. In the parallax elimination procedure, the black dot on one of the mirrors is placed on a point selected in the projection from one air station; then the black dot on the other mirror is placed on its corresponding image point in the projection from the other air station, either by moving the image with respect to the dot by tip, tilt, or swing, or by moving the dot with respect to the image by moving BX, BY, or BZ.

b. *Means of Measurement*

When the stereo model is created, there must be a means of measuring it, in both the horizontal and the vertical planes. Inasmuch as all the measurements are made in space, provisions are made to move the measuring mark along three mutually perpendicular axes. These movements are accomplished over hand scraped tracks, five feet in length, which are planed to ± 0.01 mm. However, minor variations or "bumps" may appear on some instruments due to shipping accidents, or by corrosion. It was the policy of the manufacturer to age the castings of these tracks for one year after their first machining, to insure good stability before the final finishing was completed. All verniers on which the measurements are recorded can be read to 0.01 mm. The force for moving the measuring mark and the drawing pencil, is provided for by measuring screws which are cut to 2.5 mm. per 360 degrees. For example, in terms of linear movements, a rotation of the measuring screw through 10 degrees gives a linear movement of $2.5/360 \times 10$ or 0.069 mm. These finely-pitched spindles are important when the means of plotting the stereo-model are considered.

c. *Means of Plotting*

In combination with each Stereoplanigraph, is a Coordinatograph or drawing table. The drawing table has an X and Y coordinate system and a pencil which will draw the graphical representation of the model. All X and Y coordinates in the Stereoplanigraph are transmitted to the Coordinatograph drawing pencil, by means of universal couplings and spur gears. There is some play or "back lash" in these transmissions, but the fact that the screws which move the measuring mark and the screws which move the drawing pencil are never lagging each other more than fifteen degrees, gives a plotting accuracy of ± 0.10 mm. or better. Scaling the Stereoplanigraph model to plotted control points on the Coordinatograph is accurately accomplished by means of a centering microscope 6× magnification, which has a reticle circle 0.5 mm. in diameter. This centering microscope can be inserted into the pencil chuck holder and then the chuck holder can be centered over any plotted control point to an accuracy of $\frac{1}{5}$ the reticle circle's 0.25 mm. radius. Thus the pencil chuck replaces the microscope in the holder, with the result that the pencil point is coincident with the pricked control point.

d. *Accuracy of Measuring and Plotting*

With regard to accuracy of measurements and accuracy of plotting in the stereo model, the image quality is a major factor to be considered. From each plotting camera, the infinity projected image is focused on the mirror reference plane, by means of an auxiliary system which automatically focuses the image at all projection distances. This gives a sharp image for all changes in Z or vertical datum, and likewise means that the operator can always be working at optimum projection distance. In the Stereoplanigraph, the image separation which is necessary for stereoscopic perception is accomplished by means of a binocular microscope. This microscope is focused on each of the two reference plane mirrors, the left projector mirror to the left eye, the right projector mirror to the right eye. With this binocular arrangement, the reference plane image is magnified four times. Moreover, there is no need for a color filter system to separate the images, the result being that one 15-watt lamp in each projector provides ample light for satisfactory viewing. Tests to date show the instrument to be very satisfactory, although there appears to be some variation in resolution on different Stereoplanigraphs. This variation may be due to several factors which need not be mentioned here. The net effect of the difference of image quality, however, shows up mostly as an inability to separate the X tilt parallax from the BZ parallax. In the model, the effect of the inability to separate X tilt from BZ, shows up as a "cross tilt" or skew warpage. For single model compilation, this resolution problem is negligible, but in bridging for aero-triangulation, it is very important and has a great effect on systematic curve correction accuracy.

e. *Scale Range*

The Stereoplanigraph scale range is best analyzed by hypothetically separating the Stereoplanigraph itself from the Coordinatograph, and calling the plotting scale in the Stereoplanigraph, the Stereoplanigraph scale and the drawing scale in the Coordinatograph, the Coordinatograph scale. With 100 mm. focal length, wide-angle photography, the Stereoplanigraph scale has a range from minimum 1.5 times the average scale of the photography, to maximum 3.3 times the average scale of the photography. This is actually an effective range, due to the fact that the auxiliary optical system provides a sharp image at all points within the 175 mm. projection distance range. By means of a gear ratio system, the Coordinatograph scale has a mechanical range of 0.1 to 5 times the Stereoplanigraph scale. This is not actually an effective range, due to the fact that there is a size limitation on the Coordinatograph and hence the enlargement at maximum Stereoplanigraph scale is limited to 1.4 times the Stereoplanigraph model size, and the enlargement at minimum Stereoplanigraph scale is 3.0 times Stereoplanigraph model size. In terms of total range for Stereoplanigraph—

Coordinatograph combination, the maximum plotting scale would be 4.5 times the average scale of the photography, and the minimum plotting scale would be 0.15 times the average scale of the photography.

f. *Types of Photography Usable*

The manufacturers of the instrument, namely Carl Zeiss, referred to the Stereoplanigraph as the universal plotting instrument, and stated that it could be used for single model compilation and for aerotriangulation. It is also noteworthy to mention the types of photography which could be used in the instrument as an aid to the job planning. The Stereoplanigraph is equipped with three types of interchangeable plotting cameras; Normal Angle, Wide Angle, and Terrestrial. Normal-Angle plotting cameras have an angular coverage of 65 degrees. These have the Geodar 206–211 mm. lens in combination with a glass stage plate 3.2 mm. thick. This combination was designed for use in conjunction with the Zeiss Ortho-Meter lens, and is theoretically distortion free. Moreover, these normal-angle cameras can be used with either the glass plate diapositives, or with the film negative as desired. The wide-angle plotting cameras have an angular coverage of 93 degrees with the Topogon 100 mm. lens. These cameras take glass plate diapositives only. The terrestrial cameras are made of parts of the normal-angle cameras plus a special format and lens. These plotting cameras are equipped with 190 mm. Ortho-Protar lens, and have a format 17 mm.×13 mm., to be used in conjunction with the Zeiss Phototheodolite. Both the normal-angle cameras and the wide-angle cameras can be used for oblique photography by tilting the camera mount or "bar" around its X-tilt axis. When using obliques with a tilt angle greater than 45 degrees, the Y axis is interchanged with Z axis, and by means of a gear transmission, all vertical measurements are read along the Y axis, and all horizontal movements in the model are made in the X and Z planes.

4. Factual Data on Experiments Performed

a. Up to this point, the discussion has been concerned generally, with a description of the Stereoplanigraph, and specifically with the theoretical precision and the means by which accuracy can be attained. When one thinks about accuracy, the emphasis is on results. The following is concerned with the factual data on the experiments performed at the Army Map Service.

b. Available for experimental purposes was a TVA strip (No. 120-R6) flown over an area near Chattanooga, Tennessee, with the Zeiss 100 mm. P-10 camera at 13,300 feet. Ground control was supplied by TVA, with descriptions and diagrams on the back of a set of paper prints made from the negatives. TVA vertical control averaged +4 points per model, and horizontal control averaged 0.7 point per model. In all, this flight had fifteen stereo-pairs which covered 28 miles along the flight line.

c. Though it was desirable to test the instruments for compilation from stereo-pairs, it was apparent that no adequate check of the results could be made because of insufficient ground control per model. However, it was desirable to know how accurately a single model could be reset, with respect to secondary control or control established by Stereoplanigraph spatial triangulation. Single models were reset, orienting to secondary control established by triangulation to within ±.05 mm. vertical error and 0.2 mm. horizontal error. It is interesting to note, moreover, in connection with compilation accuracy for one stereo-model, that the Zeiss specification for single model spot elevation accuracy was 1/5,000 of the flight altitude when three or more vertical ground control points were given. This accuracy specification was allegedly checked for all Stereoplanigraphs by the Zeiss firm with photography flown over a specially prepared test area in the Harz Mountains in Germany.

d. Since the time when the instruments first arrived at the Army Map Service, the biggest question was, "How would the Stereoplanigraph perform as a spatial triangulation instrument?" Consequently, most of the experimental work in connection with these instruments, has been confined to determining what triangulation results could be attained. Only four of the instruments at the Army Map Service were considered suitably adjusted for test purposes. It is expected, however, that the other instruments will produce similar results, if they meet the same calibration specifications. Experiments were confined to two specific problems in spatial triangulation: "Stereoplanigraph Cantilever Extension Accuracy" and "Stereoplanigraph Bridging Accuracy."

e. TVA flight 120-R6 was aero-triangulated six times to the fifteenth model in the strip, once each on three different instruments and three times on the fourth instrument. Two operators alternated daily and in no case, did one operator run an entire 15 model extension. Both the Cantilever accuracy check, and the Bridging Accuracy check, were made from the same "run," merely by changing the analytical approach. The Stereoplanigraph scale and the Coordinatograph scale were 1:15,000. All control was plotted on DI-RITE drawing material. The length of each 15 model extension at 1:15,000 scale was approximately 11 ft.

(1) Cantilever Extension. To test Cantilever Extension Accuracy, it was necessary to disregard all ground control supplied by TVA, except control on the first model in the flight. After absolute orientation of the first model, each succeeding model was tied to its predecessor by relative orientation procedure (parallax removal) only, its scale being adjusted to that of its predecessor by reference to pass points in the common overlap. When each model other than the first was set up, Stereoplanigraph readings were taken on all vertical points given in TVA descriptions, and Stereoplanigraph positions were plotted for all horizontal point descriptions given by TVA. After completion of the extension, the vertical Stereoplanigraph readings were compared to the true TVA values, and the horizontal point plotting of the Stereoplanigraph was compared to the true ground horizontal position as given by TVA. From this comparison, it was learned that the maximum error for both horizontal and vertical position was in the fifteenth model on all strips run. Based on experience with Multiplex Triangulation, it was assumed that this horizontal and vertical error could be corrected by methods similar to those used with the Multiplex. Therefore, in the Cantilever test, the *BZ* correction was made from *BZ* readings for each model, and the corrected Stereoplanigraph vertical readings were compared to the true vertical positions as given by TVA. In the Cantilever, no attempt was made to correct horizontal positions. The results of the comparison of uncorrected horizontal points and the *BZ* corrected vertical points are listed under Cantilever Accuracy, Table II.

(2) Bridging. To test Stereoplanigraph Bridging Accuracy, it was necessary to include in the correction for systematic error, the control supplied on the two terminal models of the extension. Bridging analyses were made for five, ten and fifteen models, and in each case six vertical and four horizontal points were used. The correction for systematic errors accumulated in the triangulation, where control at both ends of the extension is used, was the same as used in the Multiplex. The vertical correction consisted of drawing a spline curve between the graphically plotted vertical readings on the first model, where error was at a

TABLE I. STEREOPLANIGRAPH SPATIAL TRIANGULATION RESULTS

TVA Flight 120-R6 Zeiss P-10 Aerial Camera
Flight Altitude 13,300 Feet
Scale 1:15,000
BRIDGING ACCURACY

AMS Instrument No.	Machine 1				Machine 3				Machine 4				Machine 6			
	Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical		
No. of models	14	5	10	15	14	5	10	15	14	5	10	15	14	5	10	15
No. of ground control points used in the triangulation	4	6	6	6	4	6	6	6	4	6	6	6	4	6	6	6
No. of ground control check points used to check bridging accuracy	13	20	38	63	15	20	38	63	13	20	38	63	12	20	38	63
Maximum error on any one corrected check point	mm. .32	.16	.32	.32	.54	.17	.37	.45	.57	.18	.57	.57	.30	.24	.45	.45
	ft. 16	8	16	16	27	8.5	18.5	22.5	28.5	9	28.5	28.5	15	12	22.5	22.5
Average error of all corrected check points	mm. .14	.06	.09	.11	.15	.07	.07	.10	.16	.06	.13	.15	.08	.05	.15	.12
	ft. 7	3	4.5	5.5	7.5	3.5	3.5	5	8	3	6.5	7.5	4	2.5	7.5	6
Per cent of corrected points accurate to 10 feet or less	54	100	86	87	66	100	100	89	69	100	77	74	93	99	77	86

minimum, to graphically plotted readings on the last model, where vertical error was at a maximum. Then the readings between the first and last model were corrected to a minimum as per the first model, basing the correction of each point on its distance from the origin of the first model. The horizontal correction for azimuth was made by straight line correction from last to first model, and the correction for scale was made by dividing the scale error in the last model by the number of models, and correcting each model equally. After these corrections were made, the Stereoplanigraph-corrected vertical and horizontal points were compared to the true positions as given by TVA, and the results of this comparison are shown under Bridging Accuracy, Table I.

5. Discussion of Results of Experiments

a. As one analyzes the results shown in Tables I and II, some explanations become necessary. First of all, though the triangulation was run six times, the results of only four extensions are shown. This was considered ample, because the three extensions run on the same instrument showed no variation, which means that the results from machine number 1 actually represent the average of three triangulations of the same strip. This would seem to indicate that accidental error in bridging may be very slight. Actually, this theory is somewhat substantiated if the relative orientation positions of each projector in each extension are plotted and compared. Figure 1 shows the plots for the three rotational degrees of freedom: tip, tilt, and swing. Each graph shows the plotting camera position in grade relative to zero, and the degree of parallelism reflects the degree of consistency in each extension. It is believed that more than one-half of this slight variation is due to adjustment differences in the optical-mechanical systems, and that further adjustment of the systems probably will improve the consistency between machines. Again, looking at Table II, considerable variations in results are seen for the Cantilever Extension. Inasmuch as there was neither altimeter nor statoscope data recorded for this flight, the *BZ* correction, as applied, assumes a level flight line. The fallacy of this assumption is apparent from the inconsistency of the results, although other unknowns may also be contributing to the inconsistencies.

b. As shown in Table I, containing the tabulated results of four vertical and horizontal bridges on four different Stereoplanigraphs, the average vertical error for the five model bridge is 3.00 feet, for the ten model bridge 5.5 feet, and for the fifteen model bridge 6.0 feet. This average error in terms of its relationship to the flight altitude for the strip, would be 1/4,400 of the flight altitude for five models, 1/2,400 of the flight altitude for ten models, and 1/2,200 of the flight altitude for fifteen models. The horizontal accuracy could not be checked as easily as the vertical accuracy, because the density of available horizontal control points was relatively low. In addition to this lack of numbers, the horizontal points were not always well identified. Moreover, because of this sparseness of horizontal control check points, it was not feasible to check horizontal accuracy for five, ten and fifteen models. Therefore, the horizontal results are tabulated only for a fourteen-model bridge or a fourteen-model cantilever. However, if 0.4 mm. is accepted as a reasonable graphic tolerance for ordinary mapping use, the average bridging error of all the horizontal control points checked falls within this tolerance.

6. Economic Factors in Stereoplanigraph Operation

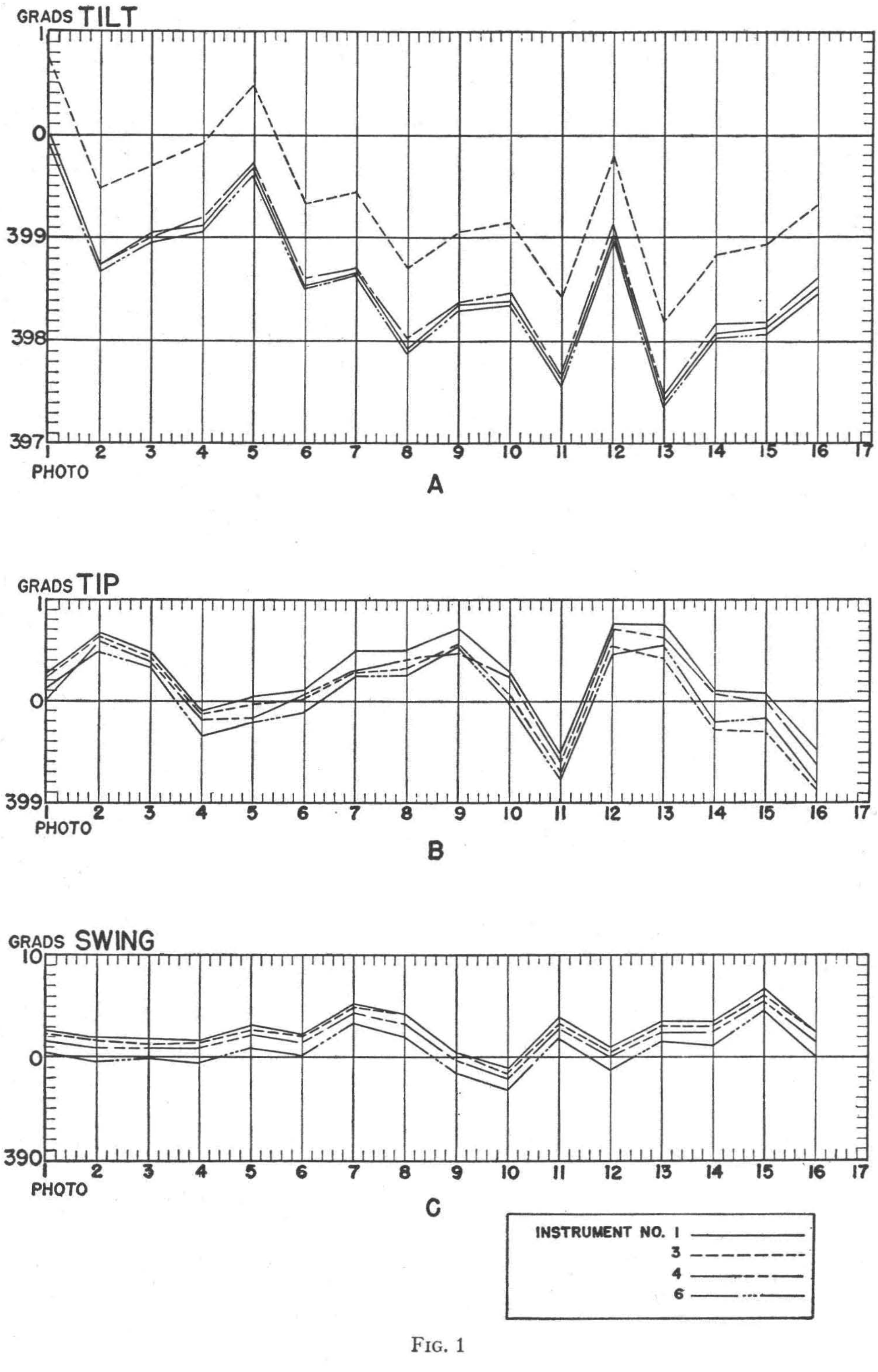
a. The discussion thus far has been concerned with the inherent precision of the Stereoplanigraph and also with some of the results which can be obtained.

TABLE II. STEREOPLANIGRAPH SPATIAL TRIANGULATION RESULTS

TVA Flight 120-R6 Zeiss P-10 Aerial Camera
Flight Altitude 13,300 Feet
Scale 1:15,000

CANTILEVER ACCURACY

AMS Instrument No.	Machine 1				Machine 3				Machine 4				Machine 6			
	Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical		
No. of models	14	5	10	15	14	5	10	15	14	5	10	15	14	5	10	15
No. of ground control points used in the triangulation	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
No. of ground control check points used to check bridging accuracy	13	20	38	63	15	20	38	63	13	20	38	63	12	20	38	63
Maximum error on any one corrected check point	mm. 2.58	.39	.90	2.7	1.35	1.6	1.6	1.6	.99	.62	.87	3.3	1.5	.88	1.29	2.05
	ft. 127.5	19.5	44.5	133.5	66.5	79	79	79	49	31	43	163	74	43.5	64	101
Average error of all corrected check points	mm. 1.88	.25	.30	.70	.75	1.1	1.0	1.1	.47	.14	.27	.90	.83	.30	.50	.64
	ft. 93	12.5	15	35	37	55	49.5	55	23.5	7	13.5	44.5	41	15	25	32
Per cent of corrected points accurate to 10 feet or less	15	40	48	28	13	0	0	1	44	85	54	33	16	50	33	25


GRADS TILT
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398
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
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B
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
PHOTO
C
INSTRUMENT NO. 1
3
4
6

FIG. 1

Other important considerations are the cost of operating the instrument and the various economic factors affecting its use. Two primary economic considerations in the operation of the instrument are: (1) Number of operators needed per instrument, and (2) length of time for training each operator. For most efficient operation, two men are needed at each instrument. One of these men should be the Stereoplanigraph Operator, a professional grade employee. The other man, the operator's assistant, who handles all work on the Coordinatograph, need be only a sub-professional grade employee. It is estimated that training an operator, with no previous stereoscopic plotting experience, will take 18 months. Training an assistant with no topographic drafting experience, should take six months. It should be recognized that many factors will influence the time needed to train, and that the caliber of the trainee, to a great extent, will determine how much training is necessary. Therefore, in those instances where personnel selected to operate the Stereoplanigraph will be qualified Multiplex Operators, and Coordinatograph Assistants will generally be topographic draftsmen, training should be only six months for the former and one month for the latter.

b. A further important economic question with regard to operational use, is the length of time needed to be taken from production time to maintain the instruments properly. Approximately three of every one hundred operational hours will be needed to maintain the instrument properly. More specifically, if two men operate one instrument, 3% of their combined man-hours will be maintenance time. This does not include recalibration time which might be necessary, due to accidents or due to cumulative day-to-day wear.

c. Inasmuch as the quantity of ground control is closely related to the accuracy desired, one must always be aware of accuracy requirements when discussing ground control quantity. Nevertheless, it is an established fact that ground control quantity is a very expensive part of making a map, and thus, it is a very important economic consideration with instruments such as the Stereoplanigraph. To obtain the full potential accuracy of the instrument, a minimum of four vertical and two horizontal ground stations per model is needed. It is desirable, of course, to obtain more than the minimum, because additional control helps to eliminate personal errors, such as misinterpretation of a point.

d. In military mapping, however, there are frequent occasions when the full potential accuracy of the instrument cannot be realized due to lack of ground control or, conversely, there may be occasions when the full potential accuracy of the instrument may not be needed. In either case, it would be desirable to establish secondary control by Aero-Triangulation. From bridging results tabulated above, it would appear that spot heights could be established within an accuracy of 1/2,000 of the flight altitude for a fifteen model bridge and that horizontal points could be plotted to 1/1,500 of the flight altitude. From this, it would appear that a contour interval of 1/500 of the flight altitude would be appropriate, when control is established by Aero-Triangulation. Thus, a thirty foot contour interval could be drawn from the fifteen model aero-triangulated control, and it might be expected that 90% of the contours would be correct to one-half a contour interval on the compilation from TVA flight 120-R6. At any rate, it can be seen that a degree of accuracy could be obtained that may have very practical value, using only six vertical points and four horizontal points in an extension up to fifteen models flown at an altitude of 13,300 feet. Continuing further, it should be possible to increase the accuracy as the length of the extension decreases; therefore, though accuracy is dependent on density of control, it is evident that the degree of accuracy attainable with the Stereoplanigraph for any given density of control, will be higher than the accuracy attainable by any other stereophotogrammetric method now in use at the Army Map Service. Hence, if it should be necessary to attain only the accuracy now acceptable for stereoscopic plotting at AMS, the density of control needed to meet that accuracy on the Stereoplanigraph, should certainly be less than is needed at present.

e. Probably the most important economic consideration is the one which includes the man-hour time needed to compile a scale model, and similarly the time needed to aero-triangulate a strip of models. It is obvious that compilation time can vary with the terrain, contour interval, and scale. As a mean value, however, the compilation of a model should be completed with 40 man-hours of work. This includes the making of tie-ins, intensification and plotting of wood overlays. With two men per instrument, this would mean only 20 hours of instrument time. Furthermore, it can be expected that the total editing time per model will be less than the normal time allotted to editing, and that finishing time will be less also. Editing time should be less than normal, because the Coordinatograph assistant is continually checking the Stereoplanigraph operator stereoscopically from paper prints, as he intensifies the planimetry. Finishing time should be less, because the sheets will be clean and well intensified when they come off the machine. Moreover, the fact that the Stereoplanigraph can almost always be worked at the drafting scale, or at the final map scale, makes it likely that mosaicing work will be reduced.

f. Triangulation time can be divided into three classifications: (1) time needed to set up the first model; (2) time needed to tie on each succeeding model in the strip and plot stereoplanigraph control; and (3) time needed to correct the systematic errors accumulated in bridging. Orienting the first model in a strip, should be completed within four hours. This apparently long set-up time is due to the fact that a high degree of precision is necessary in scaling and leveling this first model. The precision is necessary, because the correction for the systematic error in datum plane accumulated in the bridge, is based upon the first model as Zero datum. To tie on each succeeding model, and to drop Stereoplanigraph control, should average not more than one and one-half hours per model. Making the correction for datum plane error, and arriving at a solution for the triangulation generally, will take four hours. Summarizing, machine triangulation time per bridge would equal the total of the set-up time of the first model, or four hours, plus 1.5 times the number of models after the first model, plus correction time of four hours. It is likely that one Coordinatograph assistant could service two extenders and thereby reduce by one-fourth the total man-hours per extension; however, the efficiency of this arrangement still needs further investigation.

7. Conclusion

A few of the aspects which seem to be theoretical advantages were presented; likewise, it has been demonstrated in a limited sense what these theoretical advantages can produce. There is little doubt that the Stereoplanigraph should perform consistently, but surely, before any certainty can be assumed, these instruments must be tested under a greater variety of conditions. As yet, there are several adjustment problems to be solved which may or may not increase the accuracy of the instruments, but which are calculated to increase their consistency. Possibly, the most definite conclusion which can be derived from the experimental work thus far, is the one concerning consistency. More specifically, it can be said that accidental error or Stereoplanigraph operator error should be very slight. If this be true, then the most basic considerations are: (1) a determination of the systematic error present; and (2) the type of correction to be applied. Accordingly, under a given set of conditions, only one result should be obtained, and therefore, since photography is usually the independent variable, we conclude that the Stereoplanigraph will plot as accurately as present photographic processes permit.