The Photogrammetric Research Establishment and its program have been described briefly. The work is still in the initial stages. The broad program can only be realized with the co-operation and interest which the efforts have evoked on many sides, a fact which is fully appreciated. Particularly pleasing is the evidence of the same interest on the part of American colleagues, some of whom have not hesitated to come to Ottawa to discuss technical problems of mutual interest.

AEROTRIANGULATION WITH THE KELSH PLOTTER*

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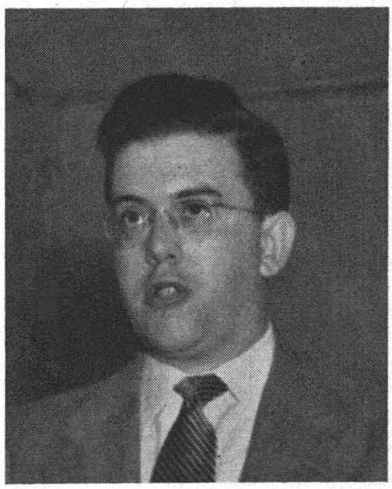
ABSTRACT

A method for aerotriangulation with the Kelsh Plotter is presented, test results are given and discussed, and it is concluded on the basis of tests made at ERDL that the Kelsh Plotter can be used successfully to bridge control stereophotogrammetrically.

INTRODUCTION

IN THE last several years we have witnessed the emergence and development of a relatively simple photogrammetric plotting instrument, the Kelsh Plotter, the capabilities and characteristics of which have attracted the attention of both government and commercial mapping organizations. The Corps of Engineers is among the organizations which have regarded the Kelsh Plotter as an instrument with a potential for solving certain aspects of its mapping problems. Through its Engineer Research and Development Laboratories at Fort Belvoir, the Corps of Engineers maintains a persistent program of evaluation of new instruments and techniques whereby the efficiency of military mapping may be improved. It is, therefore, not surprising that the Laboratories are interested in an instrument having characteristics of ruggedness, simplicity, light weight and relatively low cost closely approximating those required of a military instrument.


S. J. FRIEDMAN

A commercial model of the Kelsh Plotter was procured by ERDL in December 1948 and was made the subject of an investigation and evaluation. It was found that the basic design of the plotter lends itself readily to adaptation as a military topographic plotting instrument. Apparently the Kelsh Plotter offered a solution to the needs of the Corps of Engineers for a high precision, topographic, stereophotogrammetric instrument, simple to maintain and operate, cheap, portable, and rugged. However, one deterrent existed in that it was designed for stereo compilation and not for aerotriangulation.

Military mapping under wartime field conditions—a responsibility of the

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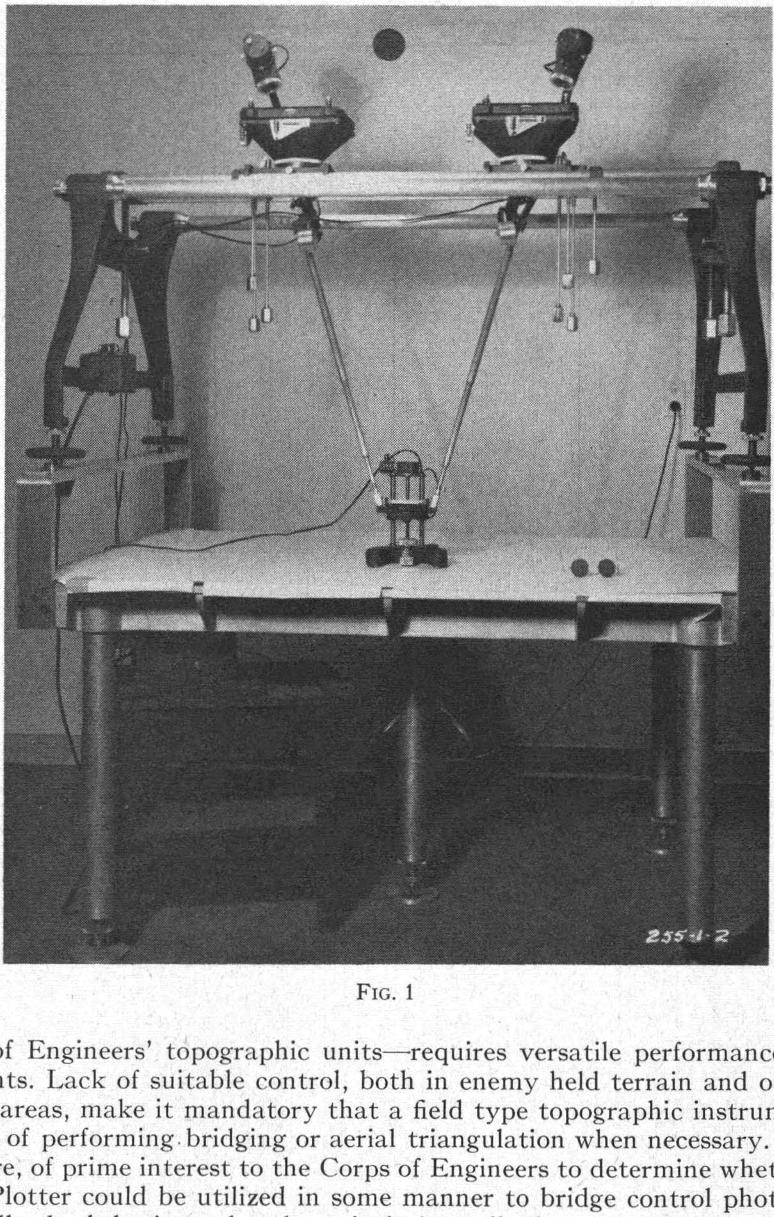

FIG. 1

Corps of Engineers' topographic units—requires versatile performance of instruments. Lack of suitable control, both in enemy held terrain and occupied foreign areas, make it mandatory that a field type topographic instrument be capable of performing bridging or aerial triangulation when necessary. It was, therefore, of prime interest to the Corps of Engineers to determine whether the Kelsh Plotter could be utilized in some manner to bridge control photogrammetrically, both horizontal and vertical. Accordingly, a test program was initiated to determine whether aerial triangulation could be successfully accomplished with a Kelsh Plotter.

To bridge successfully with a two-projector instrument, it is necessary to find a method of determining the spatial orientation of a projector, and either a means for maintaining that spatial orientation for the two stereo models of which that projector is a part, or a computational system for correcting any deviation. The early model Kelsh Plotter had no provision for meeting this requirement. A method for determining the spatial orientation of a projector was devised, using two precise level bubbles on the diapositive plate, to measure X-tilt and Y-tilt. First test bridges, using this technique, were made with the early model plotter. Test results were very encouraging and a new instrument (Figure 1) was procured which was made to the Laboratories' specifications. These specifications were designed to eliminate certain deficiencies in the early model and also to add permanently mounted precision bubble level tilt indicators and provision for using 20 degree convergent photography.

Triangulation Technique

Prior to making the test bridges, it was of interest to determine whether the bubble levels, which were of approximately 40 second sensitivity, were sufficiently precise for the intended purpose. Accordingly, a pair of precise grids was set up and absolutely oriented to form a flat stereo model. Readings were taken of the *X*-tilt and *Y*-tilt of one projector. The model was broken up, and re-formed by relative orientation. The same projector was then given the same spatial orientation by means of the tilt indicators and common tilt motions. This procedure was repeated five times. Each model had approximately the same level solution. This test indicated that the levels were sufficiently precise to reproduce the orientation of a projector within the order of accuracy to be expected from a relative orientation by means of elimination of *Y*-parallax.

Table 1

Model No.	Center Pass Point	Front Pass Point	Rear Pass Point	*X*-Tilt	*Y*-Tilt
35-34	21.45	20.60	23.00	.1561	.1265
34-33	21.45	20.85	22.70		
	20.95	19.95	21.55	.1739	.0962
33-32	20.95	19.80	21.65		
	17.85	16.45	18.25	.1869	.0803
32-31	17.85	16.45	18.20		
	16.60	13.95	15.80	.1655	.0839

The method developed at the Laboratories for using the Kelsh Plotter to bridge control is a simple and direct one. Each model of the bridge is relatively oriented as an independent unit. The models are tied together by the *X*-tilt and *Y*-tilt of the projector common to two models. Azimuth and scale are maintained by pass points common to two models. Computations are not required during the bridge. Adjustment for vertical and horizontal closure error is made upon the assumption that such errors are generated by a second degree function, parabolic in nature. The horizontal error is broken down into its components of azimuth and scale. Correction for the vertical error takes cognizance of cross-tilt and earth curvature. No argument is offered as to a preferable method of error adjustment. That subject is beyond the scope of this paper.

A detailed description of a bridge is as follows: First, a notation form for recording required information is made up. Table 1 illustrates an example of such form. Provision is made for recording the vertical readings of the front, rear, and center pass points, and the *X*-tilt and the *Y*-tilt of the projectors as read on the bubble level indicators. Assume that the bridge is to proceed from diapositive 1 to diapositive 2, to diapositive 3, and so on from left to right (see Figure 2). The initial model, formed by diapositive 1 in the left projector and diapositive 2 in the right projector is oriented to ground control. Pass points are established in the area common to the first and second models. The pass points selected are, in so far as possible, readily identifiable terrain features, both vertically and horizontally. One is established in the center, one at the

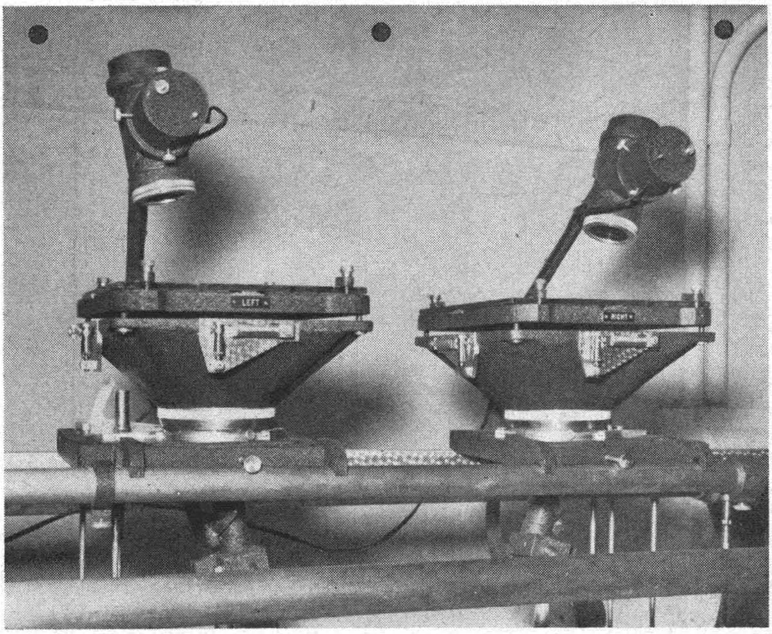

FIG. 2

forward edge, and one at the rear edge of the common overlap area. The X-tilt and Y-tilt of the right projector is read and recorded. Model 1–2 is then broken up and model 2–3 is formed with diapositive 2 in the left projector and diapositive 3 in the right projector. The new model is formed by relative orientation and the scale of the model is approximately adjusted to the horizontal positions of the wing pass points of the previous model. The X- and Y-tilt readings of the right projector in the first model are set in the left projector for the second model. By means of common X-tilt and Y-tilt of the plotter, the entire relatively oriented model is rotated until the bubbles on the levels of the left projector are brought back to their horizontal index. The left projector of the second model (diapositive 2) now has the same spatial orientation for the second model as the right projector (diapositive 2) had for the first. The model is then carefully scaled to the wing points, and re-leveled if necessary. The final step is to re-index the tracing table platen so that the center pass point elevation of the second model agrees with that of the first model. The above procedure is repeated for the 3rd and subsequent models.

TABLE 2

Type Photography	No. of Models	No. Vert. Check Pts.	No. Horiz. Check Pts.	RMSE Vertical FH Ratio	RMSE Horizontal FH Ratio
Metrogon	14	85	31	1/1,500	1/1,600
Metrogon	14	96	31	1/1,400	1/600
Metrogon	12	31	22	1/2,600	1/1,100
Metrogon	9	24	18	1/2,100	1/1,100
Metrogon	9	58	20	1/2,300	1/2,000
Planigon	13	66	26	1/2,700	1/1,100

This method of aerial triangulation was developed for bridging between two bands of control. No attempts were made to cantilever control from a controlled base. Adjustments for closing errors were made by means of second degree curves joining the initial and terminal control stations.

Table 2 lists the various bridges made; the number of models bridged, the number of vertical and horizontal check control points, and the root mean square vertical and horizontal error expressed in terms of flight height ratio.

Discussion

During the time that the plotter has been in use at ERDL, the instrument has been subjected to a wide variety of tests to determine its mechanical and optical characteristics as well as its photogrammetric capabilities. The time which could be devoted to aerial triangulation tests was necessarily limited. Therefore, the number of bridges made with the plotter were less than desirable, at least up until the time that this paper was prepared. However, the tests made, the results of which are tabulated in Table 2 are sufficiently consistent and representative to allow making some reasonable observations and conclusions.

The accuracy of vertical control established by bridges of approximately nine models will permit compilation at a *C* factor of somewhere better than 1:500, if it is assumed that the vertical control should be at least twice as accurate as the contour interval. This *C* factor is obtained by selecting the least accurate bridge of nine models and multiplying the root mean square vertical error for this bridge by a numerical factor of 1.65. The resultant figure represents the range of error for 90 per cent of the vertical control points established by the bridge. This value when multiplied by two and expressed in terms of flight height ratio gives the approximate value of a little better than 1/500.

The horizontal accuracy of the control established by the bridges as a rule did not equal the vertical accuracy; however, it was sufficient to permit a compilation meeting National Map Accuracy Standards at twice the aerial negative scale. Scale and azimuth errors were rather erratic from model to model, indicating a weakness in the passing-over technique. It is felt that the weakness in horizontal accuracy is attributable to the method used for maintaining scale and azimuth during the bridge. The accuracy with which scale and azimuth are maintained is directly dependent upon the degree of precision with which the horizontal position of wing pass points can be recovered. Using the tracing table lead to recover the position of a point, as was done in our tests, is not the most precise way. Proper viewing of the initially established position is not obtainable. Redesign of the lead chuck to permit interchange of a small bent angle microscope with the drawing lead might conceivably increase the horizontal accuracy. This feature has long been common on instruments using a coordinatograph.

It has probably been noticed that a bridge made with Planigon lens photography, the distortion free 6 inch focal-length wide-angle lens, has been included in Table 2. This bridge was accomplished by disconnecting the Metrogon distortion compensating cams and immobilizing them. Although the results of this one extension were better than the results of extensions made with Metrogon photography, there are not enough data available to justify a general statement that better results can be expected of Planigon photography bridges. However, it is reasonable to assume that a truly distortion-free lens which eliminates the requirements for distortion compensation will permit more accurate bridging, as well as improving the accuracy of any other photogrammetric process.

Some inconvenience was occasioned by the large compilation scale, which required a rather large manuscript control sheet. For a 12 model bridge there was used vinylite sheets 4 feet wide and approximately 25 feet long. That's quite a bit of vinylite. However, this problem is a transitory one. It awaits only the design of a precision pantograph which can be used with the plotter; a pantograph which will not lose the advantage gained by the large-scale projected model.

An estimate of the man-hours required to set up a bridge would have to be quite general at this time. There is continuous experimentation with the techniques and the time spent on each bridge varies. An experienced operator with a systematic procedure should be able to bridge at the rate of one-and-a-half to two hours per model.

Conclusions

The tests made at ERDL have proved that the Kelsh Plotter, an instrument designed basically to plot individual models, can be used successfully to bridge control. The degree of accuracy may possibly discourage use of the instrument for bridging on most peacetime mapping projects where supplementary control is relatively easy to obtain. However, where control is not plentiful and the mapping unit is limited to using transportable equipment, the capabilities of the Kelsh Plotter present interesting possibilities. Much work remains to be done before the ultimate accuracy of the plotter as a bridging instrument can be determined. A large number of bridges with varying conditions of photography, terrain, personnel and methods of adjustment will be required. It is hoped that other mapping organizations will be encouraged to investigate this capability of the Kelsh Plotter and that their results and techniques developed will be made available to the photogrammetric profession.

DISCUSSION OF S. J. FRIEDMAN'S REPORT: AEROTRIANGULATION WITH THE KELSH PLOTTER*

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Aero Service Corporation

I have been asked to comment on Mr. Friedman's paper, and I am pleased that there is great interest in the performance and refinement of a simple plotting instrument of the Kelsh type. Aero Service Corporation has been very much interested in the development of the Kelsh Plotter. We have performed many experiments using the same technique as Mr. Friedman, and our results have been so outstanding that we too intend to make further investigations into bridging techniques using the Kelsh Plotter. We are confident of our ability to cantilever or attach one model to an original pair, but we feel that further research in bridging a series of photographs is necessary.

I am familiar with the use of probably the most accurate vertical system in the world—the Brock mapping process. During my ten years' experience with this equipment, I saw highly accurate contours being produced using "*C*" factors up to 1800. While no one advocates such a "*C*" factor for the Kelsh

* Paper read at Nineteenth Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., January 14 to 16, 1953.

Plotter, nevertheless, the simplicity of this plotter has made it very popular for large-scale topographic mapping work.

During the past three years, numerous mechanical refinements and improvements have been incorporated into the Kelsh design. At Aero Service we feel that still further improvements are possible, and we look forward to the time in the not too distant future when the dreams and plans of our photogrammetrists and engineers will be made real, in the form of the most accurate and usable American-made plotting instrument.

This brings about a common criticism that has haunted us for a while. We have been told repeatedly that the Kelsh Plotter is a simple machine, created only to work a single model very efficiently, and that there are some who are trying to make an inexpensive instrument duplicate the feats of an expensive foreign instrument. This is a philosophy of decay. Leading government and commercial photogrammetrists accepted the Kelsh Plotter and proved that with it they could meet the mapping specifications. They also accepted it because it was economical to fabricate, and they accepted it because it was an American innovation. We feel there are many reasons to continue to explore its possibilities as Mr. Friedman has so capably done. We also feel that much credit is due the Army Map Service, the U.S.G.S. and the ERDL for laying the foundation for this research and giving freely their proven techniques for bridging.

Unfortunately, because of military security considerations, all the details of the experiments of ERDL cannot be given. However, the ratios shown by Mr. Friedman appear to be comparable to our results using similar techniques. Unquestionably, these results from such an instrument can have tremendous possibilities in the production of military maps using a minimum of control.

We feel that further consideration might well be given to the use of 20-second rather than 40-second level bubbles. Whether or not this modification would make any appreciable change in the horizontal or vertical accuracy should be investigated further. Since commercial usage of the instrument requires far greater accuracy than can be tolerated under military field conditions, additional research and instrument development must be undertaken. In addition, the commercial user may well study ground control patterns because this too plays an important part in successful bridging techniques. The analysis and adjustments of errors may well follow in a general way the rigorous methods imposed by the more precise plotting instruments. Bridging with a simplified instrument such as the Kelsh will undoubtedly call for simplified methods to yield usable results for practical map production.