THE KELSH PLOTTER

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ENGINEERING progress may be described in the simplest terms as getting "More for Less."

A realization that this progress is always a step by step advancement should prevent the use of superlatives in describing present achievements. Of all the things that will probably happen, the most likely is that whatever is done today will be improved upon tomorrow. Greater realization of that fact may tend to prevent generalized statements that often create an impression that certain results are fundamental, when actually the correctness of the stated result applies only to the particular experiment at hand.

In one of the first descriptions of the multiplex which came to my attention some years ago it was stated that it was possible to contour to an interval of 1/600 of the flying height. This claim, as made by the manufacturer, was entirely true as applied to that apparatus, but gradually it had been extended to a generalization applicable to all mapping instruments. In this form it represented an example of inductive reasoning based on very meager premises. In fact, acceptance of this opinion as a generalized truth may actually have adversely affected experimentation and development of other plotting apparatus, for if this attained contour accuracy actually represents the engineering limit, then experimentation could profitably be directed only to developing a less expensive means of obtaining the same degree of perfection; and a considerable amount of our experimentation has been so directed in the last few years.

It has been the feeling that we have not reached the limit of results in contouring, from the basic information available, that has directed the experiments described here.

In the experimental apparatus that has been constructed I would not care to claim more than that certain generally assumed obstacles to the development of plotting apparatus of this type have apparently been overcome, or found not to exist, and that the results have been sufficiently pleasing to warrant further development in this particular approach to good engineering practice in mapping.

In using the words "particular approach" I mean that it is my opinion that in evaluating a piece of plotting apparatus it is not possible to confine the evaluation solely to the relative ability of the apparatus to delineate planimetry or topography after a series of preliminary steps have been taken; unless all types of plotting apparatus require that the same steps (and to the same extent) be first taken; and this, of course, is not true. The plotter is usually designed to fit into, and become a part of a preconceived general over-all plan to produce maps; and as this general plan is developed the plotter may be designed to perform one, two, or more functions. With the multiplex for example, several steps are performed in the same machine. It bridges control, and it furnishes a means of delineating both planimetry and topography. It starts with the basic data of a certain number of control points per square mile or per photograph, and a certain number of elevations. From practice, if not from theory, a definite minimum requirement for this machine, as to the number of such points, has been established.

To successfully accomplish the plan of including the spanning of control in the operation of the plotter we may, of course, encounter the problem of size of apparatus. To hold this down to practical size may require modification in size of the individual projectors. This in turn calls for special equipment to produce the required miniature diapositives, and the smallness of these in turn tends to limit the size of the ultimate image upon which the measurements are to be made. Thus we see that including the extension of control in the plotter may create certain limitations, and that the general value of extension of control in this manner must be weighed against the limitations that inclusion of this factor may impose.

Now in another type of plotter we may not attempt to bridge control at all. However, if some other means of bridging can be developed so that we may reduce the plotter to a two photograph instrument, this in itself is no assurance that the plotter will then allow us to secure the same results as with another instrument. We may, and apparently some plotting instruments do, still require a considerable addition of vertical control to the amount needed to horizontalize the model. The amount required, and the cost of obtaining this must be considered and, of course, included in any comparative figures.

The multiplex has been used a basis for comparison here, since this instrument is more widely known in this country than any other piece of plotting equipment; and the splendid work which has been done in its development has certainly warranted its present preeminence in the American plotting field.

In fact, at the present time the problem of producing "More for Less" with plotters seems to be somewhat a question of producing a better or a cheaper result than can be produced by the multiplex system. We have in the stereoplanigraph an apparatus that certainly should be considered as a possible answer to securing better results, but the cost is so prohibitive as to eliminate consideration of this plotter by all except the organizations performing a very large volume of map work.

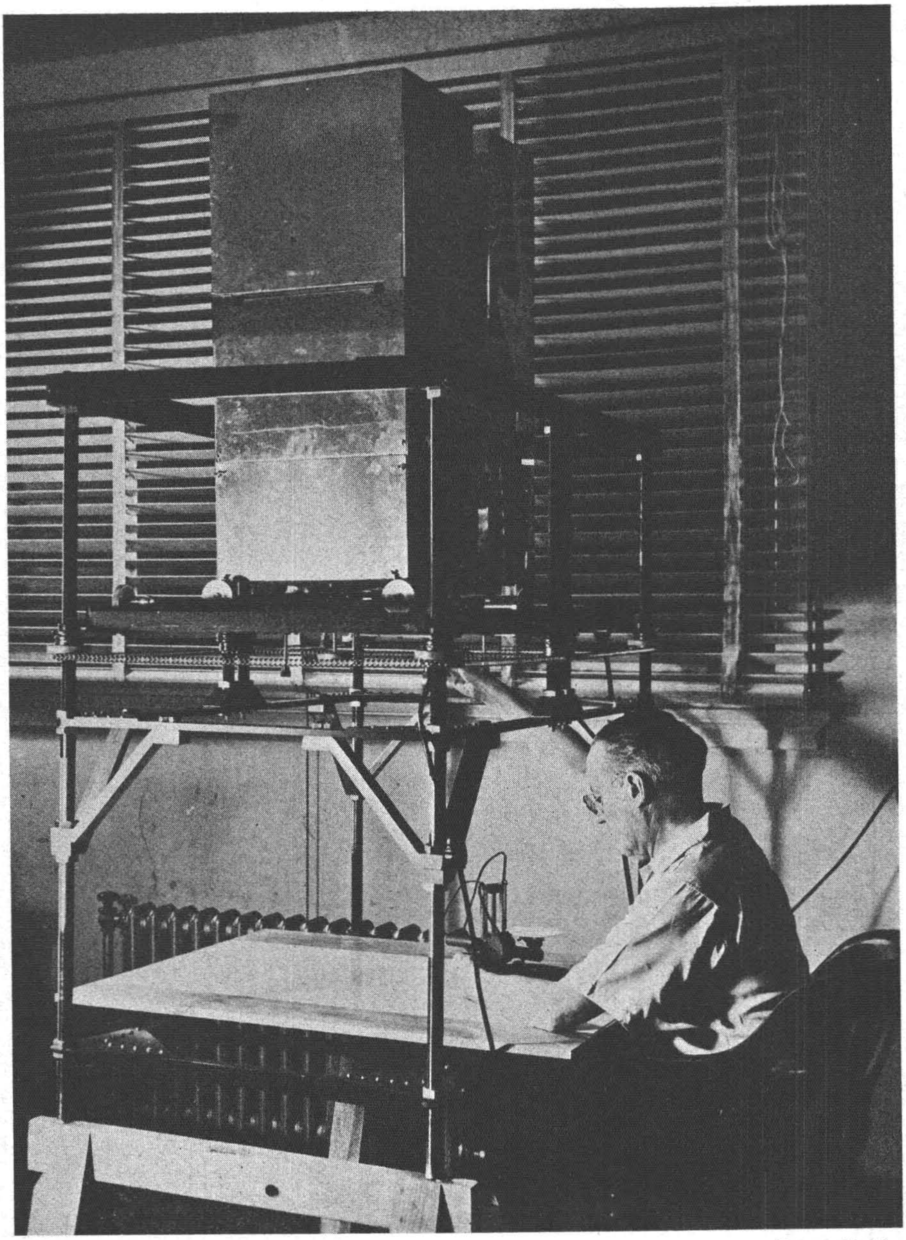
Up to now the attempts to materially reduce the cost of a plotter have largely been directed towards the elimination of the projection system and the use of paper prints rather than glass transparencies. As far as reducing the size of apparatus is concerned, we have several successful examples, and in all these the elimination of a projection system with its resultant need for special lighting conditions has been accomplished; but somewhat at the expense of limiting the accuracy of the resulting product.

The limits of vision make it possible, at reading distance, for us to differentiate a value of approximately 1/10 of a millimeter, therefore the value of this 1/10 millimeter on the actual model becomes of paramount importance.

If the viewed image is on a smaller scale than in the multiplex we can expect less accurate results. Conversely any apparatus which will give a larger image might allow a closer approximation of actual position. In most paper print plotters the image is viewed at a horizontal scale less than that of the contact prints. This is necessarily true in any apparatus (without enlargement of image) in which the eye to photograph distance is larger than the focal length of the taking lens.

The experiments described here were directed towards the production of a larger working scale than that which has been available, but still keeping the instrument within reasonable size, and also of adapting the possibilities in larger size images to the bridging of control.

The photograph of the machine will indicate its general size. While not nearly as small as a desk plotter, it is, when set-up, usable in an ordinary office. The framework is made so that it can be taken apart and packed for shipment. In the experimental model this framework is approximately five feet high, four feet long and two and one-half feet wide. The plotting table is 32 by 40 inches.



Pat. applied for

FIG. 1. The Kelsh Plotter

The frame rests on two wooden horses. The lanterns are 36 inches in height. The apparatus has a range up to about six diameters, but the experimental work has been done at approximately four diameter enlargement. From experience this seems to be about the most practical scale of enlargement. Assuming that the model width between side radial points is about eight inches this means a 32 inch enlargement; and it is not practical to sit in a chair and work a much larger model.

The apparatus is so equipped as to allow all of the motions necessary so that relative camera positions in space can be duplicated, and through the tilting adjustment of the table absolute orientation can be secured. Full scale glass positive plates are carried on adjustable stages behind the lens mounts. Lenses of different focal lengths may be used. They are so mounted that they do not rotate when the lanterns are turned. Separation of the images can be secured by using either red and green filters with red and green glasses, or polaroid filters with polaroid glasses. In the latter event the fact that the lenses do not rotate

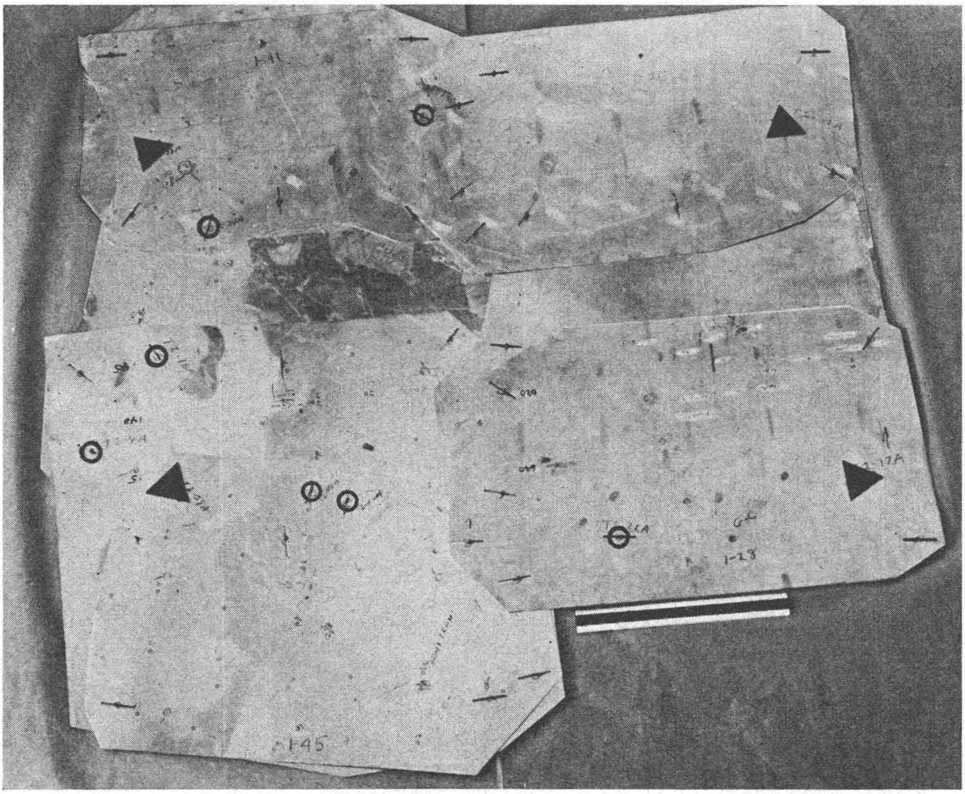


FIG. 2. Enlarged templet assembly. Scale comparison furnished by twelve inch rule. The four points used in second assembly indicated by triangles. Additional control points of first assembly shown as circles.

becomes important since the polaroid filters can then be set-up at right angles to each other and will remain in that position. A standard plotting table has been used in the present work; however a slight modification of the present design is contemplated.

The Bureau of Standards tests of the lenses used indicated that 4 diameter enlargements could be secured in which the image displacement was safely within the tolerance of standard mapping accuracy. At the enlarged image scale this opened the way to a possible means for securing necessary horizontal control at minimum cost through the use of photographs taken especially for control purposes, at considerably higher than the usual altitude for comparable scale work.

Photographs of an area in Virginia taken with a four inch lens at a scale of approximately one inch to the mile were available. Eight photographs covered approximately 90 square miles. Positive lantern plates were made by contact. Pair by pair these were placed in the lanterns and the composite image horizontalized. From this horizontalized image, at 1:15,840 scale, templets were made on sheet aluminum. This set-up allows the optical transfer of the nadir point from the lantern plate to the templet below, as well as the transfer of the geometric center; with consequent improvement in the accuracy of the templets. The use of sheet aluminum eliminates all possibility of templet distortion in use. Consequently, when such a templet can be made and dropped over five or six accurately plotted ground stations, we have a very graphic demonstration of the accuracy which it is possible to retain.

In the above area there were 11 control points. In the assembly it was found necessary to void one of the points. There is no possibility of pulling into control by the stretching of the templet medium, or indenting the slots; therefore a wrongly plotted or a wrongly identified point becomes immediately apparent. No difficulty was encountered in making the assembly. The templets were then picked up and relaid, in order to determine the position displacement possible in assembling this number of templets with this density of control. Through the first assembly in addition to the 11 control points, 20 radials had been secured. In the second assembly there was a variation in position of two of these radials in the amount of ten feet and fifteen feet respectively. This was the only measurable difference.

The assembly was taken up and four of the ground points roughly approximating a rectangle six by ten miles in size were then fastened in place. The area was then reassembled with the same templets. Twenty-six points were tested. The maximum difference was 0.27 inch representing 35 feet at this scale. The mean of the errors was 22 feet. This, of course, is well within the requirements of standard map accuracy on a scale larger than 1:20,000 and would, of course, easily allow standard accuracy on a reduced publication scale of less than 1:20,000. There was no difficulty in tracing off the planimetry from such small scale photographs on this enlarged working scale model; and since in all cases there is normally a reduction from this to the final map scale, it might be said that the results of these experiments indicated that through a projection device such as this, detailed planimetric maps can be made from photographs taken at a higher altitude than has been customary; and with consequent saving in cost. Furthermore the control test would indicate that we have here a system by which ground horizontal control may be held to a reasonable minimum. The area between the four control points is approximately 60 square miles. This would mean that over a large area control might be extended with one point per $7\frac{1}{2}$ minute quadrangle, using photographs taken at the above indicated scale; and still hold standard accuracy.

The radial points obtained by the slotted templet extension of control in this manner may, of course, be placed as desired, so as to be available for use with larger scale photographs taken over the same area. This is particularly applicable to large scale narrow strip mapping such as highway work, since it prevents "weaving" which is always a problem in single flight extensions.

For the testing of the possibility of the apparatus as a contouring medium two areas were selected; one at Beltsville, Maryland and the other at Ellicott City, Maryland. The results are given below:

Beltsville Test

Open country—low relief—minimum elevation 104 ft. maximum 265 ft.
Scale of photography 1:20,000—standard angle $8\frac{1}{4}''$ lens.
Scale of working model 1:5000.

Model set-up with 4 points in corners. Elevations of these points 146 ft.—126 ft.—195 ft.—193 ft.
30 test points on easily identifiable features (mainly road points) were secured.

Results

Maximum error 6 feet—90% of all points were within 4 feet.

Ellicott City Test

Rolling—wooded—minimum elevation 128 feet, maximum 453 feet.
Scale of photography 1:20,000—standard angle $8\frac{1}{4}''$ lens.
Scale of working model 1:5000.
Model set-up with 4 points in corners. Elevations of these points 345 ft.—274 ft.—141 ft.—381 ft.
14 test points.

Results

Maximum error 4 feet—90% of all points were within 3 feet.

The Ellicott City model was again set-up using the same four points in the corners of the whole model, and one quarter of the model area contoured to 10 foot intervals. A field test was run from a bench mark along a winding road, then over several hills along a power-line, and back to a bench mark. Total length of line $1\frac{1}{4}$ miles. It is felt that a fair and reasonably adequate test of degree of accuracy of the contouring was obtained. 51 test points were plotted.

Results

Maximum error (1 point)	11 ft. (in a small, sharp, wooded gully)
Next largest error	7 ft.
96% of all points within	6 ft.
84% of all points within	5 ft.

These tests indicate that it is apparently possible to secure results with this type of equipment comparable to those obtained with much higher priced plotting apparatus. Furthermore, with the continual development of higher flying, and renewed interest in aerial cameras using a more stable photographic medium than present film, the possibility of greater enlargement of image may be of increasing value.