MR. HARRY T. KELSH: Mr. President, Members of the American Society of Photogrammetry and all of our Distinguished Guests; In presenting this paper on the Kelsh projection type plotter, I feel that it may be of interest to describe the reasoning that has led to the present design. This will at least establish the purpose or goal that has been in my mind, and should make comparison with other plotters more equitable. There are many plotting devices on the market. Unquestionably this plotter will be compared with and rated against them, and this comparison is, of course, of real value. But at times such comparisons are not always fair. One of the reasons for this is that in the interim between the time the plotter leaves the hands of the designer, and arrives in those of the users, its original purpose and scope seem sometimes to be completely forgotten. As a result the product may be judged in a class materially higher than the one it was designed for; and it may consequently receive a lower rating than it deserves, when purpose and price are considered.

I have tried, in this presentation, to avoid comparison with other equipment, but where comparison is indicated, I sincerely trust the statement I have just made, will be borne in mind.

There is no such thing as a universal plotter. The simple form line indicators, the paper print plotters, the projection devices, the scanning instruments—chiefly of European design—and the plotter produced by the U. S. Coast & Geodetic Survey as a complement to its nine-lens camera, all do fine work in the field for which they were designed, but, as I have said, they are not universal. The use of any one brings with it definite limitations as to plate size, or print size, or type of photography best suited to its particular construction. I believe we will do a real service to photogrammetry if we keep that thought in mind, and if we use, and recommend the use of each plotter in the particular field in which its design will permit adequate performance.

I would like to refer to the work of Henry Ford in producing his famous model "T," merely to indicate a comparison of purpose. Ford set out to design a good, usable car, with one outstanding qualification—it should be reasonable in price. There were heavier, more luxurious automobiles on the market at that time. He succeeded in his purpose; not only was his car reasonable in price, but the performance was satisfactory. I think, though, that Henry was just as surprised as anyone, when it was found that under certain conditions, his product actually outperformed many of the more expensive contemporary cars.

Others attempted to undercut the Ford price, but their products in many cases did not include qualities nesessary for adequate performance; and these cars quickly disappeared from the market. There seems usually a minimum figure that cannot be reduced. I think this applies to plotters as well as to automobiles. But certainly the makers of the larger cars had not arrived at the minimum, and it is entirely possible that I also have not arrived at a minimum figure for an adequate plotter, but that has been my general aim, and time will determine the degree of success achieved.

One of the first factors that must be considered in plotter design is the size of the image on which it is proposed to work. The desire for simplicity, coupled with a very laudable desire to limit the size of the plotter may, and in this case did affect plotter design. But unfortunately there is a very definite limit to eyesight. We can distinguish in a model a minimum difference in position of an object in space of about 1/10th of a millimeter, with the unaided eye, at ordinary reading distance. Of course we can make this minimum distance represent a smaller number of feet by increasing the scale of the photographs, but this is uneconomical from all viewpoints. If it can be done successfully, it is better to enlarge the original data, securing these data at the maximum possible altitude that will permit obtaining desired results.

There is sufficient evidence available to permit making a definite statement that there is more usable data in present day aerial photographs than can be seen at contact scale. The desirability of enlargement of the original image is therefore clearly indicated; and I think it can be said that unless a plotter includes this feature, it cannot deliver maximum results.

The enlargement can be obtained either by projection, or by the use of optical trains such as are found in most European equipment. This latter system produces splendid results, but with the high labor costs of this country, its complications tend to prevent its use, unless we are willing to give up all hope of keeping the price of the equipment within a comparatively modest figure.

Upon the basis of this reasoning I confined my experimentation to developing a projection method of enlargement. The question which follows immediately is "How much enlargement?"

Recently I saw an advertisement in one of the photographic magazines which displayed a photograph of a small girl in a lace-trimmed dress. As an insert there was a 15 diameter enlargement of a portion of the lace collar. When hung on the wall and viewed from a distance of ten feet, the collar really looked wonderful but I do not think you would care to have to count the threads, at a distance of ten inches. But that is just about what we have to do in today's plotting equipment. I think it was clearly indicated that this degree of enlargement was probably beyond the capacity of today's equipment. How much beyond I am not at this time prepared to discuss.

But there is another factor that materially affects possible enlargement. The random errors, due to such causes as irregular film expansion or contraction, or failure of the film to lie flat over its entire surface at the time of exposure, cannot be removed. There is a point where these errors become big enough to render further enlargement valueless.

With a projected image, the size of the image is also a real factor that must be considered. It can easily reach a point where, from its size, it becomes awkward to work.

With all these factors in mind a four to five diameter model was decided upon. At this magnification the random errors appear to be still small enough not to cause serious trouble. The model, at this size, can be worked without discomfort; although it has been found desirable, once the model is set up, to work from both sides of the table to the center line.

But the apparent simplicity of a straight projection system is marred by the fact that we immediately run into the bugbear of photography that for years has been giving the camera manufacturers headaches. A reasonable depth of focus and a large lens aperture just will not go together. The compromise has been to reduce the size of the camera down to the popular 35 mm model, where the depth of focus has been retained by using lenses of extremely short focal length. This is one of the reasons for the miniature lanterns in some of our present projection plotters. But the aerial negative still measures 9 inches by 9 inches; and this size has become so standard that it will be difficult to change it, even if we so desire.

To obtain actual enlargement of these data, if we first reduce the image size, then the result must be greatly enlarged in the projector; and we will quickly, at least as far as definition is concerned, test the enlargement limits I have previously discussed.

The difficulties of working out a solution of the "depth of focus—size of lens aperture" problem, using full scale positive plates were recognized; but I considered that the decrease in the necessary enlargement factor made a solution well worth while. Furthermore, if we can eliminate the projection printer, another step in simplification can be achieved.

To those who have seen the Kelsh plotter I am certain the solution will seem quite simple; but I can assure you it didn't look too simple when I started on it some time ago.

There was first the question of the depth of focus actually needed. I think the Grand Canyon area, where we may have a difference of elevation of 5000 feet within a single model, may be considered as representing the maximum range in elevations. To compile this area on a scale of 1/10,000 which I think is the largest that might be desired for such an undeveloped area, would require a depth of focus of about 6 inches. Considerably less depth would be needed in large scale city or highway work; and so it was decided that this 6 inch figure probably is ample.

To achieve this with a lens corresponding to the taking lens in effective focal length we are limited to a lens aperture of not much over *f* 40. The other half of the problem is to transmit through this small aperture enough light to produce an image of sufficient brightness for use.

In practice I have found that an illumination of 8 to 10 ft. candles on the platen is desirable. This refers to light from one projector, without plate or colored filter in place. Upon experimenting with various light sources, it was found that with an efficient condensing system, the Western Union 25 watt spot source light would illuminate a small section of the lantern plate, project the light through an *f* 40 opening, and give more than the necessary amount of light on the platen of the tracing table at a distance of 33 inches from the projection lens. This is the distance required for a four diameter enlargement of $8\frac{1}{4}$ inch photography.

Since the part of the image that appears on the platen is all that can be used at any one time, then, as we move the tracing table about, if the spot of light can be made to follow it, the needed part of the image will always be illuminated. The swinging light, as incorporated into this plotter, apparently meets this requirement very adequately. Furthermore, since the light swings from the nodal point of the projection lens, the distance from the light source to that point remains constant, irrespective of the position of the light, and the drop off in illumination towards the edges of the model, which has also been a problem in projection systems, is materially reduced.

In addition to these advantages, the use of only a 25 watt light source eliminated any need for a cooling system.

There is a secondary, but still quite important problem that must receive attention in plotter design. In average mapping work the known geographic positions are never sprinkled around as thickly as we would like to have them. Secondary control must be run. This control is costly, and if by some use of the plotter, the amount of this work can be cut down, by just so much the value of the plotter is increased. Of course this is a two-fold question. Can the plotter be made to perform this function, and how much will it add to the cost to include this feature?

As applied to this plotter, I can say that the tests that have been made indicate that a row of these full size projectors can be hung on a single bar, and given independent x, y, and z movements, and in this manner bridging of a number of models is entirely practical. However the projectors are the most costly part of the apparatus, and it seemed desirable therefore to explore the possibilities of accomplishing the bridging of control through an auxiliary system that could be used with only a two-projector instrument.

From preliminary tests it appears that this plotter can be used very effectively with the slotted templet system. With the same amount of vertical control necessary in multiple lantern bridging, very accurate, fully rectified templets can be made at four or five times the taking scale.

The first production job assigned by the U. S. Geological Survey to this plotter, as an experiment, covers two $7\frac{1}{2}$ minute quadrangles, in Indiana. The photography available was standard angle material, taken at a scale of 1/20,000. Templets covering the 1st quad were made in the plotter, at an approximate 1/5,000 scale, setting up photographs 1 and 2, 3 and 4, etc. and horizontalizing each model obtained. As control for the assembly, lines of traverse on the north and south boundary were used. Six test points in a band across the east-west center line were available. These were used as radials in the assembly. When the actual positions of these points were later plotted, it was found that the maximum error of position was 22 feet, and the average error 13 feet. Since at this large scale 13 feet is approximately 1/30th of an inch, the accuracy of this templet control, when reduced to publication scale, (in this case 1/24,000) becomes very evident.

It was necessary to use cardboard templets in this first assembly, but we now have thin aluminum sheets in the required size, and these will be used for the second quadrangle.

It might be pointed out that this method produces an area distribution of error and eliminates the need for adjustment of minor errors between adjacent flight lines, which may occur in single strip assembly of secondary control.

I believe this plotter may also indicate the value of separating the securing of data for planimetry from the securing of data for topography. I think in many cases material saving can be made by covering the area with high altitude flying, carefully planned in view of already established control, and using this material for secondary control and possibly for planimetry as well; and then flying sufficiently low to secure photographs at a scale that will make it comparatively easy to contour to the small interval now generally desired, rather than to make a compromise in scale that taxes the plotter to its limit.

To complete the generalized description of the single model plotter for those who have not had the opportunity to inspect it, I will mention a number of the pertinent facts. Its overall dimensions are such that it can be used on a table approximately 44 inches by 48 inches in size. A plotting table top is now being tested that is a recent development in airplane construction. It consists of two comparatively thin sheets of aluminum separated by a very light-weight honeycomb material. However the plotter can be used on any flat surface.

The two projectors are carried on parallel bars which in turn are supported on the frame by a three point support. Control of this adjustment which brings the model into absolute orientation is through three screws projecting down a sufficient distance to be within reach of a seated operator.

The frame consists of two "A" supports, one on each end. These are separated by two spacers, front and back, that are screwed in place, so that removal of the screws will permit disassembly of the frame for shipment.

On the base of each leg of the "A" frames there is also an adjusting screw.

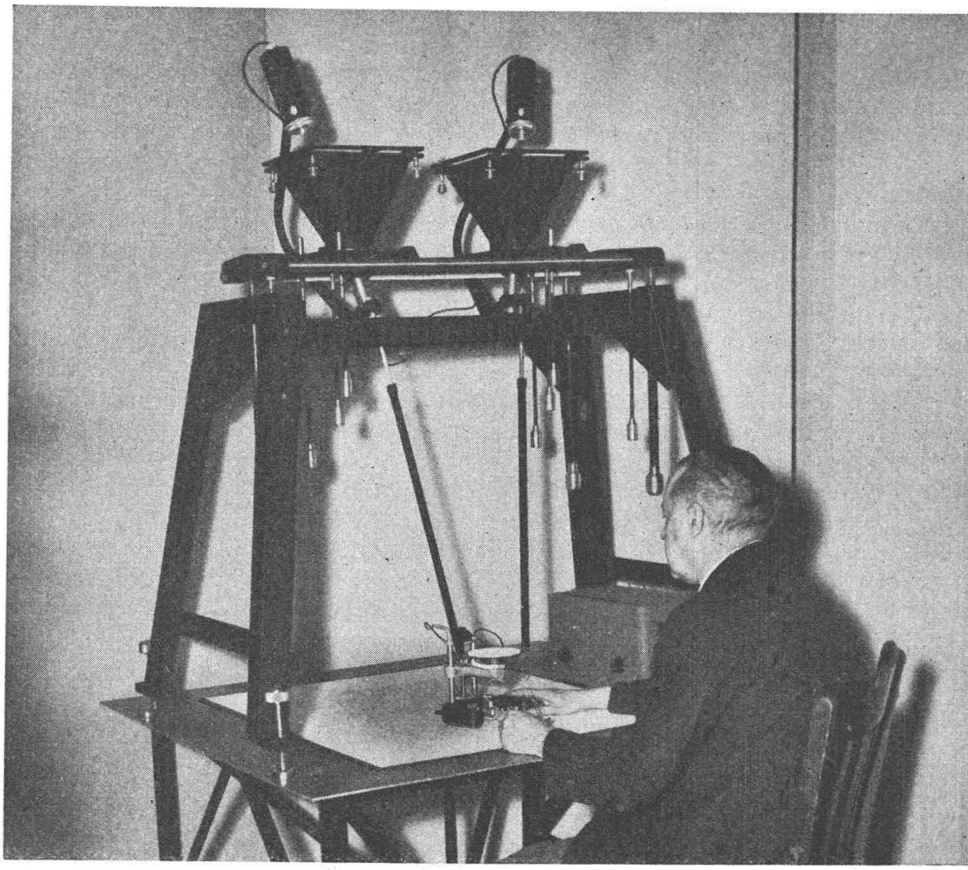

FIG. 1. The Kelsh Plotter.

The adjusting screws for the "x" motion hang down just inside the "A" frames, where they are completely out of the way but within easy reach.

The rods for tilt, tip, and swing adjustment, are on the sides of the projectors away from the center, so that they are outside the cone of light needed for the model; but since the other side of the image is also needed in templet making, these rods are equipped with universal joints so that they may be swung up out of the way, when the plotter is used for this purpose.

There is no "Y" motion in this model, since the compilation sheet can be swung as easily as the projectors.

Except for the fact that it carries a small yoke to which the light guides are attached, the tracing table at present used is the standard simple German type of multiplex design.

The Western Union lights that are used, require direct current and a special starter, and it was necessary to design a power pack that would permit starting two light units.

Either red and green filters can be used to separate the images, or polarizing filters can be used for the same purpose, but in this case a silvered platen on the tracing table is necessary to prevent depolarization of the light rays.

I believe I have covered everything except to report upon the maximum capability of the instrument in the delineation of contours. I personally am very pleased with the results obtained to date, but I do not think there has been a sufficient number of tests to make a flat statement regarding this quality. I reported in a preliminary article in the March 1947 issue of PHOTOGRAMMETRIC ENGINEERING that a thorough test of the first model set up with standard angle 1/20,000 scale photographs indicated that 10 ft. contour accuracy was obtainable. This same model was set up by another operator with equally satisfactory results.

Compilation work on the test area in Indiana has just been started. On the first model in this area there were 25 elevations that could be used as test points. The model was set up with the customary control practice—one elevation in each of the four corners. Single readings on the test points checked within five feet or less. This was so encouraging that while the office work of contouring to 10 ft. interval was in progress, additional check lines were run, resulting in 200 test points throughout the open area of the model, and a hundred or more in the wooded areas. When the open area points were compared with the delineated contours, the average found error was less than three feet, and practically all the points were within a half-contour interval. In the wooded area the apparent errors were larger, as could be expected, but none exceeded the contour interval and the total percentage within half contour was still in excess of ninety percent.

So far I have discussed only the standard-angle plotter. This was developed first, and there are a sufficient number of tests to allow a reasonably adequate report. Work on the wide angle model is progressing, and results should be available shortly.

As a matter of general interest, it appears that the present European trend is towards a return to standard angle photographs for accurate mapping. Personally I believe the correct choice of lens depends upon a thorough study of all of the problems involved in a particular mapping job, or at least sufficient study as will allow classification of the particular kind of work into a fairly representative list of the various types of mapping.

To conclude, I believe the simplicity of this plotter, and the indicated possibilities in the way of performance, should create a place for it in the field of mapping and geological study.