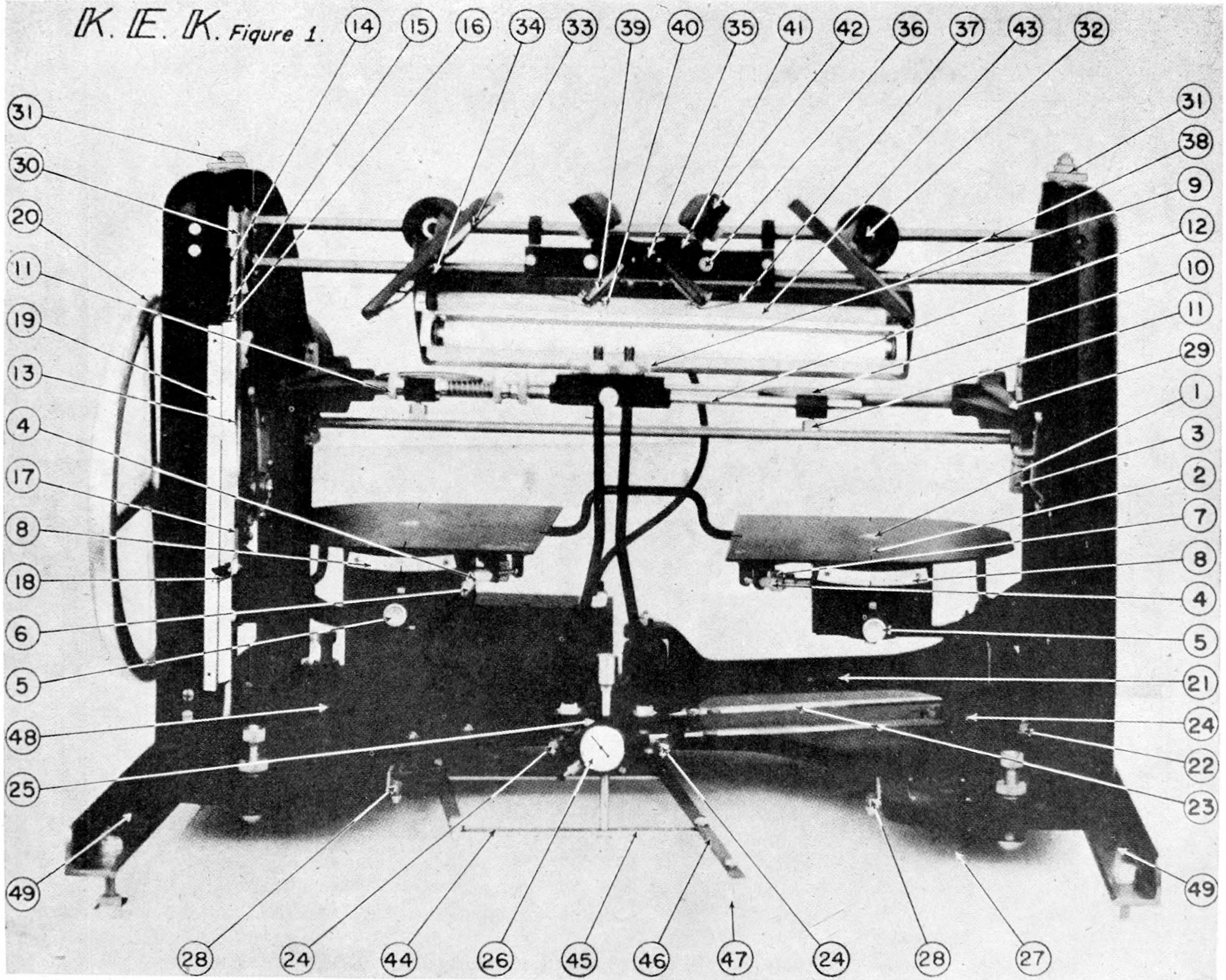


FIG. 1
The K.E.K. Stereoscopic Plotter.

THE K.E.K. STEREOSCOPIC PLOTTER

(King, Elliot, Kail *)

As used by the Photogrammetry Section Chart Construction Division, U.S. Navy Hydrographic Office.

(Extracts from H. O. Publication No. 590, Washington, 1946).

INTRODUCTION

The K.E.K. Stereoscopic Plotter has been designed to answer the urgent need for a plotting instrument that is relatively inexpensive, yet capable of automatically correcting all the information from the photographs, so that an accurate planimetric and topographic map is drawn to scale in one operation.

GENERAL DESCRIPTION

The K.E.K. Stereoscopic Plotter consists of the following four basic elements :—

1.—A front surface mirror stereoscope that is mounted so that the principal line of sight from each eye falls vertically onto the center of each photo-table, when the tables are level.

2.—A pair of photo-tables that are movably mounted in the plotter so that they can be raised or lowered vertically, with relation to the stereoscope, by means of a hand wheel on the left side of the plotter. The photo-tables are also provided with movements for rotating, tilting, and tipping the photographs in order to reproduce the relative position of the camera at the time of the original exposures.

3.—A floating mark which consists of a dot in the center of each of two lens discs which are interposed, in the line of sight, between the stereoscope and the photo-tables. The floating mark is mounted and adjusted so as to move freely in a horizontal plane.

4.—A drawing instrument that transmits the horizontal motion of the floating mark to a drawing pencil. This horizontal movement can be enlarged or reduced by the use of a pantograph that is an integral part of the drawing assembly.

The following terms are used in describing the K.E.K. Stereoscopic Plotter. The numbers refer to figure 1.

1. Photo-table.
2. Photo-table cross lines.
3. Level photo-tables, adjustment.
4. Azimuth adjustment.
5. Tilt adjustment.
6. Tilt scale.
7. Tip adjustment.
8. Tip scale.
9. Photo scale difference adjustment.
10. Dot.
11. Plotting scale change, adjustment.
12. Horizontal bar.
13. Vertical scale.
14. Vertical scale control.
15. Vertical scale pantograph ring.
16. Vertical scale gap span ring.
17. Vertical scale sliding marker.
18. Vertical scale outside pointer
19. Blank scale.
20. Handwheel.
21. Drawing arm.
22. Drawing arm perch adjustment.
23. Parallel arms.
24. Parallel arm bearing.
25. Drawing head.
26. Dial gauge.
27. Plotter table.
28. Test plate bracket.
29. Elevating arm.
30. Vertical shaft.
31. Vertical shaft cam adjustment.
32. Wing mirror bracket.
33. Wing mirror.
34. Wing mirror adjustment.
35. Eyepiece.
36. Eyepiece adjustment.

(*) Instrument can be obtained from : Philip B. Kail Associates, 2535 Elm St., Denver 7, Colorado (U.S.A.).

Patented by J. E. King, John W. Elliott and P. B. Kail, Assignors to the Secretary of Agriculture of the United States U. S. Patent No. 2,263,971.

37. Sight.
38. Stereoscope bars.
39. Eye mirror.
40. Eye mirror adjusting screws.
41. Lens holders.
42. Headrest.
43. Light.
44. Pantograph.
45. Pantograph left arm.
46. Pantograph right arm.
47. Drawing pencil.
48. Plotter base.
49. Sliding angle bars.

THEORY

The principle of the plotter is the establishment of a horizontal datum plane with the floating mark. This plane can be raised or lowered by varying the distance between the two dots which make up the floating mark. The scale at which the plotter draws is also dependent on the distance between the two dots. With this datum plane established, the stereoscopic model is then brought into this plane by raising or lowering the photo-tables.

It should be noted that, in the plotting process, the K.E.K. Stereoscopic Plotter draws both planimetry and contours to a selected scale and in its true geographic position on a map projection. This of course, is accomplished by raising or lowering the photo-tables which automatically changes the plotting scale to agree with the change in scale in the photographs due to relief in the terrain.

The stereoscope is also mounted so that the principal line of sight from each eye falls vertically onto the center of each photo-table when the tables are level. When the tables are tilted, the principal line of sight from each eye falls vertically onto the plumb point of their respective photographs. When the photo-tables are raised or lowered each dot appears to move on a line radial from its respective plumb point. Therefore, when the dots fuse into the floating mark, and that mark is then brought into coincidence with the apparent model, the intersection of two radial lines has been obtained and the solution of a radial line plot is thereby accomplished optically.

ADJUSTMENT OF PLOTTER

1° a) Level table, adjustments are on three legs for this purpose ;

b) Level the two sliding angle bars, adjustments are on four screws.

2° Install the glass test plate on the three brackets and adjusting screws in the opening in the plotter's base, and then level the plate with the three adjusting screws, using a fine spirit level.

3° Adjust the drawing arm to move parallel to the test plate :

a) Adjust only the drawing arm perch, using 2 set screws, 1 round screw and 3 bolts :

b) Adjust arm to read within .005 inches over entire test plate.

4° Remove the glass test plate.

5° Plumb the vertical shaft.—Make plumb by adjusting with cam and lock nut on upper end of vertical shaft.

6° Level the photo-tables in both "X" and "Y" axis by means of the tip and tilt screws.

7° Align the photo-tables by stretching a string between centers and revolving the tables with the azimuth screws.

8° Bring the photo-tables to the same level by means of the knurled adjustment screw on the right elevating arm.

9° Re-level the photo-tables in both the "X" and "Y" axis. (Item 6).

10° Align the wing mirrors :

a) Set at 45° ;

b) Make the horizontal axis of mirror parallel to cross-line on photo-table by measuring vertically from the line with a triangle. The adjustment is made by loosening the nut on the back of the wing mirror and then adjusting the screw on the front of the lower stereoscope bar. The distance between the cross-line and the wing mirror should be the same at both the front and the rear of the wing mirror.

11° Align the eye mirrors :

a) Check to see that mirror assembly is aligned and screws equally balanced. Screws under mirror should not be bearing. The final adjustment is made by means of three screws under the mirror ;

b) Set mirrors at 45° angle using a spirit level;

c) Set notched sight on mirror plumb with the "X" axis of the machine. Use a plumb bob dropped from the notched sight down to the taut string and move sight in line;

d) Make the taut string, and its images seen in both mirrors, line up when sighted vertically through the eye piece with one eye. Adjust image coincidence by means of the two lower screws under each eye mirror ;

e) Raise or lower edge of mirror until the center of one photo-table seems to be superimposed about 1 1/2" from the edge of the other table. Note that this distance is a variable which is dependent upon the air base. However, small changes in the air base measurement can be compensated by the use of supplementary lens pieces ranging from — .50 diopters to + 1.00 diopters.

12° Align sights.—When the sightline on the wing mirror is viewed through both the eye piece and the notched sight, it should line up with the taut string that is on the "X" axis of the plotter.

13° Set wing mirror for vertical vision onto center :

a) Loosen bolt at rear of mirror bracket ;

b) Slide mirror assembly in or out on the stereoscope bar until the dot will remain on the "Y" axis of its respective photo-table when the photo-tables are raised or lowered;

c) Tighten bolt at rear of mirror bracket;

d) Set the dot on the "X" axis of its respective photo-table so that it will remain on the "X" axis when the photo-tables are raised or lowered. Adjustment is made by twisting the horizontal bar or loosening and tightening alternate lock nuts on the horizontal bar. When the dot is placed over the center of its respective photo-table, the photo-table being level, there should be no movement of the dot when the photo-tables are raised or lowered.

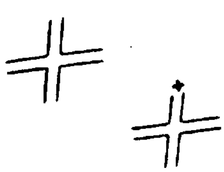
The above adjustments will result in the proper working of the instrument. However, a rapid test can be made by making a radial line template of two theoretical photographs and then check the instrument points obtained from the theoretical photographs with the radial intersections of the same points.

OPERATION

Placement of Photographs.— The first step in operating the K.E.K. Stereoscopic Plotter is to place the proper stereoscopic pair of photographs on the photo-tables of the instrument and align the collimation marks of the photographs with the cross marks on the photo-tables. This places the center of the photographs over the center of the photo-tables. The photographs should be held absolutely flat on the photo-tables by means of glass plates, spring clips, or other means, as any buckle will introduce serious errors in plotting.

Relative Orientation.—When the photographs have been properly placed and fastened on the photo-tables, the photo-tables are then rotated in azimuth, tilted, and tipped to remove all "Y" parallax. The term "Y" parallax shows up as a separation of the dots along the "Y" axis of the plotter; it may be caused by any form of incorrect relative orientation of the photographs. The images on the photographs that are being viewed have the "Y" parallax, but because the images are so numerous and the eye fuses them into a stereoscopic model, this Y-parallax shows up in the dots of the floating mark.

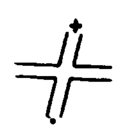
This is how they are :



The dots lined up along the "X" axis of the Plotter.
The Y-parallax is the image of the cross road.

. = left dot
+ = right dot

This is how you see it :



The images of the cross road are fused, although they have "Y" parallax thereby causing the appearance of the Y-parallax of the dots.

The movement of a photo image in any direction will cause a similar but opposite direction movement of its respective dot. Therefore, the removal of the " Y " parallax of the dots places the photographs in relative orientation to each other. The " X " parallax, due to the differences in ground elevation on the stereoscopic model is controlled by the vertical movement of the photo-tables. This parallax shows up as a separation of the dots along the " X " axis of the plotter.

The best way to detect and classify " Y " parallax is to turn the hand wheel, thereby raising the photographs until the floating mark is forced down through the ground separating the two dots by about 1/8" along the " X " axis. This places the right and left dots on their respective sides on the stereoscopic model. Any separation of the dots along the " Y " axis can then be observed. The easiest way to remove " Y " parallax is to maintain one photo-table level, and to enter all the tilt and tip into the other photo-table.

The following are the four factors that can cause " Y " parallax :

a) *Incorrect azimuth.*—Check for " Y " parallax at the centers of both photographs. Deviation of the floating mark from the " X " axis is removed by revolving both of the photo-tables by means of azimuth adjustments until the dots fuse. The removal of parallax between the centers is critical, and should be checked frequently as operations proceed.

When the photo-tables are level and the correct azimuth obtained by the removal of " Y " parallax between centers, this is known as the principal point azimuth.

However, after tilt and tip are entered into the photograph and the correct azimuth obtained by the removal of " Y " parallax between centers, it is now known as the plumb point azimuth ;

b) *Scale difference between photographs.*—Check for " Y " parallax at both the top and bottom corners on the right hand side of the stereoscopic model. If the deviation of the dots from the " X " axis is equal, but in opposite directions, it is corrected by raising one dot and lowering the other. In cases of large scale differences between photographs the entire eye mirror assembly can be shifted in the desired direction :

c) *Tilt.*—Check for " Y " parallax at both the top and bottom corners on the right hand side of the stereoscopic model. If the deviation of the dots from the " X " axis is equal, and similar in both corners the parallax is removed by tilting the right hand photo-table. An over correction of from three to five times is necessary on this adjustment;

d) *Tip.*—Check for " Y " parallax at both the top and bottom corners on the left hand side of the stereoscopic model. If the deviation of the dots from the " X " axis is equal and in opposite direction it is corrected by tipping the right hand photo-table.

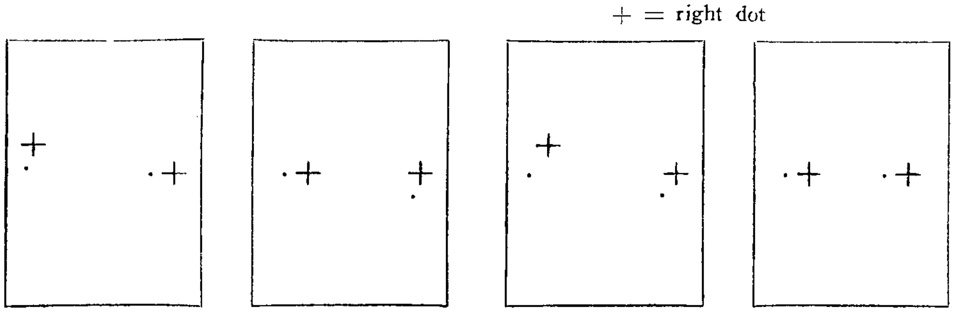
Usually a stereoscopic pair of photographs contains combinations of these conditions. The following diagrams show the possible combinations and the procedure to be followed in order to remove " X " and " Y " parallax from all portions of the stereoscopic model.

REMOVAL OF " Y " PARALLAX IN STEREOSCOPIC MODEL IN K.E.K. STEREOPLOTTER

Relative orientation.—Azimuth is entered into both of the photo-tables. The tilt and tip are entered into the right hand photo-table, however, tip, occasionally, will have to be entered into both photo-tables.

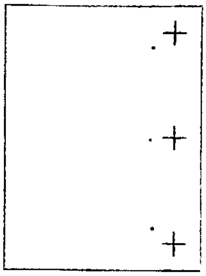
1.—AZIMUTH

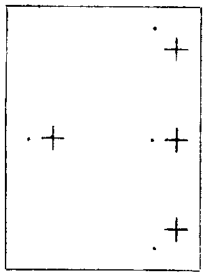
. = left dot
\+ = right dot

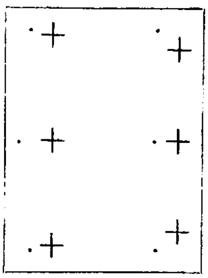


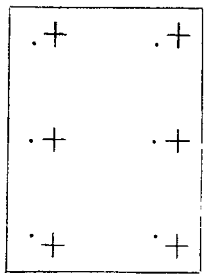
Turn right azimuth | Turn left azimuth | Turn both azimuth | Corrected

2.—SCALE DIFFERENCE


Lower right dot

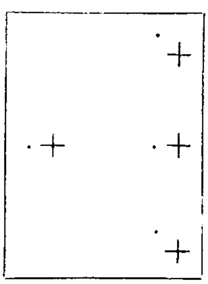

Raise right dot

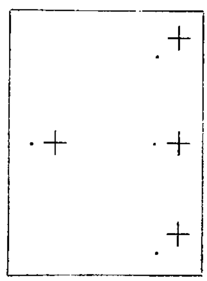

Raise right dot and raise left edge of right table


Lower right dot and raise left edge of right table

Removal of " Y " parallax can, sometimes, be speeded up by the examination of the dots on the left side of the overlap area, in addition to the right side of the overlap area, before any scale change is made. In this way the correct combination of tip and scale difference can be ascertained quickly. Whereas, ignoring the left side of the overlap area may require additional steps in the removal of Y-parallax. There are many combinations of the given examples that are possible, and many times the tip should be corrected prior to the scale change.

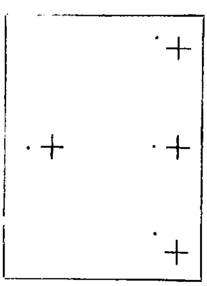
3.—TILT

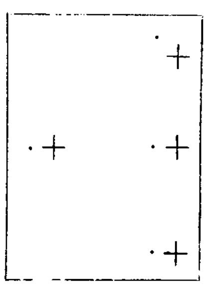

Tilt right table shift toward operator

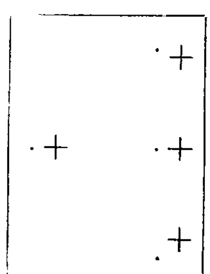

Tilt right table shift away from operator

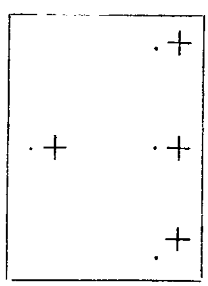
It was pointed out before that the dot moves in the direction opposite to the movement of the photo-table. Therefore, when it is desired to move the dot toward the operator the photo-table should be moved away from the operator. The tilt correction should be over-corrected approximately 4 or 5 times. Then recorrect the azimuth, Step 1.

4.—COMBINATION SCALE DIFFERENCE AND TILT



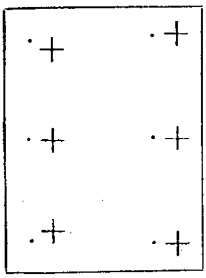




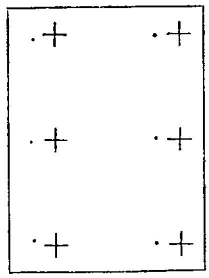


Correct with scale difference adjustment until the dot " Y " parallax is equal in both corners, that is, the right hand dot should be the same y-distance away and in the same direction, from the left hand dot. Then correct with tilt, Step 3, which then requires additional azimuth correction, Step 1.

5.—TIP



Lower the left edge of the right table



Raise the left edge of the right table

When correcting for tip, raise or lower the photo-tables, as the adjustment is being made, in order to keep the dots separated, along the x-axis, about 1/8". When the y-parallax is completely removed, by the steps that are outlined, there should not be any y-parallax left in any part of the model.

A.—Setting to Scale

After all of the "Y" parallax has been removed and the dots can be made to fuse perfectly over all portions of the stereoscopic model, the plotter is set to draw at the proper scale. This is accomplished by placing the right hand dot over the principal point of its photograph, and at that position place the drawing pencil point over the previously located principal point of the photograph on the compilation sheet. Move the drawing pencil point to the adjacent principal point of the stereo-model. The left hand dot then will have to be moved in closer or out further on the horizontal bar until the dot falls directly over the principal point of its photograph.

The plotting scale varies inversely with the distance between the dots, i.e., a greater distance produces a smaller plotting scale.

The distance between the two dots is controlled by the compilation scale, and that in turn controls the portion of the vertical scale that is used, because the distance between the two dots determined the apparent plane in which the mark seems to float. In order to be able to see the dots clearly, the photo-tables should be kept reasonably close to the dots. This can be done by changing the setting on the pantograph, thereby determining the distance between the dots.

B.—The Pantograph

The pantograph is used to set off roughly the larger differences between photographic and compilation scales. The final adjustment being made by varying the distance between the dots, as described in A. (Setting to Scale.)

The pantograph has a left and a right arm labelled respectively "L" and "R", and in each arm is a series of numbered holes. In setting to scale, the drawing head of the drawing assembly is fastened in a hole in one arm and the drawing pencil is fastened in the correspondingly numbered hole in the other arm. The position of the attachment of the drawing head is used as the determining factor in all calculations and adjustments; positions in the "L" arm exaggerate the horizontal movement of the floating mark, while positions in the "R" arm result in a reduction. The amount of enlargement or reduction varies directly with the number of the hole selected. Since most of the scale change can be handled by the pantograph, it is usually possible to select holes which will allow the dots to be set closer together and thus permit the photo-tables to operate in the upper range of the vertical motion. This has the advantage of keeping the photographs close to the operator's eye.

C.—Absolute Orientation

After the plotter has been set to draw to scale, the stereoscopic model must be horizontalized to the datum or brought into absolute orientation. To horizontalize, the stereoscopic model is tilted and tipped until the differences between the known elevations, as read on the plotter's vertical scale, coincide with the actual differences. Removing the Y-parallax placed the stereoscopic pair of photographs in its correct relative orientation to one another. Therefore, when one plate is moved in the horizontalizing process the other plate must be moved exactly the same amount and in the same direction. Excessive tipping of the stereoscopic model also causes a difference in scale between the photographs which must be corrected by readjusting the relative height of the dots.

After the model has been horizontalized, the compilation sheet should be moved to obtain the best possible scale fit on the wing points. If the drawing scale must be changed to fit the wing points, the distance between the dots must be changed, bearing in mind that the scale varies inversely to the distance between the dots.

D.—The Vertical Scale

This scale is a graphic means of measuring the vertical movement of the photo-tables. It is so calibrated as to convert this movement into actual feet for any relation between photographic and compilation scale within the range of the plotter.

The scale is a cylinder marked with vertical lines, representing the compilation scale, and spiral curves representing the vertical interval. The intersection of a compilation scale line with the vertical interval curves indicates graphically the appropriate vertical interval for the scale.

The following is the formula for computing the vertical lines representing the compilation scale.

$$x = \frac{5 \log \frac{A}{B}}{\log 2}$$

x = Distance to the vertical line in inches from the right hand side of the vertical scale, for the desired compilation scale.

B = The desired compilation scale.

A = The compilation scale as indicated on the right hand side of the vertical scale.

E.—Adjustment of the Vertical Scale

On the vertical scale is a ring with a double set of numbers, corresponding to the numbered holes in the pantograph, and designated " L " and " R " respectively to correspond to the left and right arm of the pantograph. There is also a ring with markings " A " and " B ". This ring is used to span the gap on the vertical scale.

After the correct pantograph arrangement has been found, the scale is set for the proper vertical interval by placing the " O " of the numbered ring on the appropriate compilation scale and then revolving the whole cylinder until the sliding marker, which is attached to the photo-table assembly, is aligned with the number and letter of the pantograph hole into which the plotter drawing head is fastened. The knurled screw at the top of the scale holds the cylinder in position when tightened. To make the vertical scale read correctly within the 100 foot intervals, a small adjustment can be made by shifting the vertical scale cylinder up or down on the cylinder thread. In the event that the sliding marker when aligned with the proper pantograph number, falls within the gap on the vertical scale, the procedure is as follows : Place the gap span ring so that " A " and " B " line up with the gap and then revolve the cylinder so that either " A " or " B " just clears the gap. The sliding marker is then in the proper position to move vertically over the section of the scale which gives correct intervals of elevation for the horizontal scale setting in question. The blank loftrite strip on the front of the plotter is used to mark the elevations involved in a given set-up after the vertical scale has been set.

The following is the derivation of the formula used in the calibration of the vertical interval curves of the vertical scale.

D = Distance from eye to photo-table in inches.

d = Distance from eye to dot.

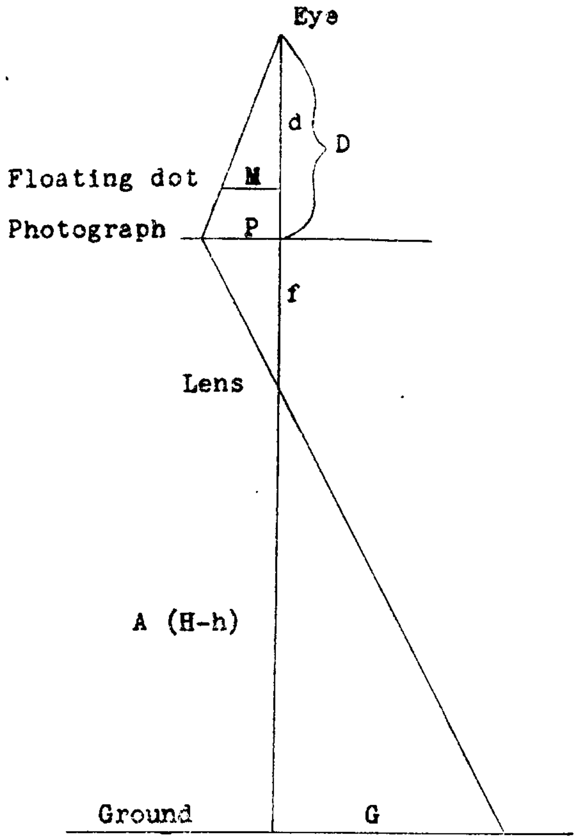
M = Distance on map or movement of floating dot.

P = Distance on photo.

f = Focal length.

A = (H-h) = height of camera above the ground.

G = Distance on ground.



By similar triangles

$$\frac{A}{f} = \frac{G}{P} \qquad \frac{D}{P} = \frac{d}{M}$$

$$AP = GF \qquad dP = DM$$

$$P = GF \qquad P = \frac{DM}{d}$$

$$\frac{DM}{d} = \frac{Gf}{A}$$

$$ADM = Gfd$$

$$D = \frac{Gfd}{AM}$$

$\frac{G}{M}$ scale of map "s"

The following is a list of the tools required for the adjustment of the K.E.K. Stereoscopic Plotter

Carpenter's level (2 foot) ; 3/8" and 7/16" socket wrench ; 6" crescent wrench ; 1 pair pliers ; 1 pair needle nose pliers ; 1 short shank screw driver ; 1 short wide base screw driver ; 5/16", 3/8", 11/32" open end wrenches ; 1 small plumb bob ; 96 Starrett Bench level — 4" base with ground and graduated vial reading 10".

For further information on the K.E.K. Stereoscopic Plotter refer to *Photogrammetric Engineering*, Volume 10, No. 4.

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Elementary Exercises in Topographic and Structural Geology (1934), by A.K. Lobeck (The Geographical Press, Columbia University, N. Y.).

Military Maps and Air Photographs, by A. K. Lobeck and Wentwork J. Tellington (McGraw Hill Book Co., N. Y.).

(*) s, f and d are known values so if a height A is substituted in the formula a distance D can be found. By changing the height A by constant differences; i.e., 100 ft. or 20 ft. the corresponding movement of the photo-table is found, and the vertical scale is plotted.