TOPOGRAPHIC INSTRUCTIONS
of the
UNITED STATES
GEOLOGICAL SURVEY

Kelsh Plotter Procedures

BOOK 3

CHAPTER 3F5

1960

TOPOGRAPHIC INSTRUCTIONS
of the
UNITED STATES
GEOLOGICAL SURVEY

Kelsh Plotter Procedures

Instructions in the standard operating procedures
for the Kelsh plotter, including
a description of equipment

BOOK 3—MAPPING PROCEDURES
Part 3F—Stereocompilation Procedures
Chapter 3F5—Kelsh Plotter Procedures

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1960

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price 35 cents (paper cover)

PREFACE

The Geological Survey Topographic Instructions describe the engineering standards, methods, and procedures used by the Topographic Division in the production of topographic quadrangle maps. Although the instructions are prepared primarily for the guidance of Survey employees, private individuals and organizations engaged in similar work find them a useful reference; therefore they are being published in a series of volumes. The preceding Topographic Instructions were published as Geological Survey Bulletin 788, in 1928. Since then, many supplements have been issued in the form of technical memorandums, and a considerable part of the present manual has been prepared in looseleaf form for use within the Topographic Division. Where applicable, all preceding instructions are incorporated into the present manual.

The Topographic Instructions are divided into five numbered books; each book contains one or more parts, designated by letters; and the parts are divided, in turn, into numbered chapters. In preparing the manual for publication the chapters have been grouped into volumes, in the established sequence, so that each volume covers a single subject or phase of activity, as nearly as possible. The series of volumes describes all the steps of map production, generally in the order in which they are carried out. The complete series will constitute a comprehensive manual of topographic surveying and mapping.

The volumes published and scheduled for publication are listed below, with the title, a short note on the contents, and the part and chapter or chapters included in each volume. For published volumes, this information is printed in boldface type, and the date of publication or revision is given. These volumes are for sale by the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

The other listed volumes are being prepared, but were not available for sale on the date this volume was published. When they are published, they will be announced in the monthly list "New Publications of the Geological Survey" (available free on request) and listed in "Price List 53" of the Superintendent of Documents.

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Chapter 3F5

KELSH PLOTTER PROCEDURES

ABSTRACT

The Kelsh plotter is a stereoscopic mapping instrument of the double-projection anaglyphic type. It has four main distinguishing features: the use of contact-size diapositives, a moving illumination system that concentrates light on the part of the diapositive image that is projected to the tracing table platen, a model scale about five times as large as the diapositive scale, and (for use only if required) a cam arrangement for adjusting the principal distance of the projectors to achieve proper compensation of the aerial camera lens distortion. Several different models of the Kelsh plotter have been successively developed. By renovation of older instruments, the Geological Survey has reduced its Kelsh plotter equipment to two types: the GSI-23 (1951) model and the Revised GS (1953) model. Careful calibration of the various component parts of the Kelsh plotter is required for proper functioning of the instrument. The orientation procedure used with the instrument is similar, in general, to that used with the multiplex, but there are some variations. Aerotriangulation for areas to be compiled with the Kelsh plotter is accomplished by use of other instruments or methods that can perform this operation more conveniently.

PRINCIPLES OF THE KELSH PLOTTER

1. Schematic similarity to multiplex and ER-55

The Kelsh plotter recreates natural terrain features at a miniature scale by double optical projection. The projected images are those of two overlapping aerial photographs properly oriented to each other and to the datum. The multiplex, ER-55, and Kelsh plotter are similar in the following respects:

a. Projection system.—For each of two projectors, light emanating from a lamp passes through a monochromatic filter, is projected through a glass diapositive, is condensed at the aperture of the projector lens, and forms an image on the viewing screen. Two properly oriented projectors are used simultaneously, one bearing a red filter and the other a blue filter; the diapositives used in the two projectors represent two overlapping photographs in the same flight strip. The pattern formed by the images projected on the viewing screen in two colors constitutes an anaglyph.

b. Viewing system.—In viewing the anaglyph, the observer wears spectacles having one red and one blue lens. One eye is thereby permitted an independent view of one of the projections, whereas the other eye obtains an independent view of the second of the overlapping pair. The combined effect of the simultaneous views is the perception of a three-dimensional model.

c. Measuring system.—A floating mark, centered in the surface of the viewing screen, or platen, provides the means of measurement within the stereoscopic model. Vertical motion of the floating mark is obtained by raising or lowering the platen; this motion can be measured by means of a height-indicating scale. Horizontal motion is obtained by sliding the tracing table, on which the platen is mounted, over the map surface; this motion can be recorded by means of a pencil or pointer mounted vertically below the floating mark.

d. Orientation procedure.—Relative orientation is achieved by the swing-swing method. Absolute orientation of a model comprises three operations: adjusting the model to the proper scale, orienting the model datum parallel to the tabletop, and positioning the model with reference to the horizontal datum.

e. Compilation procedure.—Planimetric detail is compiled by guiding the tracing table so that the floating mark follows the feature being compiled. The floating mark is kept "on the ground" by manipulating the vertical motion of the tracing-table platen. The feature is delineated on the map manuscript by a pencil that reproduces the motion of the floating mark in a horizontal plane. Contours are drawn by maintaining the platen at the appropriate fixed height and guiding the tracing table so that the floating mark remains in contact with the apparent surface of the terrain.

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2. Distinguishing features of the Kelsh plotter

a. Single-model instrument.—Because the design of the Geological Survey Kelsh plotter has been greatly influenced by economy and ease of operation, facilities necessary to relate successive models to each other have been intentionally omitted. The Kelsh plotter is primarily a compilation instrument and is dependent upon supplementary photogrammetric techniques to accomplish stereotriangulation. Because the Kelsh plotter is limited to the restoration of but one model at a time, it is referred to as a single-model instrument.

The single-model design reduces the number of precise adjustments needed on each of the two projectors of the instrument. Each projector is provided with a translating motion along only one of the three photogrammetric coordinate axes. This linear adjustment, referred to as the x motion, is parallel to a line connecting the two projector stations; the path of this adjustment is in effect coincident with the flight line between the two relevant exposure stations. Each projector is equipped with rotational adjustments about each of the three mutually perpendicular axes. The instrument also has provision for rotating both projectors as a unit without disturbance to their relative orientation.

b. Diapositives.—The Kelsh plotter utilizes contact-size diapositives; that is, diapositives having the same format as the negatives. In standard Geological Survey practice, the format is 9 by 9 inches. The 9- by 9-inch image is printed on glass plates measuring 9½ by 9½ inches. Acceptable diapositives for use in the Kelsh plotter can be made in a relatively inexpensive contact printer; however, the Geological Survey has developed a 1-to-1 projection printer for producing contact-size diapositives of superior quality.

c. Illuminating system.—A principal distinctive feature of the Kelsh plotter is its means of illumination. Each of the two lamp-filter-condenser assemblies, generally called the lamp house, rotates about the rear node of its corresponding projector lens. The positions of the lamp houses are governed by guide rods that are attached to the tracing table. The monochromatic light emanating from a lamp house passes through a part of the glass diapositive; the image is condensed at the aperture of the projector lens and is directed toward the platen of the tracing table. Almost all the available illumination is concentrated upon the part of the model being observed.

This swinging-light illuminating system, permitting the projected light to scan the diapositive, makes the use of contact-size diapositives feasible because it eliminates the bulky and impractical equipment required for direct projection of the entire 9- by 9-inch image. The intensity of the available illumination is ample for providing good imagery at the usual projection distances ranging from 23 to 36 inches (585 to 915 mm).

d. Model scale—use of pantograph.—The Kelsh plotter projectors have a nominal principal distance of 6 inches (152 mm) to match the aerial camera focal length of 6 inches. The optimum projection distance is 30 inches (760 mm) so that the image is projected at a 5-times magnification in the optimum plane of projection.

The large scale of the Kelsh plotter model contributes to the ease and accuracy of identifying and delineating map detail. However, if the map were compiled at the same scale as the model, the manuscript scale would be inordinately large in relation to the usual publication scales for Geological Survey maps. Compilation at model scale would involve several uneconomical procedures, such as the preparation and handling of a large number of original manuscript sheets and the delineation and drafting of detail at the large scale, requiring greatly increased time as compared to smaller scale work. For these reasons, a pantograph is attached to the tracing table so that the compilation may be executed at a practical scale. Furthermore, the pantograph permits a more versatile use of the available plotting instruments; for example, a reduction setting of 2.1 times on the pantograph permits interchangeability of the manuscript in the Kelsh plotter and the multiplex. Thus, stereotriangulation can be performed on the multiplex and the same base sheet can be used for compilation with the Kelsh plotter.

e. Distortion compensation.—To obtain precise results with stereoplotting instruments, it is necessary to provide some means of compensating significant optical distortion. In the Kelsh plotter this problem was solved originally by utilizing the mechanical linkage of the lighting system to adjust the principal distances of the projectors by amounts sufficient to compensate the distortion at each differential portion of the diapositive as it is scanned. The desired variation in principal distance is a function of the radial distortions introduced by the optical systems of the aerial camera and the projection apparatus. Each projector is equipped with an aspheric ball cam used to govern the variation in principal distance in accordance with the locality under observation in the model. The rotational motion of the cam is controlled by, and made identical to, the rotational motion of the corresponding lamp house about the rear node of the projector lens. This motion is transmitted from the mechanics of the lighting system to the cam by a mechanical linkage. The shape of the cam is designed so that it will raise or lower the projector lens by predetermined amounts for the various angles through which the cam can be rotated. The lens movement is restricted to a linear direction coincident with its optical axis.

Subsequent to the acquisition of Kelsh plotters by the Geological Survey, new developments have made it possible to eliminate the need for the aspheric ball cam in most cases. One development is the utilization of photography taken with low-distortion lenses such as the Aviogon, Pleogon, and Planigon; the amount of distortion in these lenses is so small that no compensation is required. A second development is the use of projection-type diapositive printers equipped with aspheric distortion-compensation plates; compensation for appreciable lens distortion is achieved in the printing operation, thus eliminating the need for the aspheric ball cams in the Kelsh plotter. In general, the cams in the Geological Survey Kelsh plotters have been deactivated, but not removed from the projectors.

f. Orientation procedure.—Although the general principles of orientation are similar for the Kelsh plotter and the multiplex, some details of the procedure are different. As the Kelsh plotter has no z motion and limited or no y motion, relative orientation must be accomplished by the swing-swing method or by some variation of it. The orientation procedure is described in article 29 below.

g. Applicability.—The stereoscopic model formed by the Kelsh plotter has favorable qualities of illumination, resolution, and magnification. According to statistical studies of accuracy checks of completed maps, the usable C-factor for the Kelsh plotter ranges from 850 to 1,200, depending on the conditions. Some of the variables affecting the usable C-factors are: flight altitude, atmospheric conditions, light intensity, character of terrain, woodland and other cover conditions, seasonal variation in appearance of terrain, and camera characteristics (including metric and photographic quality). In Geological Survey stereocompilation operations, the Kelsh plotter generally is used where a 5- or 10-foot contour interval is required.

KELSH PLOTTER EQUIPMENT

3. Types of Kelsh plotter equipment

Because of the rapid development of the Kelsh plotter, a number of different models have been produced by the manufacturers. Each successive design has represented an effort to overcome previous mechanical deficiencies and incorporate desirable features suggested by experience. A description of all the variations in Kelsh plotters is beyond the scope of this chapter; however, the principal types and their characteristics are listed in table 1.

The Geological Survey has developed and acquired several different types of Kelsh plotters, alike in principle, but differing in mechanical details. Of these instruments, the older ones have been modified in various ways to incorporate new developments so that there are, in effect, only two models in use: the GSI–23 (1951) model and the Revised GS (1953) model. The discussion of Kelsh plotter equipment in this chapter applies particularly to the Revised GS (1953) model. Important differences that apply to the GSI–23 model are noted where necessary.

TABLE 1.—*Some characteristics of various models of the Kelsh plotter*

Model designation	Manufacturer	Year	Principal distance (millimeters)	Projection distance (millimeters)	Principal distance adjustment	Y motion	Level bubbles	Center plate support	Remarks
Normal angle.	Instruments Corp.	1948	210	840	No	No	No	No	
Commercial.	---do-----	1949–53	150–156	760	1949–50 No 1951–53 Yes	1949–50 No [1] 1951–53 Yes	No	Yes	
Abrams----	Abrams Instrument Corp.	1949	150–156	760	Yes	No	No	Yes	
GSI–23----	Instruments Corp.	1951	150–156	760	Yes	[1] Yes	No	Yes	Heavy frame. No adjusting wheels on feet of frame.
Revised GS.	---do-----	1953	150–156	760	Yes	[1] Yes	Yes	No	Improved guide rods and lens assembly.

[1] Small amount.

4. Components of the Kelsh plotter

Figure 1 shows a complete Kelsh plotter manufactured according to the revised Geological Survey design. The main components of the instrument are the table frame (1), tabletop (2), supporting frame (3), projector-track frame (4), two projector assemblies (5), two illuminating units (6), two guide rods (7), tracing table (8), pantograph (9), and electrical accessories (10, 11).

5. Table frame

The table frame consists of an **X**-frame (12) and end brackets (13) joined rigidly together and supported on four legs (14). Four adjustable foot screws (22) provide stable support and a means of leveling the tabletop. The foot screws rest on flat circular footplates (23) placed in position on the floor. (The instrument should be placed on a solidly constructed floor.) The legs are braced against each other and against the **X**-frame in such a manner as to increase the stability of the frame without interfering with the operator's movements.

6. Tabletop

The tabletop generally consists of a slate slab, 2½ inches thick, with a smooth working surface on the top, measuring 46 by 56 inches. This working surface also serves as a reference plane for vertical measurements. The top surface of the table must not deviate more than 0.002 inch from a plane. When the foot screws have been adjusted so that the reference plane is horizontal and the instrument is stably supported, the table frame and tabletop are in the desired positions. A further adjustment can be made by means of four adjusting screws on the **X**-frame; these screws make it possible to obtain the proper clearance between the pantograph and the working surface.

7. Supporting frame

The supporting frame is composed of two end frames (15) connected by two spacing bars (16). Four support screws (17) provide the means of rigidly positioning the supporting frame on the end brackets (13) at the desired height above the tabletop. These screws are not intended to be used for leveling the stereoscopic model. The support screws fit in slots (18) in the end brackets. These slots permit some leeway in positioning of the supporting frame in the y direction. The supporting frame contains three screws (19), one at the left end and two at the right end for supporting and adjusting the projector-track frame.

8. Projector-track frame

The projector-track frame is composed of two parallel bars (20) (also 12, fig. 2), one round and one rectangular in section, connected by the end-connecting bars (21). The parallel bars provide the track along which the

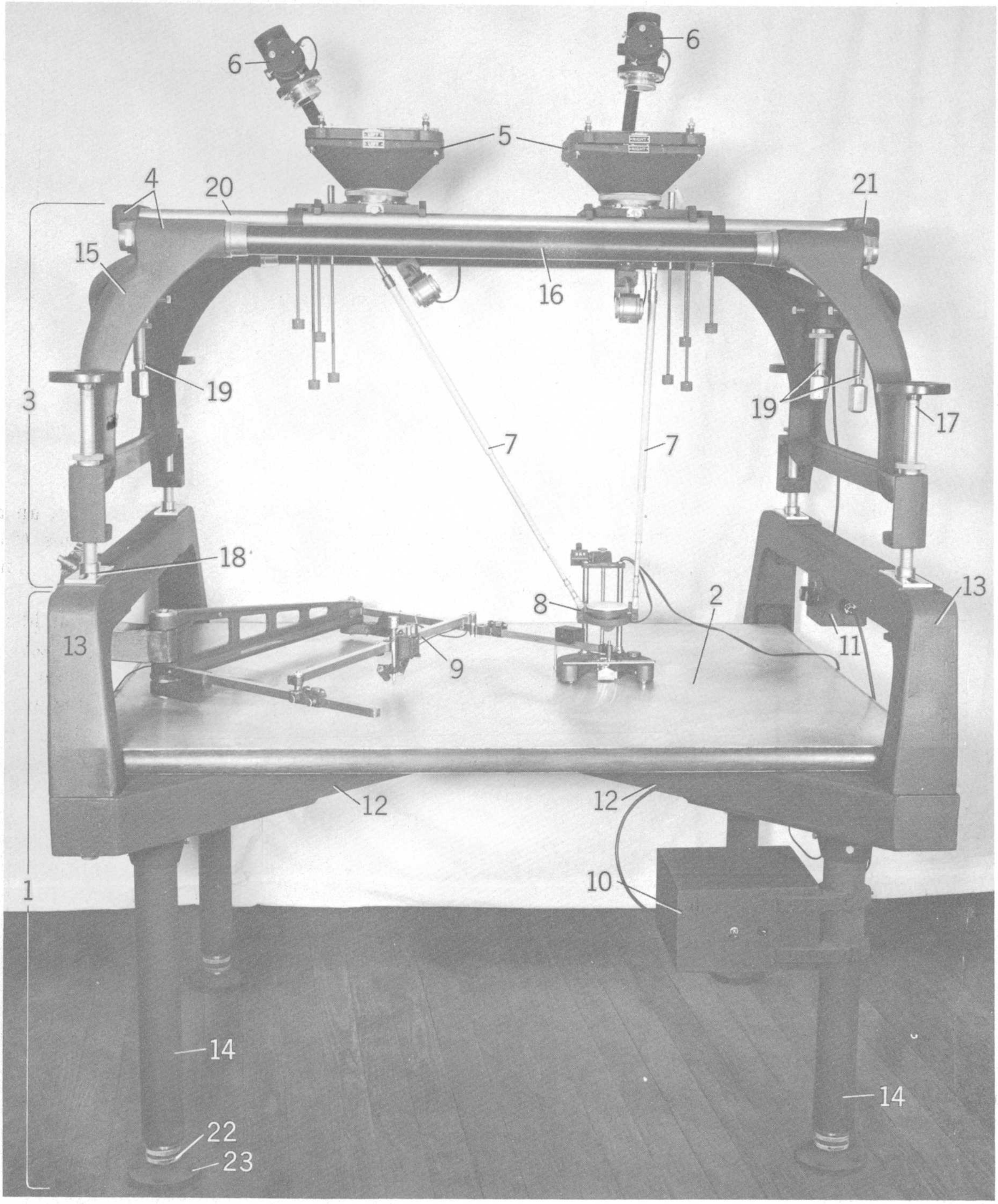


FIGURE 1.—General view of Kelsh plotter.

two projector assemblies may be moved in the x direction.

9. Projector assembly

In figure 2, a projector assembly is shown mounted on the parallel bars of the projector-track frame. The projector base is attached to the parallel bars in a manner which allows the assembly to be adjusted in the x direction. The two **V**-pads at the front of the projector base slide along the round bar, and the rear end rides on a ball-bearing roller along the rectangular bar.

For a large x motion, a clamp screw (1, fig. 2) may be loosened and the assembly moved along the parallel bars. For a small x adjustment, the clamp screw is tightened, and the fine x adjustment (2, fig. 2) is used. The projector is rotated to effect a change in the azimuth of the diapositive by a swing motion. For a large amount of swing motion, the clamp screw (12, fig. 3) may be loosened and the projector rotated to the desired position. The clamp screw is then tightened and a fine swing adjustment made with a tangent screw (3, fig. 2). The x tilt adjustment (4, fig. 2) is used to rotate the projector about the x axis; the y tilt adjustment (5, fig. 2) is used to rotate the projector about the y axis. Large y tilts for adapting the projector to convergent photography may be obtained by depressing a clip at the rear of the projector (Revised GS model only). This adjustment should always be made cautiously—the projector should be stabilized with one hand while depressing the clip with the other. The thumb screw (6, fig. 2) provides the means of imparting a limited amount of y motion to the projector.

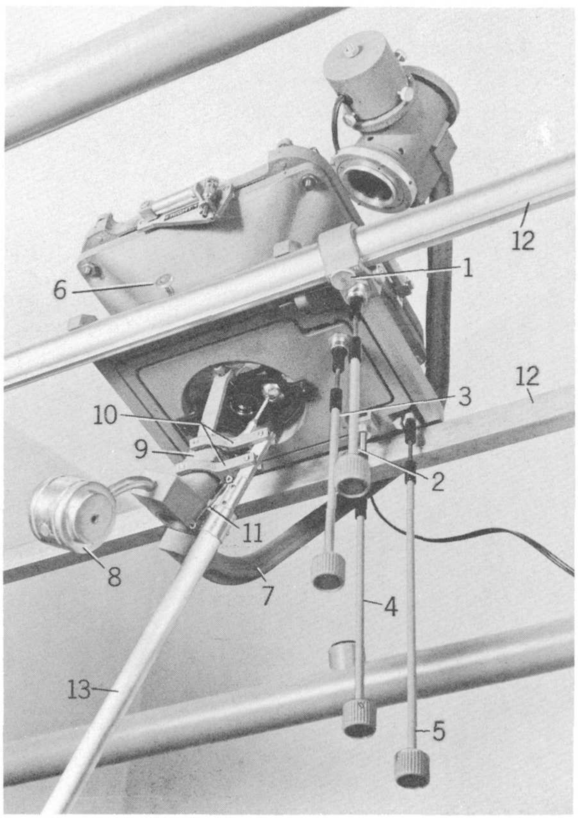


FIGURE 2.—Kelsh plotter projector.

Each projector consists of the following main components shown in figure 3: a plateholder (1), a projector cone (2), an x carriage (3), a y tilt plate (4), a principal distance ring (5), a swing adjustment ring (6), an x tilt plate (7), a gimbal ring (8), a lens (9), a lens mount assembly (10), and a yoke connector (11).

a. Plateholder.—The removable plateholders and the cones of the right and left projectors are shown in figure 4. The upper surface of each plateholder (1, fig. 4) contains a slightly raised machined surface for supporting the diapositive. The raised surface is finished to within 0.001 inch of a true plane. The plateholder must be handled with care to prevent damage to this machined surface. The plateholders for the right and left projectors are not interchangeable, and they carry identification tabs (2, fig. 4) to prevent placing the right plateholder on the left projector cone or the left plateholder on the right projector cone. Four transparent tabs (3, fig. 4) containing index marks are secured to the plateholder by screws. The intersection of lines extending across the opposite index marks indicates the principal point of the projector. The position of these tabs is adjusted during calibration and should not be disturbed. If it is suspected that they have been disturbed, a calibration check must be made. Each plateholder is equipped with 4 clamp lugs (4, fig. 4) that hold a $9\frac{1}{2}$- by $9\frac{1}{2}$-inch diapositive securely in position.

b. Projector cone.—The projector cone (5, fig. 4) is provided with four adjustable coni-

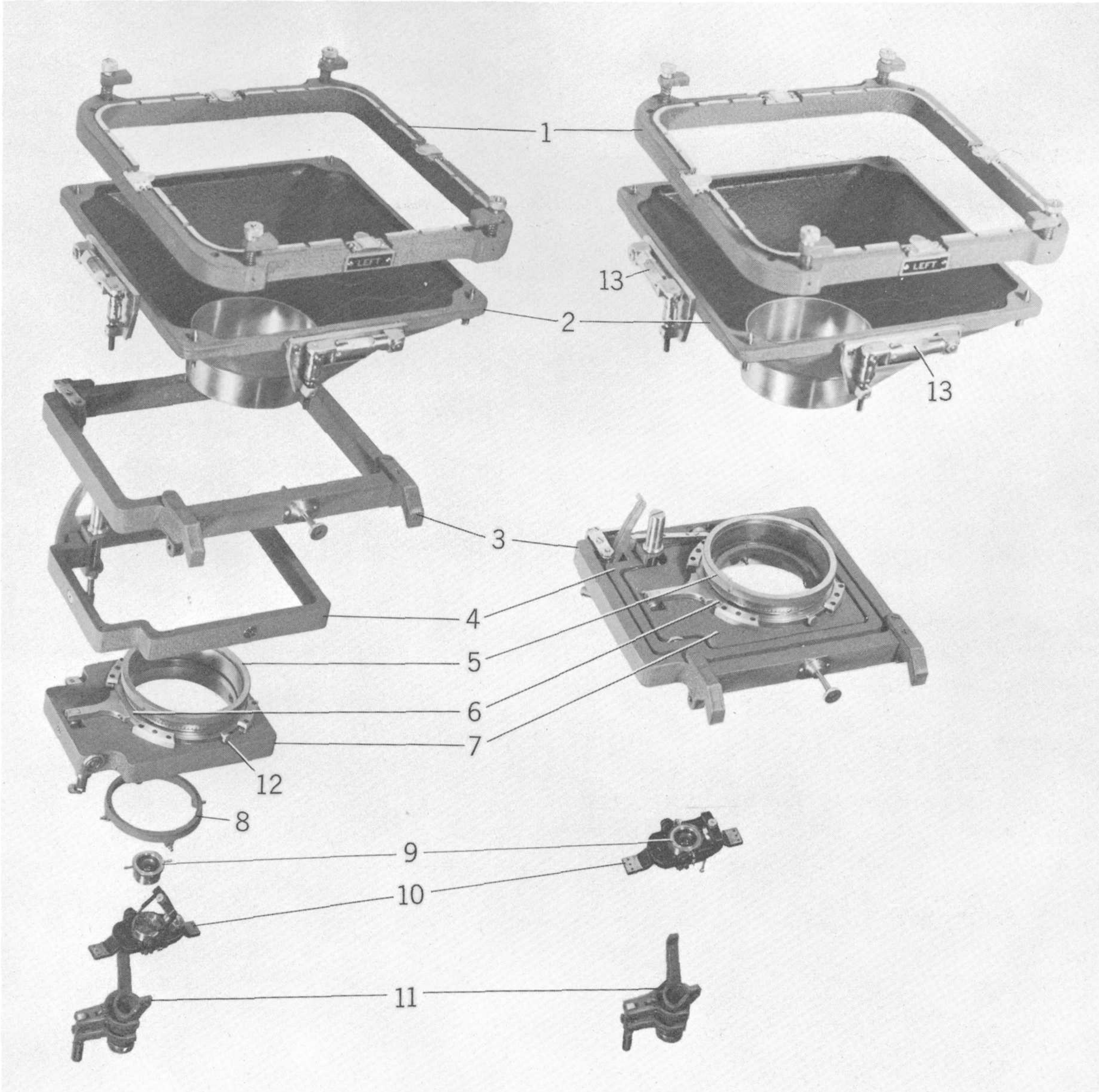


FIGURE 3.—Exploded view of projector assembly.

cally pointed screws (6, fig. 4) that support the plateholder. The points of support on the underside of the plateholder consist of a conical hole, a V-groove, and two flats. The four screws are adjusted during the calibration process to position the diapositive plane with reference to the projection lens. It is most important that the plateholder rest firmly upon all four screws. Failure of the plateholder to seat firmly on these screws indicates either the need of recalibration or a warped diapositive. (The rigidity of a warped diapositive 0.22 inch thick may be sufficient to cause the plateholder to depart from a plane.) The base of the projector cone fits into and rests upon the principal distance ring. The cones and rings of different projectors are not interchangeable and care should be taken to insure that the identification numbers stamped on the ring and on the underside of the cone are in agreement.

Two adjustable spirit levels (13, fig. 3) are mounted on each projector cone for measuring

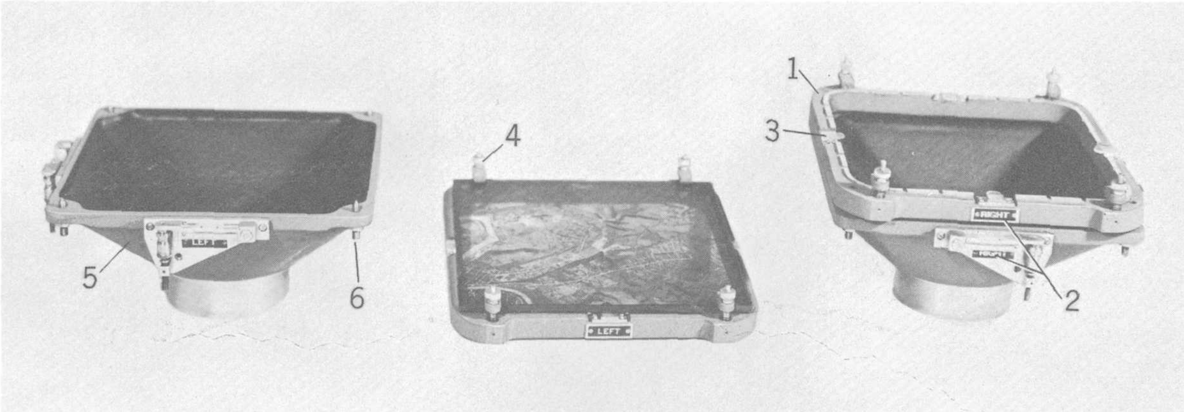


FIGURE 4.—Relationship of cone, diapositive, and diapositive holder.

x tilt and y tilt in bridging operations. As the Kelsh plotter is not used as a bridging instrument in Geological Survey practice, use of the spirit levels ordinarily is not required.

c. X-carriage assembly.—The x carriage (3, fig. 3) rests upon the parallel bars of the projector-track frame and contains bearings for supporting the y tilt plate (4, fig. 3). The y tilt plate is provided with bearings to support the x tilt plate (7, fig. 3). The x tilt plate contains the graduated principal distance ring (5, fig. 3). A swing adjustment ring (6, fig. 3) is held in position by four metal tabs attached to the x tilt plate. The swing adjustment ring is actuated by rotation of the swing adjustment handle (3, fig. 2) through a set of bevel gears and a tangent screw contained in the x tilt plate.

The gimbal ring (8, fig. 3) is supported by bearings housed in the x tilt plate. The gimbal ring is provided with bearings to support the yoke connector (11, fig. 3). When assembled, the gimbal ring and yoke connector permit the rotation of the illuminating unit about two mutually perpendicular axes that pass through the projector lens (9, fig. 3).

d. Lens mount assembly.—The lens mount assembly (10 fig. 3) is shown in more detail in figure 5. The assembly consists of a lens mount (1, fig. 5) containing a sleeve (2, fig. 5) lined with ball bearings. The projection lens (3, fig. 5), a hypergon-type lens having a nominal focal length of 5 inches (127 mm), is mounted in an outer housing (11, fig. 5) which fits into the sleeve. The ball bearings in the sleeve allow the lens to move in a direction coincident with the axis of the lens. Two springs (4, fig. 5), one at each end of the lens pin, hold the pin in contact with the lens bracket, thus keeping the cam follower in contact with the surface of the ball cam as shown in figure 6.

The lens bracket (5, fig. 5) is hinged by the bearings (6, fig. 5) and carries a cam-follower unit (7, fig. 5). The cam follower is adjustable

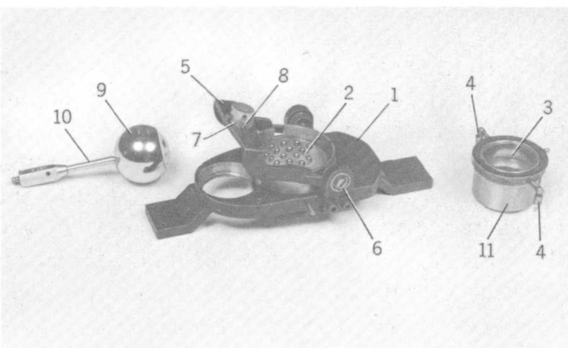


FIGURE 5.—Components of lens mount assembly.

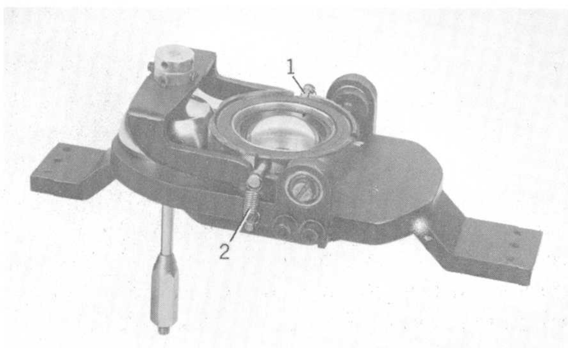


FIGURE 6.—Lens mount assembled.

in the x and y directions by four Allen setscrews (8, fig. 5). The cam follower must be centered over the distortion-correcting ball cam (9, fig. 5). The ball cam is seated in the lens mount in a manner that permits the cam freedom of rotation but restricts linear motion. A link member (10, fig. 5) is rigidly fixed to the cam and extends radially from its center. The free end of the link member is joined to the hinged yokes (10, fig. 2) linking the yoke connector (9, fig. 2) and the guide rod (13, fig. 2). The latter two form opposite sides of a parallelogram; hence the yoke connector, link member, and guide rod are parallel at all times, and the ball cam turns through the same angle as the guide rod. The yoke connector is attached to the illuminating system and to one end of the guide rod. The other end of the guide rod is joined to the tracing table.

When the tracing table is moved along the instrument's reference plane, the motion is transmitted and transformed by the guide rods, the yoke connector, and the link member into a rotational motion of the ball cam. The cam's upper surface, upon which the cam follower rides, is aspheric in shape. The cam follower is raised or lowered according to the shape of the surface of the cam, as the cam rotates. This motion of the cam follower rotates the bracket (5, fig. 5) about the bearings (6, fig. 5). Action of the bracket against the pins (1, fig. 6) raises the projection lens along its own axis. When the action is reversed, the lens is lowered by the pressure exerted by the springs (2, fig. 6).

The aspheric shape of the cam is designed to raise and lower the projection lens by predetermined amounts for the various angles of the projected image rays. The design of the cam is therefore based on specific values of radial distortion that are to be compensated. Radial distortion is, in effect, compensated by adjustment of the principal distance of the projector. As this adjustment is made by a displacement of the lens, theoretically correct distortion compensation can be designed for only one projection distance. (See "Effect of relief on cam performance," art. 26.) The compensation is designed to be theoretically correct at the optimum projection distance of 30 inches (760 mm).

10. Deactivation of cam

As stated in article 2*e*, the cams are generally deactivated because of other means of eliminating distortion. Two measures for the deactivation of the distortion-compensation mechanism are acceptable. One method is to substitute a spherical ball cam for the aspheric ball cam to provide zero compensation without changing the design of the lens mount assembly. The preferred method consists of applying a mechanical stop on the lens mount assembly to eliminate vertical movement of the projection lens, even though the ball cam may continue in mechanical operation.

This conversion is accomplished by drilling and tapping a hole for a 3–48 machine screw in the lens mount directly below the cam-follower unit and approximately 1 inch from the pivot end of the bracket. The screw is inserted from the bottom of the tapped hole and turned up until its contact with the cam-follower arm causes the cam-follower to rest about 0.001 inch above the top surface of the cam when the cam is in vertical position. A locknut placed on the upper end of the screw is tightened to bear on the upper surface of the lens mount. Movement of the cam stem through any operational position of the instrument then produces no vertical movement of the projection lens. After so modifying the instrument, the principal-distance calibration for each projector should be checked.

If it is desired to restore the aspheric ball cam to operation, the screw is turned down to permit the cam-follower to bear on the cam surface in all operating positions.

11. Illuminating units

Each illuminating unit consists of a lamp-filter-condenser assembly (6, fig. 1) that is attached to one end of a lamp yoke (7, fig. 2), and a counterweight block (8, fig. 2) that is rigidly fastened to the other end of the yoke. The lamp-filter-condenser assembly may be shifted to center the cone of light rays in the aperture of the projection lens and on the platen. The lamp yoke is supported by the yoke connector (9, fig. 2). Figure 7 is an exploded view of the lamp-filter-condenser assembly. The light-source unit (1, fig. 7) is threaded to the assembly by a knurled ring (2, fig. 7). The light source (3, fig. 7) is a 6- to 8-volt 32-candlepower incandescent lamp. Adjusting screws (4, fig. 7) are provided to permit the proper positioning of the image of the lamp filament in the aperture of the projection lens. The condenser lens assembly (5, fig. 7) has the function of condensing the available light at the aperture of the projection lens. The color filter (6, fig. 7) is threaded directly to the condenser lens assembly. The condenser lens assembly is threaded directly to the lamp housing. In the Revised GS model, the condenser lens system also can be tilted in a small segment of a ball-and-socket arrangement. This is to take the place of an adjustment between the lamp yoke and guide tube of the older model.

12. Guide rods

Each guide rod consists of four straight telescoping tubular sections (two sections in older models). One end of the guide rod is attached to the lamp yoke by two parallel connectors (10, fig. 2) and the other is joined to the tracing table. The relationship between the lamp yoke and the guide rod is fixed, and centering of the cone of light on the platen is accomplished by shifting the lamp assembly. The adjustment of the guide rod and yoke connector must be made before calibration of the projector. After calibration any change in the original relationship between the guide rod and yoke connector will upset the distortion compensation produced by the ball cam. A coil spring (11, fig. 2) serves to keep the guide rods from unseating the cam if the guide rod should stick when the platen of the tracing table is raised.

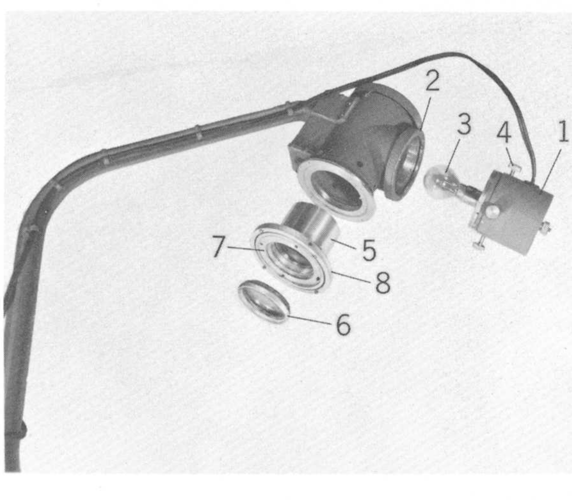


FIGURE 7.—Exploded view of lamp-filter-condenser assembly.

13. Tracing table

The tracing table used with the Kelsh plotter provides the means of relating the stereoscopic model and the manuscript. It forms the connecting link between these two. The tracing table consists of a screen on which the projected model can be viewed, a floating mark, a height-indicating scale, a plotting pencil, and a horseshoe-shaped base to support the whole. Figure 8 illustrates a tracing table designed for the Kelsh plotter. This table is equipped with a series of gears that may be arranged to yield readings directly in feet at most of the common mapping scales. It differs from the multiplex or ER–55 tracing table by the addition of a coupling assembly that consists of two swivel units (1, fig. 8), a restraining member (2, fig. 8), and a bearing plate (3, fig. 8). Each guide rod is fitted to one of the swivel units and is provided with a thumb screw (4, fig. 8) to facilitate detachment. The swivel units are hinged to the restraining member which in turn, is free to rotate about the bearing plate, giving the effect of universal joints between the guide rods and the bearing plate. The bearing plate permits the rotation of the tracing-table stand about a vertical axis containing the floating mark (5, fig. 8) without disturbance to the position of the guide rods. The primary function of the coupling assembly is to receive and maintain both guide rods in a plane that contains the line connecting the two projector stations.

The size of the platen (6, fig. 8) has been reduced from the standard multiplex platen diameter of 4½ inches to approximately 3¼ inches. This change reduces the displacement between the ends of the guide rods and the floating mark to a practical minimum. The stem of the platen extends through the center of the bearing plate and is threaded directly to the platen carriage.

When a fixed-ratio pantograph is to be used, a steel pin is provided to replace the plotting pencil. The steel pin guides the tracing point of the pantograph and must be positioned directly below the floating mark so that the steel

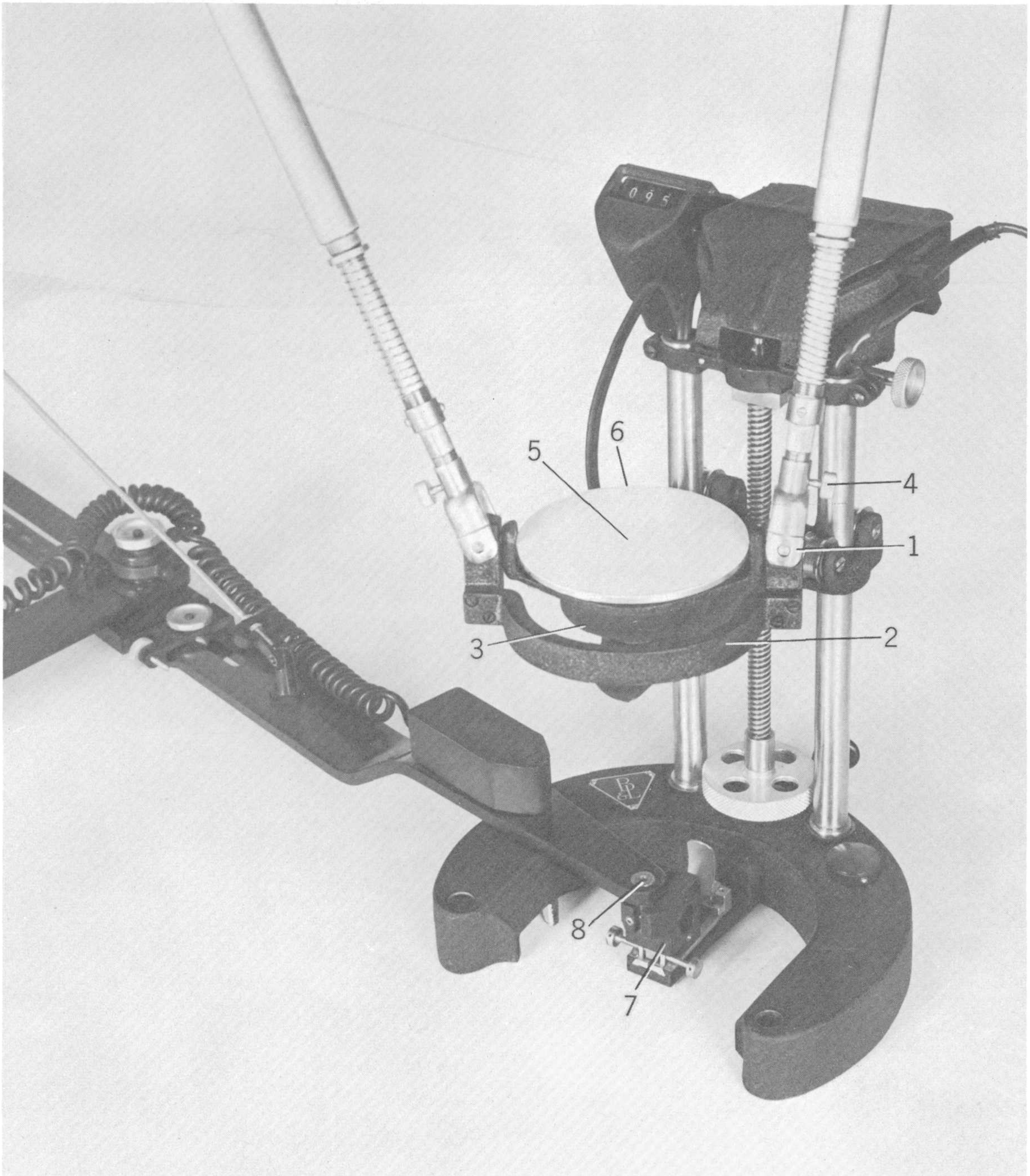


FIGURE 8.—Tracing table showing pantograph and guide rod attachments.

pin, if prolonged, would mark the orthographic projection of the floating mark on the reference plane.

When a variable-ratio pantograph is to be used, a block (7, fig. 8) replaces the standard pencil-holding block of the Bausch & Lomb type of tracing table and is locked in place by two Allen screws to eliminate any lateral motion. This block has, as an integral part, a pivot pin which fits into the pivot hole (8, fig. 8) of the pantograph to guide the tracing point of the pantograph.

The Kelsh plotter tracing table is supplied with four 6- to 8-volt bulbs, one located in each side of the base to illuminate the working surface, one below the platen to illuminate the floating mark, and one in the height-counter assembly to illuminate the dial.

14. Pantograph

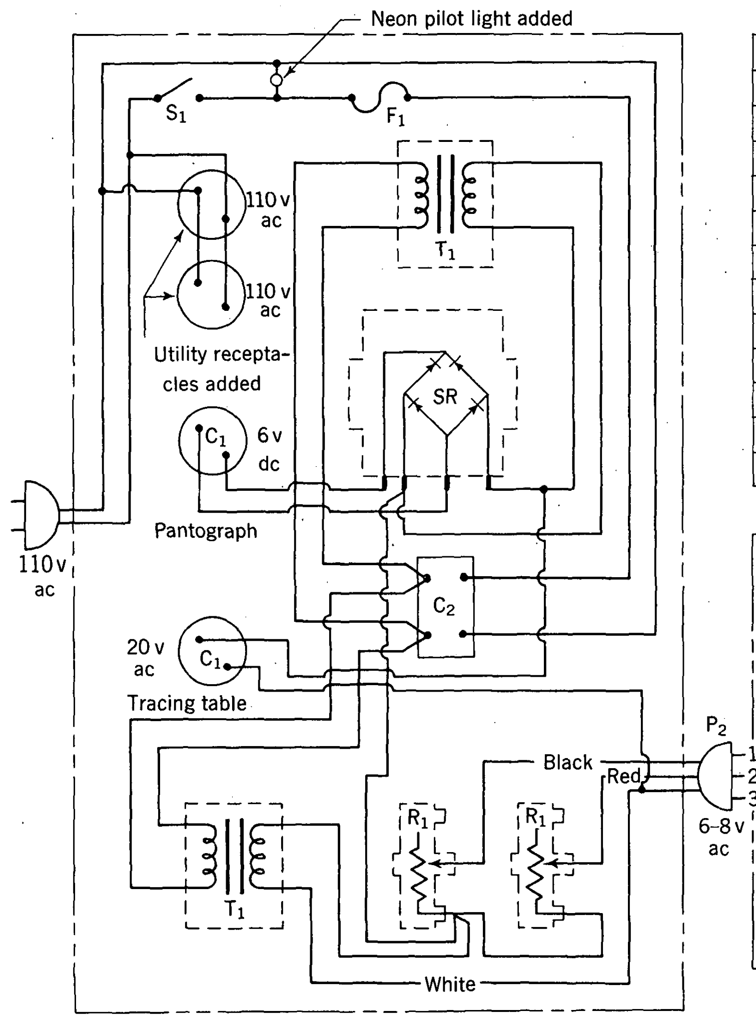
The pantograph generally used by the Geological Survey for map compilation at a scale smaller than the model scale is a variable-ratio pantograph having a continuously variable reduction of from 1.5 to 6.5 times. Some of the earlier Survey pantographs have a smaller range of reductions. The structure and operation of the pantograph are described in another chapter.

15. Electrical system

Figure 9 is a schematic diagram of the Kelsh plotter electrical system.

Single-phase 110-volt alternating current is transformed by two 5-ampere transformers to 10 volts. A resistance is introduced to lower the voltage to approximately 7½ to 8 volts for the projection lamps. The projection lamps are 32-candlepower double-contact bayonet-type lamps. Rheostats are provided to control the intensity of the light projected.

The 10-volt transformers may be connected in series to provide a 20-volt power supply for the tracing table. If a 20-volt power supply is used, the tracing-table bulbs must be wired in series; if a 7-volt power supply is used, the bulbs are wired in parallel.



Code	Quantity	Part No.
T_1	2	KP-1-53
T_2	1	KP-1-49
R_1	2	KP-1-51
R_2	2	KP-1-52
SR	1	KP-1-50
S_1	3	R-356
F_1	1	KP-1-56
C_1	2	KP-1-48
C_2	1	R-398
C_3	1	KP-2-140
P_1	1	KP-8-86
P_2	2	KP-2-140

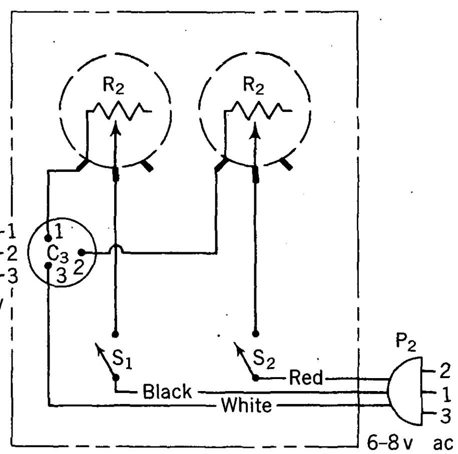


FIGURE 9.—Schematic wiring diagram for Kelsh plotter.

Two 110-volt outlets are provided for auxiliary lamps, electric erasers, and other accessories.

The pencil lift of the pantograph operates by means of a solenoid. As alternating-current operation of a solenoid is accompanied by a humming noise, it is necessary to convert from alternating to direct current to permit quiet operation of the pencil lift. This is accomplished by means of a 6- to 8-volt 2-ampere selenium rectifier.

CALIBRATION AND ADJUSTMENT

16. Compiler's responsibility for adjustments

Accurate calibration of the various elements of the Kelsh plotter is necessary to attain proper geometric functioning of the instrument and maximum faithfulness of the resultant optical model. As special tools and the skill of trained technicians are required to calibrate the plotter, any adjustments that affect the instrument's geometric performance are, necessarily, laboratory procedures. There are tests that may be performed by the stereocompiler, periodically or whenever the geometric functioning of the instrument is in question, to determine what elements, if any, are improperly calibrated.

Other routine adjustments affect the convenience, efficiency, and reliability with which the optical model can be observed and measured. As these operational adjustments influence the efficiency of compilation and do not require the use of additional equipment, they are the responsibility of the stereocompiler. Adjustments that are considered operational and routine include:

Positioning of the projector bulb.
Adjustment of the guide rods.
Adjustment of the floating-mark bulb.
Centering of the plotting pencil of the tracing table or, when a pantograph is in use, the centering of the steel pin support for the tracing end of the pantograph.

The stereocompiler may perform tests to check approximately the calibration of the following elements:

Verticality of the tracing table columns.
Centering of the pencil chuck in the pantograph.
Accuracy of the pantograph.
Plane of the diapositive as defined by the projector.
Calibrated principal distance of the projector.
Principal point indicated by the projector.
Performance of the cam.

17. Positioning the projector bulb

For maximum model illumination the image of the filament of the projector bulb must be sharply focused and centered on the aperture of the projector lens. This condition is obtained by direct observation of the image of the filament on the projector lens and adjustment of the thumb screws (4, fig. 7) provided on the light-source unit. A diapositive or a clear glass plate of equal thickness must be in place on the projector during this adjustment.

Optimum illumination is achieved when the axis of the core of the filament is inclined approximately 15° from the optical axis of the condenser lens assembly. The filament of the bulb may be rotated, after loosening the knurled lock ring (2, fig. 7), by rotating the light-source unit about its longitudinal axis. When the optimum angle between the axis of the filament core and the axis of the condenser lens assembly is exceeded, the images of the separate coils of the filament are apparent on the platen of the tracing table. When the angle between these axes is insufficient, an image of the core appears as a black spot on the platen. A comet-shaped image can be observed on the projector lens when the filament is rotated to its optimum position. After tightening the knurled lock ring the head of the comet-shaped image should be directed toward the center of the aperture of the projector lens by means of the thumb screws. This adjustment is necessary whenever a projector bulb is replaced, or when it is apparent to the stereocompiler that the optical model is unsatisfactorily illuminated.

18. Centering the cone of light

The cone of light must be centered as nearly as possible upon the platen for all positions of the tracing table within the working limits of the optical model.

The direction of the projected light may be varied in the GSI–23 model by adjustment of the coupling between the upper end of the guide rod and lamp yoke. Setscrews and lugs on the lamp yoke permit the adjustment of the upper end of the guide rod in both x and y directions. When the desired setting is attained, the guide rod must be locked securely to the lamp yoke. This adjustment should be checked before any test of the performance of the correction cam is attempted.

In the Revised GS model, the adjustment is made by rotational and lateral adjustment of the condenser housing. The four Allen screws on the aluminum ring (7, fig. 7) provide the rotational adjustment, and the four Allen screws on the rim of the aluminum ring (8, fig. 7) provide the lateral adjustment.

The telescoping action of the guide rods should be checked at frequent intervals. Telescoping sections that do not slide freely exert an undesired force upon the projector stations and the platen of the tracing table. Guide rods that do not function properly should receive immediate attention. If necessary, they should be replaced and sent to the maintenance laboratory for repair.

19. Adjustment of the floating-mark bulb

The position of the bulb beneath the hole in the platen of the tracing table affects the visibility of the floating mark, especially at the far edge of the model. Whenever this bulb is replaced, therefore, it should be repositioned as follows:

Loosen the screw on the underside of the platen carriage. Move the bulb back and forth by sliding this screw in its slot, at the same time viewing the floating mark at a low angle.

When the position of the bulb affording the brightest light is found, lock the bulb in position by retightening the screw.

20. Centering the plotting pencil or steel pin of the tracing table

If a pantograph is in use, it must be disengaged from the tracing table for this adjustment. The steel pin must be replaced with a plotting pencil of equal diameter. The purpose of the adjustment is to center the pencil directly beneath the floating mark. The pencil lead should at all times be sharpened to a carefully centered point. This adjustment presupposes that the columns of the tracing table are perpendicular to the plane of the feet of the tracing table.

Lock the platen at a fixed height (preferably at about the average plane of a model). Illuminating one projector, place the floating mark on any well-defined image point and plot this position with the tracing table pencil.

Turn the tracing table 180° and replot the same image point. If there is a discrepancy between the two plotted positions, mark a midpoint between the two.

Keeping the floating mark on the same image point, loosen the two adjusting screws at the sides of the pencil chuck. Shift the chuck by means of these screws and the one behind the chuck until the pencil point moves to the midpoint position. Tighten the side screws to lock the chuck in position.

Check the adjustment by repeating the procedure.

The stereocompiler should check this adjustment at least once a day until he is confident that the pencil will hold its adjustment for a longer period.

21. Checking the verticality of the tracing-table columns

To insure that the vertical movement of the floating mark is perpendicular to the supporting tabletop, the three agate feet of the tracing table are so mounted that each one can be adjusted up or down independently, until the columns on which the platen carriage rides are perpendicular to the plane of the feet. This is a laboratory adjustment, which the stereocompiler can check as follows:

Lower the platen as far as it will go. Illuminating one projector, place the floating mark on any well-defined image point and plot this position with the tracing table pencil, first making certain that the pencil lead is sharpened to a carefully centered point.

Without disturbing the elevation of the platen, turn the tracing table 180° and replot the same image point. If there is a discrepancy between the two plotted positions, tentatively adjust the pencil point to a midpoint position as described in article 20.

Raising the platen to its highest point, repeat the above procedure of plotting and checking a point, which may be either the same or some other well-defined image point. If a discrepancy is now apparent at this elevation, it indicates that the columns are not plumb. This adjustment needs to be checked only occasionally.

22. Checking the plane of the diapositive as defined by the projector

To achieve proper interior orientation, the diapositive must lie in a plane that is perpendicular to the optical axis of the projector lens. As the mechanical axis of the swing motion of the projector is considered to be coincident with the optical axis of the projector lens, the bossed surface of the plateholder frame must be perpendicular to this mechanical axis. This condition must be achieved before the principal distance and the principal point of the projector can be checked. The perpendicularity between the plane of the diapositive and the optical axis of the projector lens may be checked as follows:

Place a 0.25-inch thick glass diapositive plate, selected for flatness and for uniform thickness within 0.0005 inch, on the plateholder and properly orient the plateholder on the projector cone.

Swing the projector to bring the sides of the plateholder parallel to the photogrammetric x and y axes.

Center a level bubble (sensitive to 40 seconds) on the glass plate with the longitudinal axis of the bubble parallel to the y axis.

Using the projector's x tilt adjustment, rotate the projector until the bubble indicates a level position.

Center the level bubble on the glass plate with its longitudinal axis parallel to the x axis.

Using the projector's y tilt adjustment, rotate the projector until the bubble indicates that a horizontal plane has been attained.

Swing the projector 180° and, using the level bubble, check the condition of tilt of the glass plate. If the glass plate has been maintained in a horizontal plane, the plane of the diapositive is considered to be perpendicular to the optical axis of the projector lens.

The laboratory procedure necessary to achieve the desired relationship between the plane of the diapositive and the optical axis of the projector lens involves the adjustment of the four setscrews, sometimes called leveling screws (6, fig. 4), provided on the cone of the projector. As the adjustment of these screws affects the projector's principal distance, this element of calibration must also be checked when the screws are disturbed.

Failure of the plateholder to seat firmly on all four setscrews is evidence that the projector is no longer in proper calibration.

23. Checking and calibrating the principal distance of the projector

An approximate check of the calibrated principal distance of the projector can be made by the application of a simple mathematical formula to measurements made on a projected grid pattern. Calibration of the principal distance is a more elaborate procedure to be performed in the laboratory.

a. Approximate determination.—In a properly calibrated projector the principal distance ring indicates the projector's effective principal distance when the correction cam is orientated with the cam stem vertical to accommodate the axial ray of the projection. In other positions, the cam permits and governs changes in the projector's effective principal distance. The stereocompiler can make an approximate determination of the effective principal distance by using an accurate grid diapositive and the following procedure (fig. 10):

Indicate on the grid, by circling two grid intersections, a distance ab that contains and is symmetrical about the central grid intersection. This distance should be approximately 6 inches in length and measured to the nearest tenth of a millimeter.

Orient the grid in the plateholder so that the line ab on the grid is parallel to the photogrammetric y axis. (If the design of the correction cam includes a correction for the use of a glass plate of specified thickness between the emulsion of the diapositive and the projector lens, a clear glass plate of that thickness should be inserted between the grid and the bossed surface of the plateholder frame.)

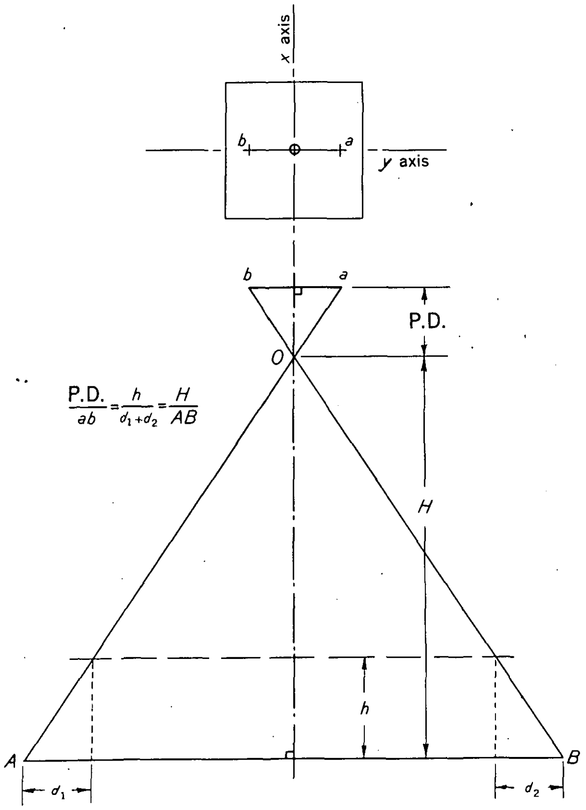


FIGURE 10.—Checking principal distance by projected grid.

Place the plateholder on the projector cone and, using the projector's tilt motions, adjust the grid plate to a horizontal plane.

Turn on the projector lights and observe the monoscopic projection on the platen.

Plot the positions of the selected grid intersections, once with the platen at its lowest possible elevation and again with the platen at its maximum height. Calculate the sum of the two displacements, d_1+d_2.

Compute the principal distance (P.D.) according to the relationship

$$\text{P.D.}=\frac{h\cdot ab}{d_1+d_2} \qquad (1)$$

where h is the vertical range of the platen and ab is the distance on the grid plate between the two grid intersections.

If the computed value is more than 0.3 mm smaller or more than 0.7 mm larger than the value indicated by the principal-distance ring, a gross error in calibration is indicated.

b. Laboratory determination.—Calibration of the principal distance is a laboratory procedure involving the use of a depth micrometer and a glass-plate diapositive having a hole, approximately one-half inch in diameter, drilled through its center. The glass plate is positioned on the plateholder frame so that the center of the hole is located at the principal point of the projector. The distance from the top surface of the glass plate to the upper surface of the projector lens is measured with the micrometer. The principal-distance ring should be set to read 153 mm, the middle of its range, and the correction cam oriented to accommodate the axial ray of the projection. A piece of soft tissue paper placed under the arms of the micrometer and another piece placed over the lens will not affect the readings and will provide reasonable protection for the lens. The distance from the top surface of the lens to its entrance node must be added to the micrometer reading. The thickness of the glass plate used to facilitate the measurement must be subtracted from the reading. The average value of the displacement between the upper surface and the entrance node of the 5-inch focal length hypergon lenses provided with the Kelsh plotters is 12.62 mm. (If the intended practice in the normal operation of the instrument is to use a glass plate of specified thickness between the emulsion of the diapositive and the projector lens, two-thirds of this glass thickness must be added to the micrometer reading to obtain the projector's effective principal distance.)

The effective principal distance is set in agreement with the indicated distance of the principal-distance ring by adjustment of four setscrews located on the projector cone. After the effective principal distance has been adjusted, the perpendicularity between the plane of the diapositive and the optical axis of the lens must be rechecked.

24. Checking the principal point indicated by the projector

The position of the principal point of the projector is indicated by the intersection of lines extending across the index tabs (3, fig. 4) on the plateholder frame. The position indicated must be in agreement with the position of the projector's true principal point. The following procedure for checking this agreement is based on the assumption that the plane of the diapositive is perpendicular to the mechanical axis of swing and that the optical axis of the projector lens is a straight line and coincides with the mechanical axis.

Place an accurate grid diapositive on the plateholder and orient the plate to bring a pair of the perpendicular lines into coincidence with the four index tabs. The intersection of the two perpendicular grid lines locates the indicated position of the principal point of the projector when the plateholder frame is properly seated on the projector cone.

Illuminate the pertinent grid intersection and observe the projected image of the intersection on the platen.

Move the tracing table horizontally to place the floating mark of the platen in coincidence with the image of this grid intersection.

Swing the projector 180° and note the horizontal displacement between the floating mark and the projected image of the grid intersection. The observed displacement represents twice the error of position of the indicated principal point at the scale of the projection. When the projection distance is set at 30 inches, the observed displacement is a 10-times magnification of the projector's error of principal point calibration.

Correction of the position of the indicated principal point is a laboratory procedure. It is accomplished by shifting the grid diapositive in the plane defined by the bossed surface of the plateholder frame to compensate half of the error indicated by the preceding test. The test and correction procedures are repeated until the projected image of the grid intersection remains stationary after a 180° swing adjustment has been imparted to the projector. The grid plate is then securely clamped to the plateholder frame to prevent further movement between the grid diapositive and the plateholder frame. The index tabs are loosened and shifted into coincidence with the grid lines that define the position of the principal point by their intersection. After the tabs are properly secured in their desired position, the principal point position they indicate must be rechecked.

25. Checking the performance of the cam

If a ball cam is used for distortion correction, its performance must be tested to determine whether the desired values of distortion compensation are attained. Two methods of making this test are given.

a. By reading the model.—The stereocompiler can determine, by measurement of a stereoscopic model formed from the overlapping images of a pair of accurate grid diapositives, the amount of deformation introduced to the datum of the model by the compensation system. The diapositives must be selected flat glass having precision grid lines etched or printed on one surface. The surface of the diapositive containing the grid lines must always be faced toward the projector lens. (If compensation for the use of diapositives with their emulsion side up has been included in the design of the cam, a clear glass plate equal in thickness to the diapositives to be used in the instrument must be inserted between the grid and the bossed surface of the plateholder frame.)

The stereoscopic grid model will contain residual y parallaxes, and the surface it defines will be warped. These conditions are caused by the introduction of distortion compensation. The precision grids do not contain the displacements introduced to photography by the distortion inherent in camera lenses. The anticipated pattern of the surface of the grid model is the reverse of the datum deformation that would be present in models formed from uncompensated photography of the type for which the cam is designed.

The deviations of the surface of the grid model from a plane are measured stereoscopically and compared with the deviations computed from and intended by the design of the ball cam. The pattern and amount of deformation of the grid model surface is dependent upon the physical dimensions of the model and the positions in the model where y parallax is removed precisely, in addition to the vertical motion of the projector lens as governed by the ball cam. For comparison, it is essential that the conditions of the grid model test be identical to those considered in the computations of the desired deviations.

The following conditions must be satisfied:

The desired values of model deformation must be computed from the same distortion characteristics that the cams were designed to compensate.

The base-height and width-height ratios of the neat grid model must be in agreement with the ratios used in the computations.

Remove y parallax at the six grid intersections defining the two projected images of the principal points and the four corners of the neat stereoscopic model.

As the computations are based on a specific magnification of the diapositive grids, the size of the grid model must be adjusted to agree. For a projector principal distance of 152 mm and a projection distance of 760 mm, the magnification is

$$\frac{760}{152}=5.0 \text{ times.}$$

The grid model must be oriented so that the grid intersections defining the four neat-model corners lie in a plane that is parallel to the instrument's reference surface. Improper centering of the cam follower is indicated when the four neat-model corners will not lie in a plane without the introduction of y parallax at one or more of the six parallax-removal points.

The stereoscopic measurement of the deviations of specific grid intersections from the plane defined by the four neat-model corners must be made with utmost care. Repeated readings should be made. The grid intersections measured must be those for which deviations have been computed. Agreement between each of the measured deviations and its respective computed value to 0.1 mm is a positive indication that the ball cam is introducing the desired amounts of distortion compensation and that the cam follower is properly centered.

Figure 11 illustrates the pattern of deformation introduced to the datum of a grid model by the compensation of distortion of a nominal metrogon lens. The computation of this pattern is based on specified base-height and width-height ratios and a specific value of magnification of the diapositive grids.

When the stereoscopic grid test indicates that the desired compensation is not attained, the laboratory procedures for checking the centering of the cam follower and measuring the vertical movement of the projector lens must be employed, as described in (*b*) below.

b. By reading cam-follower drop (*laboratory test only*).—The special equipment necessary for measuring the amount by which the projector lens is raised and lowered includes a dial indicator measuring to 0.001 inch, clamps for mounting the indicator firmly on or adjacent to the projector, a sensitive level bubble, and a templet to facilitate the determination of the position of rotation of the cam. The templet consists of a series of concentric circles whose radii are equal to the tangents of the various vertical angles of projection times 30 inches. The laboratory procedure is as follows:

Center a diapositive or grid in the plateholder of the projector to indicate the position of the projector's principal point.

Using the projector's tilt motions and observing the level bubble placed on the diapositive, adjust the diapositive to a horizontal plane.

Place the templet on the slate table so that its center is in coincidence with the projected image of the principal point. Tape the templet to the slate table and clamp the x carriage of the projector to the projector-track frame with a **C**-clamp.

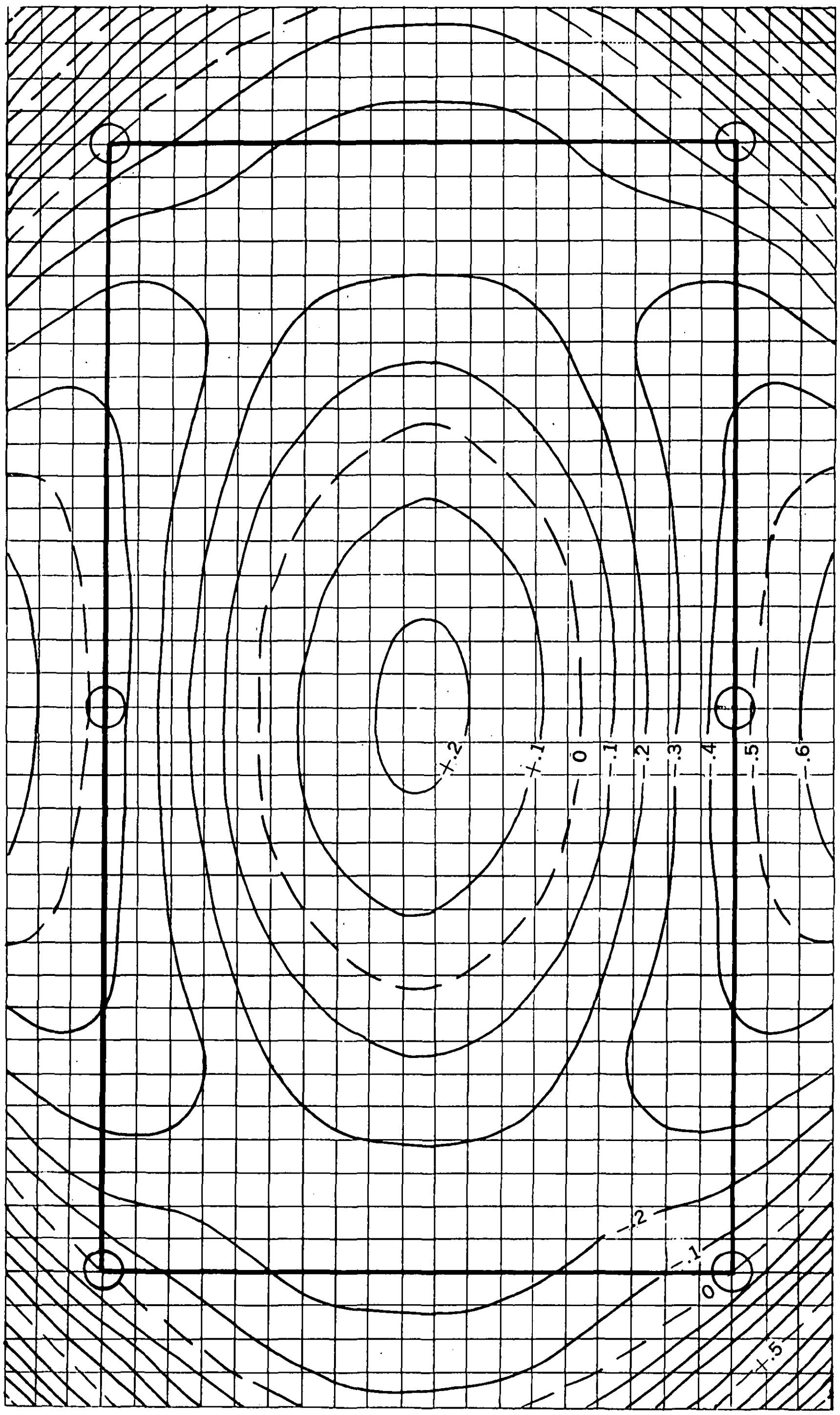
Remove the projector's plateholder and cone.

Clamp the dial indicator to the projector-track frame in a position that permits the indicator stem to rest on the locknut of the cam follower. Caution should be exercised in positioning the indicator stem to assure that a ratio of 3.5 to 1 is maintained between the measured vertical motion of the cam follower and the actual movement of the lens.

Locate the pencil of the tracing table over the center of the templet and elevate the platen to satisfy a 30-inch projection distance.

Set the dial indicator to read zero.

Move the tracing table out radially from the center of the templet and record the dial indicator readings of the cam-follower drop at vertical-angle intervals of 5°.



EXPLANATION

P.D. = 152 mm — $\frac{B}{H} = 0.62$ — Grid is at scale of diapositive

Proj. dist. = 760 mm — $\frac{W}{H} = 1.12$ — Curves show pattern of vertical deviations, in millimeters at model scale

FIGURE 11.—Pattern of a grid model resulting from compensation of nominal metrogon distortion.

If the values of drop of the cam follower are similar at equal angles from the vertical along several widely divergent radials, the symmetry of position of the cam follower is proven. If the readings do not indicate symmetry, the position of the cam follower must be reset by adjustment of the four Allen screws provided for this purpose.

For the distortion compensation mechanism to function properly, a true parallelogram relationship must be maintained by the following four pivot points: the center of the cam, the intersection of gimbal axes, the cam-stem-and-link pivot, and the link-and-connector-yoke pivot. In preference to measuring the distances forming this parallelogram, it is recommended that the cam stem be adjusted to the length that causes the cam follower to drop the designed amount for angles 40° from the vertical.

Table 2 gives the computed values of the cam-follower drop necessary to compensate the radial distortion of a nominal metrogon lens when the diapositive is used emulsion side down. Similar tables can be prepared for other lenses having significant distortion.

TABLE 2.—*Values of cam-follower drop to compensate nominal metrogon distortion*

[This table applies when the diapositive is used emulsion side down]

Angle (degrees)	Radial lens distortion (millimeters)	Cam-follower drop (inches)	
		Without hypergon distortion A–1 cam [1]	Including hypergon distortion A–2 cam [2]
0	----------	----------	----------
5	0. 001	0. 001	0. 001
10	. 003	. 002	. 002
15	. 018	. 008	. 007
20	. 042	. 013	. 012
25	. 071	. 017	. 016
30	. 103	. 021	. 019
35	. 116	. 019	. 017
37. 5	----------	----------	. 013
40	. 073	. 010	. 007
42. 5	----------	----------	. 002
45	. 116	. 013	. 017

[1] The A–1 cam is used if the hypergon projector lenses have no measurable distortion.
[2] The A–2 cam is used if the hypergon projector lenses have distortion giving a vertical error in the model of 0.1 to 0.2 mm.

26. Effect of relief on cam performance

The distortion compensation afforded by the cam is theoretically correct at the optimum projection distance of 760 mm. In Kelsh plotter models of actual terrain the projection distance varies with the relief (fig. 12). The difference between the theoretical compensation for a given projection distance and the compensation provided causes a displacement in elevation, such as Δz, figure 12. The displacement, Δz, can be evaluated, for any point, from the approximate equation:

$$\Delta z = \frac{z(\Delta \text{P.D.})}{\text{Optimum projection distance}} \qquad (2)$$

The order of magnitude of Δz in a model having high relief is indicated by the following example:

Let range of relief in the model be from 75 mm above to 75 mm below the optimum horizontal plane.

Then

$$z = \pm 75 \text{ mm.}$$

The maximum cam-follower drop shown in table 2 is 0.021 inch (=0.53 mm). As the ratio of cam-follower drop to lens drop is 3.5 to 1, ΔP.D.=0.15 mm.

Let Optimum projection distance=760 mm.

From equation (2),

$$\Delta z = \frac{(75)\,(0.15)}{760} = 0.015 \text{ mm.}$$

Thus, if all the control for the model were in the optimum horizontal plane and the model were oriented and indexed to this control, there would be a residual error of ±0.015 mm in elevations read on points at a distance of 75 mm from the optimum horizontal plane. If the model were oriented and indexed to control points all lying 75 mm above the optimum horizontal plane, there would be a residual error of 0.015 mm in points lying in the optimum horizontal plane and 0.03 mm in points 75 mm below the optimum horizontal plane. If the control points were at various elevations, the residual errors would not be greater than 0.03 mm, but an erroneous tilt might be introduced, depending on the disposition of the control points.

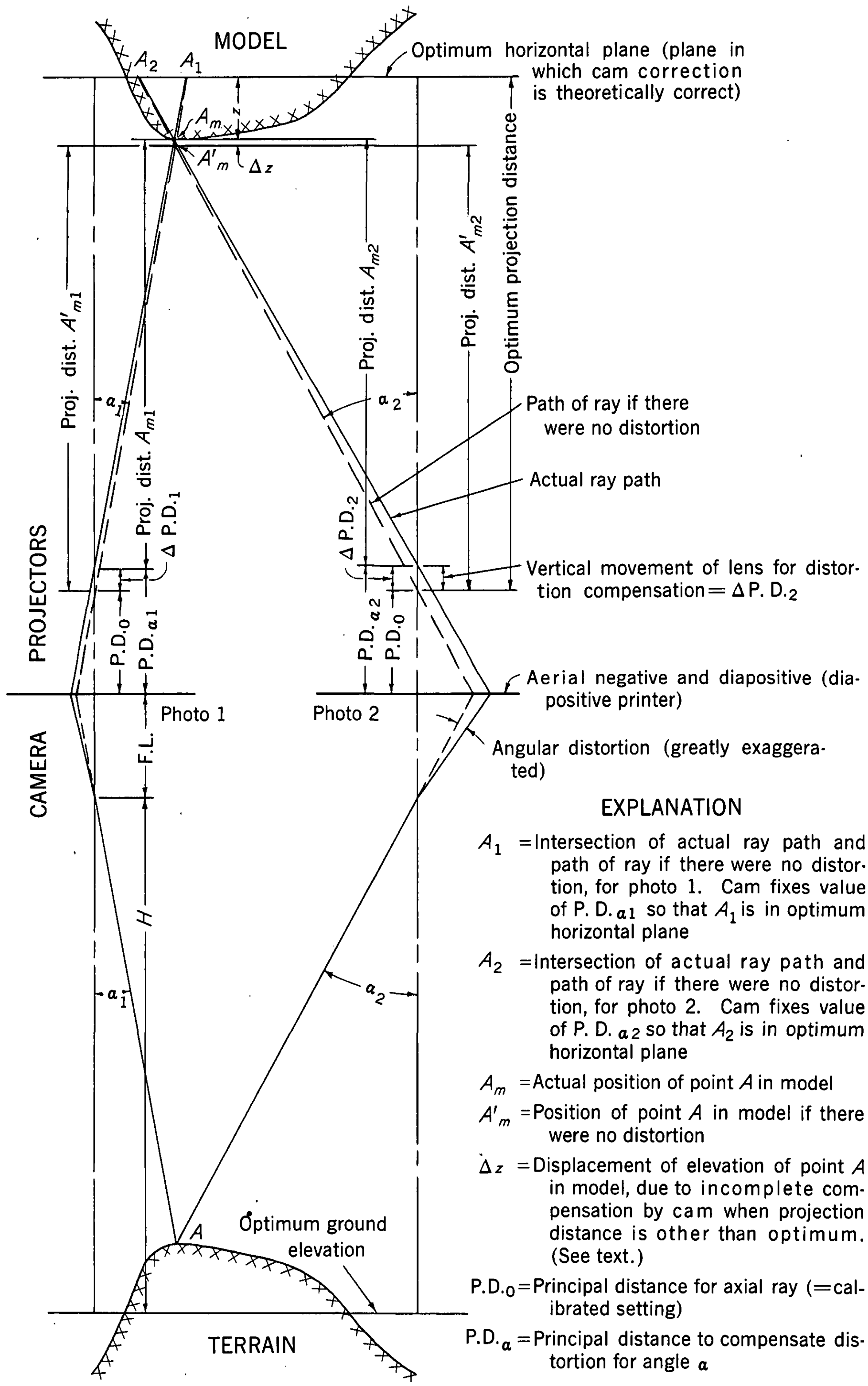


Figure 12.—Geometry of image projection in the Kelsh plotter when ball cam is used to compensate lens distortion.

INTERIOR ORIENTATION PROCEDURE

27. Conditions affecting interior orientation

The cone of light rays emanating from a projector station must be in effect identical to the cone of rays that entered the camera lens at the instant of the corresponding camera exposure. The procedure of adjusting a diapositive to a position on the projector so that this objective may be attained is referred to as interior orientation. It is accomplished when the geometric relationship of the emulsion surface of the diapositive to the perspective center of the projector lens is equivalent to that which existed between the corresponding negative and the camera lens at the instant of exposure.

The procedure of interior orientation is dependent upon, and must comply with, certain factors considered in the calibration of the instrument's projectors. These factors are (a) the nominal focal length of the camera used, (b) the distortion characteristics of the camera lens, (c) the availability of interchangeable correction cams or diapositive-printer correction plates, and (d) the kind of diapositives used. The photography formerly used most extensively in the Kelsh plotter was taken with cameras of the 6-inch metrogon category. A series of correction cams was available for use with each plotter. The series of cams provided different distortion compensation values to match the known distortion values of the camera in use.

Later, when projection diapositive printers with aspheric correction plates became available, the cams were deactivated on most Kelsh plotters. Later still, the use of distortion-free photography eliminated the need for distortion correction entirely, on many projects. Operations involving cams, as described below, apply only when the use of cams is necessary.

Until 1952, Kelsh diapositives 0.06-inch thick were used by the Geological Survey, but it was found that they were not uniform and did not meet the requirements for producing flat models. As a result, a shift towards the use of 0.25-inch plates was begun. Because the 0.25-inch diapositives are used with the emulsion side down, their thickness does not form part of the optical system and the distortion correction cams must be shaped differently from those used with 0.06-inch plates. Although the 0.25-inch plates give more reliable results, they have the disadvantages of being more expensive and requiring more storage space than an equal number of 0.06-inch plates.

28. Steps in interior orientation

The procedure for interior orientation is as follows:

Using a sharp needle point, scratch a fine cross on the emulsion surface of each diapositive at the perpendicular intersection of its fiducial lines to mark the principal point. Care should be taken not to scratch the glass because the plates are intended to be recoated for repeated use. (Although this operation is not an essential step in interior orientation, the identification of the principal point in the subsequent projected image is desirable as an aid in achieving relative orientation and in defining the base limits of the neat stereoscopic model. The marking of the principal points is performed most conveniently as the first operation.)

Select the pair of correction cams that will most accurately compensate the radial distortion of the camera lens.

Place each selected cam in its designated position on the projector. In the GSI–23 model the lens must be removed from the lens mount in order to install the selected cam in position. The lens may be removed from the mount by removing the four screws which hold the lens in place on the mount. With the lens removed, the cam-follower bracket may be raised and the proper cam placed in the cam seat. The lens is then replaced. In some of the Revised GS models, the cams may be changed by raising the cam-follower bracket (5, fig. 5) to a point where a cam may be placed in or removed from the cam seat. This is not possible with all models because in some there is not sufficient clearance to allow the cam to pass the inner surface of the gimbal ring (8, fig. 3). In such models, the lens mount assembly (10, fig. 3) must be removed from the x tilt plate (7, fig. 3) to permit a cam change. The removal of the lens mount assembly from the x tilt plate should be done in the maintenance shop or by a competent operator experienced in calibration of the Kelsh plotter.

Set the principal-distance ring to read in agreement with the equivalent focal length of the camera used. The principal-distance ring is locked in place by two diametrically opposed Allen screws. These screws must be loosened to permit a change in the setting of the principal-distance ring. The Allen screws should be tightened with caution because too much pressure may warp the ring.

Place the projector cones in their respective projectors. The cones are not interchangeable and must be used with the projectors for which they have been calibrated.

Orient the plateholder frames on a convenient working surface in approximately the same positional relationship to each other that they have in the instrument. The plateholder frames are not interchangeable. The intended front surfaces of both the cones and the plateholders are labeled "Left" or "Right" to facilitate the placement of each plateholder in the correct alinement with its proper cone.

Place the diapositives on the plateholder frames with their emulsion side down. The diapositive to be used in the right projector must be oriented so that its relevant overlapping photographic area falls in the right half of the plateholder frame. The corresponding photographic area of the diapositive to be used in the left projector must be oriented to lie in the left half of the area defined by its plateholder frame. (If 0.06-inch plates are used, with the emulsion side up, place a flat 0.13-inch clear glass cover over each of the diapositives.)

Place the frames with the diapositives on a light table capable of illuminating the fiducial marks of the diapositive through available slots in the plateholders.

Adjust the diapositives laterally to bring their fiducial marks into coincidence with the principal-point calibration marks on the plateholder frame.

Tighten the hold-down clamps of the plateholder frames to secure the positions of the glass plates. The diapositives are restricted to a flat plane defined by the plateholder frame.

Carefully place the plateholder frames on their respective projector cones.

If photography obtained with an aerial camera of nominal focal length other than 6 inches is to be used, other projector cones must be substituted. The projector cones must have dimensions capable of reproducing a principal distance equivalent to the focal length of the particular camera. The projector lenses must be of a focal length that will accommodate the proposed principal and projection distances.

Glass diapositives should be handled with the precaution necessary to avoid the placement of fingerprints on their surfaces.

The effects of errors in interior orientation of the Kelsh plotter are similar to the effects of corresponding errors in the multiplex.[1]

RELATIVE ORIENTATION PROCEDURE

29. Purpose of relative orientation

The purpose of relative orientation of the Kelsh plotter projectors is to reconstruct the same perspective conditions between a pair of photographs that existed when the photographs were taken. This reconstruction is achieved by a systematic procedure of rotational movements of the projectors, at the same time observing the images on the platen, until corresponding images are made to coincide over the entire model area.

A prerequisite to the attainment of relative orientation is the satisfactory fulfillment of the requirements of interior orientation (art. 28) in each of the two projectors.

30. Swing-swing method

The swing-swing method of y parallax removal is applicable for all existing designs of the Kelsh plotter. The y parallax removal methods that allow one of the projectors to remain undisturbed during the orientation procedure are not usable unless the projectors are equipped with y and z motions.

In figure 13, the numbered circles represent positions within the projected model area at

[1] See Chapter 3F4, Multiplex plotter procedures.

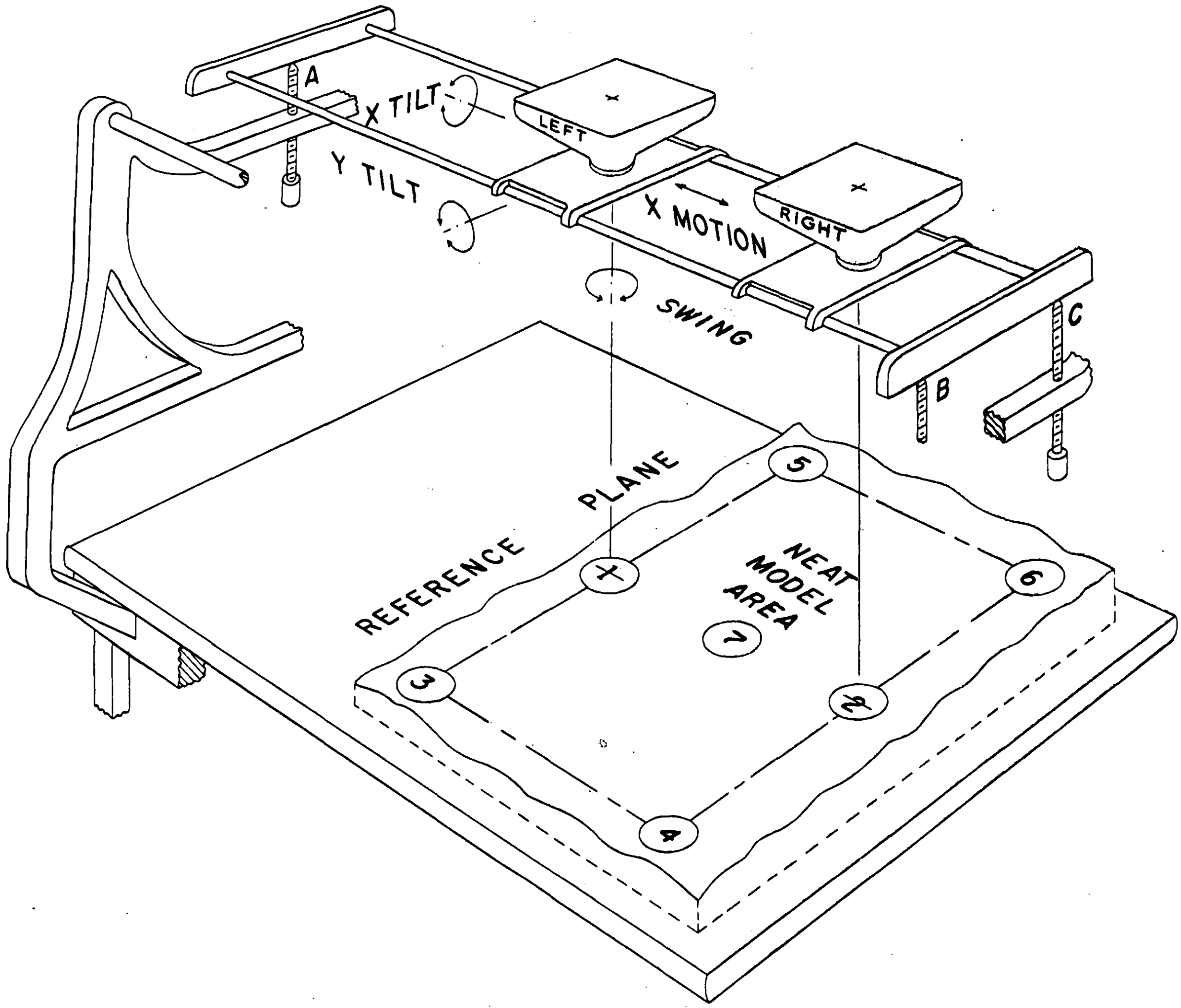


FIGURE 13.—Positional relationship of optical model to Kelsh plotter.

which y parallax is to be observed and adjusted. Point 1 represents the position of the principal point of the left projection. Point 2 represents the position of the principal point of the right projection. Points 3, 4, 5, and 6 locate the corners of the proposed neat stereoscopic model. The sequence of adjustments, as prescribed by the swing-swing method, is as follows:

Clear y parallax at 1 with swing of the right projector.
Clear y parallax at 2 with swing of the left projector.
Clear y parallax at 3 with y tilt of the right projector.
Clear y parallax at 4 with y tilt of the left projector.
Overcorrect (1½ times) y parallax at 5 with x tilt of either projector.
Repeat the above procedure until points 1, 2, 3, 4, and 5 are free of y parallax.
Observe extent of y parallax existing at point 6.

Point 6 should be free of y parallax if the other 5 positions are properly cleared. Remaining y parallax at point 6 indicates that relative orientation has not been achieved, and the procedure should be repeated until all points are free of y parallax.

31. Rationalization method

Parallax removal by rationalization is suggested as an alternative procedure that, in most instances, is more efficient for accomplishing relative orientation. This method is based on the limiting and the advantageous factors in the design of the Kelsh plotter and on the nature of the variations of tilt and crab angles at successive camera stations that generally occur in domestic aerial photography. Because of these factors, the accomplishment of relative orientation of all except the first stereoscopic model to be set up in a flight strip is facilitated when the sequence of observation, parallax analysis, and projector adjustment is as follows:

Observe y parallax at the center of the model area (point 7, fig. 13) and clear approximately half of this parallax with an x tilt adjustment of one projector and the remaining half with the x tilt of the other.

Clear y parallax at 1, using the swing motion of the right projector.

Clear y parallax at 2, using the swing motion of the left projector.

Observe condition of y parallax at points 4 and 6.

(a) If y parallax conditions at these two model corners indicate symmetry about the air base, clear y parallax at the point having the smaller y parallax with a y tilt adjustment of the left projector. Overcorrect the remaining y parallax in the other corner to an amount equal to $1\frac{1}{2}$ times its value, using the x tilt motion of the left projector. Clear y parallax introduced at point 2 with the swing motion of the left projector. Observe y parallax conditions at points 4 and 6 and repeat this sequence until points 2, 4, and 6 are y parallax free.

(b) If y parallax at points 4 and 6 is asymmetrical in direction from the air base, overcorrect the y parallax at either corner an amount equal to $1\frac{1}{2}$ times the sum of y parallax values at both corners, using an x tilt motion of the left projector. Clear y parallax introduced at 2 with the swing motion of the left projector. Observe y parallax condition at points 4 and 6, and repeat procedure (a) or (b) dependent upon the y parallax conditions existing at these points, until points 2, 4, and 6 are free of y parallax.

Clear y parallax at 1, using the swing motion of the right projector.

Clear y parallax at 3, with a y tilt adjustment of the right projector.

Point 5 serves as a check position and should be free of y parallax if the y parallax at all the other observation points has been properly cleared. The entire procedure is repeated until all points are free of parallax.

32. Basis of rationalization method

The method of rationalization is based on the following considerations:

a. Limiting factors in design of Kelsh plotter.—A projector orientation common to two successive models and determined by the orientation of one of the models cannot be maintained as an aid in orientation of the adjacent model.

The diapositive common to two successive models cannot be left undisturbed in its projector after the completion of its first relevant model, but must be transferred to the instrument's other projector as a prerequisite to the orientation of the second model.

b. Advantageous factors in the design of the Kelsh plotter.—The x axis of the instrument may be considered to be coincident with the air base of the model.

The y component of motion imparted to the projected images by a y tilt adjustment of the projectors is always symmetrical about the air base.

The condition of y parallax at the positions of projected principal points can be affected only by the projectors' swing and x tilt adjustments. (This excludes the use of the available, but limited, y motion.)

The procedure of interior orientation allows each diapositive to assume an angle of swing identical to that determined by the orientation of the diapositive which had preceded it in that particular projector.

c. Angular relationships of successive exposures.—The crews engaged in domestic aerial photography have demonstrated consistent ability to maintain straight flight lines and a nearly constant angle of crab in the successive exposures of a photographic flight line. It has proved considerably more difficult to maintain a nearly constant angular value of the aircraft's transverse tilt (x tilt) for successive exposures. A greater variation in the x tilt settings of successive projector stations than in the swing settings should therefore be anticipated.

Removal of y parallax is facilitated if each successive adjustment to the projectors diminishes the residual value of the y parallax throughout the model area. The adjustment which would reduce the y parallax values the greatest amount should be made first. When the swing-swing sequence is followed, y parallax at positions 1 and 2, which is generally caused by the improper x tilt relationship of the projectors, is temporarily removed by the swing motions of the projectors. These swing adjustments destroy the probable proximity of the projectors' swing settings to their true relative positions. The improper x tilt relationship of the two projectors remains unimproved, and, therefore, the attainment of relative orientation is delayed rather than facilitated. A more logical approach is to improve the x tilt relationship first, as is done in this procedure.

33. Observation of y parallax

Because of the long projection distance of the Kelsh plotter, small angular deviations from the true relative orientation of the two projectors result in comparatively large values of y parallax. As the amount of y parallax that can be accommodated stereoscopically by human eyes is physiologically limited, it is recommended that, in the early stages of the relative orientation procedure, y parallax values be observed without the use of the colored spectacles. The y parallax-removal adjustments should be made on the basis of color separation until the y parallax value at each of the model observation points is less than one-eighth of an inch. Colored spectacles should then be used in order that the final solution may be obtained with the full advantage of stereoscopy.

The completeness with which all visible y parallax throughout the stereoscopic model may be cleared depends upon the excellence of performance of the chain of photographic materials and photogrammetric equipment. When random errors of unknown source prevent the complete clearing of visible y parallax, relative orientation cannot be attained but merely approached. As a practical means of minimizing this effect, the residual y parallax should be distributed throughout the model area to reduce its maximum value. Because observation and measurement of the stereoscopic model are impeded by the presence of y parallax, the projectors of the more recently designed Kelsh plotters have been equipped with a y motion adjustment of limited range. It is not intended that this adjustment be used in relative orientation procedure. Its function is to provide a convenient means by which residual y parallax may be removed locally. It also serves as a means of accommodating the y parallax observation differences existing between stereocompilers.

ABSOLUTE ORIENTATION PROCEDURE

34. Purpose of absolute orientation

The stereoscopic model formed by the completion of relative orientation has an undetermined scale and undetermined relationships to the horizontal and vertical data. By the procedure of absolute orientation the scale and horizontal position of the model are properly related to the horizontal control plotted on the map sheet, and the vertical datum of the model is adjusted to a plane that is parallel to the reference plane. The slate or aluminum tabletop which forms the reference plane is presumed to define a plane parallel to sea level. The procedure of tilting the model datum to achieve the desired parallelism is, therefore, referred to as leveling.

The operational phases of absolute orientation are performed in the following sequence:

Achieve an approximate scale solution.
Level the datum of the model.
Achieve a final and most accurate scale solution.
Relate the position of the model to the map sheet.

35. Scaling the model approximately

The scale of the model is varied by adjustment of its air-base dimension, using the x motion. Because of the single model design of the Kelsh plotter, the displacement of a projector station caused by an adjustment of its x motion is in a direction coincident with the air base of the model. A minimum of two stereoscopic image points, whose known horizontal positions have been plotted on the map sheet, are needed to determine an approximate model scale. The distance separating the two known points should approach or exceed the correct air-base dimension of the model. When the horizontal distance between the model image points has been made equal to the distance between their corresponding plotted positions on the base sheet, the scale of the model is approximately equal to the known scale of the base sheet.

The tracing table floating mark must be in apparent contact with the surface of the model at the position of the image points to determine correctly their spatial positions. If available from some previous source, such as stereotriangulation of the strip, the plotted positions of the principal points may be used to define a readily identifiable distance for approximate scaling. When a pantograph is in use, the horizontal distance between the model scale points is related to the corresponding distance on the base sheet by a fixed reduction ratio. The scale of the model is approximately equal to the scale of the base sheet divided by the ratio of reduction set on the pantograph.

36. Leveling the model

A vertical control point generally is available in each of the four corners of the neat stereoscopic model. All given elevations must be converted to their equivalents in millimeters at model scale unless the tracing table is equipped with a counter reading directly in feet, geared to agree with the scale of the model.

An index or reference elevation is established by (a) adjusting the tracing table platen to the height that places its floating mark in apparent contact with the spatial position of any one of the vertical control points, and (b) setting the vertical reading of the height counter to agree with the given elevation of that point. Vertical readings of the three remaining control points indicate, by the amount of their failure to agree with their given elevations, the lack of parallelism between the model datum and the reference plane.

An examination of the discrepancies between the correct elevations of the control points and the vertical readings may indicate that the model datum fails to define a plane. Frequently, model deformation is due to the existence of minute residuals of y parallax that are beyond visual detection limits. (See "Correction of model warpage," below.)

In the following leveling procedure, points 3, 4, 5, and 6 of figure 13 represent model image points (control points) of known elevations.

a. Leveling in the y *direction.*—Establish an index at 3.

Read the model elevation at 5 and note the error. This indicates the amount of x tilt existing between the model datum and the reference plane.

Confirm by reading the elevations at 4 and 6.

Rotate the model to eliminate the indicated conditions of x tilt by either of the following methods:

(1) Tilt the projector-track frame by appropriate adjustment of screws at B and (or) C (fig. 13). Adjustment of screw at B rotates the model about a line through points A and C. Adjustment of screw at C rotates the model about a line through points A and B. Continue this adjustment until readings of the elevations indicate no slope of the model datum in the y direction.

(2) Impart a common amount of x tilt to both projectors using their individual x tilt adjustments, until there is no slope of the model datum in the y direction. This is the preferred method if the x tilt correction to be applied is large. An excessive tilt of the projector-track frame is thus avoided.

b. Leveling in the x *direction.*—Reestablish an index at 3.

Read model elevation at 4 and note the error. This error indicates the y tilt condition of the model.

Rotate the model about a line through points B and C by adjusting screw at A until the y tilt is reduced to a value of less than 0.5 mm across the model. Refinement of the leveling of the model datum is accomplished in connection with the correction of model warpage, as described below.

The leveling procedure is facilitated if it is known in advance how much x tilt and (or) y tilt is imparted to the model by one complete revolution of each of the support screws. This information is easily obtained by trial and measurement.

c. Alternative method of leveling.—An alternative method of leveling the model datum in the x and y directions is suggested for the more experienced stereocompiler. This method facilitates the operation by permitting the tilt adjustment of the model to be made with the precision of stereoscopic measurement while the model is under observation. The procedure is as follows:

Establish an index at 4, read the model elevation at 6, and note the vertical error at 6.

Raise or lower the platen of the tracing table to correct two-thirds of the amount of the error existing at 6.

Adjust screw at C (fig. 13) to rotate the model until the surface of the model at point 6 is in contact with the floating mark.

Check the model reading at 4. If further adjustment is required, reestablish an index at 4 and repeat the procedure until the model readings at 4 and 6 indicate that the model datum is level in the y direction. (The two-thirds correction is an approximation based on the normal positional relationship between the screw at B and points 4 and 6. As the stereocompiler gains experience with this method, he will become adept at varying the amount of correction needed to satisfy the conditions existing when points 4 and (or) 6 are displaced considerably from neat model corner positions.)

With the index established at 4, read and note the vertical error of the model at point 3.

Raise or lower the platen of the tracing table 1½ times the amount of error existing at 3 in the direction that overcorrects the error.

Adjust screw at A (fig. 13) to rotate the model until the surface of the model at point 3 is brought into contact with the floating mark.

Check the model reading at 4. If further adjustment is required, reestablish an index at 4 and repeat the procedure until the model readings at 3 and 4 indicate that the model datum is level in the x direction. (The 1½ times correction is an approximation based on the usual x displacement of points 3 and 4 from a vertical plane containing support screws at B and C.)

d. Correction of model warpage.—Reestablish an index at 3 and read the model elevations at 4, 5, and 6.

Determine the extent of warpage by comparing the existing x tilt of the model datum, as indicated by readings at 3 and 5, with that indicated by readings at 4 and 6.

If point 6 reads low relative to point 4, x tilt the left projector toward point 5. If point 6 reads high, x tilt the left projector toward point 3. The y parallax introduced at 1 by this x tilt adjustment should be approximately equal to the relative elevation change desired between 4 and 6.

Clear y parallax introduced at 1, with the swing motion of the right projector.

Clear y parallax introduced at 2, with the swing motion of the left projector.

Repeat these steps until readings at the corner points show no warpage.

When warpage has been eliminated, determine the y tilt condition of the model as indicated by model readings at points 3 and 4.

Adjust support screw at A to correct remaining y tilt.

Reestablish an index on point 3 and check the elevation readings of all available vertical control points within the model area.

Repeat the leveling procedure, if necessary, until a level model datum is obtained.

When model warpage is corrected, relative orientation should be improved beyond the visual limits of y parallax detection. If y parallax is increased when the four model-corner elevations indicate a flat datum, other sources of error are present.

37. Final scaling and positioning of model

Each model pertinent to the compilation of a project area must be of the same scale and bear a proper positional relationship to surrounding models. At least four horizontal control points are required to provide common positions and distances in adjacent models.

The final scale solution is attained when the size of the model satisfies most accurately all given distances within the area it defines. To check the scale, the horizontal distances between the positions of model image points are compared with the corresponding dimensions defined by their plotted positions on the base sheet. The distances between diagonally opposite model corner points are of the greatest lengths and are, therefore, the best scale-check dimensions. Frequently, the available horizontal control points define distances of apparently inconsistent scale values; the model should then be adjusted to the size that compromises the discrepancy of the scales indicated by the two diagonal distances. As an approximate scale solution has been attained previously, only a limited amount of x motion is necessary to correct air base dimension of the model. The existing y parallax and level solutions should remain undisturbed.

The model, the base sheet, or both, are adjusted in their respective horizontal planes to obtain an orthographic relationship between the model and the base sheet. The positions of horizontal control image points must plot in agreement, or as nearly so as possible, with their preestablished map positions.

The desired positional relationship in the flight direction can be achieved by adjusting the base sheet or by imparting identical x motions to each of the projectors. Positional correction in the y direction can be made by movement of the base sheet or by adjustment of the anchor point position of the pantograph, if one is in use. The base sheet must be rotated in the plane defined by the reference table to achieve a proper azimuthal relationship.

When all horizontal control points within the model area are of the same order of accuracy, positional discrepancies should be adjusted to reduce the value of residual errors of position to a minimum. When models are controlled by points differing in the order of accuracy with which their positions were established, the solution which favors points of higher reliability should be accepted. Consideration must be given to the position and alinement of certain features, such as railroads that have tangents of a length sufficient to extend beyond the area of a single model.

When a pantograph is employed, the necessary positional adjustments to the model are proportional rather than equal to the displacement errors indicated on the base sheet. A transparent overlay sheet taped securely to the reference table in a manner that allows freedom of movement to a base sheet beneath it facilitates the positioning operation. The overlay sheet must be of sufficient size to cover the area traversed by the tracing table, but must not extend into the proposed compilation area. The base sheet may then be adjusted to bring a plotted position into coincidence with the pencil point of the pantograph while the tracing table remains stationary on the overlay sheet and defines the horizontal position of the corresponding model image point.

MAP COMPILATION

38. Exception to general procedure

The procedures of map compilation are similar for the principal double-projection anaglyphic plotting instruments, including the Kelsh plotter, ER-55 plotter, and multiplex. The procedures described in another chapter [2] for compiling with these instruments apply in their entirety to the Kelsh plotter, except for the following modification.

a. Division of model into front and back halves.—A tabletop measuring 46 inches from front to back is required to accommodate the Kelsh plotter model. Because of this large front-to-back dimension, the complete model cannot be compiled efficiently from the front side of the instrument. It is convenient to divide the model about its base line and compile the near half of the model from the front side of the instrument and the far half from the opposite side. The tracing table is rotated 180° to facilitate the compilation operation from the rear side of the instrument. Any deviation of the tracing table pencil or tracing point from its proper orthographic relationship to the floating mark will cause plotting discrepancies when the tracing table is rotated 180°. To avoid positional errors, it is essential that this relationship be checked at frequent intervals.

[2] See Chapter 3F2, Development of the map manuscript.

TOPOGRAPHIC INSTRUCTIONS ○ CHAPTER 3F5 ○ KELSH PLOTTER PROCEDURES