A TRIANGULATION TECHNIQUE FOR USE WITH THE KELSH PLOTTER

Allen C. Gunn, Aeronautical Chart and Information Center

SINCE Mr. Kelsh announced the development of his stereoplotter in the March 1947 issue of PHOTOGRAMMETRIC ENGINEERING, its economy and simplicity have become well known. However, it does not lend itself to the bridging of vertical control because it does not provide an adequate means of transferring the exterior orientation of a photograph from one projector to the other. To overcome this limitation of the Kelsh Plotter, spirit levels have been used experimentally to recapture the tilt of that diapositive which had been used in the previous model.[1] Apparently this technique has not been generally accepted for the following reasons:

1. This method re-establishes only two of the required six elements of exterior orientation.
2. The calibrations (interior orientation) of the two projectors are not identical.
3. The operator cannot consistently replace a diapositive in a plate holder within 0.002 inch.

The orientation transfer technique porposed by the author has the following advantages under operational conditions:

1. It precisely recovers all six elements of the previous exterior orientation of each advanced diapositive with respect to the manuscript itself. This allows the scale transfer to be made by the use of the elevation of the center point in the model overlap and a constant index of the tracing table to control the scale.[2]
2. It does not require transferring diapositive plates from one projector to another. This eliminates the possibility of disturbing the interior orientation of the diapositive plate in its transition from one model to another.

In actual practice this technique permits an extension of horizontal and vertical control for which errors have accumulated in a systematic manner. Therefore any adjustment of raw data thus obtained will yield quite accurate results.

This technique for transferring the exterior orientation of a single photograph is based upon accepted principles of spatial resection. It may be considered as having three phases, namely, recording exterior orientation, recovering exterior orientation, and scaling the stereo model. The exterior orientation is recorded by plotting on the map manuscript, the projected images of well defined points on the diapositive that is to be advanced. This recording, or "plot" is prepared when the diapositive to be advanced is in its correct exterior orientation, in other words when the stereo model of which it is a part is in absolute orientation. The exterior orientation is recovered by resecting the advanced diapositive monocularly, and after relative orientation to the next diapositive to a "plot" of its exterior orientation as recorded in the previous model. The scaling of the stereo model is accomplished after the resection of the advanced diapositive has been made. Since this resection has established all six elements of exterior orientation, the correct model scale is determined by altering the x separation of the projectors using only the projector in which the leading diapositive is installed, until the elevation of the central point on the leading edge of the model has been reestablished by the tracing table.

The use of this procedure for transferring exterior orientation requires several well defined points on each diapositive. The points are necessary for recording of exterior orientations of each diapositive on

[1] See "Aerotriangulation with the Kelsh Plotter" by S. J. Friedman, PHOTOGRAMMETRIC ENGINEERING, Volume XIX, No. 1, pages 51 to 56, March 1953. Also see "Transfer of Absolute Orientation from One Type of Stereoscopic Plotting Instrument to Another" by Stanley W. Trow and Morton Keller. PHOTOGRAMMETRIC ENGINEERING, Volume XIX, No. 5, pages 831 to 834, December 1953.

[2] See "Photogrammetric Triangulation with Separately Oriented Stereo Models" by Lennart Ekelund, *Photogrammetria*, Volume VIII. No. 4, pages 276 to 284.

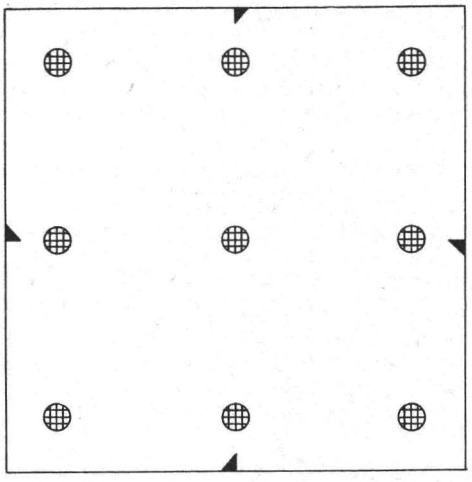

FIG. 1.—Illustration of general areas on diapositive which are double exposed with a grid negative.

the manuscript. To insure there being a sufficient number of well defined points located in strategic areas of each diapositive, the diapositives are prepared in the following manner: A 9×9 grid negative is masked to provide exposure of the diapositive plate in selected areas (see Figure 1); the diapositive plate is double exposed with this grid plate prior to processing, thus providing clearly defined reference points on the diapositive plate.

The registration of this grid negative is in no way critical with respect to the fiducial axis of the film negative. Therefore the double exposure of this diapositive presents no problems.

RECORDING THE EXTERIOR ORIENTATION

After all diapositives of the flight have been prepared as prescribed above, the triangulation may proceed as follows:

1. Orient the initial model relatively and absolutely to the control furnished in such a manner that:
   a. The projectors are as nearly centered on the x-bar as possible, so that most of the 90 degree cone of projection from each projector is visible on the plotting table.
   b. The tracing table is indexed in the upper position to allow measurement within the models, as they are formed closer to the plotting surface since the "BZ" curve will be downward.
2. Secure the index of the tracing table and do not change it throughout the triangulation.
3. Measure stereoscopically the elevation of the pass points on the leading edges of the model, and indicate on the base sheet as is customary.
4. Disconnect the telescoping guide rod from the projector containing the diapositive to be advanced.
5. Direct the guide rod manually to each of the grid areas double exposed on the diapositive. As each of these areas is illuminated, very carefully draw their position on the manuscript using a hard pencil and straight edge. Extreme care must be emphasized in this operation since the accuracy of the spatial recovery is only as precise as the recording of these positions. At this time, the initial model has been oriented absolutely to the ground control, and a "plot" of the projected grids on the diapositive to be advanced has been indicated on the manuscript.

RECOVERY OF EXTERIOR ORIENTATION

Recovery of the exterior orientation of the advanced diapositive may now be accomplished by the following procedure:

1. Rotate the projector cone containing the diapositive to be advanced 180 degrees, and perform a relative orientation to the following diapositive in a normal manner.
2. Rotate the manuscript 180 degrees.
3. Disconnect the telescoping guide rod from the projector containing the advanced diapositive, and observe the projected positions of the reference grids on the diapositive with respect to their positions as indicated by the previous exterior orientation.
4. Adjust the x-bar, using the three suspension screws so that the projected grids again fit the plotted positions on the manuscript. This step is the time consuming operation of this technique, and the price of the resulting precision.

SCALING OF MODEL

At this time the stereoscopic model is in the correct absolute orientation with the exception of scale which may be adjusted as follows:

1. Connect the guide rod to the tracing table, and observe the center pass point stereoscopically.
2. Set the tracing table to the elevation read for this point in the previous model.
3. Observe the floating mark, and change the air base by using only the projector containing the last installed diapositive, until the floating mark is on the surface of the model.

This resection in space to a previously projected plot is of course repeated throughout the strip maintaining the tracing table index of the initial model.

Instrument Errors

If the instrument is not completely calibrated, then in each successive model it may be found that the resection of the advanced diapositive to its grid plot in the previous model does not locate the stereo model in its proper horizontal position with respect to the pass points previously plotted. This x and y displacement is due to the lack of coincidence of the central axis of the lens with the swing axis of the projector cone, and it becomes apparent when the projector is rotated 180 degrees from model to model. This displacement is of no consequence, and is removed by shifting the manuscript to fit the pass points.

If, after orientation of a stereo-model by this method, the wing points are measured, there will possibly be noted some amount of inclination with respect to these same points as measured in the previous model. These lateral inclination errors may be due in part to any deviations of the slate table from a true plane. This warped condition would not become apparent if the models were not rotated 180 degrees as required by this method. However, if the projected grid points are recorded on one portion of a warped datum, and resected on another portion, these inclination errors will exist in various amounts depending on the slate table used.

Although there are residual errors in the results of this method of control extension, it will provide a systematic accumulation of errors that are highly predictable, and in the absence of more capable instruments, will allow the Kelsh plotter to extend control.