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New Kelsh Correction Cams

The film-diapositive sandwich allows the use of the new stable-base and color films.

ABSTRACT; *With the development of stable base film, both for color and for black-and-white, the reproduction of an accurate film diapositive from a film negative is now practical and economical. Two methods for accurate compilation in a Kelsh plotter from such film diapositives are explained; one method is the result of the redesign of the Kelsh correction-cam system and the other is the cams themselves. A mathematical analysis is presented showing how this development was accomplished. A second system for using film diapositives, incorporating a glass compensation plate, is suggested as an alternative for projection-type stereoplotters which do not have the Kelsh correction cam system.*

HISTORY

THE KELSH PLOTTER earned much of its early fame by having a correction cam mechanism for distortion as standard equipment in its projectors. Up until a few years ago, many of the taking cameras for photogrammetry had considerable lens distortion. Also, it was customary in a great number of applications to print glass diapositives with the emulsion up in order to allow the taking negative to reproduce the diapositive emulsion to emulsion. The Kelsh cams corrected for the distortion of the taking-camera lens, the distortion caused by the thickness of a glass diapositive, or a combination of both.

Since that time, distortion-free aerial camera lenses have been developed and are in common use today. Also, better systems for diapositive reproduction have been developed, and distortion-free photography emulsion down is now the common way of producing glass diapositives for photogrammetry. As a result, many of the old Kelsh cam systems have been deactivated with the built-in screw adjustment for that purpose, and cams have not been needed for photogrammetric compiling.

With the development of the stable base films, both for color and for black-and-white, the reproduction of an accurate film diapositive from a film negative is now both practical and economical. A study was made recently by our Kelsh Instrument Division to improve the method for utilizing film diapositives in the Kelsh plotter. As a result, improvements were made in the glass sandwich used for supporting the film diapositive on the plateholder, and in the design of the correction cam itself. It was determined that three factors make more accurate compilation possible today in the Kelsh plotter with the film diapositive method than was possible 10 or 15 years ago.

The first reason for this improvement is not only the availability, but also the excellent stability of the stable base film itself. It has been determined that no significant random deformation is present in properly printed stable-base film diapositives.[1] The second reason is the availability, at a lower cost, of high-quality optically flat glass for the film sandwich. In our experiments, only Select Twin-Ground Optical Flat glass was used. The thickness of this glass is accurate to within .0005 inch, and it is flat to within three fringes of Newton rings for any $1\frac{1}{2}$-inch diameter area.

The third reason for making more accurate compilation possible is a redesign of the Kelsh

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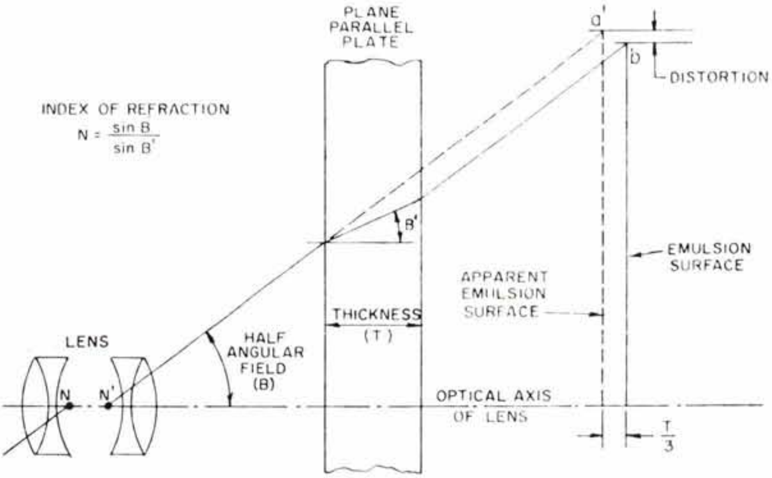

FIG. 1. A parallel glass plate causes a displacement of the emulsion surface as well as a distortion error.

cam system to a higher degree of accuracy than heretofore. This paper will be limited to the development of this more-accurate cam system and the description of another method of correcting for distortion in plotters which do not have the cam system.

ERRORS CAUSED BY GLASS PLATES

A mathematical analysis was prepared for the correction cam system, using a somewhat different approach from the method that had been used to explain this mechanism in the past. The geometry of the explanation was based on determining what could be done to the plateholder and the lens in order to keep a properly projected point on the *model surface* at the *same point*, if a parallel glass plate is introduced between the lens and the diapositive. By keeping the point on the model the same in both instances, the point itself acted as a theoretical fulcrum for the rays of light which were needed to accomplish the desired image projection.

The Second Edition of the *Manual of Photogrammetry* was used as a reference text because it gives a very complete explanation of the phenomena which occur with the introduction of a parallel glass plate. A less-complete explanation is given in the Third Edition.[2] If a parallel glass plate is introduced between an object surface (which we are calling an emulsion surface) and a projection lens, two errors occur. The first error is a displacement of the emulsion plane. This plane is moved toward the projection lens by a distance of $\frac{1}{3}$ of the thickness of the glass plate.

The second error is a distortion which makes the points on the emulsion surface appear to be farther away from the optical axis of the lens. These errors are graphically illustrated in Figure 1. Point *b* on the emulsion surface appears to be at Point *a'* if a parallel glass plate is introduced. The mathematics required to compute the values for the distortion errors may be found in the *Manual of Photogrammetry*.

THE FILM-GLASS SANDWICH

With the new stable-base film diapositives, a film-glass sandwich may be prepared for the plateholder, consisting of two optically flat plates, $9\frac{1}{2} \times 9\frac{1}{2}$-inch square of the quality mentioned earlier in this paper. The film is placed between these two glass plates. The resulting *sandwich* may then be taped together at points that would not rest on the supporting surfaces of the plateholder.

The film diapositive may be placed into the sandwich with its emulsion either up or down. If the film diapositive is used emulsion up, the thickness of the film as well as the thickness of the lower glass plate of the sandwich must be taken into consideration. Most stable-base film has a refractive index of about 1.50. This is very close to the refractive index of ordinary glass, which is about 1.52. Therefore, for practical purposes, the film base material may be considered the same as glass in computing distortion and image displacement.

Color film diapositives are best made with emulsion-to-emulsion printing. The resolution is much sharper with this method, and the reproduction process is less expensive. As the color negative is photographed in the aerial camera with its emulsion down, the color film diapositive would, with this method of printing, have its emulsion up. Improved resolution with black-and-white film diapositives may also be achieved by printing emulsion to emulsion. But it has been common practice to print black-and-white *glass* diapositives through the film negative base on to an emulsion-down glass diapositive. This latter procedure could, of course, be used for black-and-white *film* diapositives, particularly if any difference in resolution might be too small to be detected with the human eye.

CALIBRATING THE KELSH PLOTTER

If the structure of the film-glass sandwich has been established and the thickness to be corrected is known, the first step in preparing a Kelsh plotter for film diapositives is to make an adjustment of the principal distance of the projectors. Let us assume that the plotter had been previously calibrated for distortion-free emulsion-down photography. The emulsion surface of the diapositive must now be moved *away* from the lens by a distance equal to $\frac{1}{3}$ of the thickness of the glass plate (or glass plate plus film) that forms the lower half of the sandwich. This places the *apparent* emulsion surface at the proper focal-plane distance for the projection lens. (The principal distance, therefore, would be shortened by $\frac{2}{3}$ of the thickness of the lower glass plate, or glass-film combination.) Such a move should be made if the proper correction cams are in their seats in a vertical position establishing a fixed base. The new principal distance should then be set by measuring from the surface of the lens element.

The Kelsh correction cams are used to compensate for the distortion that *also* occurs with the introduction of the parallel glass plate, where the projected beam passes through at an angle to the plate. A table showing the degree of this distortion for a hypothetical 1-inch thick glass plate is shown on page 112, Volume 1 of the Third Edition of the *Manual of Photogrammetry*.

Figure 2 shows the effect of the projection of an emulsion surface for 6-inch photography through a parallel glass plate and a 5× magnification projection lens to a nominal reference surface. This reference surface, in our application, is the tracing table platen. The glass plate of thickness T is, of course, normally pressed up against the film diapositive. But for descriptive purposes, we have placed it in a lower position between the emulsion surface and the lens.

The normal emulsion plane *without* a glass plate would be at 153 mm from the upper nodal point of the lens. After making the principal distance correction, if the glass plate is introduced, the focal plane is displaced a distance of $\frac{1}{3}$ of the thickness of the plate *back toward* the lens to the dotted line labeled *apparent emulsion surface*. This returns the focal plane to the proper 153 mm object distance. At the same time, a distortion d is introduced which causes the projected image plane to be concave in respect to the lens. In other words, Point b is projected where Point a should have been on the model, or at Point 2. And Point a is projected through Point 1 on the drawing. This causes a difference in $Z(\Delta Z)$ with a higher reading than the true Z should be.

For example, without the correction cam, the projected ΔZ error for one projector would be .086 inch at the nominal reference surface for a .130-inch thick glass plate at a maximum projection angle of 45° from the optical axis of the lens. The value of ΔZ decreases as the beam is moved toward the center, and is zero at the nadir.

The new Kelsh correction cams have been designed to *lower* the lens a precise amount for each value of angle B *away* from the optical axis of the lens. As may be seen on Figure 2, if the lens can be lowered so that the light ray which passes through Point b on the emulsion surface to the upper nodal point N' is made, instead, to pass through Point c, then, in effect, the emulsion at Point a is picked up by this ray, passed through Point c, and down onto the reference surface at Point 2. This is where Point a *would* have been projected if it had been at Point a' without a glass plate.

The lens is dropped in this instance a distance of $(5/6)\ m$ with m being the distance between Points b and c. This is the proportion for a 5× magnification. For a 7× magnification, the lens is dropped a distance of $(7/8)\ m$.

The distance y that the cam drops the lens has been calculated to reorient the projection of Point a at its proper position on the nominal reference surface at 765 mm from the lower nodal point of the lens. Because of the trigonometry involved, it can be seen from Figure 2 that there will be a slight deviation from this absolute orientation if the platen is above or below this plane. For example, for a .130-inch thick lower glass plate and a 5× magnification at a Z distance of plus or minus $2\frac{1}{2}$ inches from the nominal reference surface, and at a maximum projection angle of 45°

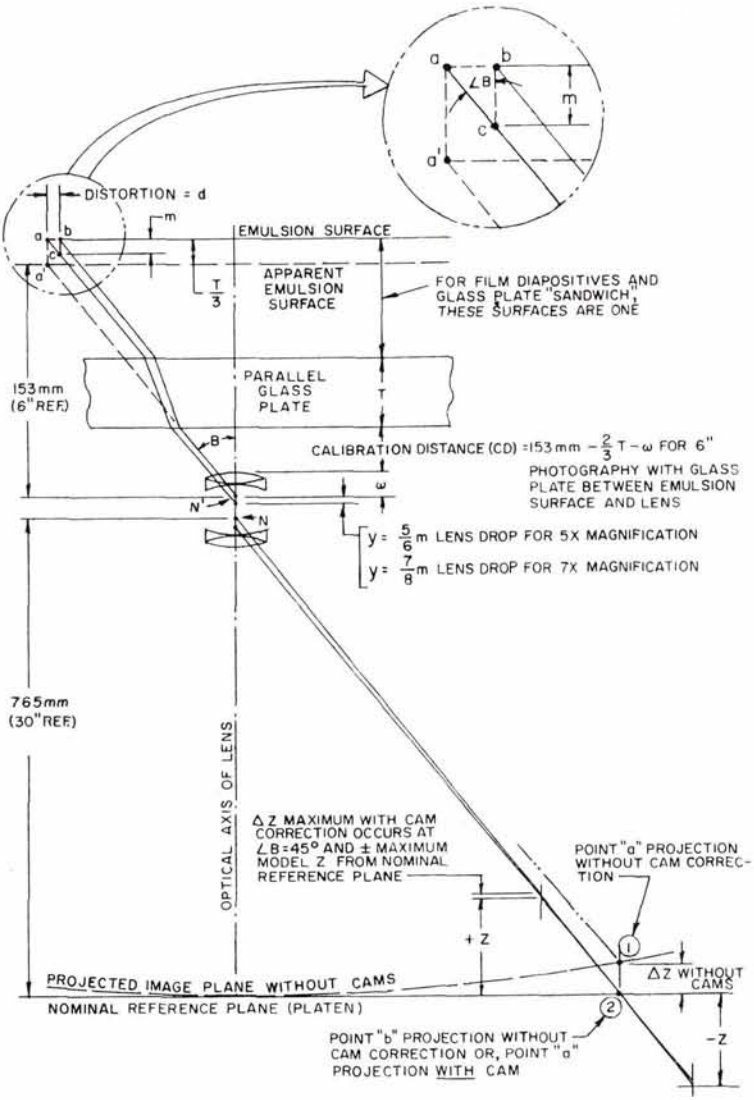

FIG. 2. With Point 2 as a fulcrum, the distance Y that the cam must drop the projection lens to correct for the distortion may be computed as a simple triangular proportion.

from the optical axis of the lens, the ΔZ error for *one* projector with a cam at either of these points would be in the order of .001 inch. The error at all other points in the projection, both toward the nominal reference plane and toward the optical center, would be proportionately less than this amount.

Without going into the mathematics involved, if the rays from *two* cam corrected beams intersect above or below the nominal reference plane, the ΔZ error is still quite close to that for one-cam corrected beam, the maximum still being in the order of .001 inch for the specifications we have used. As was explained before, for .130-inch thick glass *without* cam correction, this figure is about .086 inch.

The Kelsh correction cams have been redesigned recently, based on the above geometry, and are now being produced quite accurately. Although a Kelsh correction cam exists for each thickness of glass plate that might be used in this manner, it was found that the cam designed to correct for .130-inch thick glass seems to be most convenient for this purpose. With this cam, using the film diapositive *emulsion down*, .130-inch glass can be used for the lower sandwich plate. If using a film *emulsion up*, having a .007-inch thick base, .123-inch glass can be used for the lower plate.

However, glass plates of the optically flat quality required may not always be available in the exact sizes needed for the lower sandwich plate (such as .130 inch, or .123 inch for our example). Therefore, it is good to know how deviations from such base figures might affect the model.

In using 6-inch photography with 5× magnification, every .001-inch change in thickness of the lower sandwich plate causes a ΔZ difference of .0006 inch at the *extreme corner* of the neat model. This difference would, of course, decrease as the projected beam is moved toward the optical center of the lens. Therefore, if one uses a .007-inch thick film base emulsion up, with a more standard .120-inch thick lower glass plate instead of one .123-inch thick, the *extreme corner* of the neat model would have a ΔZ difference of .0018 inch, and *over 70 percent of the model* would have a Z difference of *.001 inch or less.*

All of the new Kelsh plotters have the long-stemmed cams that give a more precise positioning on the projected angles. Figure 3 shows a pair of these new cams. On older Kelsh plotters, the accuracy of the cam system depends, of course, on the stability of the cam-lever mechanism.

For color film diapositives, the new quartz halogen lighting system is most desirable. It produces a white light which permits a realistic interpretation of the colors in the film. The color stereo model which is projected may be viewed with either the stereoimage alternator, or the polarized platen viewing system.

Another good reason for using quartz halogen illumination for color as well as black-and-white film diapositives is the fact that more light is required. The film base is an opalescent material, causing a 15 to 20 percent loss of the projected light as compared to glass diapositives. As the quartz halogen systems put out about 40 percent more light than the old incandescent systems, the image on the tracing table is therefore about 20 to 25 percent brighter if viewing film-diapositive models with quartz halogen lighting.

Correcting the Projected Image with a Glass Compensation Plate

There is another way to correct for the distortion caused by the lower half of the film-glass sandwich. As shown in Figure 4, the same correction of the principal distance that is used for the cam system applies in this method. The emulsion plane must be moved *away* from the lens by a distance of $t/3$ where t is the thickness of the lower glass plate of the sandwich. To correct for the distortion d, a glass compensation plate may be introduced directly *under* the projector lens, and suspended from it, preferably on a three-point support. The compensation plate under the lens should be thicker than the lower plate of the film sandwich by a factor of the magnification power of the lens. For a 5× magnification, the compensation plate would have a thickness of $5t$. For the .130-inch glass sandwich plate, the compensation plate would have to be .650 inch thick. Such a plate magnifies the projected distortion five times that caused by the lower sandwich plate, and in the opposite direction, compensating for it.

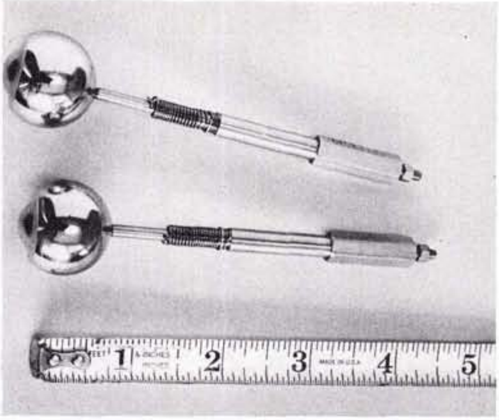

FIG. 3. New Kelsh plotters have the long-stemmed correction cams which give a more-precise position for the cam level mechanism.

The compensation plate also has the effect of lowering the optimum image plane. For a true 5× magnification, the image plane is $5t/3$ lower than in the normal emulsion down projection. Such a compensation plate must be of a homogeneous optical glass in order to eliminate distortions that might be caused by an index of refraction gradient. The plate must be ground to a high degree of flatness and parallelism. If its refractive index is different from than that of the lower sandwich plate, the compensation plate must to be adjusted accordingly in thickness. Because we are now dealing with a much thicker plate, the distortion errors are greatly magnified.

The compensation plate must be leveled so that it remains parallel with the diapositive at all times. Some reduction of the projected

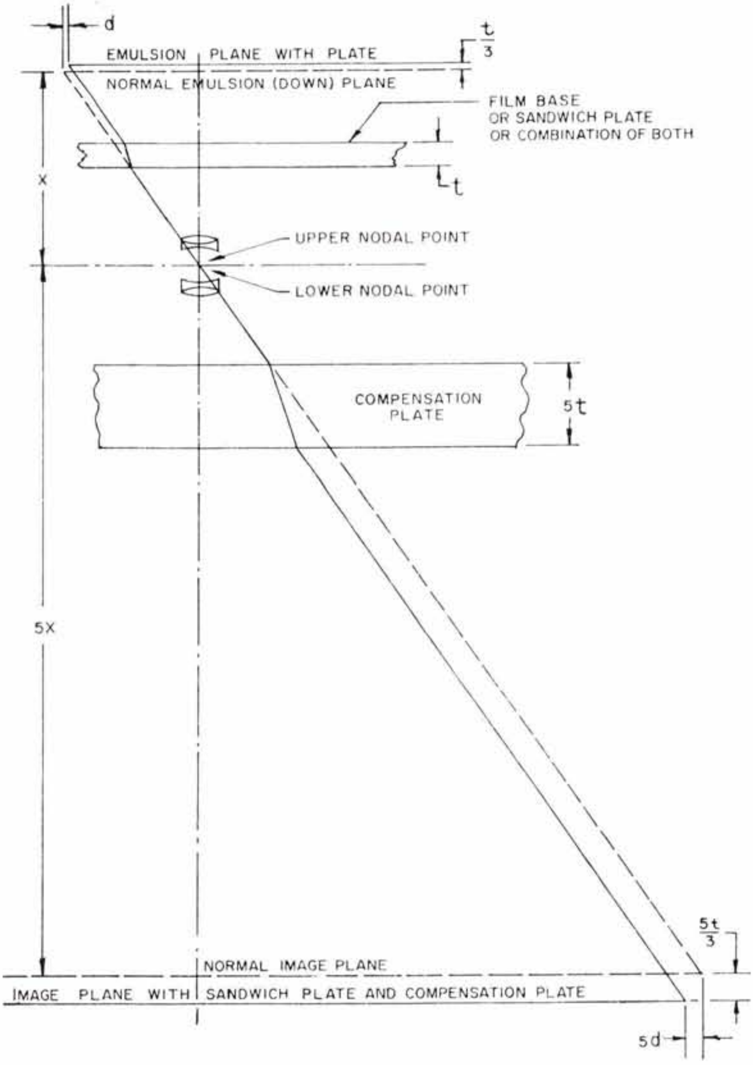

FIG. 4. A compensation plate may be used to correct for distortion in projection plotters which do not have the Kelsh cam system.

light will occur because of the introduction of this additional plate.

CONCLUSION

In photogrammetric compiling, many advantages accrue from using stable-base film diapositives, and particularly the ones in color. Some of these advantages may be listed as follows:

- The film diapositives are unbreakable.
- Film diapositives may be stored in ordinary file folders, taking up much less space than glass diapositives.
- Color film diapositives are readily available and may be purchased at about the same price as black and white glass diapositives.
- The extra detail available from color film diapositives is quite valuable in photogrammetric compiling and interpretation.
- Stable base film diapositives are themselves accurate reproductions of the film negative, and may be utilized for accurate compiling when used with the systems described in this paper.

The Kelsh correction cam system makes the use of both black-and-white or color film diapositives both practical and economical in the Kelsh plotter. And it is certainly true that color in photogrammetry is continuing to be the wave of the future. Stable-base film diapositives in color are currently being used in many Kelsh plotters. As a matter of fact, some photogrammetrists are even compiling cadastral mapping on these instruments directly from color *negatives*, which they seem to be able to interpret satisfactorily for that purpose.

The Kelsh plotter is again proving itself to be as versatile an instrument for the future as it has been in the past.

REFERENCES

1. "An Investigation of Film Diapositive Distortion," by Major M. E. H. Young, Canadian Defense Forces, a paper presented at the 1971 CIS Convention, Ottawa, Canada.
2. *Manual of Photogrammetry*, Second Edition published 1952, and Third Edition published 1966 by the American Society of Photogrammetry.

Articles for Next Month

R. M. Hoffer, ADP, multiband and multispectral digital photos.
R. K. Holz and *R. E. Boyer*, Patterns from Apollo VI photos.
R. Kamiya, the digital photo map.
K. Kraus and *E. M. Mikhail*, Linear least-squares interpolation.
G. T. McNeil, et al, Underwater photography.
L. Sayne-Wittgenstein and *A. H. Aldred*, Tree size and large-scale photos.
H. S. Williams, A theorem in least squares.

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2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; **EXCEPT** that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
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