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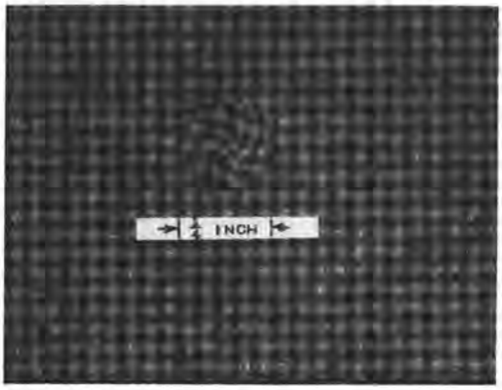

Frontispiece. Dried water spot on a sensitized plate. The Moiré fringe pattern was obtained by the rotation of KODAK Special Plate Type 083-01 and the registration master plate.

# Color Plate Metric Stability

## Color sensitized glass plates have the same quality as black-and-white—1.6 microns or less average residual error.

*(Abstract on next page)*

### Introduction

In photogrammetry, tolerances are stated for mapping and geodetic projects and it is essential to know the accuracy associated with a photogrammetric determination. To produce acceptable final results, error analysis is necessary. Recent investigations indicate that close study of the factors governing the metric properties of the photographic image can produce significant improvements in photogrammetric measurements.

Photographic plates have been generally used in systems involving highly precise measurements, but relatively few studies on the metric properties of photographic plates for photogrammetry appeared prior to 1961. Plate metric quality was discussed in several papers[2,3] originating in the field of astronomy where precise comparators for photographic astrometry were available.

Altman and Ball[5] observed in 1961: "Interest in this problem (spatial stability of photographic plates) has increased in recent years because of the use of the photographic plate in many applications requiring the utmost in dimensional accuracy . . . ." They further noted: ". . . the availability of electronic computers has made it convenient to analyze the data obtained from spatial-stability measurements more extensively than in the past."

In 1966, a related observation was published by Blachut[10]: "Today, with the introduction of precise and reliable stereo- and monocomparators, and the use of computations to replace the physical reconstruction of photographic geometry with all its accompanying phenomena, there is no doubt that the optical and geometrical quality of the photographic image lags far behind our capacity for handling the photographic data precisely."

Positional error involving photographic plates which is not random, can be corrected. Correcting equations can be incorporated in the computational program associated with the measurements. Randomness is the only ultimate limitation on precision in situations involving aerotriangulation and precision photogrammetry. Currently, it is generally known that the magnitude of the random component of physical shift of an image on a photographic plate between exposure and measurement is not great, compared to the magnitude of the errors in all the other quantities in the system.

Small as the random shift is, it is essential to have a good idea of its size. In recent years, several investigators studied the metrical and

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ABSTRACT: *The metric stability characteristics of several newer types of color, and black-and-white, photogrammetric plates were investigated by the moiré fringe measurement technique. This method utilizes the change in moiré fringe patterns produced by two halftone images to indicate whether dimensional change has taken place. Plates were exposed to a 1,000-line/inch moiré master grid and subsequently measured for dimensional excursions due to processing and relative humidity change. An average relative vector displacement was calculated which is the average level of random movement (residual error) of the image on the glass plate. The study showed the average random residual error for glass plates used for photogrammetry and geodesy is 1.6 microns or less (including 0.9 micron experimental error). Errors due to one practical problem, water spotting, were studied, emphasizing the need for good handling techniques. There is no difference in dimensional stability characteristics between black-and-white plates, and the newer types of color plates.*

spatial stability of black-and-white photographic plates using techniques adapted to their requirements. A brief review of results given in recent reports follows.

## PREVIOUS WORK ON METRIC STABILITY BLACK-AND-WHITE DIAPOSITIVE PLATES

Brucklacher and Luder[1] performed a very comprehensive study of the dimensional changes of photographic plates and films. In the study of the dimensional stability of photographic plates, a contact print of an etched glass grid was made on to plate samples. Measurements were made directly from the plates using a universal microscope accurate to ±1.8 microns. They found that non-uniform dimensional changes amounted to ±2.4 microns (lineal displacement) for a group of photographic plates. Prior to 1961, this was one of the broadest investigations conducted.

With the advent of ballistic cameras, and the use of ballistic plates with KODAK Spectroscopic Type 103-F emulsion, a project was undertaken by Altman and Ball[5] of the KODAK Research Laboratories who studied the spatial characteristics of KODAK photographic plates on an extensive basis. A master grid-comparator method was used. Positional data from comparator measurements of intersections on both grid and plates were compared by an electronic computer.

The study was set up to produce typical values of image displacement following determination and extraction of various types of assumed over-all distortion. Analysis of the image displacement (spatial stability) was treated on the principle that the net plate error consisted of systematic and random distortion or error. Computer analyses were made on the basis of no correction for systematic error (no fit), and on the basis of systematic errors following linear, quadratic, and cubic laws. Errors were calculated for both $X$- and $Y$-coordinates separately and combined into a single value "*RMS* radial error" for the sample.

The net results showed that no significant reduction in systematic plate error was obtained after the application of the second order or quadratic fit. This indicated that the coordinate positions did not lie in straight lines (linear fit), but lay on shallow parabolic curves (quadratic fit) and thus the displacements were greater at the edges and corners of the plate, in general. The Altman and Ball study indicated that where extreme spatial stability is required, a 2 cm-wide band adjacent to the edges of the plate should be avoided.

The range of *RMS* values for the residual random plate error after quadratic fit (most significant reduction) was found to be between 0.9 and 1.4 microns, with a number of residuals whose average value was 1.2 microns. Because the experimental error is included in these values, it follows that the net RMS plate error on the plates measured must be smaller than Altman and Ball's values indicate.

In 1964, Starbird[7] conducted a study of emulsion shift on ballistic camera plates. This investigation, following earlier work on spatial stability of photographic plates, used KODAK Spectroscopic Plate Type 103-F. Starbird's report showed that an assignable linear vector shift of 0.4 micron per cm existed, and the assignable random emulsion shift was determined to be in the order of 0.7

micron for Type 103-F plates. Starbird's work covered many details associated with handling plates.

In 1968 at the 11th International Congress of Photogrammetry in Lausanne, Schmid[12] observed that the contribution of random errors of the Type 103-F emulsion on glass plates had been statistically isolated and determined to be ±1.0 micron. Further, this result was observed to agree exactly with the result of independent tests (of the manufacturer).

In these reports, the value of residual random error on photographic plates is conclusively defined, but the exact change producing the residual error remained to be investigated.

Coincidental with the introduction of stable film bases, a number of studies were made using the moiré fringe technique for measuring non-uniform dimensional and deformational changes. A study reported by Adelstein and Leister[6] in 1963 provides many details on the spatial stability of master glass plates for the investigation of dimensional changes in aerial films. The mean standard deviation for KODALITH Ortho Plate Type 3 negatives was determined through this and subsequent studies, using the moiré fringe method. The results of this work were: (1) The non-uniform size changes over 9-inch distances averaged less than 2 microns; and (2) The overall standard deviation (the variation in measurements at about 3-inch intervals) was about 0.002 percent, equivalent to 1.5 microns.

The studies reviewed above indicate: (1) There are no measurable errors due to changes in relative humidity; and (2) There are no uncompensatable effects due to temperature changes.

### COLOR DIAPOSITIVE PLATES

Color diapositive plates were first used for photogrammetry late in 1963. Although production measurements indicated good metric stability for color plates, no independent data appeared in photogrammetric literature.

In 1964 Swanson[8] and later Umbach[13], both of the U. S. Coast and Geodetic Survey, reported on color (reversal type) diapositive plate tests. They observed that the standard error on a single grid intersection coordinate on color plates (Type 032–01), after least squares fit for correspondence, was less than 2 microns.

Based on these data, color plate residual errors appeared to be slightly higher than for black-and-white plates. Improvements in plate manufacturing technology, and an additional positive-type color plate were introduced subsequently.

For these reasons, an extensive study was made of the metric stability of two black-and-white plates used for photogrammetry and geodesy, and two color plates (positive-, and reversal-types). The present investigation was designed to: (1) Review the history of dimensional change measurements of photographic plates; and (2) To measure and compare color and black-and-white plate dimensional stability characteristics under ideal laboratory conditions.

## PROCEDURE

### THEORY

The moiré fringe measurement method was used for this study. Since this measuring technique has been described in detail in previous papers[6,9], only a brief description will be given here.

The moiré system uses two half-tone glass plate masters, the second having a slightly lower frequency. The first master is contact printed to the photographic test material. This master is referred to as the *exposure master*. After processing, the test material is registered with the second master (or *registration master*). Registration of these two half-tones with different dot spacings creates interference areas known as a moiré fringe pattern or moiré cancellations. Because the frequencies of the two master half-tones and the spacing of the moiré fringes or cancellations are accurately known, the metric changes of the photographic image can be calculated between time of exposure and time of registration.

The 4×4-inch half-tone masters contain a precisely ruled grid pattern with a nominal 1,000 lines/inch frequency. The two master plates have a frequency difference of about 0.18 percent. Registration of these two plates with each other yields 49 moiré fringes or cancellations in the 4×4 inch area (see Figure 1). This results in a standard cancellation spacing of about 0.5 inch. Registration of the test material with the glass *registration master* will show a larger or smaller spacing depending on the size change of the material.

A second system employs two glass master plates which have a frequency difference of 0.08 percent, yielding 9 cancellations spaced at intervals of about 1.25 inch (Figure 2). Experience with this system has shown the advantage of greater precision, (i.e., 0.1 micron for the 9 cancellation system com-

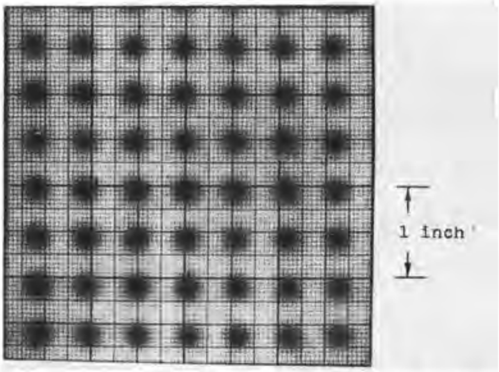

FIG. 1. Moiré cancellation spacing by registering the two master plates. This is the pattern for the 49-cancellation system.

pared to slightly less than 1 micron for the 49-cancellation system). However, the latter has the advantage of showing cancellations at smaller intervals and therefore is more likely to detect nonuniformity of size change or local distortions.

The masters used in the moiré system are sensitized KODALITH Ortho Type 3 glass plates 12×12 inches, 0.250 inch thick micro-flat glass. This emulsion was used because it has extremely high contrast with very sharp image edges. This yields high quality screen images and increases the contrast of the moiré fringe patterns. As the moiré measuring system uses glass plates as standard masters, the information to be gained by measuring glass plates with this system may be questioned. However, the primary purpose of these studies was to detect and measure random image movements in the emulsion layers, as it is well established that overall size changes do not occur in glass plates except for changes due to temperature.[2,5] Such non-uniform image movements would vary from plate to plate. Because all the test plates being measured are compared to the same master, variations in moiré fringe patterns from one another would indicate local distortion or image movement. If no variations exist, then no local image movement has occurred.

Each photogrammetric test plate studied was contact printed under vacuum at 70 F—50% R.H. to the *exposure master* and processed. The plates were then registered at 70 F—50% R.H. with the *registration master* to determine image movement due to processing. Similar registrations have been made at low relative humidity to determine humidity effects. The position of each moiré fringe or cancellation was measured. From this data, and the known location of each cancellation when the two masters are registered together, the vector displacement of each area of the tested sample was calculated in microns. The numerical average of these displacements was obtained and termed the *Average Vector Displacement*. These calculations were made using an IBM System 360 Model 65 computer. All values were extracted and translated relative to the center moiré cancellation being in perfect register. A more complete discussion of the calculation procedure appears in previous moiré method papers.[6,9]

## MATERIALS INVESTIGATED

Two types of black-and-white plates, and two types of color plates, were investigated and compared in the current metric stability study:

(1) KODAK Spectroscopic Plate Type 103-F is a negative-type plate used extensively in ballistic and other types of land-based cameras for aero-triangulation and missile tracking. It is a high-speed, medium contrast panchromatic plate. The metric stability of Type 103-F plates has been investigated previously, using non-moiré methods.

(2) KODAK Super AEROGRAPHIC Positive Plate (Medium) is an extremely fine-grain, blue sensitive plate, widely used for many years for making diapositives for both direct-view and projection-type stereo-plotting equipment. This plate provides a basic frame of reference for black-and-white diapositive plate materials.

(3) KODAK Special Plate Type 083-01 is a positive color film on a glass support. It is designed for making color diapositives from original negatives made on KODAK EKTACHROME MS AEROGRAPHIC Film 2448 (ESTAR Base), when Type 2448 film has been pro-

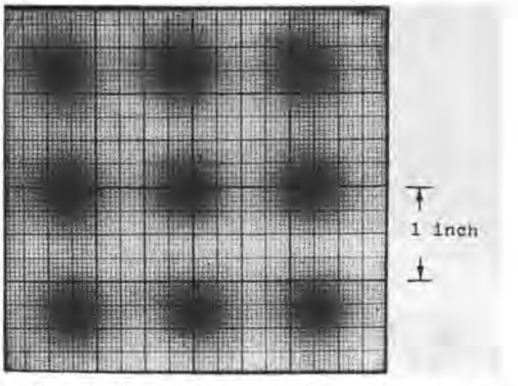

FIG. 2. Cancellation spacing obtained by registering the two master plates. This is the pattern for the 9-cancellation system.

cessed to a negative in the modified KODAK Color Film Process C-22. Color diapositives produced with this plate can be used in direct-view stereoplotting equipment, and are adaptable to projection-type plotters.

(4) Kodak Special Plate Type 032–01 is a color-duplicating film on glass support. This multi-layer reversal-type plate is designed for making color aerial diapositives from original transparencies made on KODAK EKTACHROME MS AEROGRAPHIC Film 2448 (ESTAR Base), and KODAK EKTACHROME AERO Film 8442. Color diapositives produced with Type 032–01 plates can be used in stereoplotting equipment in the same way as color diapositives made with Type 083–01 plates.

Individual plate size was $9\frac{1}{2}\times9\frac{1}{2}$ inches, 0.250 inch thick. The flatness of the glass base was maintained uniform for all sample plates by using micro-flat glass. Micro-flat glass is standard for KODAK Super AEROGRAPHIC Positive Plates, ballistic camera and color plates, as well as the master plates used in the moiré fringe measuring technique.

## RESULTS

### OVERALL SIZE CHANGE

Measurements were made at 70 F—50% R.H. after the plates had been processed. These data, shown in Table I, indicated that no overall size change occurred (relative to the black-and-white master) in any of the materials during processing. The greatest size change noted relative to the masters (0.0014) percent) was less than the average standard deviation of the measurements (0.005 percent) and would be equivalent to an overall size change of 1 micron in the test area. The overall size changes of the color sensitized plates were equivalent to the black-and-white plates.

TABLE I. DIMENSIONAL CHANGES DUE TO PROCESSING

| *Test Material* | *Size Change*, percent Measured at 70 F-50% RH* |
|---|---|
| Kodak Super AEROGRAPHIC Positive Plate (Medium) | +0.0009 |
| Kodak Spectroscopic Plate, Type 103-F | −0.0014 |
| Kodak Special Plate, Type 083-01 | +0.0006 |
| Kodak Special Plate, Type 032-01 | 0.0000 |
| Kodalith Ortho Glass Plate (Residual error for test.) | 0.0002 |

* Relative to Kodalith Ortho Glass Master.

Test System: 49 cancellations per test sample.

A one micron displacement in test area equals 0.001 percent size change.

TABLE II. DIMENSIONAL DIFFERENTIAL FROM MASTER PLATES

(Overall size change from 50 to 5% R.H.)

| *Test Material* | *Size Change*, percent* |
|---|---|
| Kodak Super AEROGRAPHIC Positive Plate (Medium) | 0.0006 |
| Kodak Spectroscopic Plate, Type 103-F | 0.0001 |
| Kodak Special Plate, Type 083-01 | 0.0001 |
| Kodak Special Plate, Type 032-01 | 0.0002 |

* Relative to Kodalith Ortho Glass Master.

Test System: 49 cancellations per test sample.

A one micron displacement in test area equals 0.001 percent size change.

The same results were found when the plates were subjected to relative humidity change. Table II demonstrates that *no* overall size changes occurred for any of the test plates relative to the black-and-white masters within the accuracy of the test.

### LOCAL OR NON-UNIFORM CHANGES

The displacement or each moiré fringe was calculated from the 70 F—50% R.H. measurements of the four plates. The average vector displacement for each plate is given in Table III. All of the plates showed average distortions in the 1.5-micron range with standard deviations of about 0.8 micron. As the accuracy of the system is about 0.9 ± 0.5 micron, no significant differences were found among the plates. The 70 F—5% R.H. readings yielded the same results. It can be easily concluded from this that no significant size changes occurred due to non-uniform, local image distortions. The dimensional errors involved in these plates are in the order of 1.5 microns or less, and probably these values are limited by the accuracy of measurement technique (about 1 micron). Similar results were found by Altman and Ball[5] on black-and-white plates.

In these non-uniform size change studies, 49 different areas of each plate were measured, giving a good picture of the overall uniformity. The above data show that the magnitude of the measured image movements seems to be limited by the accuracy of the measuring system. Fot this reason, additional limited tests were made by the 9

TABLE III. RANDOM IMAGE DISPLACEMENT AFTER PROCESSING

| *Test Material* | *Average Vector Displacement, microns* | | |
|---|---|---|---|
| | *70 F–50% RH* | *70 F–5% RH* | *Std. Dev.* |
| KODAK Super AEROGRAPHIC Positive Plate (Medium) | 1.6 | 1.6 | 0.8 |
| KODAK Spectroscopic Plate, Type 103-F | 1.3 | 1.3 | 0.7 |
| KODAK Special Plate, Type 083-01 | 1.3 | 1.3 | 0.8 |
| KODAK Special Plate, Type 032-01 | 1.3 | 1.4 | 0.7 |
| KODALITH Ortho Glass Plate (Residual error for the system.) | 0.9 | | 0.5 |

Test System: 49 cancellations per test sample.

moiré cancellation system. In these tests fewer areas were observed but with much greater accuracy (0.1 micron *vs.* 1 micron). The results in Table IV show average vector dsiplacements in the range of 0.1 to 0.2 micron for both color and black-and-white plates. The error for this system is 0.09 ± 0.05 micron. These data indicate that the bonding between the glass base and the image is very good, and the glass base is the overriding influence for sensitized plate dimensional stability.

It has been shown[2,5] that edge effects can cause some dimensional problems, but that once away from the edge of a glass plate, the image is very uniform. In the latter case, the majority of the lateral forces within the emulsion layer balance each other and any unbalanced forces would be relatively small. Such imbalanced emulsion forces would be expected to have very little effect on image movement because glass plates are more than 100 times thicker that the emulsion layer, and glass has a modulus over 10 times greater than that of the emulsion. This has been shown to be true for both the color and black-and white plates.

TABLE IV. RANDOM IMAGE DISPLACEMENT AFTER PROCESSING

| *Test Material* | *Average Vector Displacement, microns (Measured at 70 F–50% RH)* | |
|---|---|---|
| | *Mean* | *Std. Dev.* |
| KODAK Super AEROGRAPHIC Positive Plate (Medium) | 0.12 | 0.07 |
| KODAK Spectroscopic Plate, Type 103-F | 0.09 | 0.06 |
| KODAK Special Plate, Type 083-01 | 0.10 | 0.06 |
| KODAK Special Plate, Type 032-01 | 0.09 | 0.05 |
| KODALITH Ortho Glass Plate (Residual error for the system.) | 0.09 | 0.05 |

Test system: 9 cancellations per test sample.

## PRACTICAL CONSIDERATIONS

Although the outstanding metric stability of glass plates has been shown, these results depend on careful exposure, processing, and handling procedures. In practical situations, problems which may degrade the basic excellent metric stability of photographic plates must be avoided.

One large source of dimensional error in photographic products is the lack of care in drying. Water spots have been shown to cause localized size changes in photographic films.[4] Image movements of ±18 microns were encountered on aerial films. Sensitized plates will also show distortions due to water spotting. This was investigated for KODAK glass plates by allowing water spots to dry at room temperature on the surface of an already processed plate. The magnitude of the resulting image movement was determined both by using the technique of Calhoun, Keller, and Newell,[4] in which a microdensitometer trace was made of the halftone in the area of the water spot, and by microsopic observations. Image movements amounting to ±6 microns were found. The effect of a 1/4-inch diameter water spot is shown visually by the moiré pattern in the Frontispiece. This pattern was obtained by registration of KODAK Special Plate Type 083–01 and the *registration master*. The two plates were rotated relative to each other to give a greater number of moiré cancellations, thus facilitating observation of the water spot. It is evident from this study that even with highly dimensionally stable glass plates, good working procedures are necessary to obtain a maximum metric stability.

Harris, Lampton and Umbach[11] observed: "Experience has shown that, when a high degree of metric precision is required, there are numerous physical processing and measurement operations that must be carefully controlled to ensure a minimal loss in metric quality between the original aerial negative and the final photographic plate."

From the data presented in this paper the metric stability using glass plates is limited by the overall accuracy of the system and the handling techniques involved rather than the plates themselves.

### CONCLUSIONS

Color sensitized glass plates have the same metric qualities as black-and-white plates. These sensitized products show average residual errors of 1.6 microns or less. This includes total system and measuring errors as well as the metric stability of the plates. Indications from some limited measurements with a more accurate moiré system show that the residual errors are probably less than 1 micron This high stability of sensitized glass plates is dependent upon proper handling procedures as has been demonstrated. For example, 1/4-inch diameter residual water spots can cause local distortions as large as ±6 microns.

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