Physical Properties of Estar Polyester Base
Aerial Films for Topographic Mapping*

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ABSTRACT: Three new aerial camera films for topographic mapping—Kodak
Panatomic-X, Plus-X and Tri-X Aerographic Films—are now made on 0.004-
inch thick Estar polyester base. A gelatin backing provides static protection and
greatly reduces curl. Both emulsion and backing are hardened for elevated
temperature processing. The thinner base permits more exposures for a given
roll diameter and the thinner emulsion permits more rapid drying after proc­
essing, compared with present acetate topographic films. Estar base provides
superior tensile strength, stiffness, and tear strength. Humidity and thermal
coefficients of linear expansion are only about one-third that of acetate film.
Limited tests using optical interference patterns have shown less dimensional
distortion in Estar film than in acetate topographic film.

“Estar” base is made from polyethylene
terephthalate, a polyester which was
discovered by Whinfield and Dickson (1) in
England before World War II. It was first
used commercially as a textile fiber and later
as a plastic sheeting. For many years there
has been speculation and hope that it would
make an ideal base for topographic aerial
films. This interest has been due to the
superior dimensional stability and other
physical properties that can be obtained with
film base made from this polymer (2).
The characteristics of an experimental litho
film coated on pilot plant samples of polyester
base were described at a meeting of the Amer­
ican Society of Photogrammetry by J. M.
Centa (3) in 1955. At the 1960 Annual Meet­
ing, W. E. Harman, Jr. (4), described some
preliminary field tests with a polyester base
aerial film, which demonstrated definite ad­
vantages over acetate film, in the accuracy
obtainable in topographic mapping.

A new family of aerial negative films is
now available on 0.004-inch thick Estar
base:

SO-136 Kodak Panatomic-X Aerographic Film
(Estar Base)
SO-135 Kodak Plus-X Aerographic Film (Estar
Base)
SO-138 Kodak Tri-X Aerographic Film (Estar
Base)

“Estar” is a registered Trade Mark of the
Eastman Kodak Company.

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PHOTOGRAMMETRIC ENGINEERING

**Table I**

**THICKNESS OF AEROGRAPHIC FILM LAYERS**

<table>
<thead>
<tr>
<th>Film</th>
<th>Base Type No.</th>
<th>Thickness, mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodak Panatomic-X Aerographic Film</td>
<td>Estar SO-136</td>
<td>1.21</td>
</tr>
<tr>
<td>Kodak Plus-X Aerographic Film</td>
<td>Estar SO-135</td>
<td>0.31</td>
</tr>
<tr>
<td>Kodak Tri-X Aerographic Film</td>
<td>Estar SO-138</td>
<td>0.51</td>
</tr>
<tr>
<td>Kodak Plus-X Aerographic Film</td>
<td>CAB 5401</td>
<td>0.49</td>
</tr>
<tr>
<td>Kodak Super-XX Aerographic Film</td>
<td>CAB 5425</td>
<td>0.76</td>
</tr>
</tbody>
</table>

**Note:** The emulsion and backing thicknesses are typical measurements; the base thickness is nominal. CAB = cellulose acetate butyrate.

...has a matte surface which minimizes contact with the emulsion when wound in rolls. The backing on the Plus-X and Tri-X films is clear, but the backing on the Panatomic-X film contains an antihalation dye needed for photographic purposes. This dye bleaches during processing.

Estar base is manufactured by a quite different process than is cellulose acetate base. It is cast from the molten polymer and contains no solvents or plasticizer, which might slowly diffuse away and cause shrinkage with age.

**Physical Properties**

The thickness of the various layers of each of the new films is given in Table I, compared with the present Type 5401 Plus-X, and Type 5425 Super-XX Aerographic films on cellulose acetate butyrate base. Estar base for topographic mapping is 0.004 inch thick, which permits approximately one-third more film exposures for the same diameter roll. (Estar base 0.0025 inch thick has been made for aerial reconnaissance films on special order, but is not recommended for ordinary topographic mapping.) The new emulsions are also significantly thinner than formerly, which permits better definition and more rapid drying after processing.

Estar base is transparent, colorless and essentially free of imperfections. Its physical properties are summarized in Table II. The two most outstanding characteristics of Estar base for an aerial film are its greatly superior strength properties and its superior dimensional stability, compared to acetate base. The high tensile strength (Figure 1)

**Table II**

**TYPICAL PHYSICAL PROPERTIES OF AEROGRAPHIC FILM BASES**

<table>
<thead>
<tr>
<th>Property</th>
<th>Estar Base</th>
<th>Cellulose Acetate Butyrate Base</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal thickness, mils</td>
<td>4.0</td>
<td>5.2</td>
<td>ASTM D570-57T</td>
</tr>
<tr>
<td>Specific gravity, gms./cc</td>
<td>1.39</td>
<td>1.26</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Refractive index, N&lt;sub&gt;D&lt;/sub&gt;</td>
<td>1.65&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>1.48</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Water absorption, %</td>
<td>0.5</td>
<td>0.85</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Water swell from 15% RH, %</td>
<td>0.08</td>
<td>0.85</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Yield strength, psi</td>
<td>14,000</td>
<td>9,500</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Tensile strength, psi</td>
<td>28,000</td>
<td>10,500</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Elongation at break, %</td>
<td>110</td>
<td>50</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Modulus of elasticity in tension, psi</td>
<td>650,000</td>
<td>400,000</td>
<td>ASTM D882-56T</td>
</tr>
<tr>
<td>Plastic flow, %</td>
<td>0.01</td>
<td>0.25</td>
<td>ASTM D643-43</td>
</tr>
<tr>
<td>MIT double folds, No.</td>
<td>&gt;10,000</td>
<td>35</td>
<td>ASTM D689-44</td>
</tr>
<tr>
<td>Tear propagation strength, gms.</td>
<td>160</td>
<td>40</td>
<td>ASTM D1637-59T</td>
</tr>
<tr>
<td>Tensile heat distortion temperature, F.</td>
<td>325</td>
<td>275</td>
<td>ASTM D1637-59T</td>
</tr>
</tbody>
</table>

<sup>(a)</sup> Tests made at 70°F, 50% RH, except where indicated otherwise.
<sup>(b)</sup> Average refractive index in plane of sheet; index in thickness direction is 1.50.
<sup>(c)</sup> Four hours loaded, 20 lbs/inch width; four hours unloaded.
ESTAR POLYESTER BASE AERIAL FILMS FOR TOPOGRAPHIC MAPPING

and modulus of elasticity (stiffness) of this base enable it to be used in a lower thickness. The lower plastic flow of Estar base (Figure 2) means that it is much more resistant to deformations of all kinds than is acetate butyrate base. Still more important from a practical standpoint is the exceptional tear resistance of Estar base. It is virtually impossible to initiate a tear unless the film is first nicked or cut. Even when a tear is started, it requires about four times the force to continue the tear as does acetate film. This means that there is much less chance of film tearing in cameras, processing machines or other handling operations.

The possibility of brittleness is important with aerial films, which are often used at low temperatures or under dry conditions. Laboratory brittleness tests made by pulling a loop of film rapidly through a wedge (6) at 15% R.H. and measuring the width of the wedge at the point of failure are reported in Table III. (The larger the wedge value, the

Table III

<table>
<thead>
<tr>
<th>Properties(a)</th>
<th>Film</th>
<th>Panatomic-X</th>
<th>Plus-X</th>
<th>Tri-X</th>
<th>Plus-X</th>
<th>Super-XX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base(b)</td>
<td>Estar</td>
<td>Estar</td>
<td>Estar</td>
<td>CAB</td>
<td>CAB</td>
</tr>
<tr>
<td>Type No.</td>
<td></td>
<td>SO-136</td>
<td>SO-135</td>
<td>SO-138</td>
<td>5401</td>
<td>5425</td>
</tr>
<tr>
<td>Wedge brittleness at 15% R.H. Film break, inch</td>
<td>no breaks</td>
<td>no breaks</td>
<td>nobreaks</td>
<td>0.16</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Emulsion crack, inch</td>
<td>0.17</td>
<td>0.25</td>
<td>0.27</td>
<td>0.22</td>
<td>&lt;0.10</td>
<td></td>
</tr>
<tr>
<td>Backing crack, inch</td>
<td>0.18</td>
<td>0.11</td>
<td>0.12</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Film curl,(d)</td>
<td>100/R inch⁻¹</td>
<td>20% RH</td>
<td>50% RH</td>
<td>70% RH</td>
<td>20% RH</td>
<td>50% RH</td>
</tr>
<tr>
<td></td>
<td>+7</td>
<td>+12</td>
<td>+17</td>
<td>+140</td>
<td>+250</td>
<td></td>
</tr>
<tr>
<td></td>
<td>−1</td>
<td>−2</td>
<td>+1</td>
<td>+85</td>
<td>+110</td>
<td></td>
</tr>
<tr>
<td></td>
<td>−4</td>
<td>−7</td>
<td>−7</td>
<td>+67</td>
<td>+77</td>
<td></td>
</tr>
<tr>
<td>Water absorption after processing Weight of water, % of dry film</td>
<td>19</td>
<td>23</td>
<td>44</td>
<td>18</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Weight of water, lb./sq. ft. of dry film</td>
<td>0.006</td>
<td>0.0085</td>
<td>0.017</td>
<td>0.007</td>
<td>0.020</td>
<td></td>
</tr>
</tbody>
</table>

(a) All tests made at 70°F.
(b) CAB=cellulose acetate butyrate.
(c) Unprocessed film tested by American Standard Methods for Determining the Brittleness of Photographic Film, PH1.31-1958 (Method B).
(d) Processed film tested by American Standard Methods for Determining the Curl of Photographic Film, PH1.29-1958 (Method A).

Fig. 1. Stress-strain curves for Kodak Aerographic Film base at 70°F. −50% RH. Instron tensile machine at 50% elongation per minute.

Fig. 2. Creep and recovery curves for Kodak Aerographic Film base at 70°F. −50% RH. Load, 20 lbs./inch width.
more brittle is the film.) In this test none of the Estar films break, whereas the acetate films do. However, very fine cracks can occur in the emulsion or gelatin backing if the film is bent sharply, as in the wedge test, under very cold or very dry conditions. These fine emulsion cracks sometimes heal in processing and sometimes are visible as a density difference. This should not happen in a well-designed camera, where rollers in the film path are not too small in diameter. The important fact is that Estar films retain a high degree of flexibility at all relative humidities and at temperatures down to at least -60°F.

The presence of a gelatin backing is a relatively new feature for aerial film. It is used to provide static protection and reduce curl. The flatness of Estar films should be especially attractive to the user, because curl has long been troublesome in handling processed aerial negatives. The improvement in curl is indicated by the data shown for several relative humidities in Table III and Figure 3. The curl tests were made by determining the radius of curvature of a film sample approximately 3 inches square and expressing in units of 100 divided by the radius in inches. On this scale a curl value of 100 corresponds to a cylinder of 2 inches diameter, and a curl value of 200 corresponds to a cylinder of 1 inch diameter, and so forth. A positive value means curl towards and a negative value means curl away from the emulsion side.

Figure 4 illustrates the advantage of the Estar film in flatness under practical conditions. One has to feel and handle both types of film to appreciate the difference. This improvement is due to the gelatin backing, not the base. Of course, any film stored in roll form for a period of time will take on a little roll curl due to plastic flow. This effect is inversely proportional to the diameter of the roll and increases with time and temperature, but is normally small compared to the curl of unbacked film.

A gelatin backing, even though it is well-hardened, does require a few precautions. The unprocessed film is a little more susceptible to keeping troubles, because of the emulsion-gelatin contact in the roll. As already mentioned, this is minimized by the matte-surface of the backing. Storage at 60°F. or lower is recommended for periods up to six months, and 50°F. or lower for periods of a year or longer. Temperatures over 80°F. should be avoided before use. These conditions are the same as those recommended for acetate film; it is simply more important that high temperatures be avoided with gelatin-backed films.

Estar Aerographic films have been processed satisfactorily in both rewind tank equipment and in continuous machines. Obviously, both sides of a gelatin-backed film must be dried after processing. The forced-air mechanical-roll film-dryer commonly used for aerial film is designed to blow air at only the emulsion side. It must be run somewhat slower to allow the backing on Estar films to dry. However, a simple modification with enclosure or baffles, which directs some air at the back of the film, permits normal operating speeds. With a suitably designed dryer, Estar Aerographic films dry more rapidly than acetate films, because the emulsions are thinner and the base absorbs so little water that its
removal does not add to the drying load. For example, Plus-X Aerographic Film on Estar base dries in about one-third of the time required for Super-XX on acetate butyrate base. Comparative data on the water content of these films before drying are listed in Table III.

Processed gelatin-backed aerial film must also be stored with proper regard for humidity and temperature. The film should have an equivalent relative humidity of 40–50% when wound and should be stored at the same condition, at not over 80°F. (These are the same conditions recommended for conventional aerial film.) If the gelatin-backed film reaches an equivalent relative humidity of 70%, contact marks (ferrotyping) may occur and at 90% there may be actual sticking between laps. Of course, such severe humidities are dangerous to any film because of moisture and fungus attack.

Estar base is chemically very stable. It is insoluble in all common solvents, although it can be degraded by strong acids and strong alkalis. Polyester base has not been in existence as long as cellulose acetate base, so that less is known about its permanence. Accelerated aging tests have been run on coated and processed films under a variety of conditions, and all of these have shown Estar base to be chemically as stable or more stable than standard acetate base. One such accelerated test is illustrated in Figure 5, which shows the retention of intrinsic viscosity of the base for over a year at 100°C. Intrinsic viscosity is a measure of the molecular weight or average length of the polymer chains, and decreases with chemical degradation. (The control film tested in Figure 5 is on cellulose triacetate Aerexon base, which is similar in chemical stability to cellulose acetate butyrate Aerographic base.) It is apparent from this very severe test that the chemical stability of Estar base is even higher than that of acetate base, and of course, both are very much higher than the old nitrate type of base used prior to World War II. Less severe aging tests have been run for over three years at temperatures of 78° to 120°F, and humidities from 20 to 60% with satisfactory results.

With respect to safety characteristics, Estar base film ignites only with difficulty and burns very slowly. The base melts at about 510°F., and in the event of fire the molten polymer may flow, but it burns only slowly. Estar base film passes the American Standard Specifications for Safety Photographic Film, PH 1.25-1956, and has been approved by the Underwriters' Laboratories, Inc., as a slow-burning safety film.

**DIMENSIONAL STABILITY**

Although there are many properties, both photographic and physical, which are essential to a satisfactory aerial film, it is dimensional stability which is of most interest with polyester base for topographic mapping. This is a complex subject and cannot be answered simply, since no material—even glass plates—holds size absolutely.

First, compare the various dimensional change characteristics of Estar base films. These include the reversible changes caused by temperature and humidity, and permanent shrinkage resulting from processing and subsequent aging. The theory involved in various types of dimensional change in photographic films has been discussed previously (8, 9). Laboratory measurements have been made with a pin-gage on 35 mm. strips of film over a 10-inch gage length. It is realized that dimensional changes averaged over this gage length do not tell the whole story as regards accuracy for topographic mapping, but they do provide one valuable comparison. The possibility of non-uniform dimensional changes is discussed later.

Estar base film has only about one-third the thermal coefficient of linear expansion of acetate butyrate base film (Table IV). This will reduce film dimensional changes in cameras when the temperature cannot be controlled.

The humidity coefficients of linear expansion of Estar base films also average about one-third that of acetate butyrate base film (Table IV). Here it should be noted that the film dimensions versus relative humidity curve is not linear for polyester base film as it virtually is for acetate base film (Figure 6).
**Table IV**

**Typical Dimensional Change Values for Aerographic Films**

<table>
<thead>
<tr>
<th>Material</th>
<th>Base((^{1}))</th>
<th>Type No.</th>
<th>Thermal Coefficient of Linear Expansion, % per Degree F.(^{(b)})</th>
<th>Humidity Coefficient of Linear Expansion % per 1% R.H.(^{(c)})</th>
<th>Processing Dimensional Change, %(^{(d)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodak Panatomic-X Estar</td>
<td>SO-136</td>
<td></td>
<td>0.0015</td>
<td>0.0021</td>
<td>0.0023</td>
</tr>
<tr>
<td>Kodak Plus-X Aerographic Film</td>
<td>SO-135</td>
<td></td>
<td>0.0025</td>
<td>0.0029</td>
<td>-0.050</td>
</tr>
<tr>
<td>Kodak Tri-X Aerographic Film</td>
<td>SO-138</td>
<td></td>
<td>0.0032</td>
<td>0.0035</td>
<td>-0.020</td>
</tr>
<tr>
<td>Kodak Plus-X Aerographic Film</td>
<td>CAB 5401</td>
<td></td>
<td>0.0070</td>
<td>0.0075</td>
<td>-0.04</td>
</tr>
<tr>
<td>Kodak Super-XX Aerographic Film</td>
<td>CAB 5425</td>
<td></td>
<td>0.0080</td>
<td>0.0085</td>
<td>-0.05</td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
<td>0.0013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td></td>
<td></td>
<td>0.0006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass Plates</td>
<td></td>
<td></td>
<td>0.00045</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


\(^{(b)}\) Thermal coefficients measured between 70°F. and 120°F. at 20% RH on unprocessed film.

\(^{(c)}\) Humidity coefficients measured between 15% and 50% RH at 70°F. on unprocessed film.

\(^{(d)}\) Processing dimensional change measured at 70°F. - 50% RH. Both unprocessed and processed film brought to 50% RH from a lower humidity.

\(^{(e)}\) Direction 1 is axis of molecular orientation of base; direction 2 is at right angles. These are not necessarily length and width directions in the case of Estar base.

\(^{(f)}\) CAB = cellulose acetate butyrate.

The curves are much steeper below 50% R.H. where the humidity coefficients are calculated. Above 50% R.H. there is appreciably less change in dimension for Estar films with change in humidity.

The gelatin emulsion and backing are responsible for the larger portion of the humidity dimensional change in polyester base films because of the lateral compression they exert upon the base. This is the reason for the curves for the three Estar films in Figure 6 falling in the order of the emulsion thickness. In fact, there is an approximately linear relationship between the gelatin/base thickness ratio and the humidity coefficient as indicated in Figure 7. The points in this chart for zero emulsion thickness are the humidity coefficients of the base alone. Naturally, the gelatin thickness is held at a minimum in manufacture consistent with other physical and photographic requirements.

Another factor which must be considered in analyzing humidity dimensional changes of resin base films is hysteresis, that is, the failure of the film to return to exactly the same dimensions when a given relative humidity is approached from a lower and from a higher humidity. This phenomenon was explored in an earlier paper (9) on polystyrene base film and applies in a similar manner to polyester base film. It is caused by the gelatin layers, not the base. Dimensional hysteresis is of secondary importance with acetate film, because the humidity coefficients are relatively large. Typical dimensional hysteresis curves for unprocessed and processed Estar base film are reproduced in Figure 8. From this it is apparent that the humidity coefficient is really not a constant, and that one cannot calculate the dimensions of a film at a given relative humidity exactly from any coefficient.

The low rate and amount of swell of Estar base film in water (to simulate processing solutions) compared with acetate butyrate base film is indicated in Figure 9. One would expect that upon drying, a polyester base film, which contains no solvent or plasticizer, would show no permanent shrinkage. This is not true because of the compressive effects of the gelatin on the base during drying and the hysteresis effects already mentioned. Figure 8 shows the shift in the hysteresis curve for Estar base film after processing, which is
due to the decrease in modulus of elasticity and the thickness of the emulsion (9). The result of these various factors is that the net change in dimension from processing may be either a slight swell, no change, or a slight shrinkage, depending on the conditions. In spite of these complications, Estar base films show smaller dimensional changes on processing and drying than acetate butyrate film, under the same conditions (Table IV).

Another factor of interest in connection with processing topographic film is the possibility of stretching because of tension, particularly with continuous processing ma-

**Fig. 6.** Change in dimension with relative humidity for Kodak Aerographic Films (adsorption curves).

**Fig. 7.** Effect of gelatin/base thickness ratio on the humidity coefficient of unprocessed Aerographic films between 15% and 50% RH at 70°F.

**Fig. 8.** Dimensional hysteresis curves for Kodak Plus-X Aerographic Film (Estar base).
machines. Figure 10 shows the amount of lengthwise stretch remaining after strips of Aerographic film were subjected to various tensions during processing and drying. (Some widthwise contraction is caused by any lengthwise stretch, which is not shown in the figure.) Even though the Estar film is thinner, it offers much greater resistance to stretch under tension, particularly when both films are wet. Of course, the tension is deliberately exaggerated in this test. Some continuous machines have a tension in the neighborhood of 0.5 lbs. per inch, but rewind tank machines and mechanical roll film dryers have considerably lower tensions. It is not possible to state a limiting processing tension, below which either film will show no stretching, but Figure 10 should be a useful guide. Some continuous processing machines do have tensions which are undesirably high for topographic film.

The shrinkage of Estar films with age is very small indeed, because there is no solvent or plasticizer in the base. The small shrinkage which does occur is caused by relaxation of the base or lateral compression from the emulsion. Typical aging curves are plotted in Figure 11 for keeping at 78°F.-60% RH and 120°F.-20% RH. The latter is an accelerated condition. These curves do not yet extend very far because Estar base films made under production conditions are still very new. However, it is known from tests made on earlier pilot plant coatings and accelerated tests on production coatings, that the shrinkage of Estar films should not exceed about 0.05% in five years under normal conditions and may be less. This is a significant improvement over the most stable acetate film.

Uniaxialism, that is the uniformity of properties in different directions in the plane of the film, is more important in topographic mapping than over-all dimensional changes that can be corrected by a change in magnification in the stereo plotter. It is well known that acetate topographic base has very slightly different properties in the length than in the width, because it is unavoidably stretched a little in the machine direction during manufacture (8). In the case of Estar base, very slight differences in physical and dimensional properties also exist in different directions. However, the properties may not be a maximum in either the length or width direction, but at some angle in between these. Table IV shows the dimensional properties in the direction of maximum orientation and in the direction at 90 degrees to this. Every effort is made in manufacture to keep these small differentials at a minimum.

Another consideration is the effect of storing film in roll form on length-width dimensional differences. When this was first investigated some years ago, it was found to be a significant factor with acetate film. (8)
Because of plastic flow during storage, the length-width differentials increase, compared to film stored in flat strips. A preliminary study with Estar Aerographic film has shown much less effect of roll storage and, hence, lower length-width differentials.

The possibility of random or non-uniform dimensional changes in aerial film has been raised many times by photogrammetrists. However, there are so many possible sources of error in the photogrammetric system that it is difficult to determine which, if any, are caused by the film itself when properly handled. Methods of studying film distortion by means of a reseau grid exposed on the film are almost prohibitively laborious. However a new method using a halftone tint printed on the film from a glass master, which when superimposed with the original produces an interference pattern called a moiré, was described recently. (10) The evenness of the spacing of the spots in the moiré pattern provides quantitative information on the dimensional uniformity of the film. Tests made on Aerographic Film on acetate butyrate base by the moiré method showed film dimensional distortions intentionally caused by water-spotting, excessive processing machine tension and abnormal heating. When the film was handled properly, no serious random distortions were found.

Only preliminary comparisons between Estar and acetate Aerographic films have been made, as yet, by means of the moiré method. In one trial, 9½-inch wide rolls of Estar and acetate butyrate Aerographic films were exposed to a 300-line halftone tint on a glass plate at 70°F.-50% RH without preconditioning, processed in a rewind tank, and dried on a mechanical roll film dryer. The negatives were then conditioned at 70°F.-50% RH and registered with another halftone glass master, which had been accurately enlarged 0.08% from the original. (This device was necessary because a 300-line screen does not produce a sufficiently fine moiré pattern for the small dimensional changes being measured.) The moiré patterns obtained were graphically copied on a high contrast negative material (which reproduces only the dense spots of the interference patterns), with the results shown in Figure 12. The grid lines were added in printing for reference purposes. The larger moiré spots and the larger spacing between them for the Estar film, indicate a smaller over-all processing dimensional change than for the acetate film.

If the dimensional change in the film is uniform, in all directions, the moiré spots will form a perfect square. The broken lines in Figure 12 show that this is nearly true in the case of the Estar film, whereas the moiré pattern forms a rectangle in the case of the acetate film, indicating greater systematic distortion. Of course, this is a very sensitive test and it does not mean that the acetate film has actually become a rectangle of this proportion.

Knowing the number of lines in the original halftone, it is possible to calculate the size-change quite accurately, from such a moiré pattern in both length and width. It is also possible to calculate the size-change in the two diagonal directions, which gives a measure of any skewness. Furthermore, one can estimate the random distortion, if any, by the appearance of the pattern and any curvature of the rows of moiré spots.

The over-all dimensional changes as a result of processing, calculated from the moiré patterns in Figure 12 are:

<table>
<thead>
<tr>
<th></th>
<th>Estar Film</th>
<th>Acetate Butyrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>-0.022%</td>
<td>-0.045%</td>
</tr>
<tr>
<td>Width</td>
<td>-0.025</td>
<td>-0.095</td>
</tr>
<tr>
<td>Difference</td>
<td>0.003</td>
<td>0.050</td>
</tr>
<tr>
<td>Diagonal 1</td>
<td>-0.026</td>
<td>-0.065</td>
</tr>
<tr>
<td>Diagonal 2</td>
<td>-0.024</td>
<td>-0.063</td>
</tr>
<tr>
<td>Difference</td>
<td>0.002</td>
<td>0.002</td>
</tr>
</tbody>
</table>

These figures show an appreciably lower length-width distortion for the Estar film. However, the differentials in the diagonal direction are equally small for both films. It will be noted that the above values for processing dimensional change, which were meas-
ured on rolls, differ somewhat from those obtained on flat strips shown in Table IV. This is attributed to the effects of storage in roll form mentioned earlier, and possibly to some small humidity dimensional change after exposure to the half-tone master.

Analysis of the moiré patterns in Figure 12 shows that in this particular test, the Estar film relative to the acetate butyrate film has:

1. Approximately 1/3 the over-all size change.
2. Approximately 1/10 the systematic distortion between the length and width.
3. Approximately the same extremely small random distortion, indicated by the negligible curvature of the line of moiré spots.

It cannot be concluded that exactly the same result would be obtained under various other practical conditions. A great deal more investigational work with larger amounts of film remains to be done before any more definite conclusions can be drawn regarding very small distortions in Estar film.

Conclusions

These new films on Estar base offer a number of practical advantages to the user in strength properties, flatness, and dimensional stability. Limited trade tests have indicated that they can be handled in conventional mapping cameras and processing equipment. It is not yet known what increase in mapping accuracy will result from the improved film characteristics. In the final analysis, it will be the practical experience of photogrammetrists which will determine the advantages of Estar base films.

Acknowledgement

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References