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Thickness Uniformity of Kodak Aerial Films

The maximum thickness variation found in the film was less than two-thirds of that allowed for the platen of the camera.

AERIAL PHOTOGRAPHIC films are manufactured in various thicknesses to meet the requirements of different systems which use aerial photography as a means of recording information. The thickness of an aerial film is mainly determined by the thickness of the transparent plastic material used for the film support. The film support in all Kodak aerial films is polyethylene terephthalate, a polyester resin, which Eastman Kodak Company calls Estar* polyester support. At the present time Estar support is made in four different thicknesses for aerial film use. Included in the official name of each aerial film are adjectives which give the film support thickness as shown in Table 1.

ABSTRACT: *Eastman Kodak Company conducted an extensive series of tests on one of its popular aerial films which has Estar as its base—Kodak Double-X Aerographic film 2405. The materials were tested with a special electromechanical thickness gage which had an accuracy of 2.5 μm and a sensitivity of 0.25 μm. As the emulsion and film-backing coatings are very thin relative to the film base, and also have relatively small thickness variations, any noticeable variation in total thickness was essentially due to that of the base itself. The maximum variation amounted to approximately 9 μm. Thinner film bases had still smaller variations.*

Estar thick base would produce a film too thick and stiff to give good performance in existing aerial cameras so presently this support is not used for aerial negative-type films. It makes an excellent support for aerial duplicating film where dimensional stability is the prime consideration. Films of this type are beginning, in some applications, to replace glass diapositive plates used in stereo plotters.

Estar base, with a thickness aim of 102 μm, is the film support mainly used for camera negative-type films intended primarily for conventional reconnaissance and photogrammetric applications. This support is about 20 to 25 percent thinner than the cellulose ester-type film bases which were used for so many years for these types of aerial films. The physical characteristics of the 102 μm thick Estar base are vastly superior to the former thicker cellulose ester film supports.

Estar thin base and Estar ultra-thin base supports are for aerial films used in sophisticated reconnaissance systems where maximum footage and minimum weight are a prime requirement. Some conventional aerial cameras can successfully use Estar thin-base products but film transport and flatness problems can exist in other cameras. The use of Estar ultra-thin base films requires specially designed systems for satisfactory performance.

As the photogrammetrist is mainly concerned with films on 102 μm Estar base, the balance of this paper will deal primarily with the thickness and thickness variations of these products. The three principal aerial camera negative films used in mapping produced on this base are listed in Table 2.

There is a difference of 14 μm in the thickness aim among these three products. The difference is entirely in the thickness of the light-sensitive emulsion. Color-film emulsions

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* Estar is a registered trademark.

are generally thicker than black-and-white film emulsions because they contain many more individual layers. To maintain uniform photographic and sensitometric characteristics within a product, it is necessary to control precisely the thickness of the emulsion layers. The emulsion layers, being relatively thin and controlled within ±5 percent, contribute very little to the thickness variation of the total film. Results of several large studies have consistently shown that the thickness variation in a complete film is no greater than that which exists in the film support on which the emulsion is coated.

The static resistant backing on these three film products is a thin, transparent coating which reduces the possibility of static electricity generation. The backing layer being extremely thin also contributes very little to the film's total thickness variation.

The precise control over the thickness of the emulsion layers and the backing layer leaves the film support as the only significant contributor to thickness variations in the complete film.

Thickness variations for this study were measured on an electromechanical thickness gauge designed and built at Kodak Park. This gauge continuously records the thickness of a section along a center line of a 35 mm wide sample. The instrument is capable of recording the sample thickness to an absolute accuracy of 2.5 μm and of reliably detecting thickness variations as small as 0.25 μm.

A photograph of the thickness gauge is shown in Figure 1. Operation of the measuring device depends on a transducer which converts minute displacements into electrical signals. The particular transducer used is a commercially available "Linear Variable Differential Transformer" (Schaevitz LVDT—Model 100ML). It consists of three coaxial coils wound on a ceramic tube and a soft iron cylindrical armature which moves coaxially within the coils. The center coil is energized with a 2400 Hz supply. The outer coils are connected in series opposition. At some neutral position of the armature, a null signal output results. The direction and magnitude of armature displacement from this null are indicated by the phase and magnitude of the output voltage from LVDT.

TABLE 1. AERIAL FILM BASES AND THEIR THICKNESSES

Description of	Nominal Thickness	
	Micrometers (μm)	Inches
Estar thick base	178	0.0070
Estar base	102	0.0040
Estar thin base	64	0.0025
Estar ultra-thin base	38	0.0015

TABLE 2. THE AERIAL NEGATIVE FILMS AND THEIR THICKNESSES

	Thickness Aims, Micrometers			
	Static Resistant Backing	Support	Emulsion	Total
Kodak Plus-X Aerographic film 2402 (Estar base)	<1	102	7.6	110
Kodak Double-X Aerographic film 2405 (Estar base)	<1	102	10.8	114
Kodak Aerocolor negative film 2445 (Estar base)	<1	102	21.3	124

The amplifying equipment supplies the 2400 Hz excitation for the transducer and converts the electrical thickness indication into a form suitable for driving the recorder of the measuring instrument. These two items of equipment were manufactured by the Sanborn Company in Waltham, Massachusetts, and are designated as their Model 151-5460 Single Channel Basic Assembly equipped with 150-110 Carrier Preamplifier.

The 35 mm wide sample to be measured is driven through the instrument by rubber-tired transport wheels located directly under the pressure wheels. The transport wheels are designed to give a sample speed equal to the record-chart speed so that record and sample can be compared directly. The measuring spindle that includes in its structure the armature of the linear variable differential transformer has a replaceable, hardened, spherical shaped, tool-steel point which rides directly on the film surface. The anvil over which the other surface of the film slides has a cylindrical surface of sapphire to minimize wear. The measuring spindle applies a force of about 20 grams to the film surface.

In actual use an accurate feeler gauge is used to preset the instrument so that the null point is located in the center of the trace. Thickness variations of ±12.5 μm can then be recorded using the full width of the recording paper.

Shown in Figures 2 and 3 are typical thickness profile traces obtained on samples of Kodak Double-X Aerographic film 2405 (Estar base). The upper trace in each figure shows the thickness variation in the complete film while the lower trace was produced from

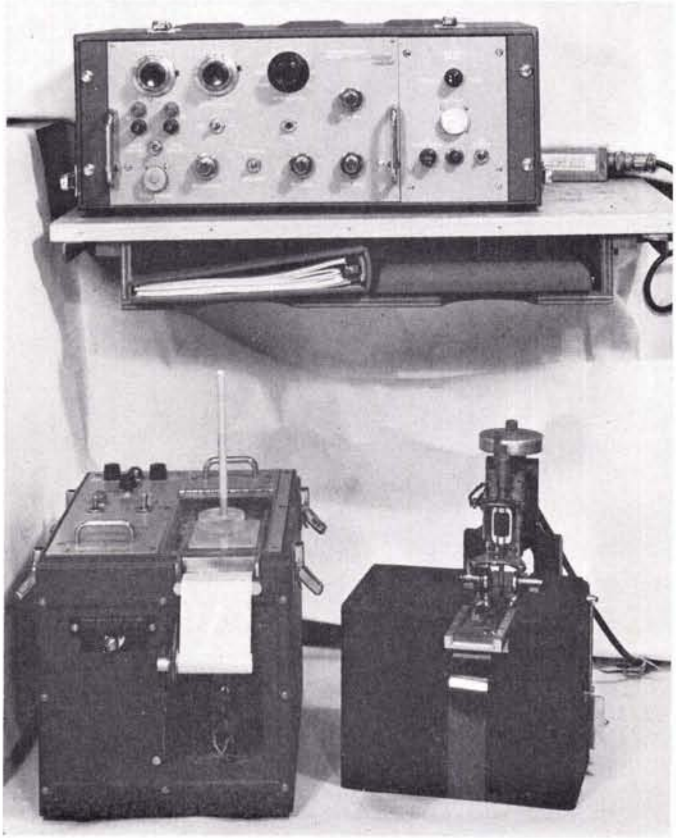


FIG. 1. Thickness recording gage.

the identical strip after the emulsion layer was chemically removed. These traces graphically show that variations in film thickness are primarily the direct result of thickness variations in the film support. Figure 2 shows a profile having about a 1.3 μm thickness variation over the 24 cm distance and represents a flatter than average film. The profile in Figure 3 shows about a 5 μm thickness variation which occurs over a distance of about 6 cm. As will be shown, the thickness variation in this profile is greater than the average found in a large study.

Thickness profiles of complete films are not made routinely so, as part of this study, a full-width production roll of Kodak Double-X Aerographic film 2405 (Estar base) was analyzed for thickness variation. Several strips 35 mm wide were cut across the width of the master roll at two locations about 30 meters apart. The remaining film between these locations was then slit into 35 mm strips in

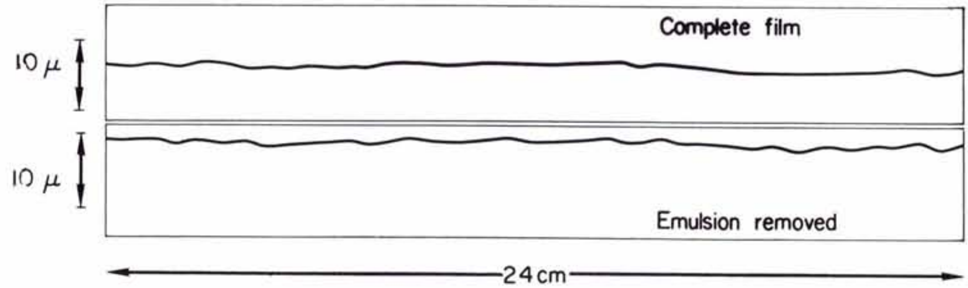


FIG. 2. Thickness profile of Kodal Double-X Aerographic film 2405 (Estar base).

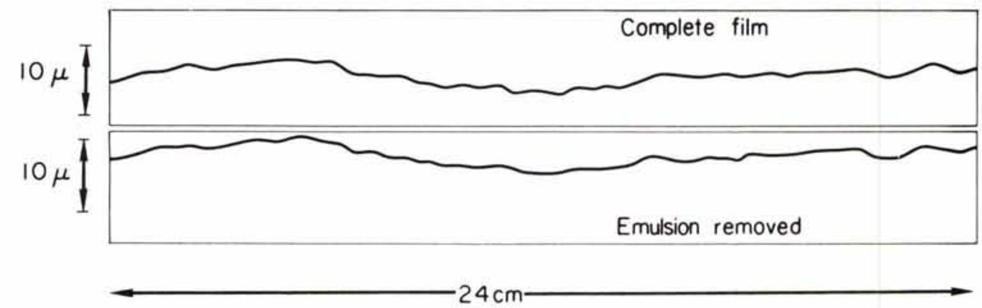


FIG. 3. Thickness profile of Kodak Double-X Aerographic film 2405 (Estar base).

the length direction of the roll. Thickness profiles were made of these strips.

Included in the analysis of these data was the thickness variation found within a 23 cm ×23 cm (9 inches×9 inches) film format. The thickness variation was determined in 54 locations over each 23 cm×23 cm-format. This procedure was repeated on 96 formats of this size randomly selected from the 30 meter length of the master roll of film. A standard deviation of the thickness variation within each format was calculated and a frequency histogram of these 96 standard deviations is shown in Figure 4. The average standard deviation was 1.4 μm with a range from 0.5 μm to 2.0 μm. From these results we would predict that the thickness variation in 95 percent of the 23 cm×23 cm formats would have a standard deviation of less than 1.85 μm.

The U. S. Department of Agriculture specifies[1] that the surface of the camera platen against which the film is held during exposure shall not depart from a true plane by more than 13 μm (0.0005 inch). The variation allowed in the unevenness of the camera platen is over 50 percent larger than the average thickness variation found in the film.

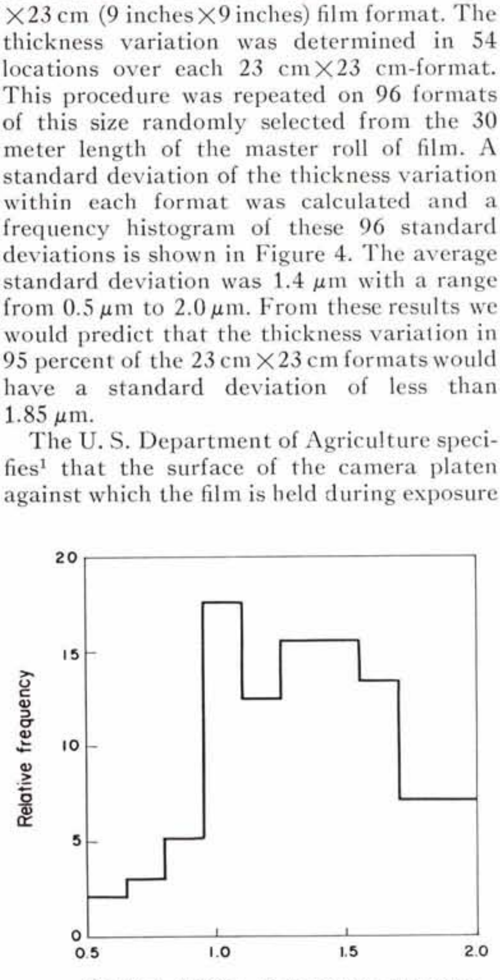


FIG. 4. Frequency histogram of standard deviation within 23×23 cm-format of Kodak Double-X Aerographic film 2405 (Estar base).

Standard deviations of the thickness variations were also calculated for across-the-width and along-the-length of the master roll. These deviations are given in Table 3.

These results show that the thickness variation across the width of the film is much greater than in an equal distance along the length. The average deviation of 1.3 μm found along a 23 cm line across the width of the film is only slightly less than the average deviation of 1.4 μm for a 23 cm×23 cm format area. The greater thickness variation found across the width of the film is inherent in the manufacturing process used for Estar support. Process changes to minimize thickness variation is a continuing engineering development program.

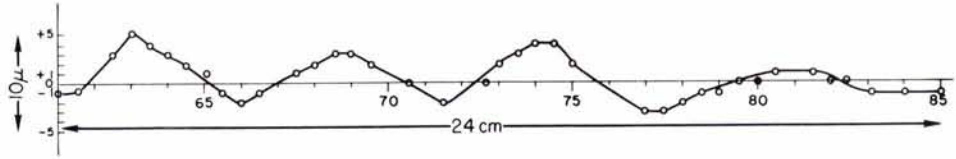
Estar support is produced on a number of different machines. During two recent large production runs of 102 μm thick film support, each made on a different machine, the routine thickness profile traces obtained from across the film width were analyzed. The average

TABLE 3. STANDARD DEVIATIONS OF THICKNESS VARIATIONS

	Standard Deviations Micrometers	
	Across Width	*Along Length*
Within 8 cm distance (Avg.)	0.8	0.5
Within 23 cm distance (Avg.)	1.3	0.6
Total Width	2.3	—
Within 360 cm distance (Avg.)	—	0.8
Within 30 meters distance (Avg.)	—	1.8

TABLE 4. AVERAGE STANDARD DEVIATIONS IN THICKNESS OF FILMS PRODUCED WITH VARIOUS MACHINES

	Across Support Width Standard Deviations, Micrometers
Within 8 cm distance (Avg.)	0.8
Within 23 cm distance (Avg.)	1.0
Total (Includes all traces)	2.8



B. Hallert, (1963)

FIG. 5. Thickness profile of Kodak Super-XX Aerographic film on cellulose acetate butyrate film base.

standard deviations calculated from these data are shown in Table 4.

The total in the above table includes lengthwise thickness variations because the samples cut across the support width were taken periodically along the length during the production runs. These standard deviations of variations in film support thickness obtained from two different manufacturing machines agree closely with those from the analysis of the complete film mentioned previously. Thus, we would expect that the standard deviation of the thickness variation within aerial products coated on 102 μm thick Estar base to be about 2.8 μm, including roll-to-roll variation and differences among emulsions of the same type.

A study of the thickness variations in aerial photographic film was reported in the literature in 1963[2]. The type of film was not disclosed but it was later found that the data were collected on Kodak Super-XX Aerographic film which was coated on a topographic cellulose acetate butyrate film base. This type of film and film base were discontinued several years ago but it is interesting to compare the early results on acetate base with a modern aerial film on Estar base. Figure 5 is a reproduction of thickness variations published for the acetate base film.

This film showed a very uneven surface with thickness variations of 8 μm occurring within a 3-cm distance. Both the average thickness variations and the frequency of their change in the Estar base films are about one-half of that shown by the obsolete acetate base.

All the results presented in this paper were obtained on 102 μm Estar base. From earlier studies the thickness variation in Estar thick base (178 μm) was about the same as for the 102 μm thick support. Estar thin base (64 μm) and Estar ultra-thin base (38 μm) film supports have a significantly smaller thickness variation than the 102 μm thick support.

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1. "Specifications for Aerial Photography," U. S. Department of Agriculture, Forest Service, January 31, 1969.
2. Hallert, B., "Definition and Determination of Weights of Fundamental Photogrammetric Data and Results," *Photogrammetric Engineering*, 29:6, 1024–1026, (1963).

Articles for Next Month

L. U. Bender, Film deformation investigation.
J. M. T. Clark, Film flatness in survey cameras.
P. A. Gagnon and *M. Perron*, Experiments in model formation.
J. Jaksic, Deformations of Estar-base films.
G. H. Ligterink, Film-glass differences.
L. M. Martucci, Image quality and image geometry.
E. L. Merritt, Camera orientation with peripheral circles.
W. Sibert, Role of federal agencies in large-scale mapping.
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J. F. Vedder and *H. Y. Lem*, Profiling with the electron microscope.
A. E. Whiteside and *C. W. Matherly*, Recent analytical stereoplotter developments.