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Film Flattening in Aerial Cameras

It seems that the short-period deviations from a plane cannot be reduced much below 4 or 5 micrometers at this time.

ABSTRACT: *Based on the premise that film is to be used in an aerial camera rather than either glass or a reseau, several tests are cited and analyzed. The film surface has deviations of 6 to 7 micrometers if it is vacuum backed; they have an extensive distribution of 4 to 5 micrometers. The deviations occur irregularly over the area of the film and ordinarily do not correspond with the holes in the camera back. An amature camera with mechanical flattening showed even larger deviations.*

INTRODUCTION

FILM IS USED almost exclusively as the base for the photosensitive emulsion layer in modern aerial cameras. For a long time a dispute persisted over the question "film or glass plate?", but today this in effect has been settled in favor of film.

The decisive factors for this outcome were largely the lower weight of film and the ease with which it can be handled. In the recent past the geometric characteristics of film have been improved considerably through the introduction of stable polyester bases (e.g., Cronar), the sophisticated design of the vacuum systems, and (in special cases) the development and application of reseau cameras.

As a result of these efforts, mean coordinate errors between 5 and 10 μm are the rule in photogrammetry today. Although this is a remarkable achievement, it also represents a challenge to find the causes and factors responsible for these remaining residual errors.

As photogrammetric photography involves central perspectives, film flatness doubtlessly is part of the problem. Deviations from the plane position are proportional to the tangents of the angle of incidence, which is especially significant for cameras having a wide aperture angle (superwide-angle cameras).

Only a few recent publications are available on the subject.[1] Interesting points were brought up by Clark and Cooper at Lisbon in 1964.[3] The suggestions were taken up and systematic investigations were conducted with Zeiss aerial survey cameras. The results of these investigations are discussed in the following.

HOW IS FILM FLATNESS ACHIEVED IN AERIAL CAMERAS?

Because film flattening is an important step in the overall functioning of aerial cameras, special attention was paid to achieve this through the appropriate structural design of the camera. A number of different solutions were possible. They are briefly reviewed in Figure 1.

Thus flattening can be achieved by mechanical and pneumatic methods. Of the mechanical methods, only the one in which the film is pressed against a precision-finished plate (register glass plate) will meet the high requirements of surveying cameras. An inherent problem of this method deserving close attention is the generation of static electricity. Of the pneumatic methods, leading camera manufacturers generally prefer the vacuum process: by creating a vacuum, atmospheric pressure flattens the film against the plate just prior to exposure. The vacuum is produced either by the air pressure of a Venturi tube or—increasingly nowadays— by a turbine which is part of the camera system.

To avoid problems, a number of points must be kept in mind in making the necessary technical preparations. Static calculations for a square film membrane of 9×9 inches (23×23 cm) indicate a pressure requirement of 2 mm Hg for proper flattening provided

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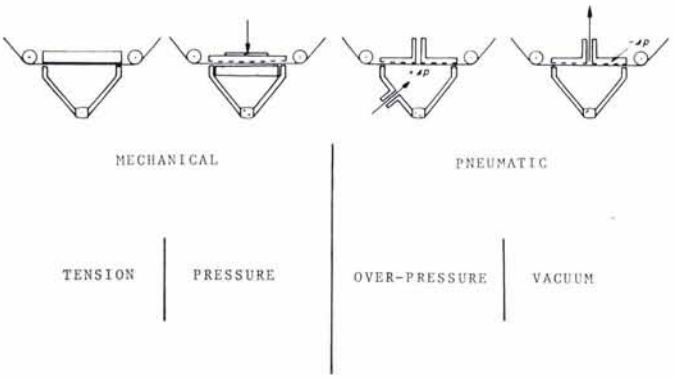


FIG. 1. Possibilities for achieving film flatness in aerial cameras.

this pneumatic force comes to bear without any interfering mechanical force. Perfect mechanical flatness is therefore an important prerequisite. Zeiss patent No. 960690 should be mentioned here because it is pertinent to the problem.[8]

In the course of the attempted standardization of specifications, there have been repeated demands to establish formally a minimum vacuum pressure value deemed necessary for proper film flattening. In these proposals it was often overlooked that too high a vacuum could do more harm than good and could result in faulty flattening. Quite a few other structural boundary values must therefore be taken into account in selecting the proper pressure, and it is for this reason that the decision should be left up to the designer of the camera.

The most important boundary condition in pneumatic film flattening, however, is the *decrease in atmospheric pressure with increasing altitude.*

This functional dependence and the vacuum pressures produced in Zeiss aerial survey cameras are shown in Figure 2. As can be seen, the critical point is reached at a flying height of 13,000 m. The reliability of film flattening was verified in flight tests up to this altitude. Above this altitude, twin turbines become necessary to keep up the vacuum pressure.

INTEGRAL DETERMINATION OF THE CAUSES OF PHOTOGRAMMETRIC RESIDUAL ERRORS

Today, camera systems with focal lengths between 85 and 610 mm are available, as made up of interchangeable structural subgroups or modules. In Zeiss aerial survey cameras, for example, the entire film transport and flattening mechanism is identical in the models RMK A 8.5/23, RMK A 15/23, RMK A 21/23, RMK A 30/23 and RMK A 60/23. In all of these cameras, the same magazines, films and vacuum pumps for film flattening are used, which really means that

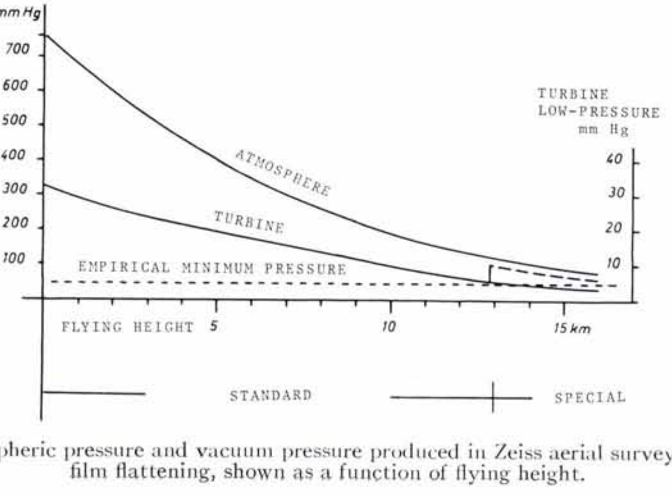


FIG. 2. Atmospheric pressure and vacuum pressure produced in Zeiss aerial survey cameras for film flattening, shown as a function of flying height.

Focal length	8,5 cm	15 cm	21 cm	30 cm
Day	April 5. 1969			
Flying height above ground	850 m	1530 m	2100 m	3050 m
Aircraft	Aero - Commander			
Air speed	~ 260 km/h			
Camera (serial number)	111 164	111 680	20 208	110 403
Filter (serial number)	B ohne	B 114 065	B 14 107	B 111 169
Film magazine (serial number)	111 599			
Film	Aviphot Pan 30 PE			
Developer	Perufin 1:10			
Development time	32 Minuten			
Developer temperature	+ 20 °C			
Drying temperature in TG-24	~ + 36 °C			
Number of frames on film leader	12			
Overlap	90 %			
Weather Visibility	20 km			
Weather Cloud cover	0/8			

FIG. 3. Flight data, Rheidt test flight.

the conditions are uniform with respect to the two anticipated major sources of error—film shrinkage and unevenness. The causes of errors are therefore the same, but due to the different focal lengths, their effects on the overall results (taking the form of mean horizontal and vertical errors) are not. This makes it possible to draw conclusions from the effects as to the cause and thereby about the extent of the film's unevenness.

Such an investigation was made in 1969.[6] After the applicable theoretical aspects had been considered,[4],[5] the following formulations were established for the error sources of film shrinkage, unevenness and residual optical errors:

Film shrinkage:

$$d_{s1} = F_0' + F_1's$$

Unevenness of film:

$$d_{r1} = (U_0' + U_1's)\frac{r}{f}$$

Residual optical errors:

$$d_{r2} = K_{c1} + K_{c2}\left(\frac{r}{f}\right)^2$$

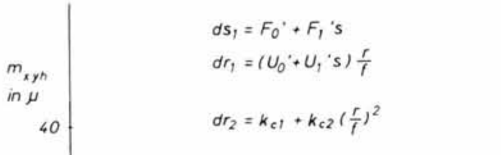
where s is the film format; f, focal length; and r, radial distance from center of the picture. See also Reference 6, Equations 5 through 7, regarding the resulting mean coordinate errors m_{xyh}.

For testing purposes it now was necessary to determine the parameters (F_0', F_1', U_0', K_{c1} and K_{c2}) of the three formulated sources of errors and, at the same time, their order of magnitude.

This was done in flights over the test area Rheidt during 1969. Four of the five aforementioned camera models were used under conditions of maximum uniformity. The data are shown in Figure 3.

The photographs taken during a flight were plotted on the Zeiss Planimat Precision Stereoplotter where the mathematical model[5] established previously was adjusted for optimum agreement of theory and practice. The resulting data are presented in Figure 4.

The two parameters U_0' and U_1' are of



$F_0' = 1{,}5\ \mu$ $U_0' = 6\ \mu$ $k_{c1} = 1{,}5\ \mu$

$F_1' = 0{,}15\ \mu/\mathrm{cm}$ $U_1' = 0{,}26\ \mu/\mathrm{cm}$ $k_{c2} = 2{,}25\ \mu$

$p = 0{,}6$ $q = 0{,}2$ $s = 23\ \mathrm{cm}$

FIG. 4. Model corresponding to Rheidt test results.

significance to the problem being considered here. As it turned out,

$$U_0' = 6\,\mu\text{m}$$
$$U_1' = 0.26\,\mu\text{m/cm},$$

with the 6 μm corresponding to $s = 23$ cm. Where U_1' represents the format-dependent large-area deformations, U_0' represents the short-period irregularities. Next, it was necessary to verify in specific and detailed physical studies the empirical results just mentioned. Agreement would considerably add to the validity of the basic mathematical model.

Specific Studies of Film Flatness

Film flatness may be defined as the unevenness in the photographic emulsion serving as the receiving *plane* for the actual image produced by optical means. Film flatness may also be broken down into:

- Planeness of the pressure plate,
- Variations in the thickness of the film, and
- Contact between the back of the film and the pressure plate.

PLANENESS OF THE PRESSURE PLATES

Pressure plates are made of high-quality materials; the plates are relieved of stresses and then optically ground. This finish removes all but large-area deformations from the plate. The plates are tested[7] pneumatically or mechanically. The deviations from the averaging plane tolerated on Zeiss plates is only ±7 μm. Attaining this accuracy presents no problem for the production department,[2] and there is proof that this tolerance will not be exceeded through years of use of the plates.

VARIATIONS IN THE THICKNESS OF THE FILM

Ahrend described extensive studies of this subject.[1] On acetate-base films of thicknesses between 120 μm and 245 μm, the measured variations were between 3 μm and 9 μm. The variations were found to be directly proportional to a film's thickness, of which they represented 3 percent fairly accurately.

Polyester-base films (not available at the time the above information was obtained) were measured only recently. With thicknesses between 80 μm and 140 μm, the variations were 3 μm to 4 μm, thus again 3 to 4 percent. The fluctuations obviously stem from the manufacturing process and may therefore be expected to occur with regularity. As in the case of the pressure plates, it is important to mention again that these are large-area deviations.

CONTACT BETWEEN THE BACK OF THE FILM AND THE PRESSURE PLATE

This one, the last of the three components is difficult to verify. However, it is somewhat easier to follow the suggestions of Clark and Cooper[3] and use interference tests directly on the emulsion surface to determine planeness. This method determines the combined effect of all three factors directly on the final result. The simple test arrangement that was selected is shown in Figure 5. A typical interferogram is shown in Figure 6.

The monochromatic filter that was used (578 nm) causes the distance between two interference fringes to correspond to an unevenness of 0.29 μm. The investigation was conducted with emulsion-coated and uncoated films in Zeiss film magazines and with

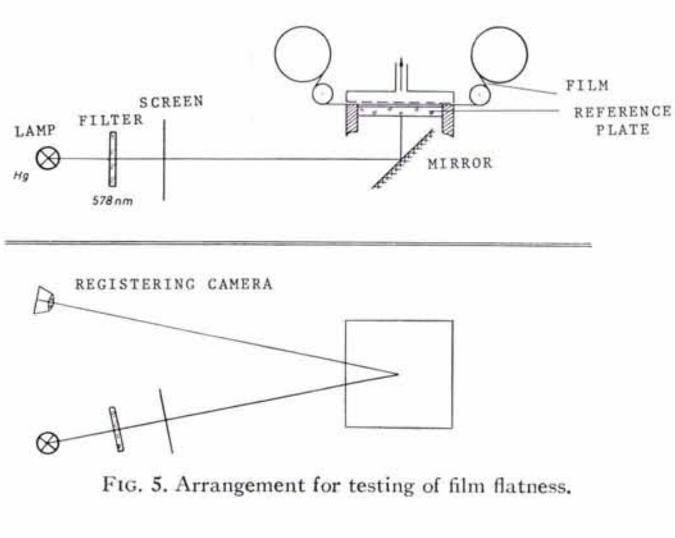


FIG. 5. Arrangement for testing of film flatness.

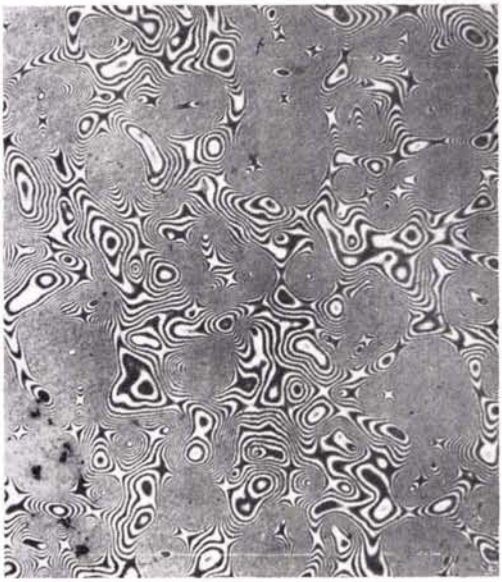


FIG. 6. Interferogram of film flatness in Zeiss aerial survey camera with Aviphot Pan 30 PE film.

emulsion-coated film between plane-parallel glass plates. The results may be summarized as follows:

- ★ The film surface has deviations from the plane of 6 μm to 7 μm (20 to 25 fringes) if vacuum-backed.
- ★ These deviations have an extension (period) of 4 to 5 mm.
- ★ The deviations occur irregularly; specifically, there is no indication that they are affected by the pattern of holes in the vacuum back.
- ★ The same holds true for coated film between two plane-parallel glass plates. Even with a very high vacuum the deviations cannot be pressed below 4 to 5 μm. Ahrend already pointed out this honeycomb structure.[1,2]
- ★ An amateur camera with mechanical flattening (Hasselblad, format 6×6 cm) was tested for comparison; it showed large-area deviations up to 25 μm.

Summarizing these findings it may be said that the Zeiss aerial survey cameras of the format of 9×9 inches which were subjected to the tests had large-area deviations of 5 to 8 μm (U_1') and short-period deviations of 6 to 7 μm. The causes for the large-area deviations are found in the vacuum pressure plate and the variations in the thickness of the film. The short-period deviations have their cause in the fact that it is almost impossible to develop a film into an ideal plane. A film seems to consist of a succession of *spherical* surfaces which, even under high vacuum pressure, will not assume the ideal plane, although pressure will cause one large *roundness* to break up into several smaller ones.

For the sake of comparison it should be mentioned that the firm Agfa-Gevaert guarantees a tolerance of 28.5 μm for the greatest vertical deviation from the plane for their Aviphot plates, size 24×25 cm, made of Ultraplan glass.

CONCLUSIONS

The results of this study, conducted specifically to determine film flattening, confirm fairly well the empirical findings of the second section and therefore validate also the basic mathematical model. The effects of the three error factors (film shrinkage, unevenness and optical errors) on the coordinate error are shown in Figure 7.

As can be seen, the effect of unevenness dominates only in the vertical error m_h, and there again only for superwide-angle cameras.

Even though the detected deviations from the plane are of a remarkably low order, the question arising immediately is whether these errors can still be reduced further. But this point would have to be taken up first with the film manufacturers who in turn would have to start a thorough investigation. Without wanting to jump to any rash conclusions, it nevertheless seems improbable that the

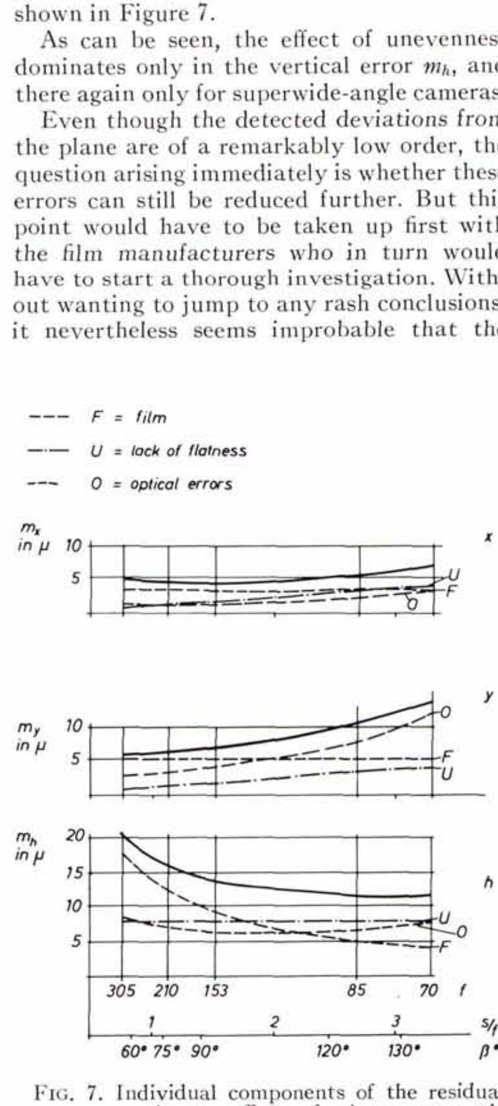


FIG. 7. Individual components of the residual error, proportionate effect of photogrammetric error sources on the mean coordinate error.

short-period deviations from the plane can be reduced significantly at this time.

Another often-discussed possibility is the use of reseau cameras.[8] In order to record unevenness in a film, the reseau must be projected from a central perspective together with the aerial photograph. At the present, reseau plates with the grid lines spaced 10 mm apart are generally used. During this investigation it was found that the spacing would have to be reduced to 1 to 2 mm in order to detect the short-period deviations. Production and use of such a reseau, however, would pose several formidable problems.

The most logical recourse seems to be an optimization of the taking conditions with a realistic attitude toward accuracy requirements. Normal-angle cameras are advisable for high horizontal accuracy, wide or super-wide-angle cameras where high vertical accuracy is desired. But above all it is the flying height in conjunction with other available means and with the very high resolution attainable today which give the engineer a flexible tool for making the most of the accuracy of the camera he uses.

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