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Film Transparencies vs Paper Prints

Film has merits and limitations for interpretation and photogrammetry.

ABSTRACT: *The definition of objects near the threshold of detection is much higher with positive film transparencies than with paper prints. This is attributed to fewer internal reflections of light trapped between the base material and emulsion layer. For example, in a test comparing the definition of film transparencies and bromide prints produced from grainy air survey negatives, it was found that a 1:16,000-scale bromide print and a 1:27,000-scale film transparency were approximately equal in definition. For fine-grain films and small-scale photography the discrepancy will be greater, thereby increasing the importance of the film transparency. A limited test indicated that both polyester base film transparencies and bromide foil card prints are satisfactory for plotting topographic maps. Furthermore, polyester base film transparencies are suitable for both analytical aerial triangulation and large-scale plotting. Dimensional changes are uniform, and they are less fragile, lighter in weight, and more easily stored than glass diapositives. Duplicate color transparencies can be more economically produced on aerial film.*

INTRODUCTION

IT IS WELL-KNOWN among professional photo-interpreters and photogrammetrists that transparent base materials are to be preferred to opaque materials for their respective tasks. To the photo-interpreter positive transparencies viewed by transmitted light offer a greater wealth of detail and in roll form are easier to handle than a set of reflection prints. To the photogrammetrist glass diapositives represent stability and flatness. However, many organizations involved in photo-interpretation work continue to use paper prints and few photogrammetrists would consider anything but glass diapositives for plotting.

Because of the general lack of technical discussion in photogrammetric/photo-interpretation literature on the relative merits of paper prints and positive film transparencies, this paper will attempt to discuss their uses and limitations in relation to both fields from a practitioner's point of view. However, before discussing the materials themselves it is well to review the requirements for good definition in the aerial photograph.

DEFINITION

Definition is of prime importance to both the photogrammetrist and the photo-interpreter and can, for the purpose of this discussion, be taken to mean the detection and /or identification of small image detail. Several variables influence definition, including: (1) human eye, (2) resolution, (3) contrast and brightness (luminance) range, (4) edge sharpness, (5) granularity, and (6) viewing system. Items 2 through 5 are related to the printing material.

HUMAN EYE

With low contrast targets representative of the aerial image, the angular resolution of the eye is approximately 2 to 3 minutes of arc, or 3 to 5 lines/mm at a viewing distance of 6 inches; however, the eye can detect objects almost infinitely small provided they are bright enough. Similarly, under favorable condi-

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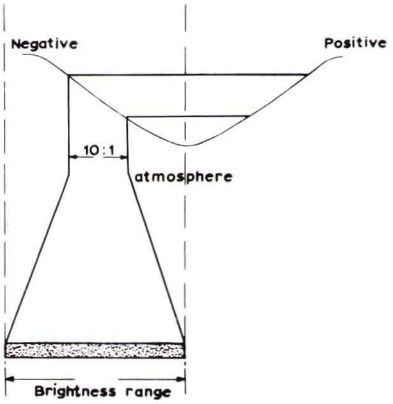

FIG. 1. Compression of brightness range by the atmosphere.

tions, the eye can detect changes in density of .02 units in the middle tones, and it is reported (Colwell, 1966) that by using variable intensity light transmission that 200 tones can be distinguished. If chromaticity is added to tone the detection possibilities are considerably increased.

RESOLUTION

Resolution in the negative is a function of the lens, type of emulsion, aperture, size and contrast of the target being photographed, image motion and processing conditions. From the standpoint of the user of aerial photographs, however, it is the resolution of the final positive copy that is important. In the case of reversal films the positive image is obtained directly, but with negative films a printing process is required (original reversal film positives can be considered equivalent to negatives). It is essential, therefore, that the printing material be capable of maintaining a high percentage of the negative resolution.

CONTRAST AND BRIGHTNESS (LUMINANCE) RANGE

Contrast in the negative rarely exceeds a brightness ratio of 1.26:1 (difference of 0.1 log units) for small adjacent objects (Carman and Carruthers, 1951) and the overall brightness range in the aerial image (Figure 1) is usually less than 10:1 (1.0 log density units); therefore the positive material must be capable of recording minute tonal differences as well as the overall brightness range.

EDGE SHARPNESS

Edge sharpness is important for the separation and identification of fine detail and is first determined in the negative by the lens-film combination and development process. In the positive, edge sharpness will be influenced by whether the light source in the printer/enlarger is diffuse or point (the latter source being preferred), the positive material and the development process. Other factors being constant, the positive material must be able to reproduce the negative image with the minimum amount of spread.

GRANULARITY

Granularity, which is the objective measure of the size and density of the clumps of metallic silver grains or color dye blobs formed in the development process, is usually directly related to the speed of the photographic material. Detail smaller than a clump of grains will not be resolved or recognized; therefore the positive material should be of finer grain than the negative. Table 1 illustrates the relationship between speed, granularity, resolution and contrast for selected Kodak films.

VIEWING SYSTEM

Viewing systems consist of front illumination for prints or rear illumination for transparencies. Either a tungsten or fluorescent light source is suitable for black-and-white materials; however, with color the light source should possess a continuous spectrum and have a color temperature of 4000° to 6000° K. Variable intensity controls are desirable in any viewing system and it must be remembered that as color dyes produce higher image densities than silver halide emulsions, a brighter light source is necessary. Regardless of the viewing system all stray light, which will fall between the photograph and the observer and cause a reduction in visual contrasts, should be eliminated.

Magnification is an inherent part of any viewing system. Theoretically, the minimum magnification necessary for *resolving* targets on the negative can be determined by lens-film resolution divided by the eye resolution. However, for detection, considerably higher magnifications may be necessary due to contrast reduction in the aerial image, stray light, mediocre equipment and imperfections in the viewer's eyesight.

SUMMARY

If any of the above mentioned factors are degraded, definition will be impaired. Generally, the human eye and viewing system can be adjusted so that the factors limiting definition are in the production of the positive

TABLE 1. THE RELATIONSHIP OF SPEED, CONTRAST, RESOLVING POWER AND GRANULARITY AS INDICATED BY DATA FOR SELECTED KODAK AERIAL FILMS (KODAK, 1965)

Kodak Film	*Aerial Exposure Index*	*Resolving Power (Lines/mm)*		*RMS Granularity*
		Target Contrast 1,000:1	*Target Contrast 1.6:1*	
Super-XX Aerographic, Type 5425	100	75	30	37
Infra-red Aerographic, Type 5424	125	89	28	39
Ektachrome Infra-red Aero—Type 8443	10	71	36	22
Ektachrome Aero—Type 8442	25	56	28	30
Special Ektachrome MS Aerographic Type 2448 (Estar Base)	6	75	40	15
Plus X Aerial, Type 3401 (Estar Base)	64	105	40	35
Special High Definition Aerial (Estar Base) Type 3404	1.6	475	200	9.7
Aerographic Duplicating (Estar Thick Base) Type 4427		138	84	161
Fine Grain Aerial Duplicating Type 8430		285	120	8.9

copy. Therefore, it is essential that the positive material be capable of (1) producing high resolution, (2) recording both overall brightness range and minute tonal differences. (3) maintaining edge sharpness, and (4) have a granularity factor smaller than that of the original emulsion.

CHARACTERISTICS OF PRINTS AND TRANSPARENCIES

PRINT MATERIALS

Black-and-white bromide print material consists of a single emulsion layer on top of an opaque base and is manufactured in several grades, classified from soft to hard, depending on the gamma of the emulsion (Figure 2). As aerial negatives normally record a brightness range of less than 10:1 it would seem desirable to use a hard paper in order to increase contrasts; however, it has been shown (Barrows, 1957) that the increase in granularity which accompanies hard papers neutralizes any benefits gained in tone reproduction. Generally, the brightness range that paper prints can reproduce varies from 8:1 to 40:1 (0.9 to 1.6 log units), depending on the material and whether the finish is matte or glossy, and is sufficient to reproduce the tonal range encountered on a properly exposed aerial negative.

Color print material, like the negative emulsion, consists of three sensitized layers and is of two types: (1) that used for making prints from reversal materials (Ansco Printon, Kodak Ektachrome Paper, Cilchrome Paper); and (2) that used in negative-positive processes (Kodak Ektacolor Paper). According to Hunt (1965), the average brightness

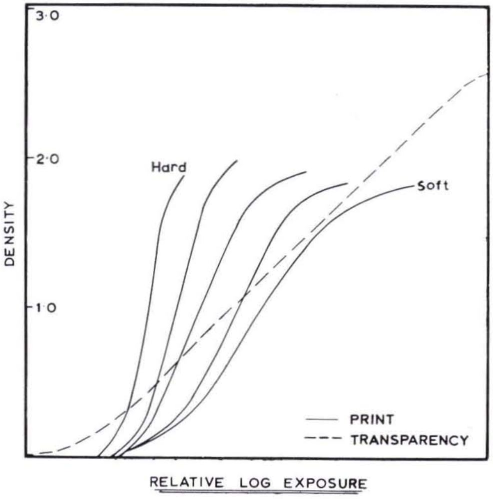

FIG. 2. Characteristic curves for typical black-and-white print and transparency material.

range of a glossy color print is 28:1 (range of 1.45 log units) which is again greater than the brightness range encountered in aerial photography.

TRANSPARENCY MATERIALS

Transparency or duplicating film is often similar to the original negative material and either positives or duplicate negatives (original negative-positive-duplicate negative) can be produced. Because length of exposure in the printing process is not a limiting factor, it is possible, in black-and-white reproduction, to choose transparency material of finer grain than the original film. By doing so, granularity can be eliminated as a degradation factor in the negative-positive process. The brightness range of black-and-white transparency material varies from 100:1 to 1000:1 (range of 2.0 to 3.0 log units) which is considerably greater than the brightness range of either print material or the images recorded on the aerial negative. This, in effect, means that there is greater scope for tonal adjustment by altering exposure, development time or developer (for example, with an over or under-exposed negative) without seriously altering the granularity as is the case if different grades of print material are used.

With color, the choice of transparency material is normally limited to original film or to a duplicating film similar to the original material. Therefore, in a negative-positive process the cumulative effects of granularity and dye diffusion may be responsible for some loss of detail. For these reasons direct reversal films are usually considered to be sharper than negative films. The average brightness range of color transparencies is approximately 100:1 (2.00 log units).

Advantages of the Positive Transparency

So far it has been shown that for a *properly exposed* aerial negative both prints and transparencies will accommodate the brightness range of the negative and that graininess may not be a significant factor. What then, in terms of definition, is the advantage of the transparency?

Work by Miss R. E. Stapleton (1964) of Ilford Ltd. on the sharpness of transparencies and reflection prints has shown that multiple internal reflections of light trapped between a reflecting base and the surface of an emulsion layer considerably reduce definition in both black-and-white and color prints. These reflections tend to degrade edge sharpness and contrast; the effects of which, from the viewer's standpoint, are most serious for small objects at low densities (Figure 3).

For example, in a direct comparison of a medium speed, fine grain panchromatic film with a bromide paper, it was found that the film negative would have to be enlarged 4 to 7 times through a high quality enlarger lens before its unsharpness equalled that of the bromide paper. Similarly, a color negative could be enlarged four times before unsharpness equalled that of a color print on an opaque white base. Attempts to reduce the internal reflections in prints have met with partial success and include: (1) placing an emulsion on a translucent polyester base so that the resulting positive can be used as a print in reflected light or as a transparency placed on a light table (Criterion Durafilm Opal); (2) using a silver-dye-bleach material (Cilchrome Print material); and 3) adding a light absorbing dye to the base of the print (or transparency) material.

Differences in Resolution and Definition

Two practical experiments where resolution or definition on different materials has been compared are mentioned below. The first is described by J. A. Eden (1963) of the Directorate of Overseas Surveys. In this instance, a fine-grain film was exposed in a Wild RC-5 camera, $f=6$ inches, over a high-contrast resolution test object (with a contrast of 0.33 log units) from an altitude of 3000 feet. All positives were produced on a Cintel scanning spot printer. Table 2 lists the results of this test and, as can be seen, there is a 25 percent difference in resolution between transparent and reflection positives.

A second test conducted by the author (Welch, 1966) compares the difference in definition between negatives, positive film transparencies and paper prints. In this in-

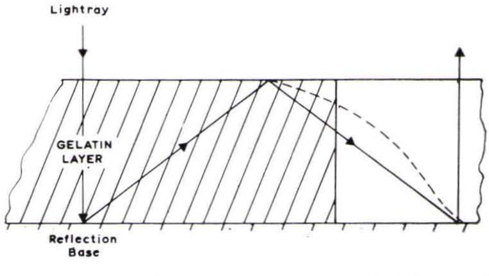

FIG. 3. Loss of sharpness due to multiple internal reflections. The shaded area is an image with a sharp edge, whereas the dashed line represents the image edge as observed on a reflection print. (After Stapleton).

stance a Wild RC-5 camera, $f=6$ inches, was used at altitudes of 8000 ft. (2440 meters) and 13,500 feet (4100 meters) to obtain photography of a test area consisting of white squares of cloth of the sizes 5, 4, 3, 2, 1 and 0.5 feet (ground contrast of 0.7 log units and image contrast of 0.40 to 0.50 log units) and other objects of known size. Films employed included: Ilford Hyperpan, a grainy air survey film similar to Super XX; Ektachrome Aero-Type 8442, which, although a reversal film, was used as a negative film in order to increase exposure latitude; and Ektachrome Infrared Aero-Type 8443. The positive prints, enlargements and transparencies were produced with diffuse light source equipment.

TABLE 2. LOSS OF RESOLUTION (EDEN, 1963)

Subject	*Lines/mm at Photo Scale*	*Smallest Viewing Magnification Necessary*	*Percentage Loss of Resolution*
Negative	68	×30	—
Glass diapositive	42	×25	38
Paper print	31	×16	54

From Table 3 it can be seen that a 1:27,000 scale panchromatic transparency is equal in definition to a 1:16,000 scale bromide print, and also, that it takes a 5× bromide print enlargement from the negative to equal the definition of a contact-scale positive transparency. With the color film, it is estimated that a 4×enlargement would have equalled the definition of a contact scale positive transparency. Other observations include: (1) that although the 5× enlargement did not seem to be as sharp as the positive transparency, all detail could be readily observed with 2× magnification—however, the physical size of

TABLE 3. LOSS OF DEFINITION

Film	*Material*	*Enlargement from Negative*	*Approximate Scale*	*Smallest White Square of Cloth which could be Detected under ×10*	*Estimated Maximum Definition*
Ilford Hyperpan	Negative	—	1:16,000	0.5′	<0.5′
	Positive Transparency	—	1:16,000	0.5′	<0.5′
	Bromide Print	—	1:16,000	1′	>0.5′<1′
	Bromide Print	×1.5	1:10,700	1′	>0.5′<1′
	Bromide Print	×2	1:8,000	1′	>0.5′<1′
	Bromide Print	×3	1:5,300	0.5′	>0.5′<1′
	Bromide Print	×4	1:4,000	0.5′	0.5′
	Bromide Print	×5	1:3,200	0.5′	<0.5′
	Negative	—	1:27,000	0.5′	<0.5′
	Positive Transparency	—	1:27,000	0.5′ or 1′[3]	>0.5′<1′
	Bromide Print	—	1:27,000	2′	>1′<2′
Kodak Ektachrome Aero, Type 8442[1]	Negative	—	1:16,000	0.5′	0.5′
	Positive Transparency	—	1:16,000	0.5′ or 1′[3]	0.5′<1′
	Ektacolor Paper Print	—	1:16,000	1′	1′
	Ektacolor Paper Print	×2	1:8,000	1′	<1′
	Ektacolor Paper Print	×3	1:5,300	1′	>0.5′<1′
Kodak Ektachrome Infra-red Aero, Type 8443[2]	Positive Transparency	—	1:16,000	0.5′	0.5′

[1] used as a negative material

[2] used as a reversal (positive) material

[3] On some transparencies the 0.5 foot square could be detected, whereas on others detection was limited to the 1 foot square.

the enlargement was detrimental to either office or field-work; (2) minor color tones were emphasized on the color enlargements; and (3) the transparencies produced from the color negative gave only slightly less definition than the reversal false color, which was of high quality.

Both of the above tests show that transparent base materials give much higher definition at the threshold of detection and are to be preferred to paper prints for detailed studies. In this regard, it should also be remembered that the higher the resolution a lens-film combination is capable of, the more important transparent base materials become. For example, Berg (1961) has shown that as negative resolution increases, the percentage loss in resolution during contact printing also increases. Therefore, any loss of sharpness or contrast in the positive material due to internal reflections and/or high granularity will cause a considerable loss in both resolution and definition.

The relative merits of transparencies and prints in terms of definition can now be summed up as follows:

- By variable intensity, rear illumination, tonal contrasts in transparencies can easily be altered. Also filters can be used more effectively.
- The greater brightness range of the transparencies permits tonal adjustment when making positives from over and under exposed negatives without seriously altering the granularity factor. Furthermore, minute tonal rendition of small objects is improved due to increased edge sharpness.
- Transparencies, because of higher definition, can be subjected to greater optical magnification.
- Prints must be enlarged from the negative several times to equal the definition of contact scale positive transparencies. The enlargement factor is dependent on the definition in the negative.

USE OF PRINTS AND TRANSPARENCIES IN PHOTOGRAMMETRY

Glass diapositives are normally used in photogrammetric work because of their greater stability and flatness. For example, Adelstein, Josephson and Leister (1966) list an average relative vector displacement (representing the nonuniformity of dimensional change within an area of four inches square) of 3 microns for glass plates. They further conclude that with careful handling the nonuniform dimensional change of topographic base films can show an average relative vector displacement of 5 to 10 microns in a 9-inch square format, although any stresses placed on the film during processing may cause errors of as large as 50 microns to occur. For polyester base film, Brock and Faulds (1963) found a random displacement of ±5 microns at the 95 percent confidence level and that the distance between images had little effect on the error.

Flatness is another variable which must be considered. Mullins (1966) gives the figures (Table 4) on the flatness tolerance ranges of Kodak plates. As film transparencies or foil card prints are usually mounted between glass plates for photogrammetric work, it is unlikely that the film lies as flat as glass diapositives. The problem of flatness also varies with the type of plotting equipment. With mechanical projection machines (Wild, Kern, Santoni) the positive material is held in an essentially horizontal plane, is often supported by a stage plate, and is viewed orthogonally. Therefore the problems caused by lack of flatness are minimal. In optical projection machines (Kelsh, Balplex, Stereoplanigraph, Photomapper), however, the diapositives may not be supported by a stage plate and, as the light rays pass through the diapositives at various angles, any lack of flatness will result in deviations from the correct ray geometry, and consequently in the intersection points of corresponding rays. This, of course, will cause small changes in height and possibly in planimetric coordinates.

It is difficult to assess the importance of the figures quoted on stability and flatness from a practical photogrammetric standpoint, particularly as they must be separated from errors in machine calibration, orientation, pointing and plotting to be evaluated. Investigations by the author at the University of Glasgow indicate that for the graphical *plotting* of medium scale topographic maps with analogue equipment, the final map differs little regardless of whether glass diapositives, film transparencies or foil card prints are used. This work is described below.

TABLE 4. FLATNESS OF GLASS DIAPOSITIVES (MULLINS, 1966)

Size of plate	*Does not depart from a flat plane by more than*
Multiplex	0.01 mm
23×23 cm, 1.6 mm thick (0.06 inch)	0.08 mm
23×23 cm, 6.4 mm thick (0.25 inch)	0.04 mm 0.02 mm

PRINTS AND TRANSPARENCIES FOR TOPOGRAPHIC MAPPING

In the initial stages, two 1:15,000 scale topographic maps of the same area, with a 10-meter contour interval, were produced from two different sets of photography and from different support materials. For the first map, 16 models were plotted using the previously mentioned 1:27,000 scale photography (topographic base). Adequate pre-marked control was available in every model and 1.6-mm glass diapositives, contact printed from the original negatives, were used throughout.

For the second map, 8 models of 1:46,000 scale photography, taken with a Metrogon lens ($f=6$ inches) calibrated to one decimal point, were plotted. Plan and height control was a combination of identifiable trig points and points transferred from the 1:27,000 photography. In this case, however, only thin, acetate base, positive transparencies of rather poor tonal quality were available. To improve tone and flatness, negatives were produced from the thin-base positives and then duplicate positives were produced from the negatives on to both glass and 0.18-mm (.007-inch) polyester base transparency material. These duplicate positives were used in the plotting. As will be seen in Figure 4, the transparencies were mounted between the distortion/altitude correction plate and a glass diapositive from which the emulsion had been removed.

Machines used in producing the first map included a Wild A6, Wild B8 and a Santoni Simplex IIC. A model-to-plot ratio of 1:1 was used throughout. Plotting of the second map was limited to the B8 for which distortion/altitude correction plates were available; however, in this case a 3:5 model-to-plot enlargement ratio was necessary. Relief in the models ranged from less than 100 meters to greater than 700 meters.

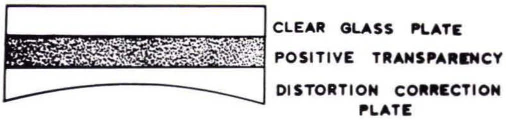

FIG. 4. Method of using film transparencies in the plotting machine.

Figure 5 illustrates contours of the same area obtained from the two sets of photography, and from both diapositives and positive transparencies. Considering the differences in photography, plotting ratios and machine tolerances, both height and plan values agree extremely well. Also, independent checks have shown that all planimetric features agree to within 0.5 mm (0.02 of an inch) and that spot heights are accurate to ±2 meters. There was no discernible difference between the transparencies and the glass diapositives.

Because of the close agreement of the maps produced from the two different sets of photography, it was decided to conduct a further test with glass diapositives, film transparencies and bromide foil card prints. For this test, positives on the above materials were produced from the same pair of 1:27,000 scale negatives. The model area and control distribution are shown in Figure 6.

In order to control the experiment as much as possible, the Wild B8 was used throughout with a photograph-to-plot (1:27,000 to

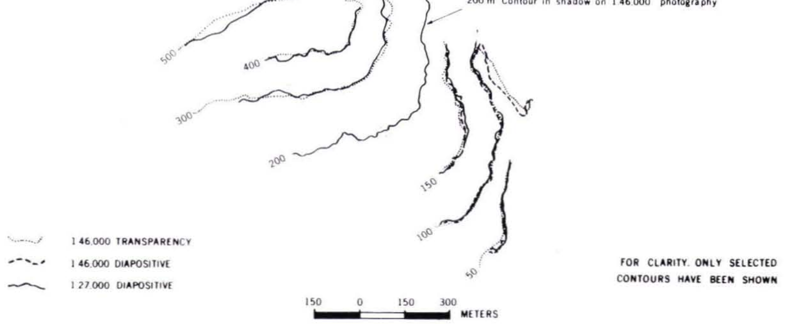

FIG. 5. Contours plotted from film transparencies and glass diapositives.

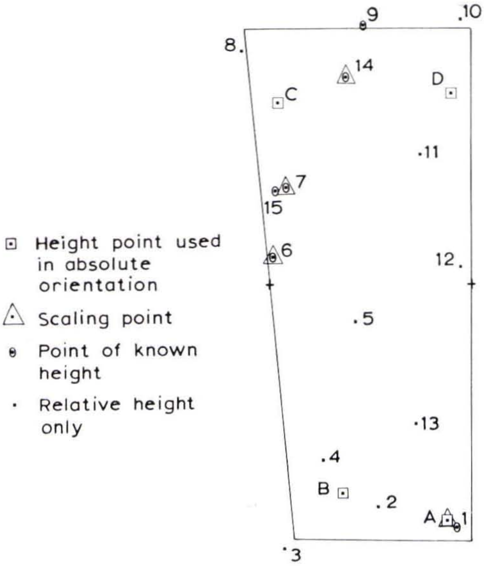

FIG. 6. Model area and control distribution for test comparing glass diapositives, film transparencies and bromide foil card prints.

1:15,000) enlargement ratio of 1:1.8. Diapositives and transparencies were mounted in the usual way; however, the foil card prints being opaque, were placed face down on the stage plate and covered with a glass plate to maintain flatness. To illuminate the prints from below, Wild provided a special lighting device which attaches to the scanning microscope of the B8 (Figures 7 and 8).

The normal procedure of relative and absolute orientation was used for each model, with scaling being carried out between points *A* and 14, and levelling at points *A*, *B*, *C* and *D*. However, in levelling the models it was necessary to take into account the effects of earth curvature, refraction and heighting accuracy, which, for a flying height of 4,100 meters, could cause errors in heighting of approximately 1 meter. It was considered, therefore, that the levelling would be satisfactory provided residuals of greater than 1 meter did not exist at points *A*, *B*, *C* and *D* (Table 5).

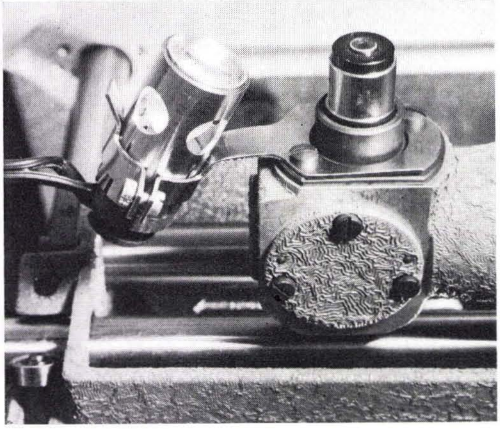

FIG. 7. Wild lighting attachment, for the plotting of prints, fixed to the optics of Wild B8. (Courtesy of Wild-Heerbrugg).

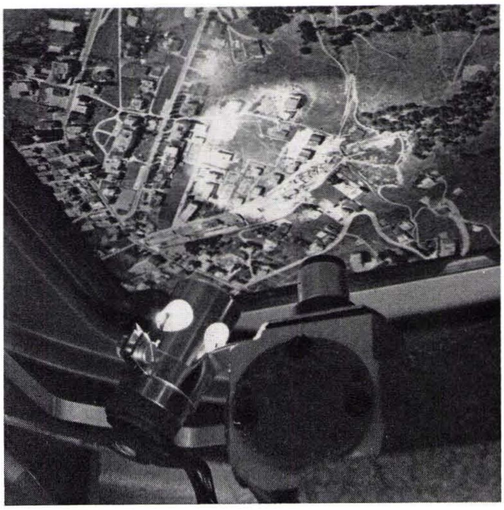

FIG. 8. Illumination of prints. (Courtesy of Wild-Heerbrugg).

Once relative and absolute orientation were completed, scaling was checked at points 6 and 7, and 5 rounds of heights were taken at points 1 to 15. Tabulations were then made of: (1), scaling accuracy, (2) means of the 5 readings at each point, (3) difference between the maximum and minimum mean readings for each point, and (4) differences from the true height at known points.

Scaling accuracy was judged on the basis of how far points 6 and 7 fell from the center of a magnifying scaling circle inserted in the pencil holder of the B8 pantograph. Both the diapositives and polyester-base transparencies checked at points 6 and 7. The foil card

TABLE 5. ABSOLUTE ORIENTATION HEIGHT RESIDUALS IN METERS

Point	*Diapositive*	*Film Transparency*	*Bromide Foil Card*
A	—	−.4	+.1
B	+.7	+.5	+.4
C	−.2	−.8	−.3
D	+.4	+.6	+.4

prints, however, showed an offset from center of approximately 0.2 mm. This offset was in the $+y$-direction at both points 6 and 7 and indicated that a dimensional change of approximately 0.2 mm may have occurred in the y-direction across the model. By distributing this error at the control points, plotting accuracy was maintained; that is, features plotted from diapositives, transparencies and bromide foil card prints coincided. Therefore, from a practical standpoint, the planimetric map accuracy was the same, regardless of the material used. This, however, may not have been true if enlargement ratios of greater than 1:1.8 had been used.

In regard to heighting, Table 6 lists the means of the five readings, the difference between the maximum and minimum means and the differences from true height. In studying the means, the foil card prints produced readings slightly lower than either the diapositives or the film transparencies. This phenomenon did not appear to be due to levelling, as would be the case if the trend were towards one part of the model, but, instead, indicated a slight, uniform shrinkage in the x-direction. Upon checking, it was found that the bx reading was 0.1 mm less than that of the transparencies. The average difference of 0.6 meters between maximum and minimum means indicates that there is no significant difference in the heights obtained with the three materials. This is confirmed by differences of less than one meter from true heights at the known points.

Because of the probable dimensional differ-

TABLE 6. COMPARISON OF THE MEANS OF FIVE HEIGHT READINGS FOR EACH POINT IN THE MODEL—GLASS DIAPOSITIVES, FILM DIAPOSITIVES, AND BROMIDE FOIL CARD PRINTS; THE DIFFERENCES BETWEEN MAXIMUM AND MINIMUM MEANS; AND DIFFERENCES FROM TRUE HEIGHT

Point	*Means and Standard Deviations of 5 Readings (meters)*			*Difference between Maximum & Minimum Means*	*True Height (meters)*	*Difference from True Height*		
	Diapositive (D)	*Film Transparency (T)*	*Bromide Foil Card (BFC)*			*D*	*T*	*BFC*
1	7.9±0.4	7.9±0.3	8.1[1]±0.3	0.2	7.9	—	—	+0.2
2	7.8±0.2	7.4±0.3	7.2±0.2	0.6				
3	5.2±0.2	4.4±0.1	3.9±0.1	1.3				
4	7.7±0.4	6.7±0.2	6.0±0.2	1.7 max.				
5	11.9±0.1	11.8±0.1	11.7±0.1	0.2 min.				
6	15.6±0.1	15.7±0.1	14.9±0.4	0.8	15.3	+0.3	+0.4	−0.4
7	40.8±0.2	41.2±0.2	40.5±0.1	0.7	40.6	+0.2	+.06	−0.1
8	29.8±0.4	30.2±0.2	30.0±0.1	0.4				
9	42.8±0.3	43.2±0.2	43.0±0.2	0.4	42.6	+0.2	+.06	+0.4
10	20.3±0.3	20.3±0.2	19.9±0.1	0.4				
11	22.3±0.2	22.6±0.2	21.9±0.2	0.7				
12	23.3±0.3	22.7±0.3	22.3±0.2	1.0				
13	12.6±0.3	12.3±0.3	12.1±0.2	0.5				
14	34.9±0.1	35.2±0.2	34.9±0.2	0.3	34.5	+0.4	+0.7	+0.4
15	26.8±0.4	26.5±0.0	26.6±0.2	0.3	27.1	−0.3	−0.6	−0.5
Mean				0.6				
RMSE						±0.3	±0.5	±0.4

[1] Maximum mean for a given point is underlined once. Minimum mean for a given point is underlined twice.

TABLE 7. AVERAGE DIMENSIONS BETWEEN CORNER FIDUCIAL MARKS

Photograph	*Calibration* (*C*)	*Negative* (*N*)	*Diapositive* (*D*)	*Transparency* (*T*)	*Bromide Foil Card* (*BFC*)
296					
Mean x–y dimension in centimeters	21.200	21.186	21.214	21.199	21.195
294					
Mean x–y dimension in centimeters	21.200	21.194	21.216	21.199	21.191

ences between materials, it was decided to determine the magnitude of these differences by measuring between the corner fiducial marks of each negative, diapositive, transparency and foil card print and comparing these values with the calibrated distances. This was accomplished using a Haag-Streit Coordinatograph mounted on a light table. Negatives, diapositives and transparencies could then be viewed with transmitted light and prints by reflected light from an overhead source. Although it was thought at first that the coordinatograph might not give sufficient accuracy to determine dimensional changes, it was found that for several rounds of readings at a given grid plate intersection or fiducial mark, a root-mean-square error of only ±10 microns was obtained. This error was negligible in comparison to the dimensional differences which actually existed (Table 7).

An indication of the effects of these dimensional differences on the test height values was obtained by computing the principal distance setting which should have been used in the plotting machine and then deriving the resultant affine deformation in its first approximation (Makarovic, 1966). Table 8 lists these deformations and as can be seen, a maximum error of approximately 1:1400 occurred with the diapositives. That this value is negligible in relation to machine and operators capabilities, is emphasised by the fact that the diapositives produced the lowest root-mean-square error in the test (Table 6). From this experience it seems likely that for graphical plotting, small errors in scaling and heighting are as much the result of machine calibration, orientation, flatness, index setting, distortion, earth curvature and refraction as they are to dimensional differences, and that both transparencies and bromide foil card prints are satisfactory for the plotting of topographic maps.

PRINTS AND TRANSPARENCIES FOR LARGE SCALE MAPPING

Although foil card prints have been widely used in third-order machines for small-scale mapping, the suitability of either transparencies or foil card prints for large-scale plotting and aerial triangulation is another question. The author is unaware of foil card prints now being used for these tasks; however, film transparencies have proved satisfactory in both instances. For example, the Ordnance Survey of Great Britian has been testing the suitability of Kodak MS aerial color films (acetate and polyester base), exposed at a flying height of 5000 feet (1524 meters) with 6- and 12-inch focal length cameras, for the production of the 1:2,500 and 1:1,250 scale planimetric map series (Woodrow, 1967). From the original reversal positive transparencies, duplicate positives are produced on MS type 2448 Estar base aerial

TABLE 8. AFFINE DEFORMATION IN THE MODEL DUE TO DIMENSIONAL DIFFERENCES

Model 296–294	*Mean Value of Principal Distance based on Dimensions between Corner Fiducial Marks*	*Principal Distance Used**	*Planimetric Scale*	*Height Scale*	*Height Scale Error (approximate)*
N	152.37	152.44	1:15,000	1:14,993	1:2,100
D	152.55	152.44	1:15,000	1:15,011	1:1,400
T	152.43	152.44	1:15,000	1:14,999	1:15,000
BFC	152.39	152.44	1:15,000	1:14,995	1:3,000

* Calibrated focal length

TABLE 9. PLANIMETRIC BLOCK ADJUSTMENT STATISTICS FOR PHOTOGRAPHY OBTAINED WITH A WILD RC8 CAMERA, $f=6$ INCHES (WOODROW, 1967).

Ordnance Survey Experimental Area	*Material Used*	*RMS Values for Planimetric Vector (microns at negative scale)*	
		Residuals at section tie points	*Residuals at control points used in the adjustment*
Beauly (1:25,000 scale photography)	Monochrome (glass diapositive)	6	10
	Color[1] (acetate base film transparency)	8	12
Halifax (1:10,000 scale photography)	Monochrome (glass diapositive)	6	11
	Color[2] (acetate base film transparency)	7	13

[1] This was one of the first tests conducted by the Ordnance Survey and the reversal color film was processed to a negative stage, from which acetate base duplicate transparencies were then produced. Mapping scale in this case was 1:10,560.

[2] Original acetate base reversal positive transparencies were used for the analytical aerial triangulation and contact scale polyester base transparencies were used in the plotting.

film at contact scale for the six-inch photography (1:10,000 scale) and at a reduced scale of 1:7,500 with the 12-inch (305 mm) photography. In the latter case, reduction from the original scale of 1:5,000 is necessary to allow plotting in the Wild A8 machines which have a maximum focal length acceptance of 215 mm. For analytical aerial triangulation, control and tie points between strips are transferred on either the original or duplicate transparencies using a Wild PUG device, and comparator measurements are performed with a Hilger and Watts Recording Stereocomparator. The plotting is carried out with the duplicate polyester base transparencies mounted between a glass plate and the stage plate of the A8.

Limited tests comparing the accuracies of the analytical aerial triangulations (dimensional changes can be treated in the adjustment) and features plotted from color transparencies and black-and-white glass diapositives of the same areas have indicated no significant difference in planimetric accuracy. Block adjustment statistics are given in Table 9. Furthermore, the additional cost of the color aerial photography is partially offset by the use of positive transparencies in place of glass plates for the photogrammetric plotting. A list of the relative costs of photographic materials is given in Table 10.

CONCLUSIONS

★ For photo-interpretation it is desirable to use film transparencies primarily because of their ability to withstand high magnification through increased sharpness, although brightness range is important when poor or high contrast negatives must be utilized. Also, through the use of variable-intensity rear illumination, contrasts can be altered when viewing.

★ Prints, while valuable for field work, must be enlarged from the negative by a

TABLE 10. RELATIVE COST OF PHOTOGRAPHIC MATERIALS

	Size	*Relative cost*
Bromide paper—double weight	10×12″	1
Color paper	10×12″	3.6
Bromide foil card	10×12″	4.4
Polyester base film (.007 inch)	10×12″	6.6
Black-and-white glass diapositives (.06 inch)	9½×9½″	8.8
Color aerial film	9½×9½″	12.0 estimate
Color transparency material	11×14″	24.1
Color glass diapositives	9½×9½″	40 estimate

factor of several times in order to equal the definition of contact scale positive transparencies—at which size they may be awkward to handle.

★ Improvements in lens-film combinations will permit higher magnification, thus lessening the significance of scale but increasing the significance of transparent base materials in both photo-interpretation and photogrammetry.

★ Bromide foil card prints appear to be suitable for the plotting of topographic maps.

★ Polyester base film transparencies are satisfactory for most photogrammetric work. Dimensional changes are uniform, they are easily stored, and are more durable and lighter in weight than glass diapositives. In addition, with color, a considerable saving in cost is possible if duplicate transparencies are produced on a roll of color aerial film rather than on color glass diapositives or sheet film.

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Articles for Next Month

Jack R. Van Lopik, *Albert E. Pressman*, and *Roger L. Ludlum*. Mapping pollution with infrared.

Dr. Merle P. Meyer and *Dr. Lucas Calpouzos*, Detection of crop diseases.

William A. Malila, Multispectral techniques for contrast enhancement.

John F. Kenefick, 60 percent *vs* 20 percent sidelap.

George H. Rosenfield, Stereo radar techniques.

Michael G. Misulia, Analogue-analytical mapping systems.

Dr. R. B. Forrest and *D. P. Hattaway*, The LR-1 portable line rectifier.

Dr. Ing. K. Szangolies, Grod plates.