RESOLUTION EXPERIMENTS IN CONTACT PRINTING THROUGH THE FILM BASE*

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EVER since over a century ago, when the first crude photographs were taken, the photographic technicians and the photographic engineers have waged a relentless struggle to improve the quality of the photographic product. During this period the term resolving power has evolved as signifying the differentiation between small details or objects reproduced in the image. Today's photogrammetrist whose responsibility it is to compile accurate topographic maps from photographs taken from the air, is especially interested in resolving power because the major job of photogrammetry is obtaining information from the photograph, and one of the fundamental limitations of the information gathering capacity of a photograph is, of course, the resolving power.

The resolving power may be quantitatively defined as the distance between two closely adjacent images which are separately rendered on the plane of the image. In customary practice the reciprocal of the separation distance is used, resulting in the expression—lines per millimeter resolved.

The resolving power is a function of the complete photographic system; resolution figures therefore have no meaning unless the factors which contribute to it are specified. The detail, for example, which can be reproduced through the medium of an aerial photograph, is a product of the entire system, the aerial camera and its lens, the film emulsion, the exposure, the processing and the instruments which utilize the photography, whether they be the eyes of a human being or the optical system of a complicated stereophotogrammetric plotting instrument.

Resolution figures obtained with so-called "resolution targets" are not always indicative of the resolution actually attained in a photograph; therefore resolving power tests should always be made as nearly as possible under the conditions which are to be used in the planned photographic process.

The purpose of this paper is to summarize the results of a series of experiments which were performed in an attempt to determine the conditions necessary in order to attain maximum resolving power when printing glass copies of aerial photographs for use in compiling topographic maps in projection-type stereophotogrammetric plotting instruments.

The simplest and most economical method of printing the $9\frac{1}{2}$ by $9\frac{1}{2}$ inch glass diapositives from the original 9 by 9 inch aerial negatives is with the negative and glass plate held in contact. The fly in the ointment here is that the plates must be printed through the base of the aerial film in order to avoid having a reversed image in the stereoplotting instrument. The thickness of the base of aerial film is approximately 0.006 inch. Other types of film base may vary from 0.003–0.008 inch.

It is well known from experience with diffused light that unless contact printing is performed emulsion to emulsion, a great loss in resolution occurs. To study the effects of contact printing through the film base a system was set up, as shown in Figure 1. This simple set-up provided means for varying the size of light source and its distance from the target, and for varying the thickness of the film base, or in other words the separation between the target and plate emulsion.

In this simple set-up, it will be seen by the figure that four major items are involved: 1) A light source of a certain size placed a certain distance from 2) a negative, in this case a master resolution target, 3) a photographic emulsion and 4) a chemical processing procedure. It will be noted that no lenses are involved in this printing procedure.

The light source used in these experiments was an ordinary incandescent tungsten filament lamp situated behind an iris diaphram covered with ground glass. The ground glass thus became the actual source of illumination. The iris diaphram gave

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provision for varying the size of the point of light.

The resolution target used in the experiments was a standard Air Force high contrast line target as shown in Figure 2. The target consists of a series of patterns decreasing in size as the sixth root of two, with a range from one quarter to two hundred and twenty eight lines per millimeter. Each target element consists of two identical patterns at right angles to each other. Each pattern consists of three lines separated by spaces of equal width. Each line is approximately 5 times as long as it is wide. The master target in this case was made up of light lines on a dark background. The difference in density between the light and dark areas was greater than 2.00.

The emulsion used in the experiments was the plate emulsion which is actually used on the stereoplotter diapositives. It is an extremely fine-grain, blue-sensitive antihalation backed plate especially designed for making diapositives from aerial negatives. The speed is about twenty five times that of Kodabromide Paper No. 4.

The developer used in the majority of the tests was a glycin metol solution conceived especially for, and conventionally used in, some agencies for processing plates for stereoplotting equipment.

The resolving power in contact printing may be affected by the following variables:

1. Type of developer
2. Developing time

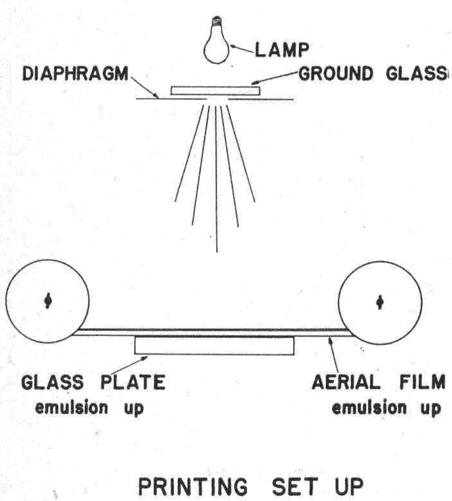

FIG. 1

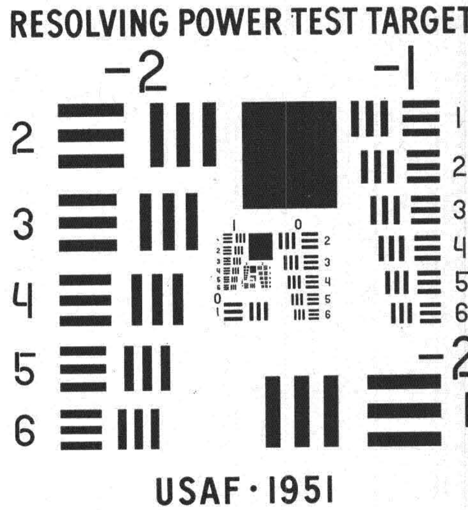

FIG. 2

3. Exposure time
4. Size of point of light used for printing
5. Distance of light from target
6. Separation distance between target and emulsion.

The question of the possibility of improving the resolving power by using different developing agents in a question that has been argued back and forth since the early 1900's. Dr. Mees[1] has stated that some fine-grain developers will improve the resolving power of some emulsions, but that this is not a universal characteristic of such developers. Several different developers were used in these experiments in an effort to determine the effects upon resolving power. These were: Hydroquinone with Sodium Hydroxide, Elon-Hydroquinone with Sodium Carbonate, Elon-Glycin with Borax. Of these developers no one was shown to give particularly better resolving power. As a result of this information the glycin-metol developer formerly mentioned was used in the remainder of the tests performed.

The next experiments were made to determine the effects of the developing time upon the resolving power. The results obtained are shown in Figure 3. The plates were printed and processed under identical conditions using the simple point light

[1] Mees, C. E. Kenneth, *The Theory of the Photographic Process*, New York: Macmillan, 1942.

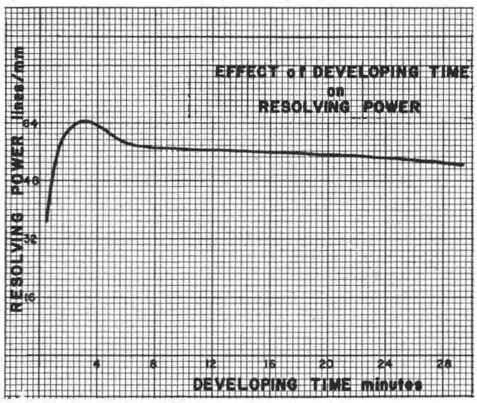

FIG. 3

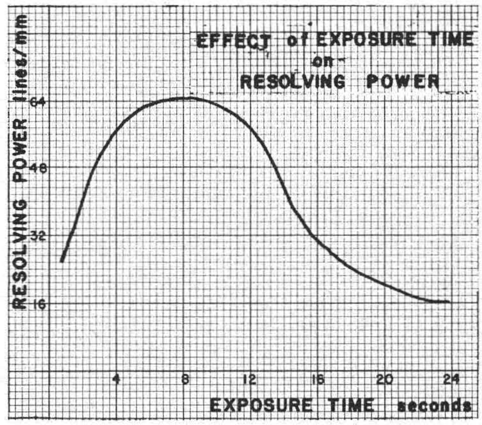

FIG. 4

source set up described. This curve substantiates the description given by Mees, who has stated that as the development time progresses, the resolving power rises rapidly to a maximum, drops somewhat and then remains approximately constant.

Figure 4 shows the effect of exposure time variation on the resolving power. It is obvious from the curve that underexposure as well as overexposure is detrimental to the resolution. The densities obtained in the test targets however were such that the average photographer should be able to maintain the exposure in the optimum region by visual examination alone.

It was immediately obvious that the physical size or diameter of the light source and the distance of the light from the target were interrelated. The two were therefore combined to give a ratio—the size-distance ratio of the light source. Figure 5 shows the results of tests made to obtain correlation between the resolving power and the size to distance ratio of the light source. These tests were run by varying the size of the light source as controlled by the iris diaphragm while maintaining a fixed distance, and also by varying the distance while maintaining a fixed light size. The curve was compiled with a separation distance between target and emulsion of 0.006 inch, corresponding to standard aerial roll film. Glycin developer was used and the optimum exposure and developing time were taken from the curves in Figures 3 and 4. The curve shows quite clearly the importance of maintaining a small size-distance ratio. A small ratio is not difficult to attain however. For example, a bare 15 watt incandescent, inside frosted lamp placed fifty inches away from the target gives a size-distance ratio of

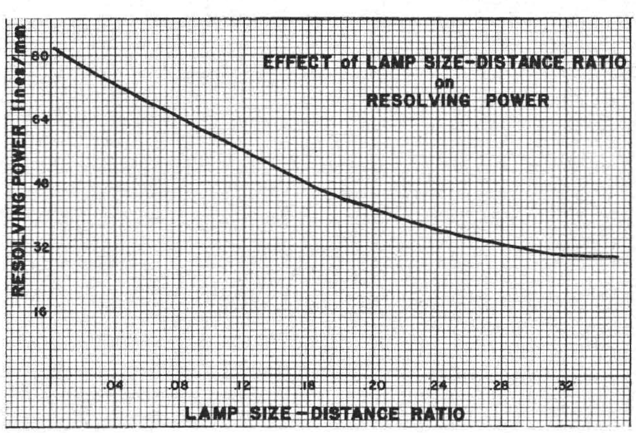

FIG. 5

about 0.02 since the diameter of the lighted portion of a 15 watt lamp is one inch. The curve shows that with a size distance ratio of 0.02 it should be possible to attain a resolving power greater than 72 lines per mm. This has been attained in practice.

Despite the most careful precautions and even though the developer, the developing time, the exposure, and the lamp size to distance ratio were all selected with great care, there remained a limit upon the resolving power which could be obtained when the target and the emulsion were separated by a finite distance, as in the case where printing must be accomplished through the 0.006 inch thick base of aerial roll film.

The destruction of resolution with separation of target and emulsion as happens in printing through the film base is evidently due to diffraction effects from the edges of the target lines. These diffraction effects are shown in Figure 6. As the target lines become closer together the diffraction lines form between the actual target lines.

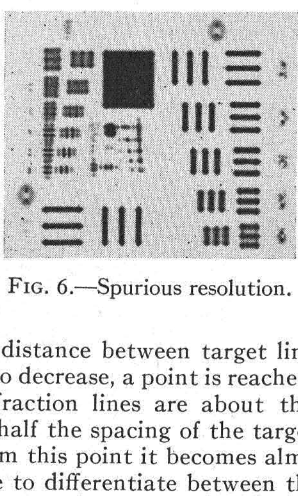

FIG. 6.—Spurious resolution.

As the distance between target lines continues to decrease, a point is reached where the diffraction lines are about the same size as half the spacing of the target lines, and from this point it becomes almost impossible to differentiate between the resolution lines and the diffraction lines. This is the practical limit of resolution of detail; further decrease in target line spacings results in successive interference and augmentation effects giving so-called spurious resolution.

A simple diffraction formula for a double slit can be used to predict the approximate practical limit of resolution for any particular separation between target and emulsion. Using the simple formula $x=\lambda L/Sn$ was worked out for a film separation of 0.006 inch or 0.15 mm. X is the distance between two dark fringes in the diffraction pattern, Lambda is the wavelength of light, L is the separation between target and emulsion, s is the slit spacing—in this case the resolution in the target—and n is index of refraction of the separation medium.

Assume

(1) $$s = 2x$$

(2) $$\lambda = 0.000530 \text{ mm.}$$

then

$$x = \frac{\lambda L}{sn} = \frac{\lambda L}{2\,xn}$$

$$x^2 = \frac{\lambda L}{2n} = \frac{0.000530 \times 0.15}{2 \times 1.5} = 0.0000265$$

$$x = 0.00515$$

$$s = 2x = 0.0103 \text{ mm.} = 97 \text{ lines/mm.}$$

In order to simplify the calculation two assumptions were made: 1) The approximate practical limit of resolution is that point at which the diffraction lines are spaced at half the spacing of the target lines; 2) Monochromatic light of 530 millimicrons was used. Actually the light of the ordinary tungsten filament lamp was used in printing, but the 530 figure was used in the mathematical calculation.

The target pattern beyond which the resolution pattern is not resolved, for a film separation of 0.006 inch is computed by the formula to be 97 lines per mm. while the experimental results yielded a resolution of 80 lines per mm. Figure 7 shows two curves, the lower curve being the experimental results and the upper curve being the computed results based on the simple double slit formula. The difference between the two curves can be accounted for in terms of the two assumptions made to facilitate the mathematical calculation. The curves apply whether contact printing through the film base or printing with an air separation between target and emulsion. The abscissa is plotted for both air and film separation and you can see that the two are related as the index of refraction of the film base which is about 1.5.

The data just presented show that the resolving power in contact printing through the film base is limited by the separation of the negative and plate emulsions, and is affected by such factors as

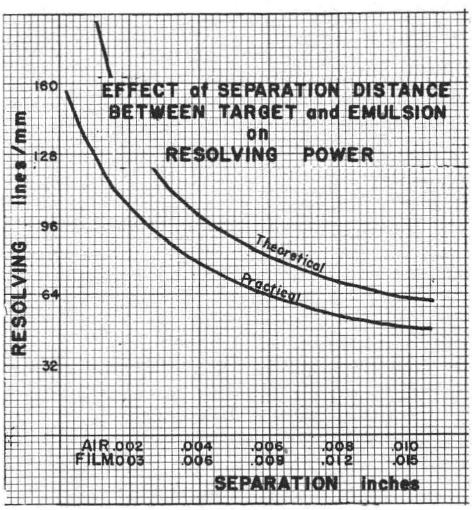

FIG. 7

size and distance of the light source, the exposure time and developing time. A change in developing agent gave no significant changes in resolving power. The data show that the simple-point light source printing set-up described will give excellent results compared to the estimated resolving power which might be possible with a 1:1 to magnification projection printer.

For the preparation of stereoplotter diapositives by contact printing through a 0.006 inch film base the following data were obtained:

Maximum possible resolution	80 lines/mm.
Optimum developing time with glycin developer	3–4 minutes
Desirable size-distance ratio of light source	0.02 or less

MINIATURE AERIAL PHOTOGRAPHY

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MINIATURE aerial photography can be a project-activity for students of elementary photogrammetry, or for anyone who is interested in taking a closer look at the manipulations of basic photogrammetric principles. Such miniature photography may promote better understanding through the use of exaggerated relief models which emphasize displacement and permit reasonable accuracy of measurement with ordinary engineers' scales, yard sticks, or metallic tapes. Of course, an error in measurement will become magnified approximately in the ratio of photo size to model size, but not to the extent encountered in true aerial photography where an error of 0.01 inch may represent scores or hundreds of feet on the ground.

In the example shown in the illustration, the materials and objects employed consisted of a 3′ 6″ by 2′ 7″ scale model of a community center. A 36 inch mailing tube served as a chimney or tower of exaggerated height, and a box kodak elevated 168 inches on a fire escape was used to take overlapping pictures above each of the two lower corners of the model. The vertical members of the fire escape were intentionally included to provide data for locating the nadir point beneath the lens, regardless of the tilt of the hand-held camera.

The resulting photographs, oriented along the flight line through the nadir points, illustrate an exaggerated effect of relief as a component of image displacement. In true photogrammetry, relief is generally provided by gently rolling ground and the base of a hill cannot be seen. Nevertheless, a hill top, unless directly beneath the camera, is displaced relative to its correct map position. The direction of relief displacement is radial with respect to the nadir point regardless of intentional or accidental tilt of the camera; this is a fundamental concept of photogrammetry and as such it is clearly illustrated by the convergence of the vertical member of the fire escape toward a common nadir point in each of the photographs.

PHOTO ENLARGEMENT NECESSARY

The scale of an approximately vertical photograph at a designated datum level depends upon the relative height values of similar triangles in which "*f*" (camera focal length) and "*H*" (camera height) are the controlling factors. Hence, the scale of a contact print is proportional to the focal