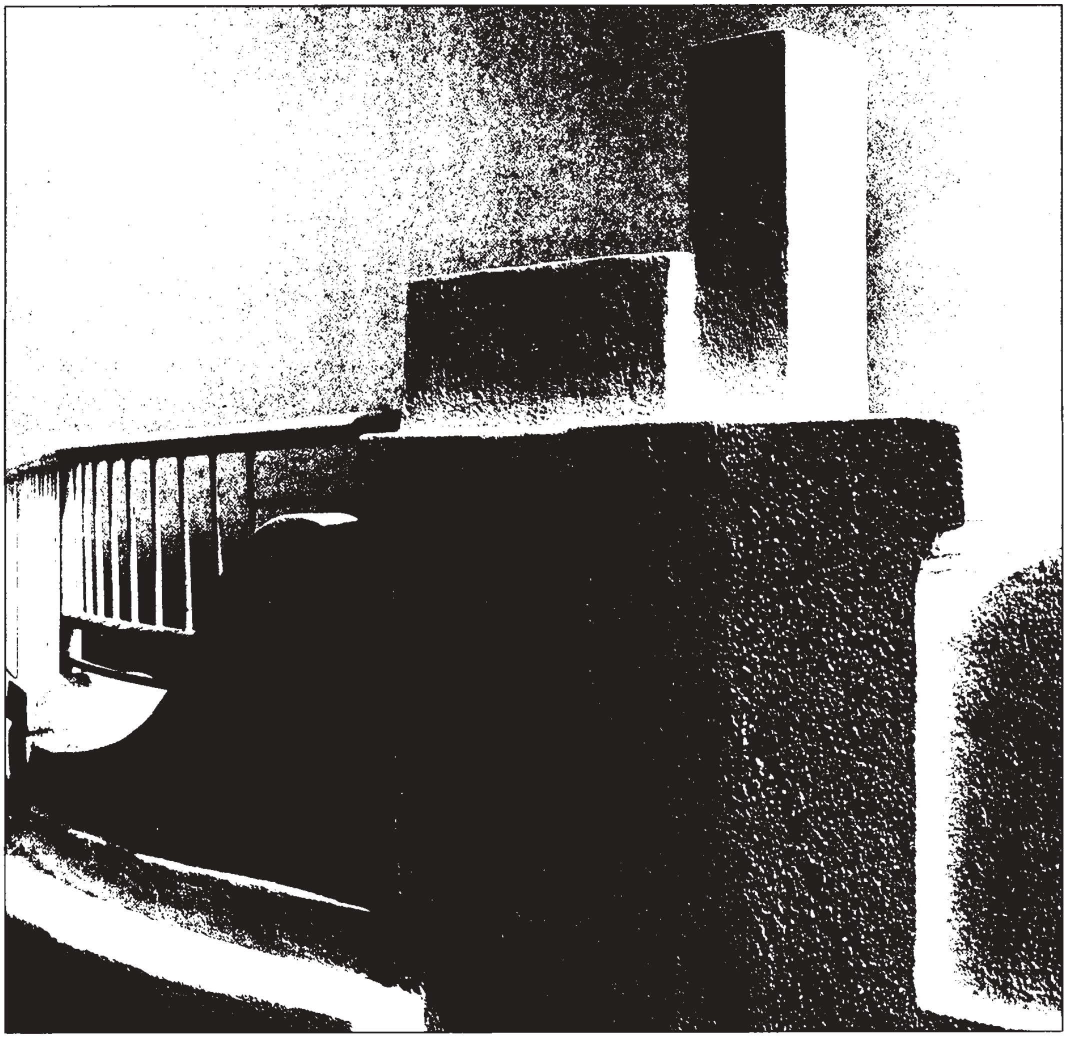

GRAND HOTEL, ST. JEAN CAP FERRAT, 1983, *was made using a Hasselblad camera, 80mm lens, and Tri-X Pan film.*

Understanding Resolution

Part I: Lens, Film, and Paper

By Ronald W. Harris

Last fall, on my annual Southeastern Utah photography trip, one of my buddies and I got into another campfire discussion. He asked me what film I was using, and I replied Tri-X and Agfa 100. I told him about the subtle tonalities one could get using Tri-X, and if I needed to increase contrast by overdevelopment, I liked Agfa 100, especially for medium-format work. "What about resolution and grain?" he asked. I reminded him of all the beautiful prints made using these films by such photographers as Ansel Adams, John Sexton (see his book *Quiet Light),* and Bruce Barnbaum (see his book of Tri-X photographs, *Visual Symphony*). Their prints seemed sharp enough to me, and I didn't find a little grain distracting. In fact, some prints seemed enhanced by the grain. And all of their photographs exhibit beautiful tonalities.

My friend, who works with the 8×10 format, proceeded to show me some 16×20 prints made using T-Max 100 and Technical Pan film. Their quality was stunning: extremely sharp, essentially no grain, and excellent tonal range. This got me interested. As soon as I got back home I started investigating the points he had made.

Test Procedures

The first thing I did was obtain a set of RIT alphanumeric resolution test objects from the Graphic Arts Research Center of Rochester Institute of Technology in Rochester, New York. These 8x8-inch resolution charts are available in three contrasts—high, medium, and low. My Macbeth 964 densitometer gives their contrast as approximately 20:1, 5:1. and 2:1, respectively. A transparent micrometer scale is provided to determine the degree of reduction of the test-target image on the negative. A look-up table gives the lines/mm of the various test-target elements recorded on the film.

I set about photographing these charts with different lenses, formats, and films. One must test for proper focus in order to eliminate focus errors. Simply examining the image on the groundglass or focusing screen with a loupe is not sufficient. This is only a starting point. I attached a scale with closely spaced lines near the focusing index mark on the camera. Exposures were made with small shifts in focus, both plus-and-minus, until best-focus was obtained. (I found my old Zone VI [Wista] camera with a Schneider 210mm Symmar "S" to have a small, but non-negligible focus shift; my acute-matte focusing screen equipped Hasselblad had none.) I used Kodak Technical Pan film, which the manufacturer states is capable of resolving 320 lines/mm at high-contrast (1000:1) and 100 lines/mm at low-contrast (1.6:1). My experience shows that their low-contrast figure is the more practical one for general photography.

The initial results are shown in Table I. Under "Resolution" the first three numbers in each line represent high, medium, and low-contrast target images near the center of the film, and the last number represents a high-contrast target image at a corner of the film. Obviously, the film was capable of recording all of the resolving capability of the lenses tested. It may surprise you that the 4x5 lens has the lowest resolution, but remember that a 4x5 negative does not require as much magnification as smaller formats. Also, 4x5 lenses require a wide field of coverage, to accommodate image shifts and tilts. Wide field design usually compromises overall performance.

In all three cases, the aperture listed was the one found to maximize the resolution of the high-contrast image at the center of the film. By stopping down one or two additional stops, the resolution at the center of the film decreases, but the resolution at the corner of the film may increase. For example, at f/16 the Hasselblad resolves 57,57,45;45 lines/mm.

I then printed these Technical Pan images onto Oriental Seagull glossy paper, using a 4x5 Beseler enlarger with a Beseler-Minolta 45A light source. I used EL-Nikkor enlarging lenses, stopped down to give maximum resolution on the print, usually one or two stops from wide open. Using a grain magnifier, I was able to determine that my enlarging lenses were capable of resolving all the lines present on the film. However, the printing paper was not capable of recording more than *13 lines/mm.*

I also visually studied the RIT resolution charts. Using prescription reading glasses, I was not able to resolve more than 4 lines/mm, at the closest possible viewing distance. So, I concluded that when making prints, 4 lines/mm in the image is adequate for viewing with the normal unaided eye. Whereas, 13 lines/mm is required for critical viewing with a loupe.

Using these print resolution limits and working backwards, I was able to determine how much camera lens resolution is required to produce the required print resolution. The results are shown in Table II.

By combining the results from Tables I and II, I then determined the maximum print size that can be made using the three formats (and respective lenses) having optimum resolution for the eye and loupe. The results are in Table III.

Remember that different lenses will perform differently; some better and some worse. For example the Hasselblad 100mm Planar lens is the sharpest corner-to-corner lens in the Hasselblad line and will permit slightly larger maximum resolution prints to be made. Schneider also has a line of higher-performance lenses. And a high resolution film, such as Technical Pan, must be used in order to match or exceed the resolving capablity of the lens.

Even though the resolution of the print image may be high, excessive grain may detract (or enhance) the image. By making prints using Technical Pan film, which has the very low granularity of "5" (by comparison T-Max 100 has a granularity of "8"), and examining these prints closely, particularly in even-tone sky areas, I was able to subjectively determine that the image appeared grainy if the magnification exceeded approximately 2.75. The resulting print sizes, shown in Table IV, are equal to or smaller than those required for maximum corner-to-corner print resolution, as examined by a loupe.

Next, I turned to investigating the use

Table I. Maximum Resolution Obtained with Different Format Lenses

Lens Format	*Resolution*
35mm (Olympus, 50mm f/2.8 at f/8)	68,61,43; 57 lines/mm
6x6cm (Hasselblad, 80mm Planar T* f/2.8 at f/8)	72,72,45; 34 lines/mm
4x5 inch (Schneider 210mm Symmar "S" at f/22)	44,42,34; 37 lines/mm

* The first three numbers in each line represent high, medium, and low-contrast target images near the center of the film. The last number represents a high-contrast target image at a corner of the film.

Table II. Lens Resolution Required to Obtain Maximum Print Image Resolution (in lines/mm).

	Paper Size (negatives printed full-frame)							
	5 x 7		8 x 10		11 x 14		16 x 20	
Format	*Eye*	*Loupe*	*Eye*	*Loupe*	*Eye*	*Loupe*	*Eye*	*Loupe*
35mm	20	66	29	94	40	132	58	188
6x6cm	8	27	14	44	19	61	27	88
4x5 inch	6	18	8	26	11	36	16	52

Table III. Maximum Print Size for Max. Corner-to-Corner Resolution.

Format	*Eye*	*Loupe*
35mm (Olympus 50mm f/2.8 at f/8)	16 x 20	4½ x 6
6x6cm (Hasselblad, 80mm Planar T* f/2.8 at f/16)	27 x 27	8 x 8
4x5 inch (Schneider 210, Symmar "S" at f/22)	37 x 46	11 x 14

Using prescription reading glasses, I was not able to resolve more than 4 lines/mm at the closest possible viewing distance. So, I concluded that when making prints, 4 lines/mm in the image is adequate for viewing with the normal unaided eye.

of the different black-and-white films that I have used over the years. To achieve as much consistency as possible, I set up the Hasselblad with the 80mm Planar T* lens and exposed test images using one roll of each type of film. Neither the camera focus, nor its position, nor the lighting was changed during the tests. In Table V I have compared the resolution results with the theoretically possible resolution, according to optics. Optical scientists have found that the image of a bright point of light is not a point, but a bright central blob surrounded by a series of faint fuzzy rings, which get progressively dimmer away from the center. (This image is called an Airy pattern.) The radius of this first bright blob is given by the Airy formula (see Photograms Jan/Feb 1991). If two closely spaced bright point-sources are imaged, the two bright blobs will overlap in the image. Rayleigh found that if the centers of these two blobs were separated by a distance equal to the radius of either blob (they are identical), they will barely be resolved as two separate blobs. Any closer, and they fuse together. Now if the point-sources were stretched out to make parallel lines, the two separate lines in the image would just barely be seen as separate. So that if one takes the reciprocal of this minimum distance one gets the maximum number of such line spaces that can be resolved in a millimeter. The resulting formula is:

$$\text{Resolution} = \frac{1}{1.22 \times W \times (\text{f/stop})_{\text{eff}}}$$

where W is the wavelength and the effective f/stop is given by the formula:

$$(\text{f/stop})_{\text{eff}} = \left[\frac{\text{image distance}}{\text{focal length}}\right] \times (\text{marked f/stop})$$

For distant objects the image distance approximately equals the focal length of the lens so that the effective f/stop on the f/stop marked on the lens become nearly equal.

In making this computation one usually chooses a wavelength, W, in the green part of the spectrum, since green is the middle. The wavelength of visible light ranges approximately from 0.000700mm (red) to 0.000400mm (violet), an average of which is 0.000550mm (green). It is common to use the specific value of 0.00546mm, since this is the wavelength of a particular green color that appears in the spectrum of a mercury-vapor lamp. Thereby, the theory may be easily tested in the laboratory. Yes, it's valid! So if test targets are set up a number of focal lengths in front of the lens, the resolution formula reduces to:

$$\text{Resolution} = \frac{1500}{\text{f/stop}}$$

My lens test results, described previously, and the theoretical maximum resolutions are shown in Table V. Not shown in the table are the theoretical maximum resolutions for f/32, f/45, f/64, and f/90. These values are 47, 33, 23, and 17 lines/mm, respectively. At these f/stops the depth-of-field is increased, but at the expense of the image resolution. Maximum resolution print sizes will be further reduced.

Table V shows several things of interest, including the following:

1. T-Max 100 performs almost as well as Technical Pan. The other films in the list clearly cannot take advantage of the resolution of the lens.
2. Center image resolution peaks at f/8, whereas corner image resolution peaks at f/16.
3. Only at large f/stop numbers does the actual resolution begin to approach the theoretical resolution. This is because lens aberration effects are diminished and diffraction effects increase as the lens is stopped down.
4. Resolution of high-contrast target images is superior to low-contrast images in every case.

As you can see, Tri-X is the worst performer on the list. Kodak data indicates that Tri-X has a high-contrast (1000:1) resolution of 100 lines/mm and a low-

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Table IV. Maximum Tech Pan Print Size for a Low Grain Image.

Format	*Maximum Print Size*
35mm	3 x 4 inches
6x6cm	7 x 7 inches
4x5 inch	11 x 14 inches

Prints this size also meet the requirements for maximum print resolution. See Table III.

Table V. Resolution (lines/mm) Tests Using a 6 x 6 cm Hasselblad 80mm Planar T* Lens.

f/stop	*Technical Pan (L Technidol)*	*T-Max 100 (D76)*	*Agfa 100 (Rodinal)*	*T-Max 400 (D76)*	*Tri-X (HC110)*	*Theoretical Maximum Resolution*
2.8	45,36,32;18	36,22,18;17	26,23,15;16	25,20,16;16	30,28,18;14	536
4.0	57,54,40;19	45,30,23;16	36,32,20;17	36,27,18;18	30,21,18;14	375
5.6	64,64,47;19	72,52,36;18	51,40,30;20	54,40,27;18	38,32,21;17	268
8.0	72,72,51;34	76,61,42;23	51,51,32;25	47,38,23;24	38,36,29;21	188
11.0	72,68,47;38	64,54,36;34	49,47,28;30	47,42,26;28	38,32,20;28	136
16.0	57,57,45;45	54,54,32;45	45,40,26;36	45,38,22;36	34,34,19;29	94
22.0	47,47,36;36	45,40,27;38	40,36,23;34	40,34,20;34	29,25,17;30	68

NOTE: As you move from left to right, grain increases.

Table VI. Maximum Tri-X Print Size for Maximum Resolution.

Format	*Eye*	*Loupe*
35mm (Olympus 50mm, f/2.8 at f/8 (corner 38 lines/mm)	11 x 14	3 x 4
6 x 6cm (Hasselblad 80mm Planar T* f/2.8 at f/16 (corner 29 lines/mm)	16 x 16	5 x 5
4 x 5 inch (Schneider 210, Symmar "S" at f/22 (corner 37 lines/mm)	37 x 46	11 x 14

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contrast (1.6:1) resolution of 32 lines/mm. Notice that our data shows that we were only able to record a maximum of 38 lines/mm, which is very close to Kodak's low-contrast value. It is also the grainiest film on the list. Now we all know that Tri-X has other virtues, such as a superior tonal rendition and brilliant, well-separated highlights. It is, therefore, interesting to use the lens resolution data and our measured Tri-X resolution data to determine the largest prints that can be made for the maximum eye resolution (4 lines/mm) and for a loupe (13 lines/mm paper resolution limit). The results are shown in Table VI on page 28.

Since the print sizes listed in the "loupe" column represent magnifications of 3× or less, the grain in the print will usually not be objectionable. Most of the fine prints I have seen made by 4×5 photographers who use Tri-X usually are 11×14 or smaller. Many small format users select other films, because of the small print sizes required by Tri-X.

Conclusion

My results indicate that you must use high-resolution films like Technical Pan r T-Max 100 to be able to take full advantage of the rsolving power of modern camera lenses, and that high resolution is required for the smaller formats. The normal unaided eye cannot resolve much more than 4 lines/mm on a print (at any viewing distance) and since the paper (Oriental Seagull Glossy) can only resolve 13 lines/mm, you can only resolve a maximum of 13 lines/mm using a magnifying loupe.

At optimum aperture the high-quality lenses I tested were able to resolve the following (at the center of the film): 35mm, 68 lines/mm; 6×6cm, 72 lines/mm; and 4×5 inch, 44 lines/mm. At the image corners the resolution drops off. In fact, how well the lens performs at the corners is an indication of the quality of the lens.

In making prints using the lenses I tested, I found that to make prints which exhibit a maximum of 13 lines/mm over the entire print, print sizes must be less than or equal to the following: 35mm, 4½×6 inches; 6×6cm, 8×8 inches; 4×5 inch, 11×14 inches. Prints this size represent small magnifications and will not exhibit much grain. In fact, images made using Technical Pan or T-Max 100 produce prints with nearly continuous tone backgrounds. Prints three times this size may be made if the prints are to be made at the limit of visual resolution (4 lines/mm), but more grain will be evident.

After viewing many prints made by myself and others using T-Max 100, I concluded that it is capable of the same sensitive tonal rendition and high-quality images as Tri-X. Most of these prints were made at the maximum print resolution size or less. Moreover, T-Max 100 also comes very close to being able to handle all of the resolving capabilities of modern lenses, and it has a finer grain. (Of course, it is also a slower film.)

If you want the ultimate in resolution and fine grain, then Technical Pan is the answer. This film may be easily developed to increase image contrast, and it too is capable of producing beautiful tonal qualities. However, this film has a slightly different spectral range, it has a slow film speed, and it is difficult to develop uniformly. For some people, it takes a great amount of work to master Technical Pan.

As a result of these tests, I have changed my choice of films. I now use T-Max 100 most of the time, switching to Technical Pan whenever I want the very highest resolution and lowest grain, or whenever I want to increase the contrast of the image. □

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