1959

Photographic graininess reduction by super-imposi

BOSTON UNIVERSITY

GRADUATE SCHOOL

Thesis

PHOTOGRAPHIC GRAININESS REDUCTION BY SUPERIMPOSITION

by

Major BERNARD W. QUINN

United States Air Force

(B.S., St. Louis University, 1950)

Submitted in partial fulfillment of the

requirements for the degree of

Master of Arts

1959

ACKNOWLEDGEMENTS

An effort of this magnitude is rarely the product of a single personality. This thesis is no exception. Without the technical knowledge and cooperation of the personnel of ITEK Laboratories, this work would not have been completed. This is a tribute to their generosity.

Approved

by

First Reader...

F. Dow Smith
Research Professor of Physics

Second Reader...

W. R. J. Brown
Research Associate

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I. INTRODUCTION

Modern aerial camera lenses often possess far greater resolving power than the ability of the aerial emulsions to faithfully record them. When a photointerpreter examines a photograph, he looks at the images and tries to see the actual objects themselves. This requires "looking" past the obscuring filters present in various parts of the aerial reconnaissance system. One of these obscuring filters is the photoreceptor itself, the emulsion. Many of its characteristics have a tendency to bury the message that has reached it. Some of these are spectral sensitivity, turbidity, acutance, contrast response, graininess, etc.

This thesis presents the results of attempts to reduce the disturbing factor of graininess and increase resolution by printing multiple exposures. In principle, given a sufficient number of samples of the same part of a message that is buried amid random noise, it is possible to separate the systematic from the random patterns. The systematic pattern has a much higher probability of occurring than any random pattern in a given set of samples. The problem resolves itself into one of finding a suitable method of performing the separation.

The solution adopted was one of successive printings using partitioned exposures. A resolution target panel was photographed in seventeen identical negative frames. These frames were printed successively on one transparency. The normal exposure time was partitioned into as many parts as there were negatives to be superimposed.

Four different aerial emulsions were investigated to obtain a correlation factor. It was expected that the reduction in graininess would be a function of emulsion thickness.

II. PREVIOUS WORK

There have been previous efforts to reduce the graininess in a photographic print. Two reasons motivated the attempts:

1. An esthetically pleasing grainless picture was desired.
2. The possibility of raising information buried in the obscuring pattern of graininess to a recognizable level.

K. C. D. Hickman,[3] in 1926, had made some suggestions for techniques to reduce graininess. One of these was the superimposition printing of more than one negative.

Blair and Stanton,[2] in 1939, described the use of 35-mm negatives to make practically grainless photomurals. Registration of the successive negatives was achieved by placing pinpricks in the easel corresponding to definite details. They mentioned the use of the same method in observatories to reduce the grain in astronomical photos. It is believed that the Lowell Observatory in Arizona, in 1927, used the superimposition of four negatives to print the image of the planet Mars.

G. W. W. Stevens,[5] of the Kodak Research Laboratories in England, published, in 1947, the most advanced efforts, as far as is known.

Stevens tried several methods to reduce graininess without sacrificing resolution in the print. He tried printing the grain slightly out of focus but found that an out-of-focus position also reduced resolution. He examined the effect of printing with parallel light, diffuse light (negative in contact with an opal), and oblique light (used a rotating printing frame inclined at an angle to the light). He also tried using all three sources, but with the negative separated from the printing material by a cellophane film 25 μ thick. These were all unsuccessful.

He tried, as Asloglou[1] had in 1941, to break up the grain aggregates by chemical means but found, in each case, a blurring of the image and a resolution loss. Stevens was successful, however, in printing by superimposing a number of negatives.

His solution of the critical registration problem was to attach registration marks to his resolution target. These marks consisted of clear circles on a dark background, attached one above and one below one of the groups of resolution test objects on an illuminated transparency.

Low contrast bicolumnar target charts were photographed. These were exposed through a 20 inch Aviar lens at f/8 on Kodak Aero Super XX film. The film was developed for ten minutes at 70° F. in Kodak D-19b developer.

The negatives were enlarged 50x's on glass plates, using a Watson "Van Heurck" microscope, fitted with a 2 inch Watson "Holoscopic" objective. The printing easel was equipped with three pins so that any of his positive plates could be removed and then replaced in the same position.

Registration marks were established on the easel by projecting the first negative and placing ink marks in the centers of the images of the registration circles. The positive plate was replaced on its three pins and the partitioned exposure made. The plate was removed and covered. The second negative was brought into registration with the ink dots on the easel in the centers of the circle images. The plate was replaced on its pins and the second exposure made. The process was repeated for each negative used.

He tried eight printings from the same negative. This resulted in a zigzag pattern in the graininess, but no effective increase in resolution or any appreciable decrease in graininess.

His multiple printings from separate negatives did result in decreased graininess and increased resolution. (See Table 1.) His resolution test chart consisted of groups of mutually perpendicular pairs of lines. Evidently his criterion of resolving a group consisted of the detection of the space between the two lines of any group in both orientations.

He also tried to solve the registration problem by using motion picture film. The perforations were to be used as index marks. This was a test of Hickman's original suggestion. He exposed a length of 35-mm film in a professional motion picture camera, using a feminine model, sitting reasonably still.

Two methods of multiple printing were tried:

1. Contact printing: A printing frame was fitted with a number of pilot pins to locate both the negative and positive film. The negatives were advanced and printed frame by frame, holding the positive still. He obtained decreased graininess using four negatives without serious loss of resolution. Due to processing shrinkage, the pitch of the perforations varied enough to cause registration errors.

2. Projection printing: He used a Kodak precision enlarger, fitted with a two inch objective and condenser. By using a 2-1/2 inch wide negative carrier, the projected image showed the perforations as well as the exposed area of the negative. The enlarger was adjusted to give 15x enlargements. Using an easel with three pins as before, he sketched out, with a pencil, the perforations on the easel. When each negative was projected, its perforations were matched with the sketch on the easels.

Thus, both the easel and the negative could be moved to achieve registration.

The results were qualitatively the same as he had achieved in the resolution target test.

III. BACKGROUND FOR PRESENT WORK

It is well known among photointerpreters that it is easier and usually more informative to study two photos of an area rather than one. This is commonly known to be true for stereo pairs, but not generally known that two prints from the same negative carry more information than one print. Continued study of stereo pairs adds to the conviction that parts of an image are contained in one print and not in the other, and vice versa.

A military photointerpreter usually must search for the most vital clues at the limits of the photoreceptor's ability to record them. For example; antiaircraft batteries are readily detected and identified by the pattern of the gun emplacements at a scale of 1/10,000. As often as not, equally important essential elements of information can not be obtained. Is it occupied now? Is it radar controlled? Is it a dummy installation? Usually, no increase in viewing magnification provides any more information. Beyond the 4x magnifications, images degenerate into shapeless granularity patterns.

A great deal of time, effort, and money have gone into refining the tools of reconnaissance to provide the missing details for the photointerpreter's use. For example, photo emulsions have been produced with capabilities to record fine detail in low contrast regions of many orders of magnitude over World War II emulsions.

If it is accepted that two conjugate photographs, when viewed simultaneously, contain more detail than one print, why not view three or more? The added dimension of depth afforded by stereoscopy is not considered in this analysis to simplify the treatment. However, its use, when possible, can be considered as an additional aid for edge discrimination.

We are limited physically to the simultaneous viewing of two photographs. Motion pictures and the television screen use the persistence of vision to superimpose many pictures. Flicker devices can be built to superimpose three photos for comparison. These three methods require great care in registration of each frame if intelligibility is to be preserved, much less a gain in information over a single frame.

This investigative approach was rejected for many practical reasons. However, preliminary study yielded a novel type of stereoscopic moving picture viewing amenable for investigation. This has been outlined in the appendix.

IV PRESENT APPROACHES

The very important details of how Dr. Stevens accomplished his results were not available during this work. The abstract which outlined his work did not list the details of his technique. This forced an attack on the critical problem of preserving registration with a minimum of information on the subject. As it developed, this was a decided advantage. It forced original thinking.

Four emulsions were selected for study. It was believed that the emulsion thickness would have a large effect on the products of the printing technique. As it happened, there were four aerial films in the perforated 35-mm size desired. These films are:

1. Kodak Tri X Aercon (RP), SO-1205.
2. Kodak Super XX, Aerial Recon, (RP).
3. Kodak Plus X, Aerocon, SO-1166.
4. Kodak SO-1213.

The last film is an experimental emulsion. It is generally described as a red sensitive Microfile emulsion.

A Contax IIA camera, with a 50-mm F/2 Sonnar lens, was used to take the 35-mm negatives. In the early stage of the investigation, the film transport mechanism jammed. The repairman reported that the focal plane shutter had not been opening at the two highest shutter speeds of 1/500 and 1/1250 second. The camera was used throughout the work without the shutter being calibrated.

Low contrast resolution targets were selected as being more representative of aerial reconnaissance conditions. Their density differences ranged from 1.0 to 0.08. They were designed to be hung on a six foot square resolution target panel and illuminated with fluorescent tubes. After serving for preliminary work, this setup was abandoned in favor of one which greatly simplified the work. This panel is described in Section V and appears as Figure 7.

The critical problem of the registration of the successive negatives in the superimposition technique went through many solutions. Contact printing was rejected. The differential shrinkage expected between frames after processing, and the small image size resulting from the use of a 35-mm negative, were the principle causes for rejection. Projection printing eliminated these two objections. It also lent itself to a solution of the registration problem. If any results of significance were to be obtained, the successive negative frames had to be registered as exactly as possible.

In the final months of investigation, a small printing jig was constructed (Figure 1). When loaded with film, the jig is clamped to a toolmaker's traveling microscope carriage. This permits micrometric adjustments to be made in the X and Y directions but no angular adjustments. This was tried in conjunction with an Omega Type D II enlarger on its own stand. A ten power microscope was used to check the focus. But the unsteadiness of the enlarger head, the coarse control for focusing, and the difficulty of seeing the projected images with the microscope did not promise very reliable results for the required registration accuracy.

A working answer appeared in the slight modification of a Carl Zeiss Ultraphot II microscope (Figure 2). An indexing negative substage was constructed (Figure 2). This holds an indexing negative just below the level of the viewing stage. Using the lowest power of the Ultraphot, each negative can be brought into registration with the markings of the indexing negative. The instrument uses a beam splitter to permit taking photographs of the field of the microscope. The viewing stage has two coordinate micrometric adjustment capability, as well as a capability of rotation. The microscope's light source is a 12 volt, 100 watt lamp. Illumination of the negatives was in accordance with Köhler's principle.

It was decided to print transparencies due to the longer tone scale. Also, transparencies could be projection printed for thesis production. Kodak Kodagraph Fine Grain Print film appeared suitable. It was selected due to its fine grain, its slow speed, and its availability in a convenient 70-mm size. Processing details are listed in Table 2.

Time, expense, and availability of equipment severely restricted approaches to all the problems that arose in the course of the investigation. These restrictions were particularly felt in solutions to the registration problem. The solution adopted involved the positioning of individual edges. This is not as good as positioning the entire field as is done in stereoscopy. This suggests the use of a comparison microscope or stereo microscope. Neither of these were available. The negatives could have been exposed using a high quality motion picture camera. During printing the negatives would be re-run through the film transport to obtain a mechanical registration.

V. RESOLUTION TARGET PANEL

The panel is shown in Figure 7. The transparencies are illuminated by 21 horizontal fluorescent lamps of the standard warm white type behind an opal glass screen. This provides an even brightness level over the screen of 8.9 footlamberts. Although no variac was used for control of the line voltage, no variation of brightness was ever noted. This could be attributed to the fact that the panel was used after 4:30 in the evening when there was little load variation to be expected.

Both of the aerial transparencies used in the panel were processed to a gamma of about 1.0. However, they were printed so that the upper transparency contains densities up to 0.20 and the lower has densities up to 0.40.

There are four series of ten isolated square versus circle pairs with a variation in object size from one inch to 0.008 inch in steps of approximately $\sqrt{2}$. Each series matches the ΔD of the resolution test charts below them. These pairs were not used except as indexing marks.

The four low contrast resolution test charts were the Buckbee Meers target type ranging in ΔD as; 0.07, 0.14, 0.26, and 0.53. The high contrast resolution chart below the aerial transparencies has a maximum density of over 3.0. The minimum density is about 0.1.

VI INTERMITTENCY TEST

The technique of the superimposition print requires that the normal exposure period be partitioned into as many parts as there are negatives to be used. Each negative must contribute equally to the total exposure of the print.

As discussed by Mees[1], the density produced by an exposure given in discrete installments is in general different from that produced by a continuous exposure of the same energy. This intermittency effect is closely connected to the reciprocity law failure. Webb's explanation of the utilization of received light quanta says:

> "During a total exposure time, t, in which the total effective exposure of a single grain (all grains assumed to be identical in size and inherent sensitivity) is y quanta, it would be required that 2,3 or more quanta would have to be absorbed by one grain in a critical time period. Of course, to build the stable (sensitivity) subspeck to developable size would require additional quanta (e.g. 6 to 8) but those quanta received after the stable subspeck is formed would be utilized with 100% efficiency and thus would not contribute to the reciprocity law failure."[2]

Thermal agitation will cause disintegration of the sensitivity subspeck if it has not reached a stable stage and additional light quanta has not been received in the critical time period.

An intermittency test was conducted on the Kodagraph Fine Grain Print film to determine its effect. Sensitometric strips were exposed on a type IB sensitometer. Table 3 shows the exposure conditions for each

1. Mees, C. E. Kenneth. "The Theory of the Photographic Process." Revised Edition. 1954. P. 213.

2. Webb, J. H. "Low Intensity Reciprocity Law Failure in Photographic Exposure." Journal of the Optical Society of America. January 1950. Vol. 40. No. 1. P. 3.

strip. Figure 8 shows the plots of the D Log E curves for the six strips. The same processing conditions were used as outlined in Table 2 except that the temperature of the developer was 70°.

The most obvious effect was the separation of the curves above the "toe". Less obvious is the erratic behavior at the "shoulder". The curves become quite bumpy and cross one another. All values in this region were checked four times when the densitometer readings were being noted.

VII EXPERIMENTAL PROCEDURES

A. Target Panel Exposures

An exposure versus resolution series was run for each of the negative films. The exposure giving the best resolution compromise for the charts on the panel was selected for each film. Each film thus exposed also was exposed in the sensitometer. The plots of D Log E and resolution versus exposure are shown in Figures 3, 4, 5, and 6. The four films were exposed for fifteen frames each, using the optimum exposure, and then a sensitometric strip was placed on the end of each. Between each of the fifteen frames, the shutter was merely cocked and tripped. The camera was screwed to a level table and only moved to change film. Due to the use of shutter speeds, equal to or greater than 1/50th of a second, it was believed that one or more of the fluorescent tubes would not be lighted. The effect was not noticed in any of the negatives.

B. Processing

The processing details are contained in Table 2. These were the recommendations of the photo physics section of Itek Laboratories. Fresh developer and fixer were used for all film to standardize results.

C. Superimposition Printing

The procedure is identical for each emulsion. One frame is removed from the strip. The images of the five resolution charts and the two aerial transparencies are cut out. The frame is mounted on the substage window with rubber cement. The mounting is observed through the Ultraphot, using its lowest power 20x. Due to the magnification, only part of the negative's frame can be printed at a time. This required the indexing negative to be positioned twice.

With the indexing negative mounted on the substage and the substage rigidly clamped to the microscope object stage, the first negative can be brought into registration. The negative is clamped to the viewing stage with a glass slide which is held, in turn, by two flat springs. Positioning is accomplished with the micrometer screws after the angular displacement is removed by manually rotating the stage. All movements are visible in the field of the microscope. Due to the indexing negative being farther away, it is slightly smaller than the negative being positioned. The positioning technique consists of getting all edges parallel and then moving corners into coincidence on one side of the field.

With the 4 x 5 film holder loaded with Kodagraph, it is inserted in the Ultraphot, the shutter is cocked, and the dark slide removed. Normal exposure required eight minutes.

Succeeding steps are just the movement into registration of each negative, in turn, and its printing until the required number of superimpositions have been made. One negative, two negative, four negative, and eight negative prints were made for each film.

D. Resolution Determination

For scoring resolution, the transparencies were viewed without visual aids. The criterion for the last resolved unit was the detection of the presence of the two spaces that separated them in both orientations. The resolutions found for the superimposed prints are shown in Tables 4, 5, 6, and 7. Normal versus superimposition prints for each of the emulsions are shown in Figures 9, 10, 11, 12, 13, 14, 15, and 16.

E. Graininess Determination

The normal and superimposed prints of the four low contrast targets were mounted on white cards. These sixteen samples were given to twenty observers. These observers were told to rank the samples in order of graininess. The twenty observers had had close contact with concepts of graininess. The distributions of the choices were used to rank the prints. Results are shown in Figure 14.

VIII. FINDINGS AND CONCLUSIONS

A. SO-1213

1. The single negative print had a background pattern not unlike a graininess pattern. This seemed to be due to the presence of small bubbles and other irregularities in the emulsion. These were very evident in the low contrast targets. Note in Table 7 the loss of resolution between the 0.53 target and the 0.26 target. This emphasizes the curvature of field of the microscope. This was not noted in the other films. The two negative print shows a general strengthening of edges. The four negative print shows definite image improvements. The eight negative print shows further image strengthening. Within the target elements, the bars are blurring. Yet, the target elements are becoming more distinct as squares.

2. Within the high contrast target, the only gain in the superimposition prints was the disappearance of the emulsion imperfections in the two negative print. The principle gains are in the aerial transparencies. Through the two, four, and eight negative prints there is a progressive strengthening of low contrast detail. Street patterns become more evident. The wharves are easier to recognize. The bridges across the inlet are more recognizable.

3. Within the very fine grain structure of SO-1213, there is sufficient fluctuation in the number of grains which develop of those which are exposed to permit the superimposition technique to be effective. These prints also demonstrate that where disturbing irregularities in the emulsion can be expected to print out, a multiple negative print will eliminate these.

B. Plus X

1. This emulsion produced the least improvement in resolution. This may be attributed to the fact that this was the first of the four emulsions printed. The technique of bringing each negative into registration was developed during this printing. The indexing negative substage was supported in a less steady manner than the clamping method used for the other three films. As a result, registration errors were very erratic. The eight negative print shows a large registration error. This may account for the two negative print being the best as regards resolution. However, the progressive gain in the .07 target as the negatives are increased is quite evident. This is matched by the image strengthening in the aerial transparencies.

C. Super XX

1. The graininess in this film is more than enough to demonstrate the smoothing of the irregular pattern of the grain from the one negative print to the eight negative print. The eight negative print had a very bad registration error the first time. It was repeated with acceptable results. The two negative print of the low contrast targets shows how critical registration is for only two prints. In the two negative print, any error in registration will have the greatest effect. The weight of such an error should vary inversely as the number of negatives used to make the print. Note how even in the two negative print of the aerial transparencies there is a definite improvement over the single negative print. It is believed that registration was nearly perfect. Resolution was held in the high contrast target.

2. Again, the lowest contrast targets show the largest improvements. The 0.07 target, even in the four negative print, has almost an

80 per cent improvement in resolution.

3. The black corners in three of the prints resulted from an attempt to cut the indexing negative to provide better indexing marks. Angular displacements between the indexing marks and the negative being printed are easier to remove with indexing marks at the edge of the field.

D. Tri-X

1. This emulsion was very difficult to index at this magnification. It was comparable to fitting two lace curtains to one another. Later, a Plus X negative was tried as an indexing negative. The difficulty of deciding when registration was achieved was amplified. There was a definite time when edges seemed together when the indexing negative was Tri X. But with the Plus X negative, no definite point could be detected. This is a basic weakness in trying to achieve registration by matching only one or two edges instead of the entire field at once.

2. It was expected that, due to this emulsion's thickness and graininess, the superimposition technique would show the best results. This was true. The degree of graininess causes a less frequent sampling of the optical image. Thus, a two negative print should show a large information gain. This proved true.

3. The most dramatic gain lay in the 0.07 target. Note in Figure 10 how the single negative and two negative prints show <u>no</u> image. Yet, the four negative shows something and the eight negative print definitely shows the first group of six subgroups and a suggestion of the second.

4. The aerial transparencies being of low contrast also show definite improvement. But, you must go to the eight negative print to see the most obvious gain in detail, as in the coastline.

E. It should be emphasized that all these prints which are reproduced in negative form here were first attempts. Only in the case of Super XX was one print repeated. The eight negative print of Plus X of the low contrast targets should be repeated, but it was included to illustrate the effect of a gross registration error.

F. The technique shows that it is possible, using emulsions of a wide range of graininess, to print pictures which contain more information than any one of the negatives used to produce it. The most obvious gains are in the lowest contrast regions. The limiting factors appear to lie in the size of the registration errors and their distribution, the number of negatives used, and the spread function of the negative's emulsion.

G. It appears that the optimum superimpositions is four. For the length of time and effort to produce them, compared to the size of the gain realized, it appears that four is a practical number. However, if registration is near perfect, even two can definitely show an information gain.

H. Note how the curves of the graininess evaluation tend toward a common point (Figure 17). This is logical. Beyond a certain number of superimpositions, there should be no real decrease in graininess. This depends on the degree of graininess to begin with. It appears that SO-1213 has reached this point at eight superimpositions.

I. It is believed that this technique would have application to any photographic recording where needed detail is expected to lie in low contrast regions. If more than one negative can be taken with substantially the same image areas appearing, then this technique may be used.

TEST CHART DENSITY DIFFERENCE	EFFECTIVE RESOLVING POWER OF NEGATIVE (1pm)			% INCREASE IN RESOLVING POWER
	DIRECT ENLARGEMENT	8 PRINTINGS FROM ONE NEGATIVE	8 PRINTINGS FROM 8 DIFFERENT NEG.	
0.1	5	5	8	60
0.2	71/2	7 1/2	12	60
0.4	13	12	16	23
0.6	15	16	18	20

DR. STEVENS RESULTS

TABLE 1

FILM	DEVELOPER	PROCESSING TIME minutes		γ	FOG
		DEVELOP	FIX		
TRI-X, AERCON, SO-1205	D-19	8	4	0.85	0.26
SUPER-XX-RP	D-19	4 1/2	4	1.14	0.18
PLUS-X, AEROCON SO-1166	D-19	6	4	1.40	0.11
SO-1213	D-19	6	4	2.90	0.23
KODAGRAPH FINE GRAIN PRINT	D-76 with 2 gm. per liter Kb.	4	4	1.43	0.06

PROCESSING DETAILS

TABLE 2

KODAGRAPH FINE GRAIN PRINT FILM

TYPE I-B SENSITOMETER, 78AA DAYLIGHT FILTER

See Figure 8 for D Log E curves.

D LOG E CURVE NO.	1	2	3	4	5	6	7
NUMBER OF EXPOSURES	1	2	3	4	5	6	20
EXPOSURE LENGTH (sec.)	20	10	6 2/3	5	4	3 1/3	1
INTERVAL BETWEEN EXPOSURES (sec)	0	10	10	30	30	30	30

INTERMITTENCY TEST EXPOSURES

TABLE 3

TEST CHART DENSITY DIFFERENCE	SINGLE NEGATIVE PRINT RESOLUTION (lpm)	SUPERIMPOSITION PRINTING RESOLUTION (lpm)			% INCREASE IN RESOLVING POWER
		2 NEGATIVES	4 NEGATIVES	8 NEGATIVES	
3.0	31.7	31.7	25.2	22.5	0 -21% -29%
0.53	25.2	28.3	25.2	25.2	12% 0 0
0,26	17.8	22.5	22.5	25.2	26.5% 26.5% 42%
0.14	12.6	17.8	17.8	20	41% 41% 59%
0.07	0	0	+	17.8	- - -

TRI-X
SUPERIMPOSITION PRINT RESOLUTION

TABLE 4

TEST CHART DENSITY DIFFERENCE	SINGLE NEGATIVE PRINT RESOLUTION (lpm)	SUPERIMPOSITION PRINTING RESOLUTION (lpm)			% INCREASE IN RESOLVING POWER
		2 NEGATIVES	4 NEGATIVES	8 NEGATIVES	
3.0	50.4	50.4	40	50.4	0 -21% 0
0.53	35.6	25.2	31.7	28.3	-29% -11% -21%
0.26	25.2	23.5	31.7	35.6	-7% 26% 41%
0.14	22.5	20.0	28.3	28.3	-11% 26% 26%
0.07	10.0	12.6	17.8	17.8	26% 78% 78%

SUPER XX
SUPERIMPOSITION PRINT RESOLUTION

TABLE 5

TEST CHART DENSITY DIFFERENCE	SINGLE NEGATIVE PRINT RESOLUTION (lpm)	SUPERIMPOSITION PRINTING RESOLUTION (lpm)			% INCREASE IN RESOLVING POWER
		2 NEGATIVES	4 NEGATIVES	8 NEGATIVES	
3.0	40	40	35.6	40	0 -11% 0
0.53	35.6	40	31.7	22.5	12% -11% -37%
0.26	31.7	35.6	31.7	25.2	12% 0 -37%
0.14	28.3	31.7	31.7	25.2	12% 12% -11%
0.07	17.8	17.8+	20	22.5	+ 12% 26%

PLUS X
SUPERIMPOSITION PRINT RESOLUTION

TABLE 6

TEST CHART DENSITY DIFFERENCE	SINGLE NEGATIVE PRINT RESOLUTION (lpm)	SUPERIMPOSITION PRINTING RESOLUTION (lpm)			% INCREASE IN RESOLVING POWER
		2 NEGATIVES	4 NEGATIVES	8 NEGATIVES	
3.0	80	63.4	71.2	71.2	-21% -11% -11%
0.53	45	40	45	45	-11% 0 0
0.26	56.5	50.4	56.5	56.5	-11% 0 0
0.14	45.0	50.4	50.4	50.4	12% 12% 12%
0.07	22.5	28.3	25.2	25.2	26% 12% 12%

SO-1213
SUPERIMPOSITION PRINT RESOLUTION

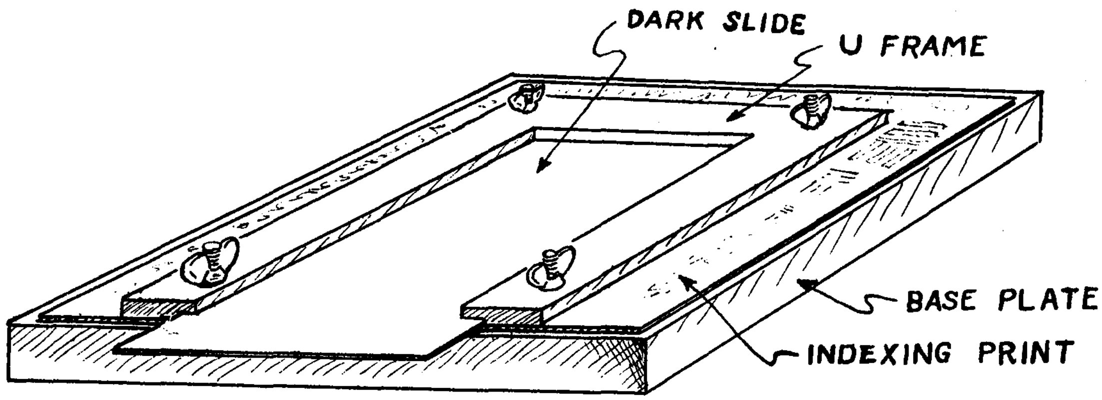
TABLE 7

Note: T is Tri X, S is Super XX, P is Plus X, M is SO 1213. Subscript is number of negatives.

RANK	T_1	T_2	T_4	T_8	S_1	S_2	S_4	S_8	P_1	P_2	P_4	P_8	M_1	M_2	M_4	M_8
1	20															
2		17			3											
3		3	4		13											
4			12	2	2	1			3							
5			3	2	2	7			6							
6			1	9		7			3							
7				6		5	3		5	1						
8				1			14		1	3			1			
9							3		2	13			2			
10								12		3	3		2			
11								6			10	1	3			
12								2			6	8	8	1		
13											1	5	9	5		
14												5		12	2	1
15												1		2	14	3
16															4	16
$\sum_{1}^{16} R_i f_i$	20	43	81	122	63	116	160	210	121	178	225	257	232	275	302	315
$\Sigma/20$	1.00	2.15	4.05	6.10	3.15	5.80	8.00	10.50	6.05	8.90	11.25	12.85	11.60	13.75	15.1	15.75

GRAININESS RANKING DISTRIBUTION

TABLE 8



PROCEDURE FOR USE:

1. Assemble the jig with the print material covering the entire top of the base plate. Holes are needed in the sheet for the screws to pass through.

2. Project the negative on the print plane so that the area of superimposition falls inside the inner ipen area of the U frame. The images which fall outside the U frame on the print material will serve later as indexing marks for the superimposition printing.

3. After exposure and processing, the inner area of the print not covered by the U frame is cut out.

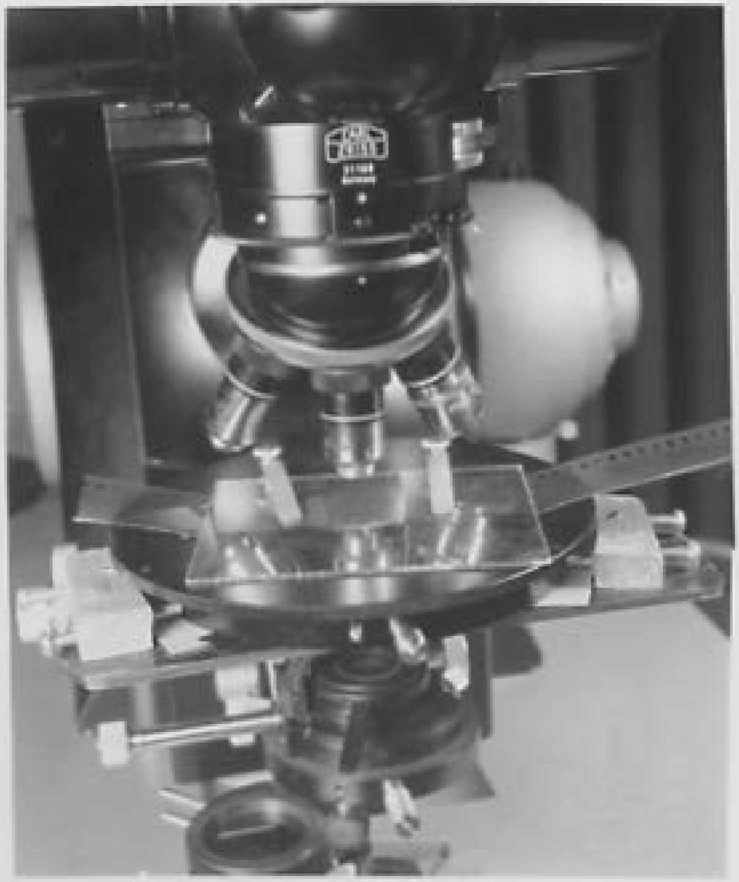
4. On reassembly, the sensitized material for the superimposition print is placed inside the cutout area. The U frame is placed over this and the jig is clamped togeather. The dark slide is then inserted as shown to cover the unexposed print material.

5. In use, the projected negative image is focused on the indexing print. The jig, if held in a toolmaker's traveling microscope type carriage, may be oriented so that the projected images coincide with the indexing print images. The dark slide may be removed and the partitioned exposure made.

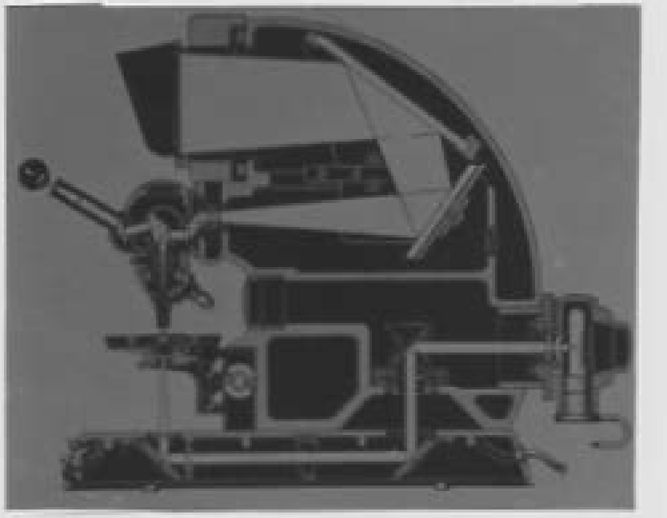
6. Succeeding steps consist of: bringing a new negative into the projector, obtaining coincidence between projected and indexing print images with the dark slide in place, and then the removal of the dark slide for the partitioned exposure.

ENLARGER PRINTING JIG

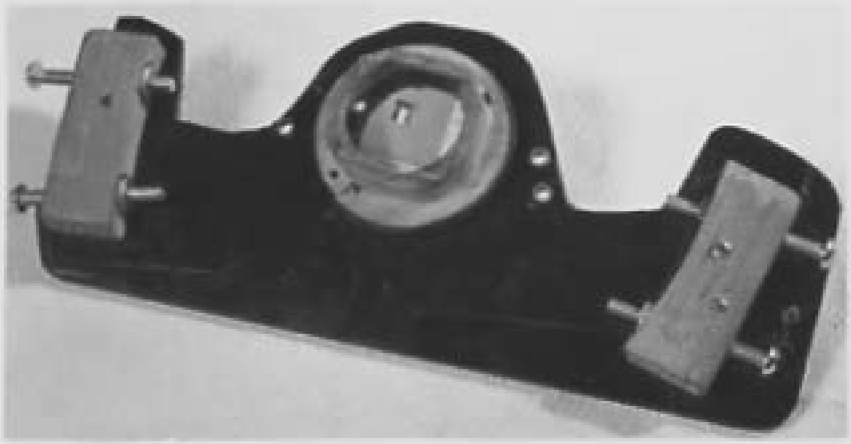
FIGURE 1



WORKING SETUP



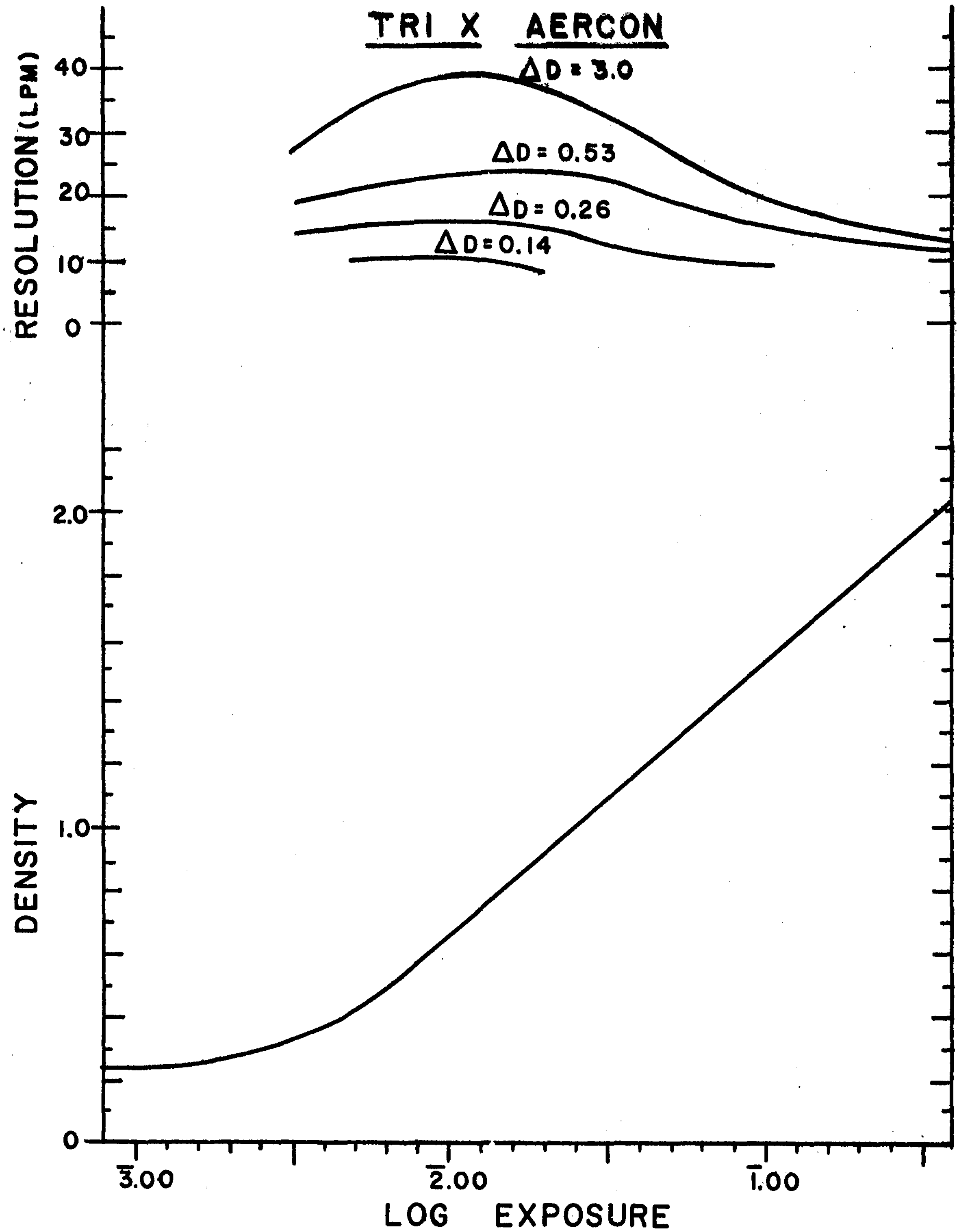
ULTRAPHOT OPTICAL TRAIN



INDEXING NEGATIVE SUBSTAGE

MODIFICATION OF ULTRAPHOT II MICROSCOPE

FIGURE 2



TRI X AERCON
ΔD = 3.0
ΔD = 0.53
ΔD = 0.26
ΔD = 0.14
RESOLUTION (LPM)
40
30
20
10
0
DENSITY
2.0
1.0
0
3.00
2.00
1.00
LOG EXPOSURE

FIGURE 3

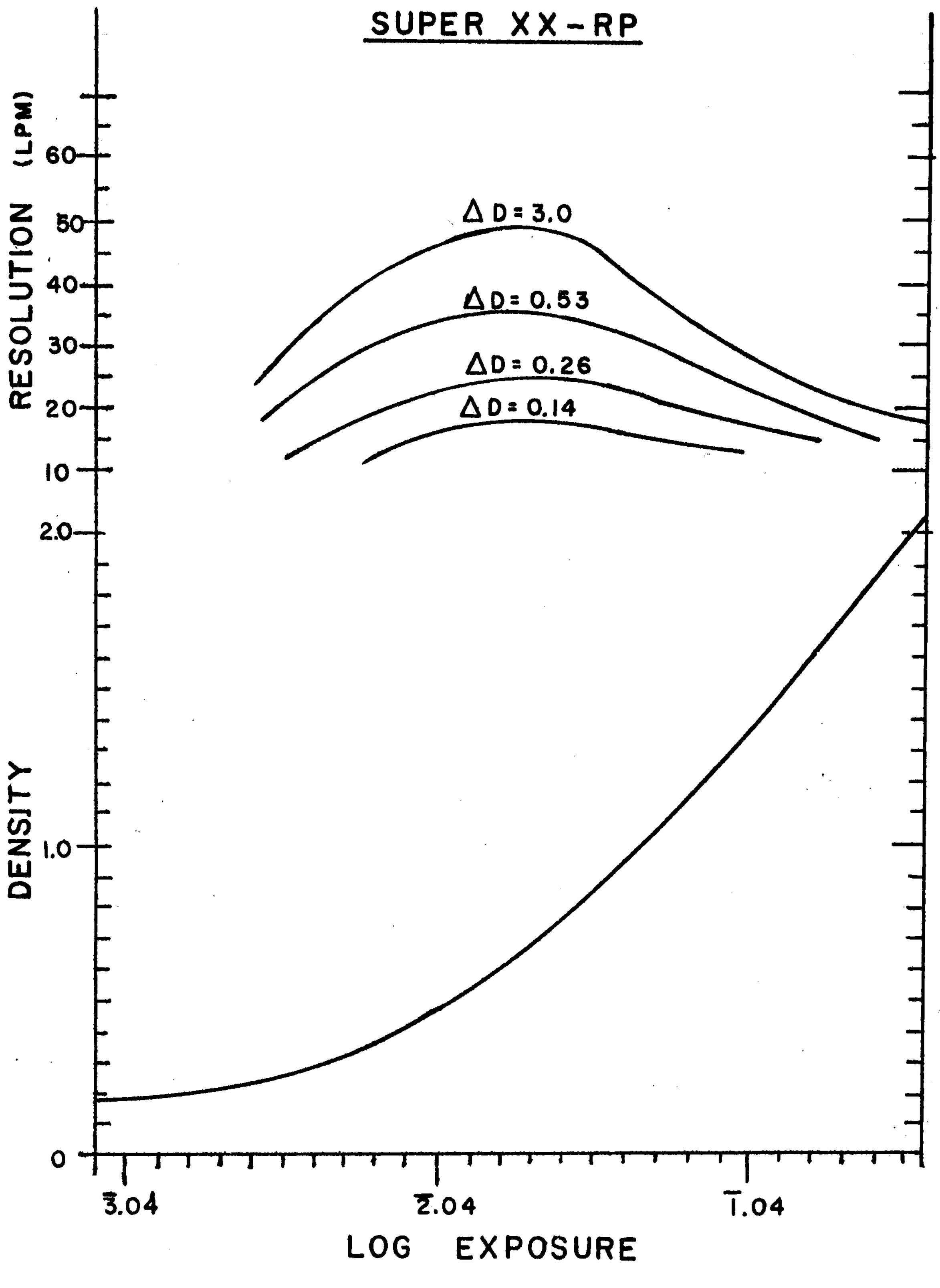

SUPER XX-RP
RESOLUTION (LPM)
60
50
40
30
20
10
Δ D = 3.0
Δ D = 0.53
Δ D = 0.26
Δ D = 0.14
DENSITY
2.0
1.0
0
$\bar{3}$.04
$\bar{2}$.04
$\bar{1}$.04
LOG EXPOSURE

FIGURE 4

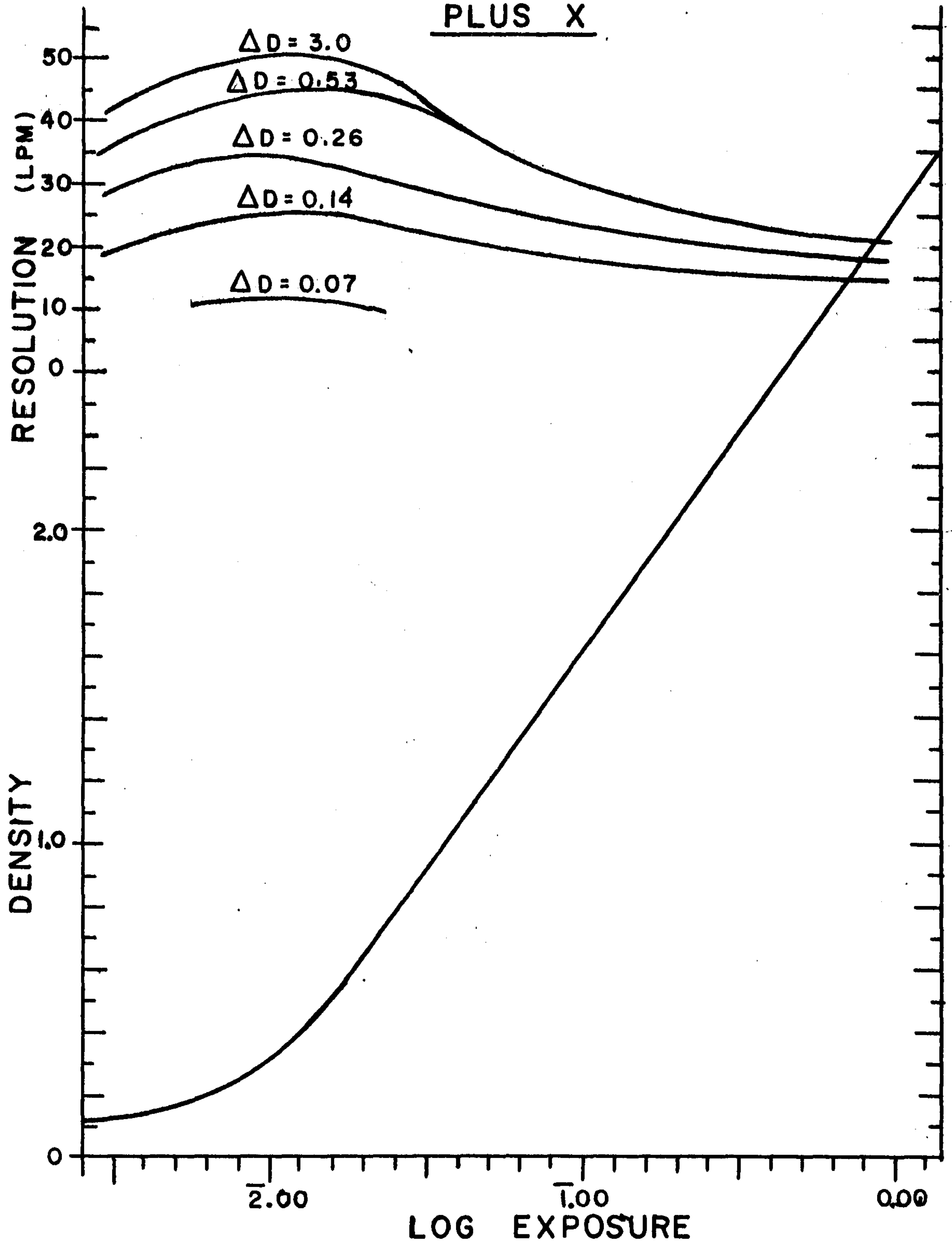
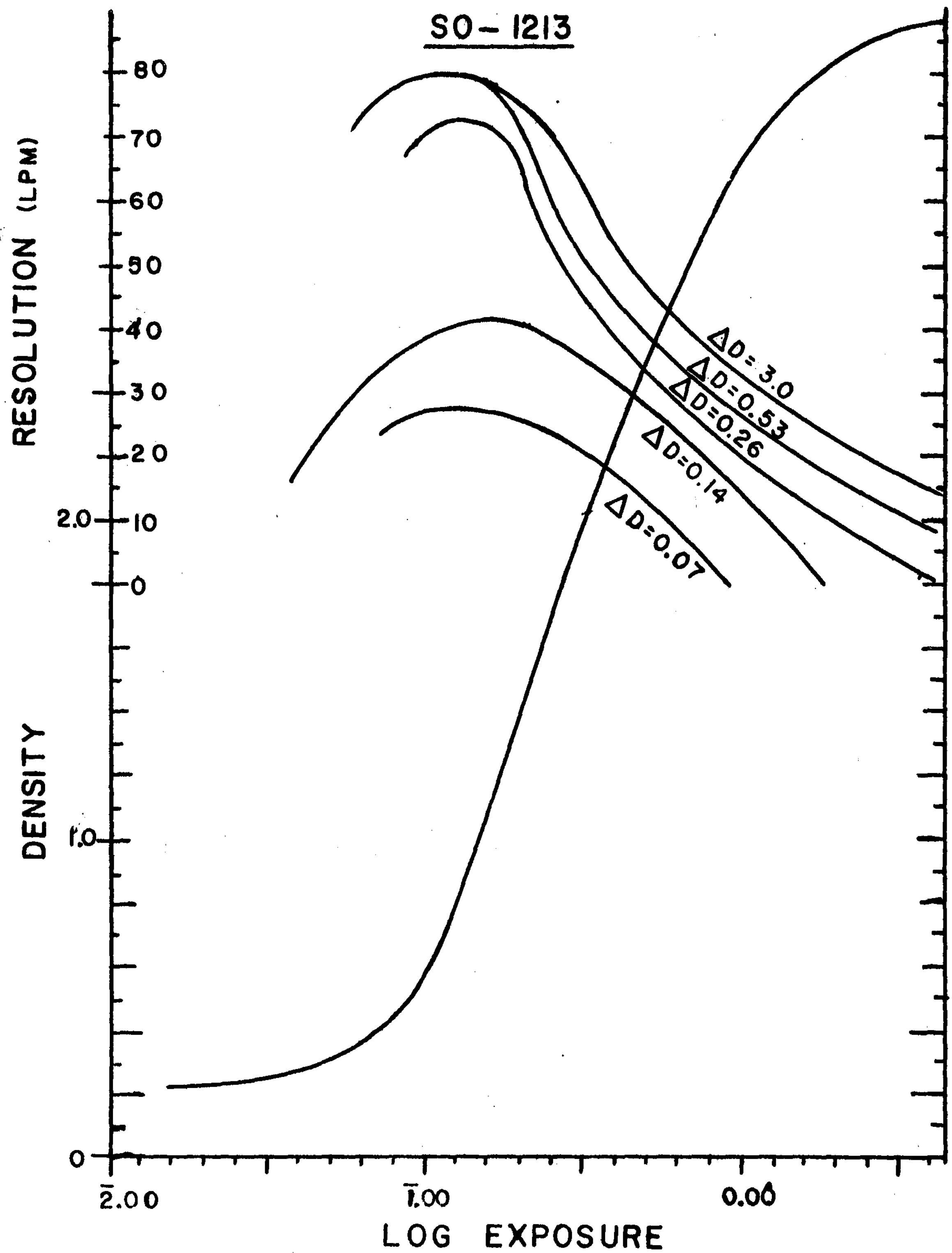
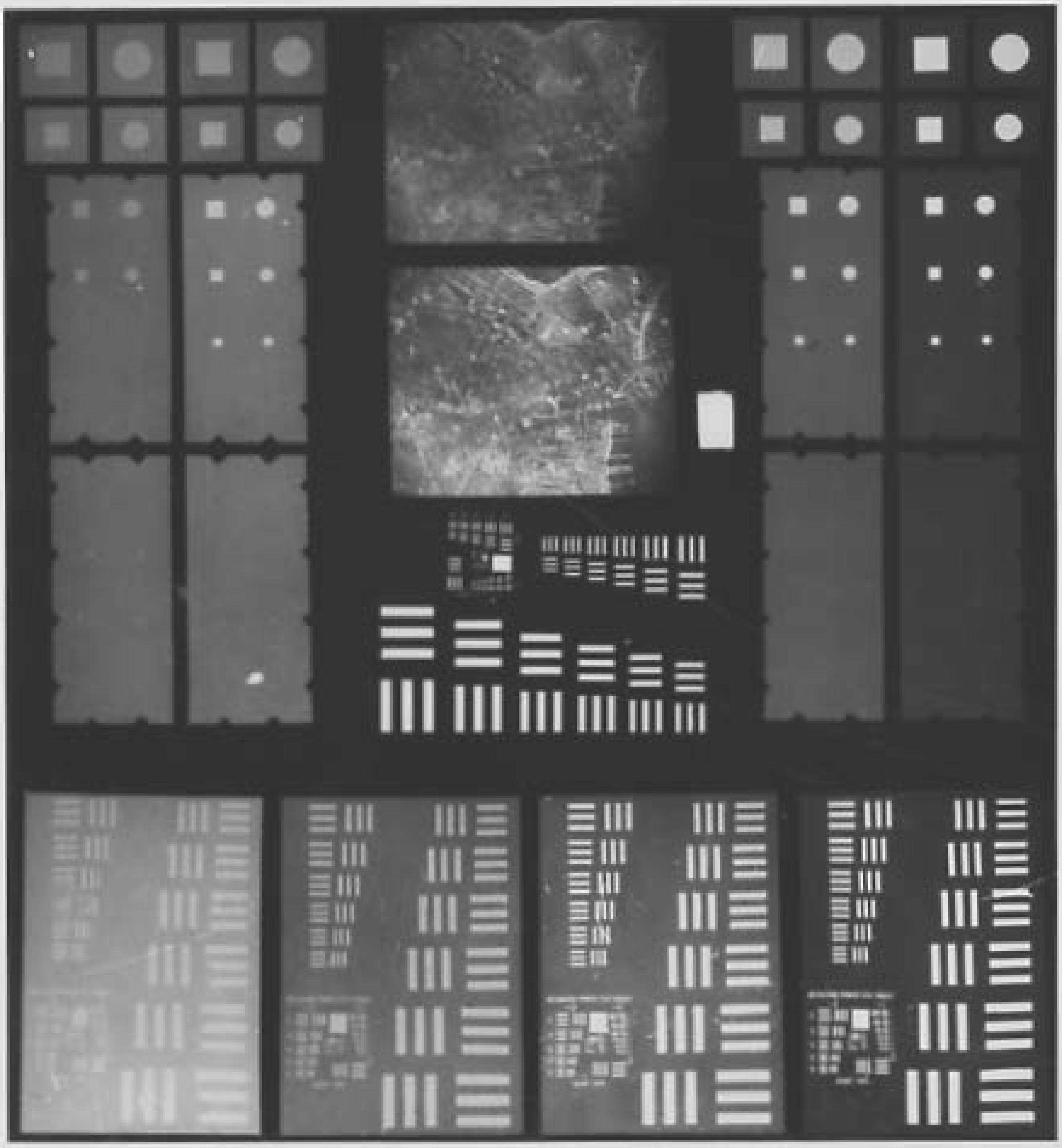

PLUS X
ΔD = 3.0
ΔD = 0.53
ΔD = 0.26
ΔD = 0.14
ΔD = 0.07
RESOLUTION (LPM)
50
40
30
20
10
0
2.0
1.0
0
DENSITY
2.00
1.00
0.00
LOG EXPOSURE

FIGURE 5



SO- 1213
80
70
60
50
40
30
20
10
0
2.0
1.0
0
RESOLUTION (LPM)
DENSITY
ΔD=3.0
ΔD=0.53
ΔD=0.26
ΔD=0.14
ΔD=0.07
2̄.00
1̄.00
0.00
LOG EXPOSURE

FIGURE 6



RESOLUTION TARGET PANEL

FIGURE 7

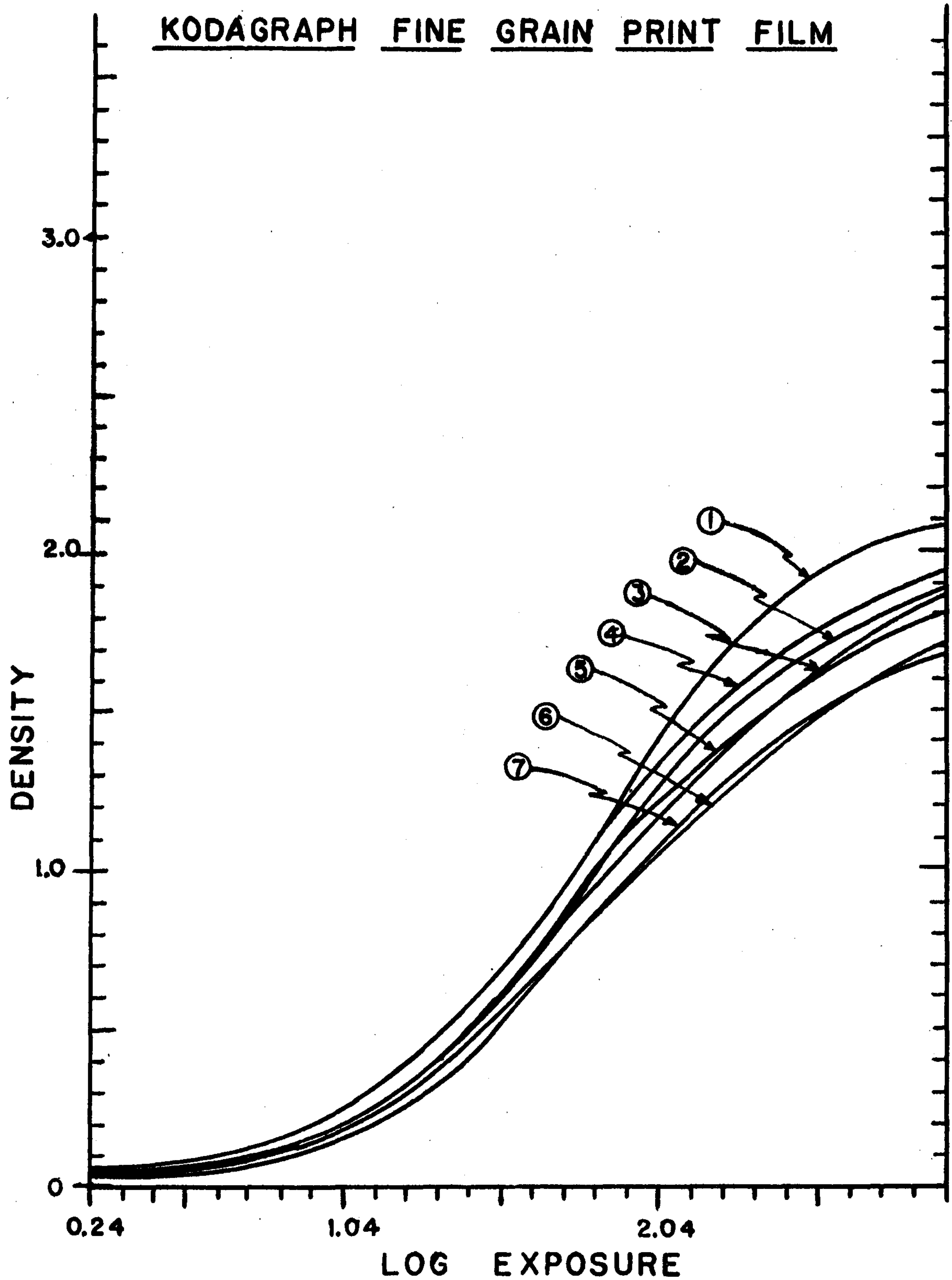
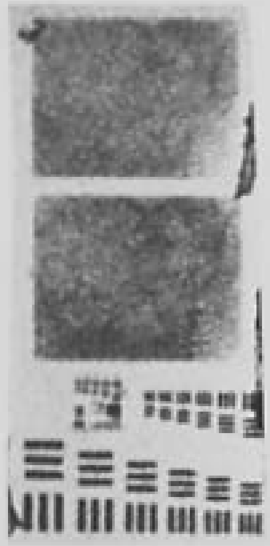
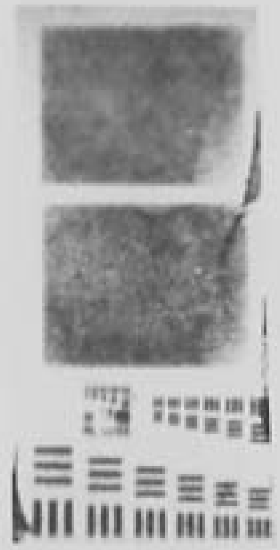

KODAGRAPH FINE GRAIN PRINT FILM
DENSITY
3.0
2.0
1.0
0
0.24
1.04
2.04
LOG EXPOSURE
1
2
3
4
5
6
7

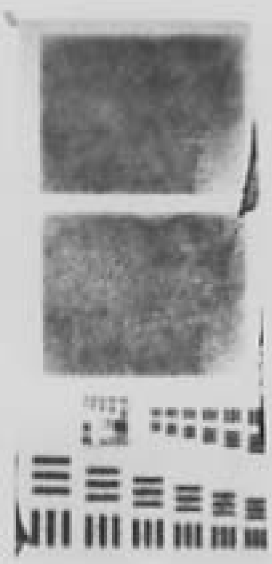
FIGURE 8



SINGLE NEGATIVE PRINT



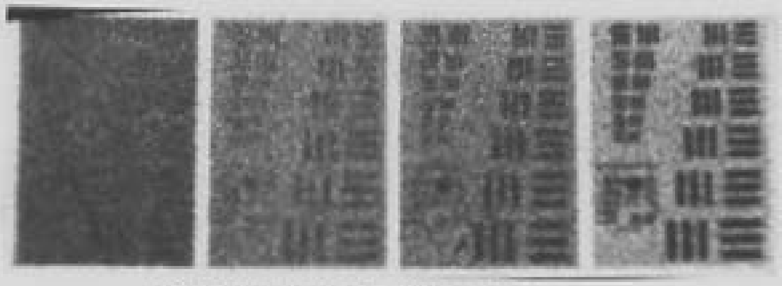
TWO NEGATIVE PRINT



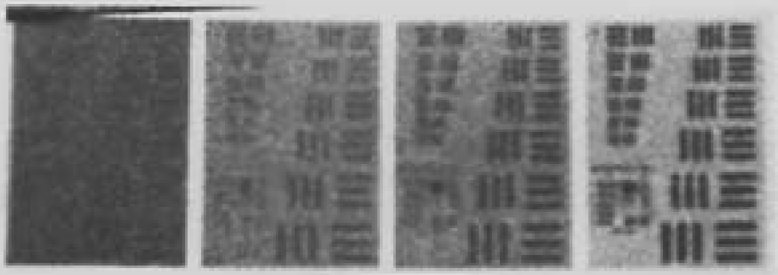
FOUR NEGATIVE PRINT

EIGHT NEGATIVE PRINT

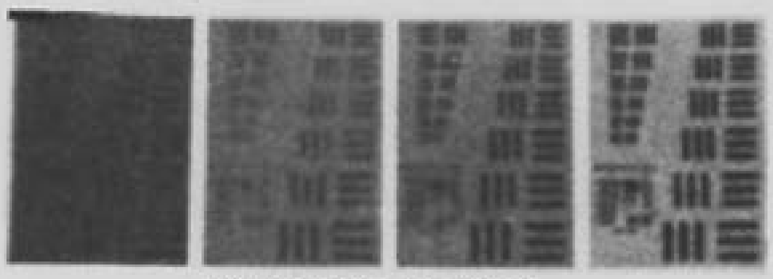
TRI-X
FIGURE 9



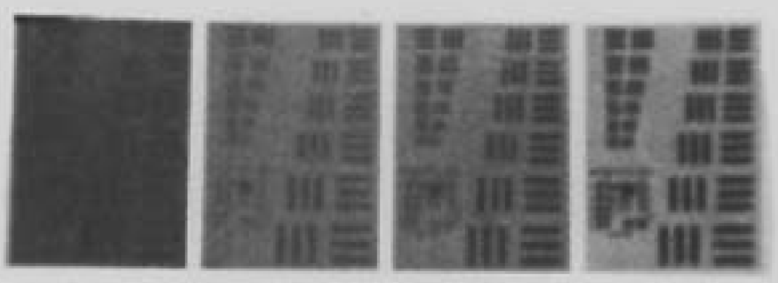
SINGLE NEGATIVE PRINT



TWO NEGATIVE PRINT

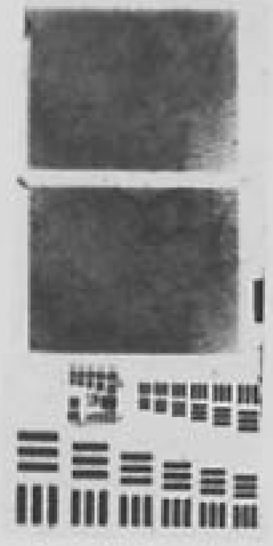


FOUR NEGATIVE PRINT

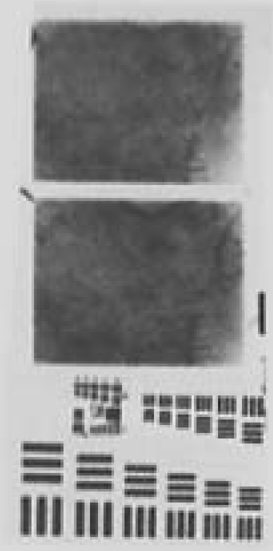


EIGHT NEGATIVE PRINT

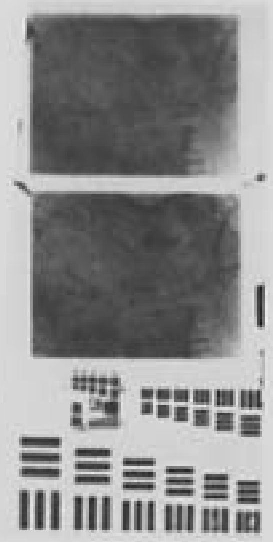
TRI-X
FIGURE 10



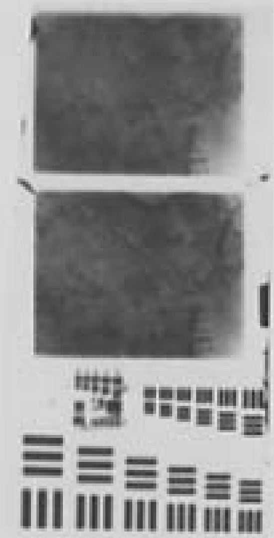
SINGLE NEGATIVE PRINT



TWO NEGATIVE PRINT

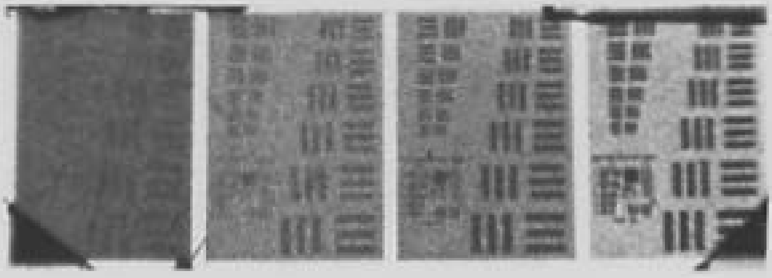


FOUR NEGATIVE PRINT

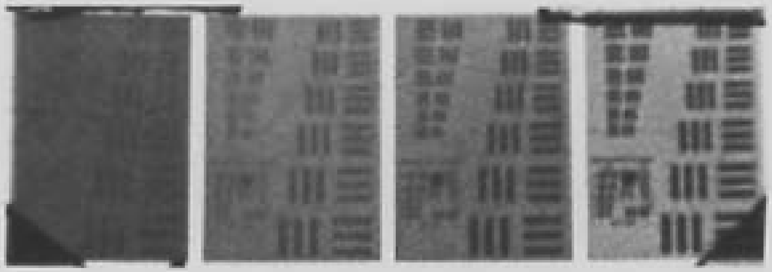


EIGHT NEGATIVE PRINT

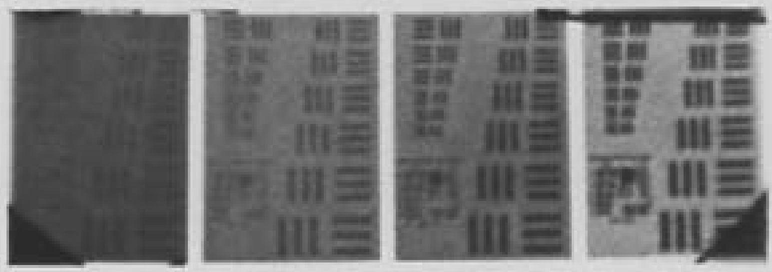
SUPER XX
FIGURE 11



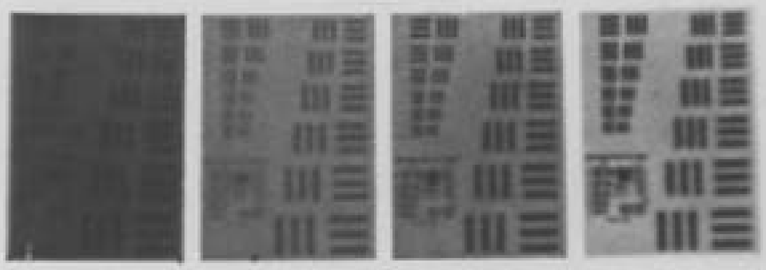
SINGLE NEGATIVE PRINT



TWO NEGATIVE PRINT

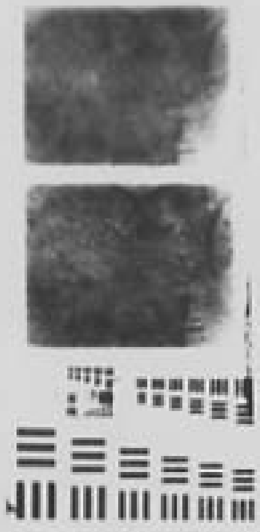


FOUR NEGATIVE PRINT



EIGHT NEGATIVE PRINT

SUPER XX
FIGURE 12



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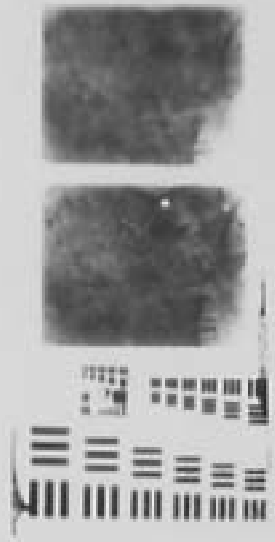

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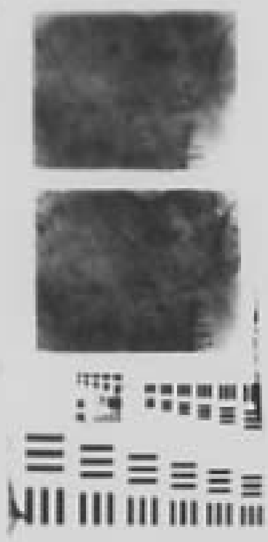
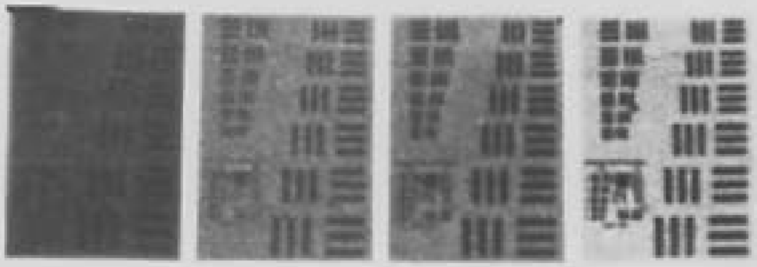


FOUR NEGATIVE PRINT

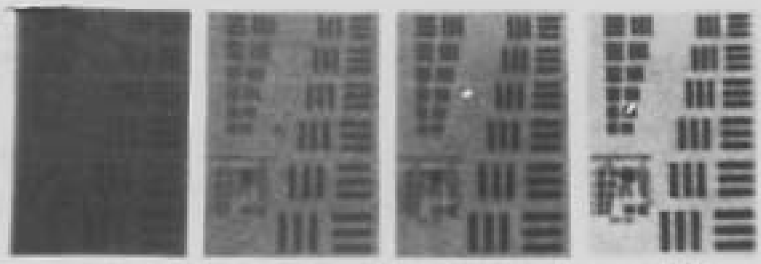
EIGHT NEGATIVE PRINT

PLUS X

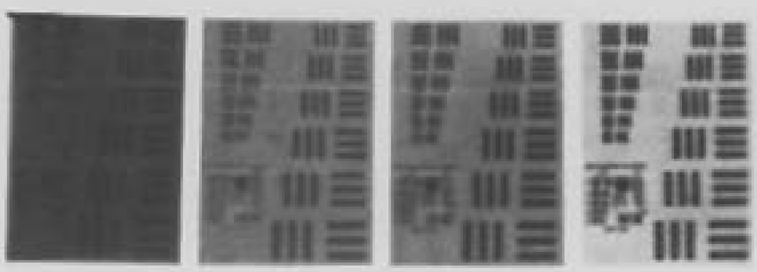
FIGURE 13



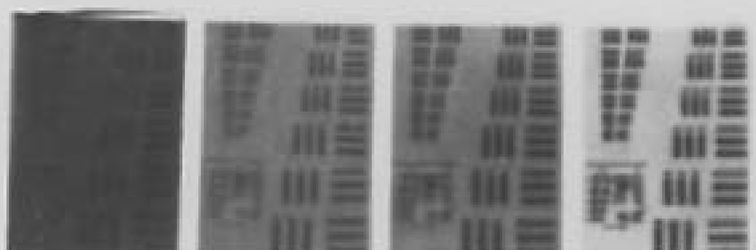
SINGLE NEGATIVE PRINT



TWO NEGATIVE PRINT

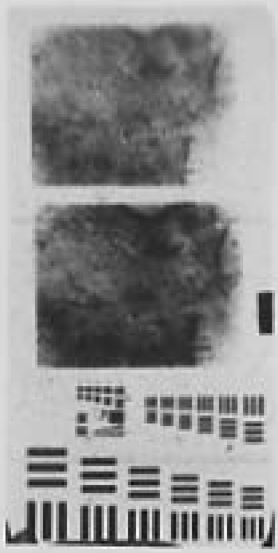


FOUR NEGATIVE PRINT

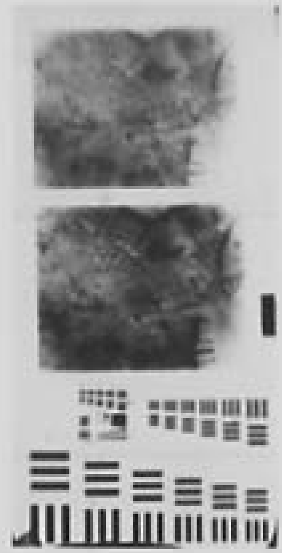


EIGHT NEGATIVE PRINT

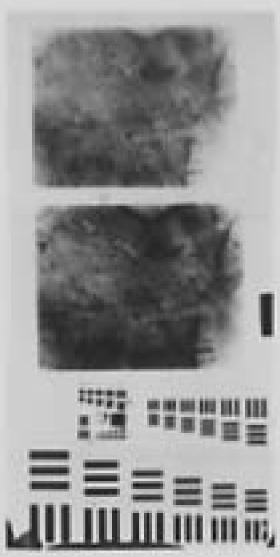
PLUS X
FIGURE 14



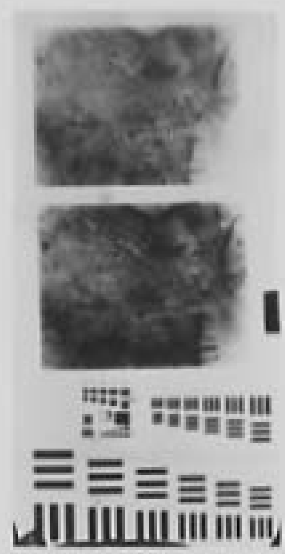
SINGLE NEGATIVE PRINT



TWO NEGATIVE PRINT

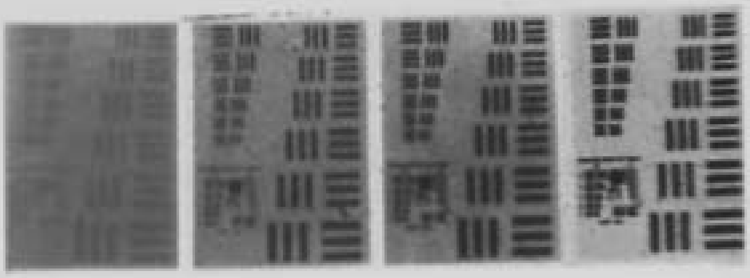


FOUR NEGATIVE PRINT

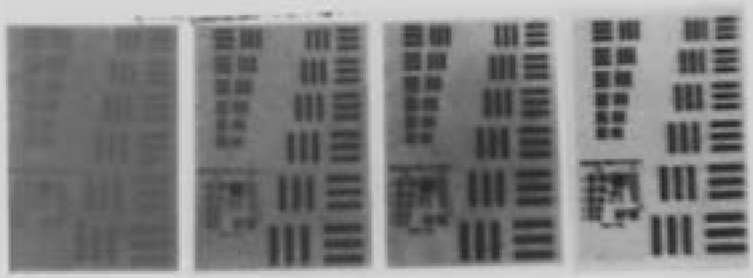


EIGHT NEGATIVE PRINT

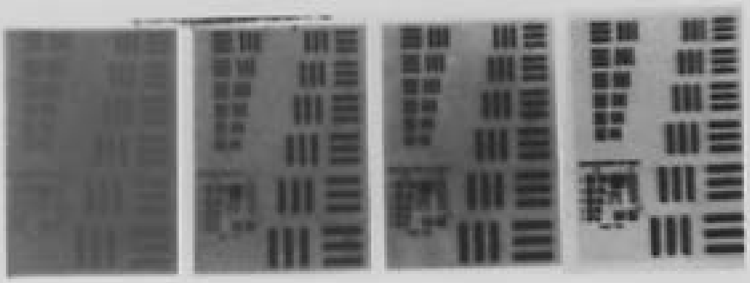
SO-1213
FIGURE 15



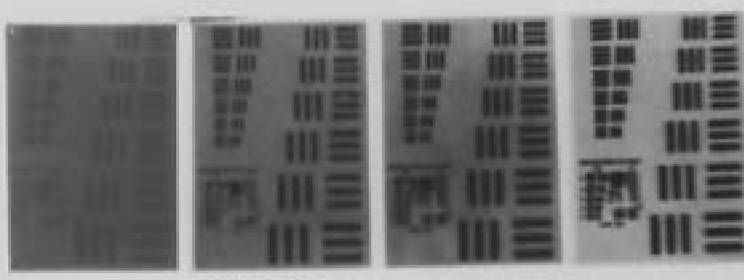
SINGLE NEGATIVE PRINT



TWO NEGATIVE PRINT



FOUR NEGATIVE PRINT



EIGHT NEGATIVE PRINT

SO-1213

FIGURE 16

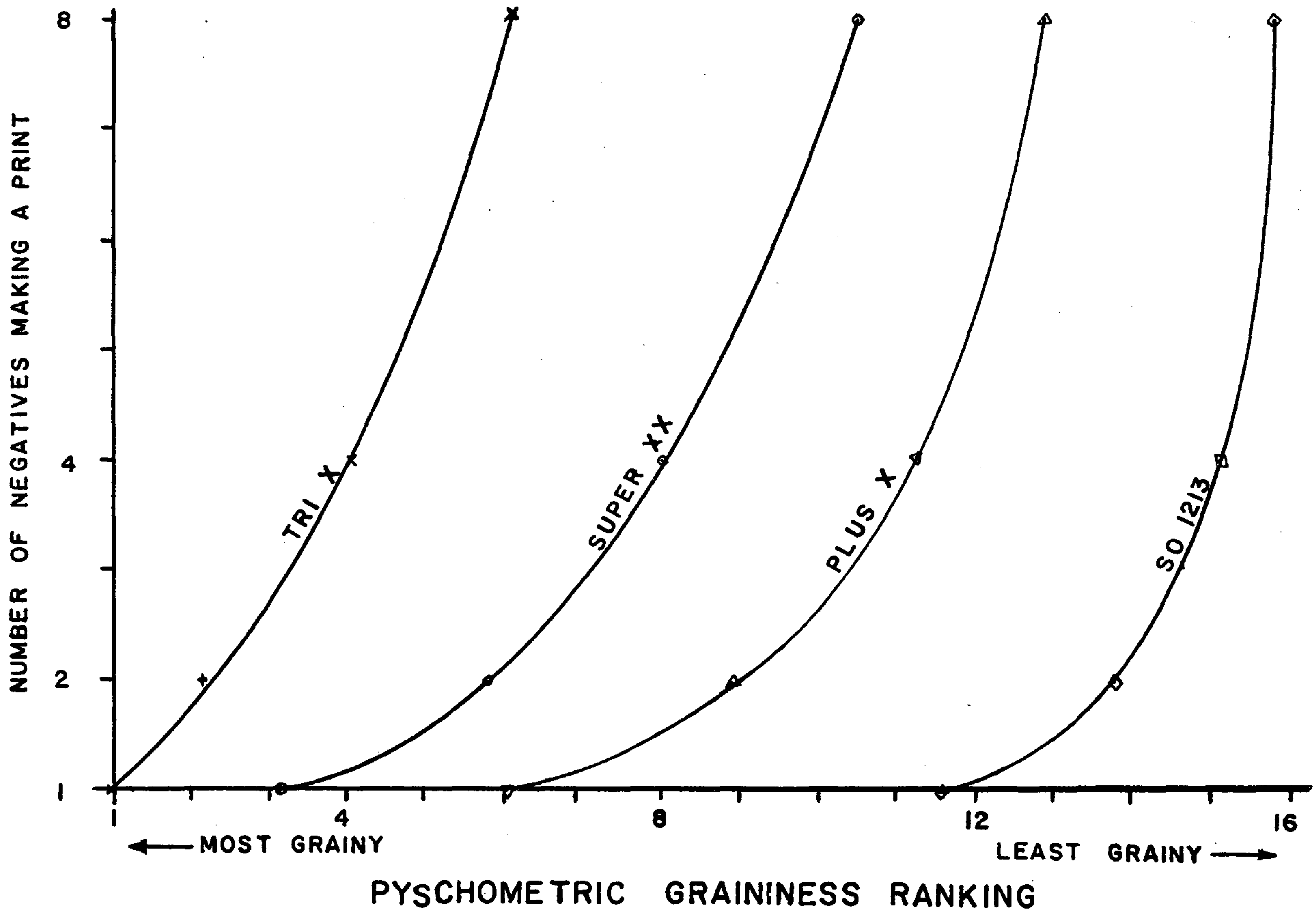

8
4
2
1
NUMBER OF NEGATIVES MAKING A PRINT
TRI X
SUPER XX
PLUS X
SO 1213
1
4
8
12
16
MOST GRAINY
LEAST GRAINY
PYSCHOMETRIC GRAININESS RANKING

FIGURE 17

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5. Stevens, G. W. W. — "The Effect of Diffusion on the Graininess and Resolution Obtained from Processed Negatives." Photographic Journal 87B: P. 74-80 1947 Abstracted in Abridged Scientific Publications from the Kodak Research Laboratories Vol. XXIX 1948 P. 236-241

6. Webb, J. H. — "Low Intensity Reciprocity Law Failure in Photographic Exposure. Energy Depth in Electron Traps in Latent Image Formation. Number of Quanta Required to Form the Stable Sublatent Image." Journal of the Optical Society of America. January 1950 Vol. 40 No. 1 P. 3

7. Webb, J. H. — "Low Intensity Reciprocity Law Failure in Photographic Exposure. Multiplet Quantum Hits in a Critical Time Period." Journal of the Optical Society of America. April 1950 Vol. 40 No. 4 P. 197

APPENDIX

When this thesis work was first outlined, it was planned to split the work into three phases. Upon advice of experienced people, only the first phase work was accomplished. It is thought worthwhile to present the outline of the other two phases.

Phase II Reconnaissance Environment Simulation

A. Equipment

One 3/4 inch sheet of plywood, 4 feet square, painted with a mottled surface, with small resolution targets in the corners.

Small models (scale 1/100) of trucks and airplanes.

Two photoflood lamps and stands.

B. Procedure

Establish two exposure stations perpendicular to the surface of the model with a base to height ratio of 0.15.

At each station, eight shots are taken. Between each, the camera is moved forward. The distance moved forward will model a reconnaissance aircraft moving at Mach 1.5 during the re-cycle time for a 70-mm camera.

The camera distance is varied to produce scales of; 1/50, 1/100, 1/200, and 1/300.

The lighting is varied through four conditions: high contrast, one floodlight on; medium high contrast, slight fillin with second floodlight giving 4-1 intensity ratio; medium contrast, 2-1 intensity ratio; low contrast, 1-1 intensity ratio.

The superimposed printing technique is utilized as outlined in this thesis. This method of taking the pictures produces stereo pairs. Quality comparisons can be made between the normal and the superimposed stereo pairs. The capability to yield length, width, and height information will be contrasted.

Phase III Superimposition by a Visual Technique

A. Equipment

Moviola type viewer, giving an image for each eye from two loops of film.

B. Procedure

The eight negatives of the Phase II work for one camera station are contact printed in sequence on a 35-mm strip of print film. The sequence runs 1 through 8, and then the sequence is printed 7 through 1. the strip is made long enough and the sequences are repeated enough so that the strip can run through the viewer and loop back to itself. The procedure is repeated for the negatives of the other camera station. The two loops are run through the viewer indexed together, so that exposure No. 1, at station No. 1, is indexed with exposure No. 1, at No. 2 station. When viewed with the strips in motion, the stereo viewpoint of the observer will shift back and forth over what he is looking at.

Qualitative judgements can be made concerning any improvements in resolution and particularly in depth perception against the normal stereo print viewing.

ABSTRACT

A method of reducing the graininess of a photographic print and increasing resolution in low contrast regions is described. The method involves the printing of more than one negative frame to produce one print. This requires a series of negatives with identical detail coverage in the area to be printed. The success of the method depends largely on the precision of the solution of the registration problem. Each negative is printed in turn, using the normal exposure, partitioned in as many parts as there are negatives to be printed. Each negative must be registered as exactly as possible in the image area.

Four different aerial emulsions were used to obtain the 35-mm negatives for the superimposition printing technique. Kodak films used were: Tri X-RP Aercon, Super XX-RP Aerial Recon, Plus X Aerocon (SO 1166), and SO-1213. The exposure versus resolution characteristics and the basic sensitometric curves were developed for these films prior to exposure of the final series of negative frames. The negatives were exposed under identical conditions with the exception of lens openings and shutter speeds at an object to image ratio of 160 to 1. The camera was a Contax IIA with a 50-mm F/2 Sonnar lens. The camera exposure settings were: Tri-X, F/16, 1/250 second; Super XX, F/11, 1/250 second; Plus X, F/16, 1/100 second; SO-1213, F/11, 1/50 second. Due to the level of brightness of the target, the camera lens was not used at its best aperture. No filter was used.

The resolution target panel consisted of two aerial transparencies and five resolution targets of the Buckbee Meers type. The five

resolution targets contained respectively the density differences of; 3.0+, 0.53, 0.26, 0.14, 0.07. These transparencies were illuminated by fluorescent tubes of the warm white type. The aerial transparencies were processed to a gamma of one. Maximum density in one was 0.4. The other covered the same area, but maximum density was only 0.2.

The camera was mounted on a sturdy table. Each of seventeen exposures was made by winding the film and tripping the shutter in succession. The four films were exposed in the same manner but with the proper lens and shutter settings.

All films were processed in D-19 developer at 68° F. and fixed with Kodak RP fixer. Prior to processing, one end of each film was exposed in a Type II sensitometer for processing control.

A working solution to the critical registration problem was achieved in a slight modification of a Carl Zeiss Ultraphot II microscope. This device employs a beam splitter to permit taking a photograph of the field. The modification was the construction of a substage which clamps to the fixed base of the object stage. This substage holds an indexing negative just below the level of the object stage. This indexing negative is taken from the film strip being printed. The part of the frame which is to be printed is cut out of the frame. The remaining image areas serve as indexing marks.

During the printing, each negative in turn is held on the object stage by a glass plate and spring clamps. The negative is moved into registration with the fixed indexing negative by means of the adjustment controls of the upper platform of the object stage. The basic exposure for a single negative print was eight minutes. Kodagraph Fine Grain Print

Film, processed four minutes at 68° F. in D-76, with 2 gm./liter of Kb added, was selected for the print material. All the negatives were enlarged 20 X. The fine grain of the Kodagraph did not contribute to the graininess patterns photographed.

Since the superimposition printing required partitioning the single negative exposure, an intermittency test was made on the Kodagraph Fine Grain Print Film. Sensitometric strips of the film were exposed in a Type IB sensitometer. The twenty second normal exposure was varied for each strip by dividing in equal parts separated by 30 second intervals. The D Log E curves plotted for each strip showed a general reduction in gamma. The reduction did not vary directly with the number of exposure partitions. The appreciable reduction in gamma occurred above the point on the D Log E curve that it was planned to print the negatives maximum density. Thus, its effect was uncompensated in the printing. Slight changes in density did appear in the superimposed prints.

The reduction in graininess achieved by this technique was evaluated psychometrically. Sixteen samples, four for each negative emulsion, were mounted on white cards. Twenty observers were asked to rank them in order of graininess. Tri-X, in an eight negative print, was about the same rank as Plus X in a single negative print. Super XX, in a four negative print, was less grainy than these two. SO-1213 had small bubbles in the emulsion which appeared as a graininess pattern. Plus X, in an eight negative print, had about the same graininess rank as SO-1213 in a single negative print.

The effects on resolution was of the same order as previously found by G. K. K. Stevens in 1946. In the high contrast target, no gains in resolution were found. Losses varied from zero to about 30 per cent. This is attributed to registration errors becoming important due to the generally high resolution displayed in the single negative print. In the three low contrast targets, the single negative prints had relatively low resolutions. The loss of resolution due to misregistration became less than the resolution in the low contrast targets. Thus, gains in resolution occurred in the superimposed prints against the single negative prints. The largest increases were found in the 0.07ΔD target for all emulsions. In this region, increases varied from 6 per cent to 78 per cent in the four negative Super XX print. Increases in the Tri X prints could not be rated percentage wise. Nothing was resolved in the one, two or four negative prints. In the eight negative print, about 18 lines per millimeter were resolved. No pattern of resolution target elements could be seen in the single negative Tri-X print.

In summary, the superimposition printing technique reduces graininess and strengthens edges. The increases in resolution that result depends upon; the basic single negative resolution, the number of superimpositions, the registration errors, and the region of contrast in which resolution is being measured. The technique amply demonstrates that a print can be obtained that contains more information than any one of the negatives used to produce it.