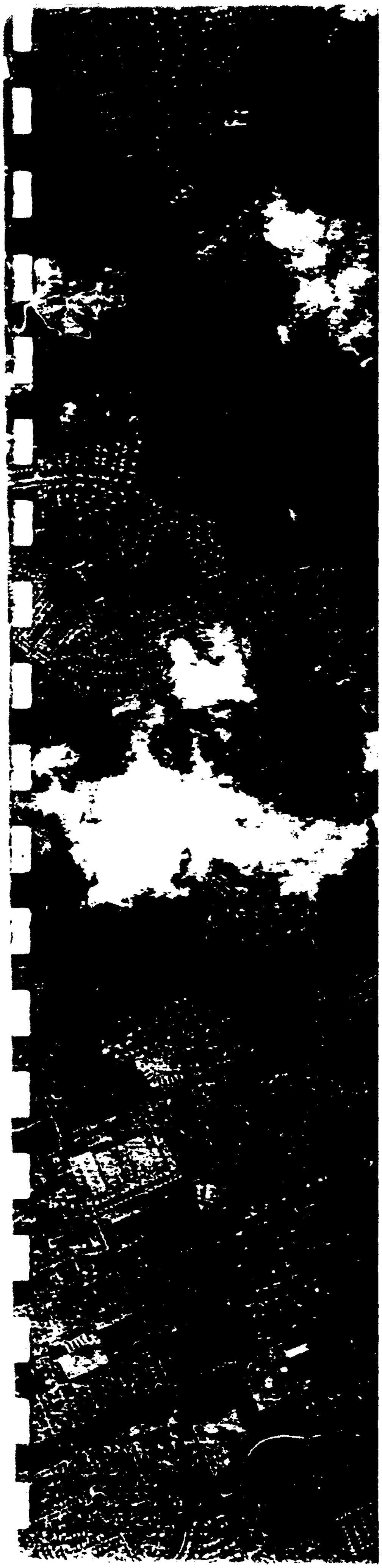

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EKIT REPORT NO.5

COMPARISON OF 3404 AND SO-362

FILM ANALYSIS
MODEL TEST
FLIGHT TEST NO. 3

Contributers: [redacted]

Approved by: [redacted]

23 JANUARY 1967

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Itek

ITEK CORPORATION LEXINGTON 73, MASSACHUSETTS

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CONTENTS

FIGURES

TABLES

1. SUMMARY

This report is number five in the EKIT series, and contains the evaluations conducted to compare Eastman Kodak type 3404 and SO-362 aerial films. SO-362 was a film intended to provide the same image quality as 3404, but twice the emulsion speed. It was the purpose of these evaluations to compare the two films to determine if SO-362 did in fact possess the characteristics (of speed and image quality) as stated above.

1.1 SCOPE OF THE TEST

The evaluation was carried out in three separate tasks. These are summarized below.

Task 1: Film Testing

A sensitometric and image quality evaluation was performed on SO-362 to determine its basic characteristics. Standard sensitometric tests were performed to evaluate emulsion speed as compared to 3404, and spectral sensitivity determinations were made. The resolving power (emulsion threshold) and granularity of SO-362 were measured. Both of these characteristics were also compared with type 3404.

Task 2: Static Pictorial Comparison

To obtain a subjective photointerpreter comparison of image quality between 3404 and SO-362 film, a test was run using the Itek model. This model is a physical reproduction of a typical urban area built to HO scale. It provides the most realistic simulation of aerial photography that is possible in the laboratory. Photographs of this model were taken with both films, at varying exposure conditions, and evaluated by photointerpreters for relative information content.

Task 3: Flight Test in 112B

The model test was aimed at only a simple comparison of the two film materials. The flight test (EKIT Flight Test No. 3) was aimed at evaluating the two materials under dynamic flight conditions. The 112B high altitude aircraft system was used for this test. It was felt that even if SO-362 was slightly worse (in image quality) than 3404, the operational advantage of emulsion speed (and hence, faster exposure times) might be significant and thereby produce better actual system resolution. Both subjective photointerpreter evaluations and quantitative analysis (resolving power and tone reproduction) were made from this test.

This report summarizes the work and results from all tasks even though Task 2 (Static Pictorial Comparison) has been previously reported in EKIT Report No. 1.

1.2 TEST CONCLUSIONS

The results of these tests allow several conclusions that are summarized in the following list.

1. SO-362 is approximately 2.8 times faster than 3404.
2. SO-362 produces a higher fog level, at a greater rate, than does 3404.
3. SO-362, in general, produces a slightly lower gamma than 3404.
4. SO-362 possesses a lower resolving power capability than 3404. This was also demonstrated in the 112B flight test.
5. SO-362 possesses a higher granularity than 3404. This was evident in the PI evaluations where the increased granularity of the SO-362 was objectionable.
6. The image quality of SO-362 degrades rapidly with overexposure in comparison to 3404.
7. SO-362 does not appear to have any real advantage for use with the J-3 system. Its use is not recommended.
8. SO-362 has been discontinued by the manufacturer. It is being replaced by SO-240. The evaluation of the replacement material is recommended.

2. TASK 1: FILM TESTING

A basic sensitometric and image quality evaluation was conducted on SO-362 and compared with 3404. The specific evaluations made were:

1. Emulsion speed
2. Filter factors for Wratten nos. 21 and 25
3. Spectral response
4. Resolving power (emulsion threshold)
5. RMS granularity as a function of net density

2.1 LABORATORY PROCEDURE

Sensitometry

Strips of SO-362, together with control strips of 3404, were exposed in the Herrnfeld model 1531CA sensitometer. The sensitometer exposure time was 1/200 second and laboratory daylight (5900 °K) was the illuminant. The exposed film wedges were processed in Eastman Kodak MX-577 (12DX90), Eastman Kodak D-19, and Itek G-4 (low gamma) developers. Agitation was provided by means of a nitrogen burst sensitometric processor. (1-second burst duration, at 8-second intervals, 15 psi.) The resultant sensitometric strips were read with a MacBeth Model 12A densitometer. The densitometer was first calibrated against a National Bureau of Standards density wedge. This wedge is calibrated to give standard ASA single diffuse density readings. This test procedure was replicated three times to give statistical validity to the test results for the emulsion batch tested.

Filter Factors

In similar manner, the above sensitometric procedures were used to evaluate the filter factors of the two emulsions to Wratten nos. 21 and 25 filters. Strips were exposed on the Herrnfeld sensitometer with Wratten nos. 21 and 25 filters added to the instrument setup noted above.

Resolving Power

Resolving power tests on SO-362 and 3404 were done on the Itek Mark III resolving power camera. This camera is essentially an inverted microscope system that provides very high resolution. Its inherent capability with Eastman Kodak Spectroscopic Film type 649-GH exceeds 2,000 cycles per millimeter. All of the resolving power testing was done in accordance with the latest ASA draft standard for evaluating the resolving power of black and white silver halide emulsions.* The film was processed in D-19. A series of target contrasts were employed to

* These procedures are in common practice at Eastman Kodak, Ansco, DuPont, NBS, Perkin-Elmer, and Itek.

enable specification of the emulsion threshold (AIM curve) for the two materials. The three-bar target transfer function of the resolving power camera was removed from the data to allow specification of the response of the two films to actual impressed modulation.

Spectral Sensitivity

Wedge spectrograms of both SO-362 and 3404 were made on the Itek Model 1 Spectrograph. The spectrograph was set up with laboratory daylight and both film samples were processed in D-19.

RMS Granularity

Film chips of SO-362 and 3404 were prepared for rms granularity evaluation. The chips were exposed by means of a uniform diffuse source, and processed in D-19 by brush agitation to minimize density variations due to processing. The chips produced yielded a series of densities ranging from approximately 0.27 to 1.6. The chips were read on the Intectron Microdensitometer using a 24-micron diameter aperture. In order to allow the calculation of rms density fluctuation (granularity), 1,000 density points were taken for each sample.

2.2 RESULTS

Sensitometry

The results of the sensitometric evaluations are summarized in Tables 2-1, 2-2, and 2-3 and shown graphically in Figs. 2-1 through 2-6. From the sensitometric evaluations, the following conclusions are possible:

1. For maximum emulsion speed processing, and approximately equal fog levels with each developer, SO-362 was from 2.3 to 3.4 times faster than 3404. In MX-577, the maximum useful speed* obtained with SO-362 was 8.1 (fog level = 0.26), and with 3404 it was 3.5 (fog level = 0.20); a speed increase for SO-362 of 2.3. With D-19, the maximum useful speed obtained with SO-362 was 5.0 (fog level = 0.14), and with 3404 it was 1.8 (fog level = 0.12); a speed increase for SO-362 of 2.8. In G-4, the maximum usable speed with SO-362 was 11.8 (fog level = 0.30), and with 3404 it was 3.5 (fog level = 0.31); a speed increase for SO-362 of 3.4.

2. In general, the fog level of SO-362 increased at a greater rate (with increased processing) than did the fog level of 3404. For equivalent processing conditions in MX-577, SO-362 produced fog levels from 0.07 to 0.48, whereas 3404 produced fog levels from 0.06 to 0.20. The results are generally similar for the other developers. The minimum fog production for all developer tests was with D-19.

3. In general, the SO-362 produced lower gammas than did 3404. In MX-577, the gammas for 3404 ranged from 2.1 to 2.9, whereas for SO-362 they ranged from 2.04 to 2.45. In D-19, the gammas ranged from 2.3 to 2.46 for 3404 and 1.9 to 2.36 for SO-362. In G-4 the gammas ranged from 0.33 to 1.14 for SO-362 and 1.0 to 1.50 for 3404.

---

* All film speeds are quoted as Aerial Exposure Index (i.e., 0.6γ speed).

Table 2-1 — MX-577 Developer at 68 °F

Development Time, minutes	γ/0.6 Speed		Fog Level		Gamma	
	3404	SO-362	3404	SO-362	3404	SO-362
1/2	1.2	3.6	0.06	0.07	2.10	2.22
1	1.6	5.6	0.07	0.12	2.80	2.26
1½	2.5	7.6	0.09	0.19	2.90	2.45
2	3.0	8.1	0.12	0.26	2.74	2.15
3	3.5	10.0	0.20	0.48	2.60	2.04

Table 2-2 — D-19 Developer at 68 °F

Development Time, minutes	γ/0.6 Speed		Fog Level		Gamma	
	3404	SO-362	3404	SO-362	3404	SO-362
3	0.70	2.6	0.06	0.05	2.30	1.92
6	1.4	4.0	0.06	0.06	2.34	2.05
9	1.4	4.5	0.07	0.07	2.38	2.10
15	1.6	5.0	0.10	0.10	2.46	2.30
20	1.8	5.0	0.12	0.14	2.44	2.36

Table 2-3 — G-4 Developer at 80 °F

Development Time, minutes	γ/0.6 Speed		Fog Level		Gamma	
	3404	SO-362	3404	SO-362	3404	SO-362
1/2		3.5		0.06		0.33
1¼		8.4		0.10		0.70
1½	3.3		0.08		1.0	
2	3.3	10.7	0.11	0.19	1.26	1.0
2¾		11.8		0.30		1.10
3	3.3		0.19		1.50	
3¼		11.8		0.38		1.14
4	3.5		0.31		1.50	
5	4.0		0.41		1.34	

SENSITOMETRIC DATA SHEET

PROJECT NO.

TITLE Family of curves 3404

FILM (TYPE) 3404

DEV. MX-577 TEMP. 68°F

SENSITOMETER Herrnfeld

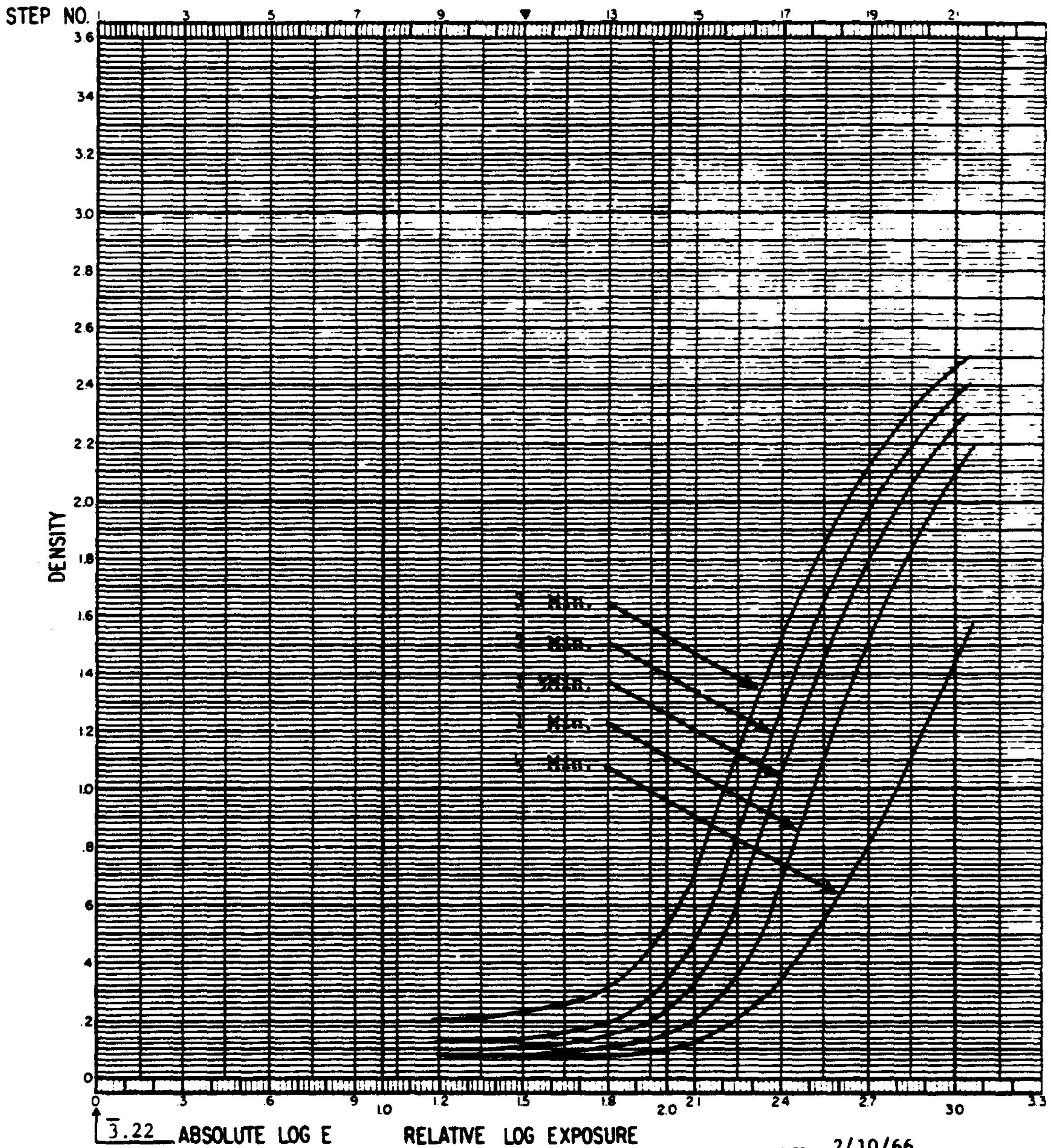
EXPOS. TIME 1/200 sec.

FILTER 1.86 N.D. & Day light

LAMP NO.

EMUL. NO.

DEV.	SPEED γ/.6	FOG	GAMMA
½ Min.	1.2	.06	2.10
1 Min.	1.62	.07	2.80
1 ½ Min.	2.5	.09	2.90
2 Min.	3.0	.12	2.74
3 Min.	3.5	.20	2.60



DATE 2/10/66

Fig. 2-1 — Sensitometric data sheet: 3404 film; MX-577 developer; 68 °F temperature

SENSITOMETRIC DATA SHEET

PROJECT NO. ______

TITLE Family of Curves SO-362

FILM (TYPE) SO-362

DEV. MX577 TEMP. 68°F

SENSITOMETER Herrnfeld

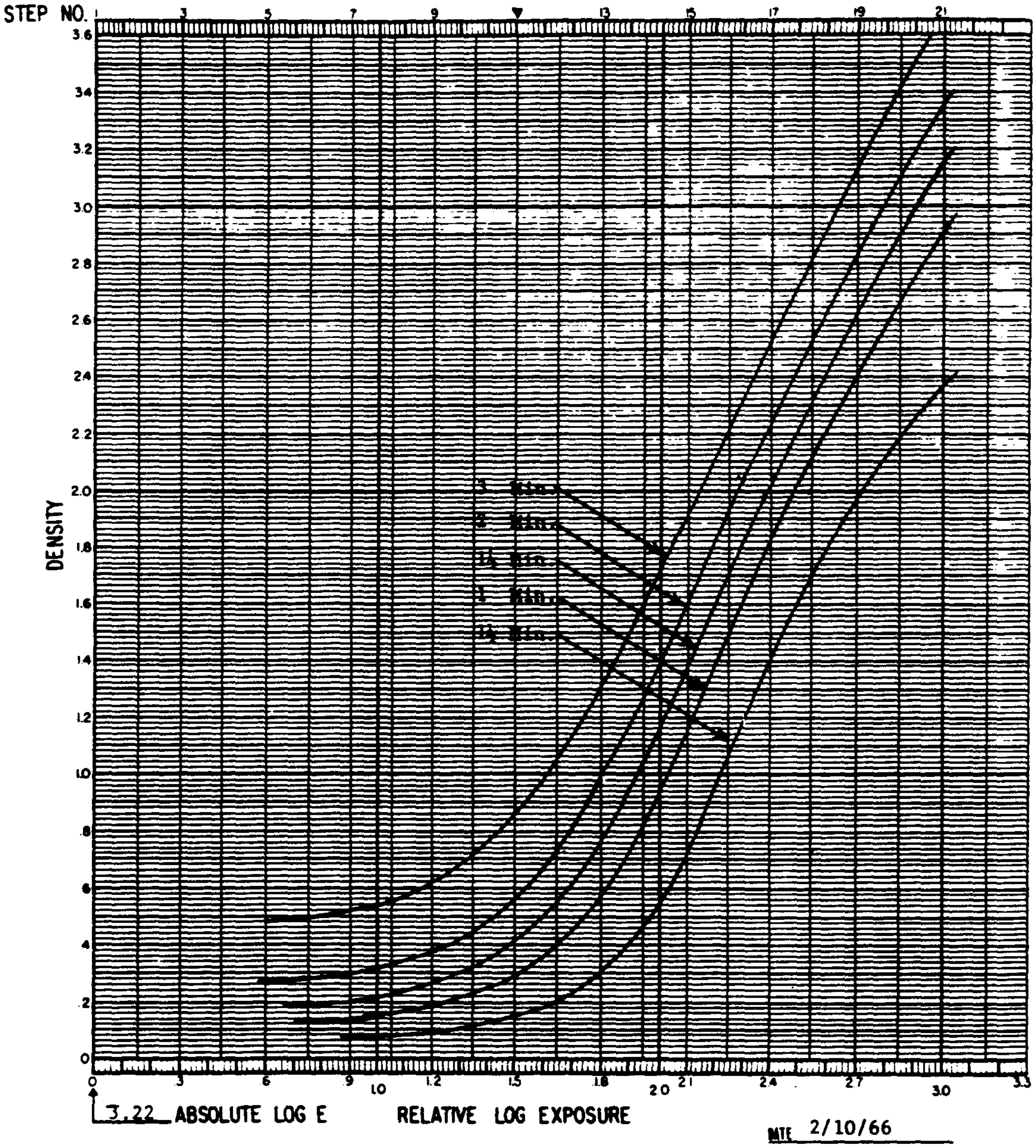
EXPOS. TIME 1/200 sec.

FILTER 1.86 N.D. & Daylight

LAMP NO. ______

EMUL. NO. ______

DEV. (Y/.6)	SPEED	FOG	GAMMA
½ Min.	3.6	.07	2.22
1 Min.	5.6	.12	2.26
1½ Min.	7.6	.19	2.15
2 Min.	8.1	.26	2.15
3 Min.	10.0	.48	2.04



DATE 2/10/66

Fig. 2-2 — Sensitometric data sheet: SO-362 film; MX-577 developer; 68 °F temperature

SENSITOMETRIC DATA SHEET

PROJECT NO.

TITLE Family of Curves 3404

SENSITOMETER Herrnfeld

EXPOS. TIME 1/100 sec.

FILTER 1.43 N.D. & Daylight

LAMP NO.

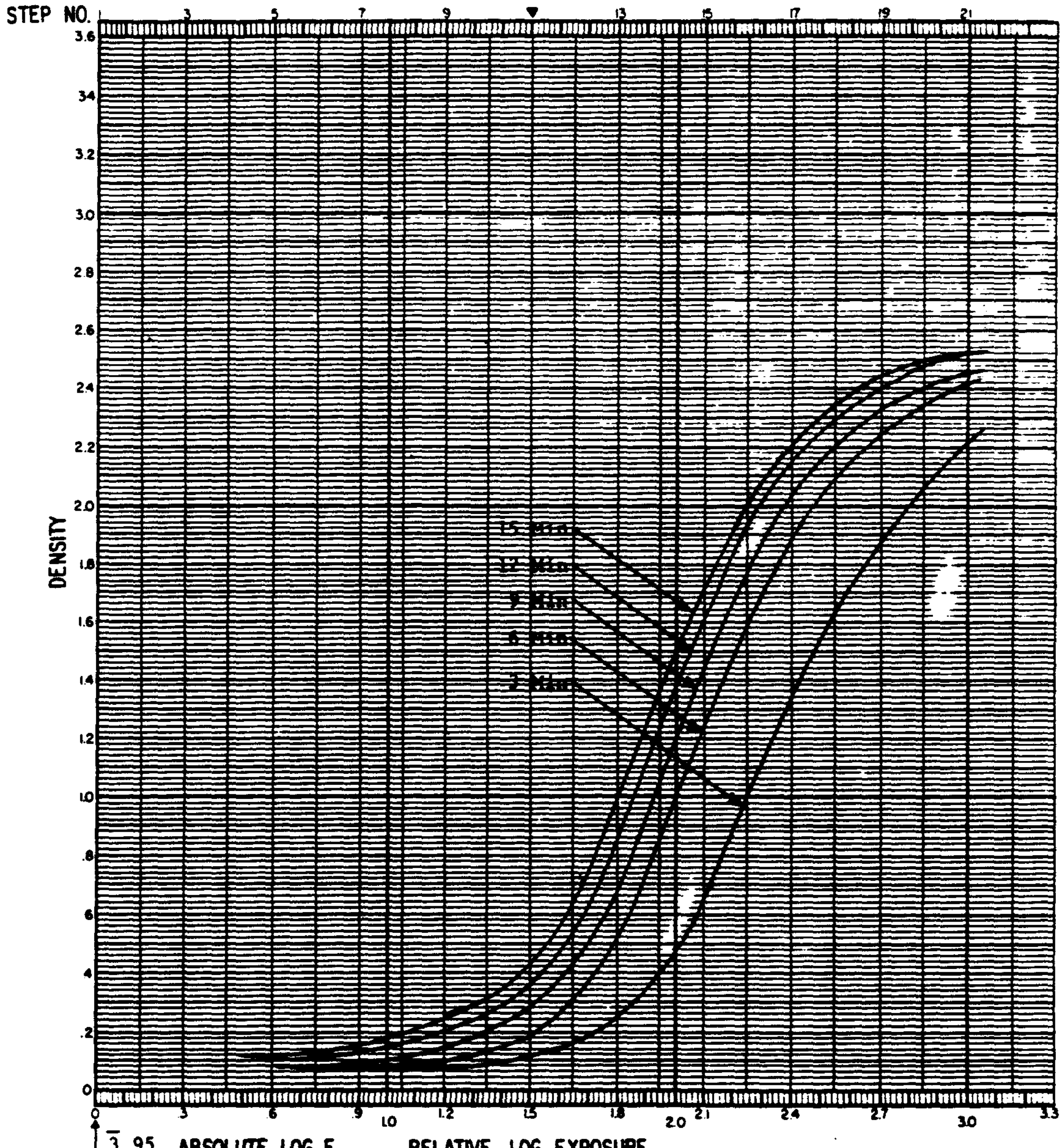
EMUL NO. 204-2

FILM (TYPE) 3404

DEV D-19 TEMP 68 °F

γ/.6

TIME	SPEED	FOG	GAMMA
3 Min.	.70	.06	2.30
6 Min.	1.4	.07	2.34
9 Min.	1.4	.07	2.38
12 Min.	1.6	.10	2.46
15 Min.	1.8	.12	2.44



DATE 3/9/66

Fig. 2-3 — Sensitometric data sheet: 3404 film; D-19 developer; 68 °F temperature

SENSITOMETRIC DATA SHEET

PROJECT NO. ____________

TITLE Family of Curves SO-362

SENSITOMETER Herrnfeld

EXPOS. TIME 1/200 sec.

FILTER 1.86 N.D. & 5900 Daylt.

LAMP NO. ____________

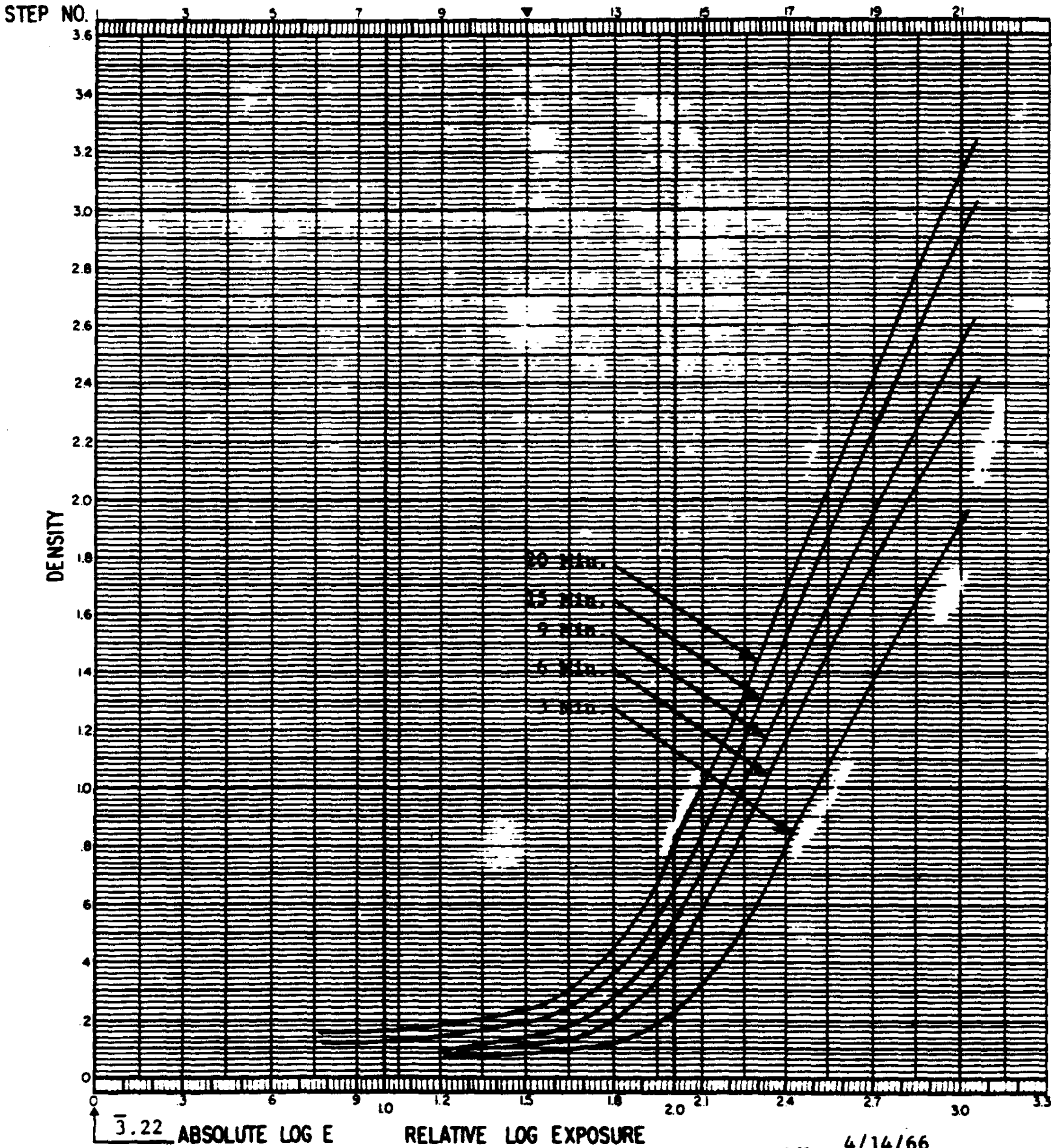
EMUL. NO. ____________

FILM (TYPE) SO-362

DEV. D-19 TEMP 68°F

Y/.6

DEV.	SPEED	FOG	GAMMA
3 Min.	2.6	.05	1.92
6 Min.	4.0	.06	2.05
9 Min.	4.5	.07	2.10
15 Min.	5.0	.10	2.30
20 Min.	5.0	.14	2.36



DATE 4/14/66

Fig. 2-4 — Sensitometric data sheet: SO-362 film; D-19 developer; 68 °F temperature

SENSITOMETRIC DATA SHEET

PROJECT NO.

TITLE Family of Curves 3404

FILM (TYPE) 3404

DEV. G-4 TEMP 80°F

SENSITOMETER Herrnfeld

EXPOS. TIME 1/200 sec.

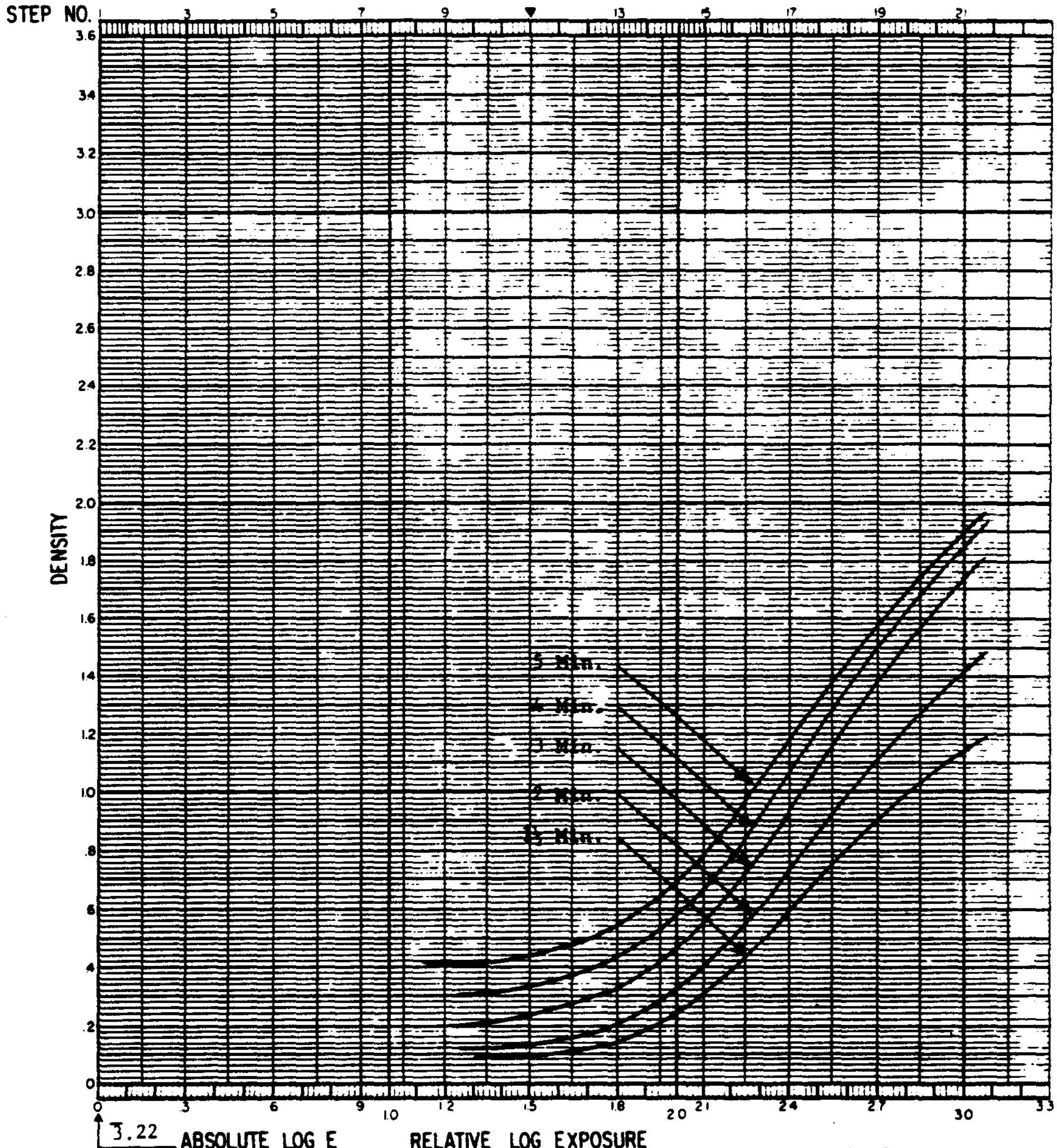
FILTER 1.43 N.D. & 5900 Daylt

LAMP NO.

EMUL NO. 73-7H

γ/.6

DEV.	SPEED	FOG	GAMMA
1½ Min.	3.3	.08	1.0
2 Min.	3.3	.11	1.26
3 Min.	3.3	.19	1.50
4 Min.	3.5	.31	1.50
5 Min.	4.0	.41	1.34



DATE 4/28/66

Fig. 2-5 — Sensitometric data sheet: 3404 film; G-4 developer; 80 °F temperature

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SENSITOMETRIC DATA SHEET

PROJECT NO. ____

TITLE Family of Curves SO-362

SENSITOMETER Herrnfeld

EXPOS. TIME 1/200 sec.

FILTER 1.43 N.D. & 5900 Daylt.

LAMP NO. ____

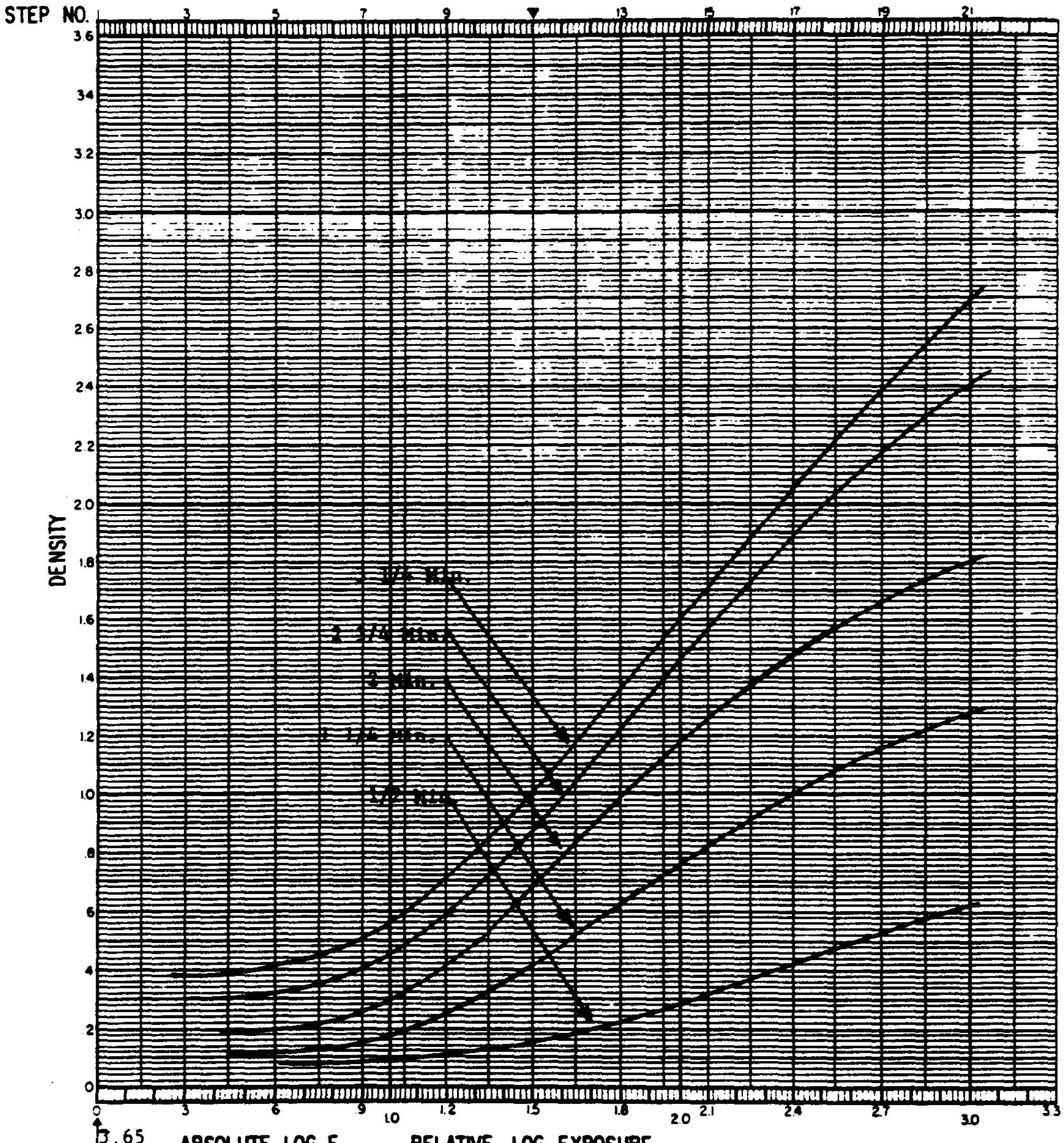
EMUL. NO. ____

FILM (TYPE) SO-362

DEV. G-4 TEMP. 80 °F

γ/.6

DEV.	SPEED	FOG	GAMMA
1/2 Min.	3.5	.06	.33
1½ Min.	8.4	.10	.70
2 Min.	10.7	.19	1.0
2 3/4Min	11.8	.30	1.10
3 1/4Min	11.8	.38	1.14



DATE 4/11/66

Fig. 2-6 — Sensitometric data sheet: SO-362 film; G-4 developer; 80 °F temperature

Spectral Sensitivity

The wedge spectrograms in Fig. 2-7 illustrate the relative spectral sensitivity of the two films. From this analysis it is evident that in the area of interest (500 to 700 millimeters) the films possess approximately equal sensitivity. This is verified by the filter factor analysis (Figs. 2-8 and 2-9) where it is shown that the filter factors for both films are, for all practical purposes, equal. The filter factors are summarized in Table 2-4.

Table 2-4 — Filter Factors

Film	Wratten Filter No. 12	21	25
SO-362	1.6	2.2	3.8
3404	1.5	2.0	3.5

Resolving Power

The resolving power test results are shown in Table 2-5 and Fig. 2-10 for D-19 processing. The data in Table 2-5 quotes the resolving power in the conventional manner (i.e., cycles per millimeter resolved versus original target contrast), whereas the data in Fig. 2-10 is plotted versus impressed target modulation. From the data it is clear that SO-362 does not possess as high an inherent resolution capability as 3404. At 1,000:1 contrast, 3404 produces 540 cycles per millimeter whereas SO-362 produces 450 cycles per millimeter. At 1.6:1 contrast, 3404 produces 200 cycles per millimeter whereas SO-362 produces 160 cycles per millimeter.

Granularity

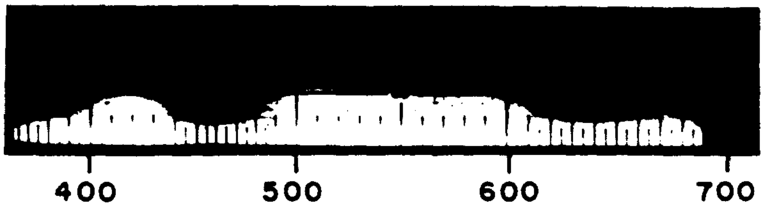
The results of the granularity comparison are shown in Fig. 2-11. At a net density of 1.0, 3404 possesses an rms granularity of 0.016, and SO-362 possesses an rms granularity of 0.0273. SO-362 maintains a consistently higher granularity (for the density range measured) over 3404.

2.3 TASK 1 CONCLUSIONS

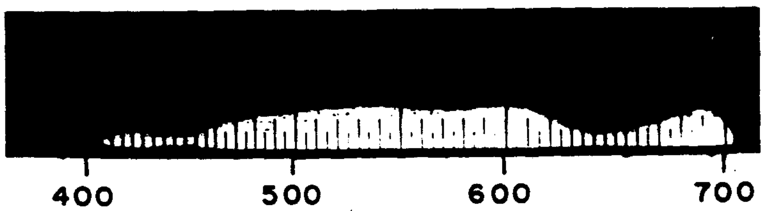
This series of basic film evaluations has indicated that under identical exposure conditions, SO-362 does possess increased emulsion speed over 3404, being approximately 2.8 times faster depending on the processing conditions. In addition, it produces generally higher fog and slightly lower gamma than 3404. SO-362 has approximately 20 percent lower resolution than type 3404, and increased granularity. Whether or not this is significant from a J-3 system standpoint cannot be proven from this series of evaluations.

Wedge Spectrograms

Exposure to Daylight



Experimental High Definition Type SO-362



Type 3404 Control

Fig. 2-7 — Wedge spectrograms exposure to daylight

SENSITOMETRIC DATA SHEET

PROJECT NO.

FILM (TYPE) SO-362

TITLE Filter Factor Comparison

DEV D-19 TEMP 68°F

Filter	Factor
W #12	1.6
W #21	2.2
W #25	3.8

SENSITOMETER Herrnfeld

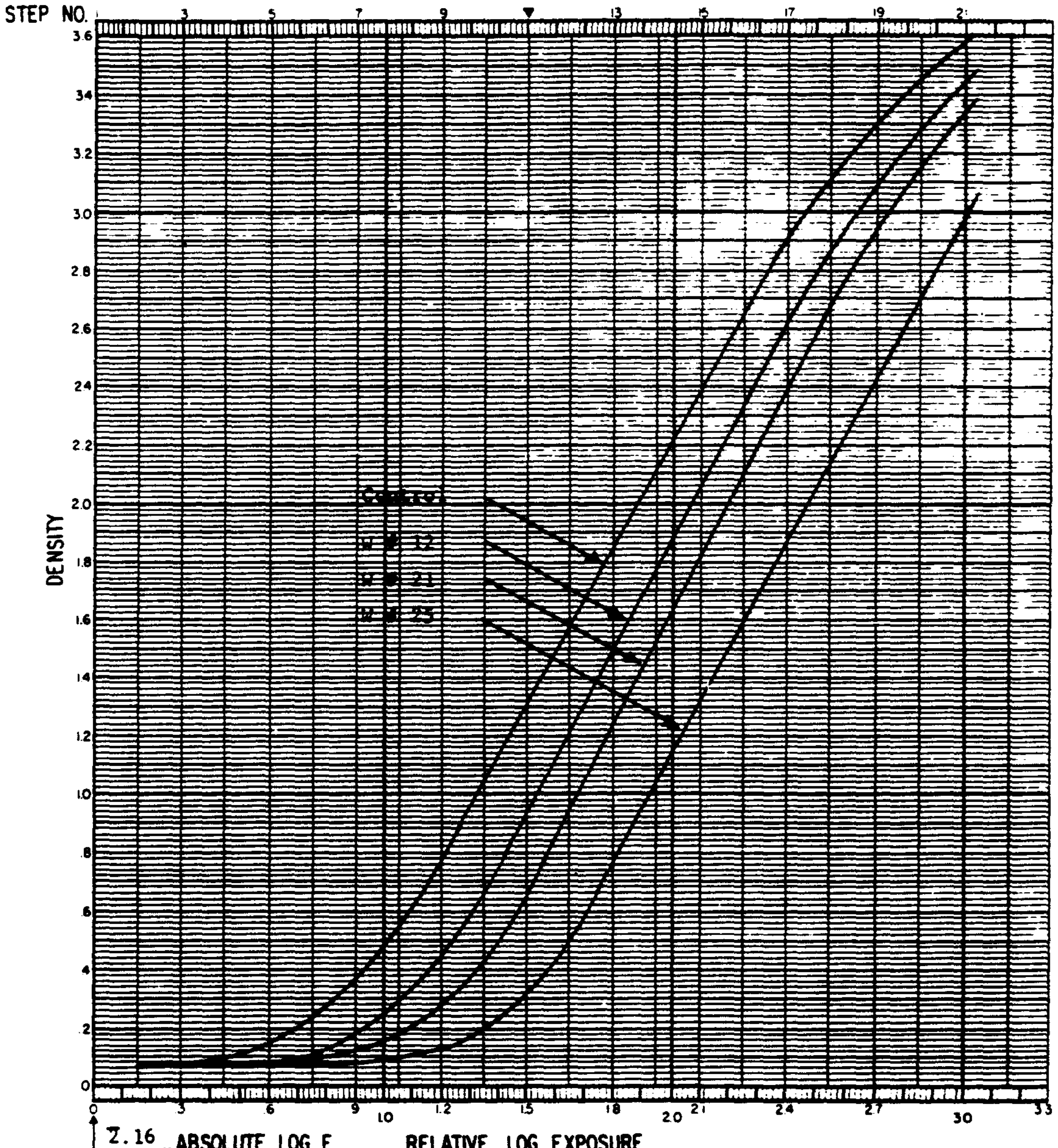
EXPOS. TIME 1/200 sec.

FILTER .92 N.D. & 5900 Daylight

LAMP NO.

EMUL. NO.

TIME	SPEED	FOG	GAMMA
Control		.07	
W-12		.07	
W-21		.07	
W-25		.07	



DATE 5/4/66

Fig. 2-8 — Sensitometric data sheet: SO-362 film; D-19 developer; 68 °F temperature

SENSITOMETRIC DATA SHEET

PROJECT NO.

FILM (TYPE) 3404

TITLE Filter Factor Comparison

DEV. D-19 6 Min. TEMP. 68°F

Filter	Factor
W#12	1.5
W#21	2.0
W#25	3.5

SENSITOMETER Herrnfeld

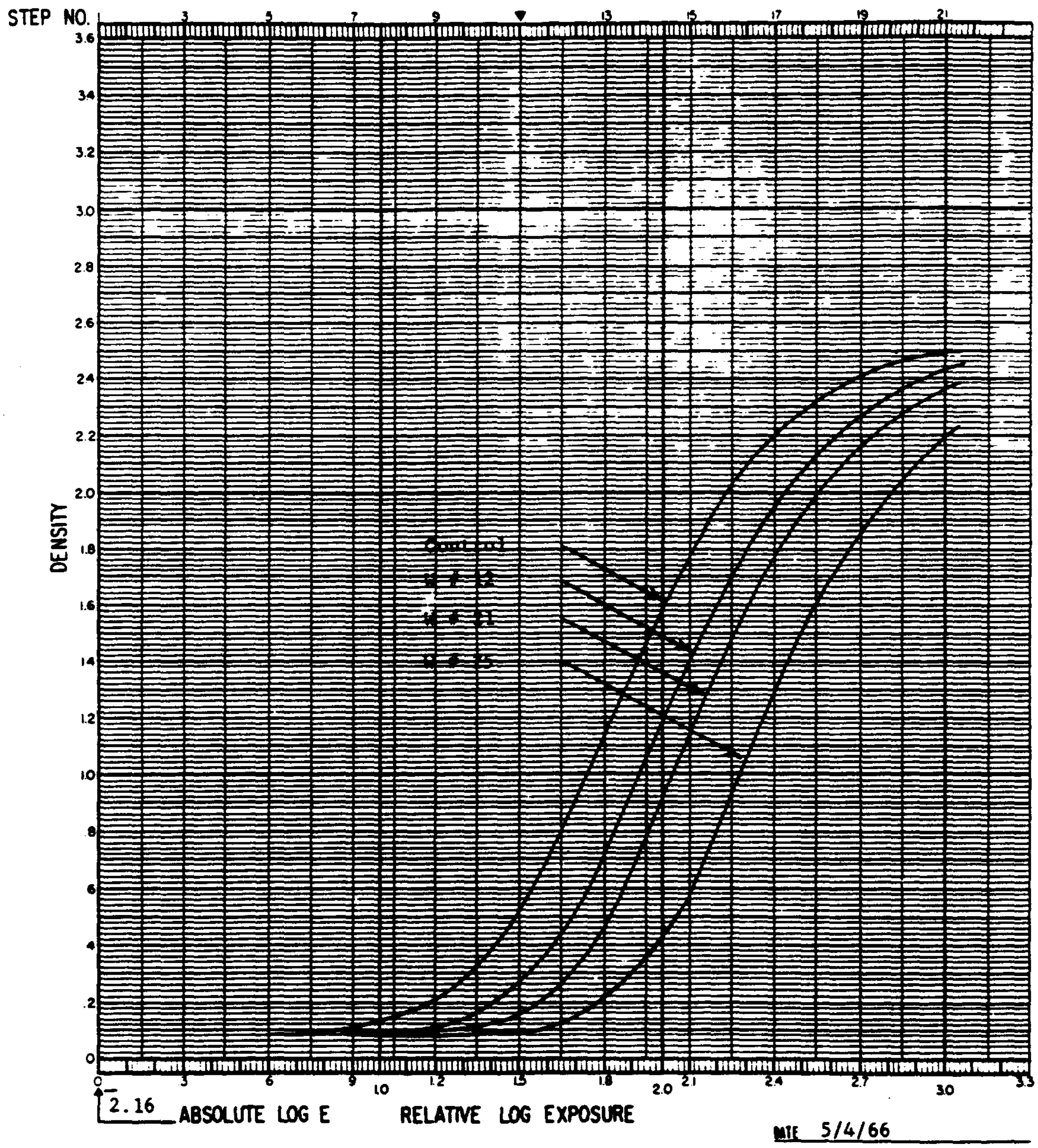
EXPOS. TIME 1/200 Sec.

FILTER .92 N.D. & 5900 Daylight

LAMP NO.

EMUL. NO.

VAR.	SPEED	FOG	GAMMA
Control		.07	
W # 12		.07	
W # 21		.07	
W # 25		.07	



DATE 5/4/66

Fig. 2-9 — Sensitometric data sheet: 3404 film; D-19 developer; 68 °F temperature

Table 2-5 — Resolving Power Comparison, cycles per millimeter

Target Contrast	SO-362 With D-19	3404 With D-19
1000:1	450	540
6.3:1	350	420
2:1	190	280
1.6:1	160	200
1.2:1	94	120
1.1:1	–	54

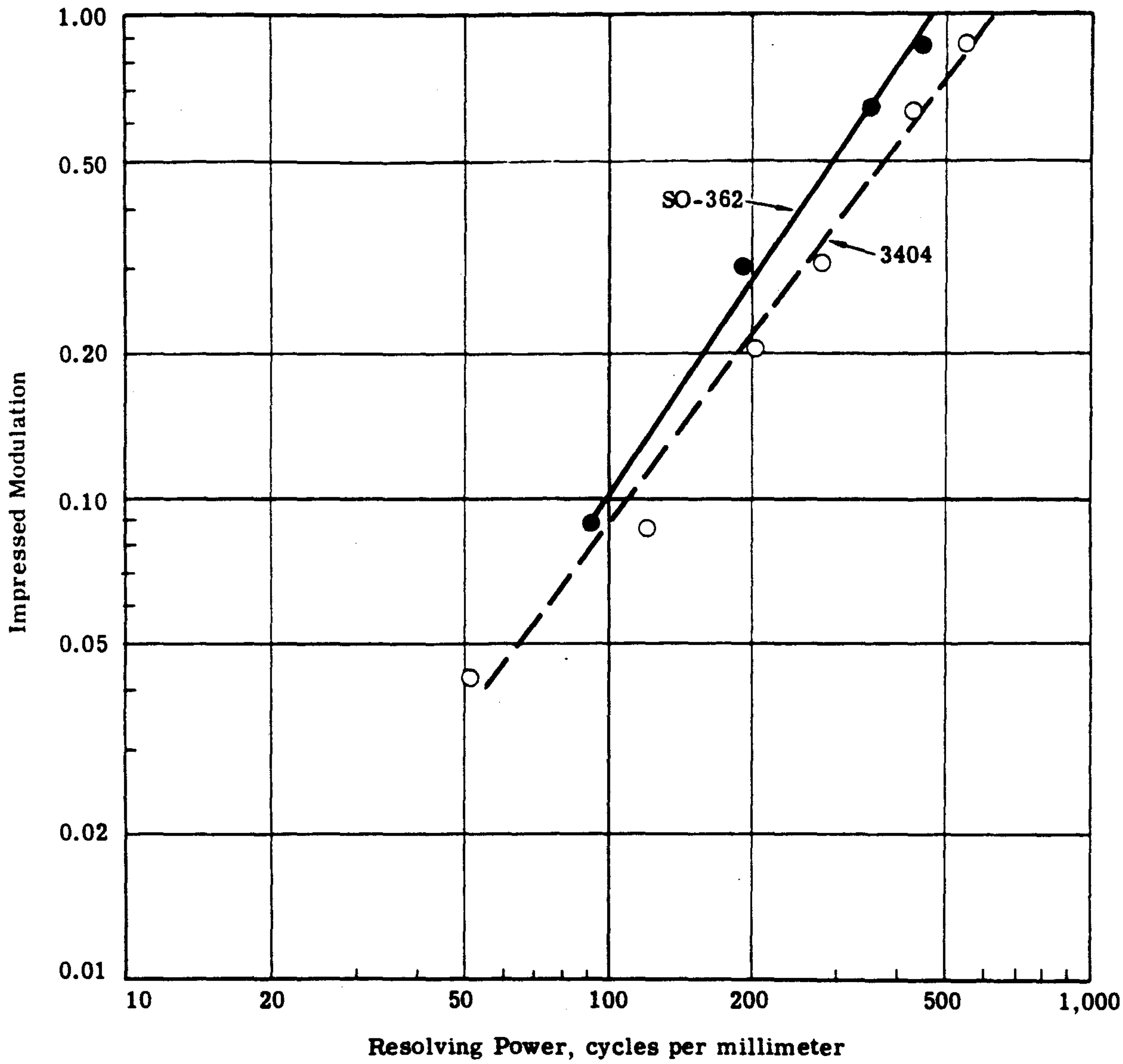


Fig. 2-10 — Emulsion thresholds (AIM curves) for 3404 and SO-362

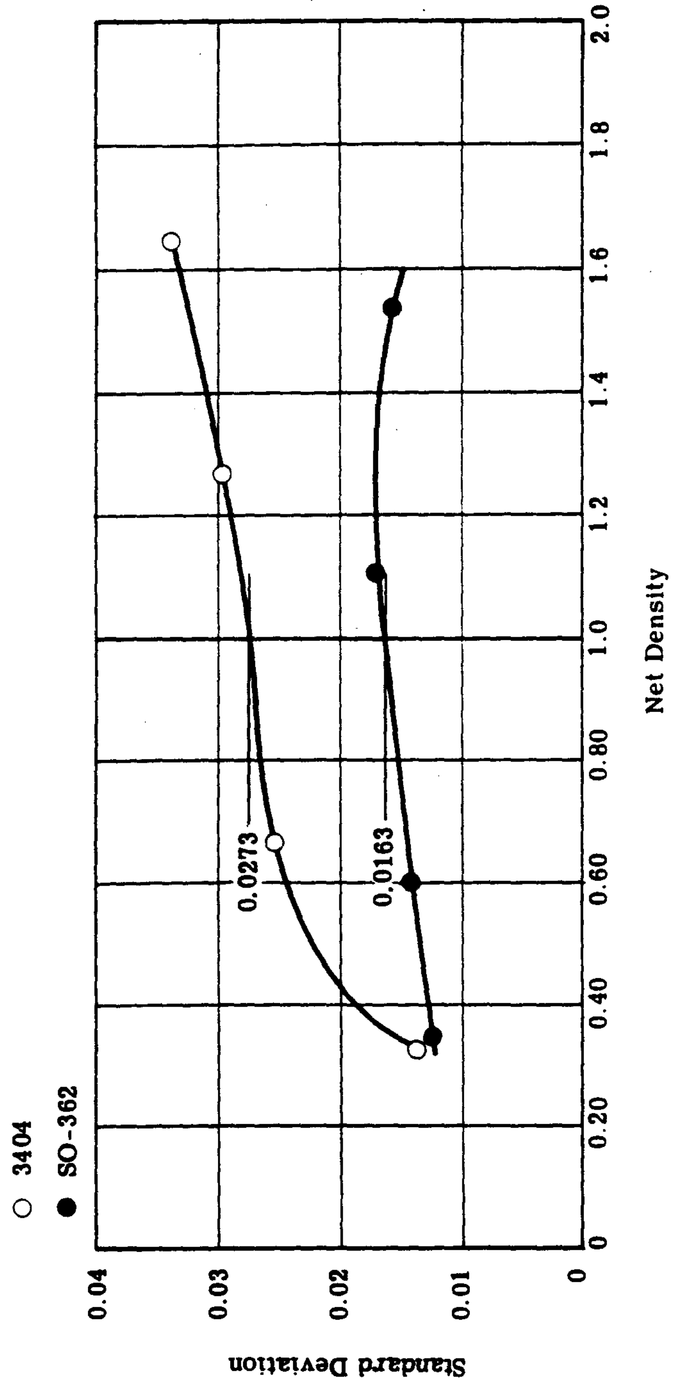


Fig. 2-11 — RMS granularity versus net density

3. TASK 2: STATIC PICTORIAL COMPARISON*

In order to simulate an aerial scene, a model was used that consisted of wooded terrain, highways, secondary roads, a railroad, and a small town. The illumination was arranged to represent a sun:sky ratio of 3:1 with the sun at a solar altitude of 55 degrees. In order to more fully simulate the operational system, a lens was chosen so that the low contrast resolution of the system would be on the order of 100 cycles per millimeter. Fig. 3-1 illustrates the model.

A series of exposures were made and the "normal" exposure was chosen for its overall qualities (i.e., enough shadow detail without blocked-up highlights). The remaining two images were compared for over- and underexposure relative to the best exposure.

All negatives were duplicated on Eastman Kodak 8430 film in order to obtain a good positive image. Since the original negatives included a wide range of exposures, the criterion for duplication was that a good positive be obtained no matter what negative was being printed. This criterion was again used with reference to the tonal reproduction of both the shadow and highlights.

Subjective evaluations were made on both the original negatives and the duplicates. Physical measures were made on the original negatives. The purpose of this task was to perform a subjective and objective analysis of the comparison of the two films, on actual imagery, without the variability normally introduced by an operational system.

3.1 SUBJECTIVE ANALYSIS

A microscopic examination of the negatives from the two systems revealed that the fine detail achieved in the 3404 imagery was superior to that of the SO-362. Objects such as railroad switching (Fig. 3-2), radar dish antenna, and houses reproduced better at the normal exposure level with the 3404. It required a very high magnification (100×), however, to detect these differences. At 15× magnification, absolutely no difference was detected in the two materials at the normal exposure. At the higher magnifications, the increased graininess of the SO-362 (Figs. 3-2 and 3-3) is immediately apparent.

It should be noted that several observers have differed on the relative merits of the two materials in specific instances. Fig. 3-3 has been included in this report to show one such case. The difference in graininess and contrast has made these particular areas appear to have similar detail.

An examination of several areas as a function of exposure has shown that there is a definite increase in image degradation with the SO-362 at the higher exposure levels. Areas such as the fine structures of the house under construction blocked up to the extent that the studs could not be

*Note: This work was reported in EKIT Report No. 1, "Model Comparison of SO-362 and 3404 Films." The data and analysis are reported here for completeness of the final report.

seen on the overexposed SO-362. The 3404 film, though, had the ability to retain the identity of the studs on its overexposed samples. Figs. 3-4 and 3-5 illustrate the differences in the two materials at one stop over and one stop under normal exposure. The resolution figures from the targets also indicated a similar trend (see Table 3-1). The normally exposed samples of 3404 achieve approximately 16 percent higher resolution. The trend of decreasing resolution with increasing exposure is evident in the SO-362 figures, while the differences in the 3404 figures are slight. The underexposed sample of SO-362 achieves resolution closer to that of the normally exposed 3404, but these should not be compared since there are tonal losses in the SO-362 that contribute to a loss in information.

3.2 OBJECTIVE EVALUATION

During the original photography, a simulated CORN target array was placed in the scene. All photography, therefore had low contrast resolution targets and edges from which MTF measurements could be made. Edge traces were obtained by scanning the edge of the photometric patch in the resolution target with an effective 0.6-micron slit. To ensure against an error being introduced by scanning an image that was perhaps slightly out of focus, all four replicate pictures were scanned at each exposure level of both films. MTF's were obtained for the SO-362 film at the one stop under, normal, and one stop over exposure levels. The MTF's for the 3404 film were obtained only at the one stop under and normal exposure levels. Since the shoulder of the 3404 characteristic curve is lower than that of the SO-362, considerable error was introduced in the 3404 overexposed MTF measurements. However, the long straight line portion of the SO-362 permitted more reliable determination of its overexposed images MTF.

Fig. 3-6 represents the two characteristic curves for the materials as used in the test. Since the SO-362 is designated as a special order film, one should not interpret its characteristic curve as representative of the material as it will be in its production run form.

The variation in MTF for the SO-362 system as a function of exposure is illustrated in Fig. 3-7. There is a distinct improvement in the measured MTF as the exposure is decreased. The characteristic curve of the SO-362 encompasses a very large log exposure range. Thus it is possible to obtain reliable MTF measurements over a wide range of exposure. The experimental error in these measurements is in comparison to the differences in these MTF's down to a modulation of 10 percent. Compare the order of transfer function with that of the resolution in Table 3-1. The trend of decreasing quality with increasing exposure is present in both the MTF's and resolution values.

The MTF's for the two exposure levels of the 3404 system are illustrated in Fig. 3-8. In this case no significant difference is found in the two MTF's. A comparison of resolution values (refer to Table 3-1) also indicates that there is no conclusive difference in the image quality; in fact, there is hardly any difference over the range of two stops in exposure.

A comparison of the MTF's for the two systems is made by comparing the 1-sigma spread of the data in both materials' MTF's, as shown in Fig. 3-9. The MTF of the system using 3404 is clearly higher over most of the transfer function.

The MTF's for the microdensitometer and for the 3404 film were divided into the 3404 system MTF. The AIM curves (from Eastman Kodak's laboratories) were used at the 4:1 and 2:1 contrasts in Fig. 3-10. The predicted resolution for the 4:1 contrast is 125 cycles per millimeter, while that of the corresponding resolution target was 146 cycles per millimeter. The lower contrast prediction is 114 cycles per millimeter as compared to the 100 from the resolution target.

In both cases, the predicted values are in error by 14 percent; however, in one case it is high and in the other case it is low. This gives an indication of the inherent error in this type of measurement, that is, plus or minus approximately a target element.

3.3 TASK 2 CONCLUSIONS

A simulated photographic experiment was used to determine the comparative image quality characteristics of Eastman Kodak SO-362 and 3404 films when used at an approximate system resolution of 100 cycles per millimeter (low contrast). A subjective evaluation showed a subtle but definite improvement in the detection capability of minute detail with the 3404, which has also been found to be less sensitive than the SO-362 to changes in exposure level.

The MTF of the 3404 system is higher than that of the SO-362 system at the normal exposure level. However, since the SO-362 MTF was found to vary as a function of exposure (whereas that of the 3404 did not), there were MTF's from the SO-362 system that were better than MTF's from the 3404. However, tonal detail was lost in these underexposed images.

It is concluded that, on an equal treatment basis, the 3404 performs in a manner superior to that of the SO-362. It does not, however, answer the question of their relative quality in an operational system where equal treatment is not the case and the exposure-time/image motion factor is included.

Table 3-1 — Resolution Comparison of SO-362 and 3404 Film

Film	Aperture	Resolution, lines per millimeter, at contrast ratio of 4:1	Resolution, lines per millimeter, at contrast ratio of 2:1
	1 stop under	145	107
SO-362	Normal	133	94
	1 stop over	125	67
	1 stop under	148	105
3404	Normal	155	110
	1 stop over	141	100

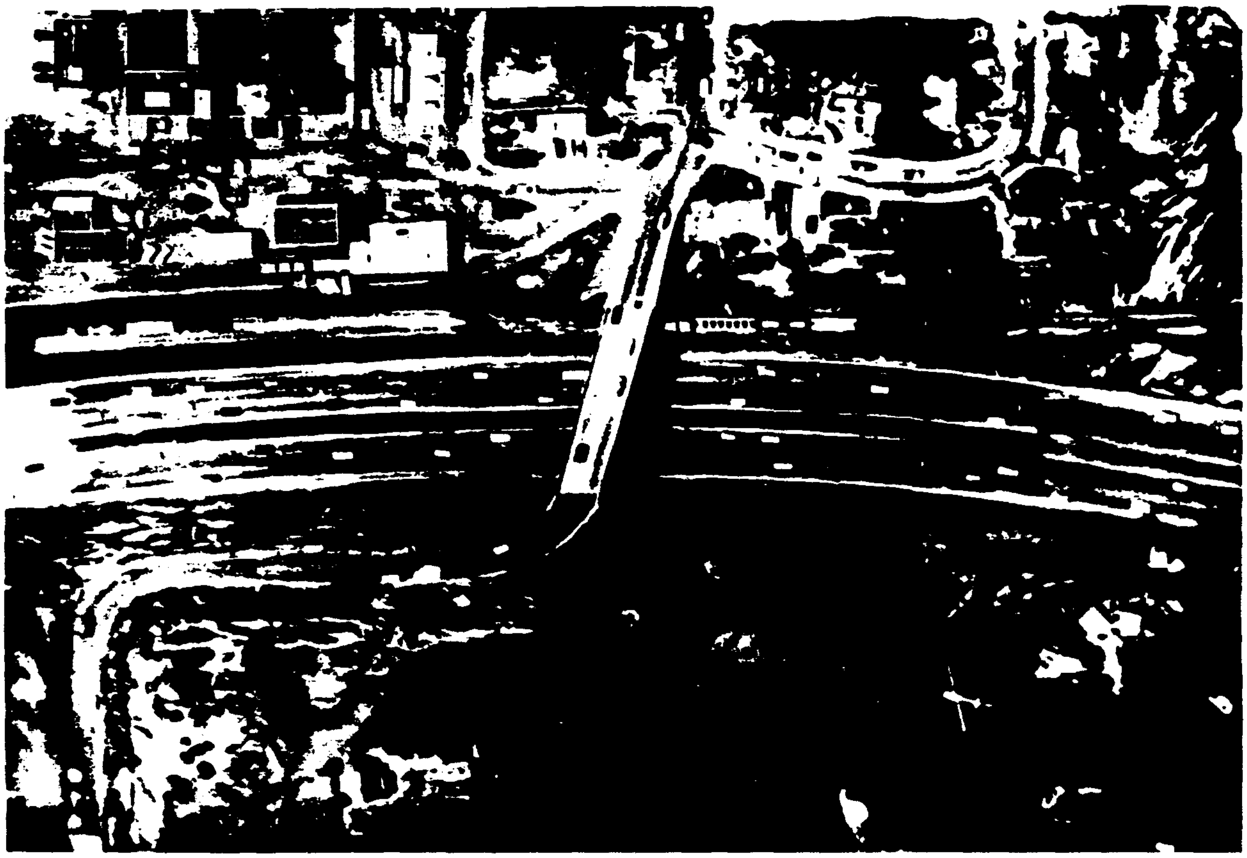


Fig. 3-1 — Model used in film comparison

SO-362

3404

Fig. 3-2 — 110× microphotographs of railroad tracks with 3404 and SO-362 at the normal exposure levels

SO-362

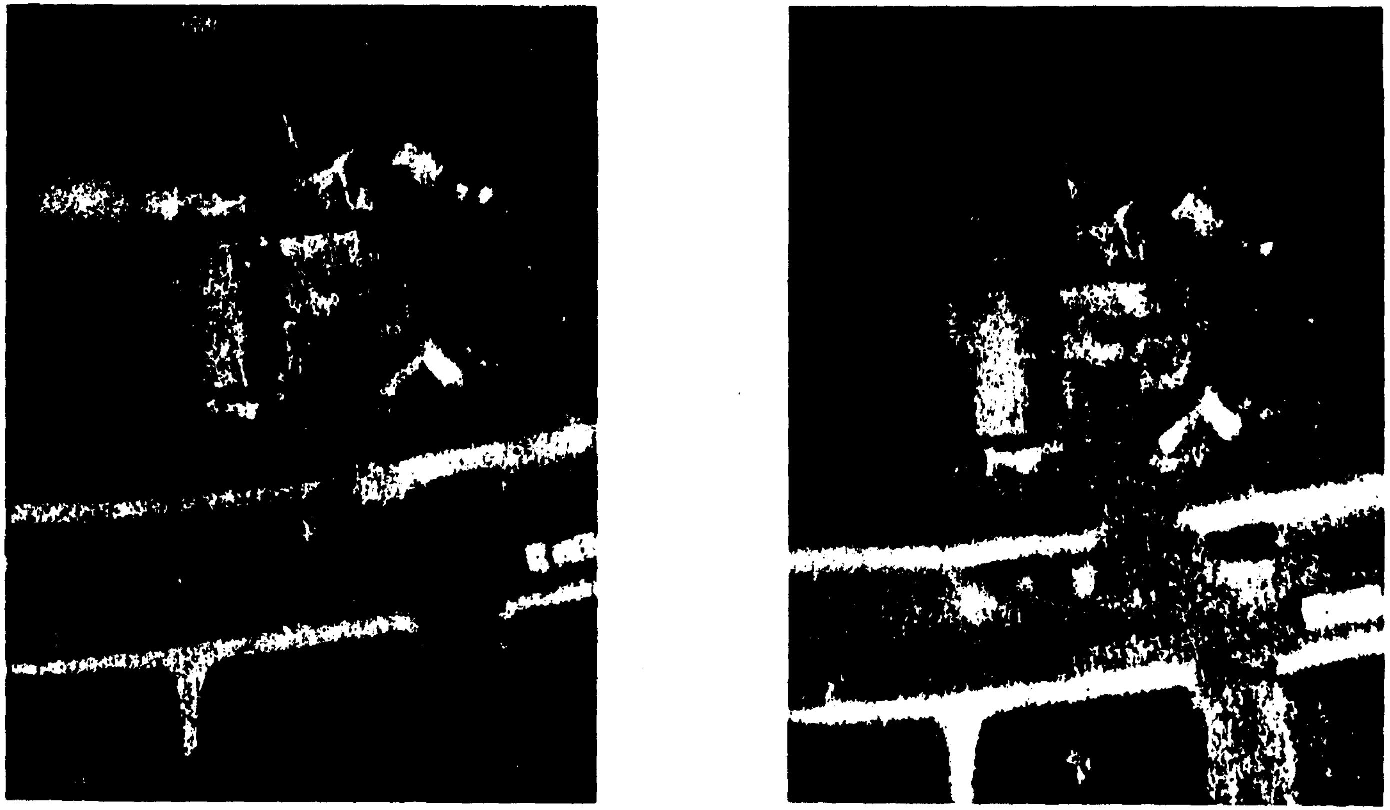
3404

Fig. 3-3 — 110× microphotographs of house construction with 3404 and SO-362 at the normal exposure levels

3404

SO-362

Fig. 3-4 — 110× microphotographs of house construction with underexposed SO-362 and 3404 film



3404 SO-362

Fig. 3-5 — 110× microphotographs of house construction with overexposed SO-362 and 3404 film

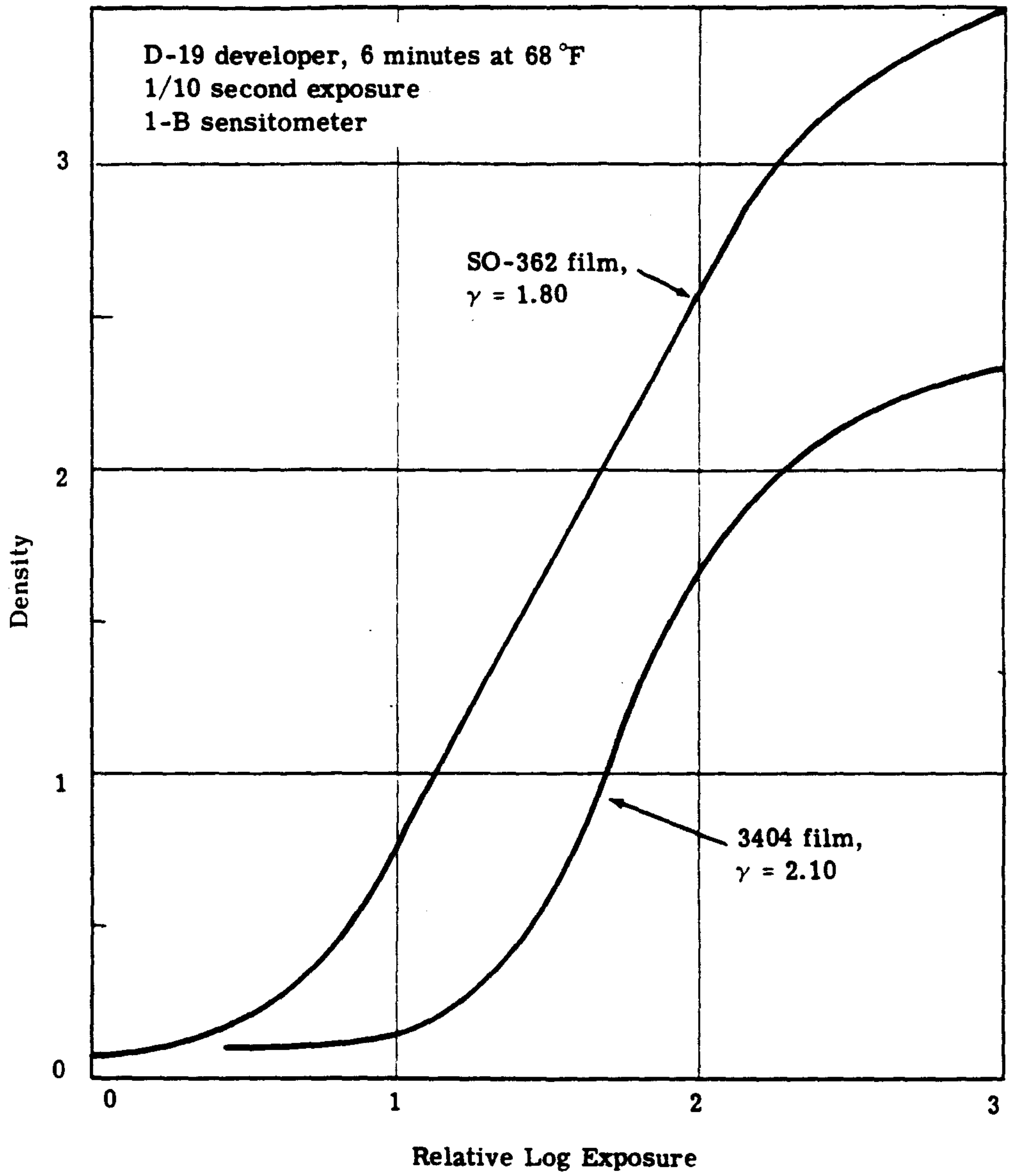


Fig. 3-6 — Characteristic curves for SO-362 and 3404 films from the model test

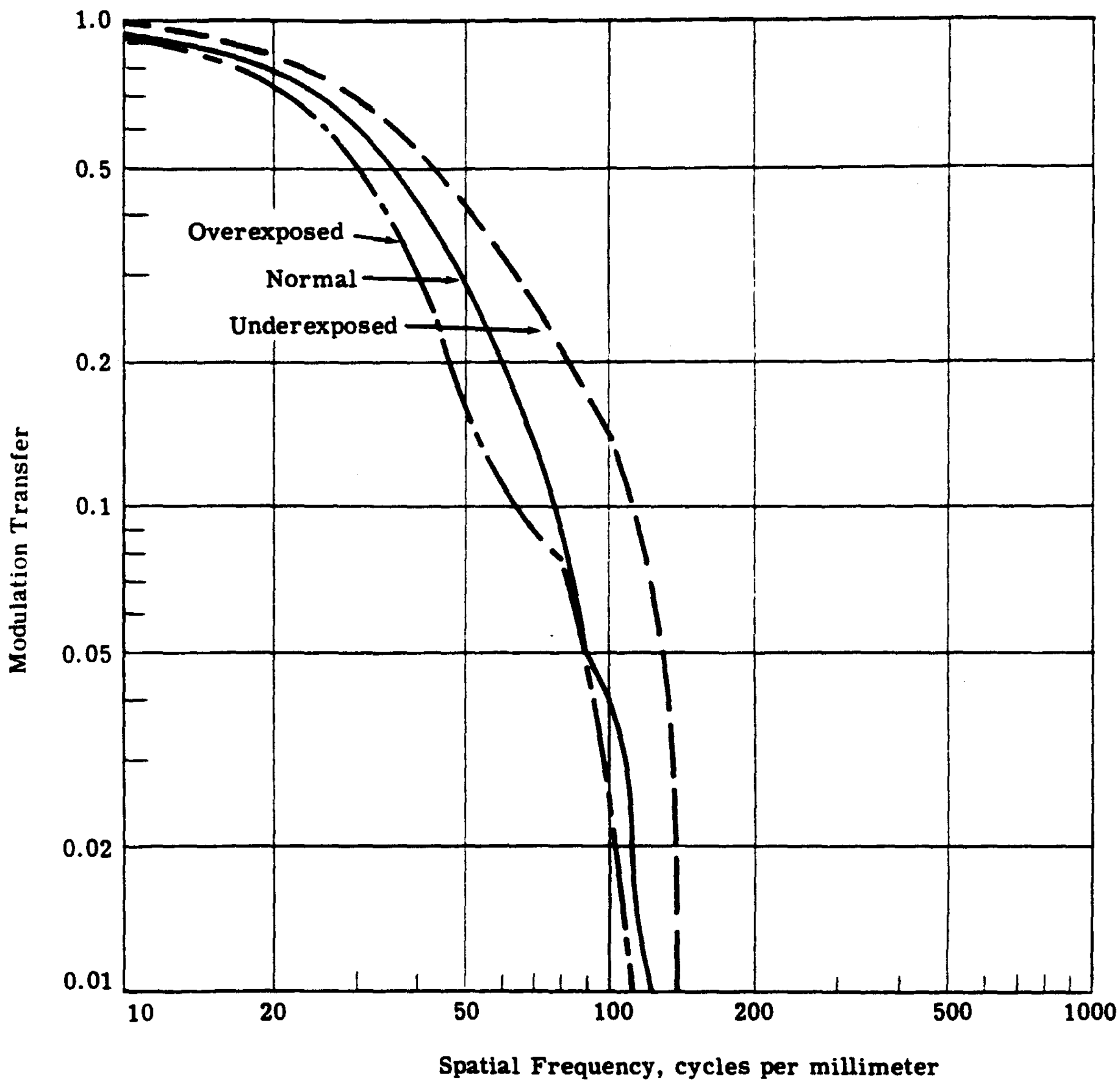


Fig. 3-7 — MTF for the SO-362 system at three exposure levels

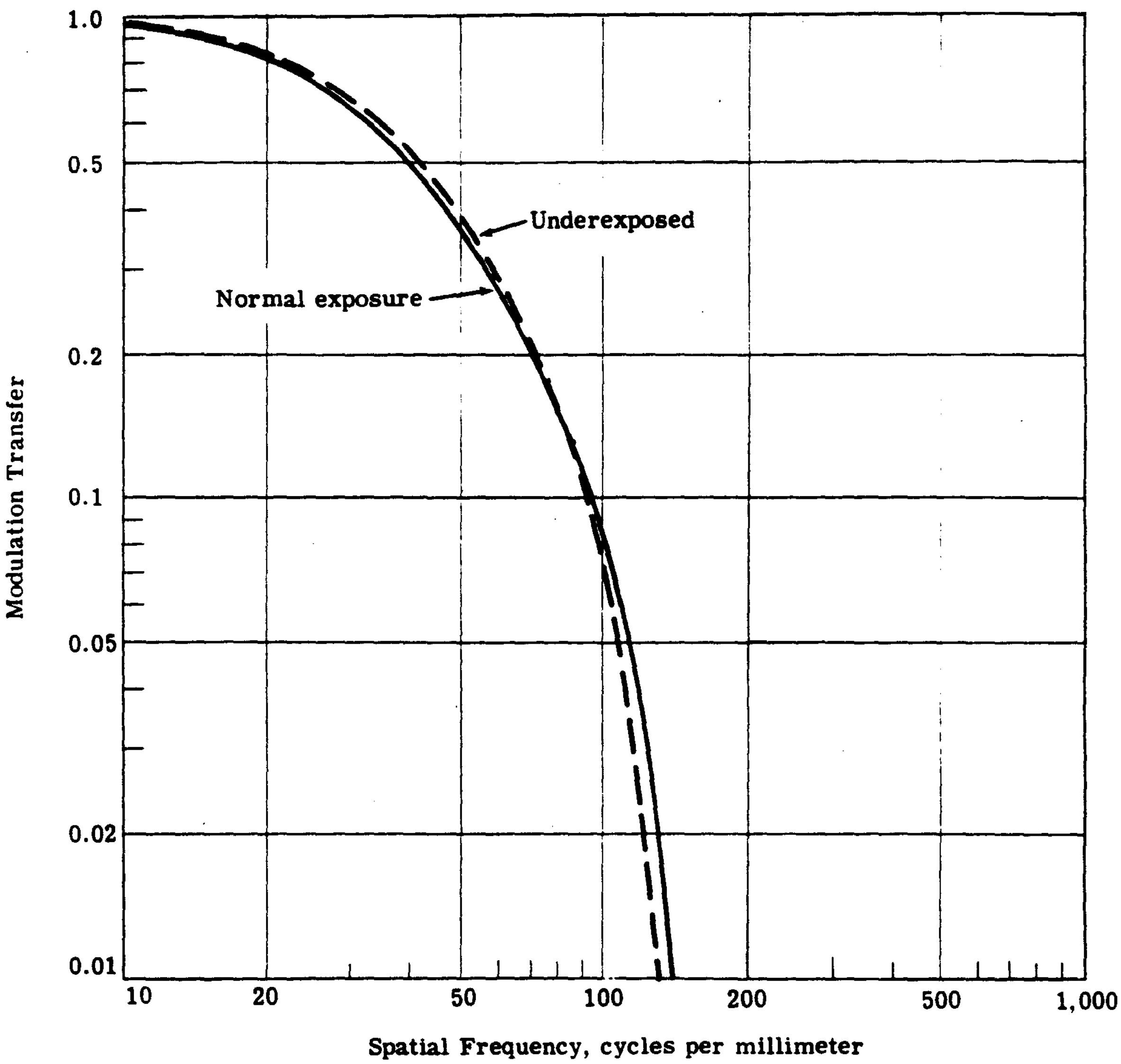


Fig. 3-8 — MTF for the 3404 system at two exposure levels

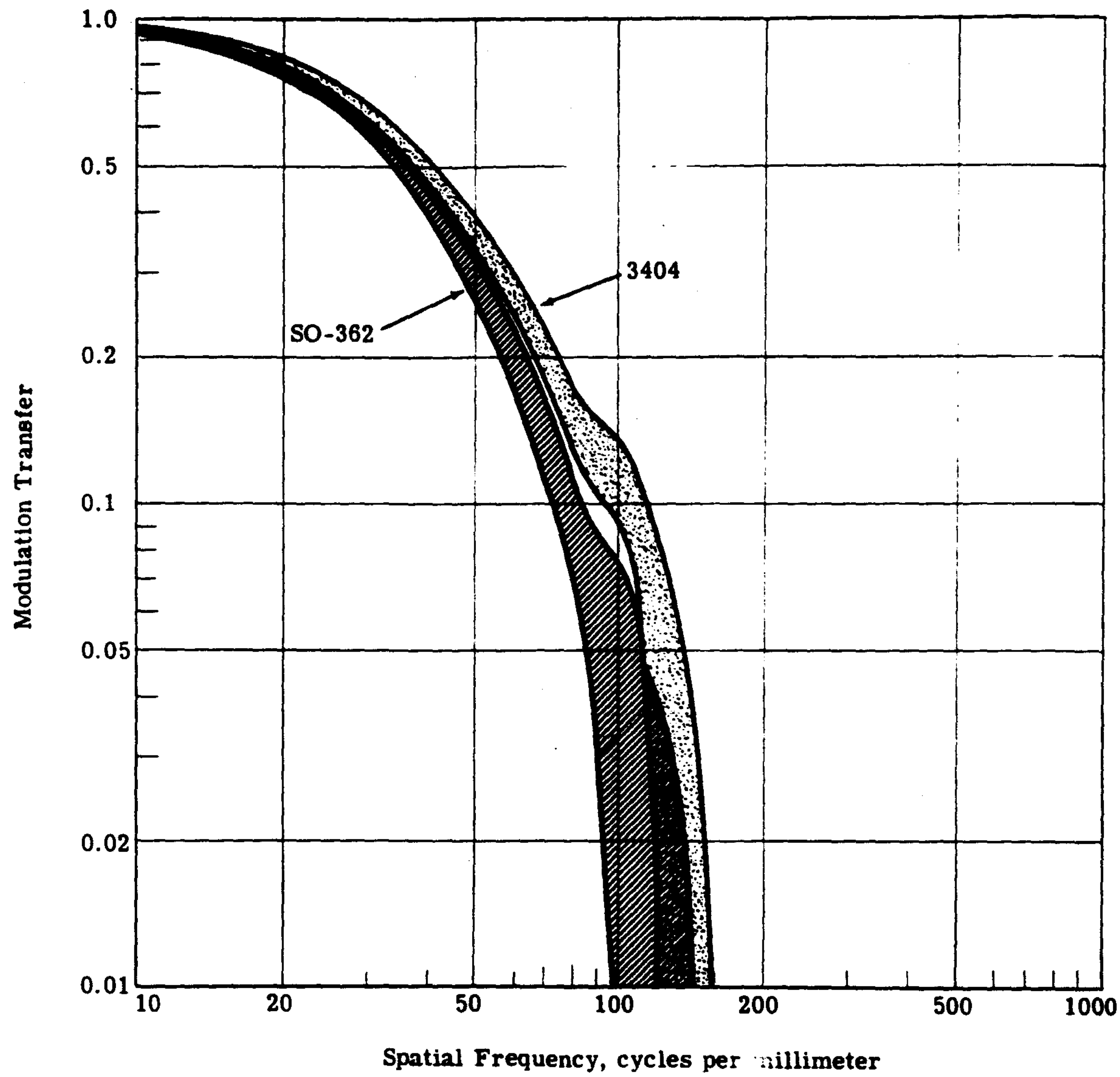


Fig. 3-9 — Comparison of SO-362 and 3404 systems (shaded area indicates 1-sigma variation in the data)

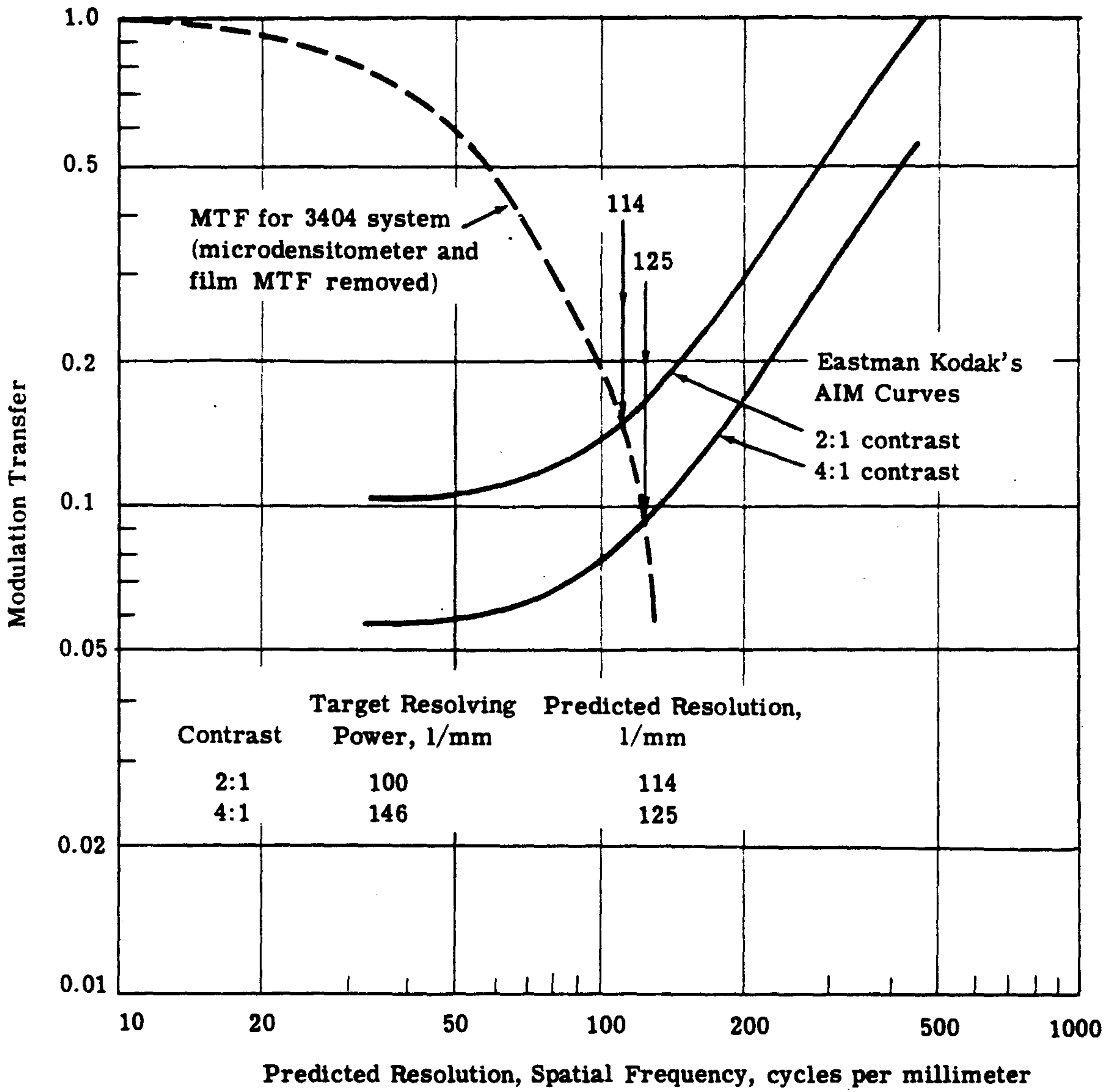


Fig. 3-10 — Predicted and observed resolution for the 3404 system with normal exposure

4. TASK 3: 112B FLIGHT TEST

Although both analyses previously discussed indicated that SO-362 was inferior (from an image quality standpoint), it was not obvious that this would be true in an operational system. The actual differences between SO-362 and 3404 were not of sufficient magnitude so that it was immediately obvious that SO-362 would be also inferior in flight operations. For this reason, it was decided to run a flight test to allow the operational comparison of SO-362 and 3404.

4.1 TEST PLAN

EKIT flight test no. 3 was flown on 2 August 1966 with the 112B system using the 112B camera configuration. The mission no. was [redacted]. The following sections discuss the 112B camera, the modifications made for this test, and the flight lines used.

4.1.1 112B Camera

A brief description of the 112B camera is warranted to introduce the system as used in this EKIT test. The camera is a pan scanning type that has been designed around a diffraction limited Petzval type lens of 24-inch focal length, with an f/3.5 aperture that covers a 6-degree field angle. To obtain stereo, a pair of these cameras is tilted from the nadir at 13 degrees each, and set face to face so that each camera scans in opposing directions. The lens is continuously rotated about its operational nodal point and scans across the line of flight, and is translated against the flight direction for image motion compensation.

During approximately 70 degrees of the lens rotation, a capping shutter is open to permit the aerial image to expose the 70-millimeter film through a slit. This slit controls the exposure time, e.g., at a 20-inch per second scan rate, a 0.040-inch slit produces an effective exposure of 1/500 second. At the completion of the photographic scan, the capping shutter is closed.

The film is continuously being transported in from the supply spool and out to the takeup spool. A frame-metering roller controls the frame length (the correct amount of film placed in the format area) and clamps at each end of the format holding the film stable in the approximate focus position. The excess film is accounted for by a shuttle assembly that gives or takes according to demand.

The focal position is determined by a scan head assembly mounted on a precise arm from the nodal point to the focus. This scan head gently lifts the film from the rails to the image plane during exposure and returns it to the rails after exposure. The rails are required only to hold the film at the approximate focus and to guide film during transport.

Recorded on the film edge outside of the format area on each frame are the frame number, binary time, and timing pips of 125 cycles per second. These timing pips are scanned on the film across the 70-degree format length with one pip blanked out to indicate when the binary time data block is printed. Three scanning rates are built in to match the V/h requirements while maintaining approximately 10 percent overlap at the format center. Increased overlap is acquired on both sides of nadir as the off-vertical scan angle increases.

4.1.2 Camera Modifications

A major consideration of all EKIT testing is that no modification be made that was not compatible with the normal system operation. Other general restrictions placed on this test series were: (1) that exposure times be short enough to prevent any vehicle disturbance to the image, and (2) that the exposure slits remain sufficiently wide enough to prevent any diffraction effects.

The test involved comparing each of the films at two different exposure levels. In order to accomplish this, special split slits were fabricated that simultaneously exposed the film for two different times.

An additional feature of this test was that split loads of film were used so that each film would be tested in each of the cameras for four different exposure times. Fig. 4-1 illustrates the relation of the various slit widths to each of the films.

4.1.3 Flight Test Plan

The specific details of the camera settings for the Delta III-4 configuration are as follows:

	Master Unit (I5) Aft-Looking	Slave Unit (I6) Forward-Looking
Film	3404/SO-362	SO-362/3404
Slit width	0.057/0.033 inch	0.045/0.025 inch
Haze filter	Wratten no. 21	Wratten no. 21
Scan mode	II (8 seconds per cycle)	II (8 seconds per cycle)
f/no.	3.5	3.5

The flight line flown (illustrated in Fig. 4-2) consisted of two passes over Fresno, four passes over Bakersfield, and two final passes over Fresno again. With this flight plan, each city was covered with both films at all four different exposure levels with both camera lenses. The presence of considerable cloud cover, though, lowered the number of comparisons that could be made. Imagery was available for a comparison of the two films at the best exposure and at an overexposed level.

4.2 SUBJECTIVE EVALUATION

Several different types of target areas were selected for a comparison of the 3404 and SO-362 from the available imagery. Although this analysis is strictly qualitative in nature, it was felt necessary to adequately describe the difference in these two materials as used in the 112B configuration.

4.2.1 Evaluation Procedure

Photointerpreters examined both the original negative and the first generation positive

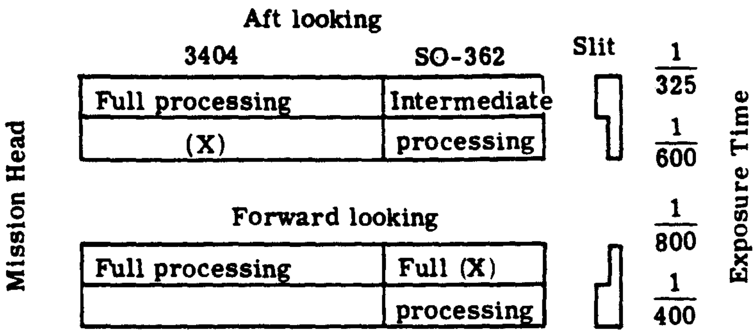


Fig. 4-1 — Slit configuration and film sequence. "X" indicates the location of the best exposed CORN targets

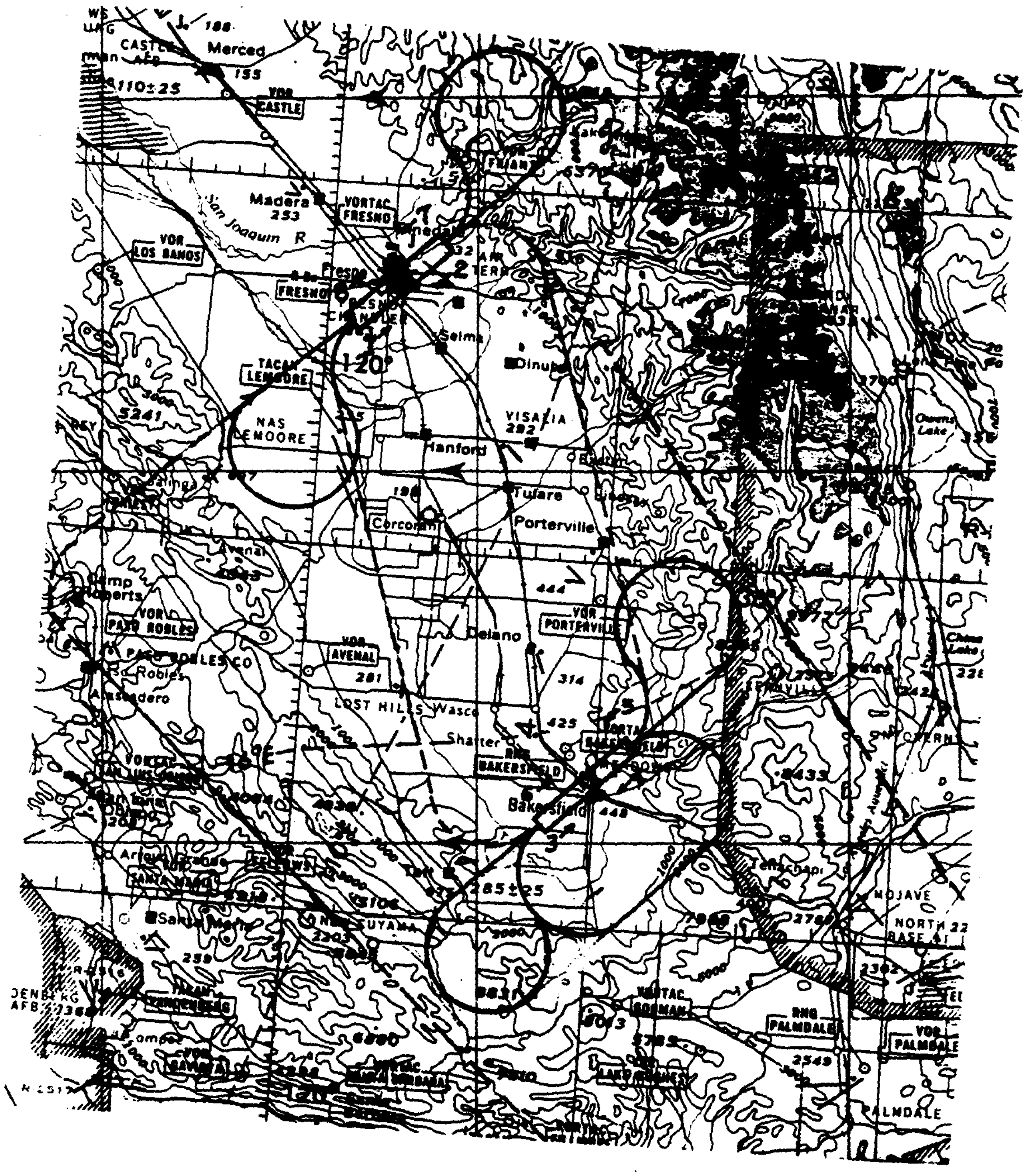


Fig. 4-2 — Flight line

under magnifications varying from 7 to 30×. The selected target areas were examined for the factors that would affect the interpretability of imagery on these materials. These aspects included contrast, resolution, graininess, and edge sharpness.

4.2.2 Available Targets

The flight test originally selected was a very well controlled experiment, e.g., target areas were to be photographed under all conditions of exposure, film, and camera. However, two aspects of the flight limited the selection of targets with the required exposure—film combination. First, though repeated passes over the same target did obtain imagery of that target, it was only by chance that specific areas were imaged on alternate sides of the frame as required with the split slits. Therefore, there were areas that did not have the full range of exposure times. The second and most influential factor was the changing weather pattern during the course of the flight. There were several areas that were clear on one pass and had thin clouds on the next pass.

There were several areas, though, that were exposed at the optimum exposure for both films in areas that had clear weather. Three of these are illustrated in Figs. 4-3, 4-4, and 4-5 and are the subject of the following evaluation.

4.2.3 Specific Target Evaluation

Fig. 4-3 is a 25-diameter enlargement of the mobile CORN target array on both 3404 and SO-362. These targets have been evaluated as 1.4-foot ground resolution for the 3404, and 2.25-foot ground resolution for SO-362.

Clear coverage of this target was acquired at 1/325 and 1/600 second on 3404 and 1/800 second only on SO-362.

The general impression of the two films at the higher shutter speeds are finer grain, higher resolution (apparent and target verified), and greater acuity for the 3404 sample, and overexposure by about 1/2 stop for the SO-362.

Details in the surrounding area such as vehicle tracks were well defined in the 3404 negative. Slight overexposure of the SO-362 negative obscured some detail to visual observation but special printing brought a great deal of detail out.

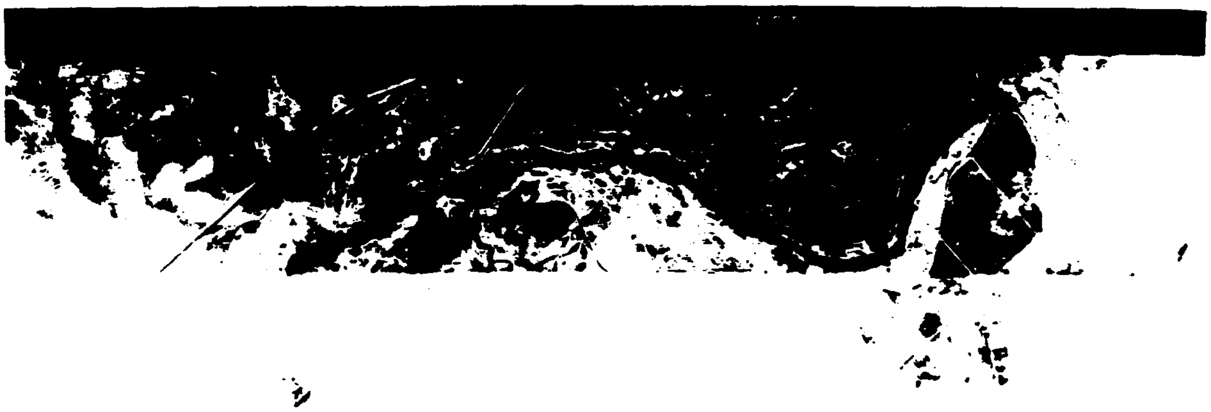
Printing under controlled conditions on type 8430 print film provided samples for objective evaluation that essentially verified the subjective phase. Information transfer was excellent and observation was made more practical by reducing the higher densities to a more practical level for visual examination.

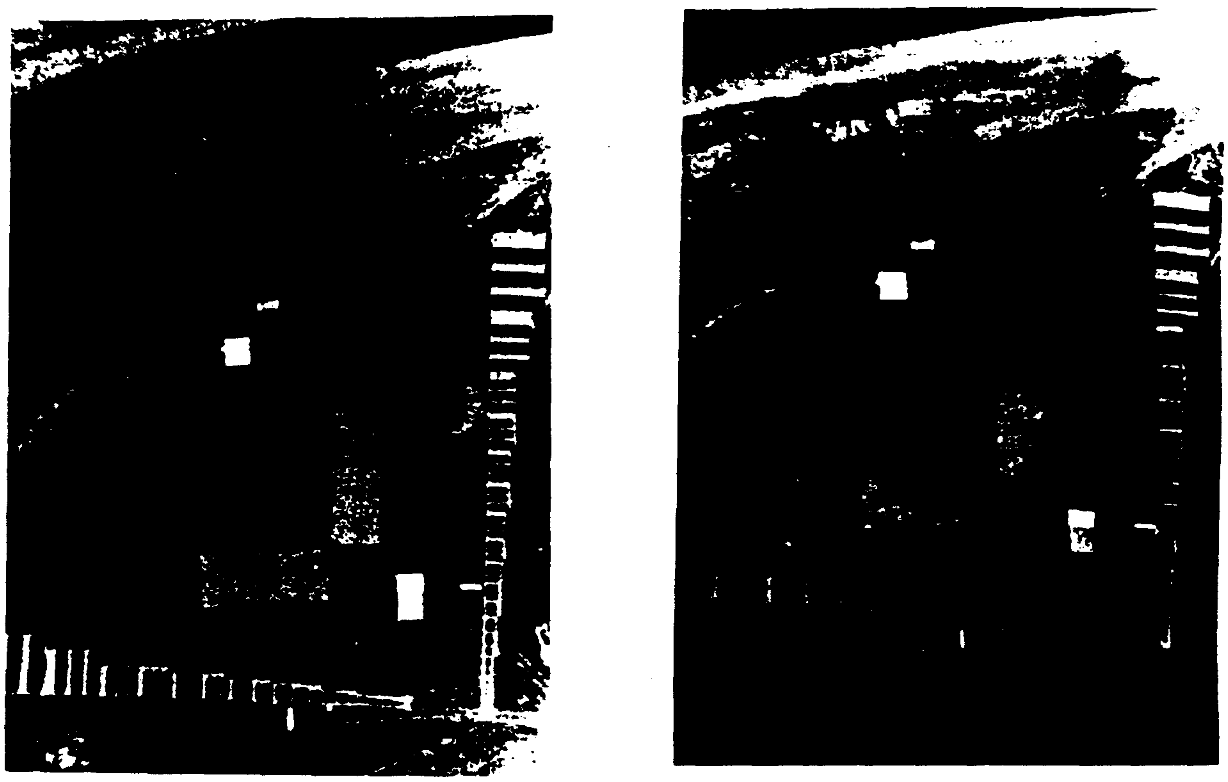
Fig. 4-4 is a 32× enlargement of an oil storage facility. There are several specific areas in this image that show the differences in sharpness with these two materials.

The 3404 has higher definition that can be seen in the valves, walkways and other small detail of the storage tank area. Exposure was optimum, edges, particularly straight ones, showed quite well with no bleeding. Smaller items are better depicted due to a combination of higher resolution, better acuity, and finer grain.

SO-362 presented a good image, well resolved (but with less acuity), higher grain, and more density due to slight overexposure. Finer linear details are broken more by grain with a resulting lower apparent resolution and acuity.

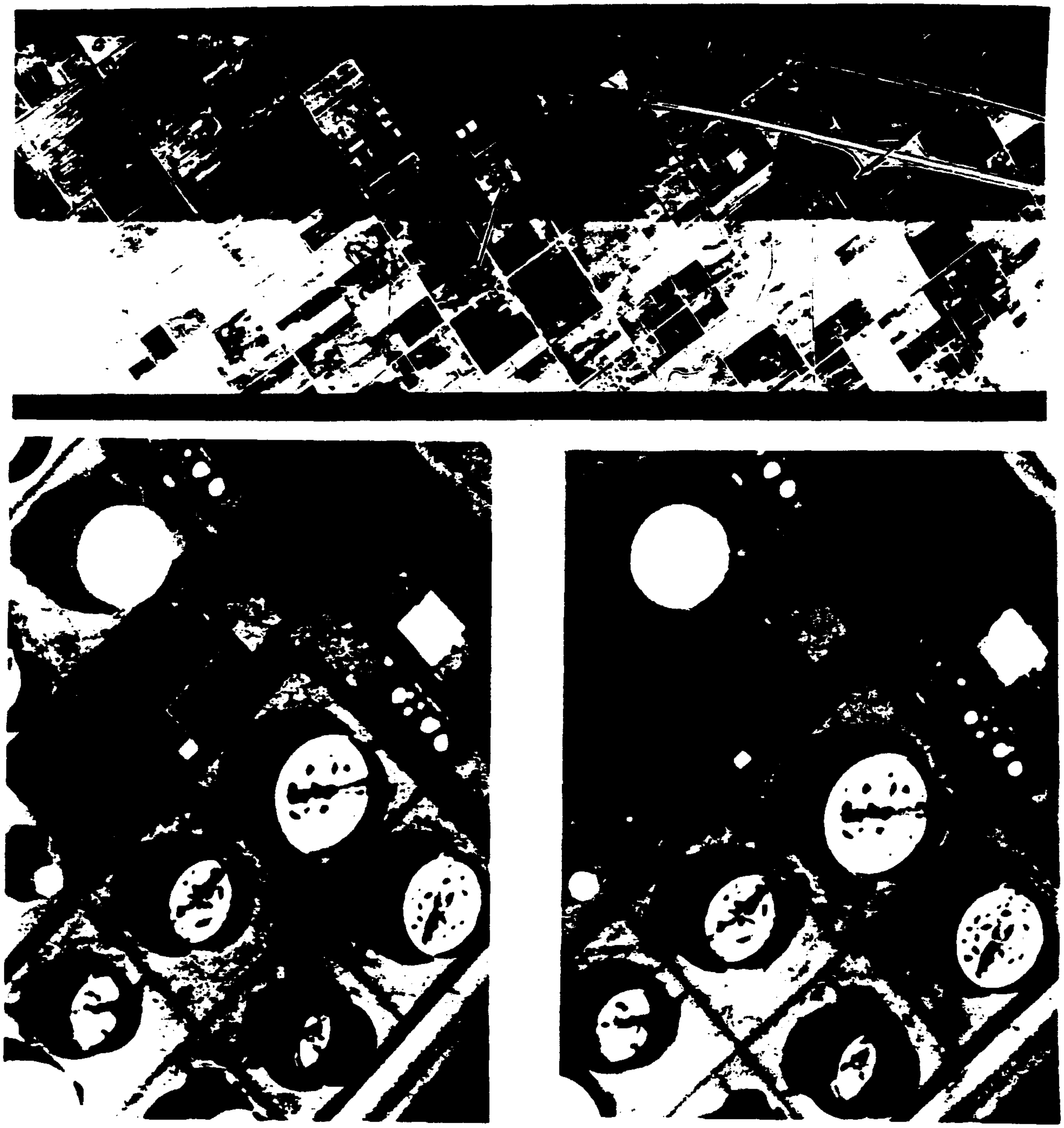
Generally, these samples are both of excellent quality and quite close by comparison.





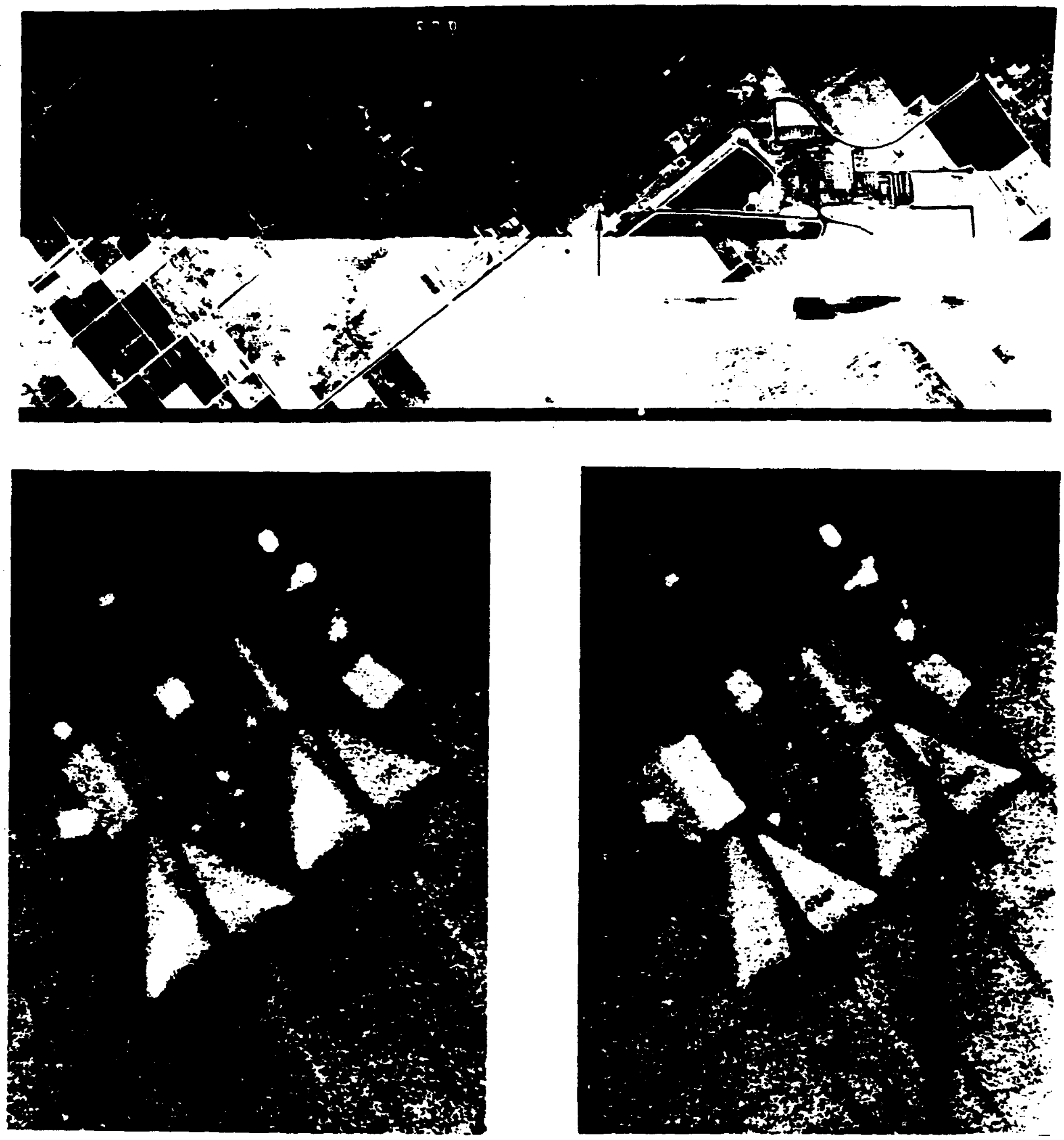
SO-362 3404

Fig. 4-3 — 25× microphotograph of CORN target array on SO-362 and 3404 film



SO-362 3404

Fig. 4-4 — 32× microphotograph of oil storage facility on SO-362 and 3404 film



SO-362

3404

Fig. 4-5 — 120× microphotograph of F-102 interceptors on SO-362 and 3404 film

Fig. 4-5 is a 120× enlargement of a pair of F-102 fighters under repair. One of the immediately noticed differences in these pictures is the increased graininess of the SO-362. This difference is supported by the granularity evaluation discussed in Section 2.

Edge sharpness is markedly superior in 3404. Aircraft and shadow configuration are better defined, particularly wing edges with adjacent shadows, making distinction between this and similar types more apparent. The black apron lines and detail in adjacent structures are also better in the 3404.

There were isolated cases when the SO-362 system did perform better than that of the 3404. But in all cases the reasons were not traceable to a characteristic of the SO-362. The most common cause was from differences in look-angle and/or specular reflections from the target areas. These cases were few and not considered in the overall evaluation.

An examination of the overexposed targets on both films indicates that, within the range of exposures encountered, the SO-362 was more susceptible to degradation due to overexposure. Edge sharpness decreased more rapidly with SO-362 than 3404 at higher exposure levels. The resolution decrease for a stop overexposure on 3404 was approximately 25 to 30 percent. This is due in part by the film and in part by the longer exposure time. Though no CORN resolution targets were available on the overexposed SO-362, an estimate of the loss in resolution was made by careful study of targets within the imagery. It was estimated that the combined effect of twice the exposure time and the breakdown of the SO-362 would lower the resolution by 50 percent.

If there had been a full factor of 2× in the shutter speeds between the materials there still would not have been any difference in the conclusion. The SO-362 would still have been inferior to the 3404. The reasons for this belief are twofold. First, at higher shutter speeds, the gains in image sharpness due to decreased blur are less and less. The difference in image quality between 1/800 second (best exposure of those available for SO-362) and 1/1,200 second (estimated optimum exposure level) would be quite small, due to blur alone. Secondly, the samples of 3404 at 1/325 and 1/400-second exposure had better image definition than the 1/800-second exposure on SO-362 even though the 3404 was considerably overexposed.

Initial evaluation of the negatives of both film samples resulted in a superior rating for 3404. Printing on type 8430 print film increased the interpretability by lowering the higher density areas to the point where visual observation became more practical. The observations in the preceding evaluations were based on optimized film positives and prints as well as original negatives.

4.2.4 Photointerpreter's Conclusions

Film type 3404 has superior image quality than SO-362 when used in an operational system. The reasons are: finer grain, higher system resolution, and better edge definition. The 3404 is less susceptible to degradation from overexposure than SO-362.

4.3 TONE REPRODUCTION ANALYSIS

A graphical analysis has been carried out to illustrate the sensitometric differences in the two films when used in the entire photoreproduction system. For this analysis the images used were those that the photointerpreter had used in his subjective analysis. The images, therefore, represented what he thought were good reproductions. The subject used was the five step CORN gray scale. The printing stock was Eastman Kodak type 8430.

4.3.1 Graphical Techniques

Fig. 4-6 illustrates the tone reproduction scheme employed. It consists of four quadrants, each one being directly related to its bordering two quadrants. The original ground subject (as represented by the five step gray scale) is the starting axis of quadrant I. This quadrant represents the atmospheric and camera effects that occurred during the photography. The original ground tones are altered as they are passed through the atmosphere by transmittance losses, added haze light, and lens flare. The first quadrant, therefore, represents this energy transfer from ground log luminance to effective log exposure at the film plane. Since both pictures were taken at approximately the same time this atmospheric effect is the same for both films. However, since there was a difference in the exposure time (1/600 and 1/800 second), the two curves are slightly displaced. This is because the log exposure axis for the negative sensitometric curve is in terms of absolute log exposure. These compressed log exposure ranges were then incident upon the film's characteristic curve (quadrant II) and transformed into densities of the negative materials. The densities of the negatives then became relative log exposures incident upon the characteristic curve of the duplication stock that is plotted in quadrant III. Since this is a printing process, it is convenient to handle this step in terms of relative log exposure. The printing material's characteristic curves can therefore be shifted to the left or right, simulating a printing exposure change. The cycle is completed by plotting the reproduced densities in the positive versus the log reflectances of the CORN gray scale. Thus quadrant IV is a plot of the tones as reproduced through the entire reproduction cycle with respect to the ground subject. This curve has a negative slope and looks like a characteristic curve of a reversal material. It is, for all practical purposes, a characteristic curve of the system as a whole.

4.3.2 Analysis of Tonal Reproductions

The best exposure for the SO-362 system was exposed slightly higher on the negative characteristic curve than was the 3404. In order to obtain good duplication of the two materials, therefore, different printing times were required. This shift is represented by the apparently faster printing stock for duplicating the SO-362. The important trait to consider in this reproduction process is the final positive image as represented in quadrant IV. Even though the gamma of the SO-362 is higher than the 3404,* the final reproductions are not that far different. The SO-362 reproduction is only slightly more contrasty than that of the 3404. The reason is that the atmospheric effects have decreased the dynamic range of the scene to a point where the slight differences in gamma had a neglibible difference in the density range of the scene on the two negatives.

One of the characteristics of SO-362 is that the product has a lower D_{max} than at the time the material was used in the model test. This could be accounted for by one of two reasons: (1) from differences in processing the film, or (2) from differences in the film itself. Since this film was in the experimental stage at the time of these tests, it seems likely that the material was changed.

The final reproductions for both systems have almost the same density range. There is a slight displacement in the two reproductions which is attributed principally to the initial exposures

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*This is an apparent contradiction to the conclusions in Section 2. In fact, both statements are correct, and the difference is directly related to the variations in emulsion batches. The majority (but not all) of SO-362 emulsions tested at Itek had lower gamma than 3404.

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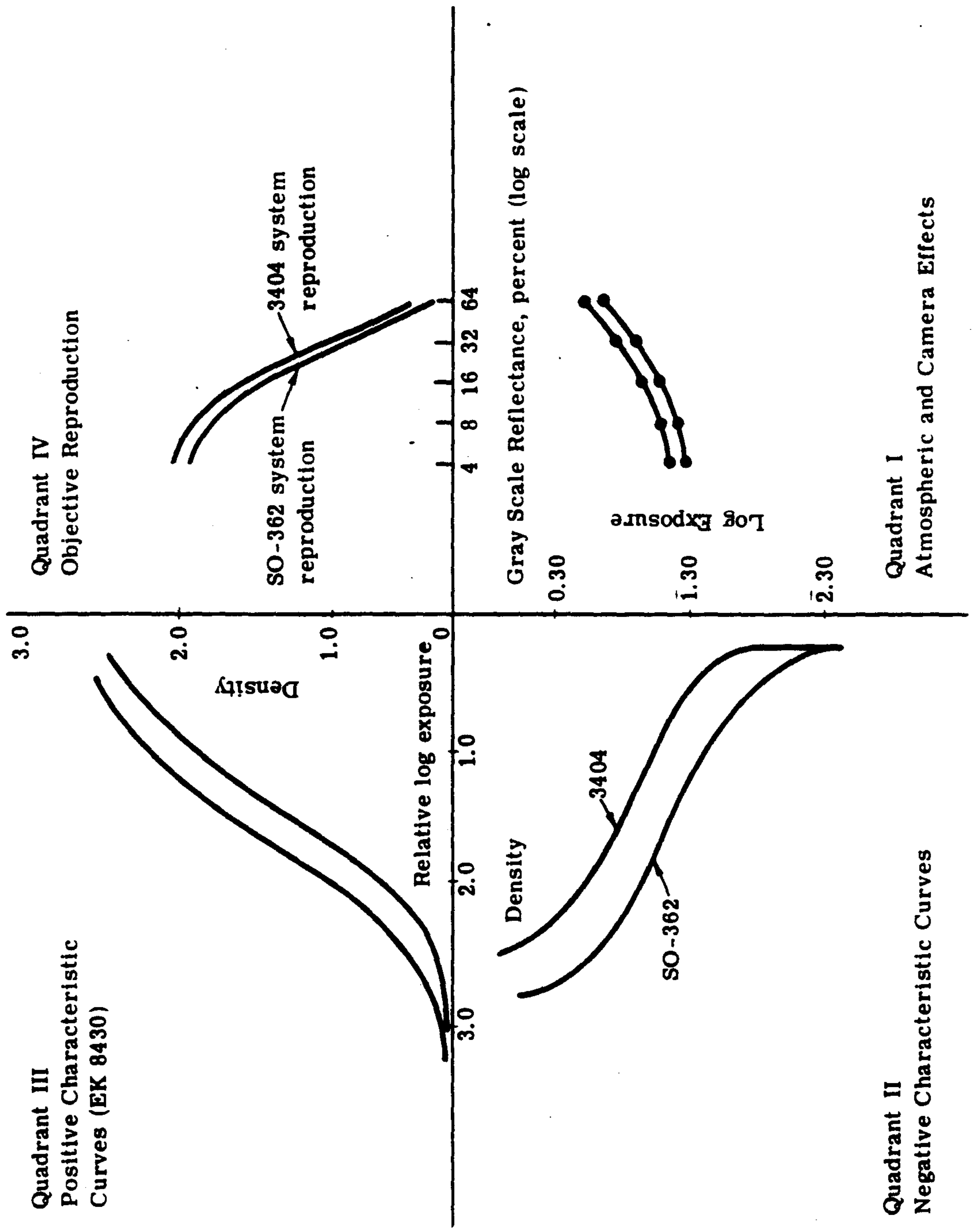

Fig. 4-6 — Tone reproduction graph

in the camera. The flexibility in the duplicating stage could alter the reproductions to a greater degree than is present between the two reproductions. Even though the tonal range of the reproduction was the same, the relation between these tones and the original scene was not the same. This difference relates directly to the visual impression of the images. The highlight tones are lighter on the SO-362 than on the 3404, which is what gives the SO-362 the impression of higher contrast. This is due to the slight overexposure on the SO-362 negative.

4.3.3 Tone Reproduction Analysis Conclusions

The atmospheric effects for the two systems are essentially the same, there being only a vertical displacement due to the difference in exposure time.

The SO-362 negative material had slightly higher contrast than the 3404. The final tone reproduction for the two systems were very similar, the SO-362 having a slightly higher contrast than the 3404. The main difference in the contrast of the final reproduction is from the relationship between its contrast and the original subject contrast, with the SO-362 reproducing a little lighter in the highlight regions.

5. J-3 SYSTEM CONSIDERATION

The purpose of this section is to compare 3404 and SO-362 films from a J-3 operational point of view and conclude which film performs better. The 3404 has a higher resolution but is less sensitive (by a factor of 2) than SO-362. The fundamental question that must be answered when comparing these films, or any two films like them, is: "Does the increased photographic speed of SO-362 yield a higher resolution than 3404 under operational conditions?" To answer this question the exposure time was determined for both films for solar angles from 0 to 60 degrees, the region of greatest illumination change for operational situations. The image blur was determined from the exposure time and the resulting resolution on optical axis was determined for the solar altitude region. This analysis also indicates the required exposure control slits for this region and presents the maximum resolution available due to the slits.

5.1 EXPOSURE TIME FOR BOTH FILMS AS A FUNCTION OF SOLAR ALTITUDE

There are various ways to describe the best exposure criterion for films. It has been generally accepted that the linear portion of the characteristic curve is the best area for images to lie in. Sometimes the center of this linear portion is assigned the point where objects of average reflectance (15 percent) lie for properly exposed films. Hence the majority of objects in the scene will lie near the midpoint of the linear portion. This argument was used in analyzing SO-121 (EKIT Report No. 4) since an over- and underexposure had to be corrected. Another method of describing the proper exposure is to assign the object with minimum reflectance to the lower-most point on the linear portion of the characteristic curve. In so doing one realizes that the remaining objects in the scene will be located above this point.

For 3404, the straight line D_{min} is 0.46 and the log exposure E_M necessary to produce this density is $\bar{1}.06$ for full processing and $\bar{1}.31$ for intermediate processing. The exposure E_M equals the illumination from the minimum reflectance object incident to the film I_f times the exposure time t. I_f is related to the ground illumination and camera system by the expression

$$I_f = \frac{B_o T_e}{4 (f/no.)^2 F} \quad B_o = I_s R_g T_a + B_a$$

where the camera characteristics are

T_e = lens transmission

f/no. = relative aperture

F = filter factor

and illumination characteristics are

I_s = solar illumination

R_g = object reflectance

T_a = atmospheric transmission

B_a = atmospheric illumination

It is defined that the object with minimum reflectance has $R_g = 0$ and hence only background illumination is incident to the camera for this hypothetical object. With this condition $B_o = B_a$, B_a versus solar altitude is presented in Fig. 5-1 and

$$I_f = \frac{B_a T_e}{4(f/no.)^2 F}$$

For the J-3 system

f/no. = 3.5

$T_e = 0.875$

F = 1.9 (for Wratten no. 21)

T_a is assumed to be = 80 percent

The exposure time t for each solar angle is

$$t = \frac{E_m}{I_f \times 10.76}$$

The exposure time as a function of solar altitude for SO-362 and 3404 is presented in Figs. 5-2 and 5-3. The exposure recommendation for the J-3 system (illustrated in dashed line) will require the use of three slit sizes. Intermediate and full processing are illustrated, however, full processing is recommended for adequate exposure coverage in the low solar altitude region.

5.2 RESOLUTION OF BOTH FILMS AS A FUNCTION OF SOLAR ALTITUDE

The resolution of the lens/film combination in a camera system is dependent on the exposure time. There is always motion relative to the film in the camera system and the ground scene. In general, the longer the exposure time the greater the image blur. For this reason image motion compensation is designed into systems like J-3. The compensation techniques reduce the image blur by a given percent, however, it is never eliminated, although at very short exposure times (1/1,000 second) it is minimized.

Before getting deeper into the blur problem it is important first to determine the static resolution, i.e., that resolution of the camera system without image motion. This can be obtained by intersecting the MTF of the lens with the threshold curves of the films. For 3404, the resolution determined in this way for a 2/1 target is 144 lines per millimeter, and for SO-362, the resolution is 120 lines per millimeter. Therefore, using the image quality criterion of resolution for the case of no image motion, 3404 is clearly superior.

It is of interest to know how this static resolution is degraded by image blur. This can be computed by the use of a modified version of Katz's formula, specifically:

$$\frac{1}{R^2} = \frac{1}{R_0^2} + (BL)^2$$

where R = resulting resolution
R_0 = static resolution of camera system
BL = image blur

This expression is derived from limited experimental work and is thought to break down at high image blur values. Figs. 5-4 and 5-5 present the resolution of 3404 and SO-362 versus image blur. Note that the rate of resolution loss is greater for 3404, meaning that in cases of very high blur it is best to go with a faster film even if it has lower static resolution. The image blur can be obtained from the exposure time and the linear compensated image motion. This image motion obtained from the error budget is for the along-track case on the optical axis. The image motion in the cross-track direction is similar to the along-track component and for the purpose of this discussion can be considered equal.

The image blur and exposure time relationship permits, with the use of Figs. 5-4 and 5-5, the determination of resolution versus exposure time. Using Figs. 5-2 and 5-3, the resolutions of 3404 and SO-362 versus solar altitude are obtained (see Figs. 5-6 and 5-7). Fig. 5-6 illustrates the resolution versus solar altitudes using full processing. Here notice that the resolution of 3404 is greater than SO-362 in all instances except at 0 degrees solar altitude where they intersect. This full processing case is important since the exposure curves recommended full processing for low solar altitudes. The dashed stepped line illustrates the resolution limit imposed by the selected exposure slits. In Fig. 5-7, notice that beyond the intersection of both resolution curves, the resolution of 3404 drops sharply while SO-362 stays significantly above it. For the case where very long exposure times are required, i.e., out of the ordinary, SO-362 would be better to use. In this analysis we are considering ordinary day photography, and for this situation 3404 is a better film for the J-3 system.

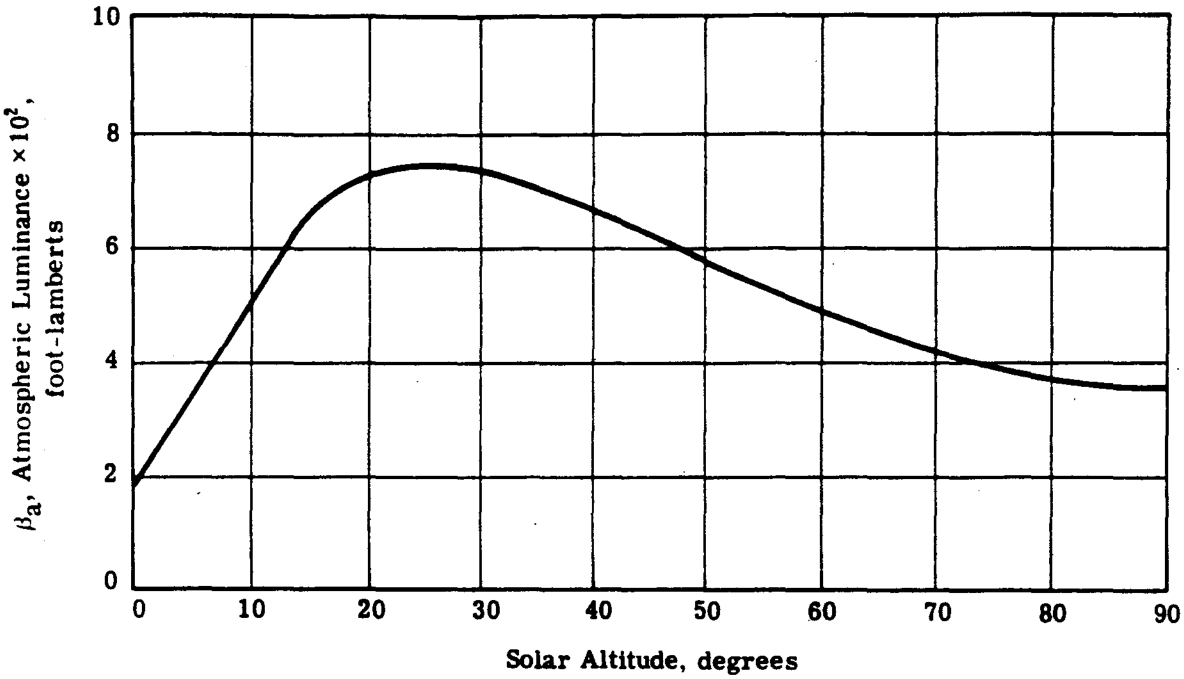

Fig. 5-1 — Atmospheric luminance as a function of solar altitude

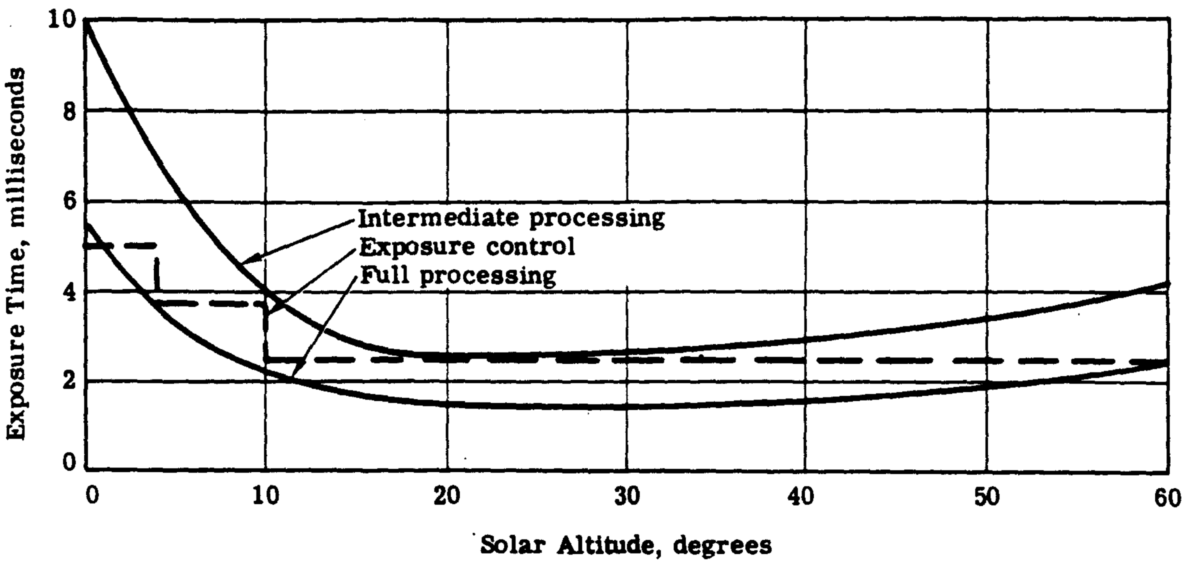

Fig. 5-2 — Exposure time versus solar altitude for objects with minimum reflectances (Rg = 0) using 3404 film

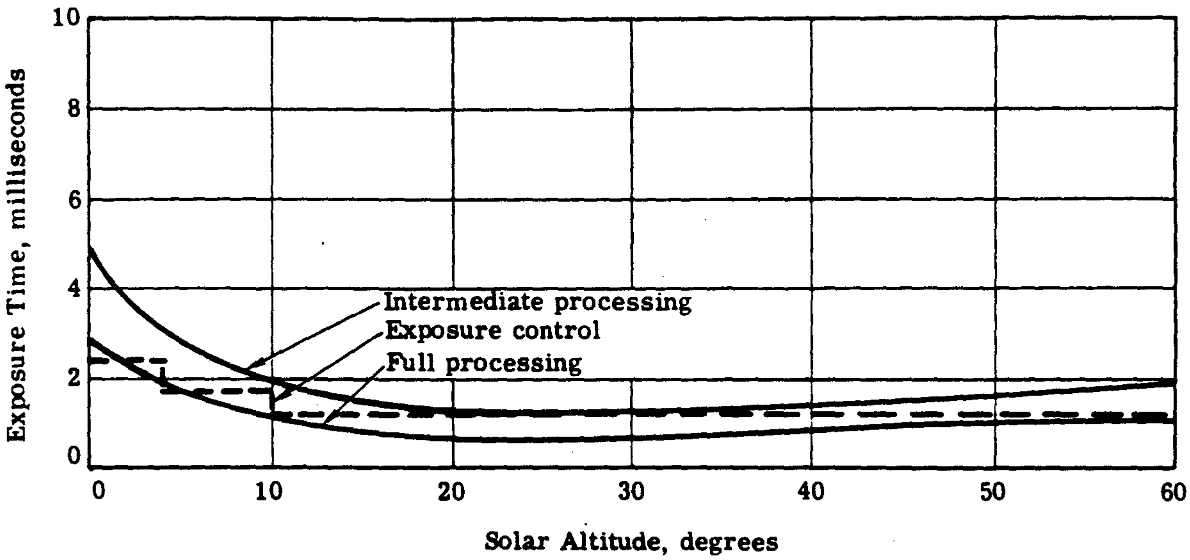

Fig. 5-3 — Exposure time versus solar altitude using SO-362 film for terrestrial objects with minimum reflectances (Rg = 0)

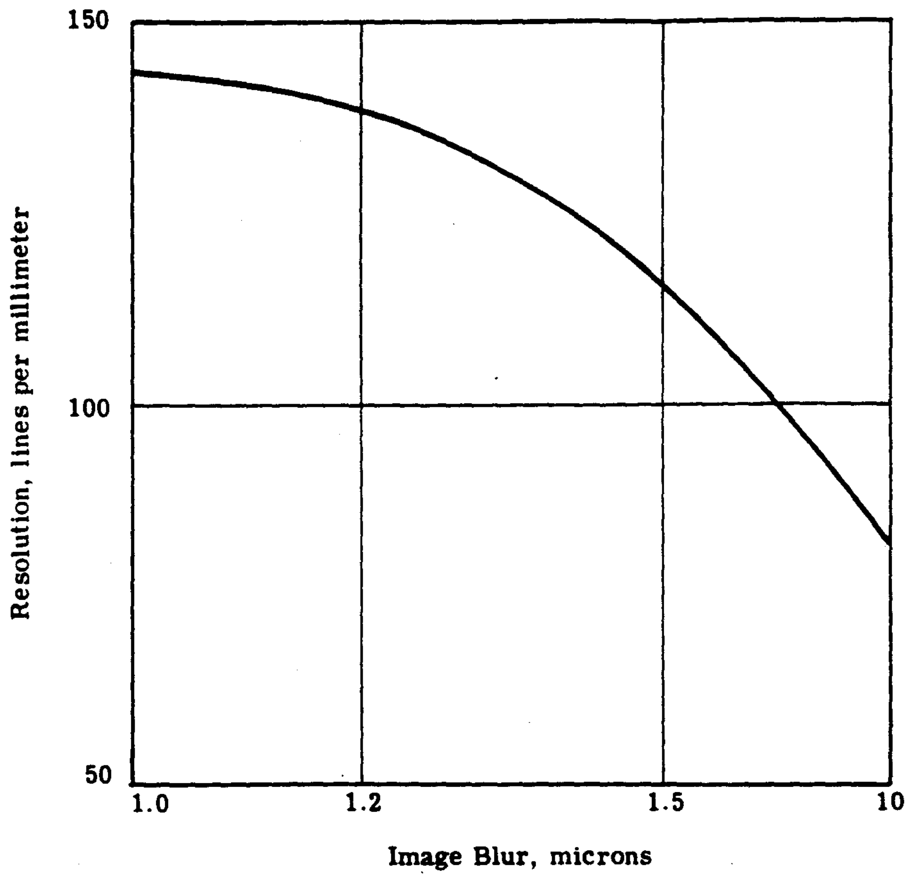

Fig. 5-4 — Resolution of 3404 film as a function of image blur

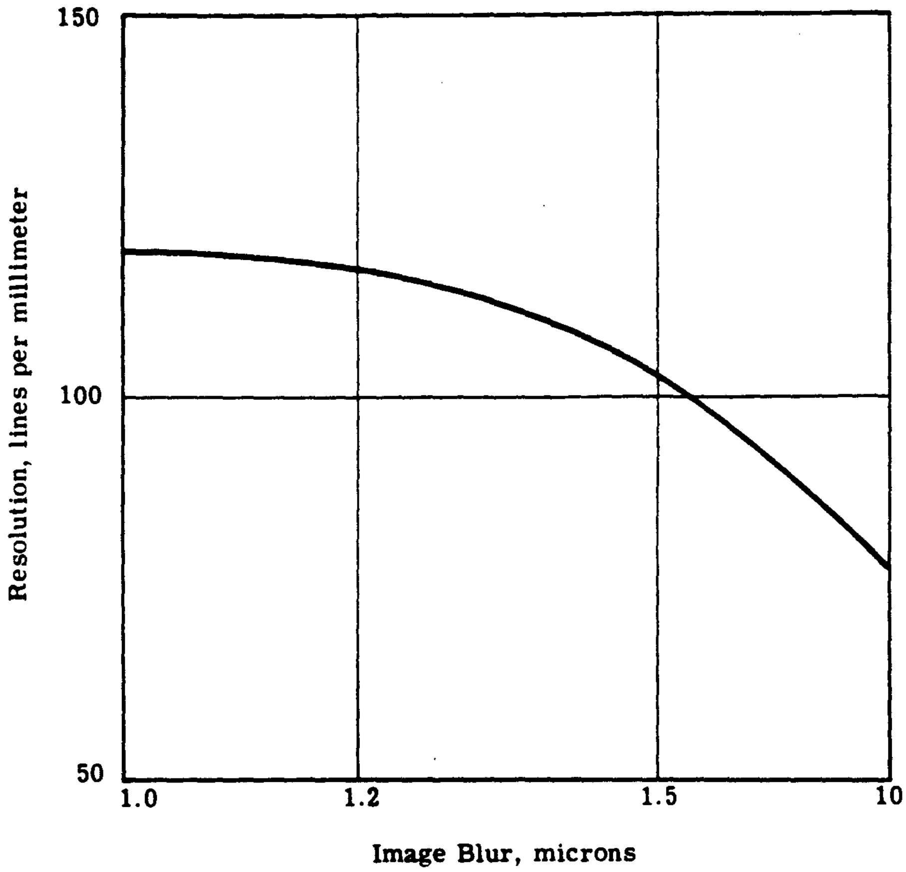

Fig. 5-5 — Resolution of SO-362 film as a function of image blur

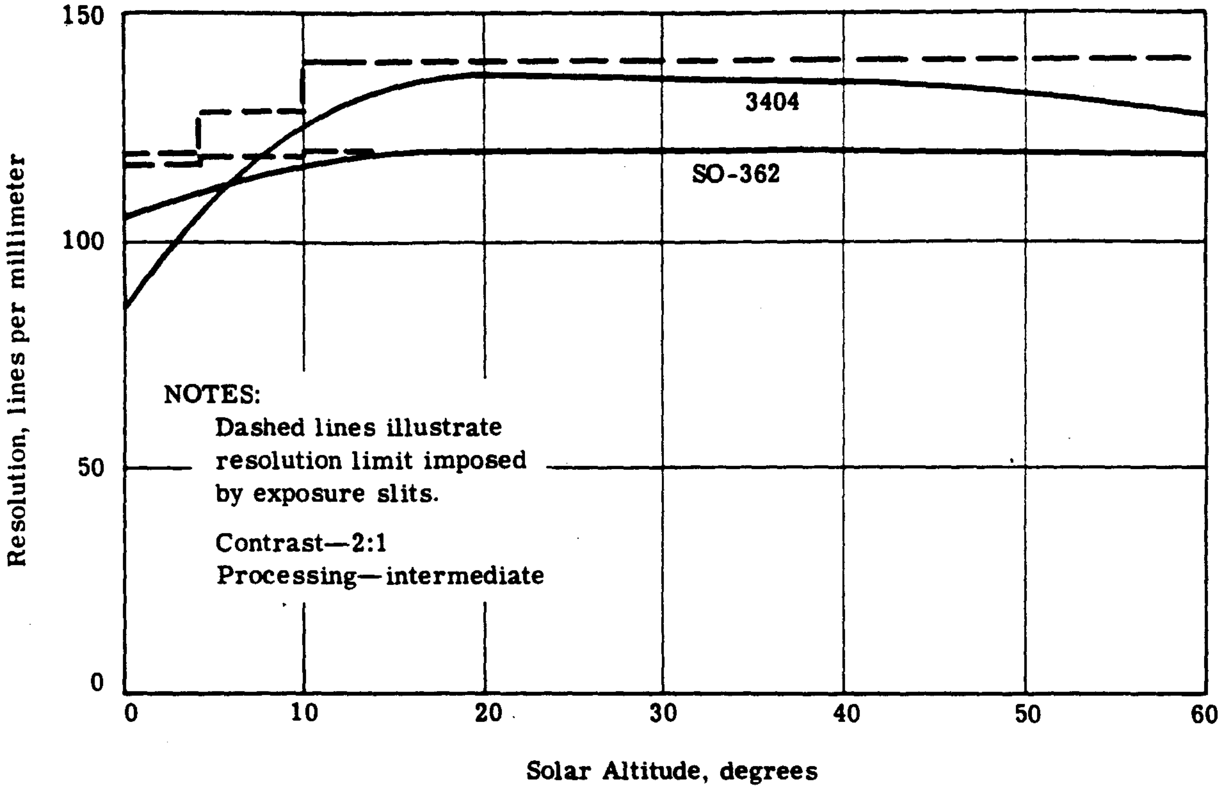

Fig. 5-6 — Resolution of 3404 and SO-362 film as a function of solar angle derived from image blur at intermediate processing. (Resolution is on optical axis in along- and across-track directions.)

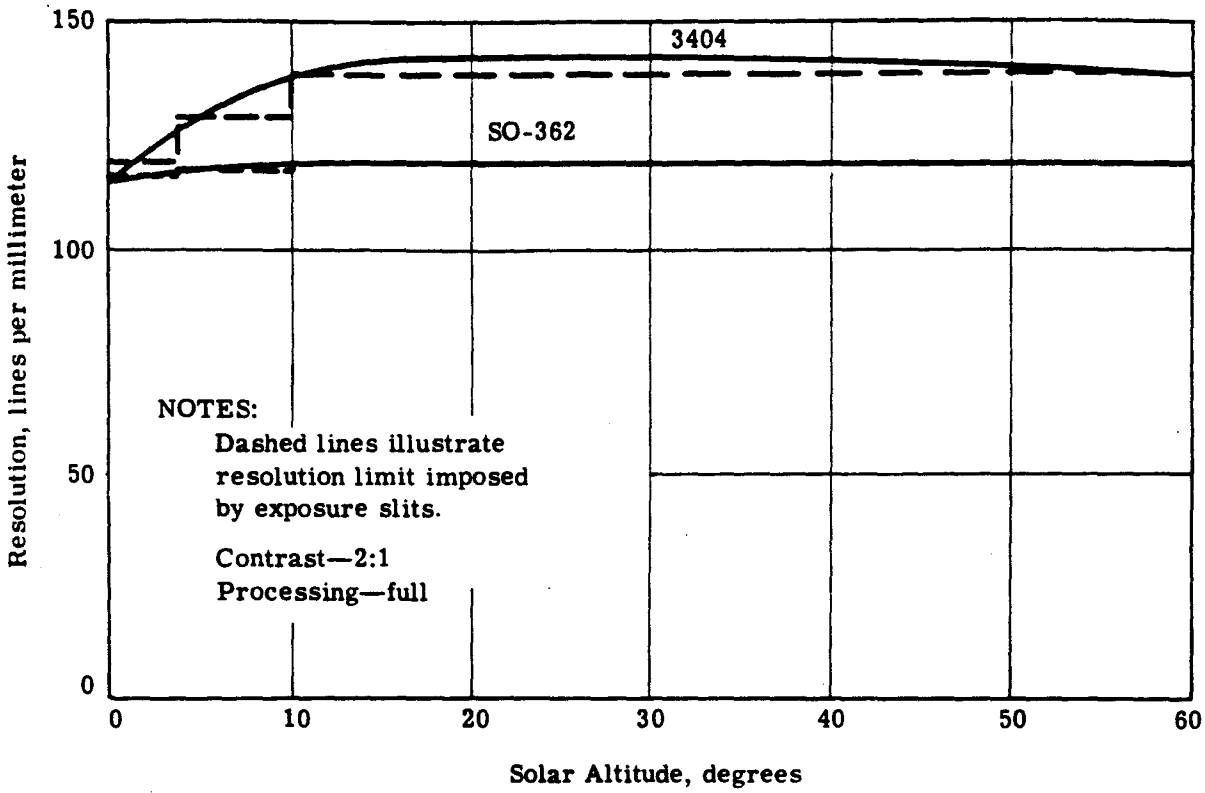

Fig. 5-7 — Resolution of 3404 and SO-362 film as a function of solar angle derived from image blur at full processing. (Resolution is on optical axis in along- and across-track directions.)

6. CONCLUSIONS

The results of the three tasks allow several conclusions. These can be summarized as follows.

1. SO-362 is approximately 2.8 times faster than 3404. This varied from 2.3 to 3.4 times faster depending on the developer formulation.

2. SO-362 produces a higher fog level, at a greater rate, than does 3404. This effect is noticeably worse with high-energy developers such as Eastman Kodak MX-577.

3. In general, SO-362 produces a slightly lower gamma than 3404, however, the differences between the two films are minor.

4. SO-362 produces lower resolution than does 3404. In all evaluation tasks, SO-362 produced a lower resolving power. This was true even in the 112B flight test. In this case, the SO-362 produced a lower resolution even though the exposure time used was one-half that employed with the 3404. For example, flight test samples of 3404 exposed at 1/325 second had better image quality than the samples of SO-362 exposed at 1/800 second.

5. SO-362 possesses both a higher granularity and graininess than 3404. The rms granularity evaluations indicated that SO-362 was approximately 1.7 × granier than 3404. This was verified in the subjective photointerpreter evaluations where the increased graininess of SO-362 was apparent to the photointerpreters who commented on this. This causes both a loss of low contrast fine detail and a degradation of edge sharpness vis-a-vis 3404.

6. SO-362 did not hold up as well as 3404 to overexposure. The image quality of the resultant photography with SO-362 was noticeably poorer with overexposure. This was verified with both the objective and subjective analyses. The photointerpreters commented on both the model test and the 112B test, that the SO-362 image quality was noticeably worse with overexposure. The MTF analysis discussed in Section 3.2 verifies this subjective conclusion as does the resolving power data.

7. The fact that SO-362 has been discontinued by the manufacturer automatically precludes its use in the J-3 system. Even if it had not been discontinued, however, its characteristics would not have warranted its use in the J-3 system.

8. It should be noted that SO-362 was a difficult film for the manufacturer to make. The characteristics of the film changed from batch to batch. This is evident from the data herein. The SO-362 used for Task No. 1 had a higher D_{max} than the SO-362 used for either the model test or the 112B test. We also understand from the manufacturer that SO-362 was a difficult film to make as concerns repeatability, i.e., from a quality control point of view.

9. SO-362 has been recently replaced with SO-~~240~~ 230. The replacement material is intended to possess the characteristics originally intended for SO-362. It is recommended that SO-~~240~~ 230 also be evaluated for it potential, and to determine if it is worthwhile to consider it for use in J-3.