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EKIT REPORT NO.9

COMPARATIVE EVALUATION OF SO-230 AND 3404 FILMS

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APPROVED BY

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CONTENTS

FIGURES

TABLES

1. SUMMARY

This report is the ninth in the EKIT series, and contains an evaluation to compare Eastman Kodak types 3404 and SO-230 aerial films. SO-230 is a film introduced recently to replace SO-362* and provide the same basic image quality as 3404 but with additional emulsion speed. It is the purpose of this report to compare the two films to determine if SO-230 does in fact possess the desired characteristics, and to examine the system considerations of using SO-230 with the KH-4B.

1.1 SCOPE OF THE TEST

The evaluation was carried out in two separate tasks. They are summarized below:

Task 1—Sensitometric Testing

A sensitometric evaluation was simultaneously performed on 3404 and SO-230 films to determine their individual characteristics as well as their differences. These standard sensitometric evaluations include: (1) emulsion speed, (2) resolving power, (3) filter factors, and (4) granularity.

Task 2—Static Pictorial Comparison

To obtain a subjective comparison based on photointerpreter analysis between 3404 and SO-230 films, a test was performed 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 as is possible in the laboratory. Varying exposures were made of this target with each film; these exposures were analyzed by photointerpreters for information content.

This report summarizes the results of these two tasks.

1.2 TEST CONCLUSIONS

Conclusions based on the results of the previously described tasks are summarized as follows:

1. SO-230 is approximately two times faster than 3404, although the exact speed difference depends on the processing conditions.
2. The SO-230 has a slightly higher fog level at all processing conditions, but the increase is not objectionable except under extended development times.
3. SO-230 produces a slightly higher gamma than 3404 when both are processed in D-19 developer, and an equivalent or slightly lower gamma than 3404 when each are processed in their recommended high energy developers.

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*SO-362 has been recently discontinued by the manufacturer and was the subject of EKIT report no. 5.

4. High contrast resolution is better with 3404, but the materials are equal at low contrast.
5. SO-230 has a higher granularity than 3404.
6. Both films hold up well under overexposure conditions.
7. A subjective analysis of model photographs favors the 3404 due to less graininess.
8. The operational high contrast resolution of SO-230 is likely to be as good as 3404.
9. SO-230 is recommended for satellite testing.

1.3 LATENT IMAGE DECAY

Although no latent image decay tests were made by Itek for inclusion in this report, it has been learned from the manufacturer that SO-230 film may exhibit poor latent image keeping characteristics as compared to type 3404. It is recommended that this parameter be evaluated and reviewed prior to any operational test.

2. TASK 1—FILM TESTING

A basic sensitometric evaluation was conducted on SO-230 and the results were compared with those of 3404. Specific evaluations of the following were made:

1. Emulsion speed
2. Filter factors for Wratten nos. 12, 21, 23A, 25, 57, 44A + 2E, Polarizing HN-38, and ISF (Itek Special Filter)
3. Resolving power (emulsion threshold)
4. RMS granularity

2.1 LABORATORY PROCEDURE

2.1.1 Sensitometry

Sample strips of both 3404 and SO-230 were exposed on the Kodak 1B Sensitometer for 0.1 second to a Corning 5900 daylight correction filter producing a color temperature of 6,100 °K. The films were then processed in D-19 developer at different times for a direct comparison, and in MX-577 for 3404 and MX-578 for SO-230 for maximum speed determination. Processing temperatures were controlled to 68 ± 0.5 °F. Gaseous burst agitation (1-second bursts) was employed at the rate of every 8 seconds at a pressure of 10 pounds per square inch. Processed film samples were measured on a MacBeth TD-100 densitometer which is calibrated in reference to an NBS certified diffuse density step tablet.

2.1.2 Filter Factors

To obtain filter factors, film samples were sensitometrically exposed to simulated daylight which was modified in turn by each of the filters, and then processed concurrently with a control sample. The log exposure shift was then measured at a point on the straight line portion of the curve 1.0 density units above gross fog.

2.1.3 Resolving Power

Resolution tests on SO-230 and 3404 were performed 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 type 649-GH film exceeds 2,000 cycles per millimeter. The resolution tests were performed in accordance with the ASA draft standard for evaluating the resolving power of black and white silver halide emulsions. A series of target contrasts was employed and the films were processed in D-19 developer. This enabled emulsion threshold (AIM) curves to be constructed for the two materials.

2.1.4 Granularity

Exposures were made on individual samples of 3404 and SO-230, with a point source light at a distance of 4 feet, at varying times, for five different density levels above and below 1.0 for rms granularity determination. These samples, which were developed in D-19 for 8 minutes at 68°F, were traced on the Intectron microdensitometer using a 24-micron diameter circular aperture.

2.2 RESULTS

2.2.1 Sensitometry

The results of the sensitometric analysis are summarized in Tables 2-1 and 2-2, and shown graphically in Figs. 2-1 through 2-4.

1. The maximum emulsion speed for SO-230 was approximately 2 times faster than for 3404.* In D-19 developer the maximum useful speed† obtained from SO-230 was 5.0 (fog level = 0.35) as compared with a speed of 2.5 (fog level = 0.25) for 3404. This represents an increase of 2 times. In the recommended high energy developer, MX-578 for SO-230 and MX-577 for 3404, 3404 has a maximum speed of 4.5, while SO-230 has a maximum useful speed of 10.2, representing an increase of 2.3. The maximum speed differential was obtained with D-19 developer at a time of 4 minutes.

2. In general, the fog level of SO-230 was consistently above 3404 except for the crossover in speeds at the 3- and 4-minute times in the high energy developers. At equivalent processing times in D-19 developer, the SO-230 has a fog level ranging from 0.10 to 0.35 while 3404 has a range from 0.07 to 0.25. The lower processing times in the high energy developers resulted in higher fog levels for the SO-230. With extended times the 3404 has a higher fog level; however, this level is well above the useful working range for satisfactory imagery.

3. The gamma difference between the two films is a function of the developer. In D-19, the gammas ranged from 1.59 to 2.11 for SO-230 and from 1.24 to 1.88 for 3404. However, in the high energy developers, the 3404 produced the higher gammas with a maximum of 2.70.

2.2.2 Filter Factors

These tests were repeated several times with a variation in the filter factors of approximately ±10 percent. The results of these tests are indicated in Table 2-3. Several filters that are not ordinarily used in mission photography were tested; however, there is a strong possibility that some of these will be used in the first KH-4B flights. The polarizing filter has an average transmittance of approximately 40 percent, thus giving it a filter factor of 2.5. However, when this filter is used in an operational situation, the filter factor varies due to the effects of look angle and azimuth on the polarized component of the atmosphere. A precise filter factor, therefore, is

* It should be noted that the manufacturer has stated that SO-230 is only 1.6× as fast as 3404 in the Trenton processor.

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

Table 2-1 — Sensitometric Data for D-19 Developer

Developing Time, minutes	AEI Speed		Fog		Gamma	
	3404	SO-230	3404	SO-230	3404	SO-230
1.0	0.5	1.0	0.07	0.10	1.24	1.59
2.0	0.7	1.9	0.07	0.10	1.60	1.93
4.0	1.0	3.2	0.07	0.10	2.00	2.20
8.0	1.8	5.0	0.09	0.14	1.98	2.08
16.0	2.5	5.0	0.25	0.35	1.88	2.11

Table 2-2 — Sensitometric Data for Recommended High Energy Developers*

Developing Time, minutes	AEI Speed		Fog		Gamma	
	3404	SO-230	3404	SO-230	3404	SO-230
0.5	1.4	3.7	0.08	0.16	2.36	1.74
1.0	2.2	5.4	0.12	0.16	2.70	2.05
1.5	3.2	–	0.18	–	2.50	–
2.0	3.8	7.4	0.23	0.22	2.22	2.20
3.0	4.5	10.2	0.41	0.29	2.05	2.06
4.0	–	10.2	–	0.47	–	1.95

*3404: (EK) MX-577; SO-230: (EK) MX-578.

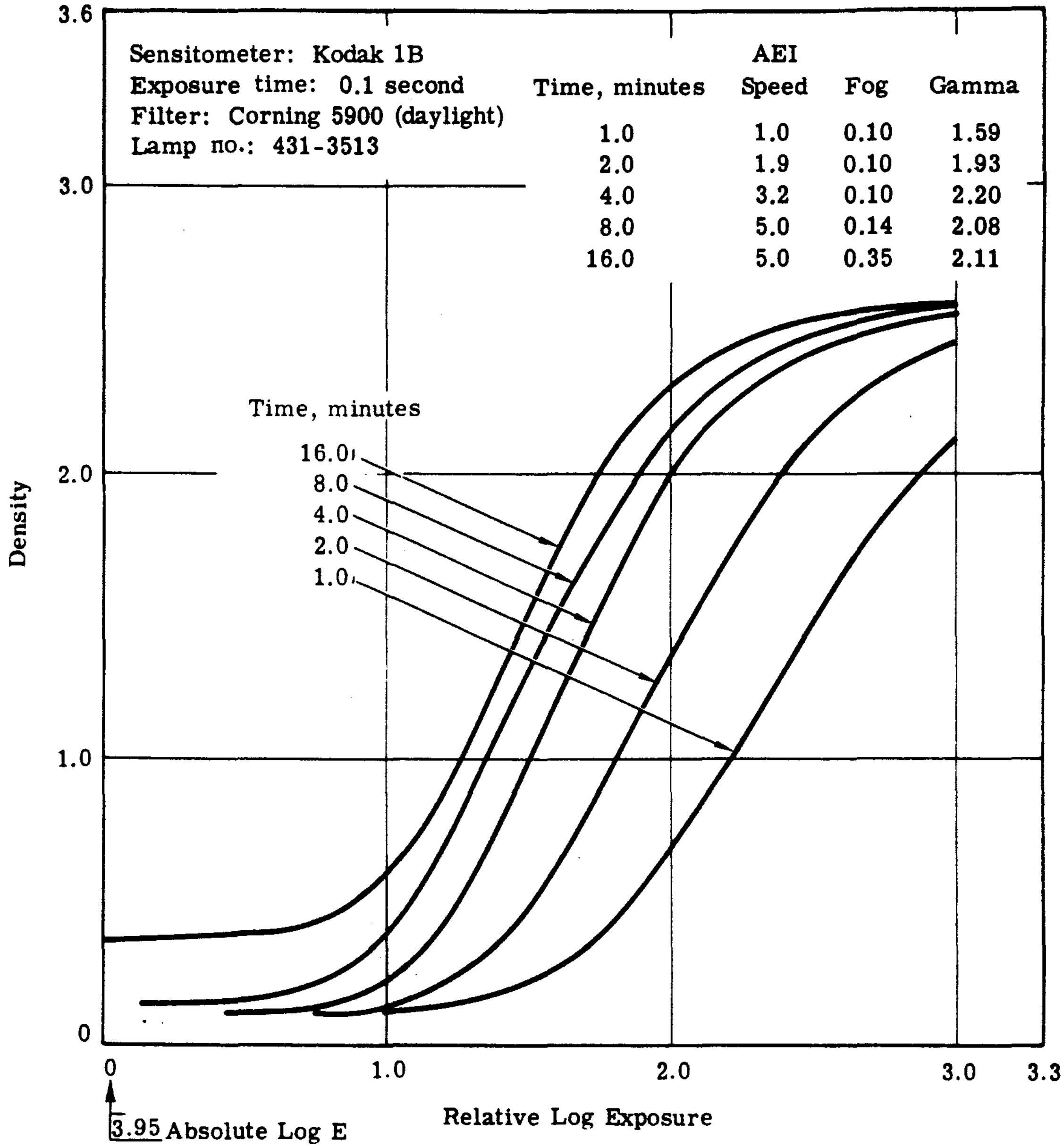
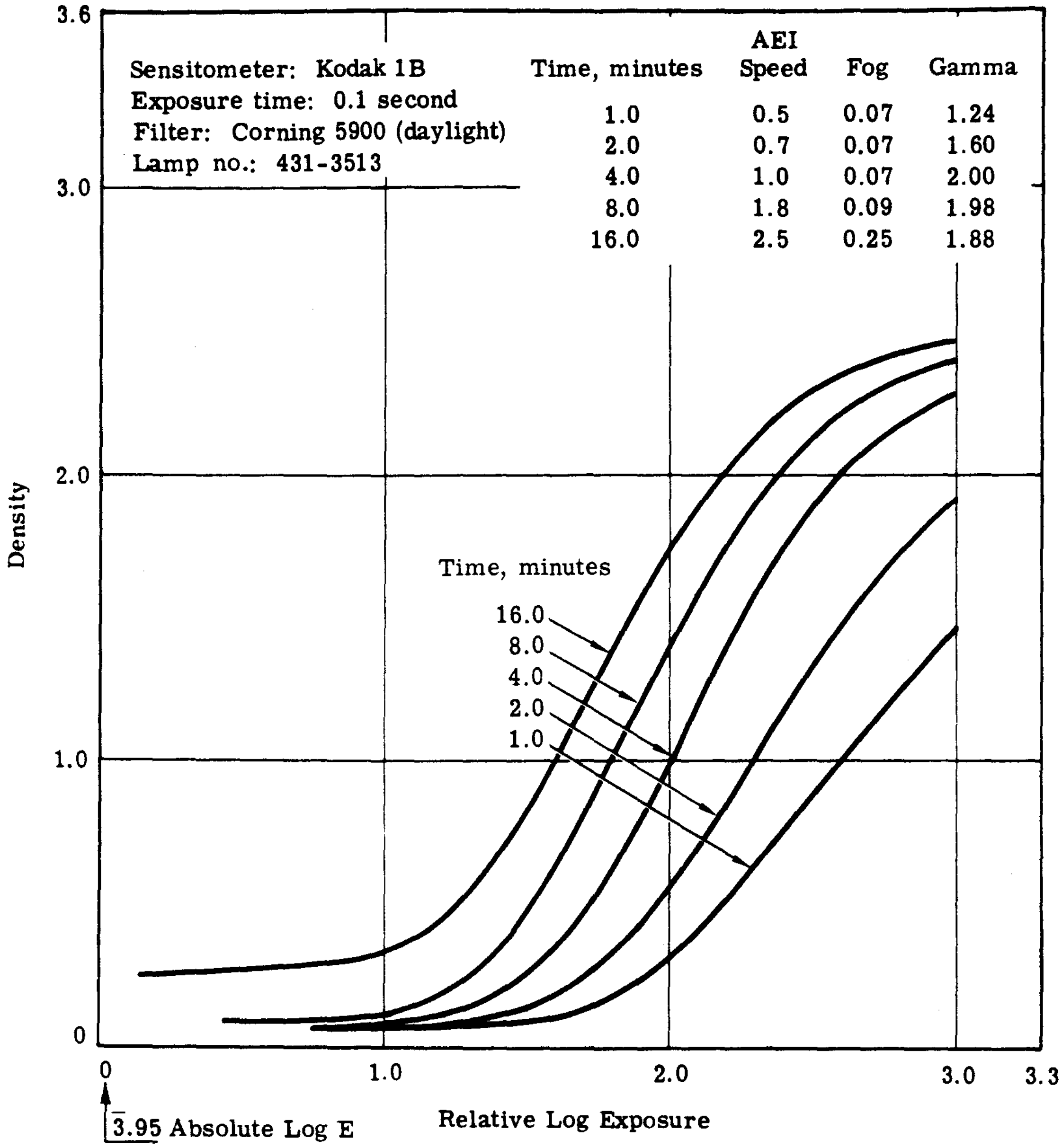


Fig. 2-1 — General sensitometry of Kodak Experimental Aerial film (SO-230, D-19 developer at 68 °F)



Time, minutes	AEI Speed	Fog	Gamma
1.0	0.5	0.07	1.24
2.0	0.7	0.07	1.60
4.0	1.0	0.07	2.00
8.0	1.8	0.09	1.98
16.0	2.5	0.25	1.88

Fig. 2-2 — General sensitometry of Kodak High Definition Aerial film (3404, D-19 developer at 68 °F)

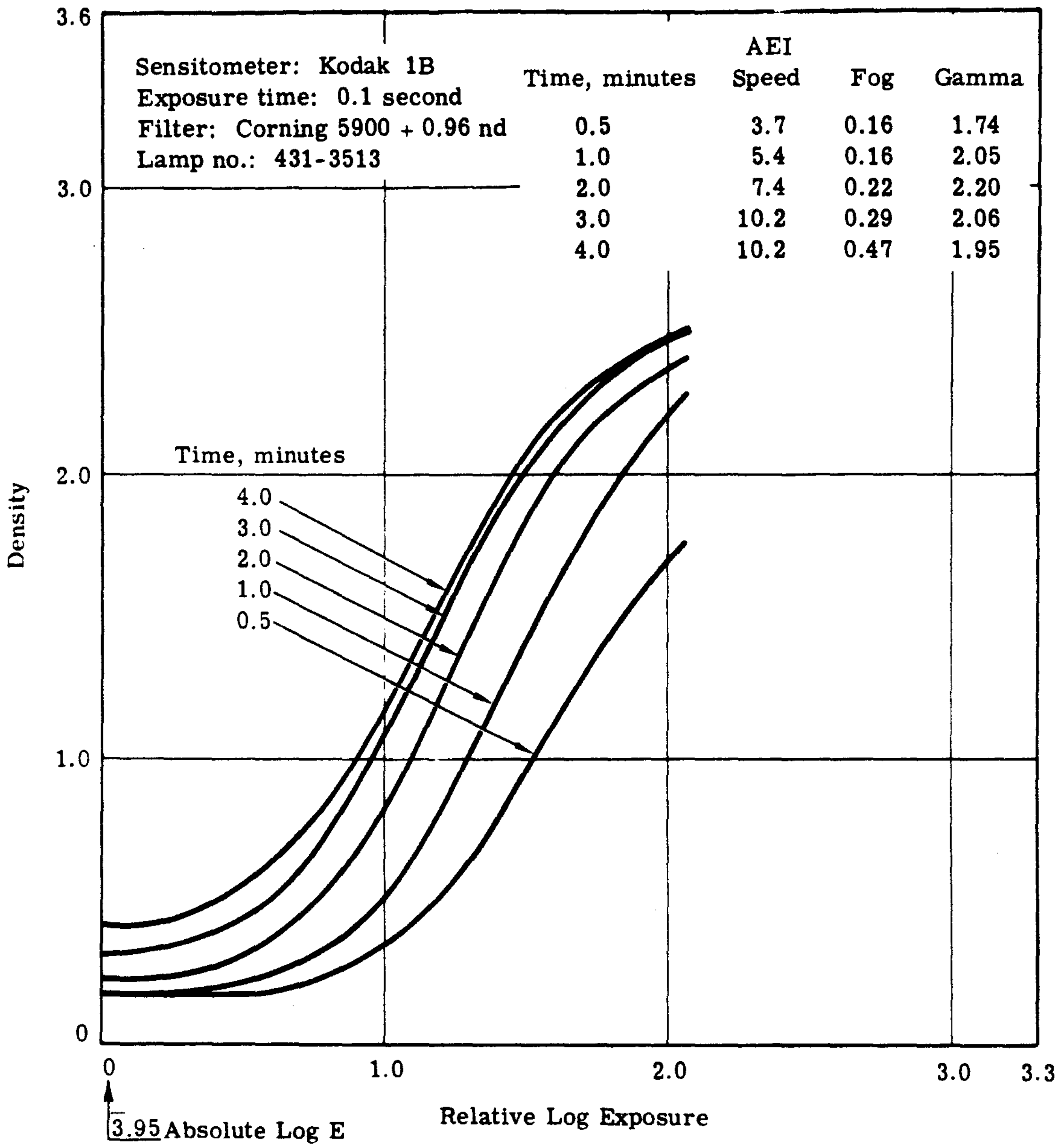


Fig. 2-3 — General sensitometry of Kodak Experimental Aerial film (SO-230, MX-578 developer at 68 °F)

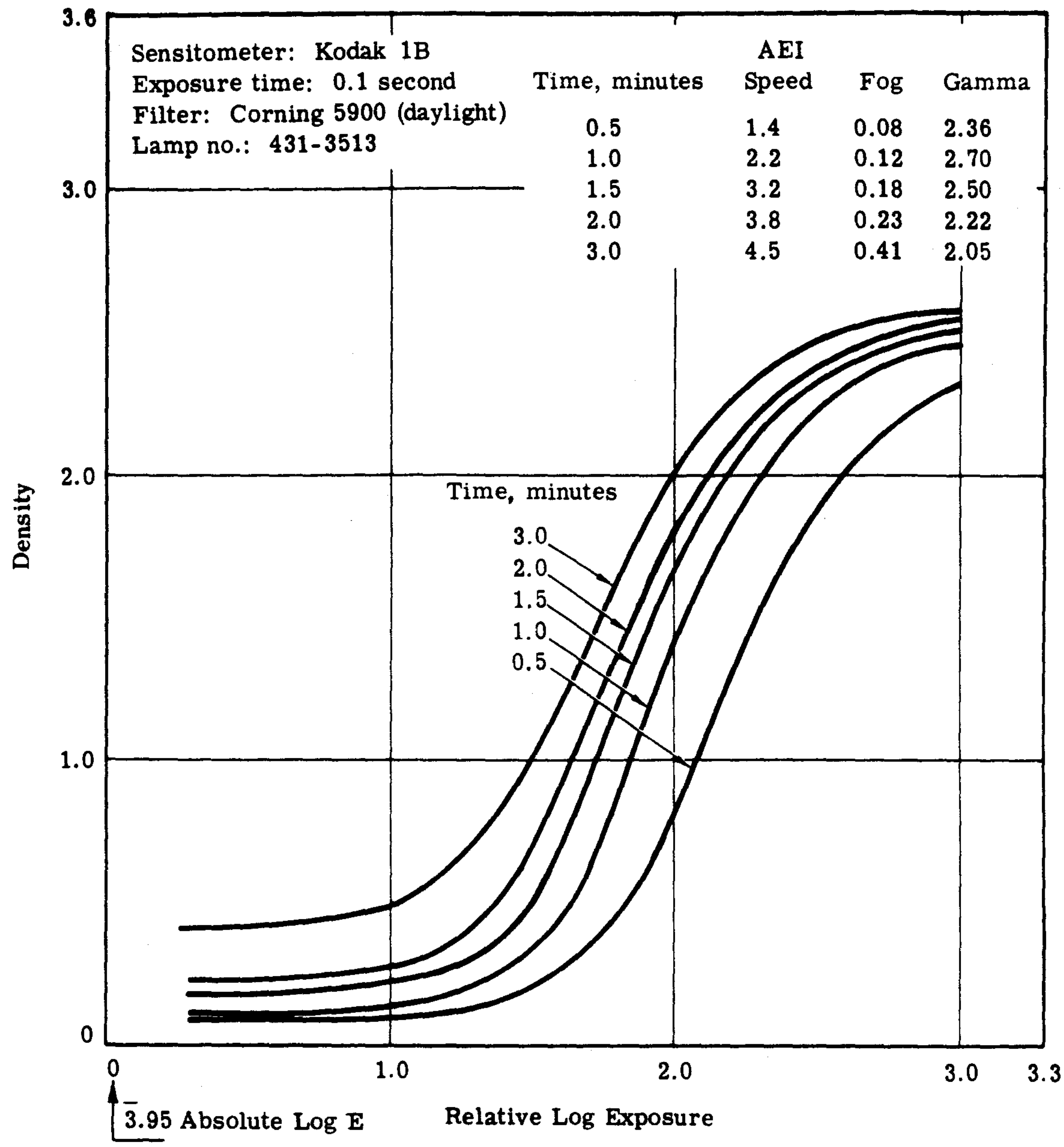


Fig. 2-4 — General sensitometry of Kodak High Definition Aerial film (3404, MX-577 developer at 68 °F)

Table 2-3 — Filter Factors for Simulated Daylight Conditions for SO-230 and 3404

Wratten filter no.	12	21	23A	25	HN-38* (Polarizer)	44A + 2E (Cyan)	57 (Green)	ISF† (Orange)
3404	1.7	2.1	2.8	3.3	2.5 to 3	15.	6.0	3.8
SO-230	1.7	2.0	2.5	2.9	2.5 to 3	15.	5.8	2.8

* The filter factor for an operational flight is a function of look angle and azimuth.
† The final ISF (Itek Special Filter) has not yet been coated on 0.007-inch quartz. This is the best estimated to date for a similar filter on thicker glass.

not possible. The Wratten no. 44A + 2E combination was originally intended for the bicolor work. However, the filter factor is too high for this system. In its place in the coming bicolor test in the KH-4B System will be the Wratten no. 57 filter which has also been used for laboratory bicolor work. The ISF has been designed to eliminate the near IR (700 to 720 millimicrons) energy. The filter is essentially equivalent to a Wratten no. 21 filter on the short wavelength (i.e., cutoff at 540 millimicrons) side with the additional cutoff at 700 millimicrons.

2.2.3 Resolving Power

The resolving power tests are shown in Table 2-4 and Fig. 2-5 for D-19 processing. The data in Table 2-4 show the resolving power versus the original target contrast whereas the curves in Fig. 2-5 represent the resolution as a function of target modulation. At high target contrast and/or modulation, there is a difference between the SO-230 and 3404, the latter being superior. However, at the low contrast level there is no significant difference between the two films.

2.2.4 RMS Granularity

At a density of 1.0 above base plus fog, the rms granularity values are: SO-230 = 0.0168, and 3404 = 0.0150. The SO-230 has a higher granularity than 3404. This is verified by the subjective analysis discussions in Section 3.

2.3 TASK 1 CONCLUSIONS

This series of basic sensitometric tests indicates that under identical exposure conditions, SO-230 has an increased emulsion speed of a factor two times that of 3404. In addition, it produces generally higher fog and increased granularity. The gamma comparison shows a dependence upon type of developer; the resolutions are significantly different at high contrast levels although they are the same at low contrast. The usefulness of SO-230 from a system standpoint cannot be proven by this series of evaluations. However, it is evident that the primary advantage is in the area of emulsion speed.

Table 2-4 — Resolving Power Data for 3404 and SO-230 at a Density of 1.0 (D-19 developer, 8 minutes at 68 °F, N_2 burst)

T.O.C.	3404, c/mm	SO-230, c/mm
1,000:1	650	550
6.3:1	500	450
1.6:1	200	200

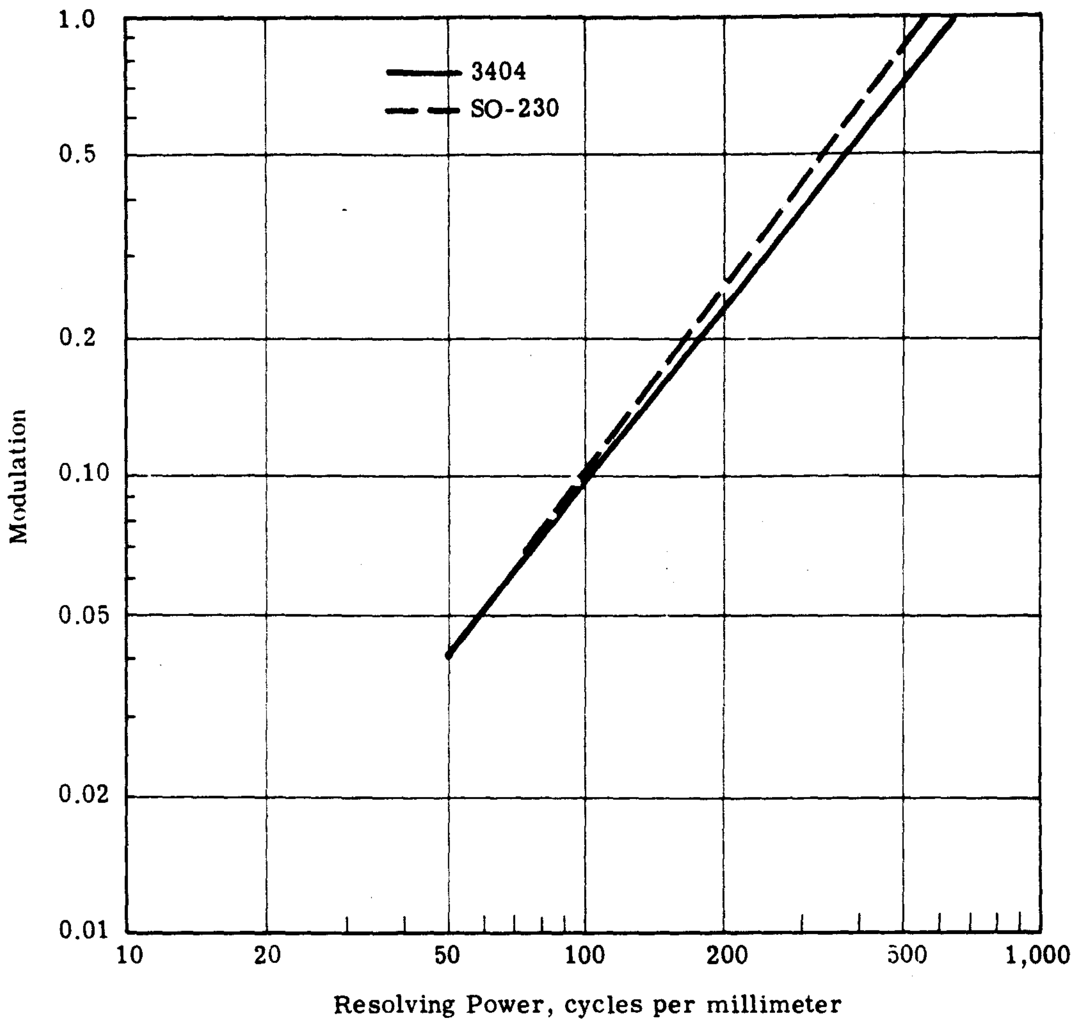


Fig. 2-5 — Emulsion thresholds (AIM curves) for 3404 and SO-230 films

3. TASK 2—COMPARATIVE SUBJECTIVE EVALUATION OF TYPES 3404 AND SO-230 FILM

The films submitted for evaluation consisted of 35-millimeter strips of SO-230 and 3404 exposed over a five-stop exposure range with the "normal" exposure value toward the middle. Two developers were used to process each emulsion, D-19 nitrogen burst and MX-578 spray. The subject was a model of a typical industrial/urban area in HO scale with a sun/sky ratio of 3:1.

All the imagery was examined in the original negative form and the "normal" case picked by consideration of density, contrast, shadow and highlight characteristics, and mental comparison with previously acquired real life photography. One exposure on either side of the normal was selected for evaluation of the overexposure and underexposure conditions.

The three samples of 3404 were processed in D-19 with one normal exposure processed in MX-578 included for comparision (Fig. 3-1), and the two samples of SO-230 were processed in MX-578 (Fig. 3-2).

Processing in MX-578 gives both films an increase in speed of between one and two stops as well as finer grain, two desirable features for any reconnaissance film.

3.1 EVALUATION OF 3404 PROCESSED IN D-19 DEVELOPER

The tolerance of 3404 to exposure changes is excellent. As would be expected, underexposure favors the high reflectance targets, with some loss of detail in shadowed areas. Normal exposure was chosen as such because of its compromise of highlight and shadow detail and because it maintains good resolution and separation in the middle tones. Overexposure produces very luminous shadows with some loss of high reflectance details.

Resolutions, as read by the simulated CORN targets included in each frame, appear to be very consistent. Resolutions in both the 4:1 and the 2:1 contrast targets are quite consistent, exhibiting only one element difference at each constrast and only one element degradation from the 4:1 to the 2:1 contrast target.

The resolutions of the overall model image varies somewhat as a function of exposure. The underexposed sample shows very fine detail, which is lost when overexposure occurs. This is in extremely fine detail, but it must be considered in conjunction with the tonal range capability when anything but an optimum exposure is considered.

Edge acuity is quite consistent throughout the exposure range. A one stop variation over or under does not produce any noticeable difference.

For comparison, a sample of a normal exposure processed in MX-578 is included. There is an apparent increase in fine line resolution, consistent tonal reproduction, and finer grain. Considered with the increased speed noted previously, this developer would seem to have merit.

3.2 EVALUATION OF SO-230 PROCESSED IN MX-578 DEVELOPER

The underexposed case shows good detail in fine line objects, i.e., roof joists, etc. Low reflectance objects are lacking in detail but high reflectance items show good detail. Resolution is comparable to 3404 in the targets but falls off when recording scene detail.

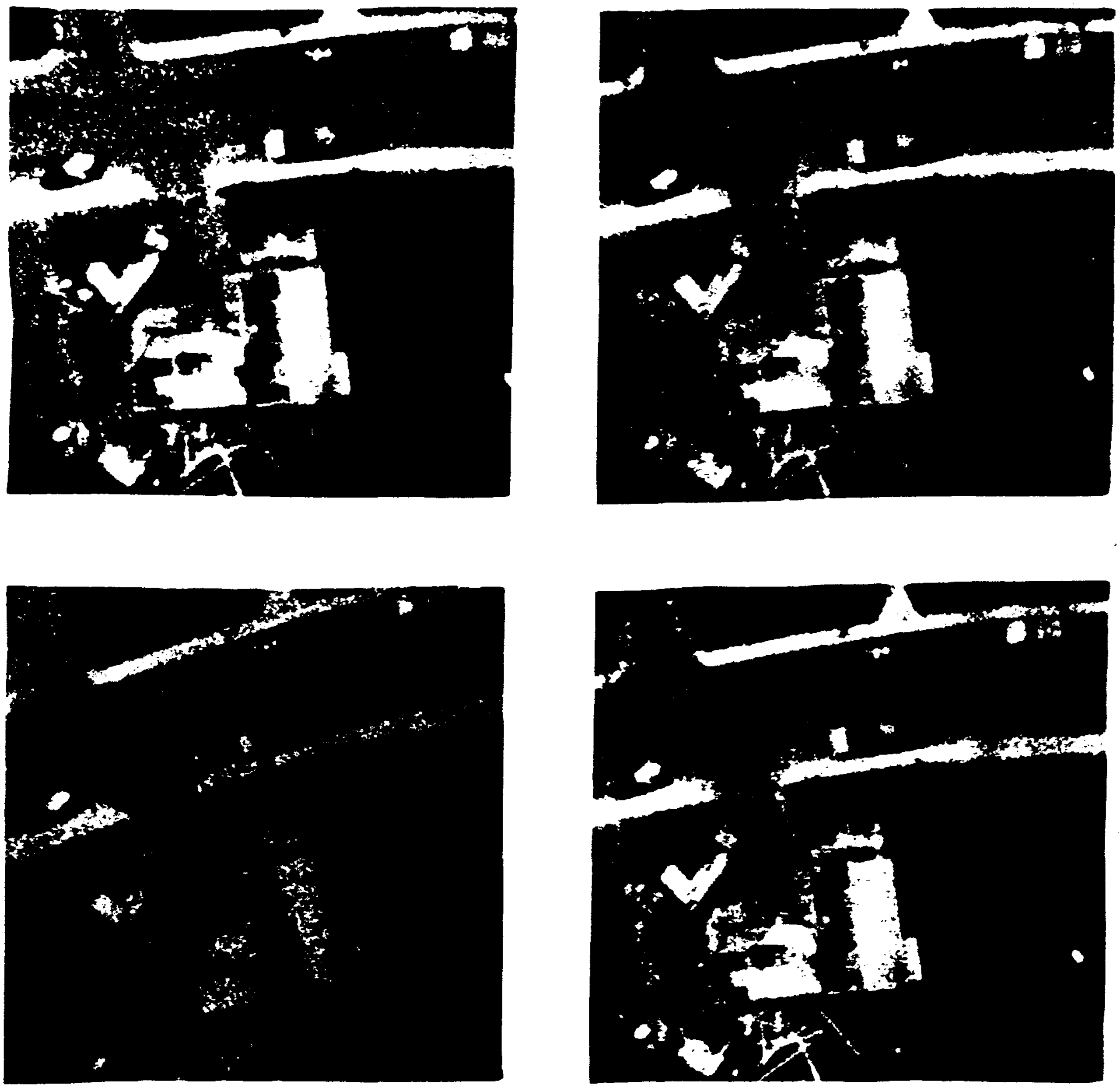
Normal exposure produces the optimum case as far as can be determined by the limited number of samples. Tonal range embraces an optimum middle range with not much degradation at either end. Again, the bar target resolutions are comparable with 3404 but the model scene is deficient generally. The quality of the image is superior to the underexposed sample in overall resolved detail and, to a lesser degree, improved the edge acuity.

3.3 TASK 2 CONCLUSIONS

The two emulsions taken individually are both good for high quality aerial photography. The fact that 60- to 100-diameter magnification is required to distinguish differences speaks well of both. Type 3404 is slower than SO-230, but the higher high contrast resolution and acuity and the finer grain structure make 3404 the superior information storage medium. Individual targets such as trucks, dish antennae, building shapes and outlines, parking lot lines, and rail facilities are all better recorded and defined on 3404. Though the low contrast resolution is the same for both materials, the slight increase in graininess detracts from the quality of SO-230.

3404, D-19, 1 stop underexposed

3404, D-19, normal exposure

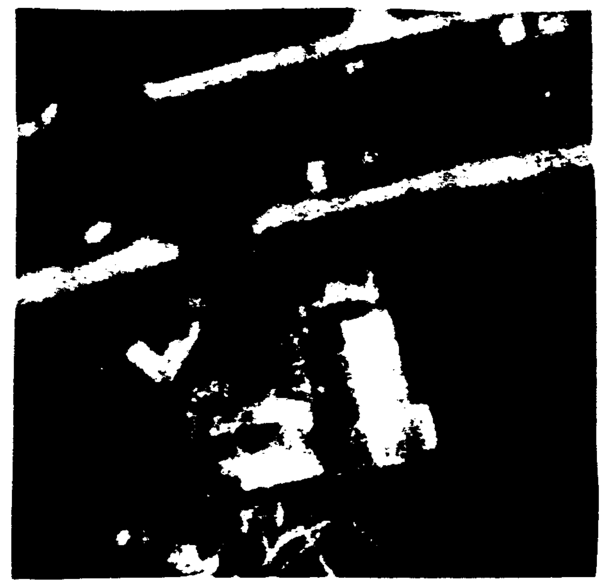


3404, D-19, 1 stop overexposed

3404, MX-578, normal exposure

Fig. 3-1 — 100× microphotographs of 3404 model samples

SO-230, MX-578, 1 stop underexposed



SO-230, MX-578, normal exposure

Fig. 3-2 — 100× microphotographs of SO-230 model samples

4. KH-4B SYSTEM CONSIDERATIONS

The purpose of this section is to compare 3404 and SO-230 from a theoretical operational standpoint so that the relative performance of the two materials in the KH-4B System may be assessed. The SO-230 has a lower high contrast resolution than 3404, but it is more sensitive by a factor of two. The fundamental question, therefore, is whether the increased speed of SO-230 will yield a higher resolution than 3404 under operational conditions. To answer this question, the exposure times were determined for each film at solar altitudes of 0 to 90 degrees. The image blur was then determined from the exposure times and the resulting resolution, on the optical axis, was calculated for the solar altitude region. This analysis was carried out at the intermediate processing level.

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

For this analysis, it will be assumed that the linear portion of the characteristic curve is the best area for exposing images. The criterion used in this analysis was to assign the object with the minimum reflectance to the lowest usable point on the linear portion of the characteristic curve. This assumes that the remaining objects in the scene will either be located at that position or result in a total scene exposure confined to the mid range (straight line portion) of the D-log E curve.

For 3404 and SO-230, the minimum density corresponding to the previously described point is approximately 0.6. This density is formed by exposures, E_m, of $\bar{2}.95$ for the 3404 and $\bar{2}.65$ for the SO-230. Note that the difference in log E indicates a speed shift of two, or one stop. The exposure, E_m, equals the illumination from the minimum reflectance object incident to the film, I_f, times the exposure time, t. The term I_f is related to the ground illumination and camera system by the expression

$$I_f = \frac{B_o \, T_\ell}{4(f/no.)^2 \, (F)}$$

and

$$B_o = I_s \, R_g \, T_a + B_a$$

where the camera characteristics are

T_ℓ = lens transmission
f/no. = relative aperture
F = filter factor

and the illumination characteristics are

I_s = solar illumination
R_g = object reflectance
B_o = object brightness
T_a = atmospheric transmission
B_a = atmospheric illumination

If it is assumed that the minimum reflectance object has $R_g = 0$, then the brightness of the object, B_o, is equal to the atmospheric illumination, B_a. The atmospheric illumination versus the solar altitude is presented in Fig. 4-1, and the previous equations can be rewritten as

$$I_f = \frac{B_o\, T_\ell}{4(f/no.)^2\,(F)}$$

For the specific system

f/no. = 3.5
T_ℓ = 0.875
F = 1.9 (for Wratten no. 21)
T_a = 80 percent

The exposure time, t, for each solar angle is

$$t = \frac{Em}{10.76\ If}$$

The exposure time as a function of solar altitude for 3404 and SO-230 is shown in Fig. 4-2.

4.2 RESOLUTION OF SO-230 AND 3404 AS A FUNCTION OF SOLAR ALTITUDE

The high contrast resolution of the system (i.e., lens, film, etc.) is dependent, from an operational standpoint, on the exposure time. As the exposure times increase, the image blur increases. The relationship is as follows:

$$\text{Blur} = \frac{\text{(velocity) (exposure time)}}{\text{scale}}$$

For this reason, image motion compensation is designed into the system. This reduces the image blur to about 1 to 3 percent.

The maximum high contrast resolution of each film can be determined by crossing their resolution threshold curves with the modulation transfer function of the Petzval lens. For 3404, the resolution is 165 lines per millimeter, and for SO-230 the resolution is 150 lines per millimeter. The reduction in resolution as a function of image blur can be calculated, therefore, by a modified version of Katz's formula:

$$1/R^2 = 1/R_o^2 + (BL)^2$$

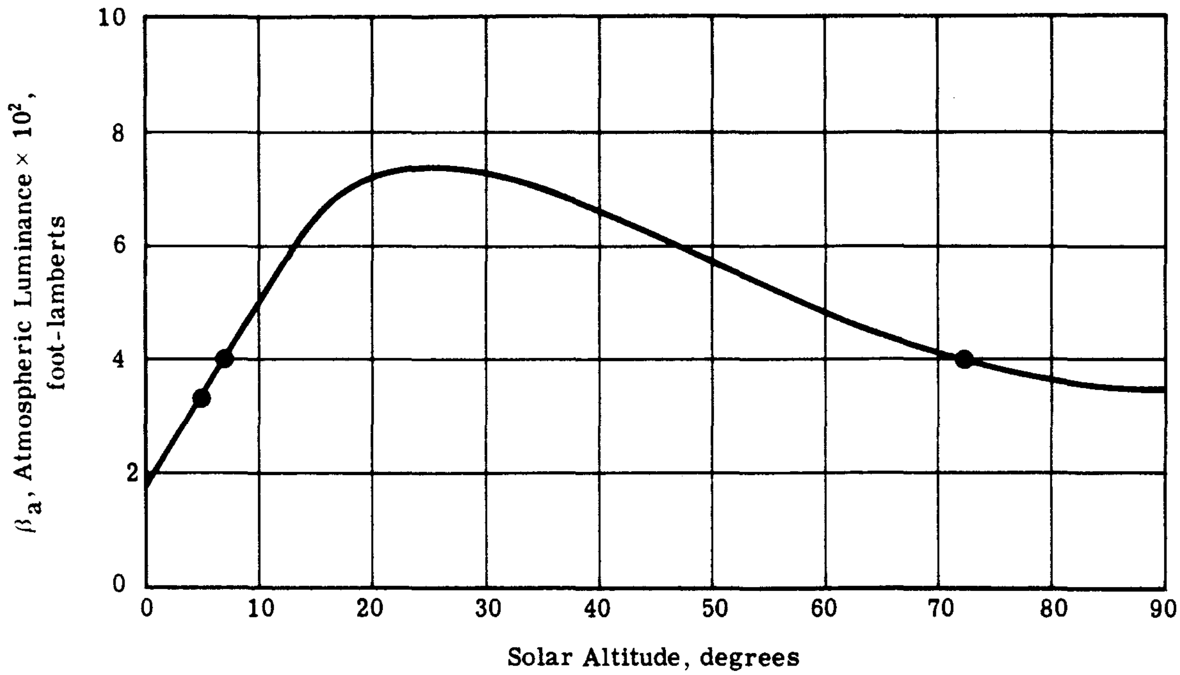


Fig. 4-1 — Atmospheric luminance as a function of solar altitude

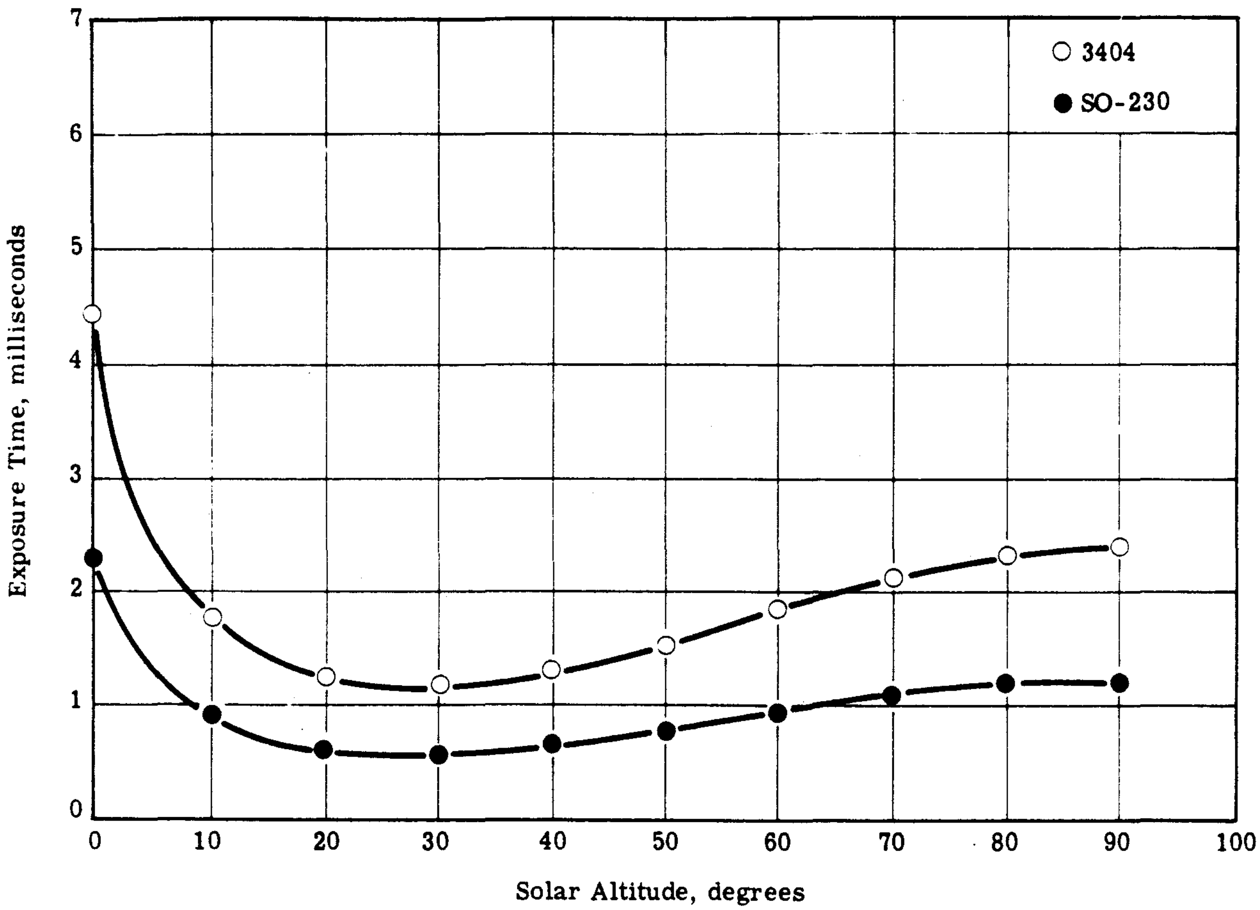


Fig. 4-2 — Exposure time versus solar altitude for objects with minimum reflectance using 3404 and SO-230 film

where R = resulting resolution
R_O = static resolution of the film
BL = image blur

Fig. 4-3 shows this relationship for the two films. It should be pointed out that the blur is in terms of the 3 percent uncompensated image motion due to the forward motion of the vehicle.

There is a specific slit width associated with each of the blur values in this figure. This slit width can be associated with a solar altitude using the sensitometric curves and atmospheric illumination curves previously discussed. With these, the system resolution for each of these solar altitudes can be calculated. This was done for both materials, and the final curve is given in Fig. 4-4.

Notice from this relationship that the operational resolving power of SO-230 is greater at solar altitudes from 0 to 5 degrees and from 75 to 90 degrees. Therefore, SO-230 has a higher resolution in the system than 3404 over certain solar altitudes.

This analysis has dealt only with the uncompensated image motion due to vehicle forward motion. There are other system motions that have not been accounted for in this analysis, such as film motion due to the scan heads lifting the film and vehicle vibrations. With a smaller slit width these would also be proportionally reduced, thereby giving the SO-230 an even greater advantage. With these added gains, the net effect could be that SO-230 and 3404 could have equal system high contrast resolution over the remaining levels of solar altitude.

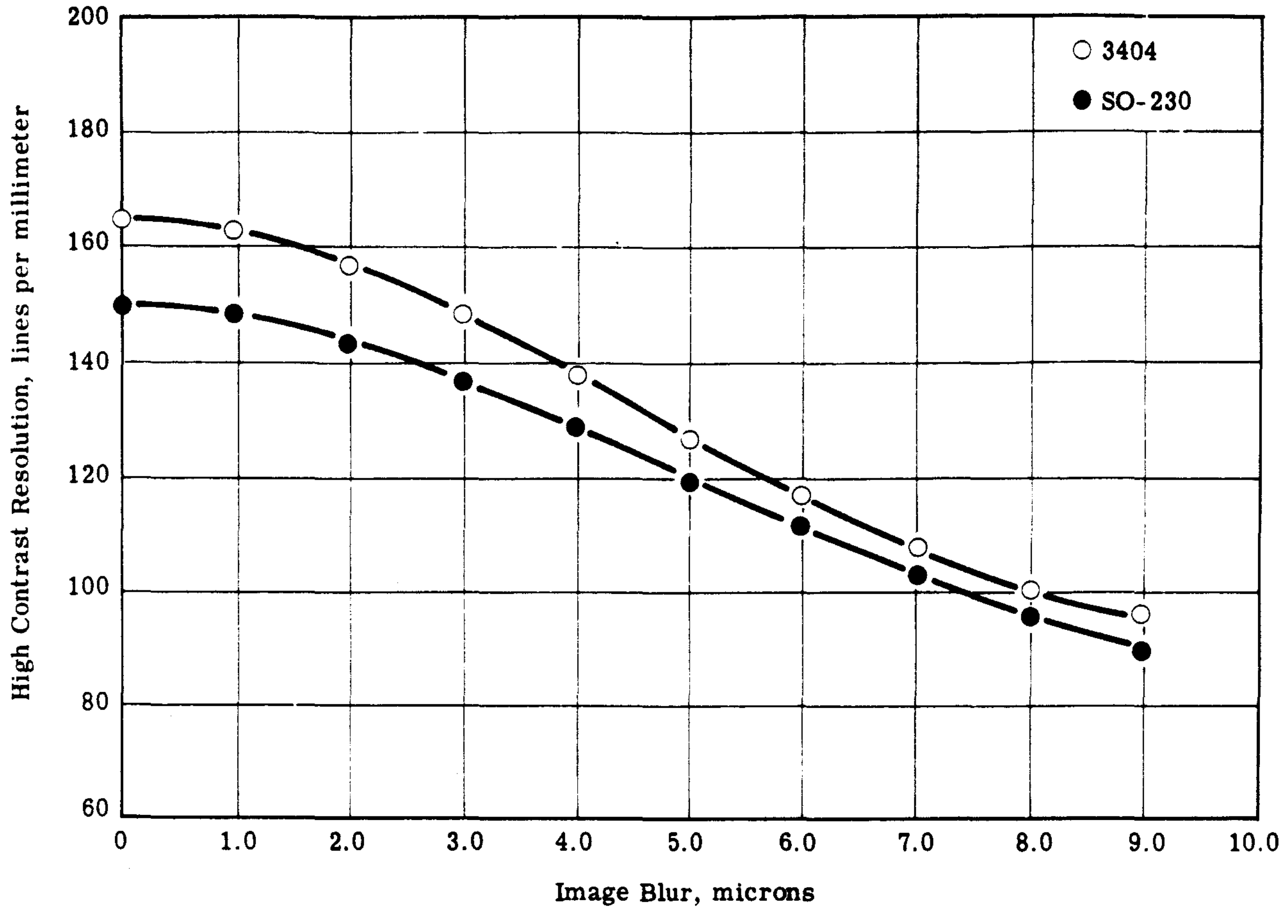


Fig. 4-3 — High contrast resolution of 3404 and SO-230 film as a function of image blur

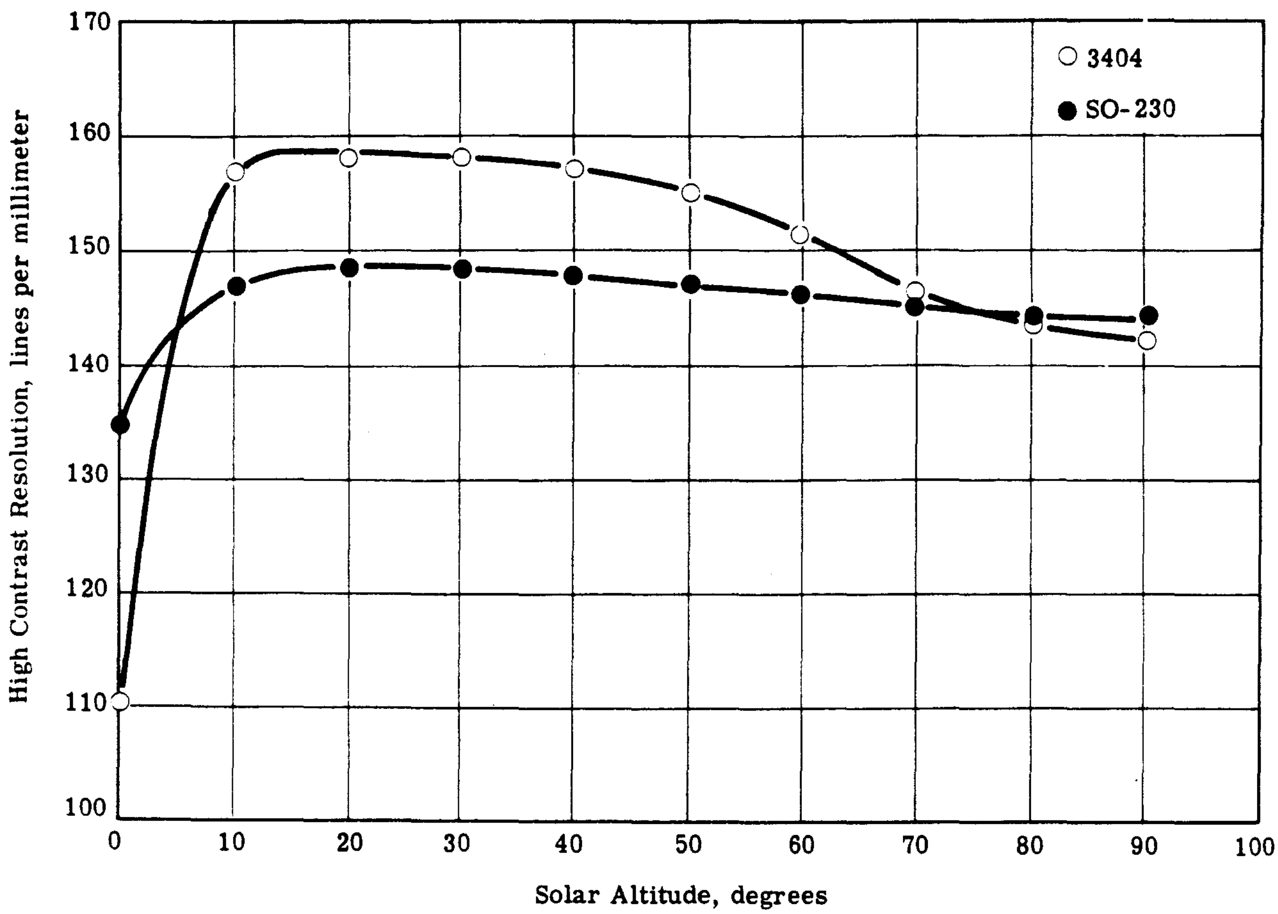


Fig. 4-4 — High contrast resolution of 3404 and SO-230 film as a function of solar altitude derived from image blur at intermediate processing

5. CONCLUSIONS

The results of the two tasks allow several conclusions. These are summarized as follows:

1. Type SO-230 is approximately two times faster than 3404, depending on the type of developer used.

2. Type SO-230 produces higher fog levels than 3404 under all processing conditions with the exception of a long time, high energy developer combination. However, this differential can be considered as insignificant because in both cases the fog density was too high for operational image analysis.

3. The variation in gamma between the two films is developer dependent. Type SO-230 produced a higher gamma when processed in D-19 but lower gamma when processed in the appropriate high energy developer.

4. The difference in resolving power of the material is significant at the high contrast (1,000:1) target range but insignificant at lower contrast levels. The low contrast resolution (1.6:1) for both materials is 200 cycles per millimeter. There is about a 15 percent difference in high contrast resolution of the films.

5. Type SO-230 has a higher granularity than 3404 by a factor of approximately 1.12×.

6. Both films hold up well under conditions of underexposure and overexposure.

7. The subjective analysis shows that 3404 is more desirable than SO-230 because of its finer grain, slightly better detail rendition, and better visual acuity. Though the low contrast resolving power of SO-230 is the same as 3404, the increased grain structure is distracting and perhaps will be a significant factor from the photointerpreter's standpoint.

8. The operational high contrast resolution of SO-230 is expected to be equal to that of 3404 at all normal solar altitudes.

9. Based on the result of this test, a KH-4B satellite test with this material is recommended.

10. Type SO-230 may exhibit poor latent image keeping characteristics as compared to 3404. This undesirable trait may reduce the speed of the former to that of the latter and over extended storage periods could degrade it even more.