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REPORT NO. 5

KH-4B SYSTEM CAPABILITY

Evaluation Of SO-380 Film For Use With The KH-4B System

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1. INTRODUCTION AND SUMMARY

The fundamental purpose of the KH-4B system is to provide extensive stereoscopic reconnaissance coverage for intelligence acquisition and to provide photogrammetric control data for the construction of accurate terrain maps. The performance of a high acuity system is dependent upon the mechanical, optical, and the film sensor components of the system. Improvements in any one of these areas increase the information return.

This report represents an evaluation of new film, SO-380, and its application in the KH-4B system. In the past, improvements in one quality of a film product have usually been achieved at some sacrifice in some other area such as sensitivity, image quality, or physical characteristics. The goal then, in improving a film product is to improve the performance in one area, while maintaining performance in the other. With the SO-380 film, the improvement is achieved in the film construction. That is, base thickness plus the emulsion thickness was reduced from 3.0 mils, the nominal 3404 thickness, to 2.0 mils with SO-380. There is no change in the emulsion thickness or gel backing of SO-380, remaining at approximately 0.24 mil and 0.26 mil, respectively.

Sensitometrically, the characteristics of SO-380 are identical to film 3404. The emulsion is basically the 3404 emulsion coated on an ultrathin polyester (Estar*) base material 1.5 mils thick, which is 1.0 mil less than 3404. The advantage of the thinner base material is a gain in film load approximately 50 percent. The increased payload of SO-380 can, therefore, permit increased acquisition, longer space usefulness and fewer launches to gain equal coverage.

The major portion of the data for this analysis was obtained from mission 1103-2 which was flown during the period of 8 through 15 May 1968. The last 1,750 feet of film in the FWD-looking camera and the last 1,757 feet in the AFT-looking camera of mission 1103-2 was SO-380 film which had been spliced onto the normal 3404 film supply.

A detailed sensitometric and image quality evaluation of SO-380 and 3404 films for both laboratory and mission conditions is presented in this report. The results show the characteristic curves for the two materials to be identical. SO-380 has a slightly lower induction period at shorter development times. After 1½ minutes processing, film 3404 and SO-380 become identical in fog levels, AEI speeds, and processing rate. The gamma appears to be a little lower with SO-380 film at all processing levels when development is carried out in the high energy developer MX-577. The resolving power and rms granularity values for SO-380 and 3404 are nearly identical.

At the transition points on the film roll between 3404 and SO-380 in the mission 1103 test, direct comparison could be made of similar imagery from the same camera. This contractor's photointerpreter analysis of mission 1103 indicates a preference for film 3404. This preference is based on marginal differences in resolution and acuity apparent at magnification levels of

*"Estar" is a trademark of the Eastman Kodak Company for its polyethylene terephthalate (polyester) film base.

30× to 60×. However, an analysis of the relative image motions indicated that this difference was more of a system difference than a real difference in the two films. The general quality of both films is comparable in most instances.

The general conclusion of the mission 1103 test is that SO-380 is equivalent to film 3404 in sensitometric and image quality characteristics and that it performed as well in this mission as film 3404. Therefore, the primary advantages of SO-380 lie in the additional coverage possibilities and the extension of missions by several days.

There have been problems in the mechanical tracking of the film through the camera system. Tests conducted at the contractor's environmental test laboratory (ETL) indicate that a film flatness problem with SO-380 film existed in vacuum, and consequently, a change in focus occurred due to film lift. Therefore, extra tests at ETL and in HIVOS* were conducted before an entire mission was flown with SO-380. These tests indicated that SO-380 would behave as well as 3404 and mission 1105 was flown with a full load of SO-380. However, this mission experienced variability in image quality which had not been predicted by the preflight tests. Since this information was contrary to the 1103 test, an additional section has been written for this report outlining the test results from the pre-1105 mission tests (Section 4). These data show that variability would be encountered, however, not nearly to the extent experienced on the 1105 flight.

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*HIVOS (high vacuum orbital simulator). The HIVOS test is a full system evaluation under simulated controlled temperature and vacuum conditions. The environment (temperature and vacuum) is programmed to simulate operational conditions of temperature and vacuum encountered by the system.

2. PHOTOGRAPHIC PROPERTIES

2.1 SENSITOMETRIC PROPERTIES

SO-380 and 3404 have virtually identical sensitometric properties. This similarity is reflected in Fig. 2-1, which compares both films in terms of gamma, AEI speeds, and fog levels when development is in high acuity film developer MX-577. The AEI speeds in MX-577 are identical at most processing times. At shorter processing times, the rate of development appears to be greater for SO-380 than for 3404. Figs. 2-2 and 2-3 (from which data for Fig. 2-1 was derived) are families of curves for both films as a function of development time in film developer MX-577. In comparing the shapes of the characteristic curves for equivalent fog levels, the curves overlap each other, except for a slight increase in D_{max} in the shoulder area for SO-380.

The laboratory results are in close agreement with data from mission 1103 R-2 process curves (see Figs. 2-4 and 2-5). The minute differences observed are negligible in this comparison.

2.2 PHYSICAL CHARACTERISTICS

Both 3404 and SO-380 are essentially identical with the exception of base thickness, both are clear polyester bases. In the manufacturing of these films, the same emulsion batch can be used to yield either SO-380 or 3404 film. When the 0.24-mil emulsion is coated on the standard 2.5-mil Estar base, the film is 3404. If the 0.24-mil emulsion is coated on a similar Estar base support of only 1.5-mil thickness, then the film is the ultrathin base SO-380. There is no significant difference in photographic properties between the standard Estar and the ultrathin base materials.

	SO-380	3404
Base	1.5 mils	2.5 mils
Emulsion	0.24 mil	0.24 mil
Gel backing	0.26 mil	0.26 mil
Total	2.0 mils	3.0 mils

In order to obtain a better understanding of the construction of these two films, microtomes were made of unprocessed samples of SO-380 and 3404. These microtomes are approximately 5 microns thick and are enlarged approximately 450 times. The subbing can be seen within the emulsion of the photographs shown in Fig. 2-6. Not evident, though, is the protective overcoat which is less than 0.01 mil thick and is on both sides of the film.

2.3 IMAGE PROPERTIES

As with sensitometric properties, the image quality of SO-380 and 3404 are very similar. Laboratory resolving power measurements in D-19 developer show that the high contrast resolving power of 3404 and SO-380 is 630 lines per millimeter. At low contrast (1.6:1) both films resolve 200 lines per millimeter. These reported values are based on the newly proposed USASI standard. An interesting point is that the resolving power peak can vary from film to film, yet, because it falls within the given range, the USASI number can be identical. Table 2-1 gives these USASI preferred values. The actual resolutions that are considered 630 lines per millimeter could lie between 563 and 707. The use of these preferred numbers tends to limit the implied three significant figure accuracy that is often reported.

Data supplied through the courtesy of [redacted] Film Evaluation and Testing group show virtually no difference in resolving power for the two films at either high or low contrast (for operational processing conditions). In Figs. 2-7 and 2-8, data for comparative resolution versus exposure and resolution versus target contrast are presented. The processing conditions for these data simulate those used in the actual mission, i.e., three stage processing in the Trenton.

Granularity* measurements made from samples of the two films processed in MX-577 developer show that the granularity values are 36 for SO-380 and 38 for 3404 at a density of 1.0. The difference between these numbers is within the normal experimental error and is considered to be equal. [redacted] reports rms granularity values of 22.3 for 3404 and 23.4 for SO-380 when processed with the normal mission process. The plots of granularity versus density level are presented in Fig. 2-7.

Laboratory determined filter factors for both SO-380 and 3404 were determined for the Wratten no. 12, 21, 23A, and 25 filters. Table 2-2 shows that the filter factors are nearly identical for both films. Since the films contain the same emulsion with the same spectral sensitivity, there should be no difference. The slight difference (less than 5 percent) represents the limit of accuracy in determining these values.

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*Granularity is an objective measure of the noise within a film. It is determined in this laboratory by making a microdensitometer scan with a 12-micron aperture of a uniform patch of density at a density level of 1.0 and multiplying this value by 1,000.

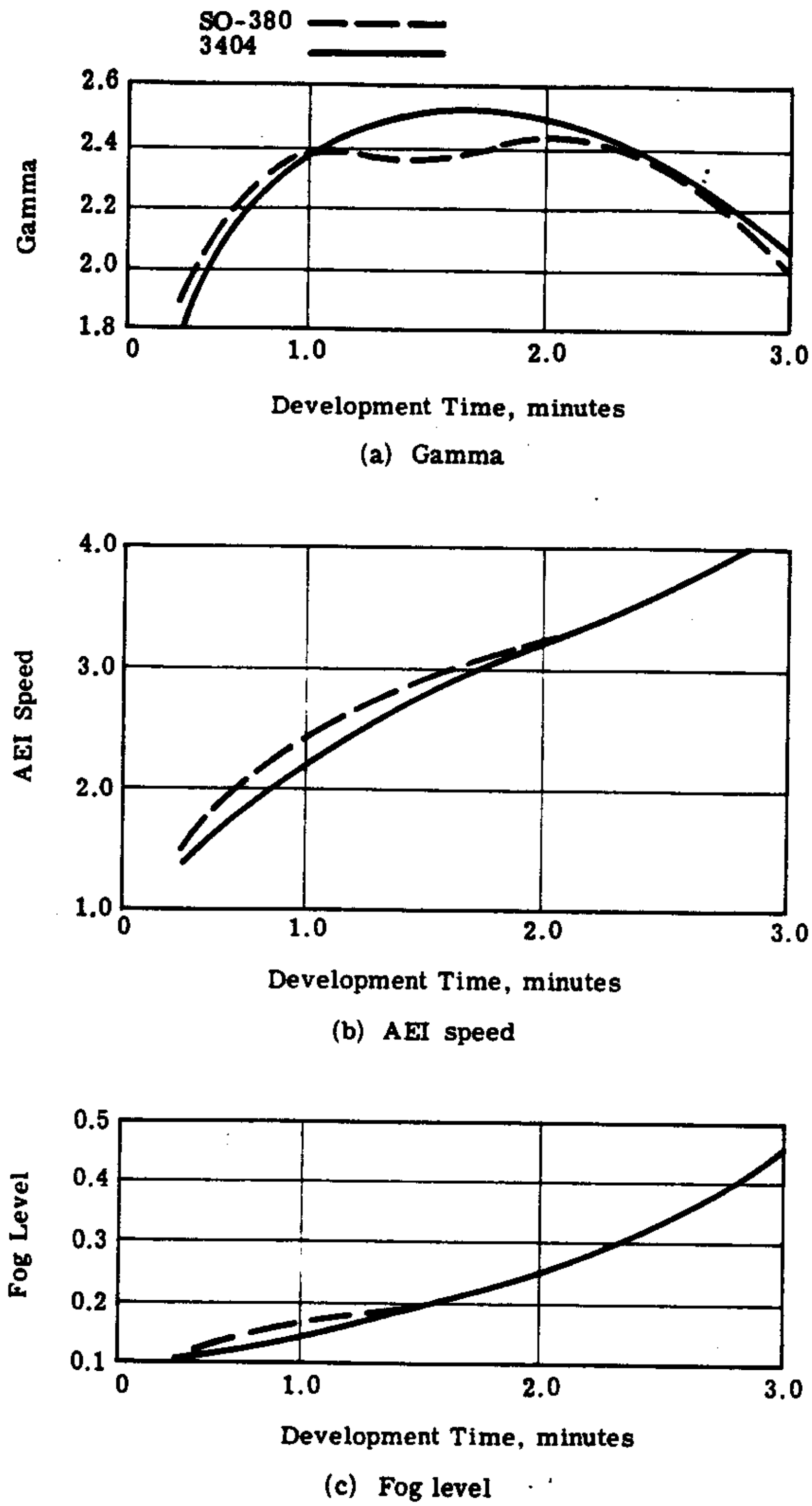


Fig. 2-1 — Gamma, fog level, and AEI speed versus development time (MX-577 developer at 68 °F)

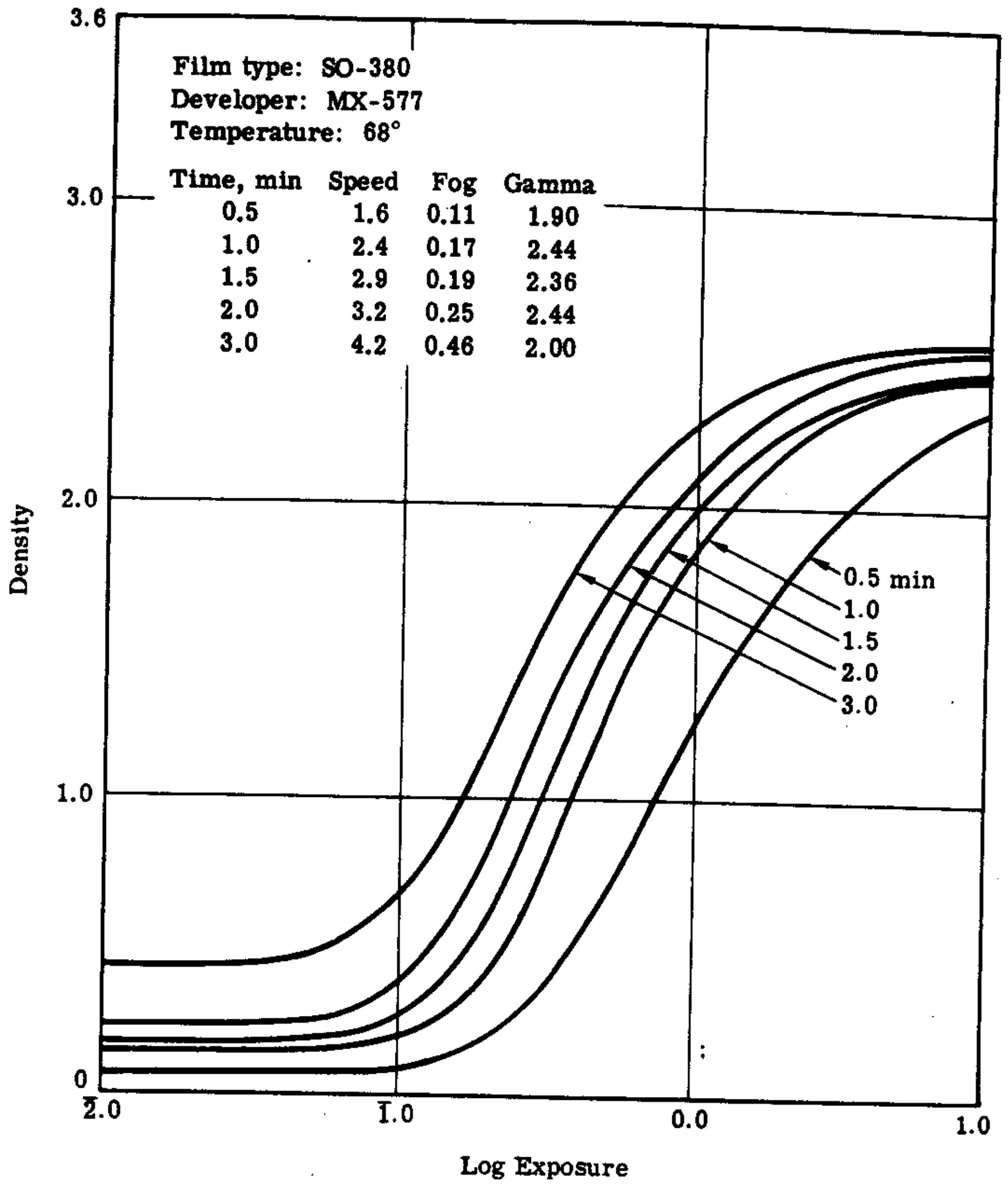


Fig. 2-2 — Contractor characteristic curves for SO-380 when exposed to simulated daylight

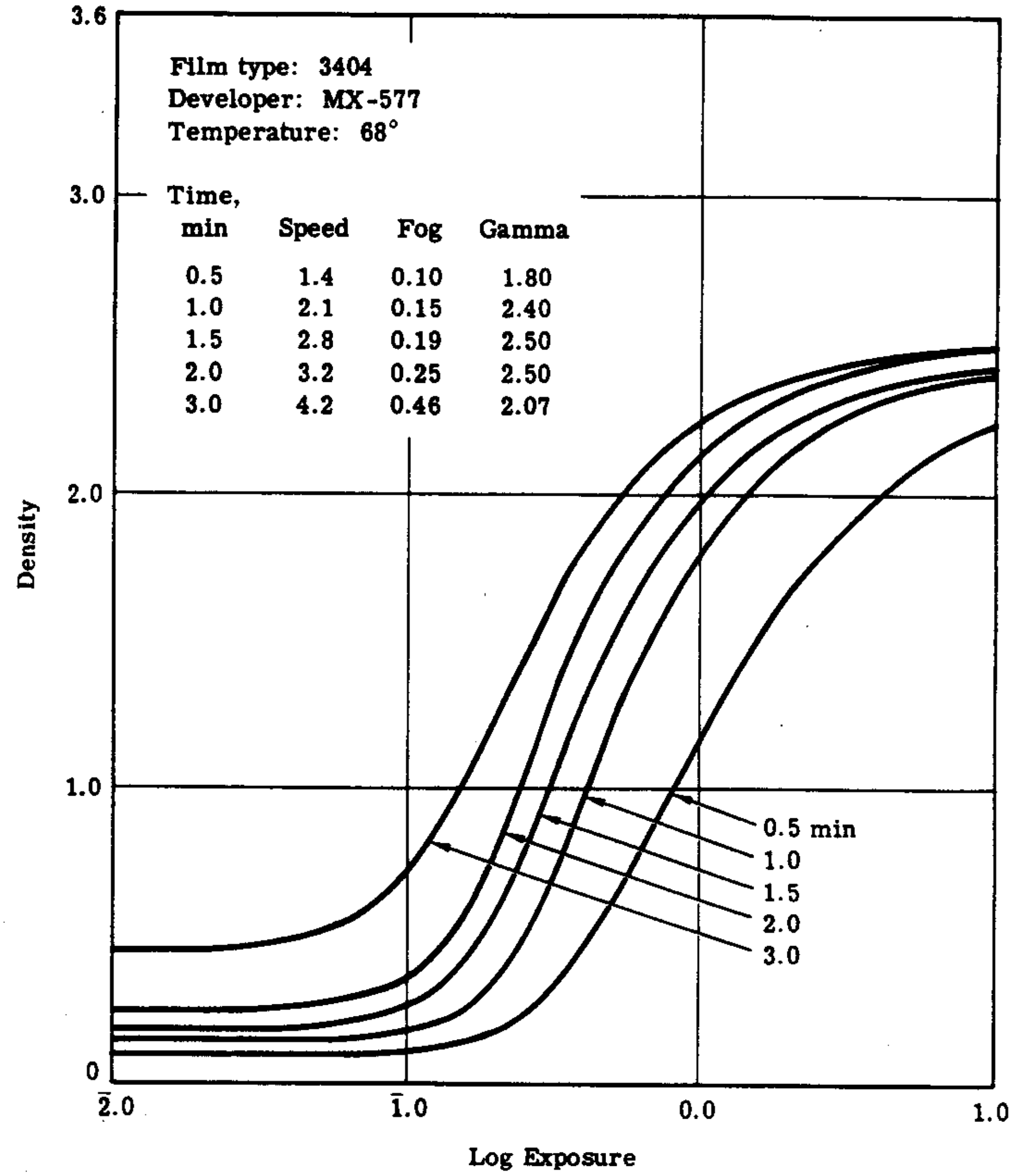


Fig. 2-3 — Contractor characteristic curves for 3404 when exposed to simulated daylight

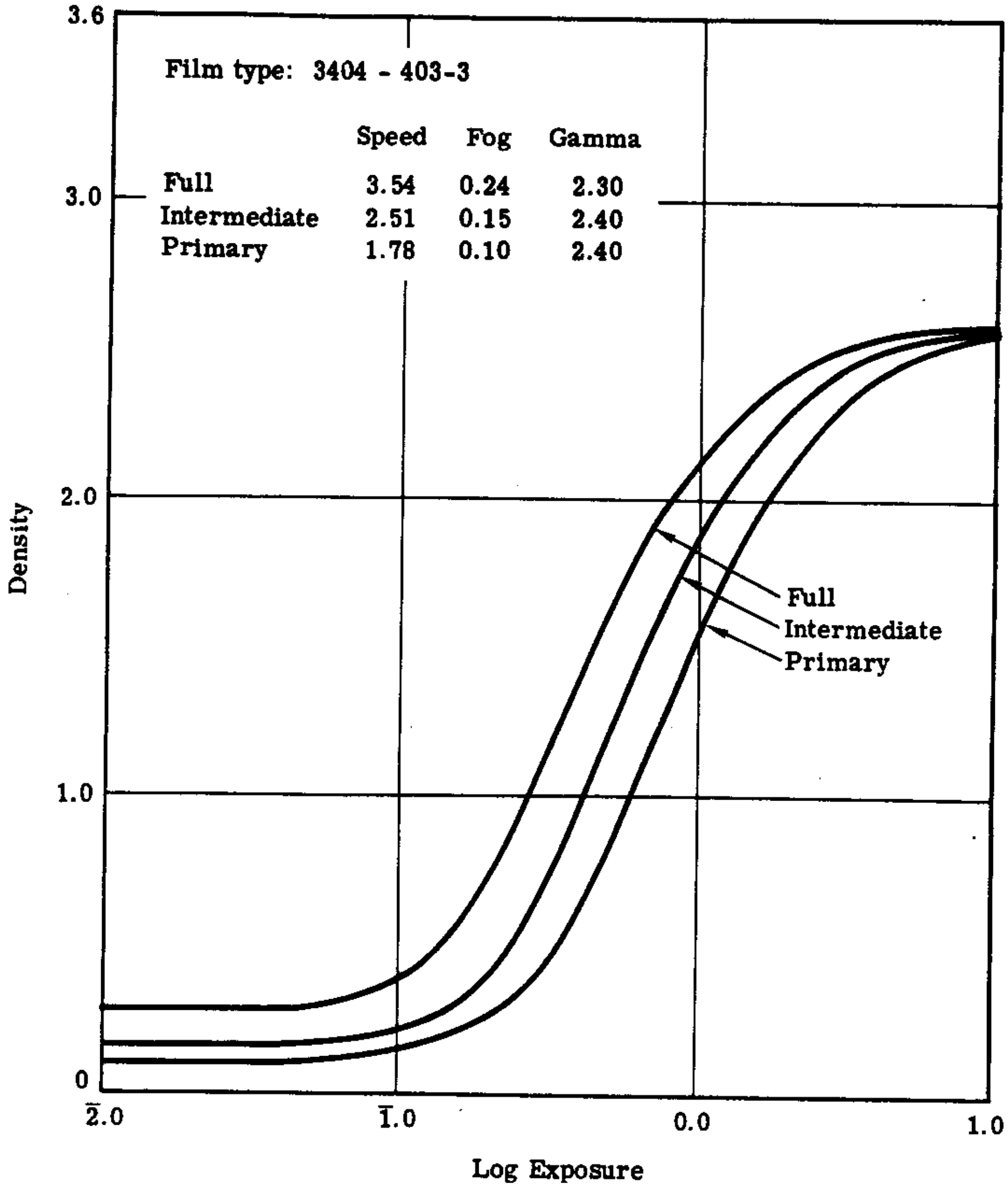


Fig. 2-4 — R-2 characteristic curve from the AFT camera process, mission 1103 (daylight at 1/25 second)

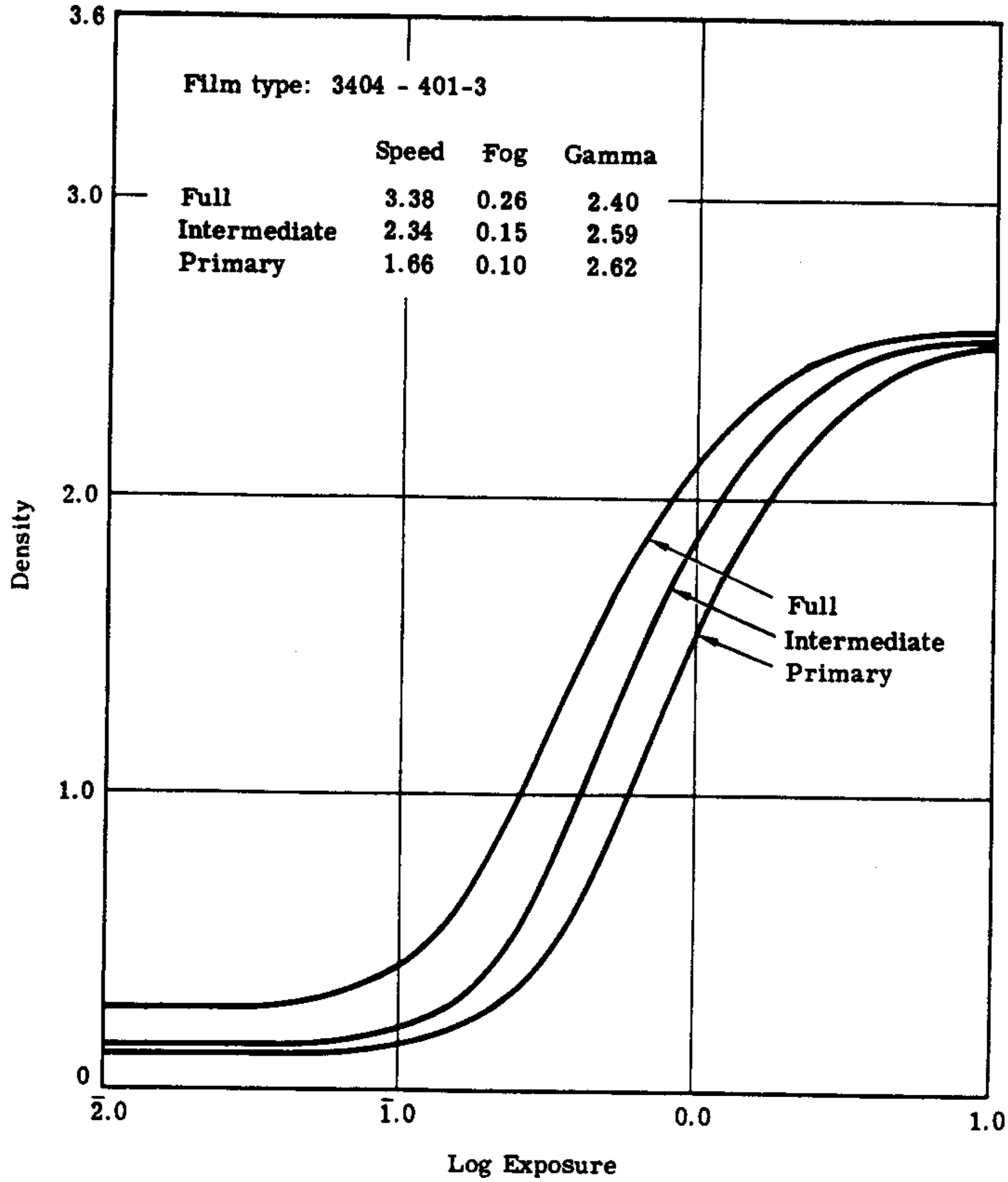


Fig. 2-5 — R-2 characteristic curve from the FWD camera process, mission 1103 (daylight at 1/25 second)

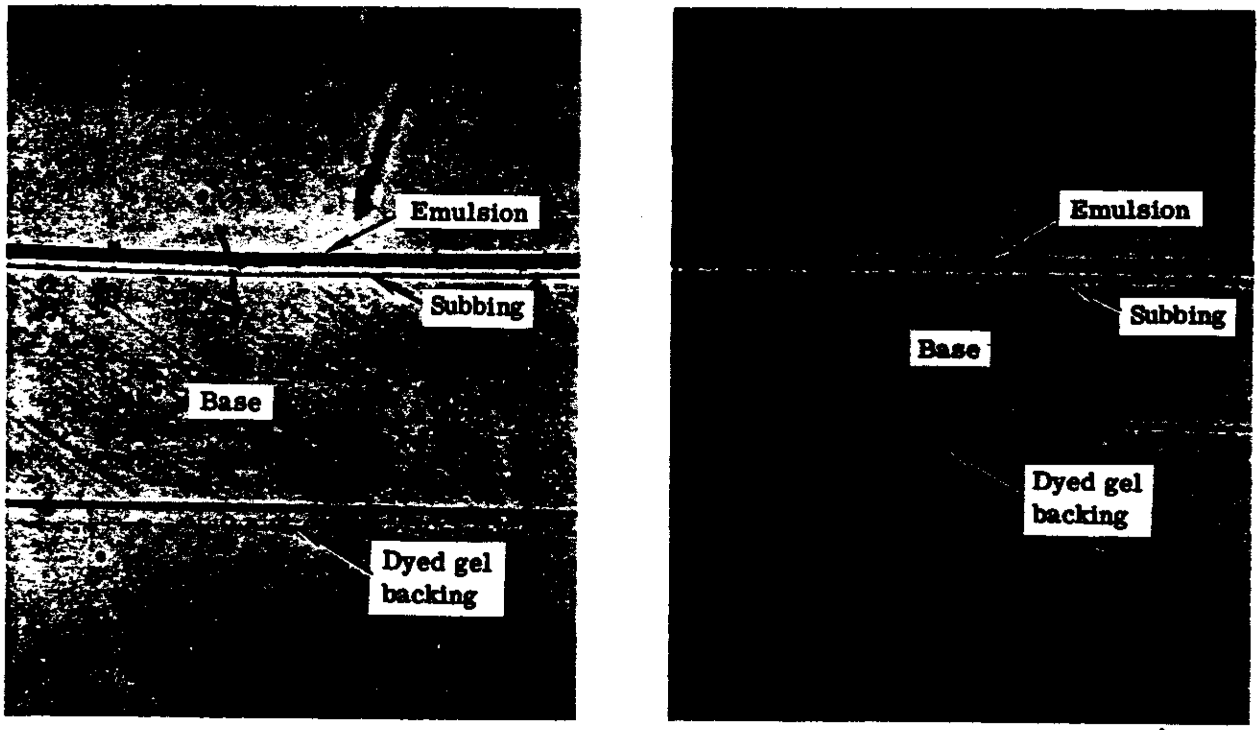


Fig. 2-6 — Microtomes of 3404 and SO-380 enlarged 450 times

Table 2-1 — U.S.A. Standard Preferred Numbers Z.17.1—1958

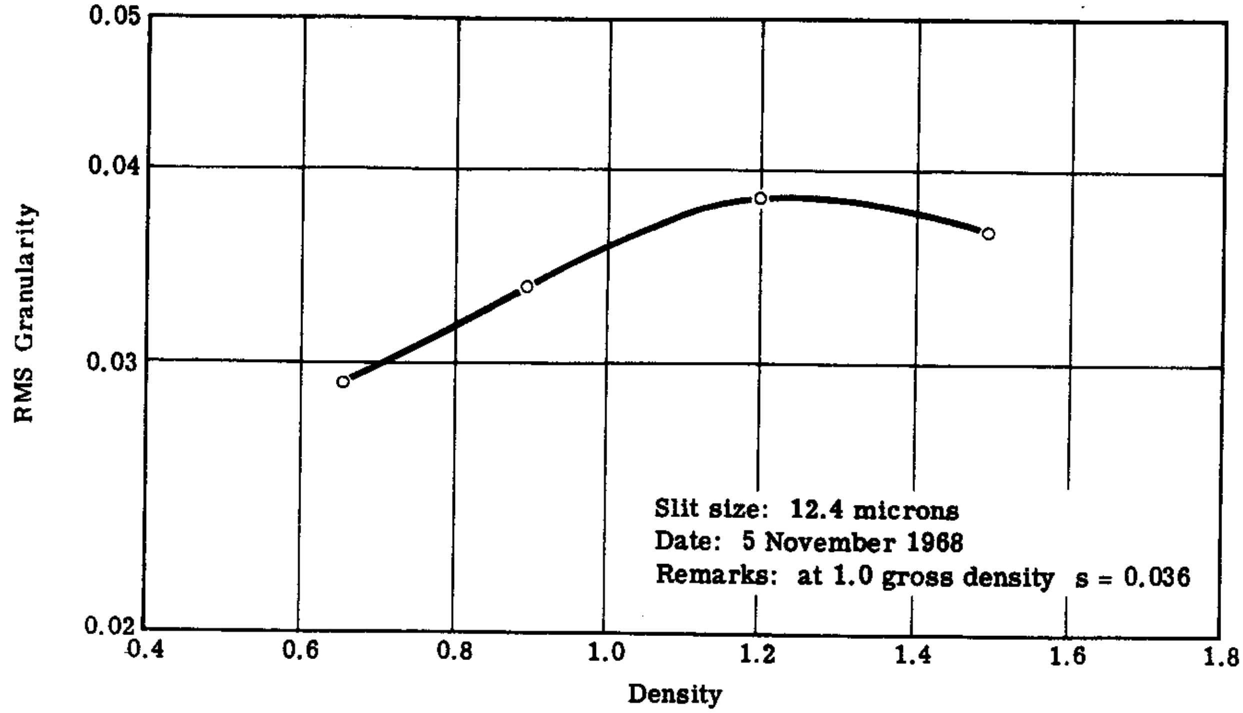
When the arithmetic average of the resolving powers of the samples lies in the range from A to B, the resolving power of the product is given in C.

Range		USASI
A	B	C
17.8	22.3	20
22.4	28.1	25
28.2	35.4	32
35.5	44.6	40
44.7	56.2	50
56.3	70.7	63
70.8	89.1	80
89.2	112	100
113	141	125
142	177	160
178	223	200
224	281	250
282	354	320
355	446	400
447	562	500
563	707	630
708	891	800
892	1,120	1,000
1,130	1,410	1,250
1,420	1,770	1,600
1,780	2,230	2,000
2,240	2,810	2,500
2,820	3,540	3,200

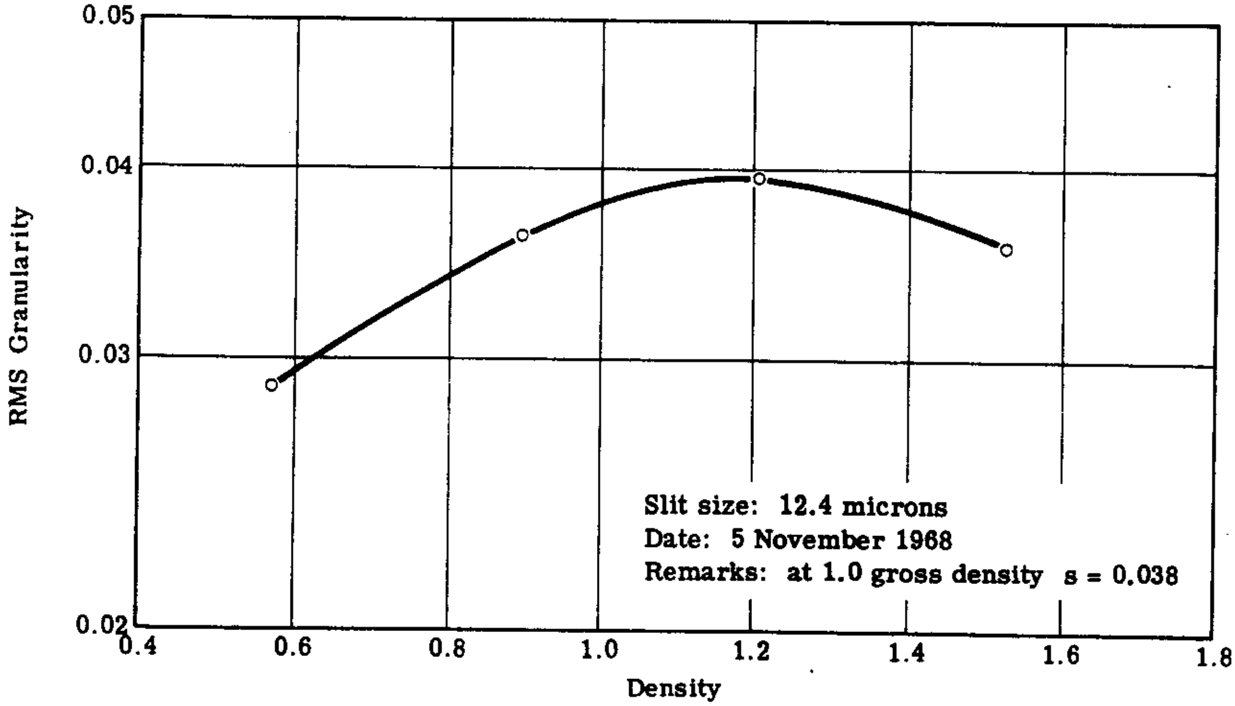
The value determined from column C is the U.S.A. Standard x-contrast resolving power of a product, where x is high or low in accordance with the contrast ratio of the test chart.

Table 2-2 — Laboratory Determined Filter Factors for 3404 and SO-380 to Simulated Daylight

Filter	3404	SO-380
Wratten no. 12	1.5	1.5
Wratten no. 21	1.8	1.9
Wratten no. 23A	2.3	2.4
Wratten no. 25	2.8	2.9

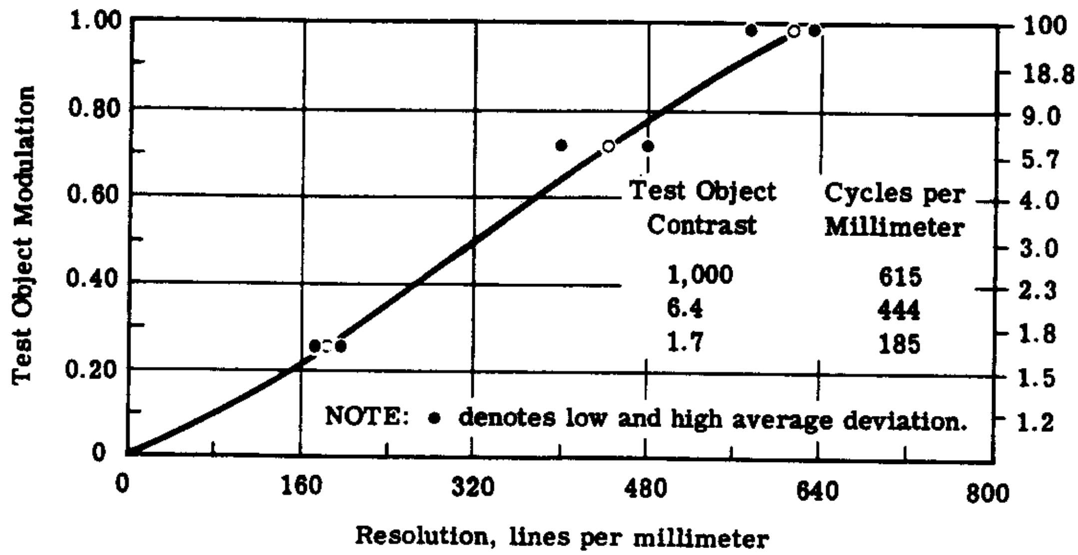


(a) SO-380 in MX-577

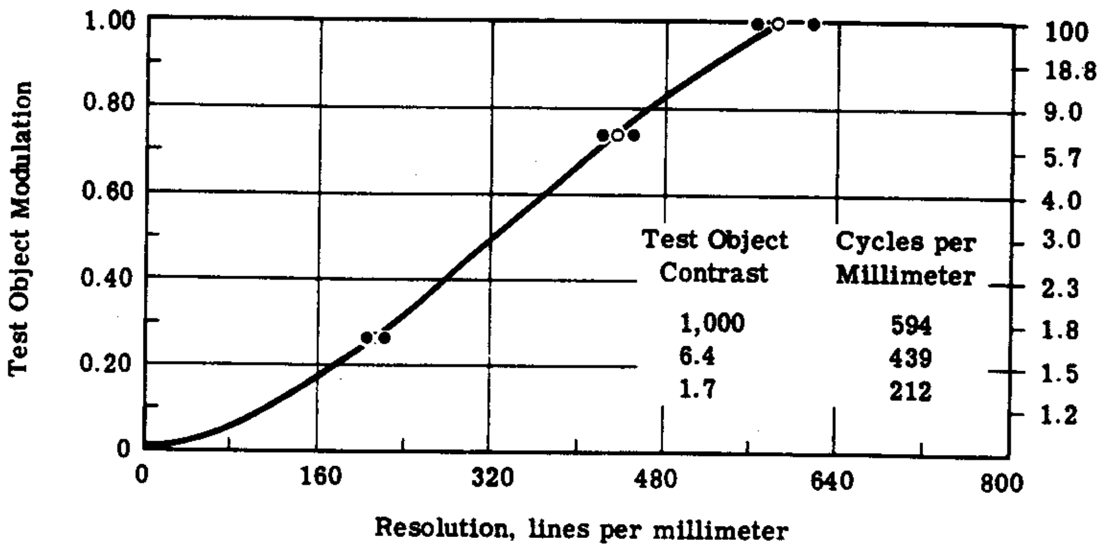


(b) 3404 in MX-577

Fig. 2-7 — RMS granularity versus density for 3404 and SO-380 films



(a) 3404 film (full level spray)



(b) SO-380 film (full level spray)

Fig. 2-8 — Test object modulation versus resolution for 3404 and SO-380 films

3. MISSION EXPERIMENT

3.1 EXPERIMENTAL CONDITIONS

The mission vehicle was launched from Point Arguello, Vandenberg AFB, California on 1 May, at 2121 Z, 1968. The first film recovery, mission segment 1103-1, was accomplished during the 103rd revolution on 8 May 1968. The second film payload, mission segment 1103-2, was recovered during the 220th revolution on 15 May 1968.

Both 3404 and SO-380 (UTB) were used on mission 1103. The SO-380 was included at the end of the film loads of both the FWD (approximately 1,750 feet) and the AFT (approximately 1,757 feet) cameras for this test. The film change from 3404 to SO-380, took place in the 143rd frame of the 187th revolution for the FWD camera and in the 142nd frame of the 187th revolution for the AFT camera.

The vehicle altitude for this part of the mission varied from 82 to approximately 90 nm. Most of the photographic acquisition varied between 69 to 17 degrees North latitude. Sun elevation for this experimental part of mission 1103-2 was from 87 to 38 degrees. In general, acquisition was at sun elevations of 40 to 80 degrees. A detailed tabulation of latitude, longitude, sun elevation, and geographic location is listed in Tables 3-1 and 3-2. Tables 3-3 to 3-5 present some of the pertinent system data.

3.2 SUBJECTIVE EVALUATION OF 3404 COMPARED TO SO-380

The purpose of the following evaluation is to form an opinion, based on subjective analysis, of the relative merits of 3404 and SO-380 from the imagery obtained from mission 1103-2.

Operational photography was acquired during passes D-187 through D-220 in both FWD and AFT cameras. The FWD-looking camera used a Wratten no. 25 in the primary position and a Wratten no. 12 in the alternate. The AFT-looking camera employed a Wratten no. 21 in the primary position and an SF-05 filter in the alternate position.

During pass D-187, the change over from 3404 to SO-380 occurred and a comparison of similar imagery from the same camera and pass was made possible. Comparison of 3404 and SO-380 imagery of the same target in a similar format position and with the same camera was also made possible in two cases. Passes D-008 and D-218 as well as passes D-009 and D-219 were practically identical in their ground tracks. As a result, the same area was covered, although separated by 13 days and with some differences in altitude.

Several other passes were compared that had sidelap of varying amounts of up to 50 percent. These were evaluated to add more knowledge to the overall study and several factors relating to time lapse and format position were considered in weighing the observations.

Table 3-1 — Mission Data for FWD Panoramic Camera No. 307, SO-380 Film

Revolution	Frame Number	Slit, inches	Filter	Center of Format		Sun Elevation, degrees
				Latitude, degrees	Longitude, degrees	
187	143 to 151	0.205	W-25	22 to 20 N	33 E	85 to 86
188	1 to 21	0.205	W-25	19 to 17 N	11 E	87
194	1 to 19	0.205	W-25	33 to 31 N	123 W	75 to 77
197	1 to 78	0.310	W-25	68 to 59 N	157 to 163 E	39 to 49
200	1 to 65	0.205	W-25	42 to 18 N	101 to 103 E	65 to 88
202	1 to 37	0.205	W-25	55 to 51 N	53 to 54 E	52 to 56
203	1 to 47	0.310	W-25	62 to 56 N	28 to 30 E	45 to 51
	48 to 185	0.205	W-25	56 to 29 N	30 to 35 E	51 to 79
218	1 to 21	0.310	W-25	59 to 48 N	54 to 58 E	49 to 59
	22 to 46	0.205	W-25			
219	1 to 53	0.205	W-25	37 to 30 N	38 to 39 E	71 to 77
220	1 to 103	0.205	W-25	54 to 42 N	12 to 15 E	53 to 66

Table 3-2 — Mission Data for AFT Panoramic Camera No. 306, SO-380 Film

Revolution	Frame Number	Slit, inches	Filter*	Center of Format		Sun Elevation, degrees
				Latitude, degrees	Longitude, degrees	
187	142 to 151	0.134	W-21	24 to 21 N	32 to 33 E	83 to 86
188	1 to 21	0.134	W-21	20 to 18 N	10 to 11 E	86 to 87
194	1 to 19	0.134	W-21	33 to 31 N	124 to 123 W	74 to 76
197	1 to 78	0.200	W-21	69 to 59 N	157 to 163 E	38 to 48
200	1 to 65	0.165	SF-05	43 to 18 N	100 to 103 E	64 to 89
202	1 to 37	0.165	SF-05	56 to 52 N	53 to 54 E	51 to 56
203	1 to 186	0.165	SF-05	62 to 30 N	28 to 35 E	45 to 78
218	1 to 46	0.165	SF-05	59 to 49 N	55 to 58 E	48 to 58
219	1 to 53	0.165	SF-05	38 to 31 N	38 to 39 E	70 to 77
220	1 to 103	0.134	W-21	55 to 43 N	12 to 15 E	52 to 65

* The SF-05 filter has a bandpass in the green spectral region and is intended for bicolor acquisition. Capability Report No. 3, Bicolor, [redacted] presents a detailed report of this type of photography.

Table 3-3 — Slit Widths and Filters for Mission 1103*

FWD Camera No. 307			AFT Camera No. 306		
	Slit	Filter		Slit	Filter
1.	0.195	Wratten no. 25, prime	1.	0.135	Wratten no. 21, prime
2.	0.320	Wratten no. 12, alternate	2.	0.185	
3.	0.320		3.	0.260	SF-05, alternate
4.	0.100		4.	0.135	
Fail safe	0.300		Fail safe	0.160	

*Confusion has arisen as to the exact slit widths that were used on mission 1103. There was a last minute change prior to launch. The values reported here are those measured at A/P.

Table 3-4 — Specific Camera Data Pertaining to the Panoramic Cameras of Mission 1103

	FWD-Looking Camera	AFT-Looking Camera
Instrument number	307	306
Resolution, lines per millimeter		
High contrast dynamic	234	205
Low contrast dynamic	147	136
Film type, footage	3404-401 14,447 feet	3404-401 14,473 feet
	SO-380-49 1,750 feet	SO-380-9 1,757 feet

Table 3-5 — Percentage of Total Frames and Number of Process Changes for Mission 1103-2 (3404 and SO-380)

Level	FWD	AFT
Percent primary	14	8
Percent intermediate	13	11
Percent full	61	69
Percent transition	12	12
Process changes	33	

Consideration was given also to the fact that the dynamic resolution does vary somewhat over the entire format and the subjects of this evaluation are representative samples of imagery, since these variations are characteristics of the system and not SO-380 itself. Tables 3-1 and 3-2 locate each pass geographically and give the pertinent information for each pass evaluated.

A number of factors are present in the dynamic operation of the camera system that lead to a degradation of image quality. A full treatment of the subject is included in the report entitled "Performance Analysis for the 1101 System."*

Essentially, the image is subject to degradation as a result of both random and systematic smearing of the camera/vehicle combination. In the static case there is no motion to be compensated so the results can be considered as optimum for the combination of camera geometry, film characteristics, and target configuration. When utilized in the dynamic mode, numerous degrading factors in the cameras, command sources, vehicle/camera interface, and vehicle operation are compounded to produce a smear both across and along the camera track. A computer program has been used to determine the magnitude and direction of the smear; it was also employed as an adjunct to the subjective evaluation of the targets included in this report. Of the photographic passes with similar ground track, only those areas that had similar smear characteristics were used in the evaluation. The computed smear values are listed in Table 3-6 for the three scenes examined in detail.

Of the three cases shown in Table 3-6, it will be noted that in all but one case (D-203, 165 FWD, across track) the smear for SO-380 exceeds that of 3404. The amounts involved are less than 3 microns in difference except the case previously noted. As minor as these differences are, they do approach a magnitude that would prejudice an opinion under high magnification. At the scales of photography involved in this test, 3 microns of image smear on the film is roughly equivalent to 3 feet on the ground.

Since most of the differences noted in the comparisons involved in the subjective evaluation are apparent only at 30× and 60× enlargements, it is reasonable to conclude that the films are so close in capability that format position would be critical.

Table 3-6 — Smear Calculations for Frames Subjectively Evaluated for the FWD Camera

Scene Number	Pass	Frame	Film	Percent Sidelap	Smear Along Track, microns	Smear Across Track, microns
1	D-008	003	3404	90	0.17	6.48
	D-218	009	SO-380		1.66	8.73
2	D-009	022	3404	85	0.14	1.20
	D-219	023	SO-380		2.27	1.51
3	D-090	015	3404	30	0.20	9.30
	D-203	165	SO-380		0.82	4.44

[redacted] 1 February 1968.

3.2.1 Individual Scene Comparison

The evaluations are subjective and are based primarily on observations made of the original negatives and the second generation duplicate film positives. Consideration has been given to prejudicial factors including altitudes, format location, and reflectance characteristics and climatological differences.

Scene 1—Pass D-218 FWD (So-380) Compared to Pass D-008 FWD (3404)

These passes occur near the Kama Reservoir, west of the Ural Mountains, in the USSR. There is about 90 percent sidelap, so the areas of coverage are essentially identical, but spaced 13 days apart in time.

A lower altitude for the SO-380 pass contributes to the impression of higher ground resolution. It appears though that both resolve equally well with no appreciable grain differences at 30× magnification. When viewed at 60×, the 3404 exhibits slightly better edges and fine detail discrimination. On a basis of point-by-point comparison, subject areas can be chosen in any frame which will show a slight superiority for either film. This indicates that the emulsions are very closely matched in recording capability.

The visual contrast of SO-380 is higher than the 3404 sample. The computed blur differences are quite small and not too great a factor in evaluating these samples.

Scene 2—Pass D-219 FWD (SO-380) Compared to Pass D-009 FWD (3404)

These passes occur over Turkey and Syria. There is about 85 percent sidelap and much scattered cumulus cloud cover. Overall density contrast in villages and built-up areas favors the 3404 emulsion. Open desert areas exhibit more contrast with SO-380, accentuating drainage and geological features and enhancing their interpretability. Structural details in buildings and fine details in the countryside are shown better with 3404. Generally, the SO-380 coverage exhibits a softness in resolution and acuity that lessens information content in this pass.

While there is a 2.13-micron difference in smear along track, it appears from reference to the DISIC coverage that the atmosphere is responsible for a part of the image degradation. The two components, smear and haze, combine to make the SO-380 the poorer image.

Scene 3—Pass D-203 FWD (SO-380) Compared to Pass D-090 FWD (3404)

Pass D-203 FWD and pass D-090 FWD covered an airfield near the West Coast of Israel and have about 30 percent sidelap. The 3404 record is dense and detail is degraded both by blocking-up and by lack of contrast with the background.

In the negative stage, the SO-380 record is the most informative and exhibits noticeably superior edge acuity. The 3404 sample shows the degrading result of blocking-up by over-exposure.

Here, as previously noted, the SO-380 is subjected to atmospheric degradation. Format position is responsible for a difference of 4.86 microns of cross-track smear between the two records. Thus, the smear appears to govern the differences between these two films.

Transition From 3404 to SO-308

In pass D-187 the transition from 3404 to SO-380 occurred during cycle 143 of the FWD camera and cycle 142 of the AFT camera. The imagery in adjacent frames (142 and 144) of the transition points were compared to determine if there were any apparent differences in the films. The use of the same camera and filter covering the same geographic region minimized the variables normally encountered in comparisons.

Imagery on 3404 was of slightly higher contrast and of superior sharpness. The area covered is a desert wilderness with no cultural features; therefore, determination of image quality was based on natural drainage features and geological patterns. Examination of 3404 at 30× magnification showed more and finer detail. These differences, although distinct, were marginal.

3.2.2 Roller Sit Marks

Preflight tests with SO-380 had indicated that a deformation in the film would occur after long sit periods. This plastic deformation was caused by the stretching of the film over rollers for a long period of time. These effects were not noticed, though, until extensive UTB data had been accumulated in preparation for mission 1105. A re-examination was therefore undertaken on the mission 1103 material in order to see if the effects were present there and missed during the initial examination.

Examination of the duplicate positives of mission 1103 for out-of-focus areas revealed three categories into which the occurrence of this condition could fall.

The least important is the small band of defocused imagery paralleling the various splices in the film loads. These are usually accompanied by scratch marks and are minor, uncontrollable occurrences.

The bonus areas at both ends of each frame exhibit areas of out-of-focus imagery. These are characteristic of the cameras and are expected. Delineation of the limits of sharp imagery shows a similar pattern for both 3404 and SO-380, but the area at the takeup end of the 3404 frames is smaller.

Attention was directed to the fourth and fifth frames of both cameras for the purpose of finding any areas that might be unsharp as a result of roller pressure during extensive periods of camera inactivity. Problems had been seen in these areas in laboratory tests with SO-380. Both 3404 and SO-380 were examined and two cases were detected. Both were 3404 records and occurred on passes D-097 and D-171.

The area on pass D-097 occurs 9 centimeters from the takeup end of frame 004 FWD at an x coordinate of 67. It covers an area of 2.4 square centimeters (0.38 square inch) and extends 80 percent of the distance across the format width.

The second area occurs on pass D-171, frame 004, and is 7 centimeters from the end of format at an x coordinate of 69. It covers an area of 1.2 square centimeters (0.19 square inch) and extends 60 percent of the distance across the format width. Sit periods for these two cases were 7 revolutions between D-097 and its predecessor and only 2 revolutions between D-171 and the previous operation.

All usable related portions of the SO-380 coverage were examined without any comparable areas of defocusing being noted. There were not too many cases with long sit periods and much of the coverage was unusable for various reasons (i.e., it is very difficult to tell defocus when the imagery is cloud covered). Pass D-218 had a period of 15 revolutions of inactivity preceding operation but not out-of-focus areas appeared on this film. It is as yet unclear why these sit marks occurred only on the 3404 while preflight laboratory tests indicated that it would occur on the SO-380.

3.2.3 Photointerpreter Conclusions

In summary, each of the films showed distinctive characteristics in relation to specific items of interest. Towns and urban areas showed higher contrast and detail on 3404, while open areas exhibited higher contrast and information content on SO-380.

Duplication of the original negatives as film positives shows an excellent and equal transfer of information for both films. A decided improvement of the contrast level of 3404 was apparent and information blocked out by excessive density in the negatives show well if the exposure level was proper.

The general quality of both films is quite comparable. The 3404 film shows a slight overall superiority for this mission for producing imagery of higher acuity and detail definition. The differences are strongly dependent on format position and are apparent only on higher magnifications (30× to 60×). In addition, the atmospheric conditions existing during the SO-380 passes caused degradation that cannot be attributed to film. It is apparent that the two films are so closely matched in their performance capabilities that the camera dynamics and atmospheric attenuation are responsible for comparative differences in the test samples from mission 1103. No evidence of roller sit marks were observed on the SO-380, while they did occur in two cases on the 3404. It is unknown why this occurred whereas laboratory results predicted the reverse to be true.

In addition, it should be noted that, due to the tag-on nature of this test, the camera system was not optimized for SO-380. Thus, it is concluded that SO-380 is no different than 3404 from a system image quality point of view.

4. BACKGROUND OF SO-380 TESTING

The combined effect of the introduction of SO-380 film and the extended useful space lifetime of the KH-4B vehicle affords considerable benefit to the total system. Substantially lower altitudes can be used, with a corresponding improvement in ground resolved distance without loss of coverage. This system gain, however, has not been an easy task since the use of this new material has created many new hardware problems. The largest problem encountered to date has been the maintenance of film flatness and, therefore, optimum focus over the entire format. In view of the recent problems encountered with SO-380 in mission 1105, a brief review of the testing performed to date is included in this section.

The initial testing with SO-380 was accomplished with a KH-4A configuration. SO-380 has significantly less rigidity across the film web and, therefore, tends to buckle downward between the camera's film supporting rails. A tension transient was created in the film with this KH-4A configuration which caused the film to pull out of the rails at normal cycle rates. With no readily apparent solution and a shortage of SO-380 material, the testing with a KH-4A configuration was discontinued.

Very early in the KH-4B program, another series of SO-380 tests was attempted using the KH-4B breadboard model. The majority of the tests were successful, although it became obvious that all transport functions were significantly more sensitive than those normally encountered with 3404. The problems encountered at this stage were tracking, edge guiding, tension transients, and flexing due to less rigid film web.

After the KH-4B program was underway, the engineering model, no. 299, became available on a part-time basis. SO-380 was tested in unit no. 299 to investigate the characteristics of takeup tension changes, film tracking sensitivities, image smearing, and structural modifications. This unit is a mono configuration and did not provide the subtle effects noted on a stereo system; it therefore was not kept up to date with the latest modifications.

One effect noted on mission 1103 was a plus density mark that occurred intermittently throughout the photography. The marks were caused by passing the film over air twist rollers set close to each other and at an angle to change the direction of the film from one plane to another. The SO-380 film base, having less strength than that of 3404, allows the film to temporarily crease or crinkle, causing excessive stress on the film in localized areas. The film responds to this strain with a minus density if the strain occurs before the image-forming exposure and with a plus density if it occurs after. There have been numerous descriptions of the shape of these marks, i.e., comma-shaped, sperm-shaped, fish hook-like, etc. The markings were not serious and were considered only a cosmetic defect in nature and, therefore, no corrective actions were taken at this time.

CR-5 was rescheduled to use an entire load of SO-380. Among the major problems encountered on CR-5 were: tracking, flatness at the ends of the format, variable resolution, and roller sit marks after long set periods. In an attempt to improve the film flatness at the ends of the format the undercut rollers (Fig. 4-1) were replaced with smaller diameter rollers (Fig. 4-2). The undercut rollers were originally necessary since there was not enough clearance between that roller and the horizon optics clamp. Use of the smaller diameter rollers gave sufficient clearance and improved the end of format flatness by supporting the entire web of film. In addition, an improvement in tracking was noted. However, while the smaller diameter rollers corrected one problem, they caused two additional problems. The placement of these smaller diameter rollers allowed an image to be formed further beyond the ends of the rails than normal, lengthening the panoramic frame. This is evidenced by the longer high density areas at the ends of the formats where the light that is used to expose the rail holes has run beyond the end of the rails.

The second problem was that the panoramic format and horizon optic format overlapped. This was caused by a combination of three factors: the increased panoramic format; the use and positioning of the smaller diameter rollers allowing the film to get to the horizon optic area in a shorter distance; and the fact that a constant amount of film was metered through the camera.

As mentioned earlier, roller sit marks had been observed on SO-380 in laboratory tests when the instrument sat under tension for long periods of time. This was seen only in two specific areas—frame 4 of the FWD-looking camera, and frame 5 of the AFT-looking camera. The deformation of the film base did not allow the film to lie flat when the scan head rollers passed under it.

Several other modifications were introduced to the CR-5 system to improve performance. The leading and trailing rollers (a total of 23) on the drum assembly were repositioned to reduce image smearing. The reduction of smear was accomplished by increasing the radial distance of the rollers from the drum rotation axis. This increase reduced the film lift at the center of the film web, resulting in less smear due to lift.

With the experience gained on CR-5, the smaller diameter rollers on CR-6 were replaced with larger ones undercut in such a fashion as to give most of the film web support and also to have room for the horizon optic clamp (see Fig. 4-3). This provided the necessary support to maintain film flatness at the ends of formats. The CR-7 system and all future systems were further modified by the installation of a single narrow undercut (see Fig. 4-4) roller which provides increased film support at the format ends.

SO-380 testing with CR-6 revealed that the strain sensitivity marks were more severe than those encountered on CR-3. In addition to the sporadic small marks (described earlier in this section), there was a long thin snake-like pattern running down the center of the test photography. This was more serious than the previously detected marks and was considered not just a cosmetic defect but a real problem. However, it was too late to make any mechanical changes to CR-5 and CR-6. In order to reduce this effect, the tensions were lowered for the mission 1105 flight. Film flatness tests prior to flight indicated that the majority of the format in CR-5 would be acceptable at these lowered tensions. Starting with CR-8, an extended path modification was added to the output of the no. 2 supply and in the takeup end of the transport assembly for both cameras. This extended path length between air twist rollers reduced, and in some cases eliminated, the strain sensitivity marks.

Throughout these tests several problems had arisen and, in general, corrective measures could be implemented. The tracking of SO-380 was very sensitive to the roller alignment throughout the entire transport system, and particular attention had to be given to prevent any edge

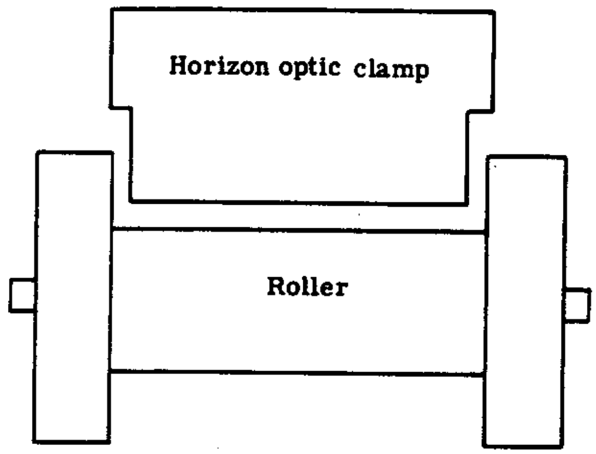


Fig. 4-1 — Horizon optic clamp and undercut roller used on CR-1, CR-2, CR-3, and CR-4

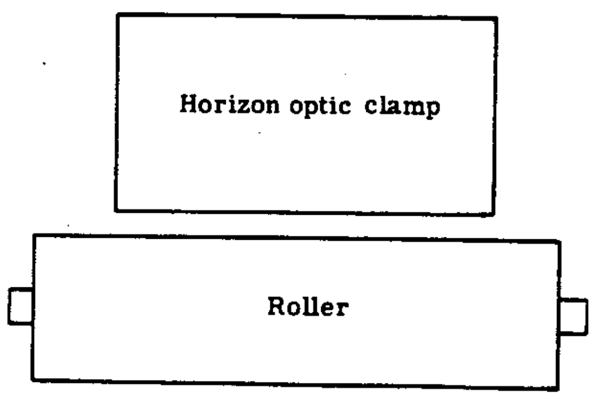


Fig. 4-2 — Horizon optic clamp and smaller diameter roller used on CR-5

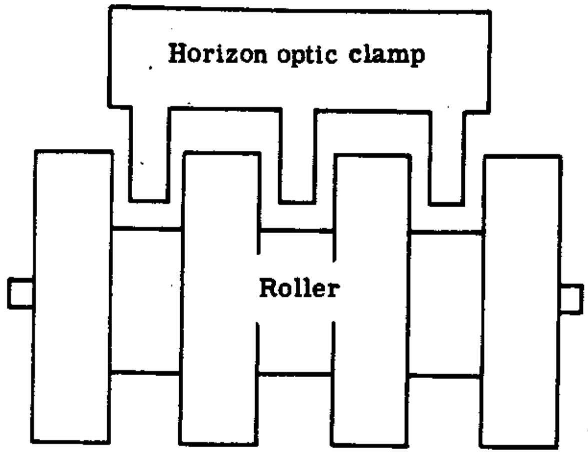


Fig. 4-3 — Horizon optic clamp and three-land undercut roller used on CR-6

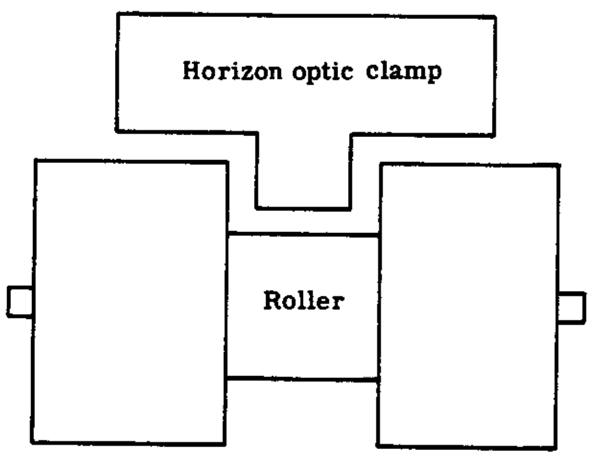


Fig. 4-4 — Horizon optic clamp and single narrow undercut roller used on CR-7 and up guiding by roller flanges or rails. Any misalignment of one roller or any mistracking was reflected through to the format area and would result in a poor film flatness condition.

Problems associated with the film pulling out of the rails have been corrected by the adjustment of the drum rollers, a reduction of the running takeup tensions, and precise alignment of the transport assembly rollers. However, the major problem associated with the use of SO-380 has been obtaining reliable and constant film flatness conditions.

In view of the film flatness problems that had been associated with SO-380, a series of tests was performed on CR-5 in preparation for the first full load of UTB, mission 1105. The data presented in the next series of figures must be examined very carefully. They represent tests run at the manufacturer's environmental test laboratory, A/P,* and in HIVOS, in both ambient and vacuum conditions. There is no common basis for a direct comparison of all these data since each test was performed under different conditions, and/or various modifications were implemented on the camera among these tests. However, these data do give one a good feeling for the level of performance that would be expected from CR-5.

The following figures represent the reduced data from the AGT tests. An AGT, commonly referred to as a "Dr. 'A' test" is a test for determining film flatness and contour under dynamic transport conditions. It is performed by placing a special test plate in front of the image plane and illuminating the plate with two separated point sources. The test plate contains parallel clear lines on an opaque background. The lines are oriented parallel to the direction of scan. The presence of two light sources causes two displaced images of each line to be projected on the image plane. There is a fixed geometry for the distance between two lines. The separation of the lines is directly related to the film lift. These separations are measured directly with a comparator. Table 4-1 lists summary comments as well as the specific conditions under which each of these tests was performed.

Measurements are taken at seven positions along the format length and at nine positions across the width. Thus, a total of 63 points describe one frame. Fig. 4-5 illustrates these positions.

The initial tests at the manufacturer's environmental test laboratory (Fig. 4-6) indicated that these instruments were operating satisfactorily under ambient conditions. These data represent the average of six frames for each camera. The frames were the 10th in each of six operations. All of the data points are within ± 0.001, while almost all are within ± 0.0007. The data plotted on Fig. 4-6 represent 756 measured values. The testing under ambient conditions at A/P produced similar results, all within ± 0.001 and all but an occasional point within ± 0.0007. The data points do not form as smooth a line since they consist of the average of only three frames rather than six. There were also minor "tuning-up" differences in the instruments between the testing represented in Figs. 4-6 and 4-7.

Fig. 4-8 represents an ambient test in the dolly just before the system goes into the HIVOS chamber and was intended as a control on the HIVOS test. These data also were acceptable, although three data points were out of tolerance on one end of the AFT-looking camera format. This was due to the fact that frame 5 was averaged with these data, and frame 5 AFT is characteristically poor with UTB. It is interesting that the FWD-looking camera data are very good even though frame 4 has been averaged. Frame 4 FWD looking is also characteristically bad since it is in the same relative position in the film transport system as the 5th frame AFT.

The data from the HIVOS vacuum chamber run are shown in Fig. 4-9. These data, although acceptable, are not as good as previous ambient condition tests. The excursions border on the ± 0.001-inch range.

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*Advanced Projects.

This same test repeated in the second bucket (FWD-looking camera only) is shown in Fig. 4-10. Here the excursions are not quite as bad, but there appears a consistently high region on the outboard side. Fig. 4-11(a) represents the type of film lift that could be expected from a roller set mark. The excursions are considerably out of tolerance on the takeup side of the frame. This problem, however, becomes nonexistent on subsequent frames as shown in Fig. 4-11(b).

In order to show the camera performance on a statistical basis, an analysis was carried out on several HIVOS chamber run frames. The data were divided into three categories: supply, center, and takeup. The results of this analysis are shown graphically superimposed on the resolution versus focal position curves for the two lenses in Figs. 4-12 and 4-13. Eighty percent of the formats measured were within ±0.001 inch for the AFT camera and ninety percent for the FWD camera. The maximum excursion, however, varied depending on the format position. An important point to remember when examining these data is that the shape and magnitude of the resolution versus focus curves are markedly different for the two lenses used on mission 1105. Although the peak resolution is much higher for the third generation lens (180 lines per millimeter) than for the second (145 lines per millimeter), the former falls off in resolution much faster with changes in focus. If the focal shift is only ±0.001 inch, the third generation lens will still be better than the second. However, with a focal excursion of ±0.003 inch, the third generation lens resolution drops to half of the resolution of the second generation lens at this same amount of defocus. Therefore, the maximum range in resolution for the AFT-looking camera is 120 to 145 lines per millimeter while the FWD-looking is 40 to 180 lines per millimeter as shown in the data block below Figs. 4-12 and 4-13.

In summary, the data from these tests indicated that CR-5 was an acceptable unit to fly with a full load of SO-380. The general appearance of the photograph was as if the focal excursions were substantially greater than those evidenced in these laboratory tests. At this point, the reason is not clear why the laboratory data is in conflict with the flight results in mission 1105.

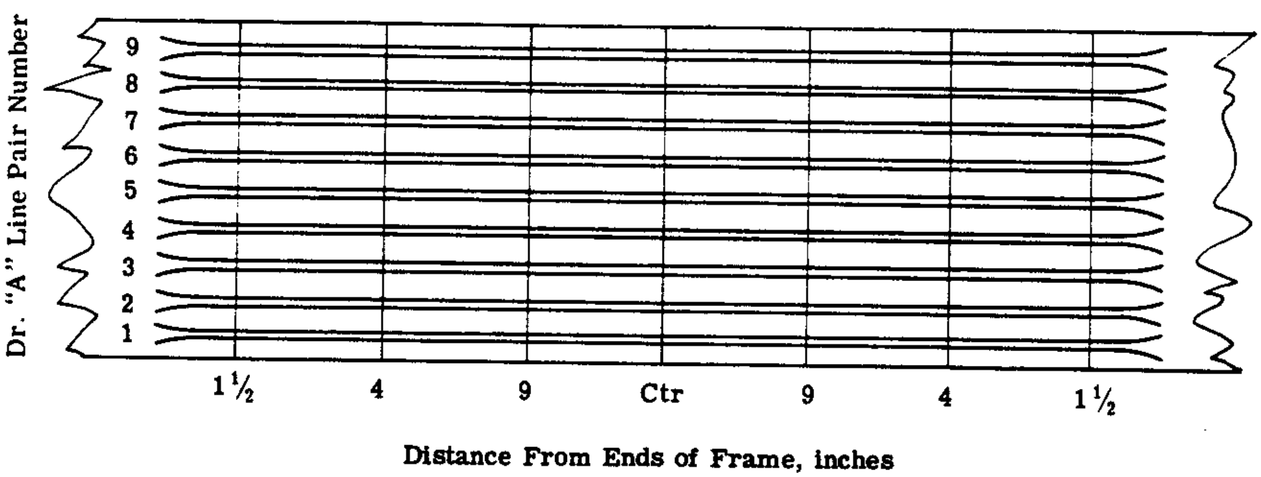
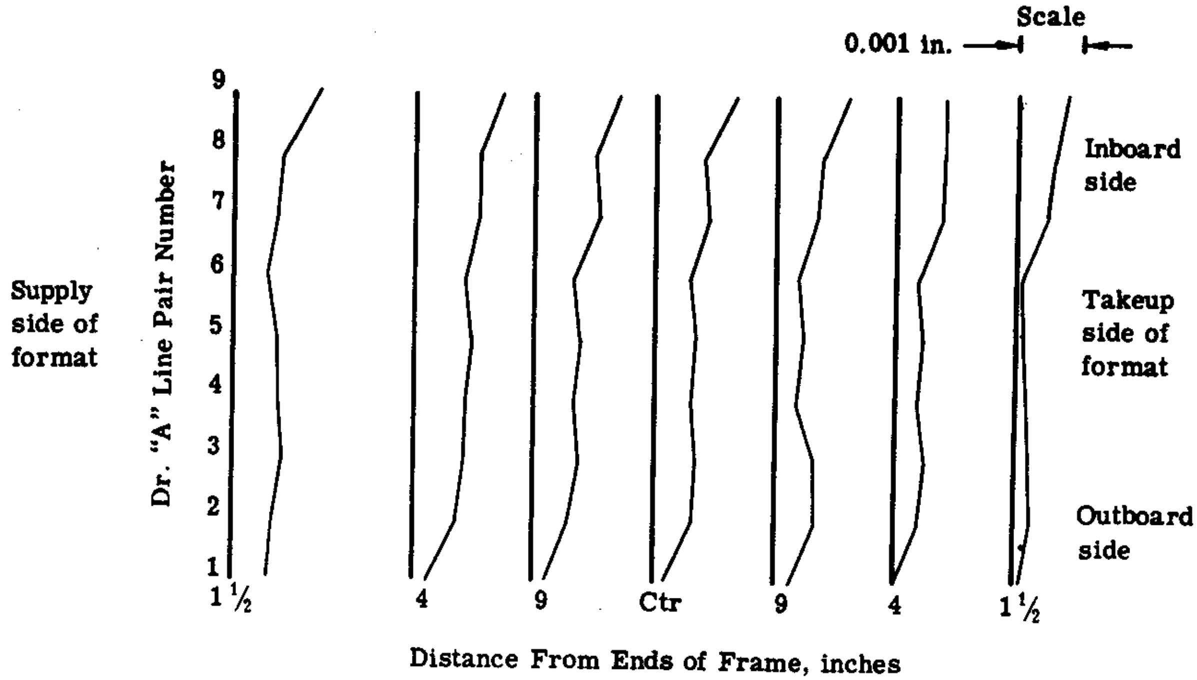


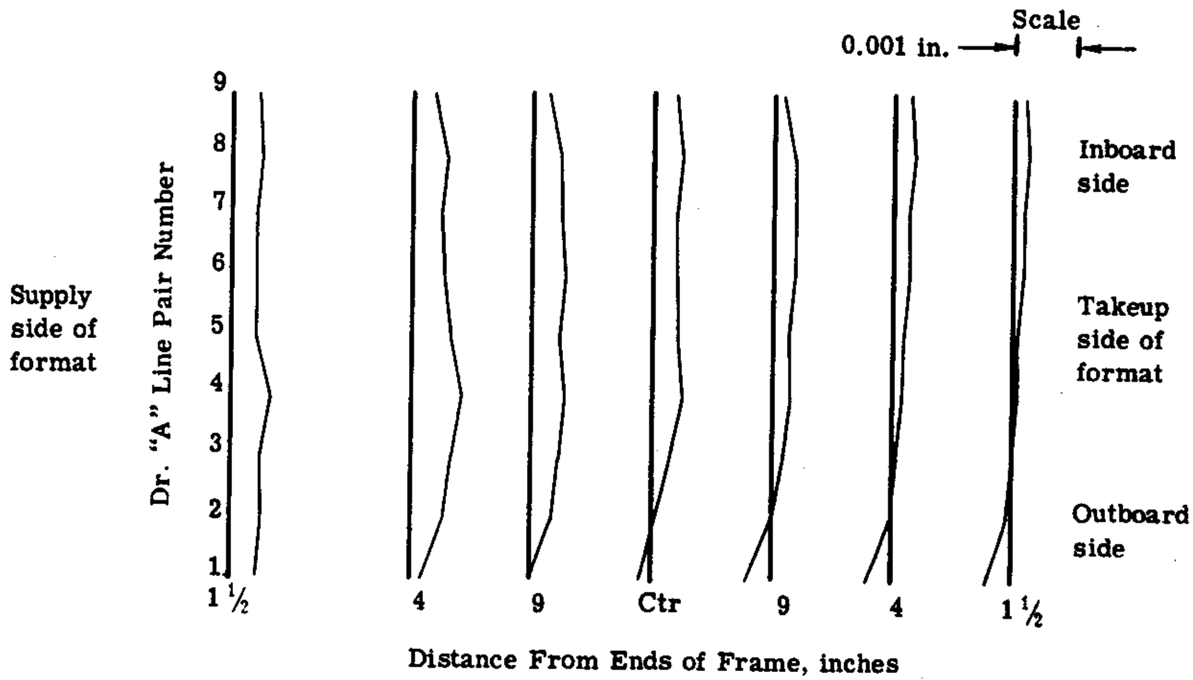
Fig. 4-5 — Format for Dr. "A" test indicating the lines and areas chosen for measurement

Table 4-1 — CR-5 Film Flatness Test Conditions

Figure	Camera	Testing Facility	Conditions	Number of Frames Averaged	Frame Numbers	Operation	Comments
4-6(a)	No. 310 AFT	Camera Mfg.	Ambient	6	10	NA	Acceptable; typical of buy-off data
4-6(b)	No. 311 FWD	Camera Mfg.	Ambient	6	10	NA	Acceptable; typical of buy-off data
4-7(a)	No. 310 AFT	A/P	Ambient	3	4-10-11	NA	Acceptable; minor adjustments made before this test and corresponding test at manufacturer's site
4-7(b)	No. 311 FWD	A/P	Ambient	3	4-10-10	NA	Acceptable; minor adjustments made before this test and corresponding test at manufacturer's site
4-8(a)	No. 310 AFT	HIVOS	Ambient	2	5-6	NA	Control for vacuum test; acceptable, although slightly high on one end due to averaging the fifth frame
4-8(b)	No. 311 FWD	HIVOS	Ambient	3	1-4-5	NA	Control for vacuum; acceptable, even though average includes the fourth frame data
4-9(a)	No. 310 AFT	HIVOS	Vacuum operation	2	10	Nos. 4-5	Acceptable, although somewhat higher than previous tests; this data is a sample of the data used in Fig. 4-12
4-9(b)	No. 311 FWD	HIVOS	Vacuum operation	4	10	Nos. 4-5-7-8	Acceptable; this is a sample of the data in Fig. 4-13
4-10	No. 311 FWD	HIVOS	Vacuum operation	9	10	Nos. 9-9B-10-11-12-13-14-15-16	Acceptable; this is the same as Fig. 4-11(b) but for the second bucket
4-11(a)	No. 310 AFT	HIVOS	Vacuum operation	5	5	Nos. 2-4-5-6-7	Portions of format acceptable, although a small portion of the fifth frame does have abnormal excursions
4-11(b)	No. 310 AFT	HIVOS	Vacuum operation	6	6	Nos. 2-4-5-6-7	Acceptable; typical of frame 6 on the AFT-looking camera; improved even though only one frame area from the trouble spot

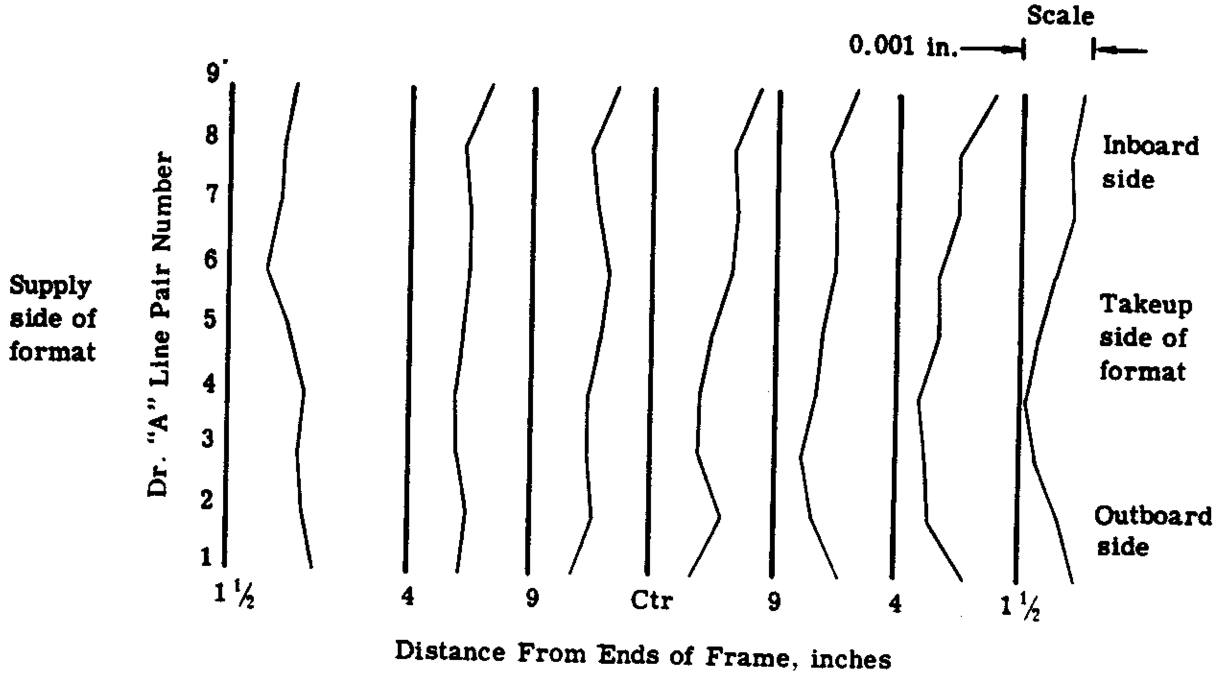


(a) Camera no. 310 AFT

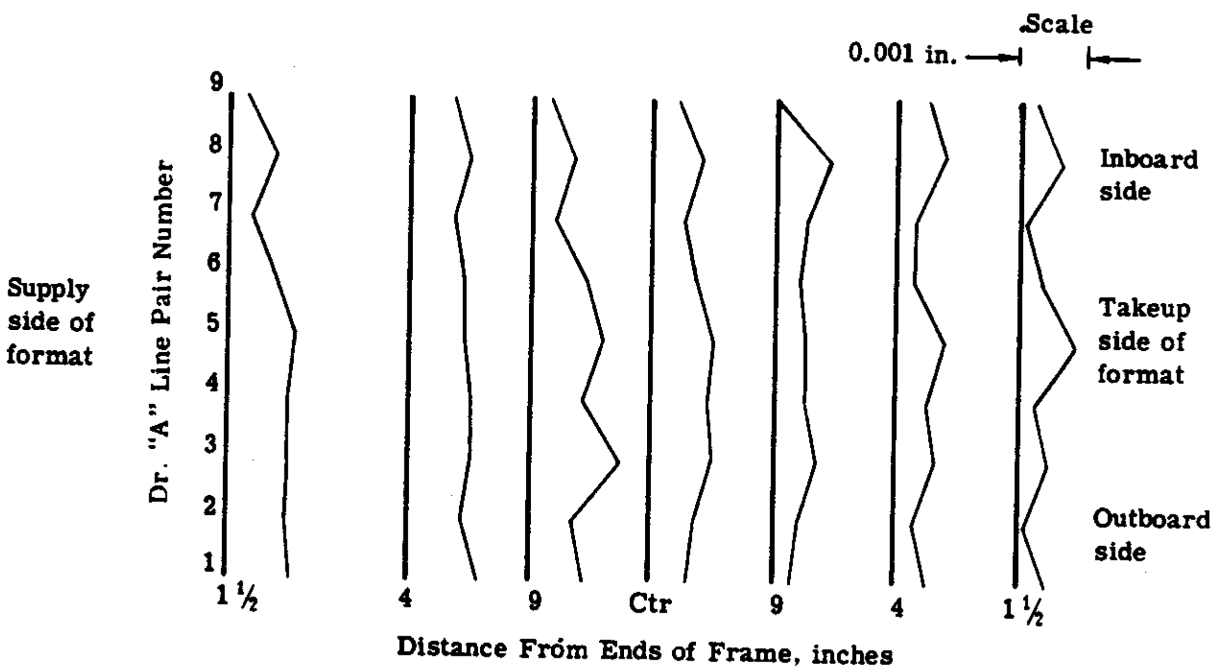


(b) Camera no. 311 FWD

Fig. 4-6 — CR-5 film flatness test at camera manufacturer's facility under ambient conditions

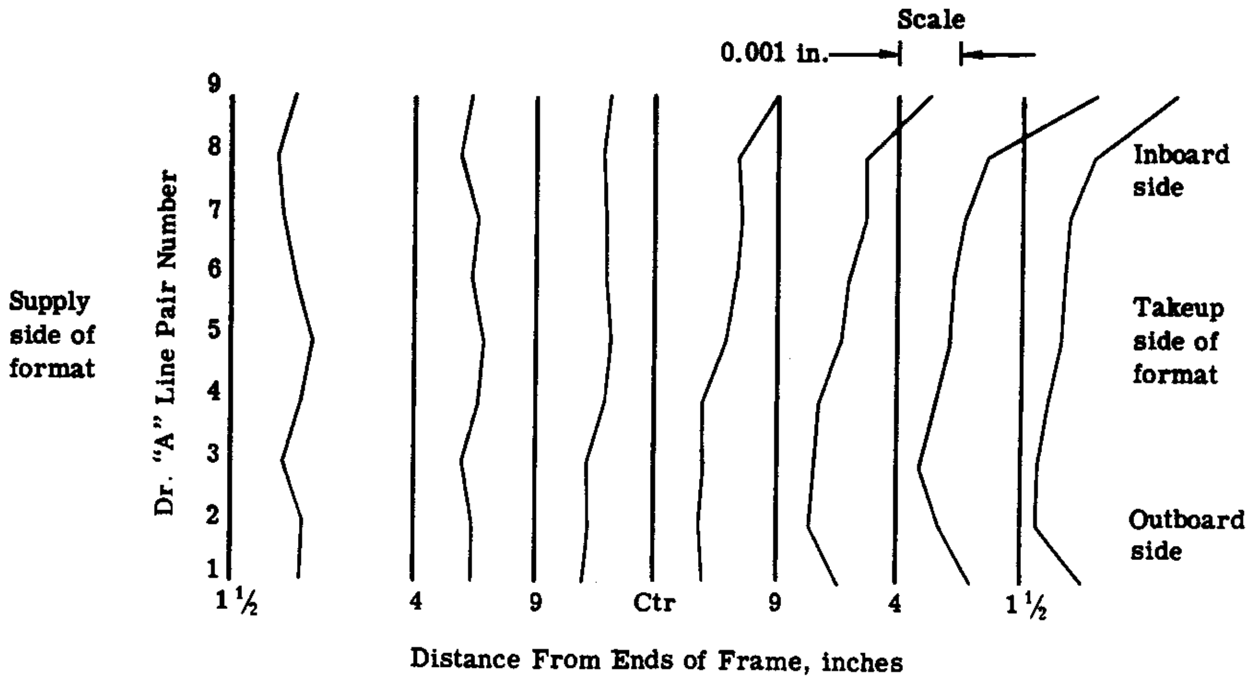


(a) Camera no. 310 AFT

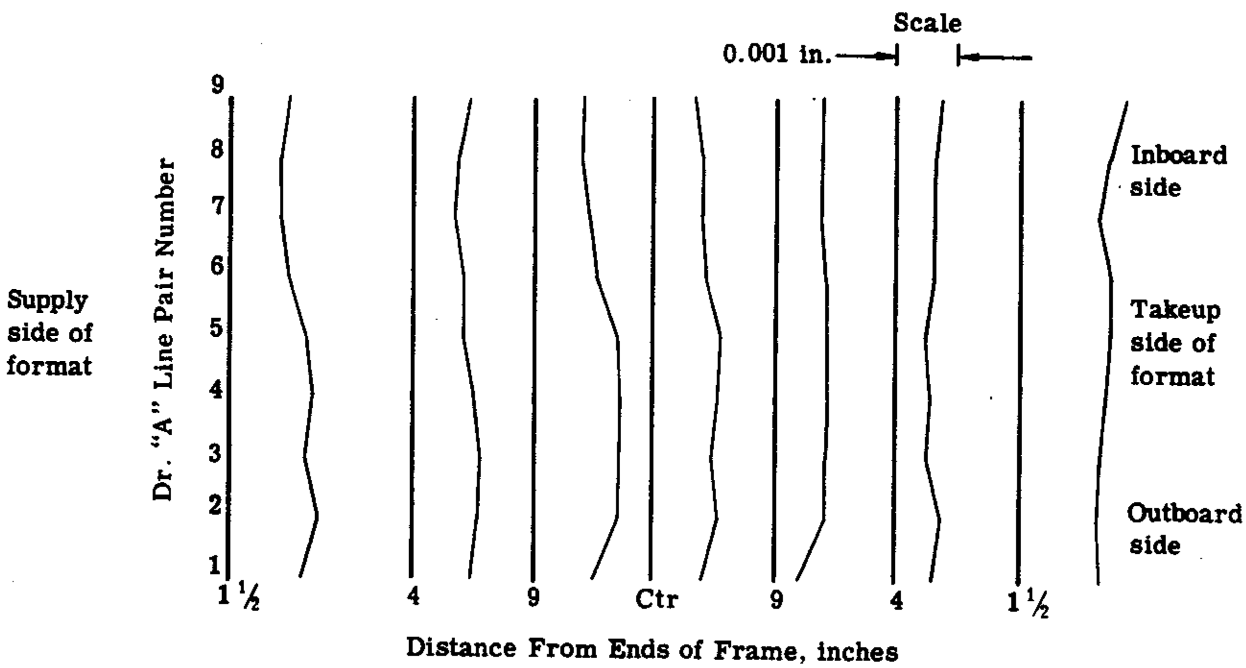


(b) Camera no. 311 FWD

Fig. 4-7 — CR-5 film flatness test at A/P under ambient conditions

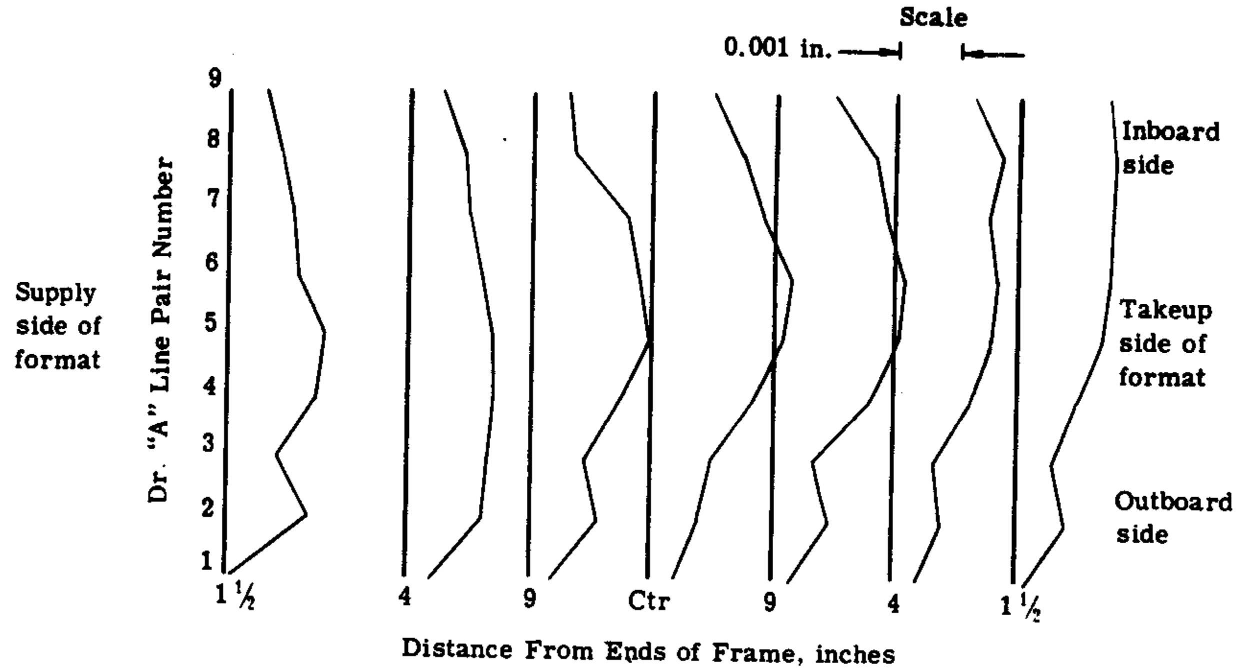


(a) Unit no. 310 AFT

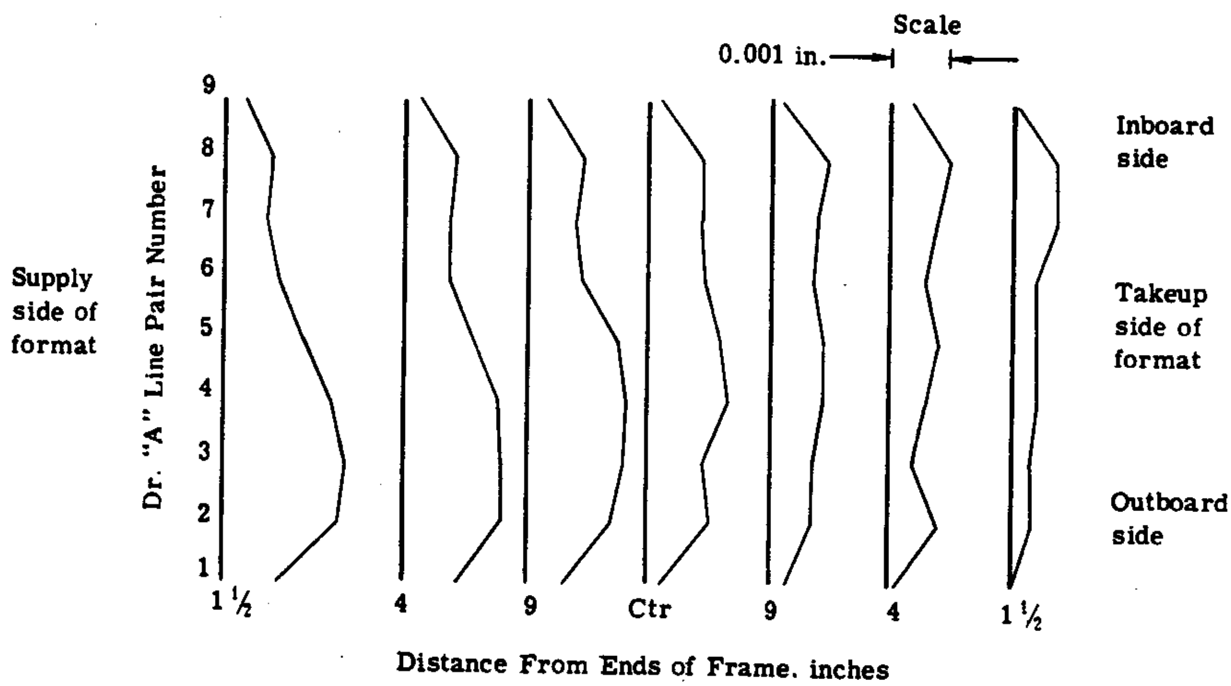


(b) Unit no. 311 FWD

Fig. 4-8 — CR-5 film flatness test in HIVOS under ambient conditions



(a) Unit no. 310 AFT



(b) Unit no. 311 FWD

Fig. 4-9 — CR-5 film flatness test in HIVOS in vacuum operation

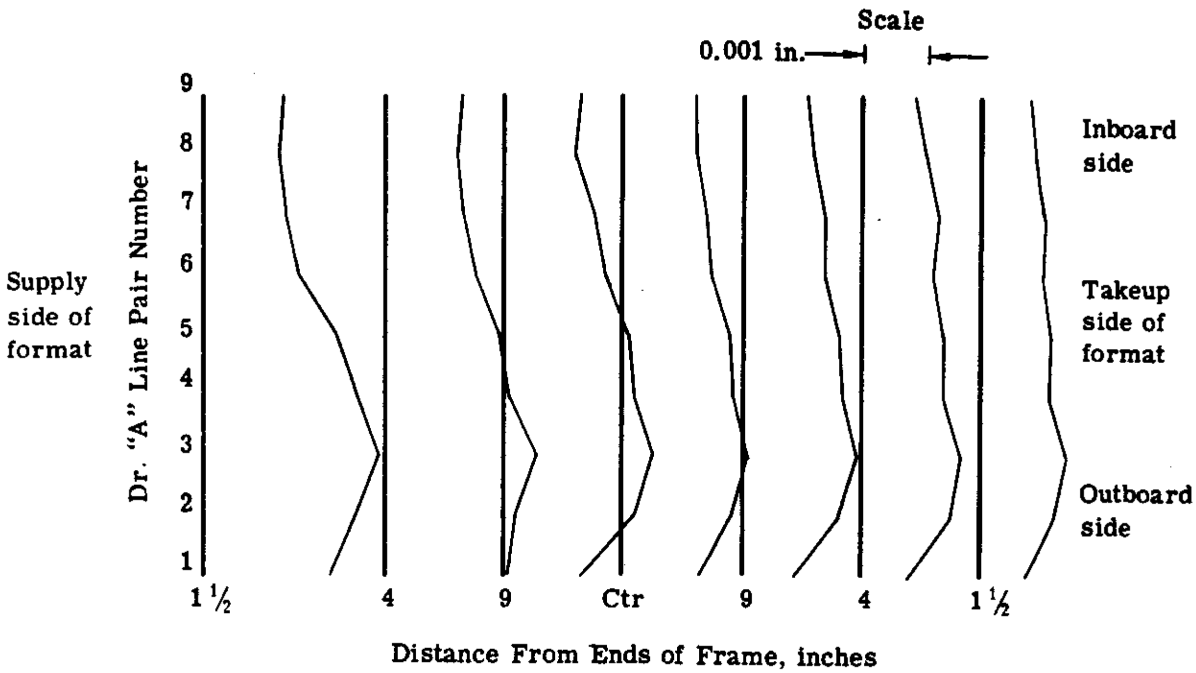
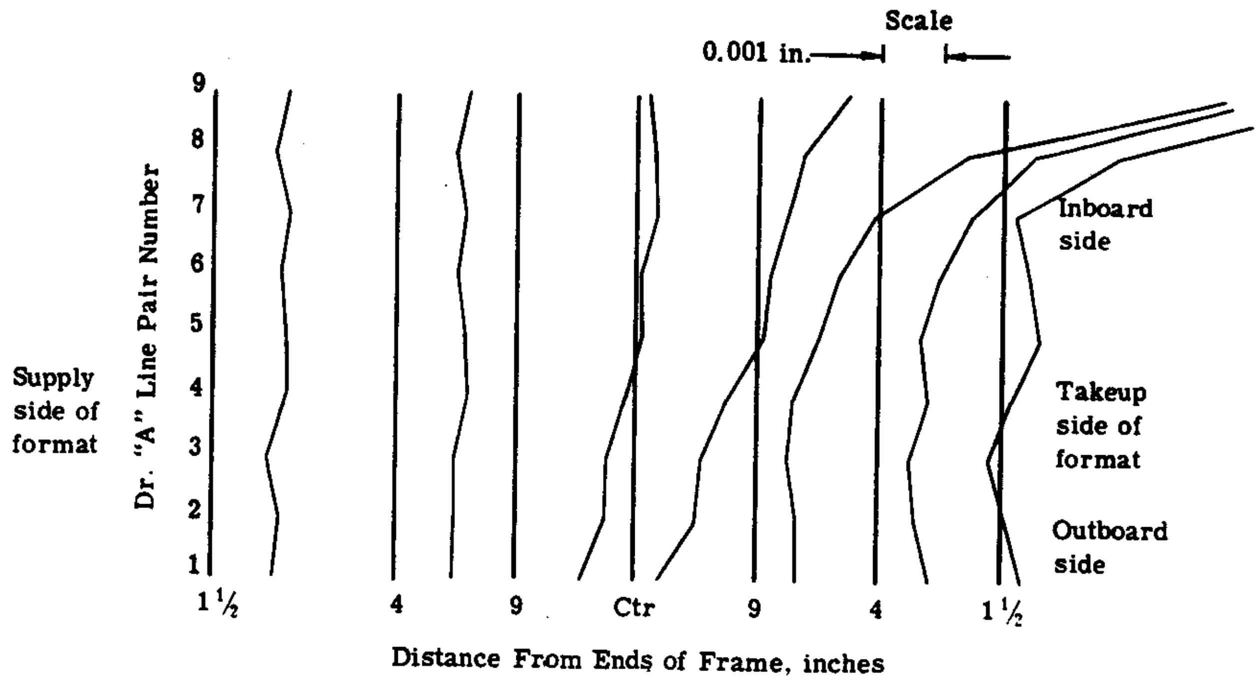
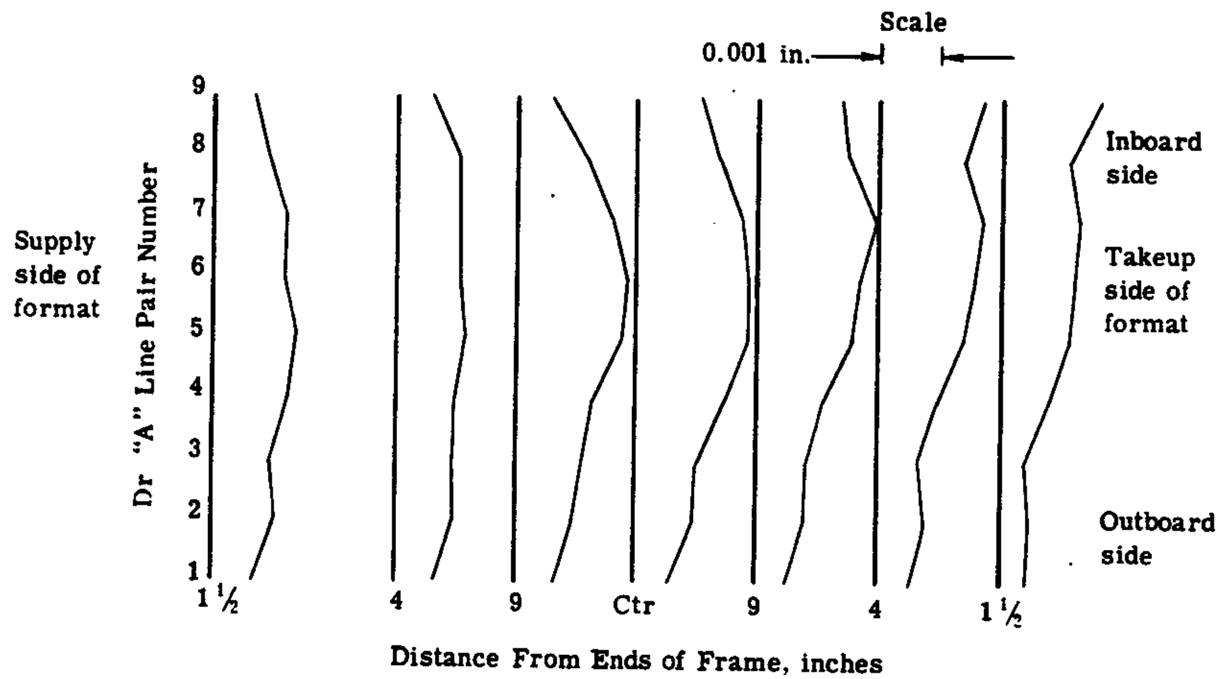


Fig. 4-10 — CR-5 film flatness test in HIVOS in vacuum operation, unit no. 311 FWD

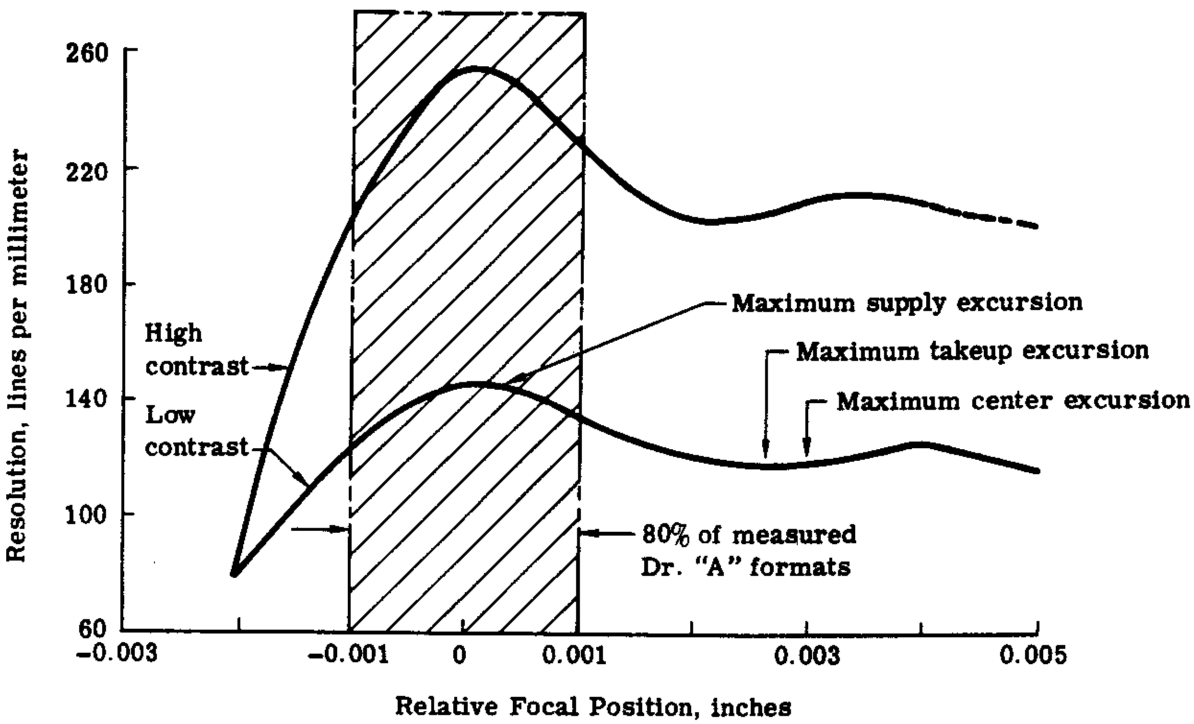


(a) Unit no. 310 AFT



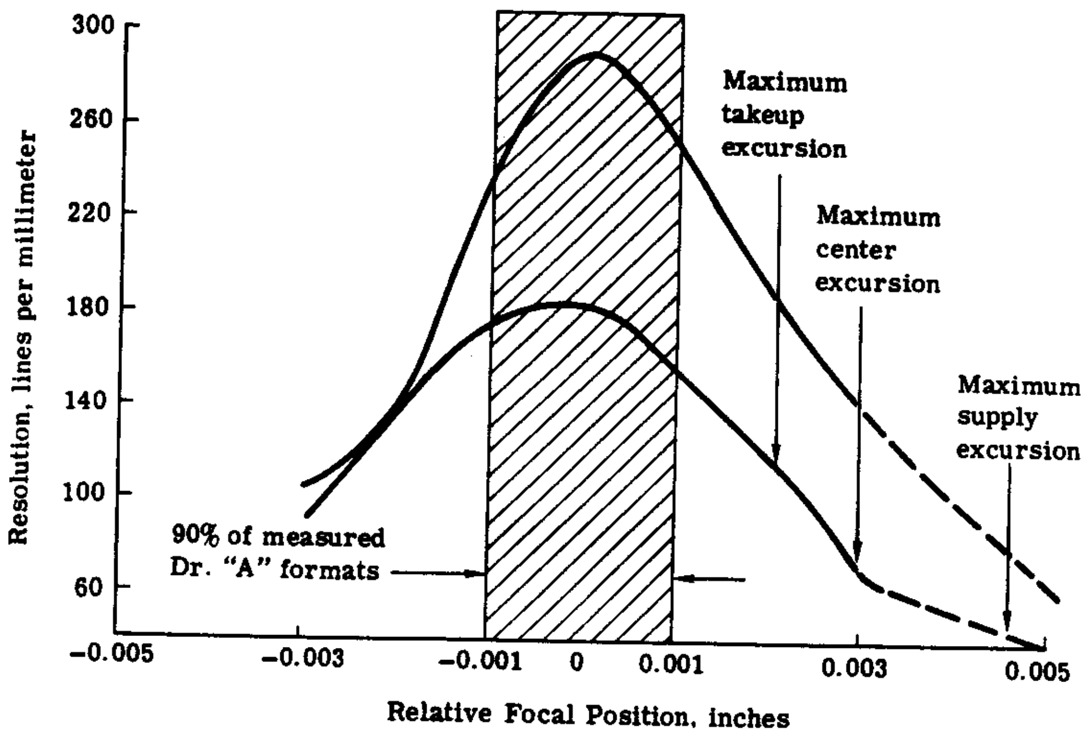
(b) Unit no. 311 FWD

Fig. 4-11 — CR-5 film flatness test in HIVOS in vacuum operation



Low Resolution Range	Maximum Range
Supply end	145 to 145
Center	120 to 145
Takeup end	120 to 145

Fig. 4-12 — Resolution versus focal position for the second generation lens (camera no. 310 AFT)



Low Resolution Range	Maximum Range
Supply end	40 to 180
Center	70 to 180
Takeup end	120 to 180

Fig. 4-13 — Resolution versus focal position for the third generation lens (camera no. 311 FWD)

5. CONCLUSIONS

The following conclusions were drawn from the mission 1103 test:

1. The sensitometric properties of SO-380 are equivalent to those of 3404. They are equal in speed, fog level, and tonal range.

2. Both films have equal filter factors and resolution and are nearly identical in rms granularity.

3. Subjective analysis by this contractor indicated a slight preference for the 3404 imagery from the mission 1103 test. However, this preference was more a function of the system dynamics at the time the pictures were taken than of real differences in the films themselves.

4. Mission 1103 provided imagery that remained flat in the focal plane with both the 3404 and SO-380 films. The full load SO-380 mission, 1105, however, did not. Preflight tests had not identified any problems and it is as yet unknown why there was apparently poor correlation between laboratory and flight results.

6. RECOMMENDATIONS

Based on the results of the mission 1103 test, SO-380 was recommended for flight. However, because of the problems found in laboratory tests after mission 1103, and the anomalies of mission 1105, SO-380 is not now recommended for further flight in KH-4B systems.

A test program is currently in progress to determine if there are any corrective measures that could be implemented on the remaining cameras. If the problems can be corrected, consideration should again be given to its use.

Appendix

GLOSSARY OF TERMS

ABRASION DENSITY. Density resulting from an abrasion mark.

ABRASION MARKS. Abrasion marks are disruptions in the emulsion surface caused by a physical rubbing of the emulsion rather than a pressure on the film. This may or may not result in producing density after processing.

AIR TWIST. A twist in the film that occurs when the film changes from one plane to another, i.e., between two rollers to change the direction of the film's travel.

BUCKLING. Denotes a general effect caused by scalloping, edge fluting, core set, roller set, spoking, and air twists.

CONVOLUTION. One wrap of film around the core, or a wrap over other layers of film.

CORE SET. An actual deformation of the film with no density effect. It is the conformity to the core shape caused by being wound around the core of the spool.

CORONA DISCHARGE. Static caused by ionization in vacuum condition. This type of static is characterized by a glow. Depending on the photographic film speed, this glow may produce a density. This density often resembles a light-leak form. The density marking is not sharply defined.

DENDRITIC STATIC. Density marks which resemble a Christmas tree. Dendritic static occurs in normal atmospheric conditions.

DIMPLES. Dimples are that effect which causes circular depressions in the film. The depression is usually an inch or so in diameter. It resembles a collapsed excess of material and is related to the stress between two rollers.

EDGE FLUTING. Edge fluting is the inverse of dimples. Edge fluting is a film manufacturing related problem. The center of the film is under greater stress than the edges. Film is then forced away from the center towards the edges to form fluting with a frequency of an inch or so.

INTEGRITY OF ROLL. This refers to the tension between two convolutions. Equal tension between convolutions is maintained to prevent film slippage from the core.

PIGSKIN. Marks on the film that look like the bumps on a football, caused by the film being wrapped over a piece of dirt or grit.

PRESSURE MARKS. Pressure marks are density marks caused by an object having a physical application of pressure. This pressure is usually applied by a relatively sharp edge. At Eastman Kodak, the pressure sensitivity of an emulsion is determined by the application of a smooth roller with a known amount of force followed by sensitometric evaluation. The test is not presently performed under vacuum conditions.

ROLLER SET. Roller set is a physical conformity of the film to the rollers. The deformation is on the order of a fraction of an inch and dependent upon the roller size. The term "set marks" is also used to denote roller set, however, the use of this term is discouraged in preference to "roller set."

SCALLOP. Scallop is similar to edge fluting in appearance. It is caused by the physical rubbing of film against the spool wall. This effect is less than an inch in frequency.

SPOKING. Spoking is indicative of a noncircular roll with an edge effect similar in appearance to a low frequency scallop. It is the physical drying out of the edges and a curling of the film around the core in the wrapping process. The term "spoking" is used because the roll looks like a polygon that has radiating spokes to the center.

STRAIN SENSITIVITY. Strain sensitivity is the increased film sensitivity that occurs from a physical strain or stretching of the material. Quantitative estimates of strain sensitivity are determined by stretching the film 5 to 10 percent and measuring the increased speed sensitometrically. The term also refers to marks caused by elongation of the film as it passes through a system.

VACUUM PRESSURE MARKS. Vacuum pressure marks are similar to pressure marks. Although occurring in vacuum, they are not necessarily attributed to the vacuum condition itself.