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REPORT NO 7

KH-4B SYSTEM CAPABILITY

Evaluation of SO-121 Film For Use With The KH-4B System

20 NOVEMBER 1969

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KH-4B SYSTEM CAPABILITY

Evaluation of SO-121 Film For Use With The KH-4B System

20 NOVEMBER 1969

Itek OPTICAL SYSTEMS DIVISION
ITEK CORPORATION • 10 MAGUIRE ROAD • LEXINGTON, MASSACHUSETTS 02173

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TABLES

1. INTRODUCTION AND SUMMARY

This is the seventh report in a series of evaluations that were designed to test the capability of KH-4B to handle unique photographic techniques. Although the tests performed in this series have been elementary in terms of photographic science considerations, they are in general novel to satellite reconnaissance photography. The program has been a success from several points of view, i.e., the basic questions of which techniques are compatible with KH-4B were answered, and the methods for implementing them were developed. In addition, these tests caused no significant interference with the primary mission of these systems—to gather intelligence information. Lastly, some of the techniques that were recommended have since been employed on subsequent missions. In some cases, they provided no additional intelligence; in others, information was gained that could not have been obtained with the conventional method of image acquisition.

It is hoped that, as new materials and techniques become available, testing will continue, and those materials and techniques that appear useful will be implemented on future missions.

The analysis of SO-121 Aero Ektachrome undertaken for this report was based primarily on missions 1105 and 1106. Mission 1105 contained a 500-foot length of SO-121 at the end of the mission.

A special filter was fabricated and used to control the color balance and film speed so that properly exposed/balanced color imagery could be obtained wherever the color material was used during the mission. The color photography acquired suffered from a system anomaly and was sharp only at the edges of the format. Subsequent to this flight, a need arose for additional color photography, and the quality level achieved on the SO-121 of mission 1105 was judged to be sufficient to satisfy the requirement. As a result, 2,000 feet of SO-121 were used at the end of mission 1106. The photography acquired from this mission had similar color balance and exposure, although the color film separated and only half of the material was recovered.

The color photography acquired from these two flights demonstrated the compatibility of SO-121 with the KH-4B system. In addition, sufficient film is available to examine the intelligence utility of the SO-121/KH-4B combination.

Throughout this report, reference will be made, where pertinent, to SO-180 Infrared Aero Ektachrome. The analysis of the only SO-180 flight is presented in the sixth report of this series.* During final preparation of this report Eastman Kodak announced the development of a new higher resolution color film, SO-242. The analyses undertaken in this report pertain only to SO-121, and the characteristics of SO-242 may be such that previously drawn conclusions relative to color may not only be inappropriate but may be false.

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*KH-4B System Capability, Evaluation of SO-121 for Use With the KH-4B System [redacted] 4 Aug 1969.

2. CHARACTERISTICS OF SO-121 FILM

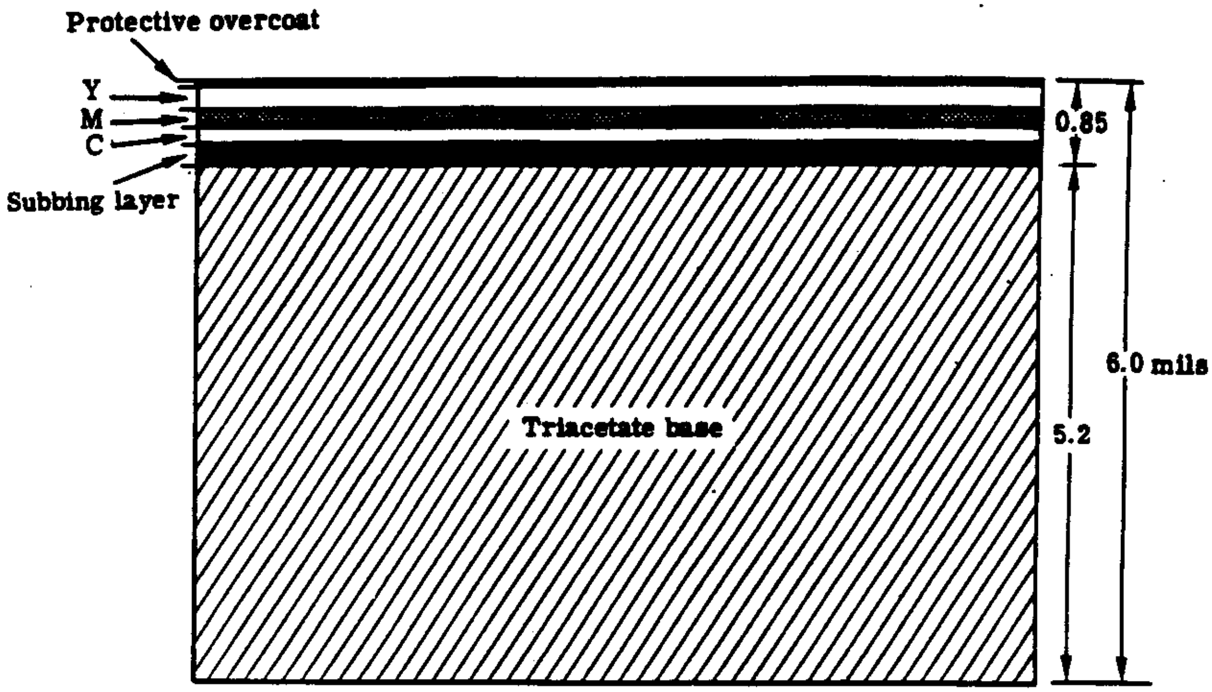
SO-121 film is an Aero Ektachrome emulsion on Estar thin base. The film's physical structure, as illustrated in Fig. 2-1, consists of three sensitive layers supported by a polyester (thin) base made from polyethylene terephthalate. This polyester base has advantages in physical strength and dimensional stability over the standard cellulose triacetate support of Aero Ektachrome film, 8442. SO-121 is not currently available on 1.5-mil ultrathin base.

The three sensitive layers of silver halide suspended in gelatin of slightly different thicknesses, along with their ancillary layers, occupy a total displacement of 0.80 ± 0.05 mil. For anticurl characteristic, a clear gelatin backing 0.45 ± 0.05 mil thick is included in the structure. With a base thickness of 2.50 ± 0.02 mils, the total thickness of SO-121 thus amounts to an average of 3.8 mils (3.75 ± 0.12). Variations are within limits established by quality control during manufacture, but additional variations are also introduced by fluctuations in moisture content resulting from changes in temperature and relative humidity. The important point is that the SO-121 color film is thicker than the 3404 and SO-380 black-and-white films (0.8 and 1.8 mils respectively). Because of this thickness difference, the film supply footage for the camera employing SO-121 in split-load missions must be less than the other camera employing a full load of 3404 or SO-380.

Image-forming energy first penetrates the green sensitive layer, then the blue sensitive layer, and finally the red sensitive layer. This is a unique layer arrangement in that it differs from the classical order of most other color films. Usually the blue sensitive layer is on top of the pack, followed by a yellow filter layer of colloid silver in order to limit the penetration of this light into the remaining two sensitive layers. Fig. 2-1 makes a comparison in the dye layer arrangements of SO-121 and a classical color film (8442).

The SO-121 dye layer arrangement, then, does require supplemental minus-blue filtration. Generally, it is a very light yellow filter such as a Wratten no. 2B in order to reduce the deep blue and near ultraviolet from the atmospheric hazelight. However, the arrangement does provide that green light (the most predominant spectral region for natural color information) be imaged with a minimum of scattering and interference from the other sensitive layers.

A more detailed examination of the SO-121 physical structure is afforded by an actual cross-section as presented in Fig. 2-2. The specimen slices depicted are less than 2.5 microns thick and were generated on a Sartorius-Werke microtome. In order to retain the dye layer differences, unexposed film was processed and dried normally, providing the material to be sampled. Microscopy was accomplished with cover glass sandwiches encasing the film specimen immersed in α-methylstyrene to minimize swelling and optimize refractive index. Photomicrographs were made on Type S Color Negative film (first generation) and Ektacolor Professional paper (second generation). In addition to the principal layers described in Fig. 2-1, three ancillary layers are to be pointed out. There is an obvious subbing layer joining the photosensitive tripack to the base



(a) 8442

(b) SO-121

Fig. 2-1 — Physical structure of cross sections of 8442 and SO-121 color films

[redacted]

(a) 8442

(b) SO-121

Fig. 2-2 — 450× photomicrographs of cross sections of 8442 and SO-121 color films support and a barely discernible subbing substrate in the yellow layer adjacent to the cyan dye layer. There is, finally, a protective coating on the front surface which comes in contact with the scan head rollers during image acquisition in the KH-4B panoramic camera. Not evident in the photomicrograph is the antihalation undercoat.

2.1 PHOTOGRAPHIC SENSITIVITY

The spectral sensitivities for each of the SO-121 dye layers are shown in Fig. 2-3. From this it is evident that selective sensitivities to red, blue, and green are more a matter of relative emphasis than clear-cut distinctions. There is good separation in sensitivity between the green and red sensitive layers. However, there is little separation between the blue and green sensitive layers. In the 380- to 480-nanometer region, there is an average of approximately a factor of 2× difference in speed, the greatest difference being a factor of 2½×. Two effects that tend to degrade the photography result from this small sensitivity difference. First, the film has a limited blue/green discrimination capability. Although color reversals would not occur, the blue reflecting objects will tend toward green in color. In fact, it is rare that one finds a blue object in SO-121 photography. Second, this limited sensitivity difference affects image quality. The image quality of the Petzval lenses in the green region is slightly poorer than the red region. This quality difference varies in magnitude depending on the lens type and focal position. Because of the overlapping green spectral sensitivity of SO-121 (into the blue region), there is an increase in image quality degradation with the Petzval lenses.

2.2 LABORATORY EVALUATION

Laboratory evaluation of SO-121 color film processed in ME-4 color chemistry provided the following color characteristics for SO-121 color film.

SO-121 was exposed for 0.01 second to simulated daylight (plus Wratten no. 2E filter) for visual neutral.

Equations for converting integral spectral density (ISD) to equivalent neutral density (END) for the dye layers using narrow bandpass filters in the optical path of the color densitometer are:

$$\text{Cyan} = 0.915D_r - 0.047D_g - 0.0005D_b$$

$$\text{Magenta} = -0.339D_r + 1.432D_g - 0.216D_b$$

$$\text{Yellow} = -0.006D_r - 0.306D_g + 1.142D_b$$

This equation is for the specific densitometry of this test.

The film's integral spectral density curve shows that image highlights will be cyan with yellow-cyan midtones, and yellow shadows. This is confirmed in the END curves. The integral spectral density curves for the mission (which was processed on the Grafton Processor) are shown in Figs. 2-4 and 2-5. [redacted] has been modifying the processing of SO-121 in order to increase the film's resolution. Their laboratory data have shown an increase in film resolution of between 20 and 30 percent. This increase in resolution was accomplished with a slight loss in film speed. However, the speed of SO-121 with this improved processing is still faster than 3404. KH-4B is operating at the threshold of minimum film speed for normal mission acquisitions with 3404. From operational considerations, split-load missions (i.e., 3404 plus SO-121) should employ the same slit sequence throughout the mission in order to properly expose both films. Therefore, SO-121 has been used with a neutral density filter. For full-load missions, the slit widths could be set specifically for the SO-121. In this case, the slight speed advantage (over 3404) still remaining after the special processing is still sufficient to allow the minimum slit widths that are mechanically possible on KH-4B.

The ASD curve, Fig. 2-6, shows the spectral characteristics of the individual dye layers. These values are a function of wavelength. The amount of each dye is expressed as its spectral density at some wavelength near its peak absorption. Each dye layer is scanned and the densities are plotted against wavelength to show both the relative concentration of dye and the overlapping absorptions. These dye shapes have no unusual characteristics and are similar to the dyes of other Eastman Kodak products.

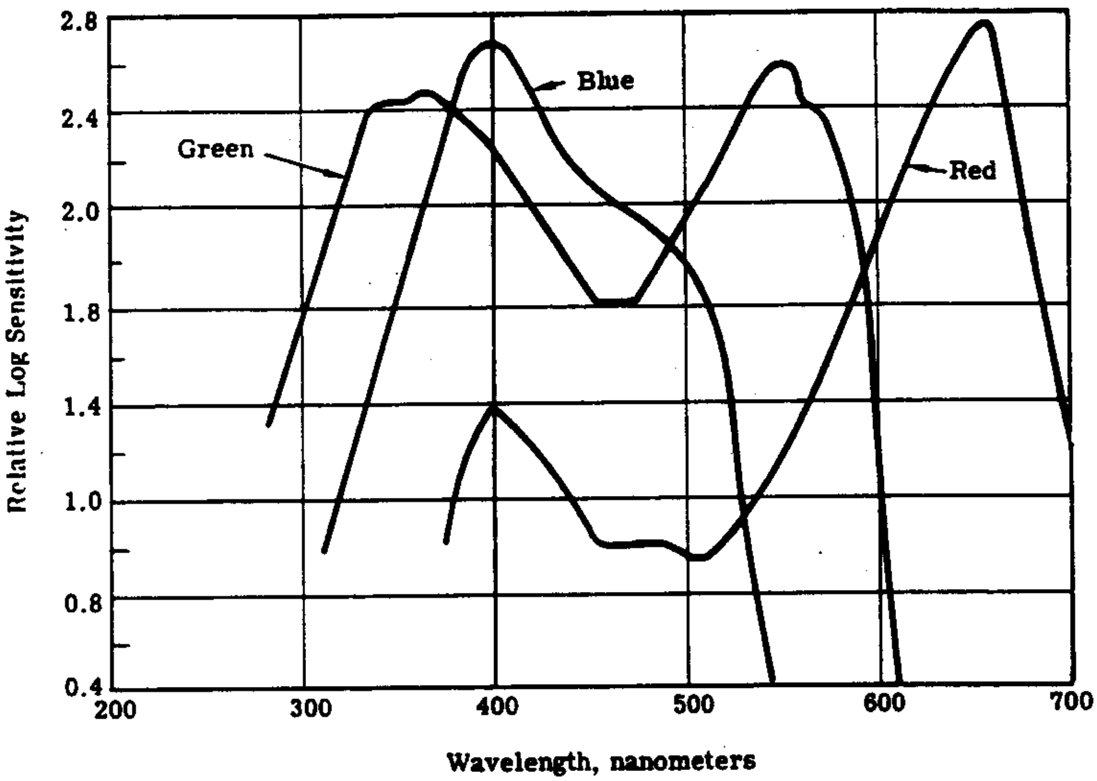


Fig. 2-3 — Spectral sensitivity of SO-121 (data courtesy of Eastman Kodak)

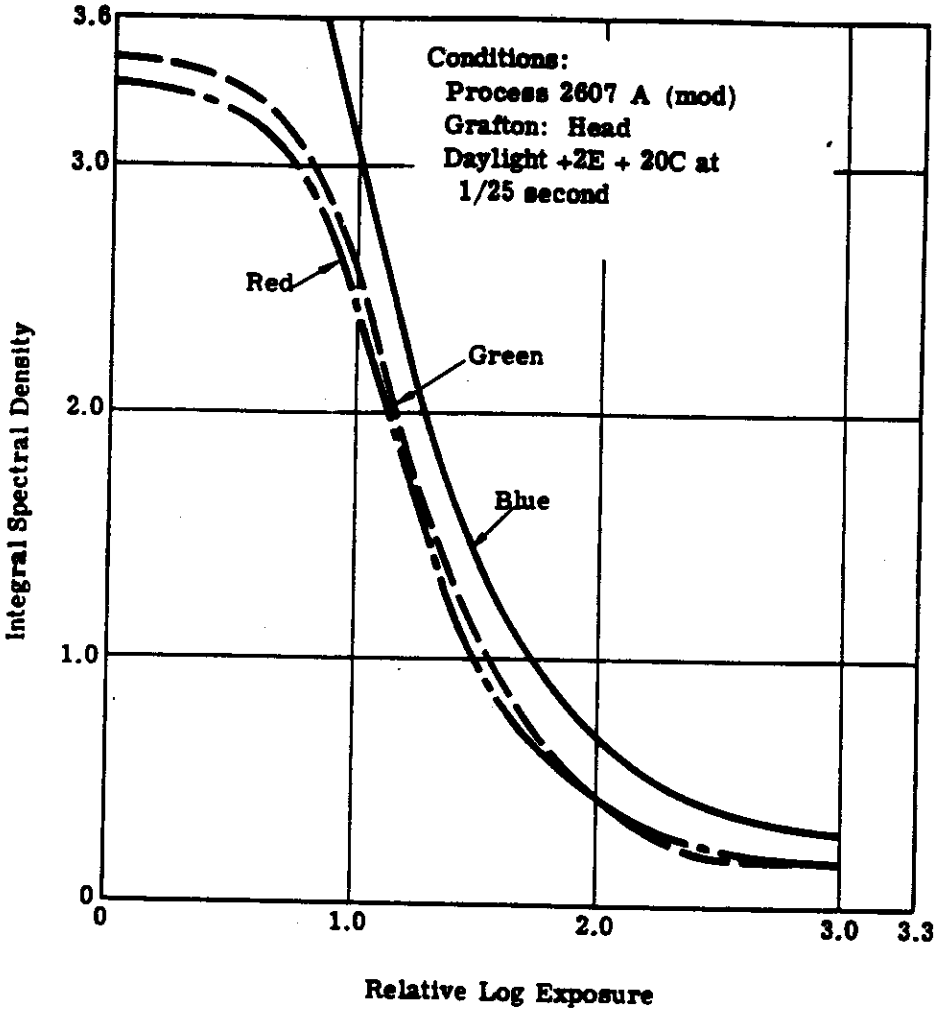


Fig. 2-4 — Integral spectral density curves, SO-121, mission 1105

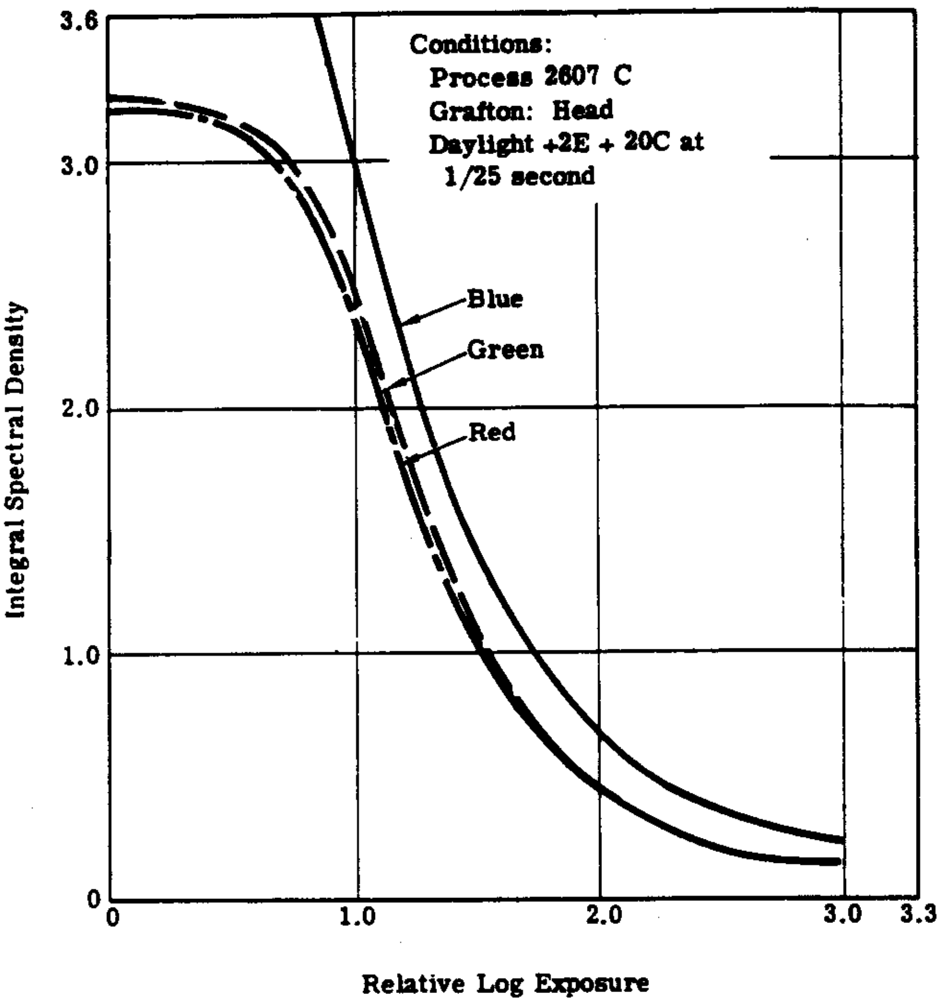


Fig. 2-5 — Integral spectral density curves, SO-121, mission 1106

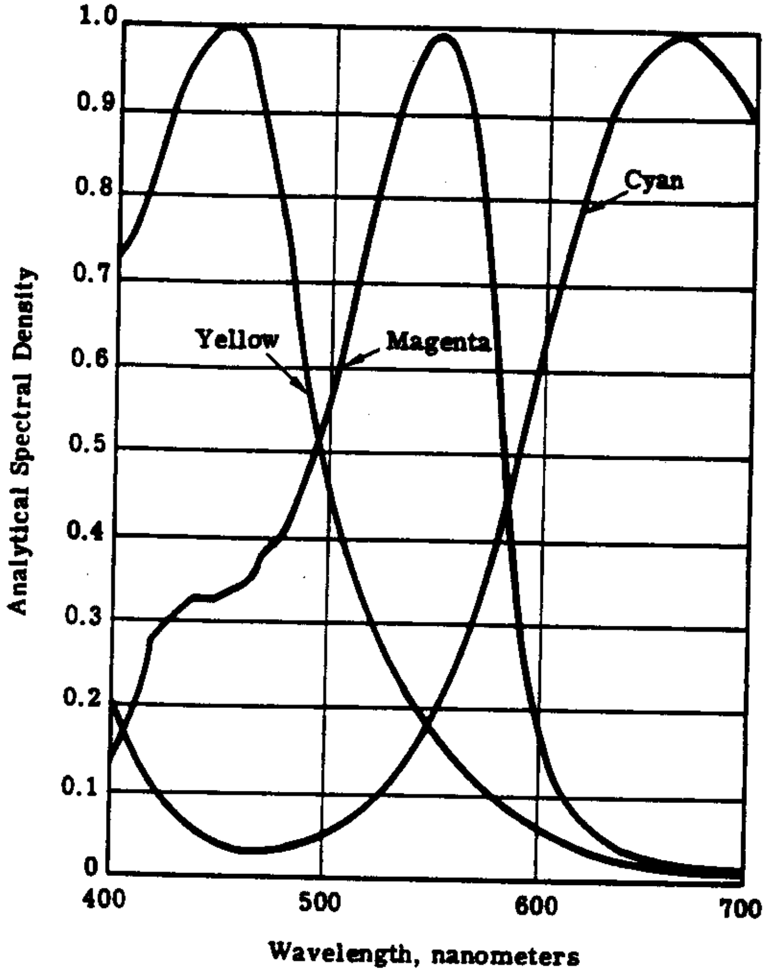


Fig. 2-6 — Dye absorption curves for SO-121 color film

3. ENGINEERING TESTS

This section describes some theoretical and practical tests that were carried out in preparation for using SO-121 in KH-4B. This section discusses the Petzval lens modulation transfer functions as a function of the spectral sensitivity bands for each of the three color film emulsion layers. Included in this section for reference is a similar analysis performed for SO-180, and comparisons are also drawn between these two types of color materials.

PETZVAL LENS MODULATION TRANSFER FUNCTIONS

Modulation transfer function (MTF) is commonly used in optical system design as a quality measure. It has been successfully employed in the optical industry for many years as a guide in lens manufacture. The lens MTF's are determined for a particular light source, a particular black and white film sensitivity, a particular filter, and a particular focal position. Since the MTF of a lens varies with wavelength, it is necessary to specify the light source employed, as well as all components that modify the spectral content of that light. Since film spectral sensitivities vary over the photographic spectrum, it is then necessary to take the distribution of exposing energy into account when determining a lens MTF. Two black and white films of equal image quality, but unequal spectral sensitivity will record various wavelength regions differently, and therefore the lens will effectively "see" different spectral regions and perform differently. Although MTF techniques have been applied successfully for lenses, these techniques have had a history of both successes and failures when used with a lens-film combination. The main difficulty occurs when a light scattering medium, such as film, is introduced. The MTF of a film, if it exists at all, is an illusive and perhaps even a variable quantity. If the film is used as the detector, it is difficult to separate the effects of the film MTF from the combined lens/film MTF.

The lens MTF itself contains a wealth of information. However, it is difficult to interpret all of this information when comparing two lenses. One can easily tell which of two lenses, as described by their MTF's, is better if one MTF is higher than the other; but it is not easy to determine the photographic significance of such MTF differences. This, coupled with other problems, such as not being able to get an MTF representative of a mission for comparison with preflight tests, has hindered the direct use of MTF's in the KH-4B system.

Resolution predictions can be obtained from lens design MTF's when combined with a resolution versus modulation curve.* The intersection of the MTF with a threshold curve can be used as a fairly reliable technique for resolution prediction. Although there are several theoretical pitfalls in this technique, it has been used with a reasonably high degree of success in lens design work.

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*This curve has a variety of names: AIM (aerial image modulation), modulation detectability curve, thresholds, and resolution threshold curve. A modification of this curve, called the TBF (three-bar function) is often used.

A lens MTF analysis similar to that carried out for black and white film can also be undertaken with color films. The same principal factors are used in the same computer programs to calculate the MTF's. However, there are some added factors to consider. For example, there are now three MTF's for a color film, one for each of the three color film spectral bands. In addition, there is the added factor that each of these sensitive layers not only records a different spectral band, but records it at a different focal position. To date it has not been possible to combine lens MTF's with respect to the three color film sensitivities with color film AIM curves to predict a resolution value. However, it is instructive to use the three MTF's themselves for an examination of the image-forming capabilities of the lenses as a function of the spectral bands defined by the color materials.

The color material can be either a conventional color film, such as SO-121, or a false color film, such as SO-180. The bulk of this analysis will be concerned with SO-121; however, reference will be made to SO-180 toward the end in order to tie together the image-forming characteristics of the Petzval lens with these two distinctly different materials. Fig. 3-1 contains the MTF's for second and third generation lenses* with respect to the 3404 film sensitivity, each filtered according to its design. The 2:1 threshold† curve for 3404 produces 160 and 190 cycles per millimeter with the two types of lenses.

Figs. 3-2 and 3-3 contain MTF's of second and third generation Petzval lenses with respect to each of the sensitive layers of SO-121 as filtered on missions 1105 and 1106. The dashed line is the MTF assuming the color film emulsions were all in the same focal plane as that of 3404. The solid line represents the MTF at an estimated focal position based on the thickness of each emulsion layer. The layer on the bottom (red sensitivity) has the greatest focal shift. The green sensitive layer has no shift since it is on top, and the blue layer lens MTF is at such a low quality level that the shift is practically nonexistent. One factor that is not taken into consideration in this analysis is the dynamic lift characteristic of the color film in this camera system. The systems are adjusted before flight for a specified amount of film lift. Although 3404 and SO-121 have the same base type and thickness, the emulsion construction is different. The three primary layers in the SO-121 could have a reinforcing effect similar to plywood that would help the film resist forming a plane between the two scan head rollers. If such a difference existed between SO-121 and 3404, it would be an added factor for consideration. For full-load color missions, the system would be adjusted specifically for the lift characteristic of SO-121.

The MTF's for the green and blue spectral regions are poor for both the second and third generation lenses. The depth of focus for a second generation lens is greater than that for the third generation lens. Notice that the change in MTF by taking into account the layer thickness

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* A second generation Petzval lens was designed for use with a Wratten no. 21 filter; the third generation Petzval lens is intended for use with a Wratten no. 25 filter and has improved performance in the spectral region.

† The threshold curve used in this laboratory has the basic shape of film resolution as a function of target modulation. However, the curve has been shifted slightly so that it does in fact provide resolution estimates very near those obtained from lens bench tests. This has proven in the past several years to be quite satisfactory for the Petzval type lens design and 3404 over the resolution range of 50 to 300 cycles per millimeter. This threshold therefore is empirically derived and is specifically not the same as that obtained from a resolution camera evaluation of a film.

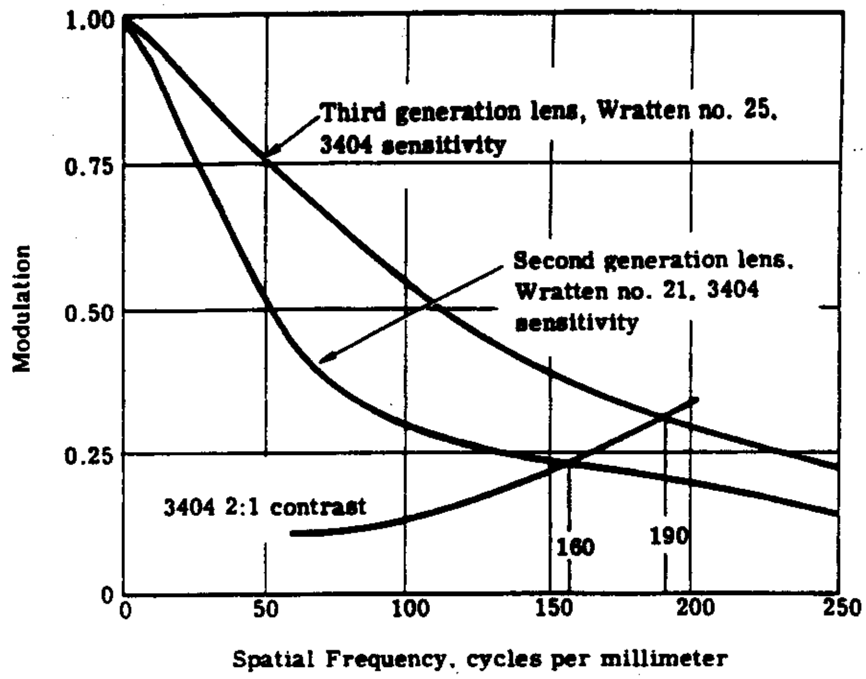

Fig. 3-1 — MTF's of second and third generation Petzval lenses

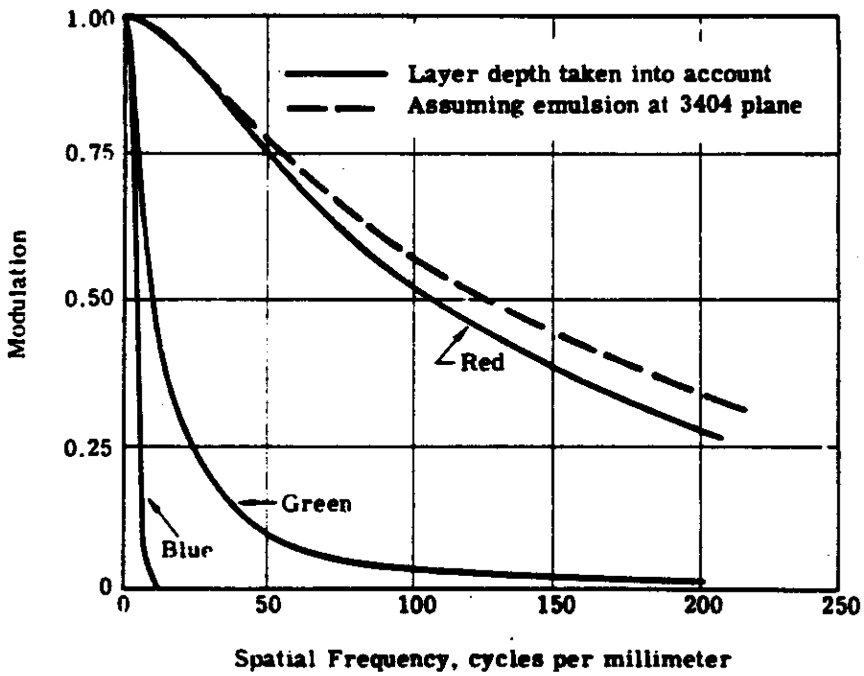

Fig. 3-2 — MTF's of second generation lens with respect to SO-121 spectral sensitivity

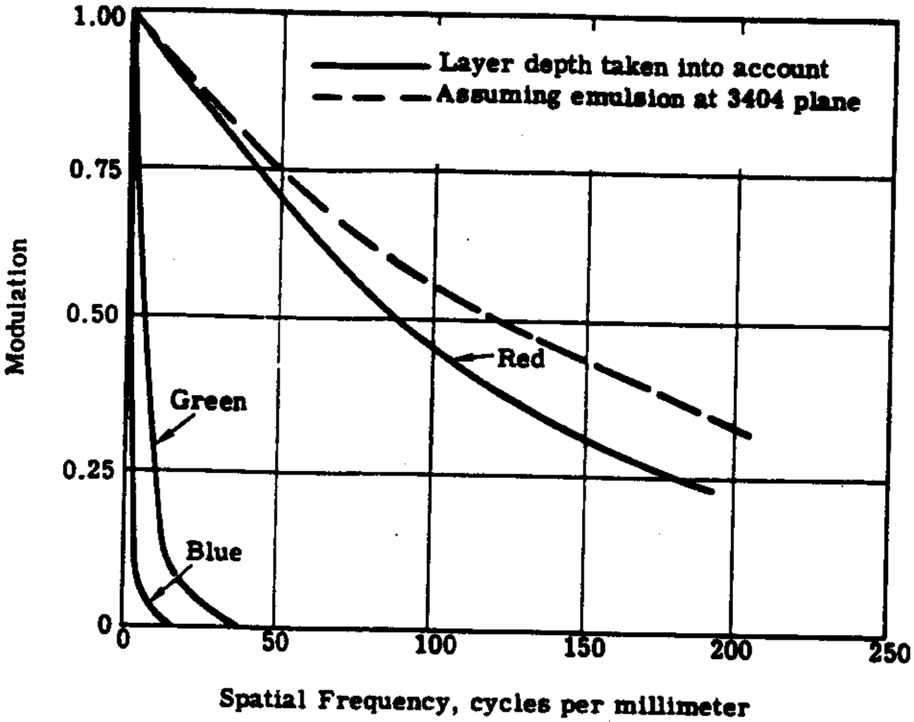

Fig. 3-3 — MTF's of third generation lens with respect to SO-121 spectral sensitivity is greater for the third generation lens (Fig. 3-3) than for the second (Fig. 3-2). The MTF of the second generation lens integrated with respect to the spectral response of the red sensitive layer of SO-121 is higher than with the Wratten no. 21 filter with 3404 film. This is due to the fact that the Wratten no. 21/3404 combination produces a wider spectral band than the red sensitive layer of SO-121. If the wavelength band were narrowed further, the MTF would improve still more. However, it would not be possible to take pictures under these conditions with 3404 without unreasonably long exposure times. Fig. 3-4 illustrates the relative response of SO-121 and 3404, each filtered with its respective filters. Here the narrower red spectral region of the SO-121 discussed above can be seen. Included also in this figure is the relative response for SO-180.

One very important conclusion can be drawn from the data presented in Figs. 3-2 and 3-3— the second generation lens performs better than the third in all three spectral bands as defined by the SO-121 layers. Although the third generation performs better than a second with a red filter on 3404, it is not the case with the red sensitive layer on SO-121. The principal difference is that the red sensitive layer is on the bottom, and this focal shift lowers the performance of the third generation due to its narrower depth of focus. In order to obtain the improved performance in the red spectral region, the design wavelength for the third generation lens was shifted from 610 to 650 nanometers. This caused a lowered performance in the blue and green regions as seen in these MTF's.

As mentioned previously, some attention will be paid to the performance of the Petzval lens with SO-180. The data presented in Figs. 3-5 and 3-6 are the three second and third generation Petzval lens MTF's for the spectral region defined by SO-180. The MTF's for both lenses in the red spectral region defined by SO-180 are comparable, but the green and infrared are not. The third generation MTF in the infrared region is better than the second generation lens. However, the reverse is true for the green sensitive region. Therefore it is not altogether clear what lens would be better for SO-180. The MTF's of the lenses in the spectral region defined by sensitive layers of SO-180 and SO-121 are markedly different. The major difference in these two sensitivities is that the SO-121 green sensitive layer has a great deal of sensitivity in the blue region. Therefore, the image-forming light is not just green, but blue-green, which indirectly causes the lowered lens performance. The SO-180, however, uses a Wratten no. 15 filter that effectively eliminates this sensitivity. In addition, both the second and third generation lenses perform better in the infrared region than the blue. Therefore, it is clear that from a lens performance point of view only, an SO-180 type of film will provide better performance than an SO-121 type of film. However, considering the quality of materials that are actually available and that have been flown, this is not the case. The inherent resolution* of SO-180 is less than half that of SO-121 which dominates the lens/film combination. If a higher resolution film could be made, the SO-180 type film would lead ultimately to the highest performance obtainable on color film with the lenses available today on the KH-4B system.

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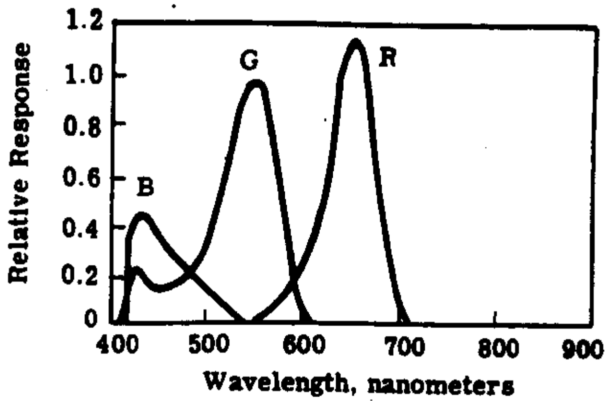
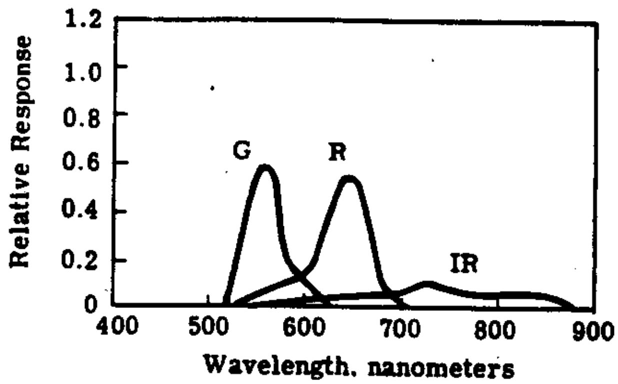
*Data from the FEAT Laboratory indicates that the resolution for SO-121 and 8443 (SO-180 equivalent on a 5.2-mil base) is:

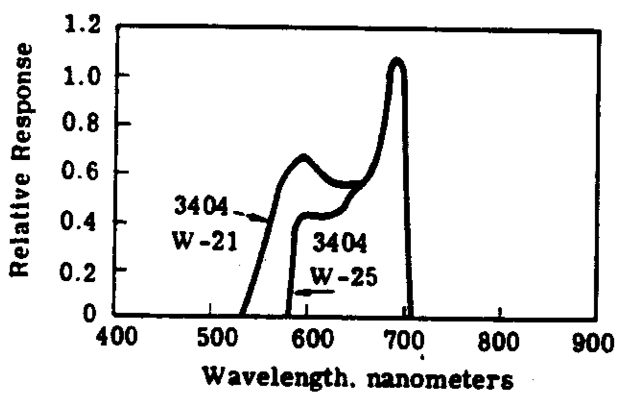
Contrast	1,000:1	1.7:1
SO-121	172 c/mm	95 c/mm
8443	63 c/mm	35 c/mm



(a) SO-121 (2E, 20ccB)



(b) SO-180 (Wratten no. 15)



(c) 3404 (Wratten nos. 21 and 25)

Fig. 3-4 — Relative response of SO-121, SO-180 and 3404 with respective filters

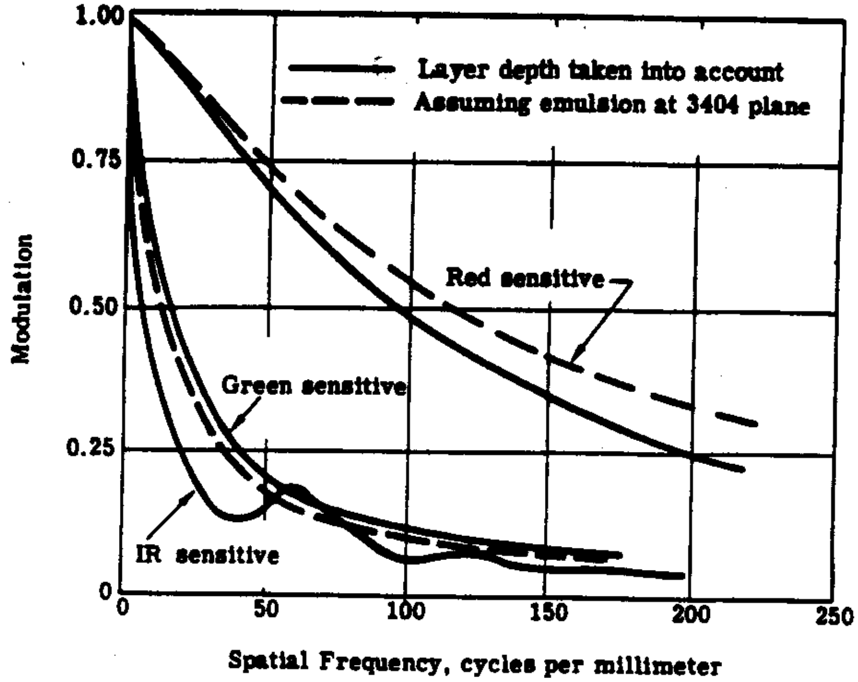


Fig. 3-5 — MTF's of second generation lens with respect to SO-180 spectral sensitivity

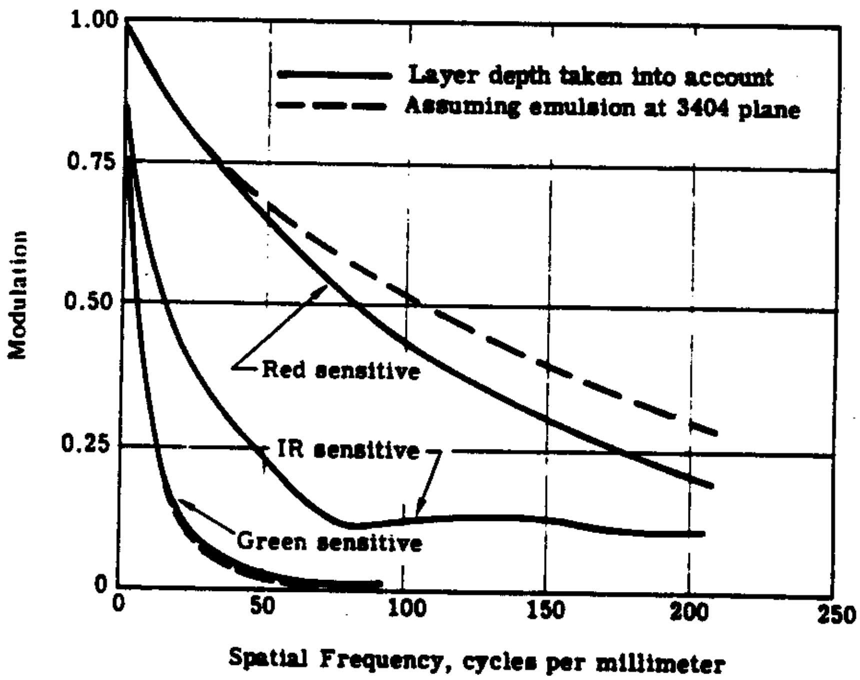


Fig. 3-6 — MTF's of third generation lens with respect to SO-180 spectral sensitivity

As discussed earlier, it is not possible at present to predict a resolution value for color film using the MTF/AIM curve technique. It would be useful to have the technical tools to perform this type of analysis. With this technique, the performance level of new films and new camera systems could be evaluated during the camera design stage. However, in order to carry this out, research must be undertaken to determine these color film AIM curves. Whether they are theoretically sound, or like black and white AIM curves—empirically determined—is unimportant. All that is of concern is that they do in fact predict a reasonably accurate resolution value.

4. MISSION EXPERIMENTS

SO-121 Aero Ektachrome, a high definition aerial color film, was flown for the first time in the KH-4B system on mission 1105. This mission contained 500 feet of color film spliced to the end of the primary mission film load, SO-380. The mission was launched on 3 November 1968; the second bucket was recovered on 21 November 1968.

The purpose of the color film test on this flight was to:

1. Obtain, for the first time, conventional color photography from KH-4B
2. Demonstrate the capability of KH-4B to handle SO-121.

In conjunction with the major purpose, actual targets supplied by CIA intelligence analysts were furnished for consideration in the flight plan in an effort to realistically evaluate the film. These targets included the J-Complex at Tyura Tam, SA-2 and SA-5 sites in the USSR, Launch Complex A at Sary Shagan, and certain areas in Vietnam and China.

Of particular interest was Site A-1 at Kartaly, USSR, where the Soviets are suspected to be using camouflage. Unfortunately, these targets were not covered on the color portion of the mission.

A material change detector automatically brought an alternate filter into position for the color portion of the mission. Color coverage was acquired on five passes. The first pass, 273, covered portions of central USA; the second, 274, covered the coast of California. The ground track was almost identical to the SO-180 coverage of this area on mission 1104. Thus, comparable coverage of a single area, although during different seasons, became available. Clear weather photography was obtained over Korea, and of the two remaining passes over the Soviet Union, one was cloud-covered and the other was partially cloud/snow-covered.

Subsequent to mission 1105, a requirement was levied upon the KH-4B system to acquire color-oriented information in central China. Although there was an anomoly on mission 1105 (discussed in Section 4.3), the quality level obtained on that mission was judged to be adequate to satisfy the requirement. In order to have a high probability of acquiring this target area, 2,000 feet of SO-121 were authorized as a tag-on film load on mission 1106.

Mission 1106 was launched on 5 February 1969, and the second bucket was recovered on 14 February 1969. Although the specific target area of interest was not acquired, three passes of color photography were obtained. Two were snow-covered areas of the Soviet Union and one was clear weather coverage of Southern China and North Vietnam.

4.1 FILTER PREPARATION FOR MISSIONS 1105 and 1106

The KH-4B system has an in-flight filter-changing capability that provides for either one of two filters. The change can be implemented on a real time basis when the vehicle is within range of a tracking station. There is also a material change detector that automatically changes the filter when a new film comes into use during the mission. The primary filters for KH-4B missions have been Wratten filters of 0.004-inch thickness. The alternate filter for some past experiments on KH-4B has been special vacuum depositions on 0.005-inch thick quartz. For these SO-121 missions, however, the approach taken was similar to that of the mission 1104 SO-180 test. Composite gelatin filters were fabricated by Eastman Kodak for these flights. The filters have three components:

1. Haze cutting—this is similar to a Wratten no. 2E and cuts off the deep blue light.
2. Color correction—this is a 20cc cyan and is used to adjust the color balance. It counteracts the excess yellow color from the haze-cutting component.
3. Neutral density—this is an Inconel overcoat metal deposit used as a final adjustment for exposure control.

In preparing the filter for flight, there are two basic considerations—color quality and exposure. The laboratory testing at Eastman Kodak established the filter requirements for color quality. However, mission operational considerations dominate the choice of a neutral density coating for the filter. The KH-4B system has an automatic sequencing mechanism that changes the exposure as the vehicle progresses from the northern latitudes toward the equator. The sequence is then reversed for the Southern Hemisphere. The systems are set so that this sequence will provide correct exposure for the prime mission material (3404) with the primary filter (Wratten no. 21 or 25). However, if another film that has a different photographic speed is used, this sequence of exposure will be off in one direction or the other depending on the film speed. There is no way to interrupt this sequence except by real time commands that are only practical over the United States. There is, though, some flexibility available in the starting time of the slit changing sequence. Therefore, in order to obtain correct exposure over desired areas, a neutral density coating is employed on the filter such that the equivalent speed of SO-121 is the same as 3404 appropriately filtered. There are, then, long range plans that are necessary in preparing this filter. If, for example, there were to be a change in the primary filter, from a Wratten no. 21 to 23A perhaps, there would have to be a similar adjustment in color film filter neutral density to account for the difference in filter factor between the new and old primary filter. This did occur on mission 1105 when a last minute decision* was made to use the SO-121 on the AFT-looking camera (which uses a primary Wratten no. 21 filter) instead of the FWD-looking camera (which uses a primary Wratten no. 25 filter). The new filter was coated and used on mission 1105 on the AFT-looking camera. Mission 1106 was flown 3 months after mission 1105, and, although the color correction and haze-cutting components remain unchanged, there was a requirement for a different amount of neutral density. This was due to the change in the required slit widths for that mission.

Fig. 4-1 illustrates the transmittance characteristics of the components of the filters. Fig. 4-2 shows the composite for each of the two missions.

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*The original decision to obtain SO-121 photography from the FWD-looking camera was based on having the option of acquiring color photography through the bi-color mode, before reaching the color film. The bi-color filter would have been used on the AFT-looking camera since that unit employed a second generation Petzval lens. The SF-05 filter for this mission was miscoated, and, therefore, since bi-color was not available, the SO-121 was moved to the AFT-looking camera. Thus, it was used on the camera that, according to the study performed in Section 3, would provide the highest performance level.

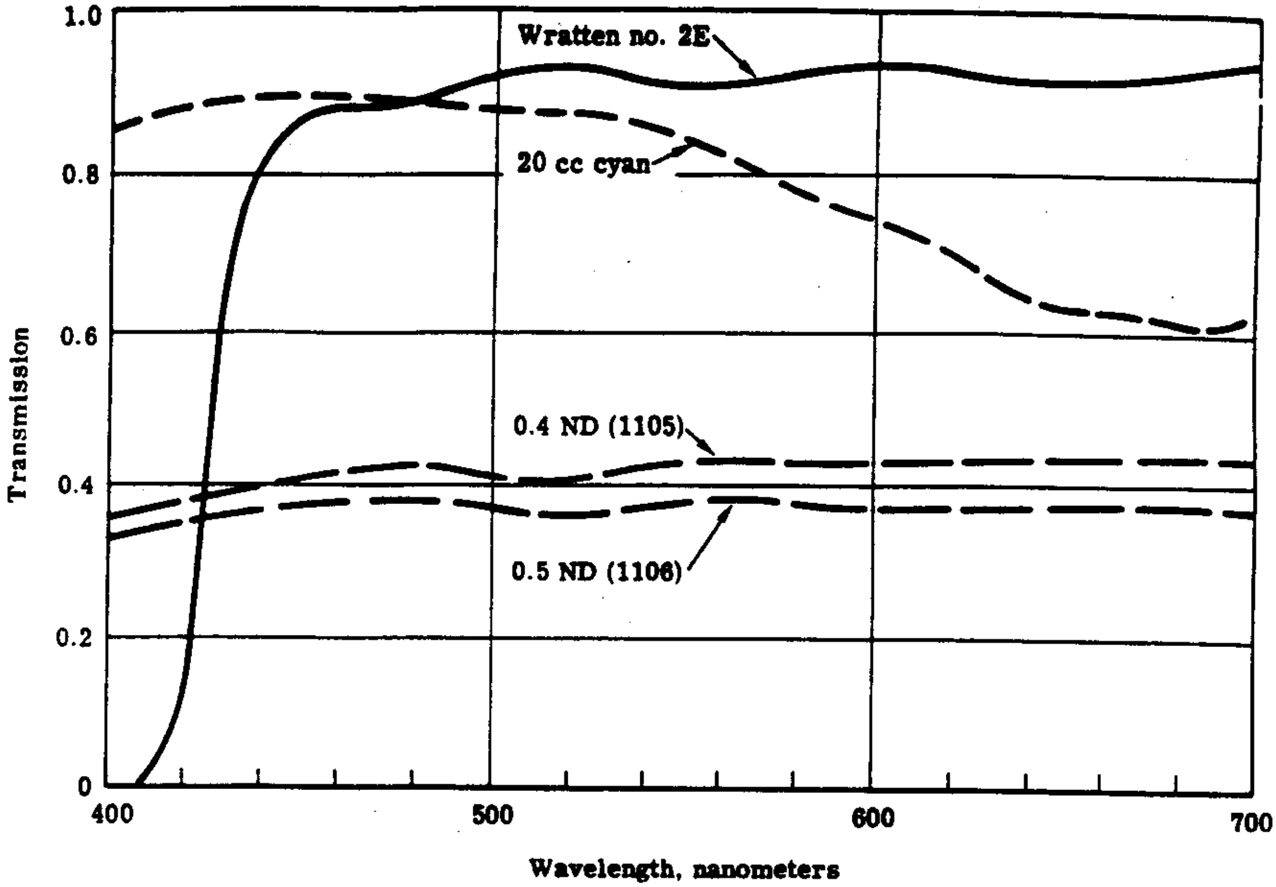

Fig. 4-1 — Spectral transmittance of the components of the filters used for SO-121 on missions 1105 and 1106

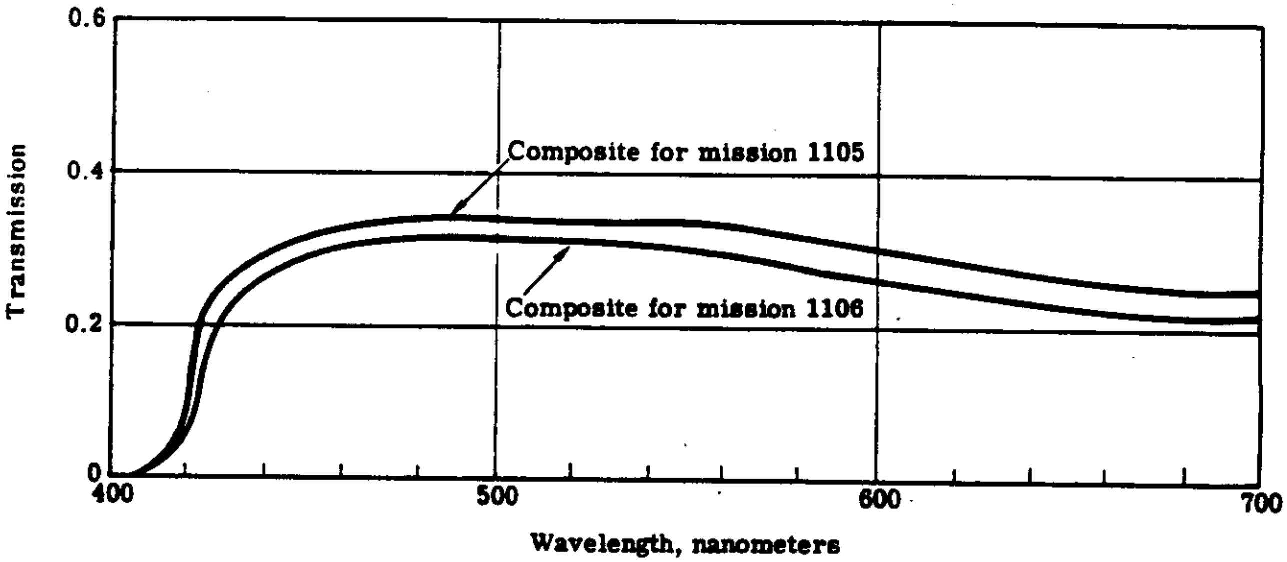

Fig. 4-2 — Spectral transmittance of the filters used for the SO-121 missions 1105 and 1106

Dynamic resolution tests were conducted on a 120-inch collimator with the filters intended for use on mission 1105. The SO-121 was attached to the end of a film load of SO-380 on the AFT-looking camera of CR-12. This system employed a second generation lens, I-184, similar to that of CR-5. Through-focus runs were made at each of three exposure levels. Test samples were processed in this laboratory, and the primary test film was sent to [redacted] for processing. Recent work at [redacted] has provided an increase in resolution of 20 to 30 percent in SO-121 through proprietary formulations. This increase in resolution is achieved at a cost of photographic speed. However, since SO-121 is faster than SO-380, the loss is of no consequence for KH-4B operation. Resolution data were also acquired on SO-380, and the data for both films are shown in Figs. 4-3 and 4-4. The 2:1 contrast resolution for SO-380 was 130 cycles per millimeter, while the SO-121 produced slightly over 50 cycles per millimeter. At an altitude of 80 nm, this would provide a resolution level of 16 feet. It is interesting to note that the depth of focus is at least 0.004 inch.

Resolution tests were also performed on the filter that was used for the SO-121 on mission 1106. The test was performed on a first generation Petzval lens in a static condition. The target was changed in order to more accurately represent the resolution values over a wider focal range. The average resolution for this test was 40 cycles per millimeter, which would produce a ground resolution of 20 feet at 80 nm. Since this was a static test, a master resolution target could be used to obtain resolution values below 40 cycles per millimeter. The difference in performance between the tests of these two filters arises from several factors. Principally, the first test employed the improved processing by [redacted] and used a better lens.

In summary, although the low contrast resolution of SO-121 is slightly more than 100 cycles per millimeter, only half of that resolution level can be achieved with the KH-4B system. The expected resolution level for a mission flown at 80 nm is 16 to 20 feet.

4.2 MISSION DATA

Tables 4-1 through 4-4 and Figs. 4-5 and 4-6 contain the specific data for missions 1105 and 1106 as well as an identification of the areas acquired in color.

4.3 MISSION 1105 ANOMALY

One of the major difficulties encountered on the color portion of this mission was what appeared to be a film curl during exposure. The photography was sharp at the edges of the format, but became progressively softer toward the center of the film web. As stated in the mission 1105 PEIR:

> ". . . THE IMAGE QUALITY OF THE SO-121 RECORD WAS EXTREMELY VARIABLE, AND RANGED FROM GOOD TO VERY POOR. THE AMOUNT OF GOOD QUALITY IMAGERY IS LIMITED AND IS GENERALLY RESTRICTED TO THE EDGES AND ENDS OF THE FORMAT. THE CENTER PORTION OF THE FORMAT IS GENERALLY POOR. THIS CONDITION WOULD APPEAR TO HAVE BEEN CAUSED BY THE FILM BEING CURLED AWAY FROM THE FOCAL PLANE DURING EXPOSURE. THE BEST IMAGERY APPEARS TO BE COMPARABLE TO THE BEST THAT COULD BE ACHIEVED WITH THE CORONA CAMERA AND SO-121 FILM. THE BEST GROUND RESOLVED DISTANCE IS ESTIMATED TO BE

ABOUT 15 TO 20 FEET. PRELAUNCH SYSTEM TESTING INDICATED THAT A POTENTIAL 15 FEET GRD (LOW CONTRAST) COULD HAVE BEEN ACHIEVED. . . ."*

The system tensions for mission 1105 were reduced by approximately 20 percent (from 46 to 36 ounces) in order to minimize the strain sensitivity marks on the primary film load, SO-380. It appeared at that time that this lowered tension was not enough to pull the film flat across the scan head rollers during exposure. The following SO-121 flight, mission 1106, provided photography that was of uniform quality across the format.

The PEIR for this mission stated:

". . . ALTHOUGH THERE WERE SOME AREAS OF THE SO-121 FROM MISSION 1105 THAT WERE BETTER THAN THIS MISSION, THE OVERALL IMAGE QUALITY OF THIS FLIGHT WAS BETTER THAN THE 1105 COLOR. THE IMPROVED OVERALL IMAGE QUALITY OF MISSION 1106 IS CREDITED TO (1) INCREASED SYSTEM TENSIONS PULLING THE FILM FLAT AND/OR (2) THE SHORT TIME PERIOD BETWEEN LAUNCH AND EXPOSURE LIMITING POTENTIAL DRYING-OUT OF THE COLOR FILM IN VACUUM . . ."†

It is not altogether certain why the material remained flat on the second flight. The time interval between launch and the first color photography on mission 1105 was more than 17 days. The time period for mission 1106 was only 6½ days. Little is known about the rate of evaporation of volatile materials from the film under orbital conditions. It is possible that the reason for the improved flatness was not the increase in film tension, but the 1/3 time of exposure to vacuum. Although it is believed that increasing the tensions solved the problem, it is possible that another flight with higher tensions, but extending over a longer time period, could again produce curled imagery.

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*NPIC message no. [redacted] Dec 1968.
†NPIC message no. [redacted] Feb 1969.

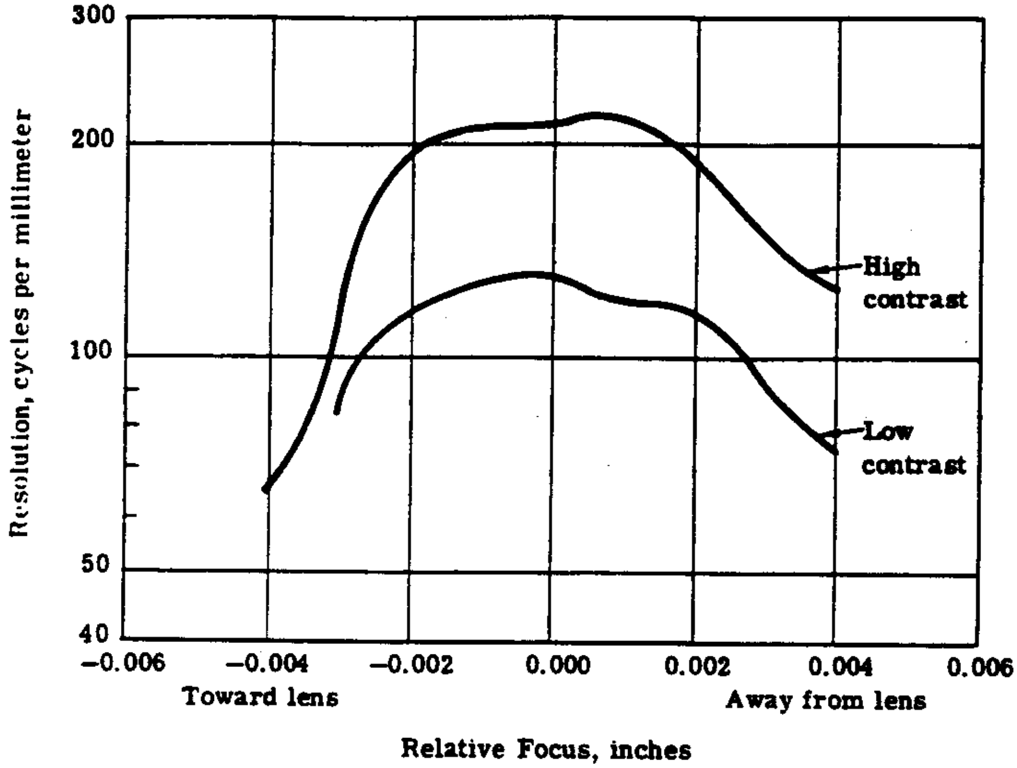

Fig. 4-3 — Through-focus resolution curves for SO-380 in unit no. 324

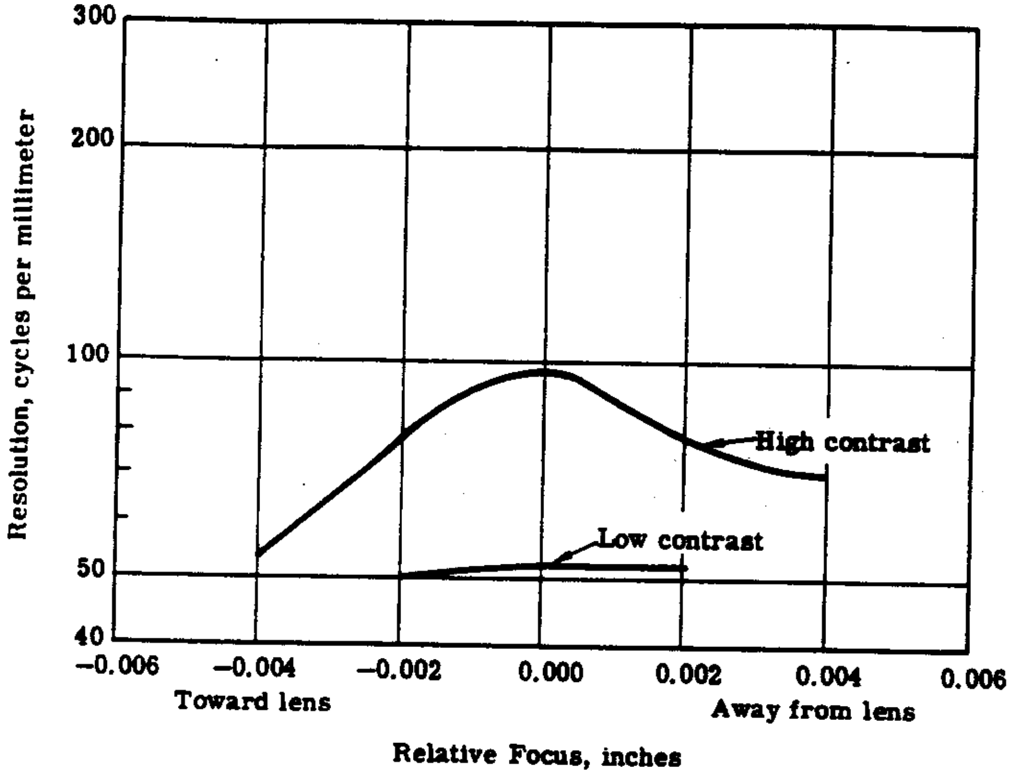

Fig. 4-4 — Through-focus resolution curves for SO-121 in unit no. 324, best exposure level

Table 4-1 — Specific Camera Parameters for Mission 1105

Camera	FWD-looking	AFT-looking
Instrument no.	311	310
High contrast dynamic resolution, c/mm	279*	265†
Low contrast dynamic resolution, c/mm	187*	158†
Filters—primary	Wratten no. 25	Wratten no. 21
alternate	Wratten no. 23A	Special composite: Wratten no. 2E + 20 cyan + 0.4 ND
Slit widths, inches 1.	0.180	0.138
2.	0.229	0.149
3.	0.310	0.192
4.	0.340	0.271
FS.	0.305	0.198
Emulsions	SO-380	SO-380/3404/SO-121
Code	157-5-10-6-10-8	157-10-10-8/415/44-1
Film lengths—Preflight	485	485
1105-1	11,805 (SO-380)	11,804 (SO-380)
1105-2	11,714 (SO-380)	10,660 (SO-380) 50 (3404) 489 (SO-121)
Total	24,004	23,488

*Resolution tested with a Wratten no. 25 filter.
†Resolution tested with a Wratten no. 21 filter.

Table 4-2 — Specific Camera Parameters for Mission 1106

Camera	FWD-looking	AFT-looking
Instrument no.	313	312
High contrast dynamic resolution, c/mm	266*	194†
Low contrast dynamic resolution, c/mm	184*	130†
Filters—primary	Wratten no. 23A	Wratten no. 21
alternate	Wratten no. 25	Special composite: Wratten no. 2E + 20 cyan + 0.5 ND
Slit widths, inches 1.	0.160	0.134
2.	0.195	0.150
3.	0.245	0.185
4.	0.305	0.230
FS.	0.245	0.185
Emulsion	3404	3404/SO-121
Code	428-1-1-9	428-1-1-9/44-1
Film lengths, feet—1106-1	8,164 (3404)	8,226 (3404)
1106-2	8,051 (3404)	5,765 (3404) 899 (SO-121)
Total	16,215	14,890

*Resolution tested with a Wratten no. 23A filter.
†Resolution tested with a Wratten no. 21 filter.

Table 4-3 — AFT-Looking Panoramic Camera No. 310, Mission 1105, Color Segment Data: SO-121

Rev	Frame	Slit, inches	Center Format Latitude, degrees	Center Format Longitude, degrees	Sun Elevation, degrees	Location
273	37 to 67	0.192	38 to 34 N	98 W	30 to 43	Kansas, Oklahoma
274	1 to 21	0.192	37 to 33 N	120 W	32 to 35	South
	22 to 28	0.271	37 to 33 N	120 W	32 to 35	California
279	1 to 17	0.271	41 to 35 N	126 to 127 W	27 to 31	Korea
	18 to 30	0.192				
281*	1 to 22	0.271	52 to 48 N	79 to 80 E	16 to 20	
	23 to 27	0.192				
283	1 to 19	0.271	56 to 46 N	33 to 36 E	11 to 22	Moscow
	20 to 84	0.192				
	85 to 88	0.138	8 N to 0.2 S	41 E	61 to 69	

*Snow and cloud cover.

Table 4-4 — AFT-Looking Panoramic Camera No. 312, Mission 1106, Color Segment Data: SO-121

Rev	Frame	Slit inches,	Center Format Latitude, degrees	Center Format Longitude, degrees	Sun Elevation, degrees	Location
103	171 to 212	0.187	26 to 21 N	102 E	48 to 52	China, Laos, Vietnam
104	001 to 176	0.234	68 to 40 N	64 to 78 E	8 to 35	Ob River Estuary to Lake Balkash, Russia
105	001 to 129	0.234	67 to 24 N	44 to 51 E	10 to 24	Arkangelsk to Caspian Sea, Russia

[redacted]

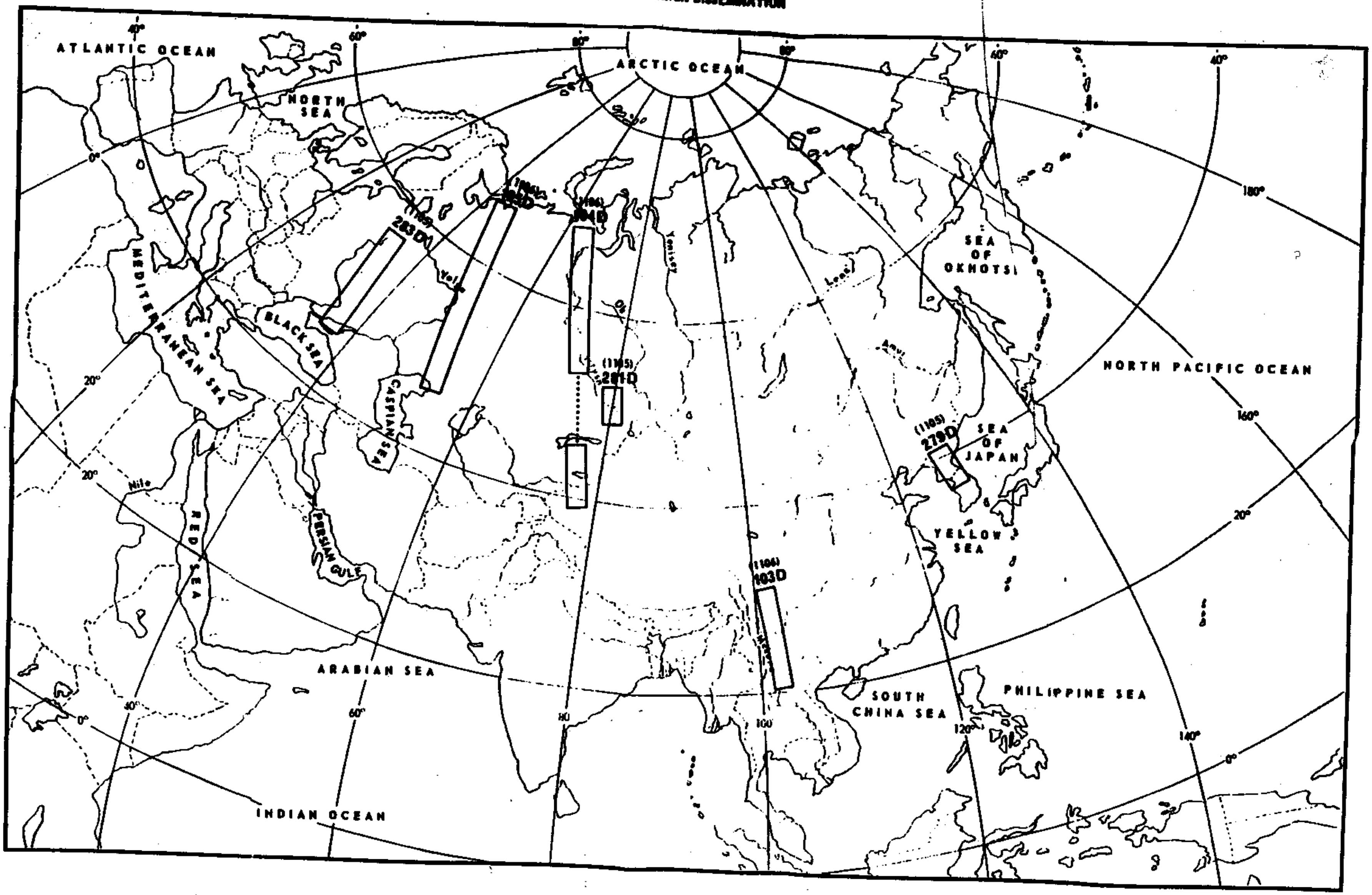

Fig. 4-6 — Ground tracks for the mission 1105 and 1106 passes over Eurasia

5. PHOTOINTERPRETATION ANALYSIS

5.1 INTRODUCTION

In general practice, the world of the photographic interpreter or analyst is an abstraction of reality rendered in white, gray, and black. From this monochromatic record he must, and does, read and interpret the actions of both man and nature.

The "real world" is a place of more than the density differences seen in black and white photography; it is a world of hue and saturation. The advent of color in most fields of intelligence gathering is looked upon as an unusual presentation, when in fact it is much more of a reality.

The conditioning of the senses and mind to black and white that has evolved through years of study makes the acceptance of color difficult for some persons. However, for those whose work has placed them in the position of interpreting radar, infrared, SLAR, or laser imagery, the transition should be minor and basically a matter of orientation. This transition is applicable both to "false" and natural color materials.

This evaluation will deal mainly with seven areas of interest that cover the broader areas encountered in contemporary interpretation, i.e., culture, military, vegetation, cultivation, geology, hydrology and atmosphere. Comparisons will be made on an overall and/or point-by-point basis, whichever is necessary to make a point.

5.2 OPERATIONAL DESCRIPTION

The configuration of the camera system allows acquisition of target imagery in a convergent stereo mode resulting in coverage of the same items with a 30-degree difference in look angles and with a short time differential. For most purposes, the time difference is of no consequence and the stereo capability has proved to be an almost indispensable asset.

Two missions, 1105 and 1106, were researched for evaluation. Mission 1105 occurred in November 1968 and mission 1106 in February 1969. Seasonal differences were readily apparent and much of the 1106 coverage in the Soviet Union is of snow-covered areas. Mission 1105 had more ground color because of the launch date, but suffered from degraded imagery over much of the format as discussed in Section 4.3. The edges and ends of the format had enough sharp imagery to permit evaluation and several frames were acceptable over the full format area.

An approximation of the operational resolution limits of the film/system combination was arrived at by indirect means since ground resolution targets were not deployed in the areas of coverage. The technique involved searching the black and white record and the color record simultaneously for man-made objects that somewhat resembled resolution targets, i.e., equally spaced light and dark linear objects.

In selecting an appropriate target, the imagery of the color record must be at the limit of resolution. A glass resolution target is then placed over the black and white image and a match of spacing is made with the three bar targets. This gives the film resolution in lines per millimeter at the SO-121 threshold of resolution. With this figure established, the operational parameters are extracted from the Mission Ephemeris, and the ground resolved distance is then calculated.

$$R, \text{ feet} = \frac{10.7a}{r \cos \theta} \text{ (IMC direction)}$$

$$R, \text{ feet} = \frac{10.3a}{r \cos^2 \theta} \text{ (scan direction)}$$

where a = vehicle altitude in nautical miles
θ = absolute value of scan angle from center of format in degrees
r = determined film resolution in lines per millimeter

These equations take into account scale changes due to the 15-degree look angle and the variable scan angle as well as geometric perspective in the IMC and scan directions.

The best resolution figure obtained from the SO-121 record occurred during mission 1105-2, rev D-273. The frame and universal grid coordinates are:

FWD frame 057: x-coord = 66.5, y-coord = 2.5

AFT frame 064: x-coord = 10.7, y-coord = 0.1

The resolution measured on this film was 45 lines per millimeter and the calculated ground resolved distance is 24 feet. This figure compares favorably with results obtained in the EKIT Test* series using CORN targets. However, this is not considered an ideal case because the color resolution pattern was rather well defined and not at the threshold of interpretability. Thus, the best GRD achieved is expected to have been better than 24 feet. Experienced observers have judged the resolution level to be anywhere between 15 and 25 feet.

Resolution information extracted from this technique on mission 1106-2 was limited in this case by the lack of suitable ground objects. The best one found though provided 32 lines per millimeter, which reduces to a GRD of about 27 feet. Visual comparison of the imagery from both missions substantiates the superiority of the best imagery of 1105-2 over the best imagery of 1106-2.

5.3 SUBJECTIVE EVALUATION

There were a total of 8 revs of photography acquired with SO-121 film on missions 1105 and 1106. The ground tracks for both missions are given in Fig. 4-5 and 4-6.

Mission 1105-2

Rev	Area	Comments
D-273	Covering parts of Kansas and Oklahoma	Good exposure with generally clear weather

* EKIT Report No. 4, Evaluation of SO-121 at Low Solar Altitudes, [redacted] 16 Nov 1966.

Rev	Area	Comments
D-274	Covering the California coast from San Francisco south to the Santa Barbara Channel	Scattered inland clouds, coast cloud bank, good exposure
D-279	Covering North Korea	Good exposure, scattered clouds, low color contrast, snow in north end of pass
D-281	Covering an area northeast of Lake Balkash	First half of pass is overcast coverage of snow-covered farms and forest; last half is cloud obscured
D-283	Beginning northwest of Moscow and extending to the Black Sea	Good exposure, clear weather, some snow-covered areas

Mission 1106-2

Rev	Area	Comments
D-103	Included part of Southern China and Northern Laos	Good exposure, mostly clear weather
D-104	Two parts: the first covering the area of the Ob River estuary sourth to the central area of the USSR and the second starting south of Lake Balkash and crossing the Chinese border in the Tien Shan mountains	Cloud cover at start of first part; good exposure of snow-covered ground at end; thin cloud cover and snow in second part
D-105	Started at the coastline near Arkhangelsk and ceased between the Caspian and Aral Seas	Snow-covered taiga and farm land somewhat obscured by haze

As mentioned previously, there was a considerable amount of degraded imagery on mission 1105, but the ground was clear and did permit a certain amount of evaluation, particularly at the edges and ends of the format. Rev D-274 was particularly useful because of the duplicate coverage of SO-180 from mission 1104 and the general familiarity with the area.

The imagery in areas of snow cover becomes essentially monochromatic, and only in scattered instances is significant information obtained by color distinction. Normal panchromatic film with the higher resolution and acuity and lesser graininess is far better for this situation. In both cases though, the capability to delineate buildings, forests, rail and highway rights of way, in fact, any item that protrudes through the snow cover, is excellent.

As an aid to presentation of the subjective evaluation results and as a standardized reference frame, the comparisons contained in this report have been assigned values (see Table 5-1).

Culture, as defined for this evaluation, consists of those works of man of a civil nature as opposed to those of a military nature. Cultivation will be an exception to this guideline, though strictly, it is a work of man.

Table 5-1 — Relative Interpretability Ranking

The following numerical ranking is to be used in conjunction with the special subjective evaluation forms devised for orderly and definitive analysis of comparison items.

Quality Rank	Criteria
1	Image of comparison case is not interpretable with respect to standard
2	Image of comparison case is at threshold of interpretability
3	Image of comparison case is poor compared to the standard
4	Image of comparison case is fair compared to the standard
5	Image of comparison case is good compared to the standard
6	Image of comparison case is equal to the standard
7	Image of comparison case is better than the standard
8	Image of comparison case is superior to the standard
9	Image of comparison case is exceptional compared to the standard
10	Image of standard is at threshold of interpretability
11	Image of standard case is not interpretable with respect to comparison

The evaluations are subjective in nature and based on the judgment of the observer, weighing all those factors applicable to the particular subject. Such factors may not be applicable in other cases and no attempt is to be made to execute a "forced fit" for the sake of uniformity or conformity