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KH-4B SYSTEM CAPABILITY

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

20 NOVEMBER 1969

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20 NOVEMBER 1969

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

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Pages i and ii of the original document were unnumbered, and pages 4-12, 5-11, 5-16, and 5-20 were blank and unnumbered.

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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

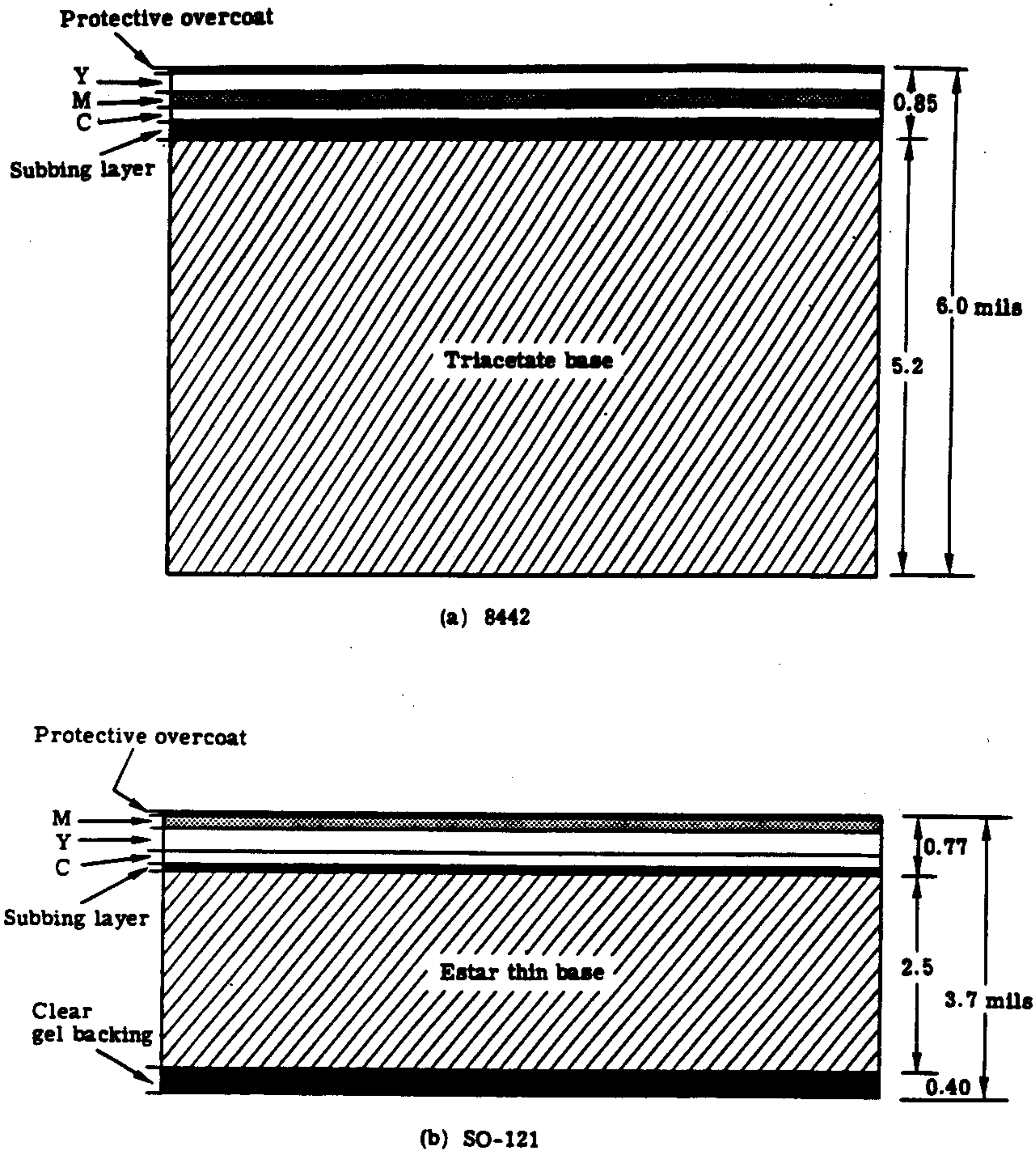

Fig. 2-1 — Physical structure of cross sections of 8442 and SO-121 color films

[redacted]

(a) 8442

[redacted]

(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.

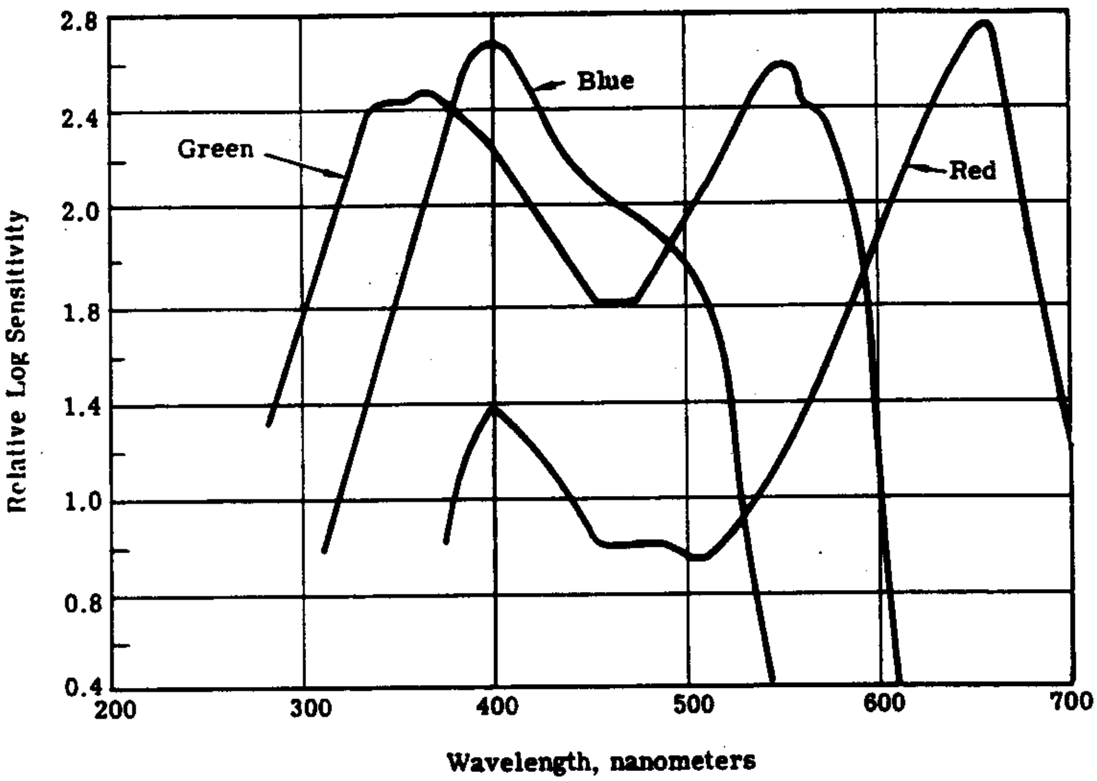

Fig. 2-3 — Spectral sensitivity of SO-121 (data courtesy of Eastman Kodak)

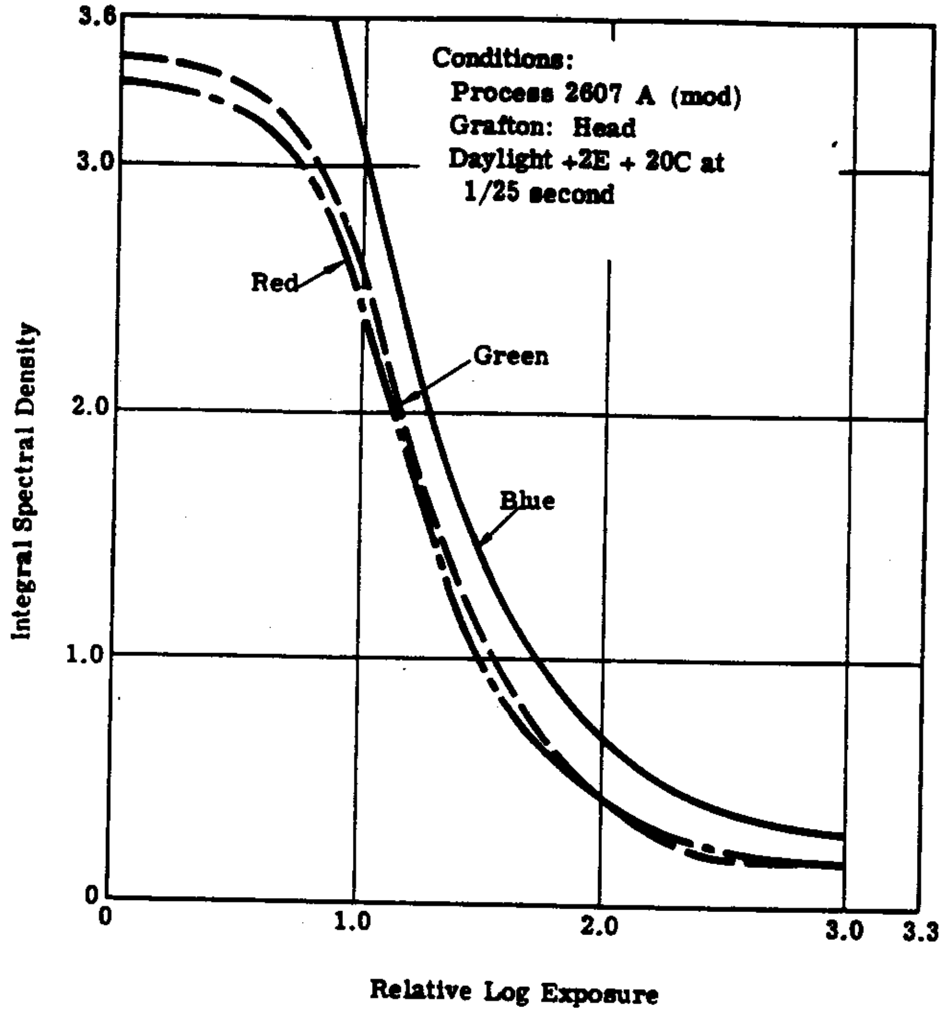

Fig. 2-4 — Integral spectral density curves, SO-121, mission 1105

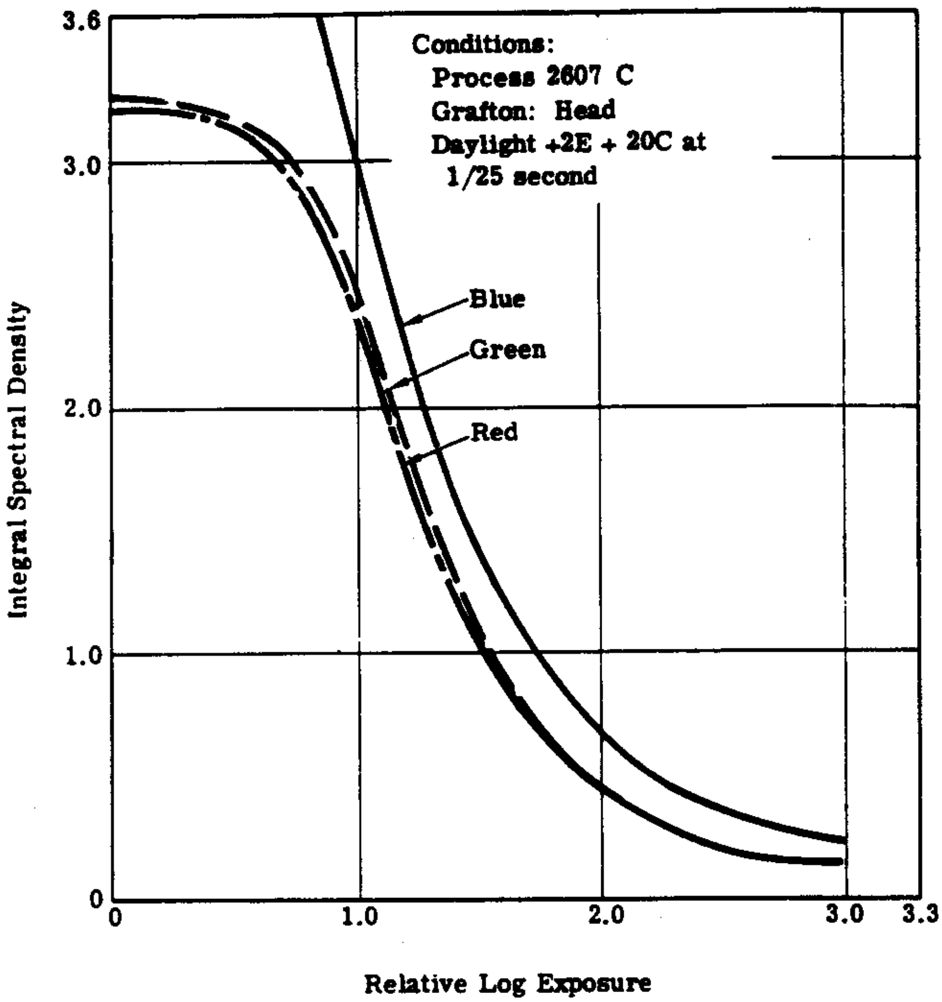

Fig. 2-5 — Integral spectral density curves, SO-121, mission 1106

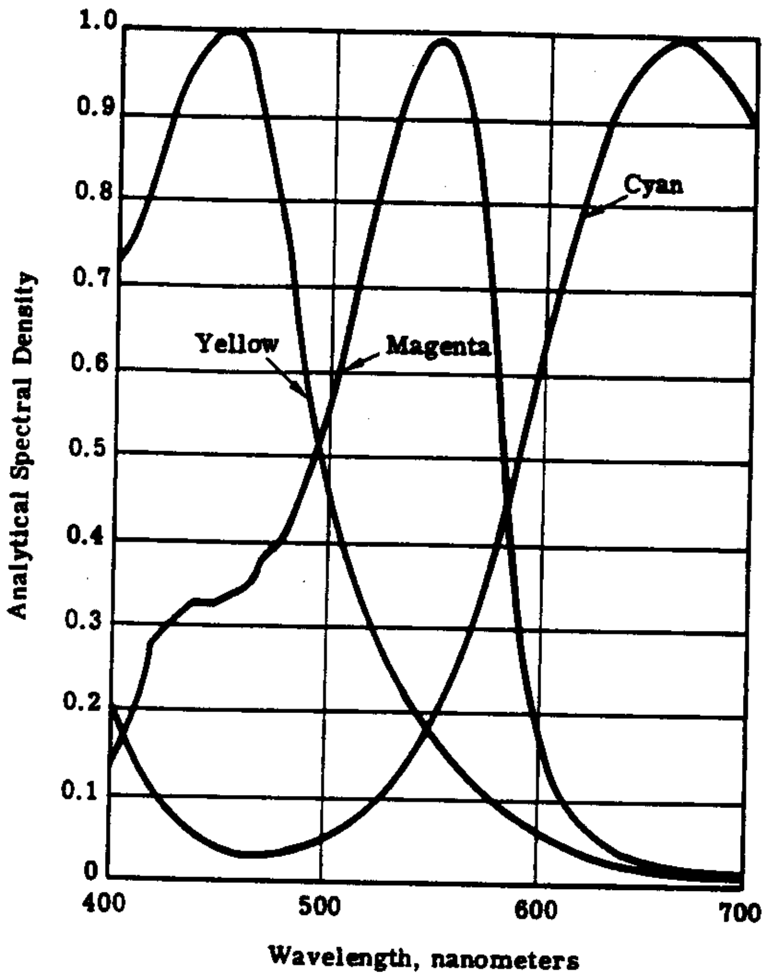

Fig. 2-6 — Dye absorption curves for SO-121 color film

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.

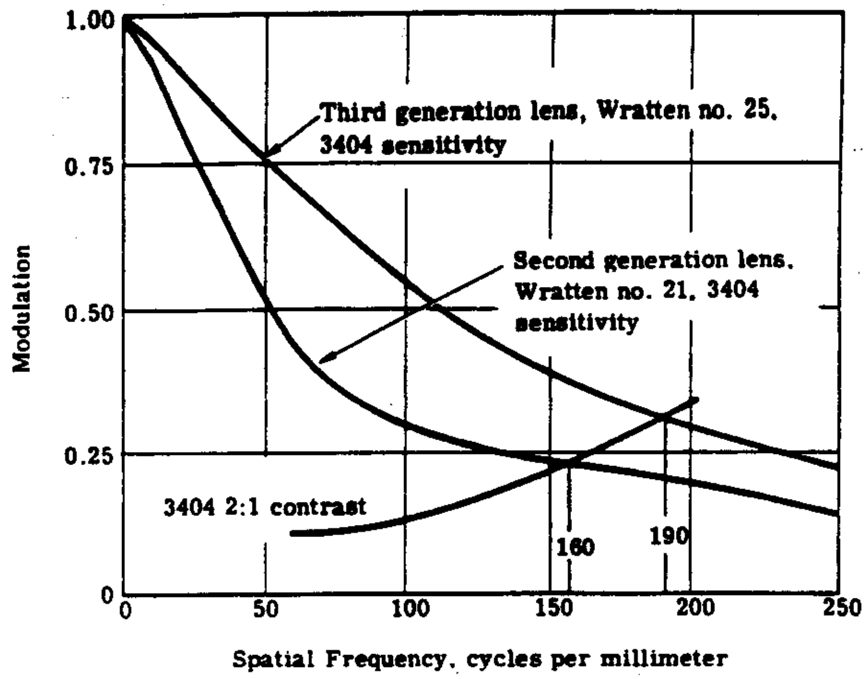

Fig. 3-1 — MTF's of second and third generation Petzval lenses

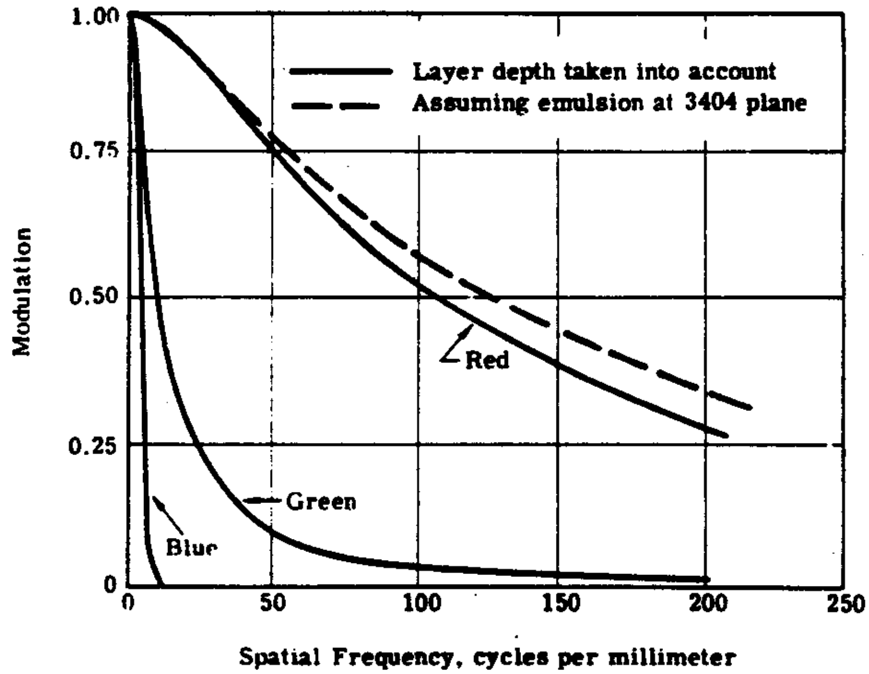

Fig. 3-2 — MTF's of second generation lens with respect to SO-121 spectral sensitivity

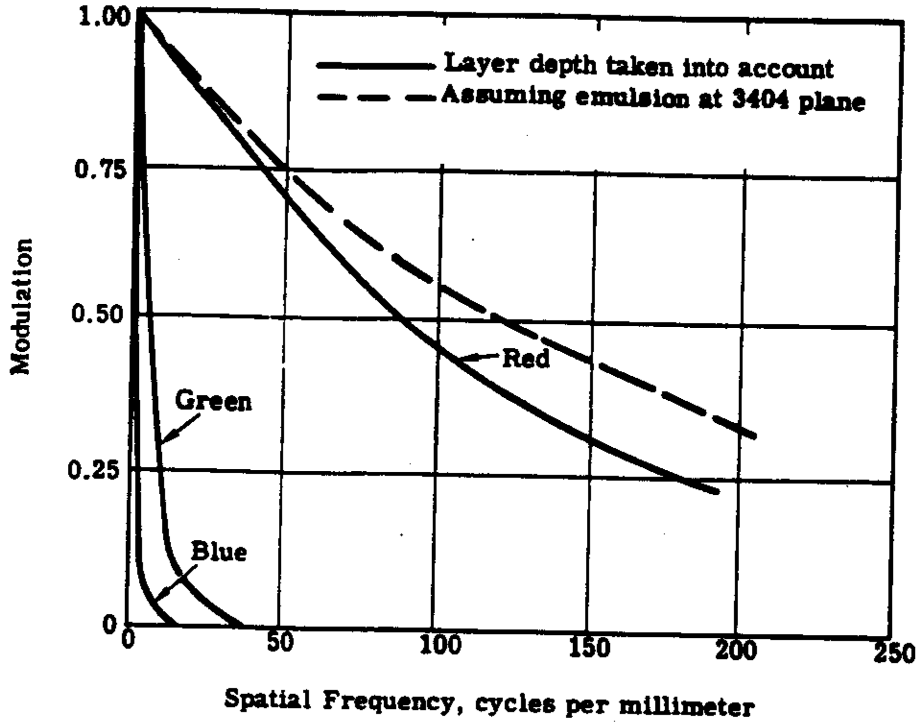

Fig. 3-3 — MTF's of third generation lens with respect to SO-121 spectral sensitivity is greater for the third generation lens (Fig. 3-3) than for the second (Fig. 3-2). The MTF of the second generation lens integrated with respect to the spectral response of the red sensitive layer of SO-121 is higher 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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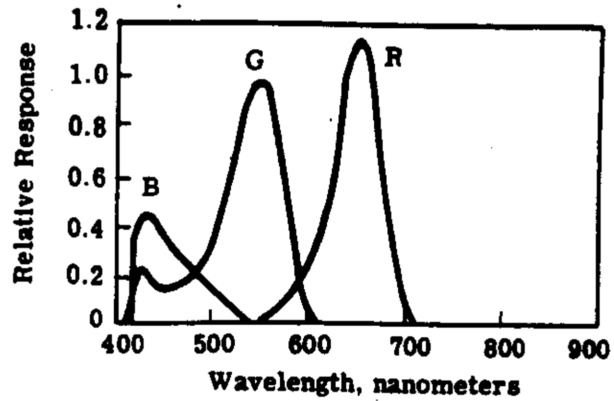
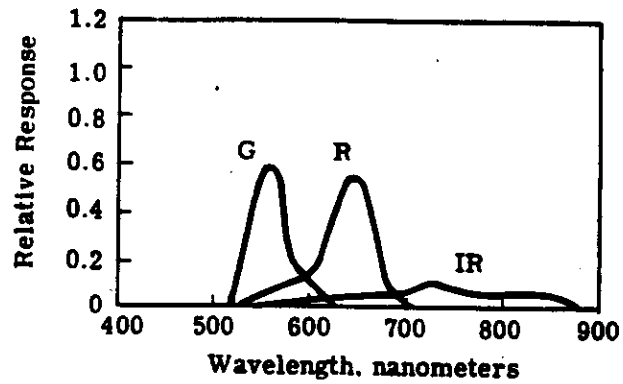
*Data from the FEAT Laboratory indicates that the resolution for SO-121 and 8443 (SO-180 equivalent on a 5.2-mil base) is:

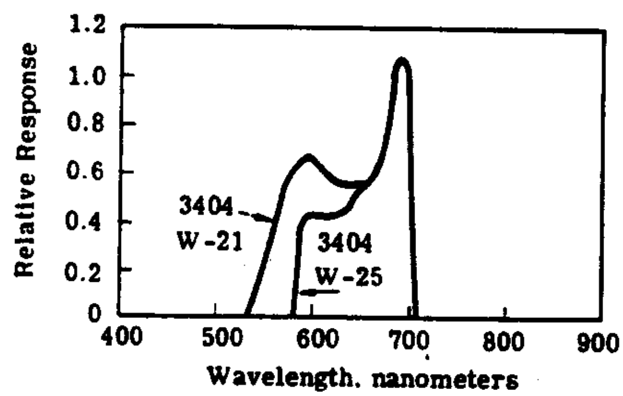
Contrast	1,000:1	1.7:1
SO-121	172 c/mm	95 c/mm
8443	63 c/mm	35 c/mm



(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

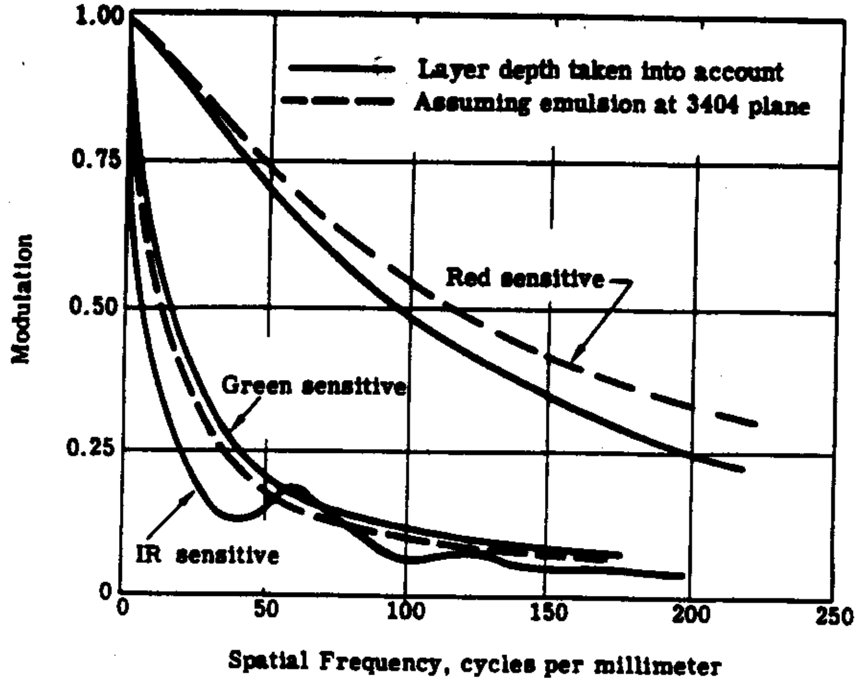


Fig. 3-5 — MTF's of second generation lens with respect to SO-180 spectral sensitivity

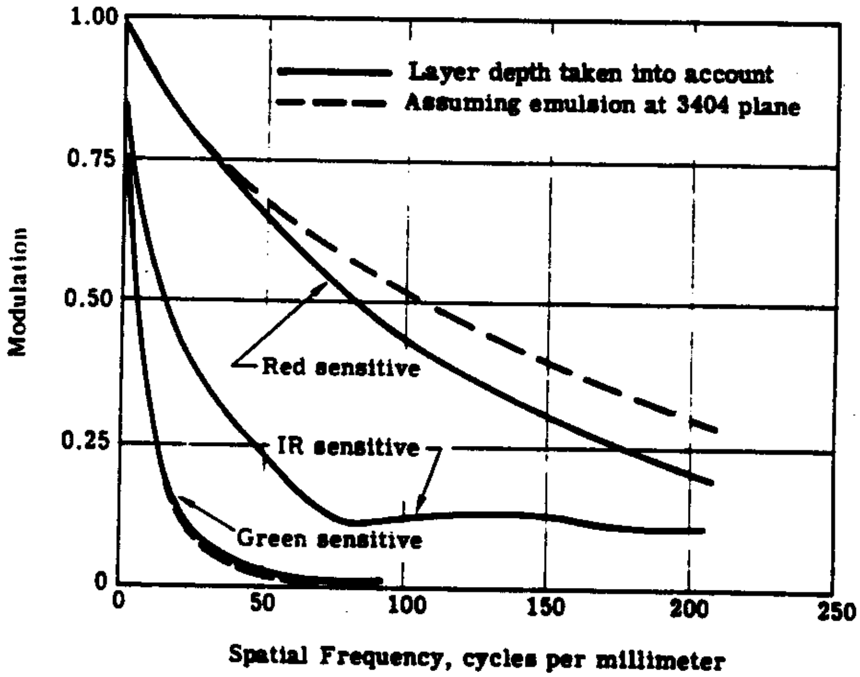


Fig. 3-6 — MTF's of third generation lens with respect to SO-180 spectral sensitivity

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.

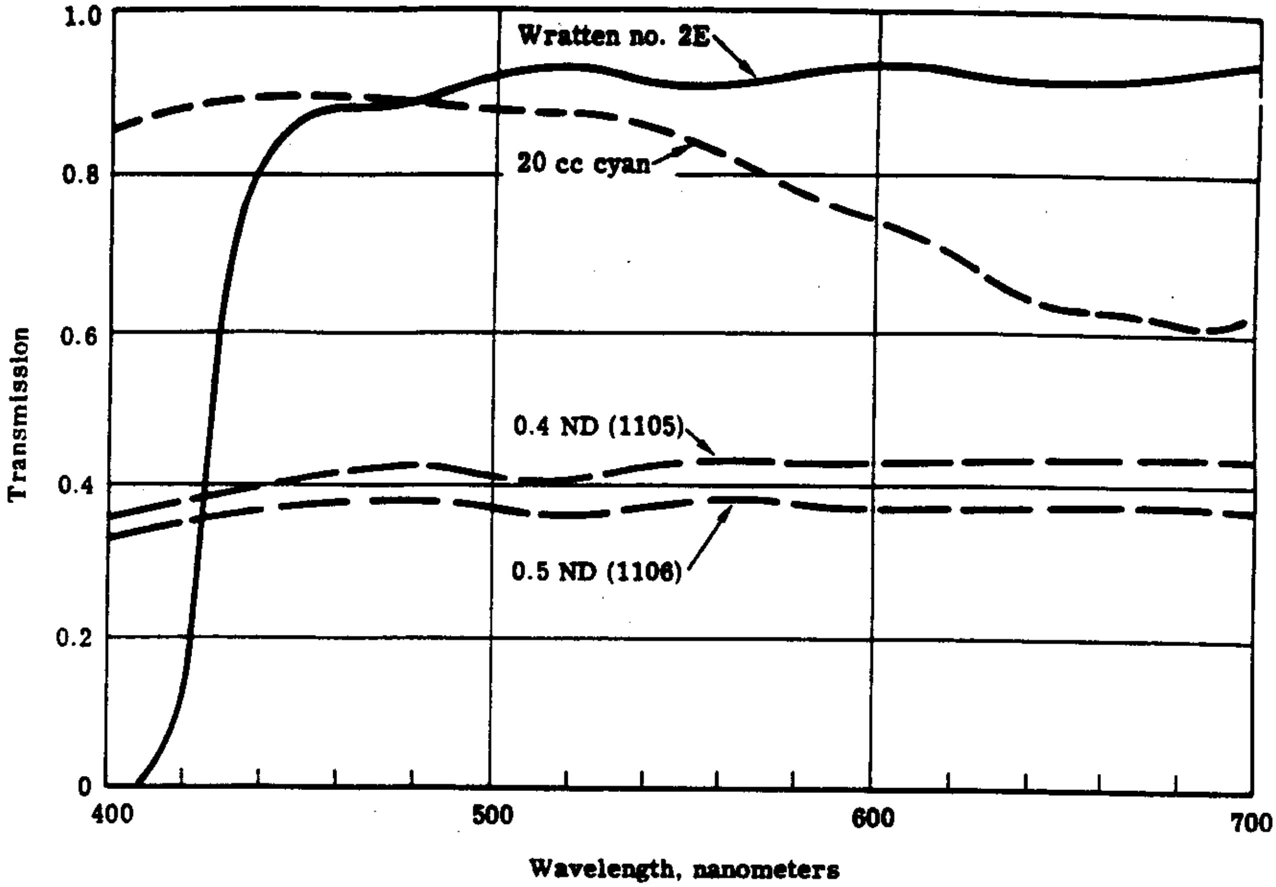

Fig. 4-1 — Spectral transmittance of the components of the filters used for SO-121 on missions 1105 and 1106

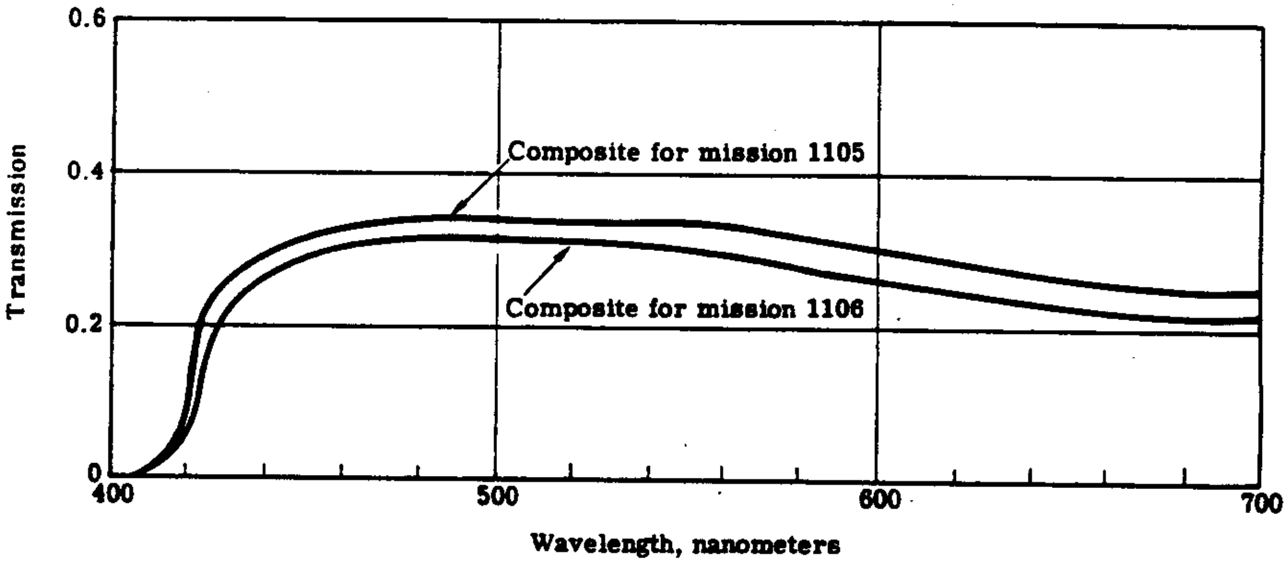

Fig. 4-2 — Spectral transmittance of the filters used for the SO-121 missions 1105 and 1106

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.

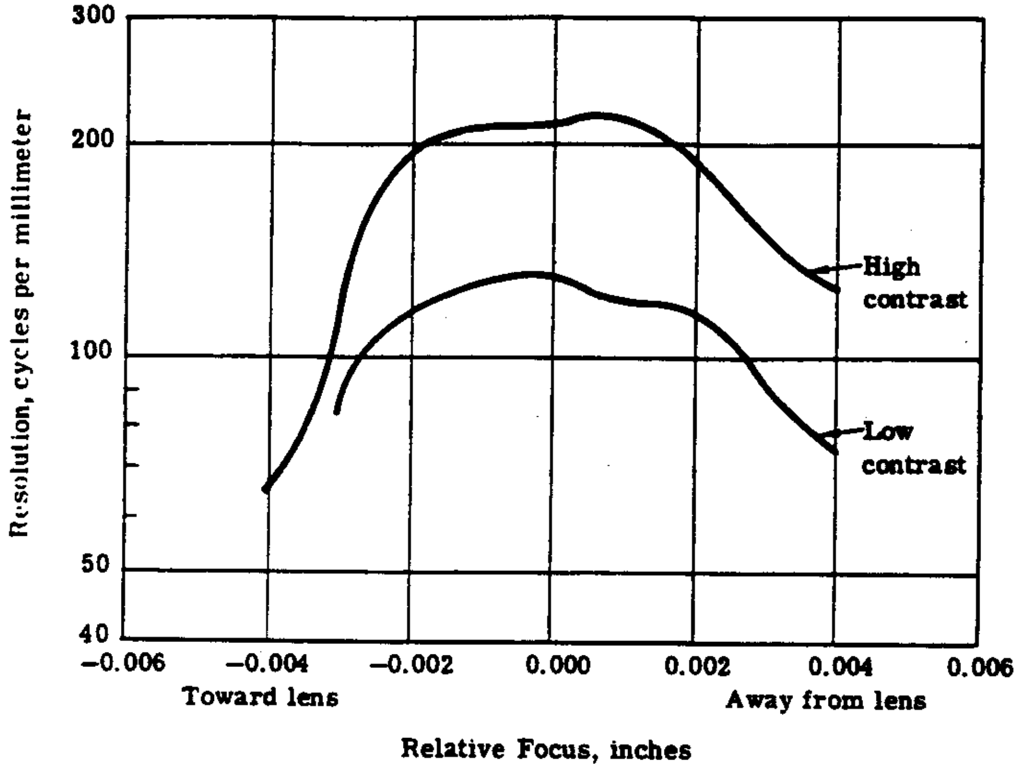

Fig. 4-3 — Through-focus resolution curves for SO-380 in unit no. 324

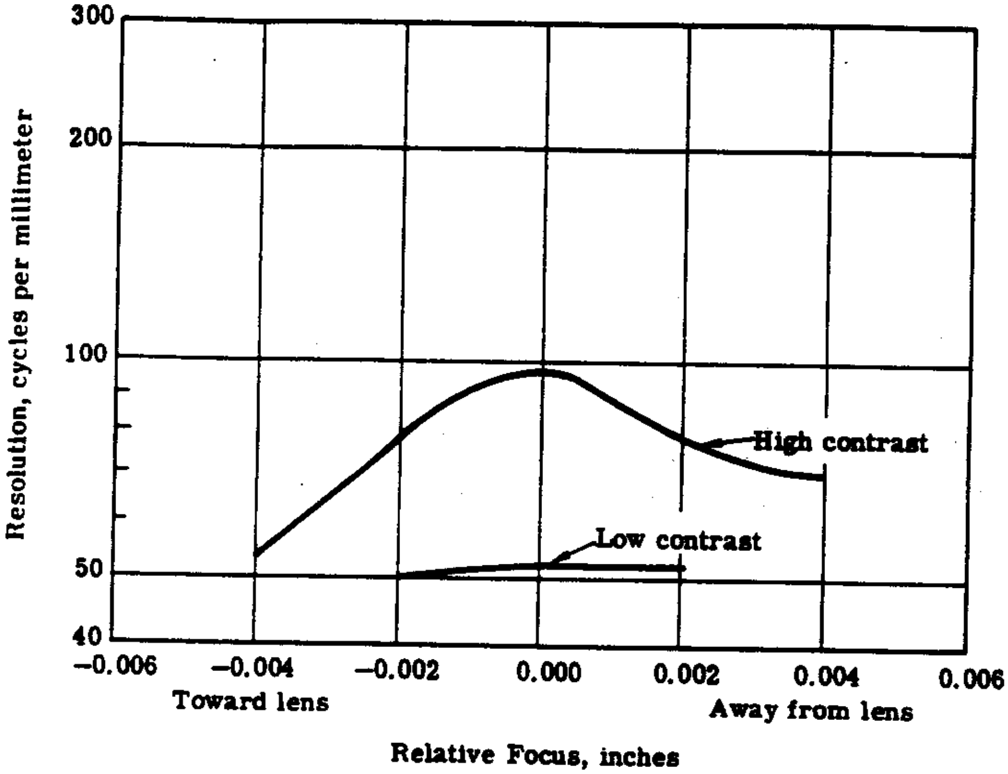

Fig. 4-4 — Through-focus resolution curves for SO-121 in unit no. 324, best exposure level

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]

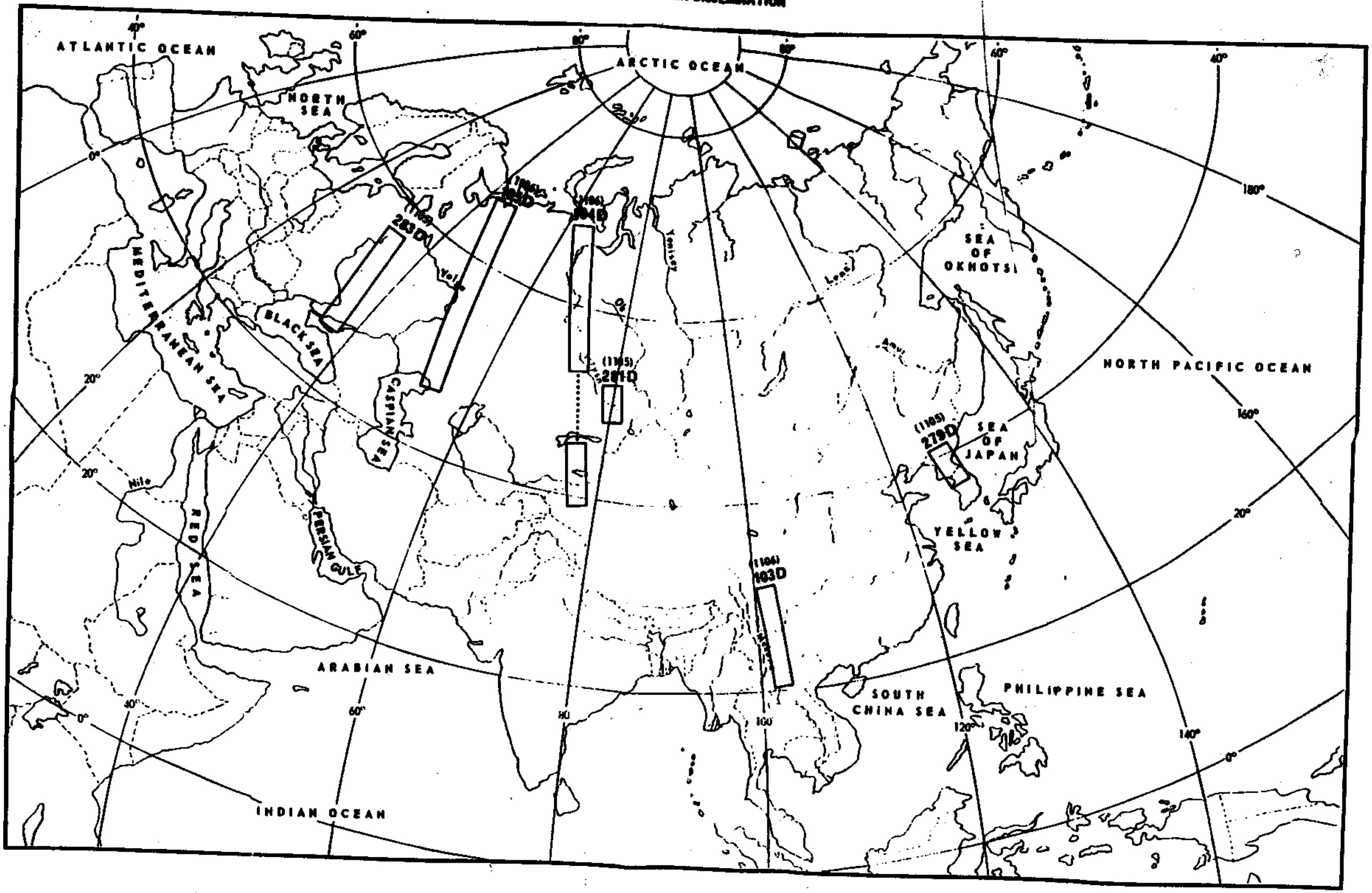

Fig. 4-6 — Ground tracks for the mission 1105 and 1106 passes over Eurasia

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

Residential areas, both wooded and clear, rate as fair compared to the 3404 record. This is primarily due to the smaller physical size of the structures in such areas and their lack of distinctive colors. As with any recorded object, the contrast between the structure and its background will influence detection capability, but details in these structures are minimal.

Industrial plants generally are poor to fair (rank 3 to 4) compared to 3404. Again, resolution is a strong determinant. Light industry usually ranks higher on the scale because the contrast is higher, the buildings more widely spaced, and the area is generally less cluttered, particularly in the United States. Heavy industry, as illustrated in Fig.5-1, ranks lower by virtue of having characteristics opposite those of the light industry just mentioned. The contrast is generally low, particularly if the complex is old, due to the weathering of paint and structural materials and deposition of airborne wastes on both the buildings and ground. Resolution of details is limited and seriously hinders interpretation.

Color, where it appears, can be a helpful adjunct to interpretation. Hue differences that may appear quite similar in a monochromatic record are often in striking contrast when rendered in their natural colors. The airborne waste products of many facilities have colors present that are signatures as to their origin. In Fig. 5-2, both of the above conditions are present and contribute to the overall interpretive value.

A comparison of Figs. 5-3 and 5-4 shows the importance of unique color signatures. This complex contains a petroleum storage area, a thermal-electric generating plant, and a magnesia extraction facility. To a trained observer, the interdependence of these items would probably be evident on the 3404 record. On the SO-121 record, however, the characteristic blue through white hues of the precipitators are arresting to the eye and are a definite signature of plant purpose.* Large items of characteristic shape may define a function without regard to fine resolution or characteristic color. The tank storage complexes in Figs. 5-3, 5-4, 5-5, and 5-6 are defined as such by their circular shape, size and clustering. This provides detection capability for both 3404 and SO-121, but further information is dependent on resolution, color, or the combination and/or integration of both. Generally, petroleum-oil storage areas rate fair (rank 4).

The road networks observed in the color coverage varied from poor (rank 3) to fair (rank 4) in mission 1106 and 1105, respectively. It appears that this feature is at a critical resolution balance for these missions, the size being such that the slight performance difference changes the category of relative interpretability.

Construction of new highways is readily detectable with SO-121 by the color differences between the base and the paved segments. Several instances were observed where the 3404 showed little or no distinction. Where a more urban culture has developed, the delineation of road patterns is considerably easier because of the alignment of trees, buildings, and other cultural items along the right of way. Snow cover accentuates the location of well used roads, but totally obscures the unused ones. Black and white and SO-121 are both capable of recording this condition. Ancillary items such as bridges show fair (rank 4) by comparison in the observed cases, and shadows cast on snow-covered rivers greatly aid structural interpretation.

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* Note that this is not a stereo pairing; records were taken during two different missions. 1104 and 1105, 3 months apart.

Color photography from these missions shows railroads by form, i.e., the geometric layout of the road bed. Details are essentially absent except where a large enough associated item such as a bridge occurs (Figs. 5-7 and 5-8). Terminals and yards generally rate as not interpretable (rank 1) or at the threshold of interpretability (rank 2) on SO-121. A few exceptions do occur with the larger yards rating as poor (rank 3) compared to the standard 3404.

At KH-4B photography scales, vehicle imagery is mostly a matter of simple detection, since details would be nonexistent under most conditions with either SO-121 or 3404. Motor vehicles are generally not interpretable (rank 1) with color. Railroad cars and engines, being somewhat larger, are either at the threshold of interpretability (rank 2) or poor (rank 3) (see Fig. 5-2). Steam engines have a signature in their plume of smoke and steam and are separable from other rolling stock in both color and black and white.

Civil airfields are easily detected on SO-121 by their size and configuration. The interpretability of the overall area rates as fair (rank 4) because much of the runway markings and edges are lost to graininess and lack of resolution. Facilities for aircraft servicing, passenger handling, and cargo transshipment are limited in information content by lack of resolved detail and are rated poor (rank 3); aircraft count varies from not interpretable (rank 1) to being at the threshold of interpretability (rank 2) depending on size. Recognition of aircraft is not possible and is ranked in category 1. Film 3404, however, permits at least a classification of planes by type and in many cases by model, depending on size.

Extraction industries showed no advantage by being recorded in color. Oil and gas fields were recognizable primarily by pattern and are equal (rank 6) in one case, but more generally fair (rank 4) in most cases compared to the standard.

For items falling in the category of culture, the relative interpretability ranking rarely exceeds fair (rank 4). Color seems to be a factor only in those areas where distinctive color signatures are found, i.e., mineral extraction and processing and construction. Certain areas appearing as low contrast in monochrome take on more separation in color, as witnessed in industrial areas. The lack of resolution limits the usefulness of color in the quite colorless cultural areas viewed.

Military items and installations can be considered essentially cultural in nature, but are designed and constructed for offensive or defensive military operations and are therefore considered as a separate topic. Airfields are rated the same as civil airfields; fair (rank 4) for the overall installation, poor (rank 3) for facilities, at the threshold of interpretability (rank 2) for aircraft count, and not interpretable (rank 1) for identification of aircraft. The B-52's in Fig. 5-12 are an exception, and identification of the image is based on the isolation of the aircraft, the type of facility, and corroboration by the 3404 record.

The few missile facilities viewed during the analysis included both defensive and offensive types. A fair rating (rank 4) can be applied to detection of the sites; but based on detail rendition, they rate only as poor (rank 3) compared to the standard 3404. The degree of information required for an intelligence analysis would determine which ranking is applicable.

Fixed radar facilities of medium size are at the threshold of interpretability (rank 2); therefore, mobile units would be undetectable.

Naval vessels are rather large items and for purposes of counting are classified fair to good (ranks 4 and 5). Since the type of vessel is determined by details as well as size, they are at the threshold of interpretability for this function (rank 2). In cases where civil and military ships have a similar use, such as tankers, transports, and service craft, no distinction as to their controlling authority is possible. Barges are readily identified because of their size, configuration, and lack of superstructure detail and were classified fair (rank 4).

The smallest items of military equipment located were armored vehicles though they fell at the threshold of interpretability for SO-121. Several factors aided their detection and should be noted for the sake of completeness. One is that their presence in a given area was indicated by other information sources (photographs and text in a popular magazine) and the fact that they were clustered and presented a detectable pattern.

The overall classification of military items recorded on SO-121 film is similar to those of cultural items covered above. Color is a minor signature at this scale and the resolution limit imposed by the film severely restricted its usefulness.

The general category of vegetation as used in this evaluation is distinct from cultivation though they both deal with growing plants. The reason for this distinction is primarily to separate the cultivation of crops from the indigenous ground cover occurring in any given area. Crop interpretation has its uses and will be covered in the following section.

Wooded cover can be of great use in military planning and activities of both offensive and defensive natures. The knowledge of extent, height, canopy and growth density are useful for planning or detecting concealed troops or material. Avenues and obstructions to cross-country movement can also be determined. In the KH-4B system, the 3404 film is used with red filtration. Unfortunately, as the filter shifts more to the red (Wratten no. 25 as compared with Wratten no. 21) the vegetation in the camera field of view becomes more and more dense and loses textural details. SO-121 is ideal for the detection, delineation and analysis of vegetation. By comparison with the standard 3404 panchromatic record, it is consistently better (rank 7) or superior (rank 8) (refer to Figs. 5-5 and 5-6). When employed in a stereo mode, the combination of monochromatic high resolution and a color record provides an excellent image for detailed analysis. There is a loss of color saturation with this technique; however, it can be controlled with the use of neutral density filters. This technique can also provide a lumination balance so that there are minimal eye dominance problems.

Cultivation of food, forage, and commercial crops is economically important to all nations. Those "have" nations blessed with the resources for industrial development are dependent to some extent on cultivated crops. Others, the "have not" nations, are almost completely dependent on their agricultural capability. The economic and military stature of a country is closely linked with the productivity of its soil. Color coverage of agricultrual areas provides an indication of the state of growth and types of crops. This information is limited in black and white photography to a degree. Both color and black and white provide a complete record of the extent of land use.

The SO-121 has the additional color descriptors of hue and saturation, and the capability of distinguishing growing fields from fallow ground is apparent. A number of areas having like densities on 3404 are defined in their true nature on SO-121 by color differences: refer to Figs. 5-3, 5-4, 5-9, and 5-10, 5-11, and 5-12. Extent of crops was rated from equal to 3404 (rank 6) to superior (rank 8). Crop type determination showed as better (rank 7) and superior (rank 8) when compared to black and white.

Details of cultivation techniques, such as plowing alignment, are usually minute and near the resolution limit of SO-121. These details ranked from poor (rank 3) to the threshold of interpretability (rank 2). Subtle differences in soils or crops are well detected in cultivated areas.

The characteristic differences in soils and plants that occur with changes in season or environment recorded on SO-121 are better (rank 7) or superior (rank 8) to those recorded on 3404.

The superiority of color film in monitoring crops is notable in those categories not dependent on resolution capability. Generally, it is the preferable medium for acquiring intelligence on cultivation. Again, used in stereo with high resolution 3404, the combination is superior to either record alone or in stereo.

Color photography with SO-121 expands the information content by allowing more complete interpretation on the basis of hue. There is no disputing the superiority of the standard 3404 film in defining the details of the geology and morphology of a region. Relief distinctions with SO-121 are rated from poor (rank 3) to equal (rank 6) in comparison to 3404. There is a dependence here on the contrast of the area and the amount of relief present. The greater the contrast the better the images will appear photographically, and the greater the relief the more pronounced will be the stereopsis. Distinction of geological features is accentuated by color and is rated as superior to the black and white standard. Stratification is accentuated to a degree rated as better (rank 7) than 3404 and the color differences in various layers is apparent provided it is within the resolution capability of the film. Soil classification in monochromatic coverage is based on the photographic density, texture, location in proximity to other features, and keyed to ground observation made on the site. In denied areas, ground observations are obviously not permitted and if past records are not available, the interpretation must be deductive.

The color dimensions remove much of the uncertainty from soil evaluation. Various colors are indicative of distinct mineral constituents and misinterpretation caused by vegetative cover is virtually eliminated. The use of a haze cutting filter in panchromatic coverage reduces many tonal differences in rock and soils that would be useful. This is not the case with color and much of the contrast present is by virtue of color differences in the areas of interest. In the samples of parent/soil and soil responses observed, the rating is exceptional (rank 9) compared to the 3404 black and white (refer Figs. 5-9 through 5-14).

Areas of hydrologic activity are limited mainly to those areas adjacent to or surrounded by land masses. The subject encompasses water courses as well as open bodies of water. It was noted in evaluating the coverage of rev D-274 over California and rev D-279 over Korea that disparate ratings were emerging. These two areas are good illustrations of how interpretation rankings can vary as a result of the environment of the subject matter, the point being that in some cases target/background context is more important psychologically than isolated target ratings.

The Korean area is one of subdued color contrast, the streams and surrounding ground having differences but of a very monochromatic nature. The Bay of Korea is quite shallow and at the time of the photography it was almost impossible to show the demarcation lines between water, mud and shoreline. Sediments are quite similar to the solid land in color and the bottom gradient produces a very gradual change in color as a function of depth. The ranking of the various features were all below 3404 in quality. Shorelines and water courses rated poor (rank 3) to fair (rank 4), subsurface indicators were at the threshold of interpretability (rank 2) with some instances of equality with 3404 (rank 6). Obstructions were either poor (rank 3) or at the threshold of interpretability (rank 2), depending on their size or composition in relation to the shore or bottom as noted above.

The California coast, on the other hand, exhibited quite the opposite conditions. The area is colorful, in good contrast, and has a very steep subsurface gradient (refer to Figs. 5-3 through 5-6). Water courses are superior (rank 8), especially when delineation through vegetation growth was sought. Shorelines are equal (rank 6) to 3404 and in some observations better (rank 7). The color differences encountered in sand and water allow for a more positive determination of the shoreline position. The categories of obstruction detection, currents, depth determination, and ecological indications are all rated superior (rank 8) for the SO-121 coverage as compared to the 3404 panchromatic standard.

Much of the superiority of SO-121 for hydrologic interpretation is attributable to the filtration and sensitivities of the films used. Film 3404 with the Wratten no. 25 filter is recording information from 600 to 720 nanometers into the red while rejecting information in the green and blue regions. Penetration of water is best accomplished in the vicinity of 500 to 550 nanometers, and the SO-121 possesses considerable sensitivity in this band. It is little wonder that the ratings should be so biased. Most of the items mentioned above fall within the resolution capability of the test film. Definitive items such as high tide flotsam lines and wharf configurations are better shown on the high resolution standard film 3404, but in the main, SO-121 appears to be superior.

Atmospheric considerations in the interpretability ranking of SO-121 are very consistent. In all cases, the clouds, haze, and atmospheric pollutants rated equal to rank 6 or better than rank 7. Clouds showed a tendency to separate from the background better with color in a few instances, but the most noticeable difference appeared in the characteristic color of smoke plumes. Film 3404 could indicate a density difference but SO-121 defined the differences in color descriptors allowing for a more accurate interpretation (refer to Figs. 5-1 and 5-2).

5.4 SUMMATION

Comparison of SO-121 and 3404 in these tests provides an index to the usefulness of color as an intelligence gathering medium. The results show that for fine detail 3404 has a decided advantage. Military and cultural items are quite monochromatic and depend on resolution for maximum exploitation. Should there be a color film made available with comparable resolving power, the balance would shift heavily in favor of color because of its added dimensions. Color signatures aiding interpretation of cultural, industrial, and military analysis need not be well defined. The presence of distinctive hues in supply, product, or waste depots is often adequate to answer a specific requirement.

Large objects are well presented on SO-121. The categories of land forms, cultivation, vegetation, hydrology, and atmosphere are at the least equal to 3404 in information content and far more informative in most instances. On the other hand, items of detailed configuration are better presented on 3404. The categories of transportation, culture, and military are superior in most instances on 3404. Comparisons between these different target categories as quantified by the psychometric working technique utilized in this evaluation are presented in summary form in Fig. 5-15.

When color content has been reduced by the character of the target area, atmospheric interference, or ground cover by snow, the usefulness of SO-121 is greatly reduced. Low monochromatic contrast is enhanced more by 3404, and the monochromatism of snow-covered areas negates the hue distinction advantage of color.

Stereoscopic observation with color and black and white records is a useful tool which integrates the color and resolution capabilities. Image dominance may be controlled by appropriate insertion of neutral density filters in either optical path.

Regardless of the technique used for extracting useful intelligence, color has decided advantages when judiciously utilized within the range of its capabilities. Specifically, the color films of today's resolution level should be used as a supplement to high resolution black and white photography where color information is needed. However, with high resolution color films of the future, the conclusion is not so clear. In this case, it may be useful to replace black and white film altogether.

Evaluation of the color segments of missions 1105-2 and 1106-2 has supplied a measure of the usefulness of the KH-4B camera system utilizing SO-121 as the film load. The conclusions arrived at are applicable in the whole only to this combination. Changes in any of the parameters would lead to differences in the information content. This could be in either direction, ideally an increase, but possibly a decrease.

[redacted]

Fig. 5-1 — 10× enlargement of urban-industrial area, USSR; 3404 film, mission 1105-2, rev D-283, 065 FWD

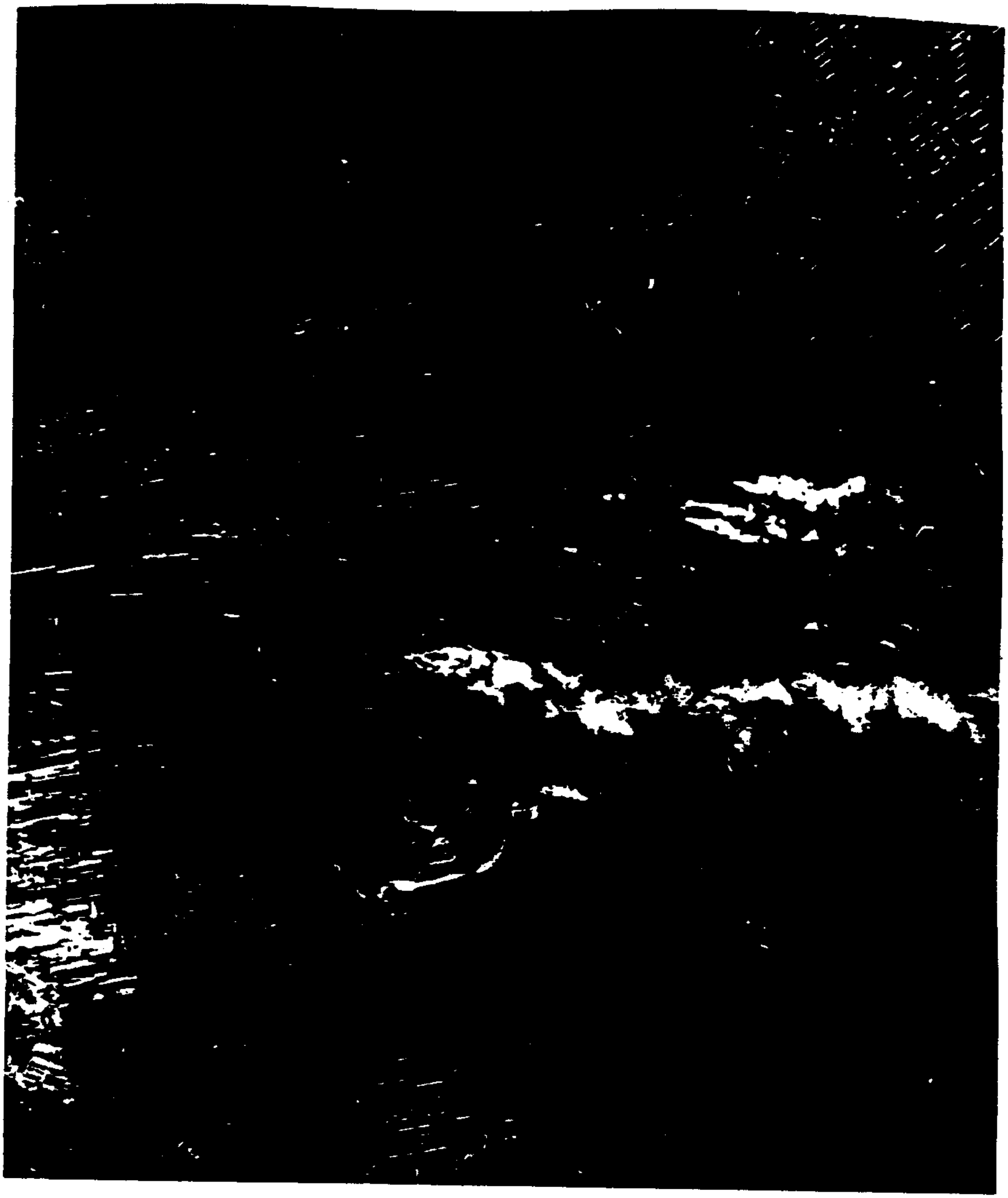


Fig. 5-2 — 10× enlargement of urban-industrial area, USSR; SO-121 film, mission 1105-2, rev D-283, 071 AFT

 [redacted]

Fig. 5-3 — 10× enlargement of magnesia and thermal-electric facilities adjacent to coast; 3404 film, mission 1104-2, rev D-210, 001 AFT

[redacted]

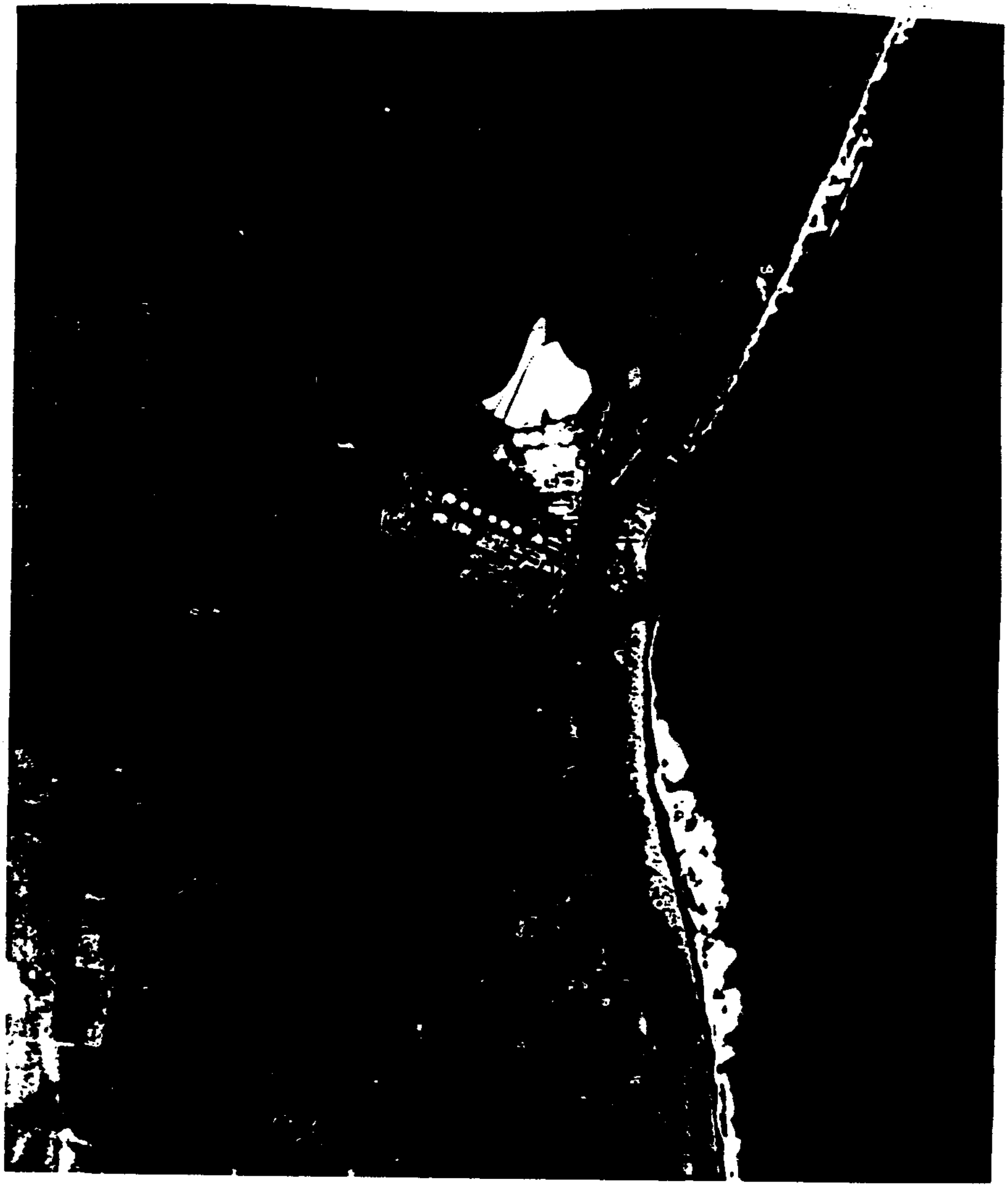


Fig. 5-4 — 10× enlargement of magnesia and thermal-electric facility adjacent to coast; SO-121 film, mission 1105-2, rev D-274, 003 AFT

[redacted]

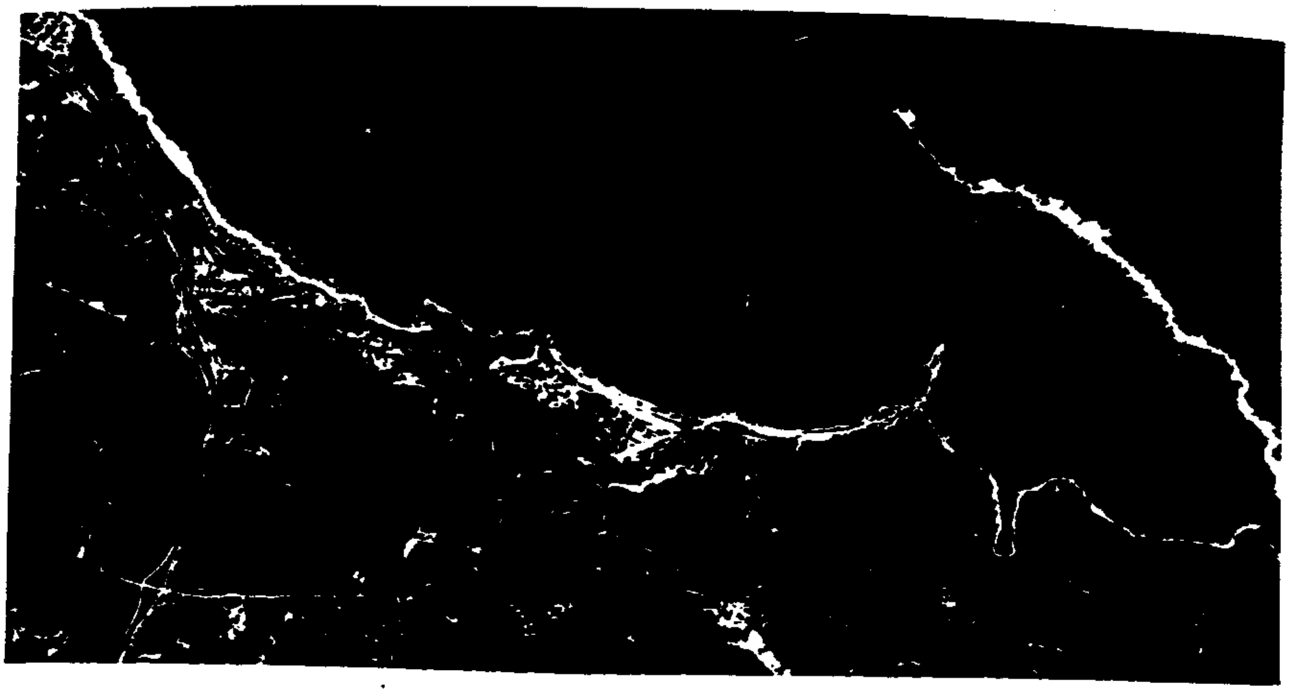


Fig. 5-5 — 5× enlargement of coastline with offshore features, an urban area, POL storage, and natural ground cover; 3404 film, mission 1105-2, rev D-274, 011 FWD

Fig. 5-6 — 5× enlargement of coastline with offshore features, an urban area, POL storage, and natural ground cover; SO-121 film, mission 1105-2, rev D-274, 017 AFT

TOP SECRET [redacted]

NO FOREIGN DISSEMINATION

Fig. 5-7 — 10× enlargement of urban-industrial area with snow cover, forests, and transportation facilities; 3404 film, mission 1106-2, rev D-105, 084 FWD

TOP SECRET

NO FOREIGN DISSEMINATION

HANDLE VIA
TALENT-KEYHOLE
CONTROL SYSTEM ONLY

Fig. 5-8 — 10× enlargement of urban-industrial area with snow cover, forests, and transportation facilities; SO-121 film, mission 1106-2, rev D-105, 090 AFT

Fig. 5-9 — 5× enlargement of urban area with extensive cultivation; 3404 film, mission 1105-2, rev D-273, 032 FWD

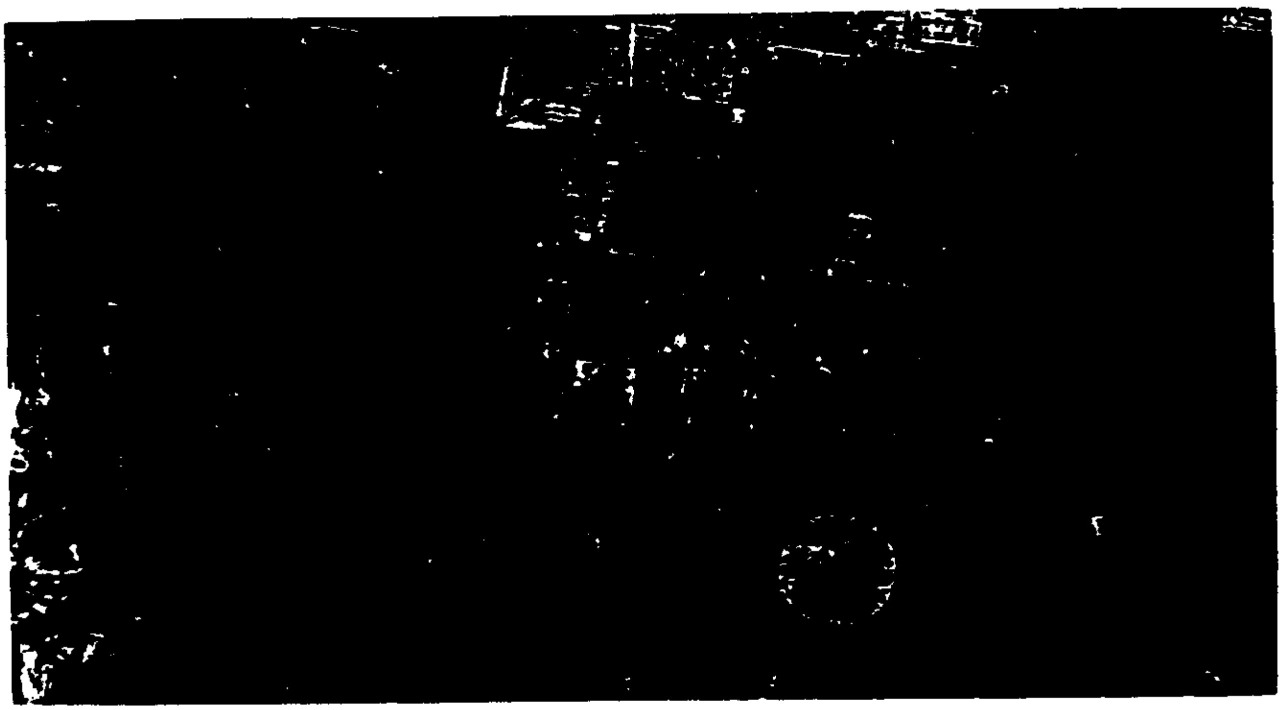


Fig. 5-10 — 5× enlargement of urban area with extensive cultivation; SO-121 film, mission 1105-2, rev D-273, 038 AFT

[redacted]

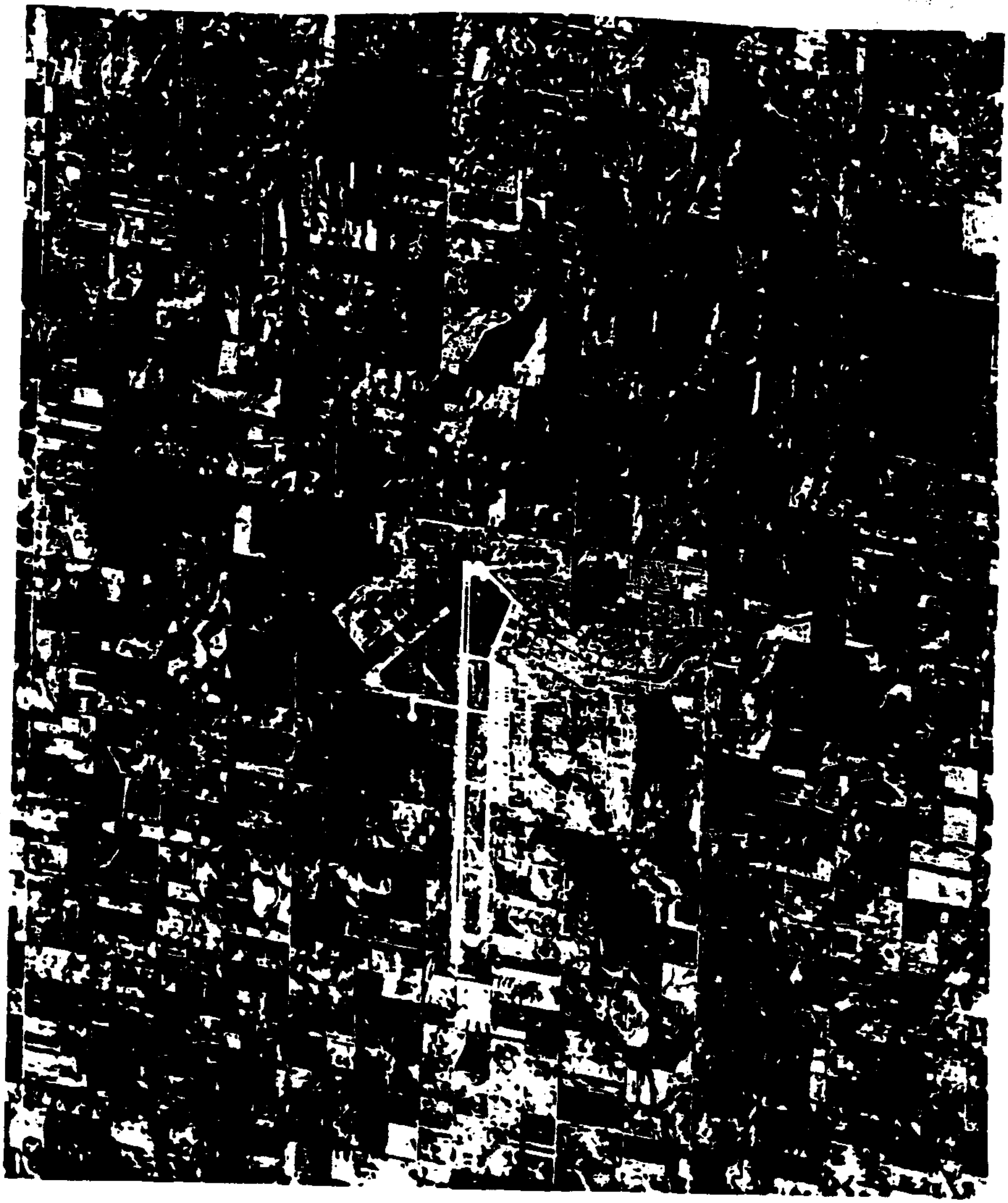


Fig. 5-11 — 10× enlargement of Clinton Sherman AFB, Oklahoma, and extensively cultivated surrounding area; 3404 film, mission 1105-2, rev D-273, 056 FWD

 [redacted]

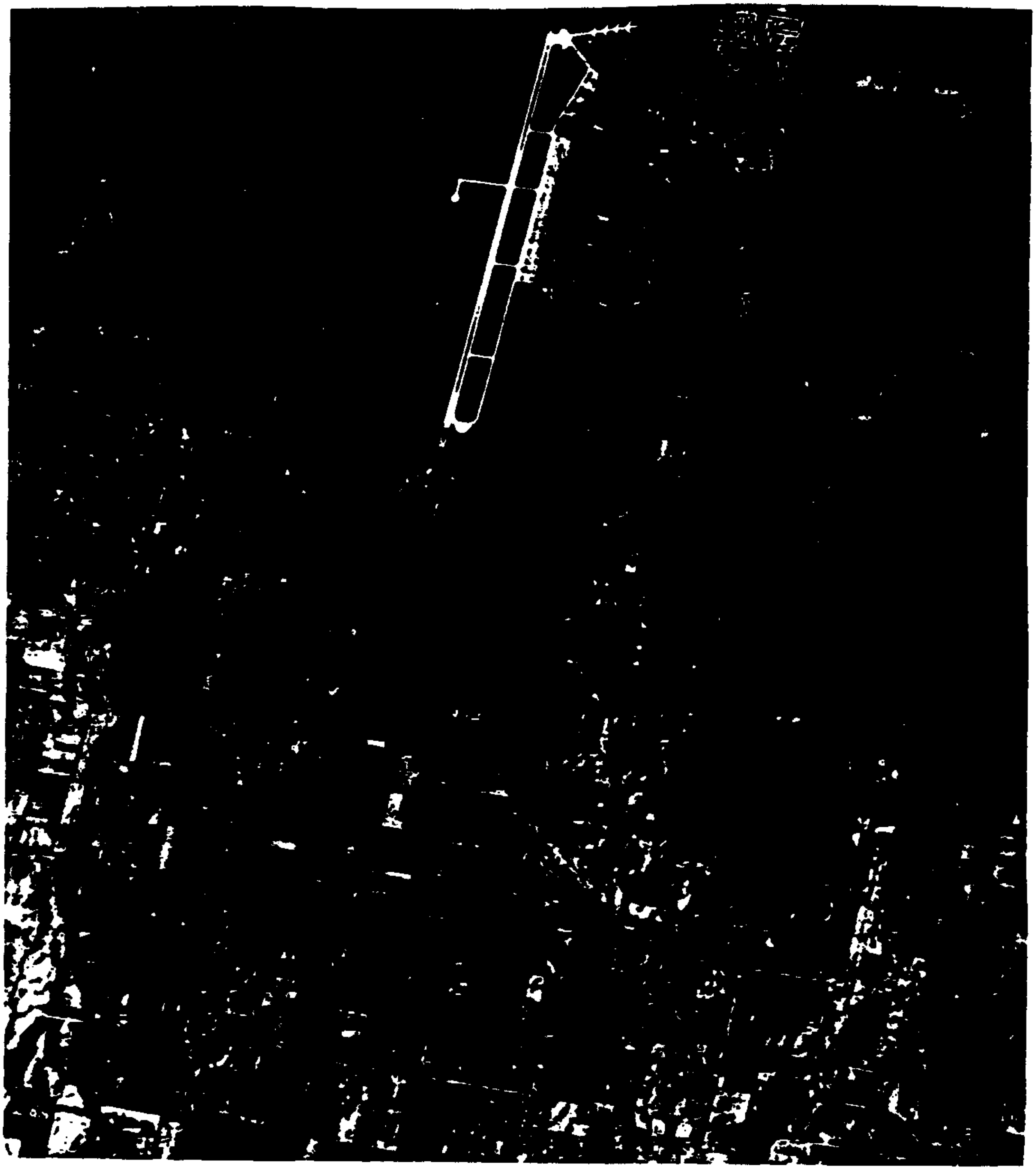
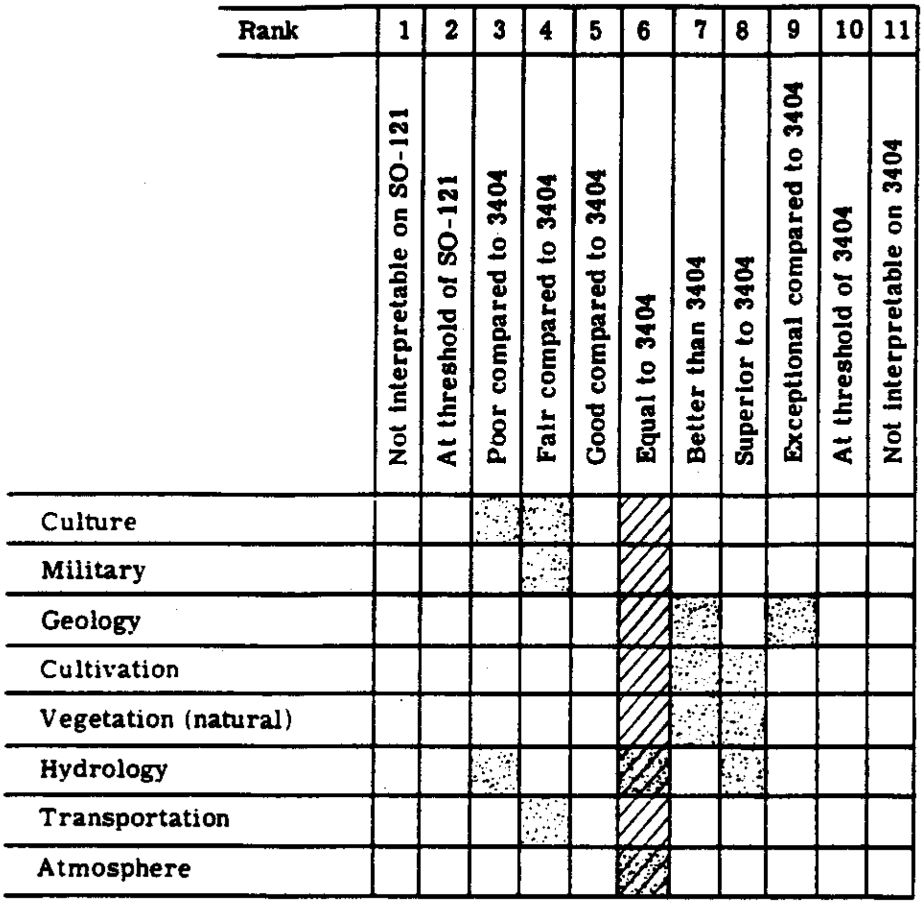


Fig. 5-12 — 10× enlargement of Clinton Sherman AFB, Oklahoma, and extensively cultivated surrounding area; SO-121 film, mission 1105-2, rev D-273, 063 AFT

[redacted]

Fig. 5-13 — 10× enlargement of the Kun Yang Hai Lake region of Southeast China showing cultivation and mineral coloration; 3404 film, mission 1106-2, rev D-103, 175 FWD

Fig. 5-14 — 10× enlargement of the Kun Yang Hai Lake region of Southeast China showing cultivation and mineral coloration; SO-121 film, mission 1106-2, rev D-103, 181 AFT



Note: This figure is intended solely as a rapid assessment presentation: specific targets or features within each subject category may vary from the ranking shown. Hydrologic features. for instance. are shown ranking 3. 6. and 8. Reference is made. therefore. to the text for definitive information regarding any item.

Fig. 5-15 — Graphic presentation of the general results of the subjective relative interpretability ranking

6. SUMMARY OF SATELLITE COLOR TECHNIQUES

There are basically three techniques for obtaining color photography in satellite systems:

1. Conventional color films
2. False color films
3. Multispectral techniques.

To date, all three techniques have been tested and in some cases employed against specific color-oriented problems.

Conventional color films, such as SO-121, provide a color image that is very similar to the original ground scene. These materials attempt to reproduce colors as we see them through the use of three separate emulsions coated on one base. For high altitude photography, where there is prevailing blue hazelight, these films must be used with a light yellow filter in order to reduce the effect of haze and provide a reasonable approximation of the ground scene. SO-121 is a medium speed color reversal film coated on an Estar Standard thin base. In addition to the KH-4B missions 1105 and 1106, SO-121 has been used in recent years in many low to intermediate altitude systems as well as in four [redacted] flights and one recent [redacted] flight, mission [redacted]

Although SO-121 is among the highest resolution color films available today, it is decidedly poorer in resolution than 3404. The best ground resolution that could be expected from SO-121, in the KH-4B system, is approximately 15 feet, while an average of 20 to 25 feet would be normal.

The second technique for obtaining color photography, false color films, also involves a multi-layer coated film on a single base. Infrared Aero Ektachrome, SO-180, is representative of these materials. Unlike SO-121, it has a unique spectral sensitivity that enables the material to record in the near infrared region of the spectrum. The film has green, red, and near infrared sensitive layers. The sensitivity of the film has been designed so that the infrared layer records as red, the red records as green, and the green records as blue, thus providing a "false" color image.

To date, SO-180 has been flown in only one satellite flight, the KH-4B mission 1104, in August 1968.*

The third category, multispectral (or bi-color in the case of two records) does not employ a single film. With reversal color film, the final image is obtained on the same material as used in the camera, and the reversal is accomplished in the processing stage. Color photography can also be achieved by photographing the same scene with three individual black and white emulsions, each altered with the appropriate filtration to record the blue, green, and red components of the spectrum. With this type of color photography, the reconstitution of the image is accomplished in

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* KH-4B System Capability Report No. 6, Evaluation of SO-180 Film for Use With the KH-4B System, [redacted] 4 Aug 1969).

the laboratory where the three black and white records are superimposed and exposed through the appropriate filters. This process is called tri-color additive photography.

Traditional color theory dictates that it is necessary to use three primary colors—red, green, and blue—to produce a print with a full range of colors. It is possible, however, to obtain a pseudo color print using only two records: green and red. This type of photography is called bi-color (or bi-spectral) since the color record is formed by superimposing only two records. Although it is impossible to obtain a full range of colors with the bi-color technique, theoretical tone reproduction studies have shown that the range of colors that can be achieved is large enough to produce a reasonable approximation of normal color photography when consideration is given to the degrading effects that the atmosphere has on conventional reversal color films. The KH-4B camera system has the capability to acquire bi-color photography by using the normal red filter in the FWD-looking camera and an alternate green filter in the AFT-looking camera.

It has been used in a test on mission 1102* and on missions 1103 and 1104 in an effort to satisfy color-oriented problems.

Properly assessing the value of a particular approach to color acquisition requires that it be considered in the context of the color problems as a whole. For example, there is no doubt that the bi-color approach is particularly attractive with the mechanics of current satellite acquisition. However, synthesis and exploitation of the resulting color photography is difficult to accomplish. This is particularly true for convergence stereo panoramic systems. Some applications require information on the degree of color shading, for which the bi-color approach is suited. Some applications require more precise quantitative information in at least three bands, for which bi-color is not suited at all. Concerning conventional tri-pack emulsions now available (e.g., Ektachrome), their resolution limits their utility in very small scale photography. While a very large field or settling pond may be represented properly in terms of its color, it is not possible to distinguish color bands on aircraft or the color of a missile warhead at the scales encountered in KH-4B. The kinds of problems which are solvable with this material do not necessarily require high resolution either in the sense of cycles per millimeter or color "resolution."

The choice of a color technique must be based on the specific color problem that is to be solved. It must consider the scale of the photography, the types of information required, the time allowed for exploitation, as well as the engineering aspects discussed in Section 6.2.

6.1 FUTURE USES OF COLOR PHOTOGRAPHIC TECHNIQUES

The various tests conducted during this test series have demonstrated that the use of color for intelligence purposes is feasible, and, in fact, encouraging. Evaluation of natural, false, and bi-color techniques have given an indication as to the scope and wealth of information that can be collected by one or more of these methods.

Monochromatic recording of optical imagery is the currently predominant method in reconnaissance. Stereo capability compounds the information extraction capability by adding a third dimensional axis to the format. Color adds the two more dimensions, hue and saturation, to expand capability even more.

It has been demonstrated that in the cases where color films have been used, overall usefulness is limited primarily by lack of high resolution capability. Cultural and military subjects

*KH-4B System Capability Report No. 3, CR-2 Bi-Color Experiment, [redacted] (27 Sept 1968).

are relatively small when compared to hydrologic, geologic, cultivated, or natural vegetative cover. Consequently, they are not as well depicted at small scales. Image size and the resolution capability of the optics are critical factors in determining the image content of a color exposure. If a film has the capability to resolve all the detail imaged by a lens, then color film is the obvious choice. On the other hand, it would be a waste of system capability to utilize color if the emulsion did not provide the resolution necessary to find the target area.

Expansion of programs utilizing color photography appear to be one of the next logical steps in aerospace reconnaissance. The feasibility of using color as a supplement or replacement for panchromatic records in the fields of cartography, forestry, agriculture, and hydrography is being demonstrated by Government agencies in unclassified work. The relationship of the color stereo model to the real world experience results in a more rapid and accurate identification of features. As experience is gained, more ambitious projects will be undertaken, and the equipment limitations will be overcome by manufacturers. One need only notice the increasing emphasis being placed on color techniques at the various conventions and expositions to realize that in these fields there is recognition of both the vast potential of the medium as well as the obstacles. Instrumentation shortcomings are being overcome and human factors are being oriented for maximum utilization.

The promise of higher resolution color films that will more nearly match system capabilities is tantalizing. An increase of just a few percent would greatly extend color capabilities into those areas now considered the exclusive domain of special panchromatic films. Transportation networks, urban and military complexes, and airfields would be the first to benefit, then progressively smaller targets would come into useful service.

High fidelity color is not an absolute necessity at the scales currently being used. What is important is hue separation and a somewhat realistic representation of those colors present in the original scene.

Of the three color systems used, SO-121 represents the true color technique, that is, the colors present in the film record are well related to those of the original scene. Small items of a cultural or military nature are not as well recorded on SO-121 as on 3404. But when the information is above a resolution limit, the use of color is decidedly superior. The gross features of the world, both natural and man made, are very well presented in color. Geology benefits by the inclusion of rock and soil color clues. The synoptic view of large earth structural features will permit a more comprehensive outlook on earth resource utilization. The clues to mineral deposits are more apparent when the colors of the rock and outwash are apparent. Photogeology is already a well established discipline, but to date most of the work is done with black and white coverage and on a rather limited scale. The excitement among earth scientists caused by the release of manned spacecraft photographs of various parts of the earth indicates the importance of color coverage. Intensive and efficient utilization of the planet's natural resources will be necessary if the current rate of use continues. Techniques for exploitation must include color photography. Fresh water resources are usually spread over vast areas in the form of watersheds. The dependence of agriculture and urban life on the available supply of water elevates this subject to one of great concern. Most of the features of the surface phase of hydrologic activity show well in color. The snow fields and glaciers at the source, the tributary and main streams, and areas of impoundment, i.e., lakes and reservoirs, are all recorded with outstanding detail. The capability to monitor the quantity and quality of the water is present on a grand scale. Political or economic units sharing water rights would have an inventory of resources and usage that could be used for planning or policing in event of agreement violations. The various pollutants discharged into a water course could be located, and in cases where distinctive color signatures are present, they might be identified. Additionally, true color would allow determination of silt conditions.

Hydrologic interpretation of tidal waters and open seas, particularly along coastlines, have great potential. Again reference is made to manned space vehicle photographs showing any number of phenomena. The sensitivity of SO-121 permits water penetration that shows bottom detail to a useful degree in many areas. Silting is evident in harbors, the discharge patterns of distributaries are shown, and the direction and extent of littoral currents can be determined. The uses are manifold and color has shown a capability to record many items worthy of investigation and monitoring.

Mining activities are large scale operations and both the extraction and refining processes have characteristic colors. Determination of the nature of the process being performed in a plant can be determined by color in the absence of other signatures. Obvious signatures are seen at copper, magnesium, and steel plants, but some of the more subtle modern techniques require additional information. Color has shown the capability to provide supplementary data, and with experience and refinements should develop into a very useful tool for the analyst.

Both cultivated plants and those in their natural state are reproduced well. Forests are typically dark with panchromatic photography acquired with red filters. Color, however, shows distinctions by hue separation that are nonexistent monochromatically. Fields show in the true color of the crops planted, and changes with maturation or disease are readily evident. Inventory of quantities may be performed at any time in the growth cycle with a rapidity not possible by conventional methods.

False color film produces a set of signatures quite different from those of SO-121. Since the blue light is filtered out before reaching the film and the near infrared radiation is recorded, the response to a given stimulus will be quite unique. Obviously a new frame of reference must be established to allow interpretation.

Color translation as experienced with SO-180 can be an asset in urban or military analysis. Encroachment of built up areas into undeveloped regions is readily apparent in both panchromatic or color coverage. However, the chlorophyl response in false color indicates how much of a given area is structurally occupied and how much has vegetation. Discrimination thus accentuated provides a reference that may be used for building analysis, determination of economic status, nonresidential use, and prediction of returns for other sensors (i.e., radar, infrared).

Geologically, the real color hue of beds and deposits is lost, but the extended long wavelength sensitivity may provide signatures unobtainable with other bands. The hue contrast present is quite often adequate to provide information not found in black and white. An investigation or study of the signatures found in SO-180 geological records might be compiled for use alone or in conjunction with true color or panchromatic films.

There is an ambiguity in the use of SO-180 for hydrological interpretation. Blue light, which has the deepest penetration in water, is absent and the infrared is absorbed near the surface. This leaves only the green sensitivity and this is translated. In spite of all these omissions, absorptions, and translations, SO-180 is excellent for tracing drainage patterns because of the recording of the vegetation along water courses stimulated by the presence of moisture. Subsurface or intermittent streams are detectable and the demarkation of water and plant is distinctively blue against red. Algae, silt, and some pollutants are readily detected, but mostly in the surface layer of the water. SO-180 has the capability for hydrological intelligence. For this reason, an effort should be made to investigate and maximize information extraction with this material.

The development of false color infrared films was originally intended for the detection of vegetation differences. These films exhibit a superiority over black and white in the separation of plant types and the extent of propagation that is quite unique but of the same quality as SO-121. A combination of both color types would provide voluminous data in this category.

Bi-color techniques have had operational success in unique target detection, so practicality has been demonstrated. As has been explained previously, the color gamut is limited by the number of records. For targets having particular spectral responses, bi-color can fill a need. Problems regarding handling and exploitation must be overcome before widespread use can be a reality. The high resolution of the panchromatic records used to generate the integrated print also satisfies the requirements of the intelligence community.

Areas and facilities active in mineral extraction and refinement are targets to which bi-color is applicable. Hue differences in slurry ponds, stock piles, and effluent outlets are distinguishable. In order to utilize the information content, though, a method of calibration must be initiated to allow for specific data extraction. The color integration should be a controlled process rather than the empirical technique now used. If colors other than the red and green now used in printing or viewing are required to provide image contrast, there should be capability for a change without a loss of information.

In summary, color films have more capability for recording information than panchromatic films because of their hue and saturation sensitivity. This is an expansion over the density recording capability of black and white that is analogous to adding two more dimensions. To the observer, the image bears more of a relationship to the real world than any other method. The film used must match camera capabilities in resolution and color correction or the results will be disappointing. True color, false color, and bi-color techniques have indicated that the potential for reconnaissance in the earth, biological, and cultural sciences is huge even with current limitations. Each technique has its merits and limitations, but a judicious use of each technique will yield the best results for specific problems.

The foremost requirement for future color films is for an increase in resolution capability to equal or approach that of the panchromatic emulsions now in use. This would expand interpretation and general utilization of mission photography many-fold and would increase both information extraction and reliability.

To further expand the usefulness of color, more rapid processing and duplication techniques must be developed to make the data of more immediate importance. This is particularly true in tactical or rapid response situations.

Acquisition systems should be modified or designed to match the requirements of color photography.

Handling equipment, particularly for bi-color, must be developed beyond the laboratory or special purpose stage into operational status before general use becomes practical.

Target signatures should be acquired, catalogued, and made available for mission planners and intelligence analysts. Optimum use of the medium is dependent on how well the target can be identified.

Mission planning, ideally, should utilize all possible sources of ancillary intelligence in determining which film(s) would be best for the particular job.

Controls in the form of standard premission targets should be included with each film unit to show the analyst what anomalies, if any, are present and might bias his judgment.

6.2 REQUIREMENTS FOR FUTURE COLOR FLIGHTS

As discussed in Section 6.1, there are merits in the KH-4B System to each of the three color techniques available. Questions of a color-oriented nature for some types of targets can be answered with more than one technique, thereby providing more operation flexibility. Some questions, though, can be answered only with one of the techniques. Whatever the options are, there are numerous preparatory steps that must be taken in order to continue to acquire color photography from KH-4B.

The major unresolved question concerning the use of SO-121 in KH-4B is reason for the film curl on mission 1105. The fact that the film remained flat on the subsequent flight did not provide a solution to the problem. As discussed in Section 4.3, there are two possible causes for the film flatness problem: reduced tensions or excessive evaporation of the volatile material in the color film emulsion. Although the probability is high that raising the tensions has corrected the problem, the risk is too great not to make a test before the next flight. Recent modification to the HIVOS* chamber enables simulator flights to be made with a Dr. A test.†

The SO-121 flights that have been performed to date with KH-4B have employed a special composite gelatin filter with an inconel overcoat. These filters have been approximately the same thickness as the primary filters employed on these missions, 0.004 inch. A coating is required that is large enough such that a few selected small areas are uniform enough for flight. Although a satisfactory area can generally be located, on one ocassion there were no satisfactory areas and an alternate filter had to be used. From an operations point of view, though, it does not matter how difficult these filters are to fabricate; they can be made providing that there is sufficient time for the manufacturing. Unfortunately the decisions to fly color materials have been made at such a late date that filter fabrication has been time limited. The obvious solution to this problem for future flights has already been implemented by Eastman Kodak. They have fabricated a whole family of filters from which to choose for the next SO-121 flight.

Therefore, there are minimal filter problems with SO-121 flights, until CR-14. At this point a design change will be implemented that allows flight with 0.040-inch glass filters.

An effort was undertaken to replace the gelatin Wratten filters with glass filters in the KH-4B System. Wratten filters are approximately 0.004-inch thick. The work started with obtaining 0.005-inch fused quartz to maintain nearly the same focal position. However, the glass was so fragile that it was not possible to polish the surface to a quality level any better than the Wratten gelatin filters. In addition, the breakage rate was exorbitant. Therefore, thicker glass filters

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*High vacuum orbital simulator.

†One of the difficulties that remains with this capability, though, is that the Dr. A lamps must be burned at a high voltage in order to expose 3404. This burns them out quickly. In order to avoid this problem and enable the bulbs to last through the entire simulation, the Dr. A samples are normally only taken twice a day. This problem will be substantially reduced with the higher speed SO-121 and will allow more complete sampling through the mission simulation to determine if indeed the same condition does exist.

were employed (0.040 inch) and an appropriate adjustment in focus was made. The system so set are:

CR-14 QR-2
CR-15 CR-8*
CR-16

Additional glass thickness causes a focal change of 1/3 the thickness of the glass medium itself. These 0.040-inch-thick filters will therefore cause a focal shift of 0.012 inch. Obviously, the special gelatin filter cannot be used at this new focal position.

The best solution to this problem appears to be similar to the approach taken with bi-color, dichroic coatings on glass. The spectral shapes have been identified; however, production of these filters has not as yet been accomplished and the problems to be encountered are not yet known.

There was a similar filter problem with SO-180 on the last five missions incorporating the 0.040-inch filters. The solution to that problem is also to make 0.040-inch filters with dichroic coatings. There would be similar manufacturing problems in producing these filters as the ones for SO-121. There are also, of course, the static and speed loss problems with SO-180 that have been discussed in the SO-180 capability report.

Bi-color photography has two filter problems that must be solved. The same glass thickness problem exists; however, it is minor in nature since the technology has been developed for making the appropriate spectral shape. However, the systems that will employ two third generation lenses do present a problem. An analysis was undertaken after the bi-color† report was completed to determine the change in resolution with the new lenses. Two filters were used in this study:

1. SF-05-G. A general filter that precisely meets the 490- to 600-nanometer design goal; this filter does not exist but nearly represents an average of the filters made to date.
2. SF-04-12. A specific filter that is available at this time; it is shifted slightly to the red end of the spectrum and is therefore representative of one of the better bi-color filters from a performance viewpoint.

The analysis consisted of determining the MTF's of the second and third generation lenses with respect to 3404 and the SF-05 in question using the lens design data. Since the manufacturing process and glass characteristics vary somewhat, the resolution achieved on any one system will not be exactly as shown here. These MTF's were then crossed with the threshold curve discussed in Section 2.2 to produce a predicted resolution. With focus set for the primary mission filter, the resolution‡ was:

	Second Generation	Third Generation
SF-05-G	100 cycles per millimeter	25 cycles per millimeter
SF-05-12	125 cycles per millimeter	45 cycles per millimeter

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*Refurbishment of this instrument will include modifying it for 0.040-inch filters.

†KH-4B System Capability Report No. 3, CR-2 Bi-Color Experiment, [redacted] (27 Sept 1968).

‡All resolution values are for an apparent 2:1 contrast target at the lens aperture.

With a second generation lens, the general bi-color filter produces 100 cycles per millimeter while the specific filter currently available has a 25 percent improvement in resolution, 125 cycles per millimeter. When the general filter is used with the third generation lens, the performance is at a much lower resolution level, 25 cycles per millimeter, and the specific filter (SF-05-12) gives 45 cycles per millimeter. The improvement in performance for the specific filter is due to a slight shift toward the red end of the spectrum. This provides a clue for further increases in performance with these types of green filters. However, shifts toward the red end of the spectrum cannot be too great or there will be a loss in color discrimination. It is also possible to increase the performance of the third generation lens and the SF-05 type of filter with a focus adjustment. The KH-4B system does not have an inflight focusing capability. However, it is possible to adjust focus by varying the thickness of the glass filter. The Petzval design is such that refocusing for colors other than red (i.e., green) needs a decrease in glass thickness. This would then mean that extraordinarily thin filters, or glass filters of possibly negative thickness, would be necessary for systems employing 0.005-inch filters. However, with the 0.040-inch glass filters, a reasonable degree of focus adjustment is possible. The predicted resolution levels at optimum focus for each filter/lens would then be:

	Second Generation	Third Generation
SF-05-G	115 cycles per millimeter	80 cycles per millimeter
SF-05-12	125 cycles per millimeter	90 cycles per millimeter

There is a 15 percent improvement in resolution with the second generation lens and the general filter with a focus adjustment of 0.001 inch. There is no change in performance with the specific filter with this lens since optimum focus occurs at the same position with the primary Wratten filter and the SF-05-12 filter. There is a large increase in performance with both filters when used at their optimum focal position with the third generation lens. The general filter improves performance by over a factor of three, the specific one by a factor of two. This amount of improvement can be implemented by making SF-05 filters on glass between 0.025 and 0.030.

Table 6-1 summarizes the availability of each technique with respect to filter considerations only. This table assumes that CR-8 will be refurbished and that it will be set for 0.040-inch glass filters. If other instruments are also refurbished, this information will not necessarily apply any longer. In summary, SO-121 and SO-180 can be flown on the next five systems only and bi-color on only three of the next four. Work is currently proceeding on the filter fabrication problem and presumably the problem will be solved.

Table 6-1 — Availability of the Three Color Techniques From a Filter Consideration Only

System	Lens Types	SO-121	SO-180	Bi-Color
CR-9	3/2	Available	Available	Available
CR-10	3/3	Available	Available	Not feasible
CR-11	3/2	Available	Available	Available
CR-12	3/2	Available	Available	Available
CR-13	3/3	Available	Available	Not feasible
CR-14	4/4*	Special dichroic coatings must be prepared on thicker glass	Special dichroic coatings must be prepared on thicker glass	New filter design required for wavelength and focal shift
CR-15	4/4	Same as above	Same as above	Same as above
CR-16	4/4	Same as above	Same as above	Same as above
QR-2	4/4	Same as above	Same as above	Same as above
CR-8	3/1*	Same as above	Same as above	Standard coating needed on thicker glass

* First and second generation lenses perform virtually identically, and third and fourth in the generation are very nearly the same. There are, however, different manufacturing processes as well as glass types.

7. CONCLUSIONS

The following conclusions were reached concerning the capabilities of SO-121 in the KH-4B system:

1. The KH-4B system has demonstrated its capability to handle SO-121 and provides well exposed imagery of good color balance.

2. The ground resolution achievable with SO-121 in this system is, at best, 16 feet. Although no resolution targets were acquired, the best color coverage from mission 1105 is estimated to have reached this maximum. An average of 20 to 25 feet would be an average ground resolution to be expected on future KH-4B missions.

3. Electrostatic markings are not a problem with SO-121. Although this was a severe problem with the SO-180 flight (mission 1104), the sensitivity of SO-121 to the radiation causing these markings is below the threshold for causing fog.

8. RECOMMENDATIONS

The following recommendations are made concerning the future use of SO-121 in the KH-4B systems:

1. Prior to the next SO-121 flight in the KH-4B system, a Dr "A" test should be run in HIVOS to determine the cause of the film curl on mission 1105. Although the chances of this problem reoccurring are small, the exact cause is not known.

2. An effort must be undertaken to fabricate filters for SO-121 for the last five KH-4B systems if color is to be flown. These systems employ a glass filter of 0.040-inch thickness. The systems are focused for this condition and therefore will be out of focus by 0.012 with the 0.004-inch gelatin filters that have been used with the SO-121.

3. After completion of the Dr "A" tests in HIVOS, SO-121 should be used to gather color-oriented information where a resolution level of 20 to 25 feet is sufficient.

4. Work should be initiated to develop the technology for performance assessment with color films. It is recommended that the MTF/AIM approach be taken. Most of this work should be concerned with the resolution characteristics of the color film; for example, can an AIM curve (or three) be employed; how does the resolution of each layer contribute to the resolution of the whole tri-pak, etc? This information will be valuable in assessing the performance of new color films (such as SO-242), not only from a performance point of view, but from an engineering viewpoint in setting focus/filtration.