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REPORT NO. 3

J-3 SYSTEM CAPABILITY

CR-2 Bi-Color Experiment

27 SEPTEMBER 1968

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J-3 SYSTEM CAPABILITY

CR-2 Bi-Color Experiment

27 SEPTEMBER 1968

AUTHORS: [redacted]

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

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CONTENTS

FIGURES

TABLES

1. INTRODUCTION AND SUMMARY

Mission 1102 was launched on 9 December 1967; the cameras were equipped with alternate filters for carrying out two experiments—polarization and bi-color. The polarization experiment was the subject of Capability Report No. 1,* and this report, the third in this series, discusses the bi-color experiment.

The bi-color experiment was designed to test the feasibility of obtaining color photography through additive color techniques. The primary advantage of this approach to color photography is that color films need not be used. Rather, when the vehicle covers a target, all that is required during the acquisition stage is a simple filter switch. This technique avoids the practically insurmountable problems inherent in attempting to splice a section of color film into the mission film so that it will be exposed exactly at the time the vehicle is over the desired target. Another possibility for obtaining color photography would be to commit one half of a mission (or a substantial portion of it) to color film. This technique must be considered undesirable since it requires that a high number of targets that are not needed in color nevertheless be photographed in color at a substantial loss in resolution. However, with bi-color, all but the few passes that required color will yield the normally expected high resolution results, and even these few bi-color passes will suffer minimal resolution loss in comparison with the resolution levels attainable with conventional color film.

In order to perform the bi-color test, a special filter that efficiently transmits the green portion of the spectrum was fabricated. During seven photographic passes of mission 1102, this alternate filter (called an SF-05) was commanded into position; the other camera maintained the Wratten no. 25 red filter. These seven passes, therefore, yielded negatives containing all the spectral information necessary for bi-color images.

Generally, bi-color photography is obtained from a camera system that takes two pictures of the same object (1) at the same time, and (2) from the same look angle. Under these conditions, the color synthesis process is relatively simple. In order to carry out the bi-color experiment on the J-3 system, however, the distortions due to different camera aspects must either be removed or at least reduced in magnitude. Three distortion correction techniques were used—rectification, orthoprinting, and direct viewing with the ARES viewer. It was found that the rectification process did not correct enough of the distortion to provide satisfactory bi-color prints. Orthoprinting was very effective and must be considered the best technique available to date for providing a hard copy print.† For rapid access viewing, the ARES viewer with a bi-color attachment has been fairly effective; however, this instrument has a severe area-of-viewing limitation, giving the operator a viewing area between 1/8 and 3/8 nautical mile (nm) on a side from a 10× enlargement.

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*Report No. 1, J-3 System Capability, CR-2 Polarizer Experiment (11 May 1968).

† Further advances have been made since the date of this report, and a summary has been included in the appendix.

The black and white imagery from the seven test passes was examined to evaluate the effect of the special filter on the normal mission photography. There was a slight loss in resolution and edge definition; further, there was a lessening of contrast. In general, however, it was felt that the bi-color portion of the mission was comparable in quality to a typical J-1 mission and that the normal photointerpreter needs would be satisfied.

It should be pointed out that the key to bi-color photography is through special filtration when using conventional black and white aerial films (i.e., Type 3404). New black and white materials (i.e., Types SO-380, SO-230, and SO-205) have become available and may be used on J-3 systems in the near future. The substitution of these films for Type 3404 will have no effect on the bi-color acquisitions.

The mission 1102 test was considered very successful, and it is recommended that this approach to color photography be used over those operational targets for which there is a need for color information.

2. BASICS OF BI-COLOR

The basic principles of bi-color photography and the general techniques used for obtaining bi-color pictures are discussed in this section. In addition, the advantages and disadvantages of this technique as it applies to the J-3 camera system are examined.

2.1 BI-COLOR PRINCIPLES AND TECHNIQUES

Color photography is ordinarily obtained by exposing a scene onto a film with three layers, each of which is sensitive to approximately one-third of the visible spectrum—blue, green, and red; this film is generally referred to as an integral tripack. 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 a laboratory where the three black and white records are superimposed and exposed through the appropriate filter. This process is called tricolor additive photography.

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 color print using only two records—green and red. This type of photography is called bi-color, 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, considering the degrading effects that the atmosphere has on conventional reversal color film.

The two J-3 cameras provide a stereo pair with a 30-degree convergence angle at the center of format. The stereo pair presents some difficulties in the exploitation process; this problem is discussed in more detail in Sections 2.2 and 4. In order to obtain the required negatives for bi-color photography, the in-flight filter switching capability is used. The forward-looking unit uses a conventional Wratten no. 25 filter, and the aft-looking unit uses a green filter (SF-05) from the alternate position of the filter holder. A series of special filters (dichroic coatings on thin quartz) has been fabricated for this and other tests. Some of these filters are spectral equivalents of Eastman Kodak Wratten filters and some, like the SF-05, have nonequivalent spectral characteristics. The SF-05 filter is similar to a Wratten no. 57 filter; however, the SF-05 has a much higher transmittance giving it a filter factor half that of a Wratten no. 57. At the appropriate time during the mission, the alternate (green) filter is switched into place, and the slit width is changed to obtain proper exposure. The entire revolution is then taken in bi-color. The next time the vehicle passes over a command station, the filter is switched again to the primary position.

Once the original negatives have been processed, there are several stages necessary before color printing can be performed. The stereo convergence angle causes a problem at this point, since the camera-induced distortions and relief due to local ground elevations must be corrected in order to make color prints that are in register. A rectifier can be used to eliminate the panoramic distortions; however, this is not suitable even for large flat areas near the center of format. In order to completely correct the distortions, the relief displacement must be removed through orthoprinting. Once this has been accomplished, the images can be color printed by either an integrating enlarger or a pin register board, a process that will be explained in more detail in Section 4.4. This process uses conventional color processing technology and requires special filtration in the printing stages to obtain satisfactory color balance.

2.2 ADVANTAGES AND DISADVANTAGES OF BI-COLOR

There are several advantages afforded to the J-3 system with the bi-color approach to color photography, the greatest advantage being the capability to acquire color pictures with a minimum of operational problems. It is unnecessary to attempt the practically impossible task of splicing a conventional color material at the exact position in the film load that would ensure the targets of interest being color photographed. The bi-color filter switching technique allows changes in the operational program due to variations in the orbital parameters and changing weather patterns so that color photography can be acquired even over those areas that, prior to launch, were not intended to be covered in color.

A second advantage to the bi-color approach is that a color print can be made from a chip of photography at the interpreter's option. Once the target of interest has been covered in bi-color, this option of having a color print is available at any time in the future. In the meantime, these targets are recorded on black and white 3404 film and can be used in the routine analysis stage with the normal viewing techniques. The fact that one record has been taken with a green filter does not substantially alter the information on the black and white record, although some loss in definition and slight tonal changes can be expected.

Another advantage of the bi-color process is that in retaining the normal Wratten no. 25 imagery, the inherent high resolution is still present. The passes that do not use the bi-color mode also retain the Wratten no. 21 or 23A high resolution imagery. For the particular revolution that does use bi-color, there is a slight loss in resolution on the green record, a loss that is more in the form of a lowering of contrast which indirectly lowers resolution. The laboratory resolution for lenses with a green SF-05 filter has been the same as the resolution with a Wratten no. 21 filter. Even though the operational resolution is lower, the bi-color process still has a fundamentally higher resolution than conventional color films (such as SO-121) in the J-3 system. This slight loss in quality is not fundamental to the bi-color process. It is possible to design a lens specifically for the wavelength region of the SF-05 type filter. Since this is a shorter wavelength than those conventionally used, the theoretical resolution limit is even higher than currently available lenses.

The bi-color flown to date has used the green filter on a second generation Petzval lens, which normally uses a Wratten no. 21 filter. If the green filter were to be used on a third generation lens, which normally uses a Wratten no. 25 filter, there would be a noticeable loss in resolution.

Future camera systems will employ both second and third generation lenses. The focal shift as a function of wavelength is quite different for these two lenses, the third generation lens being designed for a Wratten no. 25 filter, whereas the second generation was designed for a Wratten no. 21 filter. Fig. 2-1 compares both cases. Therefore, since the curve is shifted away from the spectral region of the green filter, the focus shift will be considerably worse with a third generation lens. However, if the time does come when bi-color is to be acquired with a green filter on the third generation lens, a more complete test will have to be performed to see how serious this problem would be.

There are several disadvantages of bi-color that must be considered. First, one should be aware of the fact that the color obtained is not accurate; however, neither is it absolutely accurate with conventional color films. This drawback is not serious as long as one keeps in mind the concept of bi-color photography giving color "clues" and not necessarily accurate color information. For example, reddish-yellow objects would be clearly distinguishable from blue-cyan objects. However, it may not always be possible to distinguish a red from an orange or to distinguish a green from a green-blue. In short, bi-color does not have as wide a chromatic dynamic range as tri-color photography.

The second disadvantage of bi-color is that although the prints are available at the interpreter's option, it does take considerable time and effort to produce them; at present, it takes several days due to the transportation of the materials involved. However, with the right type of equipment located in the right place, it seems reasonable to expect that a 1-day service could be established.

The advantages and disadvantages of bi-color photography can be summarized as follows:

Advantages

1. Bi-color can be acquired at any time in orbit by operational commands.
2. Color "clues" are available at the interpreter's option.
3. High resolution black and white imagery is maintained.

Disadvantages

1. Contrast of the green filtered imagery is slightly lower.
2. Absolutely accurate color reproduction is impossible.
3. Synthesis process is slow at this time.

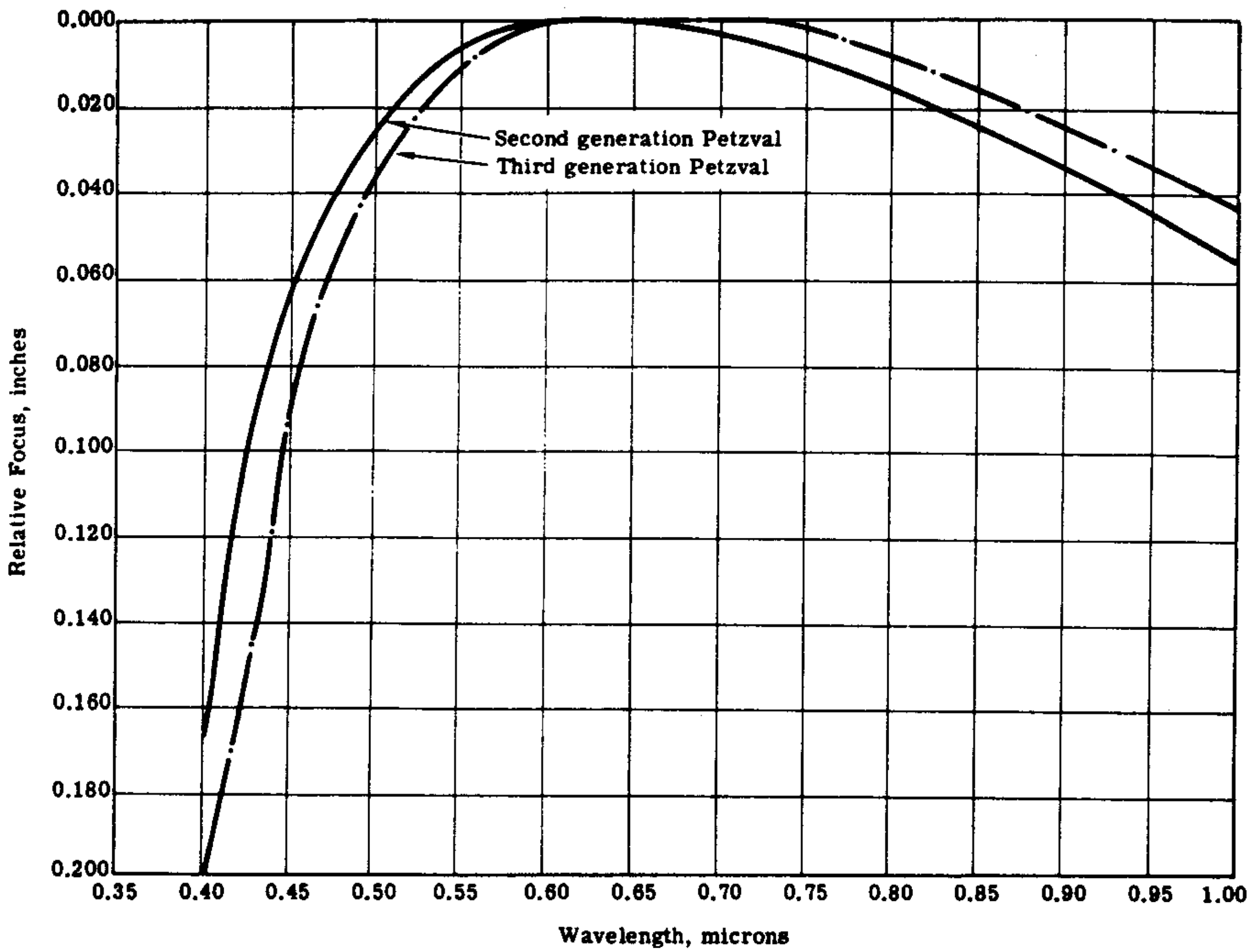

Fig. 2-1 — Focus versus wavelength for 24-inch Petzval lenses

3. MISSION 1102 BI-COLOR TEST

3.1 PURPOSE

The intent of the mission 1102 bi-color test was to obtain, for the first time, satellite color photography in the J-3 system through the bi-color mode. This was a test of the compatibility of the bi-color technique with the entire taking and exploitation stages of the process.

In order to be considered usable, the technique must first work properly in the acquisition stage of the system. This means that it must be possible to command the alternate filter into position at the right time. The imagery thus obtained must be usable for normal photointerpretation purposes, and it must also have retained the spectral information necessary to make a bi-color print. In addition to acquisition, the bi-color process must work properly in the synthesis stages; that is, it must be possible to make a bi-color print from the J-3 photography. The distortions must be corrected and the color must be suitable for the interpretation needs.

The purpose of this experiment was to deal with these problems and to recommend the best method for obtaining useful photography from the J-3 reconnaissance system.

3.2 BI-COLOR FILTER

In order to obtain bi-color photography, a special filter must be used on one of the cameras, while the normal Wratten no. 25 filter is used on the other camera. Consideration must be given to many characteristics of the total system in order to select the best spectral transmittance band of this filter for bi-color photography. This filter, fundamentally, must be blue or green. Experience has shown that the exact nature of filters is not as important as might be suspected as far as the color reproduction is concerned. The basic filter requirement for bi-color is that one filter allow passage of the long wavelengths, and the other allow passage of the short wavelengths.

For successful bi-color photography, the filters must be chosen with one prime consideration, namely, image quality. Blue or blue-green filters must be eliminated, therefore, due to the severe loss in resolution caused by using the lenses in spectral regions for which they were not designed. A green filter, however, can be used with little or no loss in resolution with a second generation Petzval lens. Extending the filter further into the green-yellow spectral region would not substantially increase system resolution, but would cause a significant loss in color information since the color discrimination would be lowered.

With the filter choice limited to a green filter, a very practical problem must be solved. Dye filters that transmit in the blue-green spectral region characteristically have high filter factors. One filter that works quite well (although it has a filter factor of 6) is a Wratten no. 57. It has been used to obtain bi-color photography in the EKIT* bi-color test. The filter factor, however, is too high for use in the J-3 system.

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* EKIT Report No. 16, Bi-Color Evaluation (15 Sept. 1967).

In order to solve this problem, a special green dichroic filter (SF-05) was fabricated and used in this mission to acquire the bi-color imagery. The filter is visually similar to a Wratten no. 57, though at a much higher transmittance level to give an acceptable filter factor of 2.8.

A plot of the three filters is shown in Fig. 3-1. As can be seen, the SF-05 has a much higher transmittance than the Wratten no. 57. The filter factor of the SF-05 is comparable to the Wratten no. 25 which has a filter factor of 3.0 when using type 3404 film under simulated daylight conditions.

3.2.1 Test Details

The bi-color experiment on mission 1102 was performed on seven passes, six over domestic areas, and one over the Soviet Union. During each bi-color operation, the forward-looking camera employed the Wratten no. 25 red filter, and the aft-looking camera employed the SF-05 green filter.

An attempt was made to photograph several strategically important areas in the USA; however, weather problems (snow and clouds) obscured these targets. There were several other target areas in the United States that proved to be very interesting in bi-color even though they are of little strategic significance. The most startling was the copper mine slurry located near Bisbee-Douglas, Arizona. This is discussed in more detail in Section 3.3.3.

Table 3-1 gives the specific locations and camera system parameters for the bi-color acquisitions. The ground tracks for these missions are shown in Fig. 3-2.

3.2.2 Special Glass Filters and Their Performance With the Petzval Lenses

An effort has been undertaken by the contractor to fabricate glass filters to be used in both the primary and alternate positions in the J-3 system. This task started with the goal of possibly improving system performance by replacing Wratten gelatin filters with high quality glass filters, of which the SF-05 is one. Problems encountered in the production of these glass filters have to date precluded their qualification for use in the primary position. The glass, 0.005-inch fused quartz, is so thin that the polishing has not been sufficient to produce results any better than normal Wratten filters. Table 3-2 lists the filters that have been produced thus far; some may be used in future tests and are listed in ephemeris printouts and messages with their "SF" designation.

As stated, the SF-05 green filter was used on the aft-looking camera of mission 1102; this camera used a second generation lens. The question of resolution performance was answered in two ways, theoretically and by laboratory experiment. The laboratory experiment indicated that resolution values were practically identical for the Wratten no. 21 and SF-05 filters when using a second generation lens at optimum focus for each filter.

The 2:1 contrast resolution for the Wratten no. 21 was 135 lines per millimeter, while the SF-05 was 130 lines per millimeter. However, as pointed out earlier, the contrast reduction due to the effective increase in atmospheric haze light with the green filter will indirectly lower the resolution. In addition, the higher filter factor (2.8 as opposed to 2.0 for the Wratten no. 21) forces longer exposure times which decrease the system dynamic performance due to image blur. Finally, the SF-05 filtered imagery is acquired operationally in the focal position for the Wratten no. 21 filter, which is not quite optimum for the SF-05, and this lowers the resolution performance to some degree.

3.3 ANALYSIS OF RESULTS

An analysis of the photography obtained from mission 1102 was undertaken by both NPIC and this contractor. The NPIC analysis was summarized in a message which is quoted in its entirety in paragraph 3.3.1.

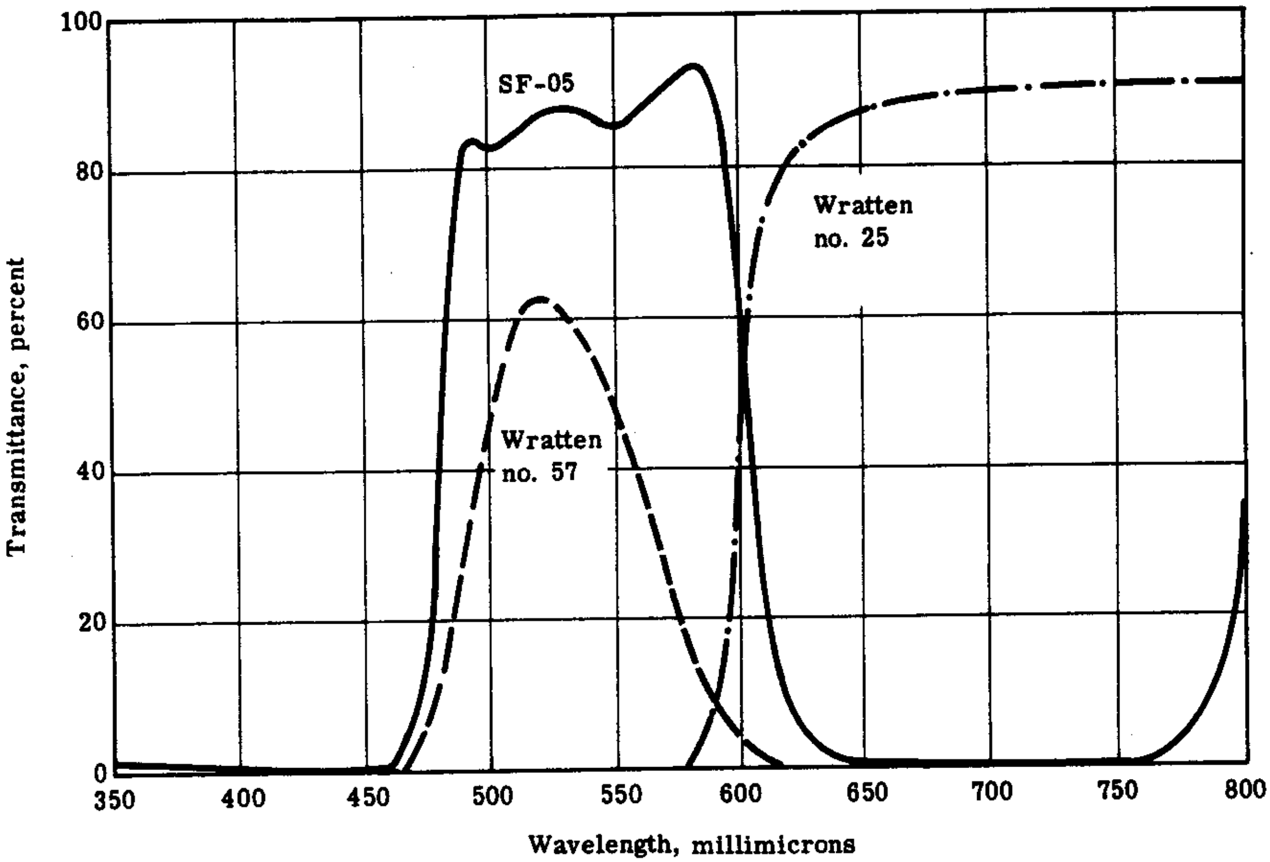


Fig. 3-1 — Spectral transmittance of the SF-05, Wratten no. 25, and Wratten no. 57 filters

Table 3-1 — Specific Mission Parameters for the Seven Bi-Color Passes

	Beginning of Pass		End of Pass	
PASS D-048				
Frame	1		61	
Date	12 Dec 1967		12 Dec 1967	
Hr, min, sec (GMT)	21, 21, 0.125		21, 22, 52.813	
Solar Elevation	22°42'		28°25'	
Solar Direction	38°48'		40°48'	
Geographic Location, center format, forward only	Colorado		New Mexico	
Latitude	37°32.5'N		29°53.5'N	
Longitude	110°44.8'W		109°35.1'W	
Weather Conditions	50% clouds; 50% clear		20% clouds; 80% clear	
Exposure	Slit	Time	Slit	Time
Forward	0.340	1/237	0.340	1/242
Aft	0.270	1/298	0.270	1/308
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	
PASS D-064				
Frame	1		16	
Date	13 Dec 1967		13 Dec 1967	
Hr, min, sec (GMT)	20, 57, 08.437		20, 57, 38.937	
Solar Elevation	19°8'		20°47'	
Solar Direction	35°30'		35°48'	
Geographic Location, center format, forward only	Wyoming		Wyoming	
Latitude	43°6.7'N		41°3.2'N	
Longitude	108°26.3'W		108°1.1'W	
Weather Conditions	10% clouds; 90% clear		100% clear	
Exposure	Slit	Time	Slit	Time
Forward	0.340	1/234	0.340	1/239
Aft	0.270	1/295	0.270	1/298
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	

Table 3-1 — Specific Mission Parameters for the Seven Bi-Color Passes (Cont.)

	Beginning of Pass		End of Pass	
PASS D-079				
Frame	1		49	
Date	14 Dec 1967		14 Dec 1967	
Hr, min, sec (GMT)	19, 7, 57.250		19, 9, 51.250	
Solar Elevation	26°41'		32°46'	
Solar Direction	35°24'		37°18'	
Geographic Location, center format, forward only	South Carolina		Florida (Cape Kennedy)	
Latitude	34°36.7'N		26°51.6'N	
Longitude	81°10.3'W		80°6.8'W	
Weather Conditions	100% clear		100% clear	
Exposure	Slit	Time	Slit	Time
Forward	0.340	1/239	0.340	1/245
Aft	0.270	1/298	0.270	1/305
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	
PASS D-097				
Frame	1		27	
Date	15 Dec 1967		15 Dec 1967	
Hr, min, sec (GMT)	21, 40, 47.625		21, 41, 36.687	
Solar Elevation	23°50'		26°37'	
Solar Direction	31°36'		32°12'	
Geographic Location, center format, forward only	North of San Francisco, California		South of San Francisco, California	
Latitude	39°8.9'N		35°49.4'N	
Longitude	122°57.6'W		122°23.2'W	
Weather Conditions	100% clear		100% clear	
Exposure	Slit	Time	Slit	Time
Forward	0.340	1/242	0.340	1/248
Aft	0.270	1/305	0.270	1/312
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	

Table 3-1 — Specific Mission Parameters for the Seven Bi-Color Passes (Cont.)

	Beginning of Pass		End of Pass	
PASS D-113				
Frame	1		36	
Date	16 Dec 1967		16 Dec 1967	
Hr, min, sec (GMT)	21, 18, 45.125		21, 18, 44.937	
Solar Elevation	25°50'		25°11'	
Solar Direction	29°48'		30°36'	
Geographic Location, center format, forward only	Bakersfield, Fresno, California		Bakersfield, Fresno, California	
Latitude	37°34.7'N		38°20.2'N	
Longitude	119°18.5'W		119°29.3'W	
Weather Conditions	25% clouds; 20% haze; 55% clear		50% clouds; 10% haze; 40% clear	
Exposure	Slit	Time	Slit	Time
Forward	0.340	1/245	0.340	1/248
Aft	0.270	1/305	0.270	1/312
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	
PASS D-154				
Frame	1		47	
Date	19 Dec 1967		19 Dec 1967	
Hr, min, sec (GMT)	9, 46, 55.980		9, 48, 23.117	
Solar Elevation	13°27'		18°55'	
Solar Direction	22°0'		22°18'	
Geographic Location, center format, forward only	Classified		Classified	
Latitude	–		–	
Longitude	–		–	
Weather Conditions	80% clear; 15% haze; 5% clouds		92% clear; 3% haze; 5% clouds	
Exposure	Slit	Time	Slit	Time
Forward	0.340	1/236	0.340	1/243
Aft	0.215	1/373	0.215	1/383
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	

Table 3-1 — Specific Mission Parameters for the Seven Bi-Color Passes (Concl.)

	Beginning of Pass		End of Pass (with comparable aft-looking photography)	
PASS D-210*				
Frame	1		21	
Date	22 Dec 1967		22 Dec 1967	
Hr, min, sec (GMT)	20, 31, 32.625		20, 32, 7.875	
Solar Elevation	29°56'		32°15'	
Solar Direction	15°24'		15°42'	
Geographic Location, center format, forward only	Bakersfield, Fresno, California		Santa Barbara, California	
Latitude	36°11.9'N		33°48.1'N	
Longitude	120°48.3'W		120°25.5'W	
Weather Conditions	Not evaluated		Not evaluated	
Exposure	Slit	Time	Slit	Time
Forward	0.215	1/396	0.215	1/396
Aft	0.134	1/628	0.134	1/643
Filters				
Forward	Wratten no. 25		Wratten no. 25	
Aft	SF-05		SF-05	

*Partial mono coverage, therefore bi-color possible on only a portion of this pass.

Fig. 3-2 — Plots of bi-color passes over the United States

Table 3-2 — Special Filter Designation and Description

Filter Designation	Description	50 Percent Transmittance Points, millimicrons	Nominal Filter Factor With 3404	Nearest Wratten Equivalent
SF-01	Long-wave pass, orange	550	1.8	W-21
SF-02	Long-wave pass, orange-red	580	2.3	W-23A
SF-03	Long-wave pass, red	600	2.5	W-25
SF-04	Visual-band pass, orange	570 to 680	3.1	None, visually looks like a W-23A
SF-05	Visual-band pass, green	490 to 600	2.8	W-57, but higher transmittance
SF-06*	Long-wave pass, yellow	530	NA	W-15 + 1.0 ND
SF-07†	Polarizer, 0° axis	Neutral	3 to 6	0.45 ND
SF-08†	Polarizer, 10° axis	Neutral	3 to 6	0.45 ND
SF-09†	Polarizer, 20° axis	Neutral	3 to 6	0.45 ND

*This filter is for use with camouflage detection color films such as SO-180.
†Axis of polarization measured from the long dimension of the filter.

Whereas the NPIC analysis dealt with only the black and white imagery, this contractor's analysis was concerned with both the black and white imagery (paragraph 3.3.2) and the production of color images (paragraph 3.3.3). In that analysis, three specific scenes have been analyzed, two of which were orthoprinted and a third which was only rectified prior to color printing. Also, an additional set of images has been included to indicate the improvement that has taken place since the EKIT bi-color test was performed.

3.3.1 NPIC Analysis

NPIC analysis of the mission 1102 bi-color experiment was reported by TWX on 28 February 1968. This message is quoted in the following pages.

"IN RESPONSE TO REFERENCE, NPIC HAS COMPLETED THE FIRST PHASE OF ITS BI-COLOR EVALUATION. THIS CONSTITUTES A DETERMINATION OF DEGRADATION TO THE PHOTOGRAPHY EXPOSED IN THE BI-COLOR MODE COMPARED TO THAT OF THE NORMAL MODE OF OPERATION. THE PROCEDURE AND RESULTS FOLLOW:

A. SUBJECTIVE COMPARISON OF WRATTEN NUMBERS 25, 21 AND SF-05 RECORDS:

1. PHOTO-SCIENCE EVALUATION: TO ESTABLISH A BASIS FOR THE BI-SPECTRAL IMAGE EVALUATION, THE MISSION MATERIAL EXPOSED THROUGH THE PRIMARY FILTERS WAS ANALYZED. THE MATERIAL SELECTED FOR ANALYSIS HAD ESSENTIALLY THE SAME ACQUISITION PARAMETERS AS THE BI-SPECTRAL MATERIAL. DIFFERENCES IN DENSITY, CONTRAST AND IMAGE QUALITY ARE NEGLIGIBLE. THE PHOTO-INTERPRETATION REPORTS INDICATE SIMILAR QUALITY RATINGS FOR BOTH RECORDS. ASSUMING NO CAMERA MALFUNCTIONS, SUBJECTIVE AND OBJECTIVE RESULTS BASED ON THIS EVALUATION INDICATE THAT ANY DIFFERENCE IN THE SF-05 RECORD AS COMPARED TO THE WRATTEN 21 AND WRATTEN 25 RECORDS IS THE RESULT OF THE FILTER. THE OBJECTIVE EVIDENCE IS CONTAINED IN PART B OF THIS REPORT.

THE SF-05 RECORD AND CONJUGATE IMAGERY FROM THE WRATTEN 25 RECORD WERE VISUALLY COMPARED. A COMPRESSION OF DENSITY EXTREMES IS READILY APPARENT IN THE GREEN FILTER RECORD. DUE TO THIS COMPRESSION, LOW CONTRAST AREAS SHOW A DECIDED INCREASE IN INFORMATION CONTENT ON THE WRATTEN 25 MATERIAL. WHILE IN SOME INSTANCES THERE IS MORE APPARENT DETAIL IN THE SHADOWS ON THE POSITIVE MADE FROM THE SF-05 RECORD, THIS DIFFERENCE IS ATTRIBUTED TO THE PRINT DENSITY DICTATED BY COMPROMISE OF THE D-MAX AND D-MIN.

THE IMAGE QUALITY OF THE WRATTEN NO. 25 RECORD IS SUPERIOR TO THE SF-05 FOR INFORMATION CONTENT. OBJECTS THAT APPROACH THE RESOLUTION CAPABILITY OF THE SYSTEM APPEAR MUCH SHARPER. APPARENT EDGE SHARPNESS OF OBJECTS VIEWED AT LOW MAGNIFICATION IS GENERALLY COMPARABLE. HOWEVER, THE WRATTEN NO. 25 RECORD RETAINS THIS APPARENT SHARPNESS MUCH LONGER AS MAGNIFICATION IS INCREASED.

2. PI REPORT: THE PHOTO-INTERPRETERS PREFERRED THE WRATTEN NO. 25 RECORD OVER THE SF-05. HIGHER CONTRAST AND OVERALL SHARPER IMAGERY WERE THE TWO MAJOR REASONS FOR THIS PREFERENCE. THEY ALSO EXPRESSED THE OPINION THAT WHEN SHADOW DETAIL IS NEEDED, A LIGHTER PRINT FROM THE WRATTEN NO. 25 RECORD WOULD BE MORE DESIRABLE THAN THE LOWER CONTRAST OF THE SF-05 MATERIAL, WHICH SEEMS TO PROVIDE MORE SHADOW DETAIL ON A NORMAL PRINT. SMALL OBJECTS PRESENT IN THE WRATTEN NO. 25 RECORD CAN BE DETECTED IN THE SF-05 RECORD; HOWEVER, IDENTIFICATION OF THESE OBJECTS IS MUCH MORE DIFFICULT. THE GENERAL CONCLUSION OF THE PHOTO-INTERPRETERS IS: THE MAJORITY OF THE REQUIREMENTS LEVIED FOR THE J-3 SYSTEM COULD BE ANSWERED WITH PHOTOGRAPHY GENERATED IN THE BI-COLOR MODE BECAUSE WHEN USED IN STEREO, THE TWO RECORDS COMPLEMENT EACH OTHER. IN ADDITION, THE OVERALL INFORMATION CONTENT OF THE PHOTOGRAPHY EXPOSED THROUGH THE GREEN FILTER IS COMPARABLE TO AN AVERAGE J-1 MISSION.

B. OBJECTIVE ANALYSIS:

1. MICRO-D TRACES: TO SUBSTANTIATE THE RESULTS OF THE SUBJECTIVE ANALYSIS, MICRODENSITOMETRIC TRACES OF 11 TARGETS WERE GENERATED. SIX TARGETS WERE SELECTED FROM THE NON BI-COLOR PORTION OF THE MISSION AND FIVE TARGETS WERE CHOSEN FROM THE BI-COLOR PORTION. EACH TARGET WAS TRACED. THE TRACES WERE GENERATED BY THE MANN MICRODENSITOMETER WITH AN EFFECTIVE SLIT APERTURE OF 10 MICRONS. VISUAL COMPARISONS OF THE TRACES FROM NON BI-COLOR MATERIAL INDICATED THE SIMILARITY THAT EXISTS BETWEEN THE WRATTEN NO. 25 AND 21 RECORDS. HOWEVER, COMPARISONS OF THE TRACES FROM THE BI-COLOR MATERIAL INDICATE THAT A SUBSTANTIAL DIFFERENCE IN DENSITY AND CONTRAST EXIST BETWEEN THE WRATTEN NO. 25 AND SF-05 MATERIALS.

THE MINIMUM DENSITY, MAXIMUM DENSITY, AND THE DENSITY RANGE OF EACH TARGET HAS BEEN DERIVED FROM THE TRACES AND IS TABULATED BELOW. THE SIMILARITY OF THE WRATTEN NO. 25 AND NO. 21 RECORDS, AND THE NON-SIMILARITY OF THE WRATTEN NO. 25 AND SF-05 RECORDS IS EVIDENCED BY THE VALUES IN THE TABLE.

FIGURE	PASS	FRAME	FILTER	D-MIN	D-MAX	DELTA
1	D-16	6 FWD	25	0.72	2.37	1.65
2	D-16	12 AFT	21	0.70	2.48	1.78
3	D-16	12 FWD	25	0.75	1.64	0.89
4	D-16	18 AFT	21	0.78	1.78	1.00
5	D-16	13 FWD	25	0.65	1.60	0.95
6	D-16	20 AFT	21	0.92	1.85	0.93
7	D-79	7 FWD	25	0.45	1.15	0.73

FIGURE	PASS	FRAME	FILTER	D-MIN	D-MAX	DELTA
8	D-79	13 AFT	SF-05	0.58	0.93	0.35
9	D-79	7 FWD	25	0.35	0.98	0.63
10	D-79	13 AFT	SF-05	0.42	0.72	0.30
11	D-97	12 FWD	25	0.62	1.27	0.65
12	D-97	19 AFT	SF-05	1.00	1.32	0.32
13	D-97	38 FWD	25	0.36	1.13	0.77
14	D-97	44 AFT	SF-05	0.40	0.88	0.48
15	D-129	4 FWD	25	0.80	2.47	1.67
16	D-129	10 AFT	21	0.75	2.47	1.72
17	D-129	27 FWD	25	0.70	1.65	0.95
18	D-129	33 AFT	21	0.75	1.77	1.02
19	D-129	32 FWD	25	0.95	1.57	0.62
20	D-129	39 AFT	21	1.20	1.92	0.72
21	D-154	4 FWD	25	0.84	1.92	1.08
22	D-154	10 AFT	SF-05	0.75	1.44	0.69

2. RESOLUTION TARGETS: FOUR RESOLUTION TARGETS WERE PHOTOGRAPHED DURING THE NON BI-SPECTRAL PORTION OF THE MISSION. SEVEN TARGETS WERE PHOTOGRAPHED DURING THE BI-SPECTRAL PORTION; HOWEVER, DUE TO WEATHER CONDITIONS AND/OR FORMAT LOCATION, ONLY ONE OF THE TARGETS IMAGED IN THE BI-COLOR MODE IS SUITABLE FOR THIS EVALUATION. THE AVERAGE GROUND RESOLUTION OF THESE TARGETS AS DETERMINED FROM THE ORIGINAL NEGATIVE IS PRESENTED BELOW:

CAMERA	PASS	IMC	SCAN	FILTER
FWD	16-D	5.7	6.3	25
AFT	16-D	5.7	8.0	21
FWD	16-D	8.0	8.0	25
AFT	16-D	9.0	9.0	21
FWD	32-D	12.0	12.0	25
AFT	32-D	12.0	10.0	21
FWD	129-D	7.6	8.7	25
AFT	129-D	7.6	8.7	21
FWD	48-D	6.3	5.7	25
AFT	48-D	9.0	8.0	SF-05

AS CAN BE DETERMINED FROM THE ABOVE LIST, THE NON BI-SPECTRAL PASSES (16-D, 32-D, AND 129-D) INDICATE VERY LITTLE RESOLUTION DIFFERENCES BETWEEN THE FWD AND AFT CAMERA RECORDS; HOWEVER, THE BI-SPECTRAL MATERIAL (PASS 48-D) SHOWS A DIFFERENCE OF 2.7 FEET IN THE IMC DIRECTION AND 2.3 FEET IN THE SCAN DIRECTION BETWEEN THE FORWARD AND AFT CAMERA RECORDS. THIS DIFFERENCE, ALTHOUGH SUBSTANTIAL, REPRESENTS

ONLY ONE BAR GROUP. ALSO, IT SHOULD BE NOTED THAT THE 9.0 FEET AND 8.0 FEET READINGS ARE COMPARABLE TO A NORMAL J-1 MISSION.

C. SUMMARY AND CONCLUSIONS:

1. THE CONTRAST RANGE IS SIGNIFICANTLY REDUCED WHEN THE SF-05 IS USED IN PLACE OF THE WRATTEN NO. 21 OR THE WRATTEN NO. 25.

2. APPARENT IMAGE SHARPNESS IS REDUCED BY A NOTICEABLE DEGREE ON THE SF-05 PHOTOGRAPHY COMPARED TO THE WRATTEN NO. 21 AND WRATTEN NO. 25.

3. THE ONLY SUITABLE RESOLUTION TARGET DISPLAY IMAGED DURING THE BI-COLOR ACQUISITION INDICATES A SIGNIFICANT DIFFERENCE IN GROUND RESOLUTION BETWEEN THE SF-05 PHOTOGRAPHY COMPARED TO THAT OF THE WRATTEN 25.

4. THE EFFECT OF IMAGE QUALITY DEGRADATION CAUSED BY THE USE OF THE SF-05 FILTER IS MINIMIZED WHEN THE PHOTOGRAPHY IS VIEWED IN STEREO WITH THE HIGHER QUALITY, HIGHER RESOLUTION PHOTOGRAPHY EXPOSED THROUGH THE WRATTEN 25.

5. THE RESOLUTION OF THE GREEN FILTERED RECORD IS GENERALLY COMPARABLE TO THAT OF A NORMAL J-1 MISSION."

3.3.2 Contractor Analysis of Black and White Imagery

In general, exposure times were approximately 1/300 second for the SF-05 green filter and 1/250 second for the Wratten no. 25 filter. While the SF-05 record seemed to lack the expected increase in shadow areas, a compensating increase in exposure would almost certainly produce an overexposed negative. Shadow details, in most cases, were about equal for both the SF-05 and Wratten no. 25 records.

There is full snow cover in the pass number D-154, and the shorter exposure time compensated for the high ground reflectance in the SF-05 frames. The Wratten no. 25 frames were exposed at 1/250 second, which was common exposure time for the other areas, and, as a consequence, were slightly overexposed.

Comparison of the two camera records for D-210 on a point-by-point basis is not possible because of the mono operation of the camera during the pass. However, a comparison of the SF-05 records of D-097, 1/300 second, and D-210, 1/600 second, shows considerable differences. The shorter exposure time produced negatives that lacked contrast and low reflectance detail. Highlights fall well below the shoulder of the characteristic curve and only very large items were shown in a usable manner. Considerable haze in the area helped degrade the 1/600-second frames, but it was very obvious that the shorter exposure time only detracted from the results.

Edge quality was noticeably inferior in the green SF-05 filtered photography. This shortcoming was consistent throughout all the bispectral passes. Resolution, based on fixed and CORN target readings of eight observers, is higher for the Wratten no. 25 than for the SF-05 record. The best resolution is predominantly in the FMC direction as opposed to the scan direction, usually by approximately one target element.

The tonal reproduction qualities of the two filter records is heavily in favor of the Wratten no. 25 record. There is much better separation of tonal differences in rocks and soil, more contrast between vegetation (particularly grasses) and top soil, and slightly more shadow detail in mountain valleys. Structural details of man-made objects are well separated and generally better defined. Urban areas, particularly residential ones, are shown to better advantage with buildings, trees, fences, etc., being more easily detected. Delineation of interfaces between two different bodies of water is far superior with the Wratten no. 25 filter.

The SF-05 record is more useful for delineating the texture in large stands of timber and tidal estuary vegetation.

Snow fields stimulate approximately the same response in both filter records, but contrast is particularly high in the Wratten no. 25 photography when there are urban areas or villages.

The spectral separation of certain objects is particularly noticeable in the areas of mineral processing when the red and the green filtered imagery are compared. Processing tanks at copper refineries show marked differences, and salt pans along San Francisco Bay provide extreme examples of tonal differences caused by the two different spectral responses.

Exposures made with the SF-05 filter are limited in image quality, but at the same time provide a tool for detection of spectral differences either by direct black and white comparison or by additive color techniques. The multispectral aspect of bi-color has a potential for gaining information about a subject. However, it is quite difficult to determine these spectral differences from black and white imagery unless they are quite pronounced. The specific areas where good separation occurs are limited. The bi-color reproduction, however, brings the subtle differences out, aiding the eye in this type of analysis.

Many of the shortcomings of the green record are eliminated or minimized when it is used in stereo with the Wratten no. 25 record. The resolution and contrast of the Wratten no. 25 coverage dominates, and the textural delineation of the SF-05 coverage adds to the overall information content.

3.3.3 Contractor Analysis of Bi-Color Prints

Copper Mine and Refinery (10× Orthoprinted Enlargement) Figs. 3-3 and 3-4

The film positive color integration of the red and green spectral records is a good example of how the information stored in each record can be combined to form a graphic chromatic representation of these differences.

This scene has been balanced to present the subject as a bispectral record, and at the same time keep the color in a frame of reference with the impression of what it should look like. Use of more extreme printing colors might possibly make the density differences more pronounced, but it would remove it from the "real" world of color photography. Extremes have a definite use, particularly in cases of difficult interpretation. Being able to perceive a somewhat natural scene and at the same time detect spectral differences would appear to be the more desirable alternative.

The hues present in the transparency are generally related to the subject with which they are associated. Scrub and desert vegetation appear green; sand and aggregates appear neutral and light; and slurry from the refining of the copper ore appears red or green, colors that are normally associated with this metal. However, there are areas of artifically induced colors, such as the reddish color (in Fig. 3-4) from a cloud shadow. In this case, one camera has recorded the ground terrain while the other has recorded the cloud.

The density differences that show as hue differences in the transparency are also detectable in the film positives as obvious density differences. By viewing them stereoscopically, a three-dimensional image is presented, and careful comparison will show where and to what degree the differences manifest themselves. However, this is a tedious process for extensive analysis and is best used as a cooperative procedure in conjunction with a bi-color presentation.

Airfield, Support Facilities, and Surrounding Area (10× Orthoprinted Enlargement) Figs. 3-5 and 3-6

The overwhelming characteristic of this scene is the green hue that dominates the area. This is not a saturation of the image by the color of one of the printing filters at the expense of other hues since good neutral taxiways and natural colored soils are present. Vegetative cover is very well defined and delineated, and barren areas are equally well defined by the reddish brown soil color.

The delineation of structures at the airfield is enhanced by the red record to a degree not possible with the green record alone. Finely resolved detail is lost, and there is overall degradation of the image by the method of restitution and superimposition parallax contributed by the integrating printer. The integration of the two spectral records in a graphic color presentation is an important contribution to the analysis of the scene.

Saturn V Assembly Building at Cape Kennedy, Florida (20× Rectified Enlargement) Figs. 3-7 and 3-8

Comparison of the film positive bispectral records with the bi-color integration shows a marked overall degradation of image quality and information content. Both black and white film positives show the subject area in great detail. The red record appears to be superior to the green in most areas including vegetative delineation and at least as good in rendering shadow details visible. This last factor is of dubious importance since few objects have shadow areas large enough to hide details at this scale.

The bi-color integration presents no additional information except that the area has scrub ground cover over the undeveloped areas. Resolution is extremely low as demonstrated by the automobiles which are visible in the individual positives but completely obscured in the bi-color print. Relief displacement of the assembly building is so extreme that when ground detail is in coincidence, the structure is an incomprehensible jumble of red, cyan, and neutral tones. Clearly, this type of subject is not compatible with bi-color integration constructed from rectified images.

Conclusion

The quality of the bi-color record has generally been shown to be acceptable from a practical as well as an operational standpoint. Although the SF-05 record has a significantly lower contrast than the Wratten no. 21 record (the filter it replaces on the aft-looking camera), this factor does not deter the information content of the scene when the SF-05 filter record is viewed in a stereo mode with the Wratten no. 25 record. It should be noted that the contrast can be brought up to the level of the Wratten no. 25 image in the duplication stage. From an operational standpoint, the SF-05 has a filter factor of 2.8, which is acceptable for the present camera system. The system resolution capability of the SF-05 with the second generation Petzval lens when the lens is focused at the Wratten no. 21 filter position is slightly lower than that of the Wratten no. 21 filter. However, this reduction in resolution does not appear to be a significant factor in influencing the filter's usefulness. Image quality losses on SF-05 records in Wratten no. 21 focal position with third generation lenses are expected to be more serious.

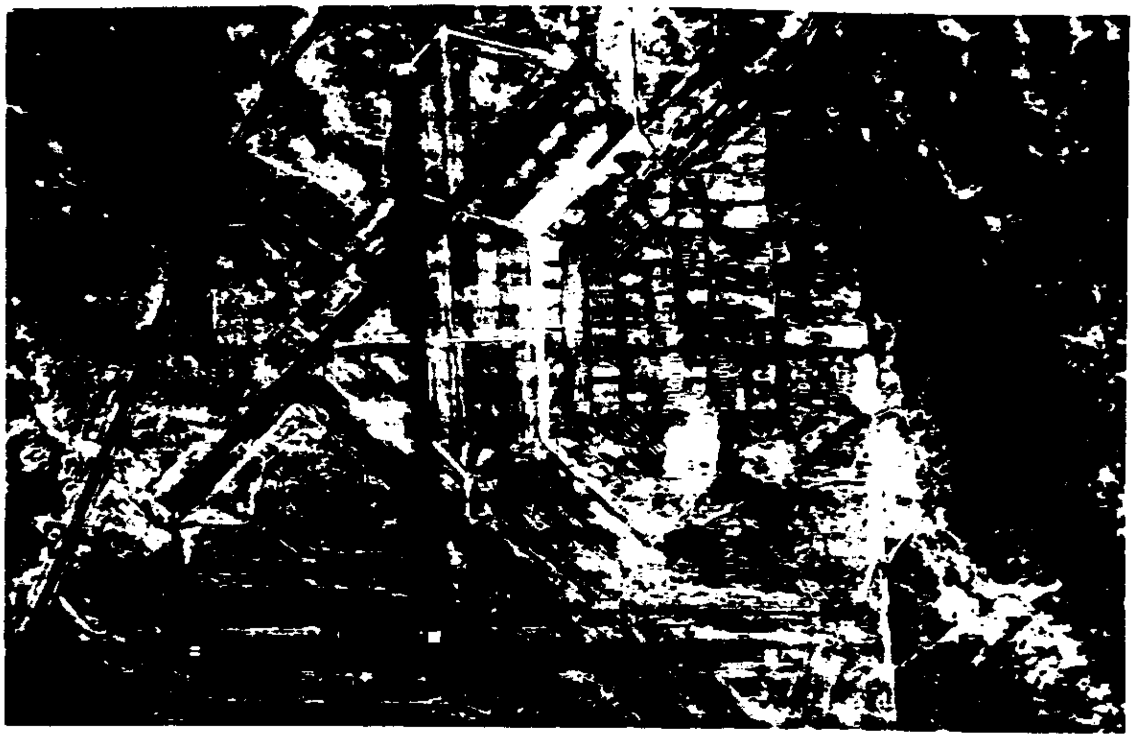
The various deformations introduced by camera geometry, spatial parallax, and relief displacements must be minimized for best results. Optical geometric rectification will remove camera and parallax deformations and still produce a high resolution positive with good tonal range. Optical orthophotographic instruments will remove positional errors induced by relief in the scene as well as rectify the positive. This also produces a good positive for integration. Electronic orthophotographic reproduction will also remove relief distortions, but the image suffers an information loss in the process. Scan lines and sweep paths both introduce "noise" which results in density differences across each scan line. The amount of information masked in electronic orthoprinting is dependent on the scale and target types of the scene. Lower altitude or larger scale photography with their larger image sizes are less affected since the scan lines cover a smaller percentage of each object. Definition of fine detail does suffer to some extent. At higher altitudes and with smaller scale photography, the items that were considered gross at lower altitudes are much smaller and more easily degraded by scan lines. As a result, the information loss appears to be greater with small scale photography than with large when electronic orthoprinting techniques are used.

(a) 20× orthoprint from red filtered negative

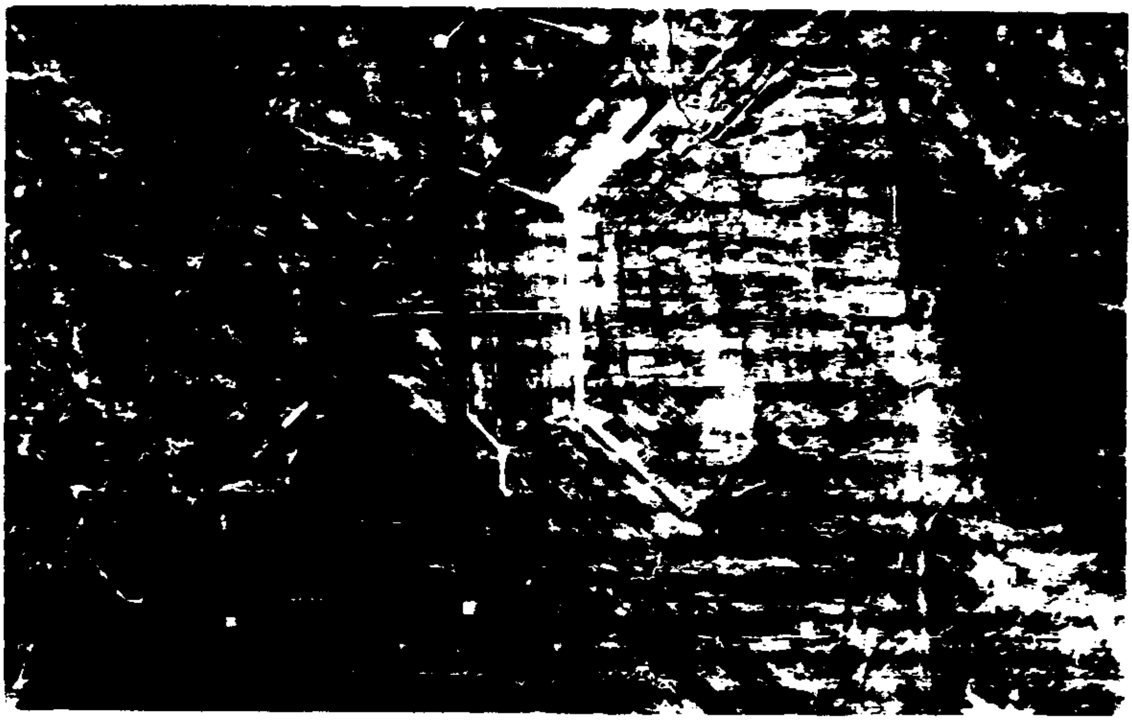
(b) 20× orthoprint from green filtered negative

Fig. 3-3 — Copper mine slurry, Arizona, 20× orthoprints

Fig. 3-4 — 20× bi-color integration made from green and red orthoprint records



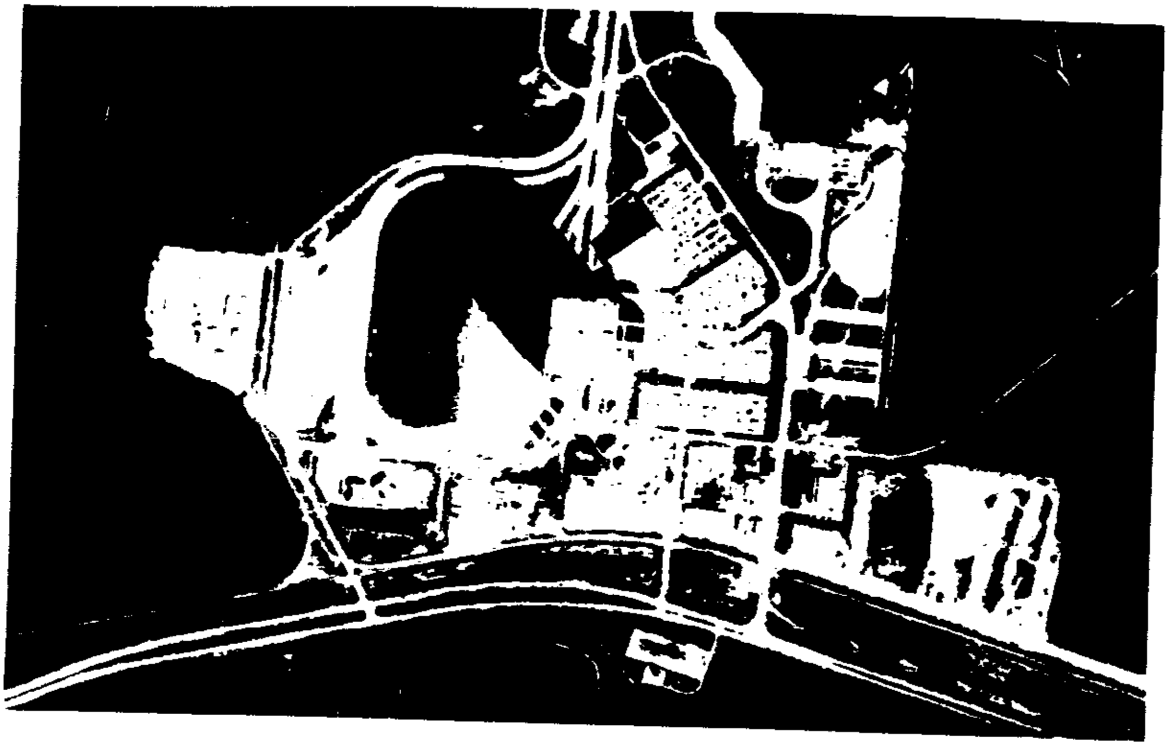
(a) 20× orthoprint from red filtered negative



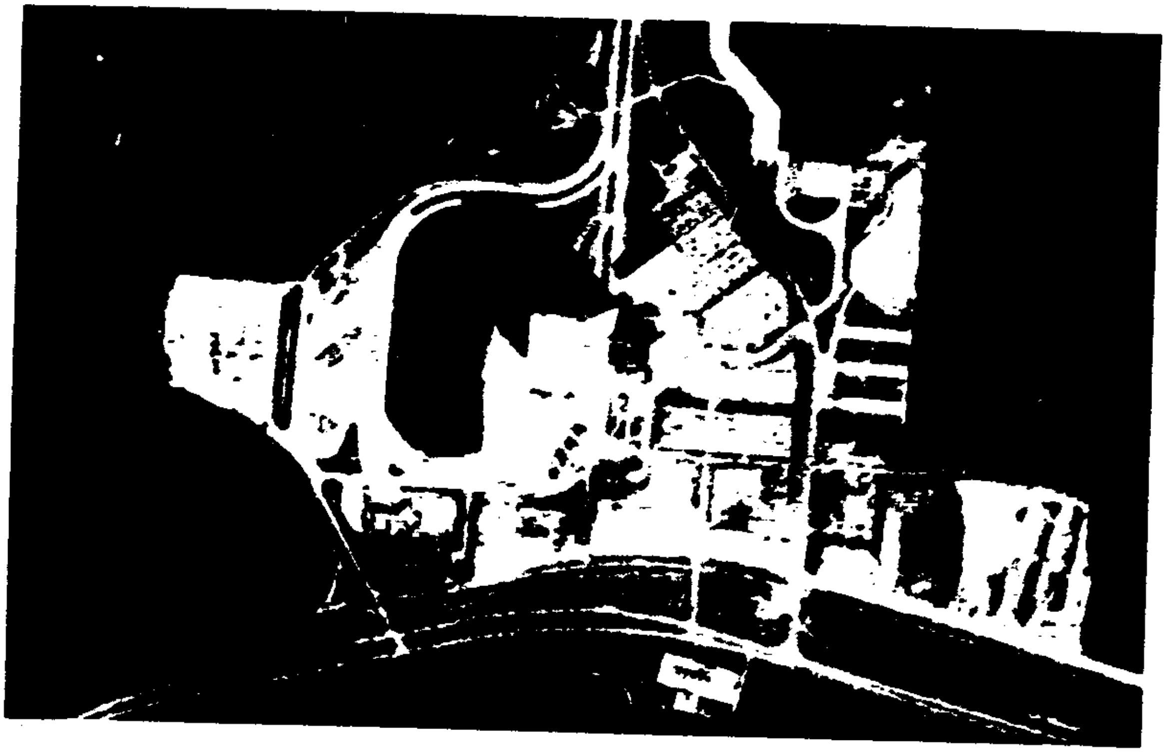
(b) 20× orthoprint from green filtered negative

Fig. 3-5 — Bisbee/Douglas International Airport, Arizona, 20× orthoprints

Fig. 3-6 — 20× bi-color integration made from green and red orthoprint records



(a) 20× rectified print from red filtered negative



(b) 20× rectified print from green filtered negative

Fig. 3-7 — Cape Kennedy, 20× rectified prints

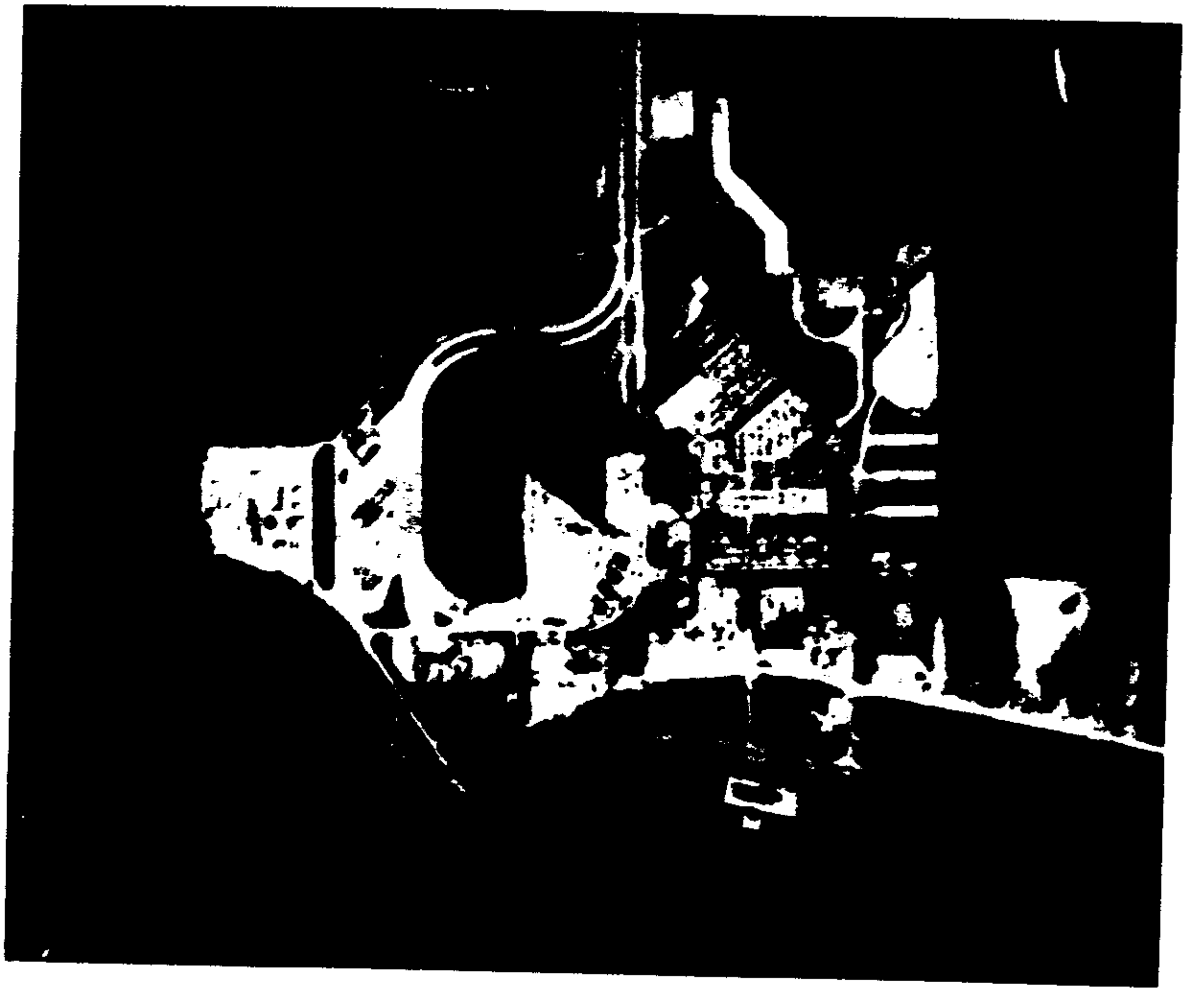


Fig. 3-8 — 20× bi-color integration made from green and red rectified records

4. EXPLOITATION TECHNIQUES AVAILABLE FOR BI-COLOR ACQUISITIONS

The successful use of bi-color photography is dependent upon the ability to precisely register the two color records during the simultaneous printing operation. This need for perfect registration requires that the relative positions of all image points within the printing area be identical on both records. The two original negatives will meet this requirement only if they are taken from the same point in space relative to the target and if they are taken with the same camera or two identical cameras; only then will the combined effects of geometric camera distortions, relief displacement, and target perspective be the same for both images. With any other camera configuration, these distortions will combine in completely dissimilar ways and result in two geometrically dissimilar images.

This dissimilarity of images will occur when using the J-3 convergent panoramic system. Although the two cameras are identical, the coverage of a given target is obtained from two widely separated points in space and consequent separation in time. In order to generate images suitable for registration under these conditions, it is necessary to remove or correct the dissimilar image displacements caused, in this case, by panoramic distortion, relief displacement, and perspective or convergent distortion. The precision with which the bi-color records can be registered is dependent upon the amount of correction that can be attained with the various techniques available.

Three techniques were considered for producing bi-color imagery—orthoprinting, rectification, and veiwing on the Automatic Registration Electronic Stereoscope (ARES) with a bi-color attachment. Each of these techniques corrects the image distortions to a different degree, and each presents the bi-color image to the photointerpreter in a different mode. Of the three, orthoprinting is the most sophisticated in that it corrects all three distortions. The rectification and ARES techniques will correct for the panoramic and perspective distortions, but will not compensate for the relief displacement.

The area of coverage can best be described by Fig. 4-1. In this illustration, a 0.8-inch square section of the panoramic frame was enlarged 10×. This chip covers an area of 3 nm on a side. The entire 8- by 8-inch image can be put on the ARES viewer; however, only a 1- by 1-inch area of this enlargement can be seen at one time with minimum zoom. This is equivalent to 3/8 nm on a side. At maximum zoom, the area of coverage is 1/8 nm on a side.

A description of these techniques and discussions of their advantages and disadvantages are provided in the following paragraphs.

4.1 RECTIFICATION

While orthophotography has the capability of removing all three J-3 image distortions, rectification can correct only the panoramic and perspective distortions. The relief displacement would remain uncorrected and cause problems in bi-color registration. For this reason, rectification is not generally as desirable as orthoprinting.