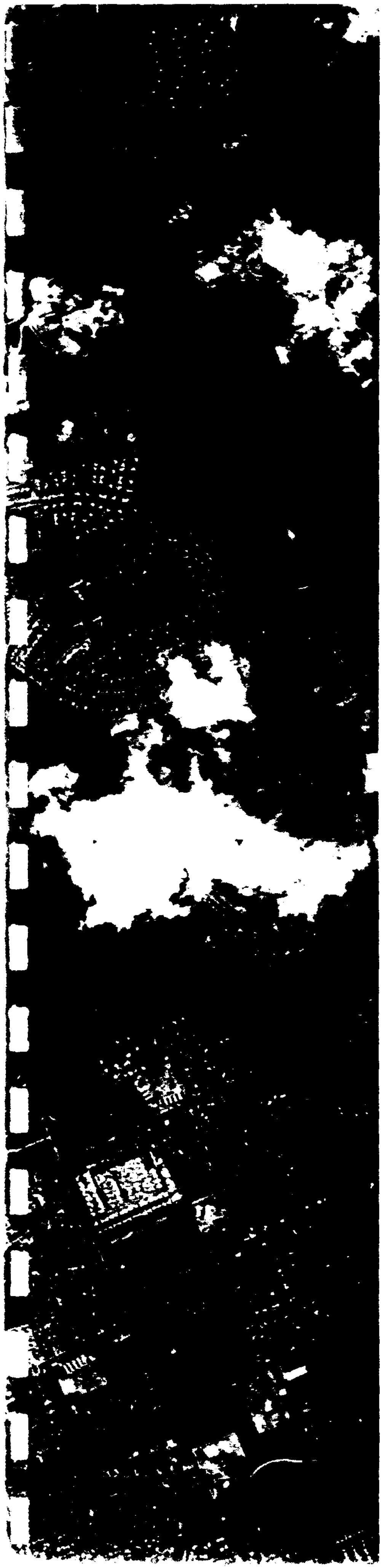

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EKIT REPORT NUMBER 15

METRIC COMPARISON BETWEEN SO-121 AND 3404

SEPTEMBER 1967

CONTRIBUTORS: [redacted]

APPROVED BY:

[redacted]

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1. SUMMARY

This test is intended to indicate what change, if any, is to be expected in dimensional intelligence accuracies based on mensuration precision when color (SO-121) material is used in conjunction with or in place of the standard black and white (3404) material for KH-4 missions. Of particular interest is any change in the precision of image point coordinate measurements and stereoscopic parallax measurements. These are the basic photogrammetric operations and, as such, are common to both the dimensional intelligence and area mapping activities.

It is generally expected that the precision of pointing and parallax measurements will be directly related to the inherent resolution of the imaging material. Therefore, it is assumed that when the two test materials are used independently of one another, the material having the higher resolving power will systematically permit measurements of higher precision. It is also assumed, then, that if the two materials are used in combination in a stereo operation, the precision of the resulting measurements will fall somewhere between the precisions of the materials had they been used independently.

There are, however, factors other than resolving power alone which influence measuring precision in that they add to the identification or interpretability of the target. Of these, the most pertinent to this study is the color discrimination afforded by the SO-121. It has been recognized in the promotion of color for the KH-4 Systems that, in a purely photointerpretive operation, the information gained through color discrimination often outweighs that lost due to a lower image resolution. It is the intent, then, of this test to determine whether this is also true for a metric or mensuration operation.

Complete black and white and color stereo coverage of a suitable target area was selected for this test from the material obtained during EKIT flight no. 12. EKIT test no. 12 consisted of an aircraft test in the 112B Camera System using color film type SO-121 in one camera and type 3404 in the other unit. The photography consisted of a cloverleaf pattern centered over the mobile CORN targets near Tucson, Arizona. A series of laboratory separation images were made through red, green, and blue filters. The maximum resolution of the best separation was 75 percent of the SO-121's resolution. Within the area covered, a group of measuring points were chosen. These points were then measured, making monoscopic pointings, stereo pointings, and stereo parallax measurements. The black and white and color materials were used both independently and in combination for these measurements. All of the measurements were repeated a number of times to provide sufficient statistical data for a comparison of the materials. These steps and the evaluation of the results are described in the following sections.

The following list presents the conclusions of this report. These conclusions are discussed in greater detail in Section 5.

1. Black and white separation positives can be made from type SO-121 color film.

2. The resolution of the separation positives will range from 50 percent (for the red record) to 75 percent (for the green record) of the resolution of the original SO-121 image.
3. In this test, none of the pointing or parallax measurements showed any definitive dependence upon the color of the target.
4. Due to the "colorless" nature of the targets selected, the precision of measurement on the targets was not appreciably influenced by the color film sensitivity but, as expected, will vary only as the image resolution.
5. No conclusion should be extrapolated from this test to cover type SO-180 (infrared color film) since its image formation and system resolution are not the same as type SO-121.

2. TEST PLAN

EKIT flight no. 12 [redacted] was flown on 16 August 1966 over the Phoenix-Tucson area of Arizona. The flight line was a cloverleaf pattern centered on the mobile CORN targets. This section of the report deals with the camera configuration, the scope of the test, and the specific flight plan that was used.

2.1 112B CAMERA SYSTEM

Although fully described in previous EKIT reports, a description of the 112B configuration is again included for the benefit of the new reader. The camera, a pan scanning type, has been designed around a diffraction-limited Petzval type lens of 24-inch focal length, with an f/3.5 aperture that covers a 6-degree field angle. To obtain stereo, a pair of these cameras is tilted from the nadir at 13 degrees each, and set face to face so that each camera scans in opposing directions. The lens is continuously rotated about its operational nodal point and scans across the line of flight and is translated against the flight direction for image motion compensation.

During approximately 70 degrees of the lens rotation, a capping shutter is opened to permit the aerial image to expose the 70-millimeter film through a slit. This slit controls the exposure time, e.g., at a 20-inch per second scan rate, a 0.040-inch slit produces an effective exposure of 1/500 second. At the completion of the photographic scan, the capping shutter is closed.

The film is continuously being transported in from the supply spool and out to the takeup spool. A frame-metering roller controls the frame length, the correct amount of film is placed in the format area, and clamps at each end of the format hold the film stable and in the approximate focus position. The excess film is accounted for by a shuttle assembly that gives or takes according to demand.

The focal position is determined by a scan head assembly mounted on a precise arm from the nodal point to the focus. This scan head gently lifts the film from the rails to the image plane during exposure and returns it to the rails after exposure. The rails are required only to hold the film at the approximate focus and to guide film during transport.

Recorded on the film edge outside of the format area on each frame are frame number, binary time, and timing pips of 125 cycles per second. These timing pips are scanned on the film across the 70-degree format length with one pip blanked out to indicate when the binary time data block is printing out. Three scanning rates are built in to match the V/h requirements while maintaining approximately 10 percent overlap at the format center. Increased overlap is acquired on both sides of nadir as the off vertical scan angle increases.

The exposure slit and filter are preselected for the V/h requirement and subject illumination and consistently produce the correct exposure.

2.2 SCOPE OF THE TEST

The photographic coverage for this test was obtained using a color material, type SO-121, in one camera and a black and white material, type 3404, in the other unit. The flight path was basically two cloverleaf patterns over selected areas in Arizona. Mobile CORN targets were located in the center of the area of main concern. The objective of the test was to use the two types of materials and determine differences in mensuration capabilities with them as they are produced from this type of panoramic scanning system. The measurements were made at Itek's Data Analysis Center in Alexandria, Virginia. The primary measuring instrument was a Wild STK-1 Stereocomparator with EK-6 Electric Coordinate Printer.

In order to obtain the maximum benefit from the material available, black and white separation positives were made from the color film. These images were measured along with the color and 3404 samples at DAC.

2.3 SPECIFIC CAMERA DETAILS

Table 2-1 lists the specific camera settings that were used on this mission. For optimum results with type SO-121, the camera focus must be shifted slightly. This was not done on this mission, and, as a result, the color material had a resolution of 48 lines per millimeter, instead of the expected 60 lines per millimeter as judged by the repeated (a total of eight) passes over the CORN targets.

Table 2-1 — Specific Camera Settings

Camera	I3 aft-looking	I4 forward-looking
Film	SO-121	3404
Slit width	0.049 inch	0.049 inch
Shutter speed	1/385 second	1/385 second
Filters	Wratten no. 2E + 0.68ND + 30CC Blue	Wratten no. 21
f/no.	3.5	3.5

3. COLOR SEPARATION PHOTOGRAPHY

Color photography will present many new problems to the mensuration and mapping community that were not present with ordinary black and white imagery. The inherent resolution of today's color films is lower than that of type 3404. There are two reasons for this: (1) the fact that there are actually three photographic emulsions stacked on each other puts a severe limitation on the quality; and (2) the dye globules themselves tend to "fall apart" when viewed under very high magnifications. When used in a camera system that is designed to use a Wratten no. 21 or 23A filter, additional problems in image quality are introduced. These lenses are not designed for the blue end of the spectrum and consequently do not perform well in that region. Despite these limitations, medium contrast operational resolutions as high as 48 lines per millimeter have been obtained (with an expected 60 lines per millimeter with optimum focus) on type SO-121 color film.

In addition to the problems encountered in obtaining an image, there are similar problems with the instruments that are to use these materials in mensuration and mapping. In order to assess the full impact on the community, a study would have to be undertaken to examine (1) the quality of the optics in regions of the spectrum in which they may not ordinarily be used, and (2) the spectral sensitivity of the instruments if a device other than the eye makes the final judgment.

3.1 BLACK AND WHITE IMAGES FROM COLOR ORIGINAL NEGATIVES

One possible solution to these problems may be found by using, not the actual color material, but a black and white positive image from this color film. Some form of duplicate must be made and there is no reason for that duplicate to be a color image. In fact, there are several reasons why it would be beneficial to use a black and white separation positive rather than a color image, the most obvious being that the image to be used is like the very familiar black and white positive obtained from the type 3404 record. The resolution may be lower but the essential point is that it is a familiar looking image.

The color positive contains three separate images of the original scene, each in a different dye layer—yellow, magenta, and cyan. The three dyes each control approximately one third of the visible spectrum; yellow controls the blue, magenta the green, and cyan the red. In printing these color originals, ordinary white light or white light and a filter can be used. Assuming that the print stock is sensitive to the entire spectrum, a negative made from the color transparency with a red filter (i.e., Wratten no. 25) would look almost the same as a 3404 original negative also made with a Wratten no. 25 filter. It should be noted, however, that the tonal relation between the real 3404/Wratten no. 25 record and the simulated record will be very close but not exactly alike. The spectral reflectance of natural and/or manmade objects in the original scene is only approximated by the color film dyes.

Black and white prints can also be made from the SO-121 with other separation filters, i.e., a green (Wratten no. 57 or 61) and blue (Wratten no. 47 or 47B). These filters would each give a black and white image that very closely resembles that which would have been obtained if the original 3404 photography had used the same filter. The blue separation record, as might be expected, will be very low in contrast and not very sharp.

3.2 SAMPLES FOR THIS EFFORT

For this test, four separation negatives (and subsequently positives) were made from one of the SO-121 images of an airfield and CORN targets.

They were made with three Wratten filters, and in one case with no filter at all (see Table 3-1). The final images are presented in Fig. 3-1(a) through 3-1(f).

Since there were very large differences in contrast, the duplicate negatives had various gammas in order to compensate for these differences and give a set of fairly well balanced images. Although this is not a particularly colorful part of the world, there are several areas where distinct alterations of the subject tones take place. The most obvious of these areas is that of the CORN targets (in particular the T-bar and its desert-like background). In the red separation record [Fig. 3-1(c)], the T-bar clearly stands out against the background, but in the green [Fig. 3-1(b)] and especially the blue [Fig. 3-1(a)] separations, it almost fades into the background because the reddish-brown background around the predominantly black T-bar is very dark with respect to the blue sensitivity of the SO-121. Object and background both being dark results in a loss of contrast for that particular part of the scene.

It is interesting to note the resolution values for each of these six samples; they are presented in Table 3-2.

The 3404 positive image, as would be expected, has the highest resolution. The next best is the SO-121, which has approximately 60 percent of the resolution of the 3404. Of the four separation positives, the green light and white light records are the same with the red light a close second. The blue record has the all-time low of 9 lines per millimeter. The reader can see these relationships with a small 7× or 10× magnifying glass; however, it is not fair to compare the color image in this text, since it is a reproduction of the original and, therefore, has a serious loss in resolution.

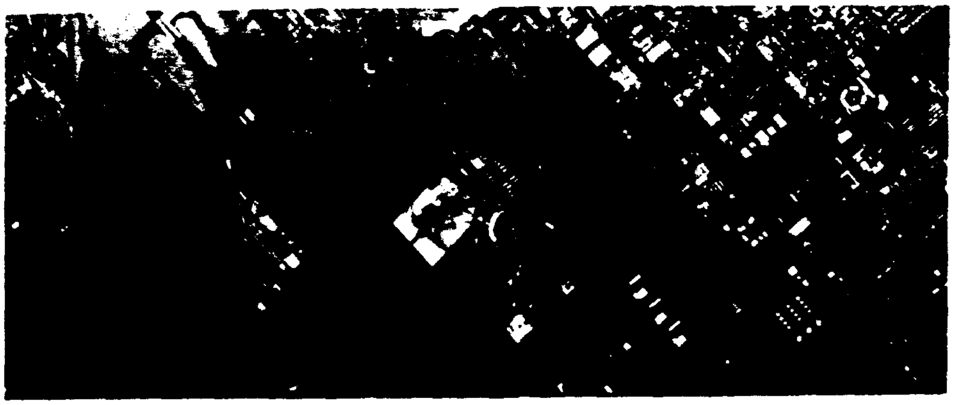
All of the resolutions of the black and white separations are lower than that of the SO-121 color image itself. The reason is that a two-stage printing process is required to obtain a positive image from the SO-121. The loss is attributed to the printing process involved. The reason that the green separation's resolution is higher than that of the red is explained by the color film's construction. Type SO-121 has its green sensitive layer on top, while the red sensitive layer is on the bottom. The spectral sensitivity of the green sensitive layer of SO-121 is not very far from the region of optimum results with the Petzval lens. The red sensitive record, which obtained an image from the spectral region in which the lens performs well, was degraded by the light scattering on its way through the color film down to the bottom layer. It is difficult to explain why the white light record is the best (equal to the green) since it should have had some degradation from the blue record. Perhaps there has been an "unsharp mask" effect taking place here such as in the graphic arts industry experiences in its separation and registration work.

Table 3-1 — Type of Images in Fig. 3-1 and Filter Used

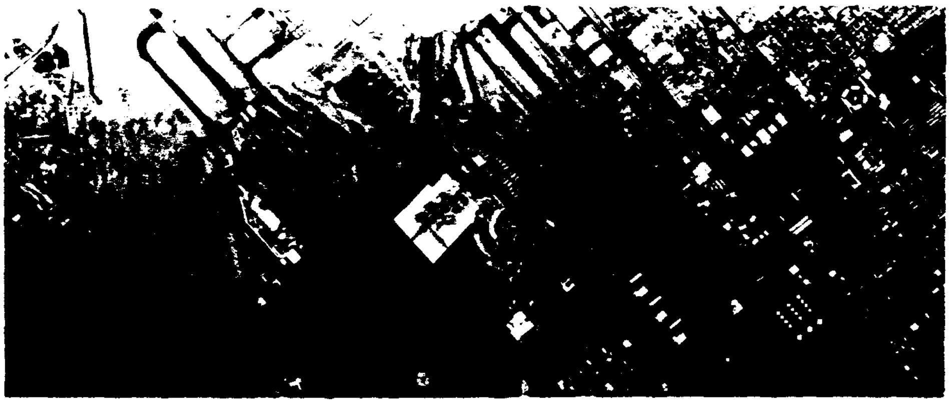
	Mode	Filter
Fig. 3-1(a)	Blue separation	Wratten no. 47
Fig. 3-1(b)	Green separation	Wratten no. 61
Fig. 3-1(c)	Red separation	Wratten no. 25
Fig. 3-1(d)	White light	None
Fig. 3-1(e)	3404 original	None
Fig. 3-1(f)	Color original (Ektacolor paper)	Not applicable

Table 3-2 — Resolution Values of Samples

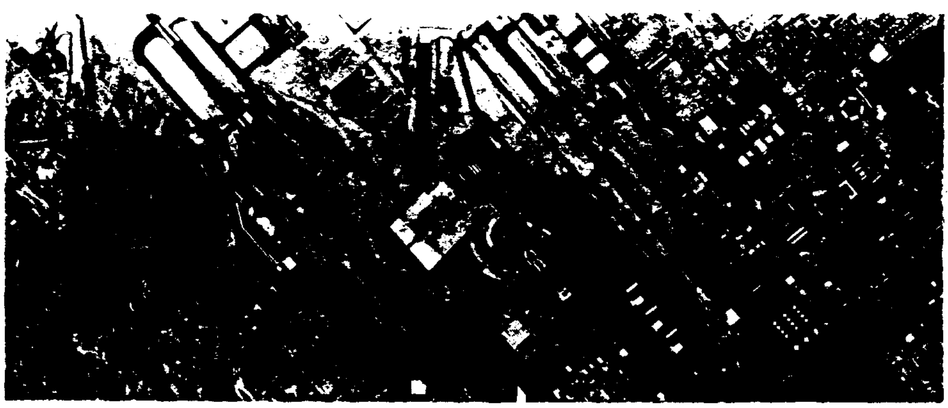
	Image	Resolution, lines per millimeter
Fig. 3-1(a)	Blue	9
Fig. 3-1(b)	Green	30
Fig. 3-1(c)	Red	24
Fig. 3-1(d)	White light	30
Fig. 3-1(e)	3404 original	77
Fig. 3-1(f)	Color (SO-121) original	48



(a) Blue separation record from SO-121

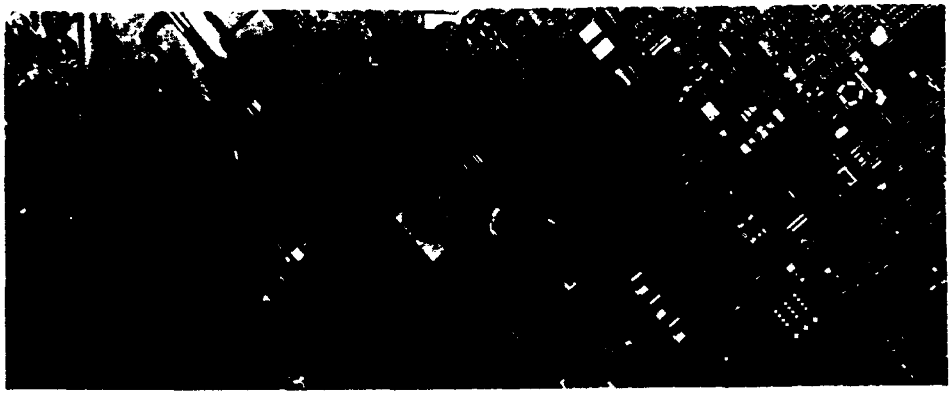


(b) Green separation record from SO-121

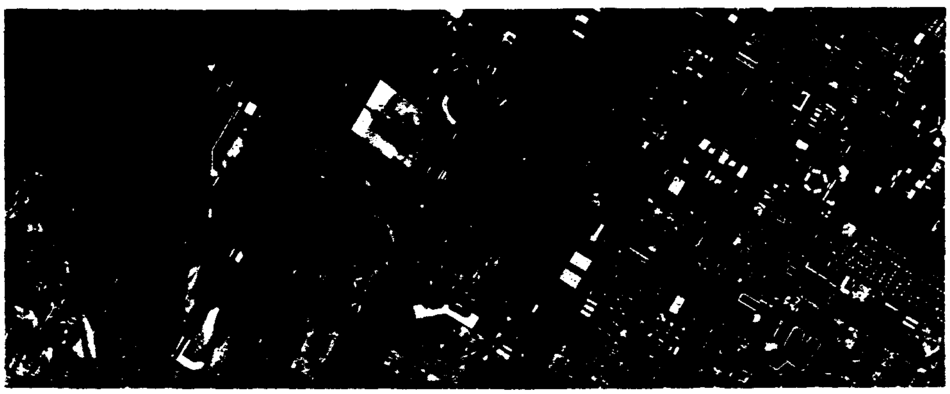


(c) Red separation record from SO-121

Fig. 3-1 — Examples of images made from separation negatives



(d) White light separation record from SO-121



(e) From original 3404 image

(f) From original SO-121 image

Fig. 3-1 — Examples of images made from separation negatives (Cont.)

4. MENSURATION ANALYSIS

4.1 SELECTION OF TEST AREA

To obtain complete stereoscopic coverage in both black and white (aft camera) and color (forward camera) with the split 112B System, it is necessary to make two photographic passes over a given target, the second flight line being identical to the first, but flown in the opposite direction. The EKIT no. 12 flight provided this duplicate coverage over two areas, one in the vicinity of Phoenix, Arizona and the other near Tucson (see Section 2). The photography of these areas was carried one step further in that it was flown in a cloverleaf pattern. This pattern resulted in complete stereoscopic coverage along two mutually perpendicular flight lines.

The photography of both areas was compared for stereo coverage and image content. The Phoenix area was then selected for this test primarily because of the presence of mobile CORN targets including a step tablet, color patches, and a resolution T-bar. Also, these flights, being centered on an airfield, provide the greatest variety of suitable target points over the smallest area. It was possible, then, to locate a sufficient number of targets within a single stereo model. The CORN targets permitted a comparison of the image qualities and spectral characteristics of the frames selected. Four frames were chosen: 3404 stereo pairs and SO-121 stereo pairs obtained from the same camera on different legs of the cloverleaf pattern. In addition, a separation positive was made from each of the SO-121 samples. That portion of the field covered by these exposures is shown in Fig. 4-1 which is an enlargement of the separation images in Fig. 3-1.

4.2 SELECTION OF TARGETS

The two photographic materials being evaluated in this test are to be compared as to the precision or repeatability of pointing and parallax measurements of individual points on selected targets. It was pointed out earlier that the major factor determining the precision of these measurements, other than the precision of the measuring instrument, is the interpretability of the targets, this interpretability, in turn, being determined by the resolution of the material at the contrast of the particular targets and the color of the targets. A complete evaluation of the potential of these materials requires a selection of target points which encompasses the full range of colors and contrasts recorded by the films.

Although the primary considerations during the selection of target points were contrast and color, targets at various elevations were selected to provide differences in stereo relief. Also, targets were considered which typify those for which dimensional intelligence information might be extracted and those which might be used for map control. At the scale of the EKIT and KH-4 materials, very few of the relatively small intelligence type targets display a single pure color. Therefore, the color panels were also included as measuring points. In all, 14 targets were chosen. The 14 were subsequently reviewed in detail on the measuring instrument and 10 of these selected for measurement. These are identified in Table 4-1 and annotated on Fig. 4-1.

Fig. 4-1 — Photograph illustrating areas measured for the mensuration test

4.3 PREPARATION OF MATERIALS

In addition to satisfying the immediate objectives of this test, the types of material required (original, duplicate positive, duplicate negative, etc.) were selected based on the best judgment of which were most likely to be used by the dimensional intelligence and mapping groups. These materials can take many forms including that of the color separation records described in Section 3. These color records may, for instance, find extensive use in map production as aids in delineating color features such as vegetation and water. However, for strictly mensurational applications, the choice of materials was narrowed to three.

Table 4-1 — Target Number and Type Used in Measurement Tests

Target No.	Description
1	Corner of red panel
2	Corner of blue panel
3	Corner of white panel
4	Corner of black panel
5	Third frame on hangar roof
6	Intersection on taxi way
7	Corner of terminal building
8	Right wing tip of aircraft
9	Third vent on building roof
10	End of building roof peak

First, as long as one-half of the KH-4 System retains the 3404 material, all of the user community will continue to receive duplicate positives of this material. In any event, duplicate positives of the 3404 are necessary in this test to supply a comparative baseline representing present operations. Duplicate positives on 8430 film were prepared from the original 3404 negatives.

Second, the original color positives, if intended to fulfill their objective, will have to be supplied to the community in the form of duplicate positives. For the purposes of this test, the originals of the color frames were used instead of duplicates.

Intermediate negatives used to produce all black and white positive duplicates of the SO-121 record were made on SO-243 film; a panchromatic emulsion of flat spectral response, extended red sensitivity, high resolving power and processing characteristics that fit our requirements very well.

Finally, black and white duplicate positives of the two SO-121 stereo images, also on 8430, were prepared. These positives will provide a separation between the mensuration characteristics of the SO-121 based on its color and resolution together and that based solely on its resolution. For this test, the white light print (described in Section 3) was used. The positives also simulate the material which would of necessity be used in a mapping operation, should equipment somewhere along the line be unable to handle color material.

The types of material selected for mensuration were prepared for each of the four frames covering the Phoenix target area and cut to approximately 10-inch lengths for mounting on the measuring instrument. Also, a paper print of the area at about 5× enlargement was prepared as an aid for the instrument operator. The target points were outlined on this print and numbered for ease of identification.

4.4 TARGET MENSURATION

The instrument on which the pointing and parallax measurements were made is a Wild STK-1 Stereocomparator with EK-6 Electric Coordinate Printer located at the Itek Corporation Data Analysis Center, Alexandria, Virginia. Resolution tests were performed on the viewing optics of this instrument prior to the preparation of the mensuration materials to ensure that the optics would fully utilize the quality of the test material. If the resolution of the viewing system were less than that of the test material at original scale, the material would require magnification. The resolution readings taken with both high and medium contrast targets through the full range of viewing magnification are listed in Table 4-2. The resolution readings were the same for either half of the viewing system using both the high and medium contrast target. The highest and most comfortable viewing magnifications for the test materials proved to be 20× or 22×. The 20× magnification was selected for measuring. At this setting, the resolution of the optics is beyond that of the materials to be used, and therefore, no photographic enlargement was necessary.

Table 4-2 — Comparator Resolution
(High and Medium Contrast)

Magnification	Resolution, lines per millimeter
6	40
11	64
12	64
20	128
22	128
40	161

The six strips of test material were mounted on the stage plates of the stereocomparator as indicated in Fig. 4-2. This comparator is designed for orthogonal viewing of the imagery from underneath the glass stage plates. The optics of the viewing system, therefore, are fixed to look through the stage plate at imagery placed face down against the plate. In order to obtain proper stereo of the nine possible models formed by the six films, the duplicate positives of the 3404 material were mounted emulsion side down, while the SO-121 and SO-121 (B&W) had to be mounted emulsion side up. The slight defocusing introduced by the emulsion up mounting of the SO-121 and SO-121 (B&W) did not cause any loss in viewed image quality at a level which would affect the results of this test. Also, because of the orthogonal viewing, the emulsion up mounting has no geometric effect. The films were secured in place with a cover plate and remained covered throughout the entire mensuration sequence.

Before measuring was started, the targets on each of the six film strips were identified on the comparator with the aid of the paper print prepared for this purpose. The 10 best targets were selected for mensuration and numbered as indicated in Fig. 4-1.

The monocular x and y coordinate measurements of the targets on the left stage were made first. These measurements were begun by pointing on each of the 10 targets on the 3404 frame at one time and then proceeding similarly through the two SO-121 frames. This procedure constituted one measuring pass. The sequence was then repeated for a total of 10 passes. By separating the pointings in this way, a degree of independence was maintained between the 10 pointings on any one point. The x and y coordinate values for the 300 pointings were automatically recorded on punched cards together with a code number identifying the target, frame, and pass.

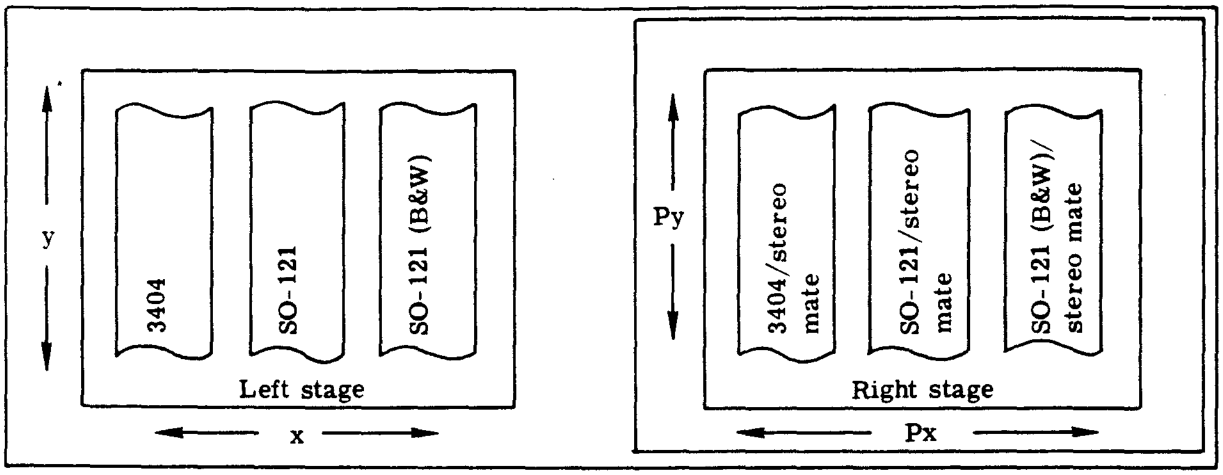


Fig. 4-2 — Film orientation on comparator

Of the nine possible stereo models, six were selected for the stereo pointing and parallax measurements. These are listed below in the order in which they were measured.

Model	Left Stage	Right Stage (stereo mate)
1	3404	3404
2	3404	SO-121
3	SO-121	SO-121
4	SO-121	SO-121 (B&W)
5	SO-121 (B&W)*	SO-121 (B&W)
6	SO-121 (B&W)	3404

Here again, independent readings were desired. Therefore, each target in the six models was measured once; the sequence then repeated. This time only five passes were made. Fig. 4-2 shows the film orientations on the instrument.

* (B&W) indicates the black and white duplicate positives of the SO-121.

The individual measurements in the stereo mode consisted of a pointing on the target on the left stage as before, and a removal of P_x and P_y parallaxes on the right stage. The final clearance of P_y parallax was done by rotating this parallax parallel to the eyebase using the dove prisms in the viewing system. After each setting was completed, the x and y coordinates of the left stage and the P_x and P_y coordinates of the right stage were recorded on punched cards with the appropriate code number.

4.5 COMPUTATIONS

The target coordinates recorded on punched cards during mensuration were processed through a special computer program in preparation for the final precision analysis. This program sorts the coordinates according to their identification code and computes the standard deviations of the repeated measurements on each target. The individual coordinate values as obtained from the comparator through the EK-6 Coordinate Printer are given to the nearest micron. As a result of the averaging of repeated values by the computer program, the final standard deviations are carried to one additional decimal place.

The program first computes the standard deviation in both x and y for the monocular pointings of each target on the left stage plate. The individual x and y standard deviations for each target were later combined into a single value representing the total pointing precision on that target. These combined values for the monocular pointings are listed in Table 4-3.

Table 4-3 — Standard Deviations (in microns) of Monocular Pointing ($\sigma_P^2 = \sigma_x^2 + \sigma_y^2$)

Target	3404	SO-121	SO-121 (B&W)
1	2.0	2.8	2.9
2	1.8	2.3	2.0
3	1.2	1.5	1.5
4	1.4	2.6	2.1
5	1.6	2.6	1.8
6	1.5	1.5	1.3
7	1.4	1.4	1.5
8	1.5	1.5	2.3
9	1.2	2.1	2.7
10	1.5	3.2	2.7

Next, the program computes the standard deviations for the x and y coordinates of the left stage recorded during the stereoscopic pointings. These were also combined to give a single value representing the stereo pointing precision on each target. The combined values are listed in Table 4-4.

Finally, the standard deviations are computed for the P_x and P_y coordinates of each target on the right stage as recorded during stereo pointing. These values were to be used in an analysis of the parallax measuring precision of the test materials. However, this is not possible using these standard deviations directly.

The parallaxes for each stereo pointing are defined as $\Delta P_x = x - P_x$ and $\Delta P_y = y - P_y$. The computer program has determined the precision of both the x, y and P_x, P_y coordinates.

However, because of a direct correlation between the left and right stage measurements, the precision of the parallaxes cannot be determined through any simple combination of the coordinate precisions above. The precisions of the parallaxes were determined, therefore, by going back to the original x, y and P_x, P_y measurements and computing the ΔP_x and ΔP_y parallaxes for each stereo pointing. The standard deviations of the parallaxes for repeated pointings on each target were then computed and are listed in Table 4-5.

Table 4-4 — Standard Deviations (in microns) of Stereoscopic Pointing ($\sigma_P^2 = \sigma_x^2 + \sigma_y^2$)

Target	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	2.6	2.8	3.7	2.4	2.6	3.5
2	1.8	1.7	2.2	2.5	2.2	2.6
3	1.3	2.3	3.2	1.4	1.6	3.4
4	1.9	1.7	3.0	3.0	1.9	2.8
5	2.1	1.4	2.9	2.6	1.8	1.8
6	1.2	1.9	1.6	1.7	2.1	1.2
7	2.7	1.7	2.2	2.4	2.4	1.7
8	1.2	2.3	2.4	2.2	1.4	2.1
9	1.9	1.8	2.0	2.6	1.7	3.3
10	2.4	3.0	3.0	2.1	2.9	2.1

Table 4-5 — Standard Deviations (in microns) of Stereoscopic Parallax ($\sigma_{\Delta P}^2 = \sigma_{\Delta P_x}^2 + \sigma_{\Delta P_y}^2$)

Target	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	2.1	4.3	4.9	3.2	1.6	4.2
2	1.7	3.4	2.0	4.2	2.4	3.7
3	1.8	2.8	2.7	2.6	2.5	1.7
4	2.0	1.9	3.8	2.4	3.8	2.8
5	3.1	2.1	3.7	2.5	3.5	1.3
6	1.2	2.3	1.9	1.5	2.2	1.6
7	1.8	3.3	3.0	3.4	6.1	1.7
8	1.2	2.4	4.7	1.8	2.3	2.3
9	1.6	1.5	2.8	3.3	2.4	1.5
10	2.4	2.8	2.4	2.9	1.9	2.4

4.6 ANALYSIS

4.6.1 Monocular Pointing

The standard deviations of monocular pointing on each target for each film type as listed in Table 4-3 are displayed graphically in Fig. 4-3. The horizontal lines on the graph represent the standard deviation of all the targets for each film. A comparison of the three plots indicates that:

1. The pointings on the 3404 material are generally more precise than those on SO-121 or SO-121 (B&W). The pointings on the color materials are, at best, only equal to the average precision of the 3404 pointings.

2. The pointings on the 3404 material are more uniform and show less variation between the individual targets. The uniformity of the 3404 pointings through the 1.25- to 1.5-micron range and the cutoff of the color pointings at that level point to the 1.25-micron value as being about the limiting precision of the total mensuration procedure. Later it will be seen that the best of the stereo pointing and parallax measurements approach, but never exceed, this value.

3. The relatively large variations in pointing precision with SO-121 and SO-121 (B&W) are not correlated to the color of the targets in that the most precise and least precise of these pointings occur on targets having no significant color.

4. The pointing precisions with SO-121 and SO-121 (B&W) are primarily dependent on their one common characteristic, image resolution, as evidenced by the similarities in their variation with the individual targets.

In general, it appears that the gain in image interpretability provided by the color does not overcome the loss due to the inherently lower resolution. This is particularly true of manmade intelligence type targets which have very little or no color. The overall effect then, in substituting SO-121 for 3404 film, is to lower the monocular pointing precision of these targets. Those targets which do show equally good pointing precisions on all materials (targets 3, 6, and 7) have a common characteristic in that they are all light-colored, well-defined targets on medium or heavy density backgrounds. This result may be put to advantage in the selection or signalization of control points for color mapping operations.

4.6.2 Stereoscopic Pointing

The standard deviations of stereoscopic pointing on each target as listed in Table 4-4 are displayed graphically in Figs. 4-4 and 4-5. Fig. 4-4 shows the results of measurements taken from balanced models, those in which both frames are of similar material; and Fig. 4-5 shows the results from mixed models, those in which the two frames are of dissimilar materials. A comparison of this data with the monocular pointing data displayed in Fig. 4-3 indicates a generally lower pointing precision in the stereoscopic mode. As the average precision in pointing has decreased, the variations in precision between targets on the 3404 material have increased; and, the most precise of these pointings remains at the 1.25- to 1.5-micron level noted for the most precise monocular pointings. This is taken as an indication of the limiting precision of the overall mensuration procedure.

Although the stereoscopic pointing precision as shown in Fig. 4-4 is generally lower than the monocular, this is specifically true only for the 3404 and SO-121 materials. These two materials have also maintained the spread in their average pointing precisions which was previously correlated to their difference in image resolution. The pointings on the SO-121 (B&W) material do not show this drop in precision between monocular and stereoscopic pointings. The average precisions with this material are about equal in both cases. This shift in the SO-121 (B&W) data with respect to the others destroys any definitive correlation of the stereo pointing precisions with image resolution.

The three curves in Fig. 4-4 also show some differences in precision between the materials for pointings on the color targets (targets 1, 2, and 3). These were not so evident from the monocular data. There are, however, differences of equal magnitude between the materials for

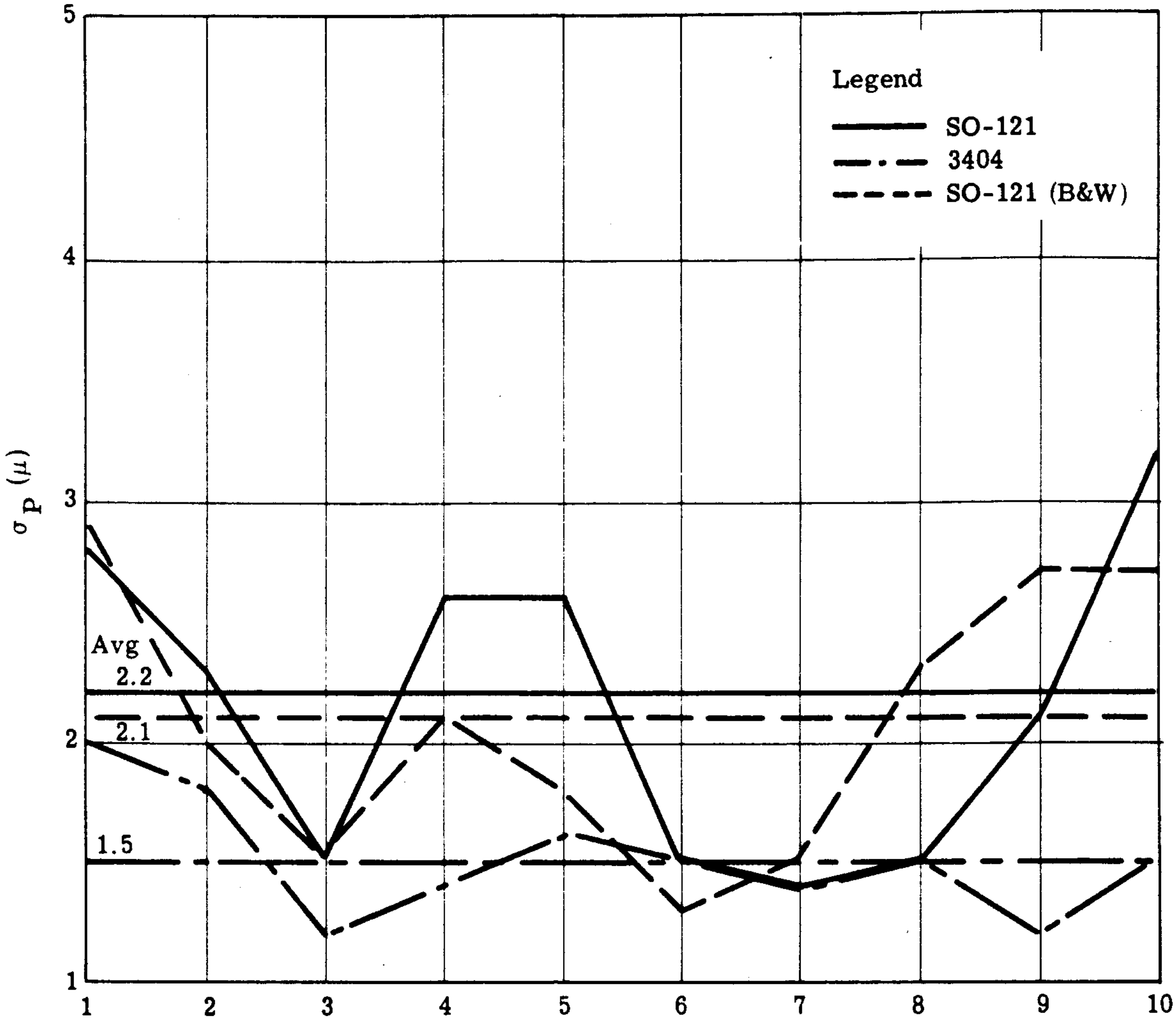


Fig. 4-3 — Monocular pointing ($\sigma_P^2 = \sigma_x^2 + \sigma_y^2$)

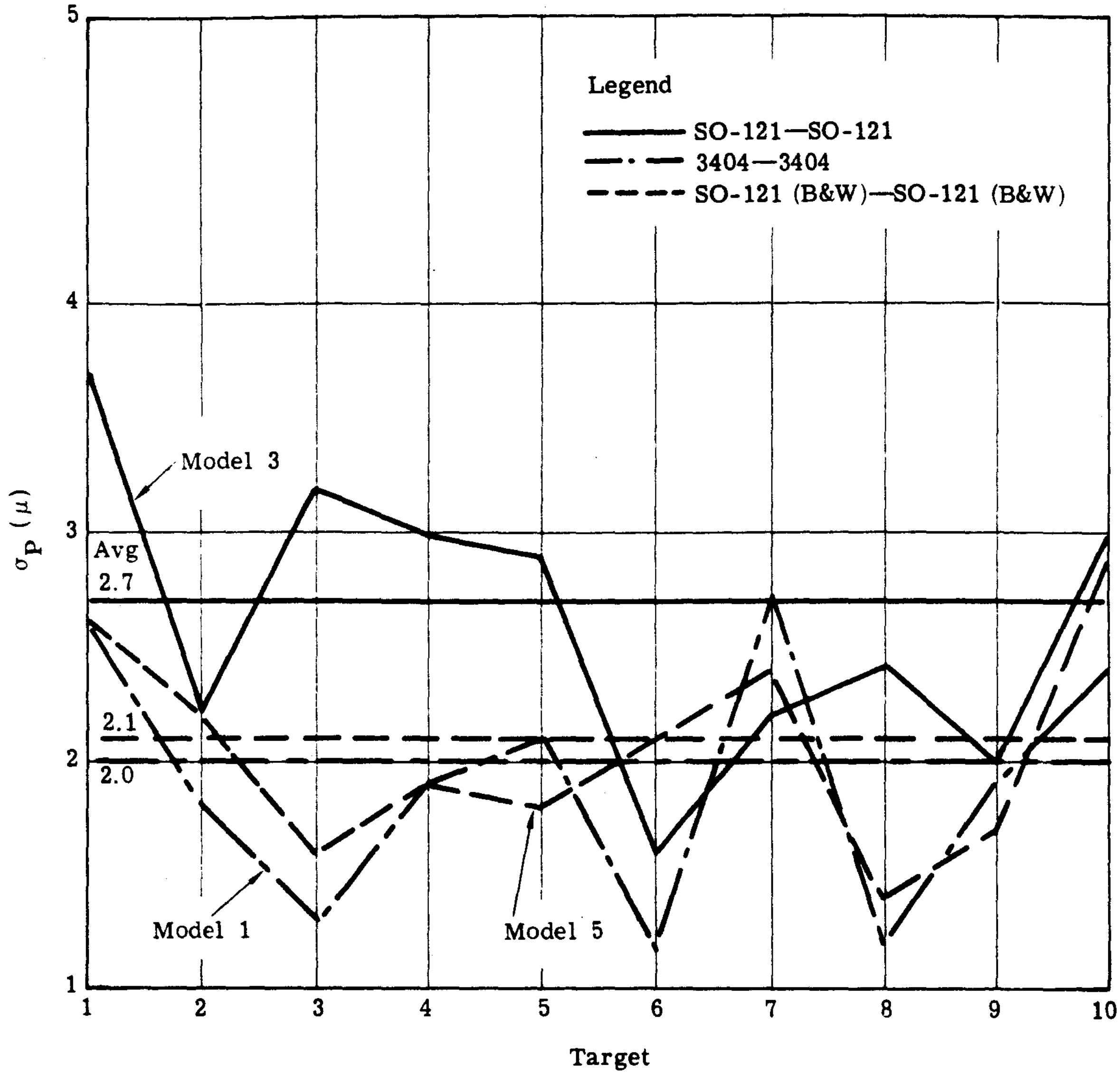


Fig. 4-4 — Stereoscopic pointing of balanced models ($\sigma_P^2 = \sigma_x^2 + \sigma_y^2$)

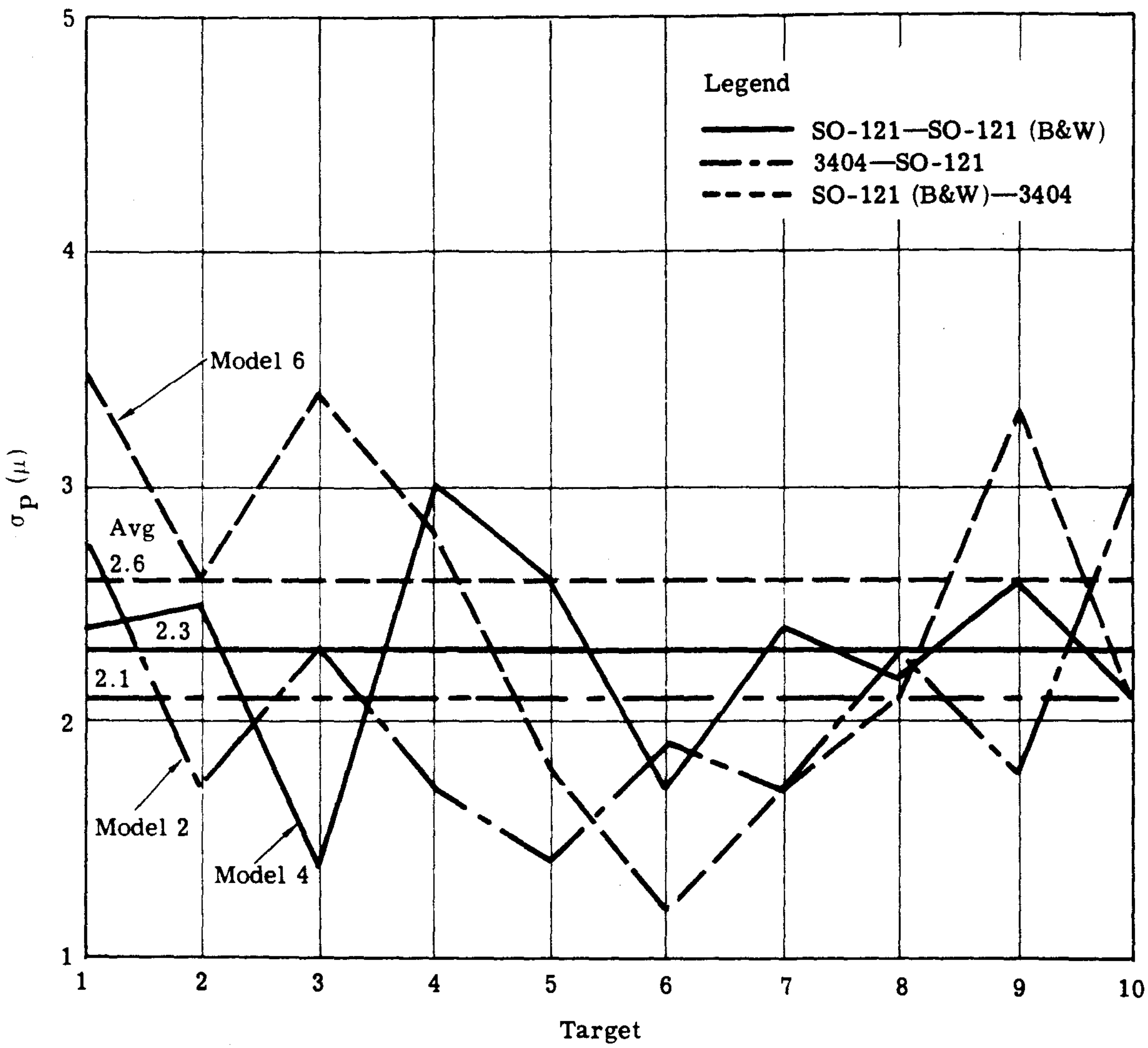


Fig. 4-5 — Stereoscopic pointing of mixed models ($\sigma_P^2 = \sigma_x^2 + \sigma_y^2$)

pointings on targets which have no color. This makes it impossible to distinguish the effects of color sensitivity of the materials from random variations in the precision of the data.

Additional evidence of the random nature of this stereo data can be found in a comparison of Figs. 4-4 and 4-5. There are several inconsistencies in the changes in pointing precision when converting from a balanced to a mixed model. For instance, when the low resolution black and white model, SO-121 (B&W)—SO-121 (B&W), was changed to the SO-121 (B&W)—3404 model through the substitution of the higher resolution black and white frame, the pointing precision became worse. It might be expected then, that a balanced model of low resolution will afford a higher precision than a mixed model even though one frame is of higher resolution. However, in contrast to this, when the high resolution black and white model, 3404—3404, was converted to the 3404—SO-121 model through the substitution of the lower resolution color frame, the pointing precision was unchanged.

These comparisons of the stereo data lead to the conclusion that the variations in the pointing precisions between the selected targets, as determined by mensuration accuracy and target quality, are sufficiently large to cloud any significant differences between the materials. A more definitive test would require a larger number of targets which fall into well-defined categories of target color and target quality.

4.6.3 Stereoscopic Parallax

The standard deviations of stereoscopic parallax measurement for each target as listed in Table 4-5 are displayed graphically in Figs. 4-6 and 4-7. Fig. 4-6 shows the results of measurements taken from balanced models and Fig. 4-7 shows the results from mixed models. This data shows significant similarities to that of both the monocular and stereoscopic pointings.

Figs. 4-6 and 4-7 indicate that the precision of stereoscopic parallax measurement is generally about the same as stereoscopic pointing. The similarity between these precisions is even greater if the two or three targets showing gross errors in parallax measurement are excluded from that data as blunders. The average parallax precision of the SO-121 and SO-121 (B&W) models in Fig. 4-6 would then increase to 2.9 microns and 2.6 microns, respectively. Also, there are differences in precision between the materials in the measurement of the color targets similar to those seen in the stereo pointings which, again, cannot be related directly to the color of the targets.

Fig. 4-6 also shows great similarities to the monocular pointings in Fig. 4-3. The close agreement between the SO-121 and SO-121 (B&W) curves in Fig. 4-6 and the relative values of the average parallax precision for each material indicate a correlation between the parallax precision and image quality of the materials resembling the correlation noted in the monocular data. This correlation was not seen in the stereo pointing data.

A comparison of Figs. 4-6 and 4-7 indicates a more systematic trend in the change of parallax precision between balanced and mixed models. In each instance, the mixing of two dissimilar materials to form a stereo model affords a parallax precision which is about midway between the precisions of the two materials when used in balanced models. This result was predicted in the introduction in the event color had no influence and image quality alone determined the measuring precision.

Overall, this data appears to be more meaningful and conclusive than that of the stereo pointing. But here again, the relatively large variations in precision between the individual targets make any differences between materials appear insignificant.

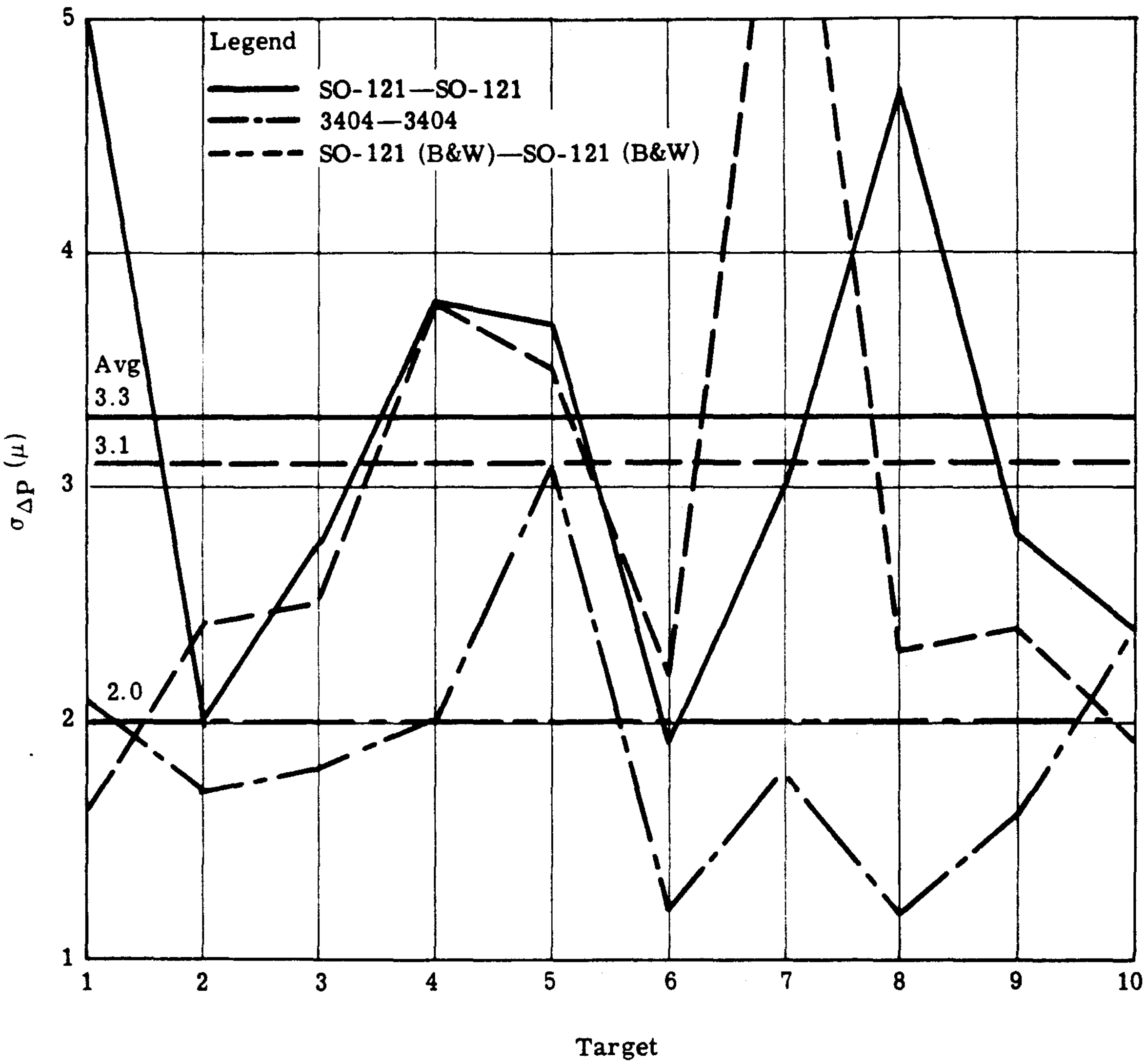


Fig. 4-6 — Stereoscopic parallax of balanced models ($\sigma^2_{\Delta P} = \sigma^2_{\Delta P_x} + \sigma^2_{\Delta P_y}$)

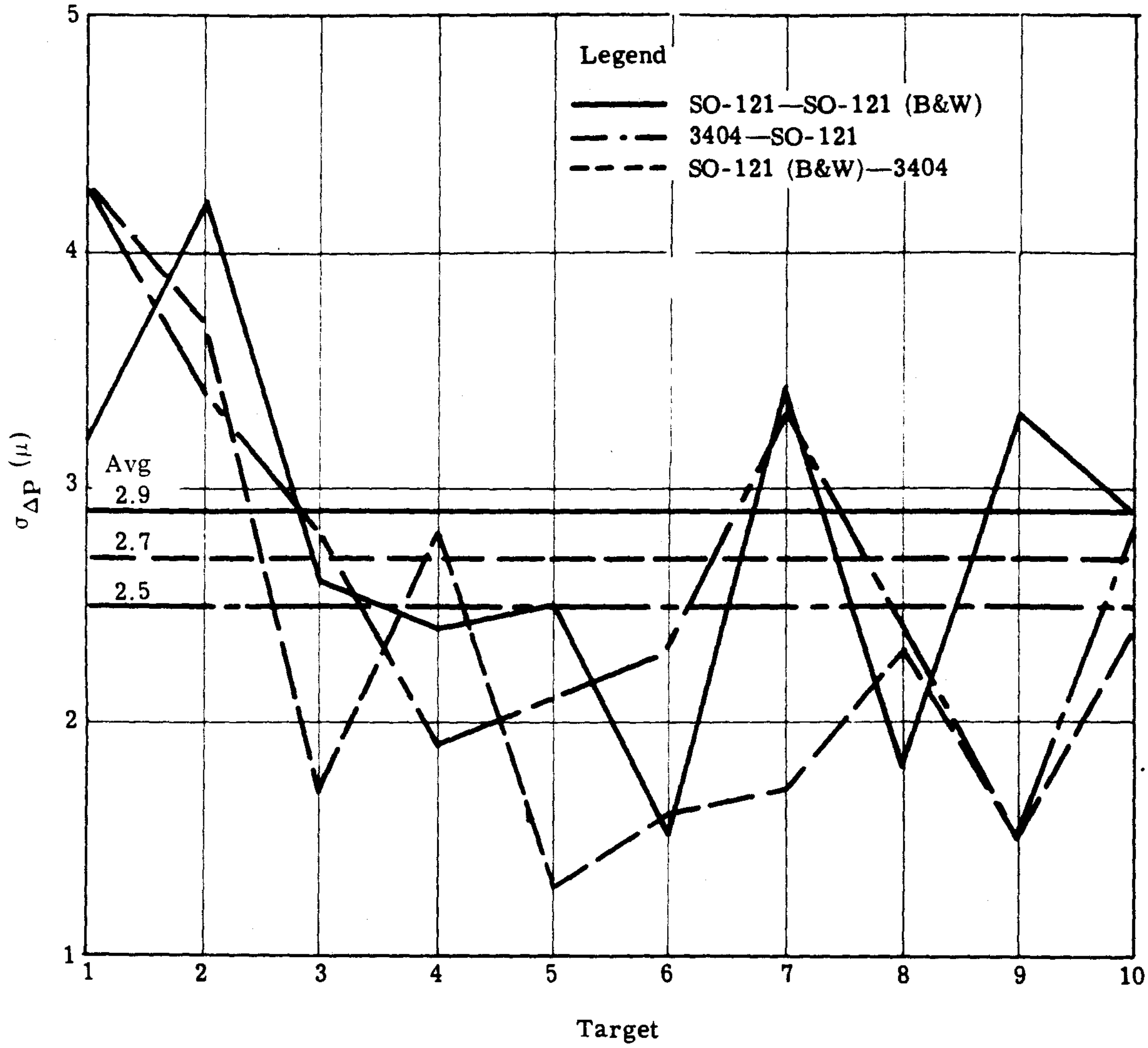


Fig. 4-7 — Stereoscopic parallax of mixed models ($\sigma^2_{\Delta P} = \sigma^2_{\Delta P_x} + \sigma^2_{\Delta P_y}$)

5. CONCLUSIONS

The intent of this test was to determine what effects, if any, the use of color material would have on mensuration precision. It was of particular interest to determine whether or not the color information would add enough to the mensuration precision to overcome the expected loss due to the lower resolution of the color material. To investigate this question specifically from the intelligence aspect, measuring points were selected on targets which are typically of interest to an intelligence operation. It became apparent that these targets, mostly manmade structures, have very little color. To provide more dramatic color data for this test, the red, blue, and white color panels were also chosen as measuring targets.

The following conclusions are drawn from this analysis:

1. Black and white separation positives can be made from type SO-121 color film. The tonal relationships in this positive can be made to have a similarity to type 3404 when used with a red filter.

2. The resolution of the separation positives will range from 50 percent (for the red record) to 75 percent (for the green record) of the resolution of the original SO-121 image. Under the worst conditions, the resolution falls to 20 percent (9 lines per millimeter with the blue record).

3. In this test, none of the pointing or parallax measurements showed any definitive dependence upon the color of the target. This held true even for the color panels.

4. Due to the "colorless" nature of the targets selected, the precision of measurement on the targets was not appreciably influenced by the color film sensitivity but, as expected, will vary only as the image resolution. The precision of these measurements follows much the same pattern as would be expected if a black and white material of lower resolution were used instead. Although this test indicates a consistent trend for the measurements on the higher resolution material to be somewhat more precise than those on the lower resolution material, the magnitude and significance of the numbers associated with these precisions needs some qualification. The average measuring precisions on the 3404 and SO-121 materials differ by approximately 1/2 micron while the precisions of the individual targets on both materials differ as much as 1.5 to 2.0 microns. The magnitudes of the average precisions then, may vary through this 2-micron range depending on the particular selection of targets. The average value for both materials, however, should vary together, thus maintaining a spread of approximately 0.5 micron. This would indicate then that the choice between the two materials for the measurement of intelligence type targets would only be important in the most precise operations where a difference in measuring precision of 0.5 micron or even 1.0 micron would be significant.

5. No conclusion should be extrapolated from this test to cover type SO-180 (infrared color film) since its image formation and system resolution are not the same as type SO-121.