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INVESTIGATION OF ADDITIVE COLOR PHOTOGRAPHY AND PROJECTION FOR MILITARY PHOTO-INTERPRETATION

III. Comparison of additive color and panchromatic aerial photography

Contract Nonr 3137(00)

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Technical Report - 3
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They also express sincere appreciation to LCDR George M. Dougan and his crew, especially PH1 Skidmore, of the Fleet Air Photographic Laboratory at North Island Naval Air Station, whose support to this research in the field was magnificent and invaluable.

SUMMARY

This report describes continued research on Office of Naval Research Contract Nonr-3137(00). An experimental study was conducted to compare the number of targets which could be detected and the size of detail which could be resolved with various projections of additive color and its separate components against a panchromatic system and a simulation of panchromatic film. This study parallels the preceding laboratory study under this contract except that similar targets were photographed from the air using the additive system and comparison film was taken. Considering separate viewing of additive records as a single condition, the separated records provided the highest performance. The minus-blue filtering used with the comparison panchromatic system appears to have reduced its effectiveness considerably under the conditions of the present experiment.

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I. INTRODUCTION

This report describes a combined field-laboratory study under Dunlap and Associates' present program on the evaluation of additive color techniques for enhancing photographic interpretation information.

Two previous reports (1 & 2) have been issued which describe the early phases of the program. The first report (1) described an additive system and hypothesized some of the values of an additive color system for military photo-reconnaissance. It was pointed out that aerial color photography has, in several various applications, provided substantial advantages over black and white photography, and that an additive color system eliminates objections based upon added film, storage and processing costs of color film. On the negative side however, imaging area requirements may be increased and special lens packaging development is involved. In addition, an additive color system introduces minor complexities to an already complex aerial camera system and present interpretation equipment and procedures. Such considerations are basic to the evaluation of an additive color system and must be kept in mind while further investigation of the system is in progress

It has already been pointed out that workable techniques are available for achieving aerial color photography inexpensively and that there are many applications which point to the value of color in aerial reconnaissance. However, regardless of the method used for achieving color, the use of color in military photo-reconnaissance does not appear to have been justified sufficiently While further research into the application of "full" color is felt to be important, it has not been included in the scope of this project. Rather, the direction taken has been to assess the ability of an additive color system to provide contrast enhancement through spectrally separated records which are integral in the additive process.

The second report (2) of this research program describes an experiment which demonstrates the degree to which separated additive records can increase the dectability and visual resolvability of a random set of color targets which were mocked-up in the laboratory. That experiment demonstrated that the increased contrasts available on separated records is sufficient to enhance the detection and resolution of targets, within the conditions which could be simulated in the laboratory.

In the experimental work carried out thus far in the program a great deal of artificiality has been involved. The reason for artificiality is two-fold. First, it is important in the qualitative description of a system to be able to analyze the effects which are a function of the system without confounding by extraneous variables. Second, an objective description of the capability of a system requires that the system be tested in a manner which will yield objective data. Two related criteria have been employed in the laboratory experiment with the additive color system: increased target detectability and increased resolvable detail. Successful demonstration of the system's capability based on those criteria leaves open two immediate and critical questions. Will such gains as have been demonstrated in the laboratory persist over the great camera-to-target distances involved in aerial reconnaissance, and do the conditions which have been produced artificially constitute a valid test?

II. THE EXPERIMENT

This report describes the third step in the evaluation program. It is essentially a replication of the laboratory study with a limited sample of similar artificial targets photographed from the air. In addition, several military targets were photographed from the air; they will be the subject of a later report.

The study is a limited test of the ability of an additive color system to enhance target detection and resolution under actual conditions of aerial photography. In addition to the introduction of variables associated with aerial photography, including a limited amount of atmosphere, a presumably valid basis for comparison with existing aerial photography was added by simultaneous use of a comparison camera exposing Super XX film. In general, testing procedures used in the present experiment adhere to those developed for the previous laboratory study.

Apparatus

The apparatus for the experiment consisted primarily of an additive color projector. Details of the projection system are described in Technical Report No. 1 (1). The major deviations of the projector from a standard projector are as follows: rhomboid prisms are used to form three independent but equivalent light paths; the three paths are focused in a common plane by separate projection lenses, each equipped with an independent iris adjustment; a slide mechanism permits simultaneous entry into the light paths of Wratten filters 29, 47, and 61, or three neutral density filters which balance the brightness of the three paths to simulate projection of a panchromatic film.

The projector was mounted at the subject's left on a triangular-shaped table, which was enclosed except for an aperture through which the light is projected. A front surface mirror at the far end of the projection table reflected light onto the rear of a neutral density, ultramatte screen. Viewing distance was maintained by a foam-covered headrest extending from the wall on the subject's right

Ambient illumination was provided by a 40-watt tungsten filament bulb, shielded to illuminate only the area below the subject's waist. The comparison panchromatic film was projected through one of the optical paths of the additive projector.

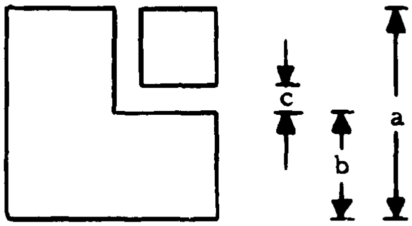
Stimulus Materials

Aerial photographic sortis for the purpose of obtaining film which could be used in this study were coordinated with Fleet Air Photographic Laboratory, LCDR Dougan, Officer-in-Charge. A preliminary flight was performed in April 1961, in order to acquaint the personnel involved with the N. C. Mitchell camera modified by addition of the Colorvision lens and anticipate the problems which might be involved in mounting the camera and conducting extensive flight tests. Although it was impossible to evaluate the additive system on the basis of those preliminary pictures, it seemed practical to use the existing equipment for further testing.

Artificial targets were photographed on 19 October 1961, from an SNB-SP-type aircraft carrying the 35 mm. N. C. Mitchell supplied by VU-7 and a 35 mm. N. C. Mitchell adapted by Colorvision, Inc., for mounting their additive color lens system. The camera mounts (specially constructed by VU-7) permitted simultaneous exposure of the two systems which were suspended to provide vertical pictures.

The targets were photographed from 1250, 2500 and 5000 feet. Atmospheric conditions were described as slight haze, medium sunlight (between 1 and 3 PM), and visibility 5 - 10 miles. Both cameras were focused for infinity and used 30° of shutter. Both cameras were run at 24 frames per second; the Colorvision camera at f2, comparison at f16. The comparison camera was used with a 75 mm. lens and 15G filter; the Colorvision camera was used with a nominal 125 mm. (actual 250 mm.) lens and a #85 filter. Both cameras used Eastman Kodak XX5222 (B&W) film which was developed to a gamma of 65 and printed with P-1 developer for high contrast by General Film Laboratories, Los Angeles, California.

The artificial targets were fabricated of cardboard according to the following dimensions: (a) 52.09 in., (b) 26.04 in., (c) 6.51 in.



Those dimensions were chosen so that the resulting images photographed at specified altitudes and projected in the laboratory would correspond to three target sizes used in the previous laboratory study.

Based on the above dimensions, the diagonal of the target was approximately 73.7 in. or 6.25 ft.

On a 35 mm. negative in the additive system

$$\text{image size} = \frac{\text{object size} \times \text{focal length of additive lens}}{\text{altitude}} \times \text{correction factor for additive system re-imaging optics}$$

With the target dimensions described above photographed from 5000 ft.;

$$\text{image size} = \frac{6.25 \text{ ft.} \times .82 \text{ ft.}}{5000 \text{ ft}} \times .288 = .000245 \text{ ft. or } .0035 \text{ in.}$$

When that image is projected by the additive color projector with 24X magnification, it becomes .084 in. When viewed by the subject from 28 in., the .084 in. diagonal size of the target subtends approximately 10.8' of visual angle.

Similarly computed, the filmed targets resulted in the following projected sizes, (expressed in minutes of visual angle at 28 in. viewing distance) when photographed from 5000 ft., 2500 ft., and 1250 ft.

	Diagonal (Visual Angle)	Critical detail (dimension "c" above) (Visual Angle)
5000 ft.	10.8'	1.00'
2500 ft.	21.5'	2.00'
1250 ft	43.0'	4.00'

A very close approximation to the image size on the additive system negative was attained on the comparison negatives by using a 75 mm. lens with the standard Mitchell. Image size on the additive film and comparison film were compared visually and the projected images measured on the projection screens: no differences were measurable.

Six basic paint colors were used on the targets: red, yellow, orange, green, blue-green, and blue. A light desaturated, set was mixed to be used against a light background and a dark, saturated set, achieved by increasing the proportion of pigment, was mixed for targets to be used against a dark background.

Two matrices consisting of 24, sixteen-inch squares were layed out in rectangles 96 ft. x 65 ft. Targets were assigned randomly from the 6 light colors to positions and orientations to a matrix against a light background. A total of 15 targets were assigned: 3 yellow, 3 blue, 3 green, 2 red, 2 orange, and 2 blue-green. Targets were assigned in a like manner from the six dark colors to a matrix against a dark background. A total of sixteen targets were assigned: 3 green, 3 orange, 3 red, 3 blue-green, 2 yellow, and 2 blue.

Immediately following the photographic flight, the twelve different targets were photographed on the ground against the backgrounds on which they were placed. Film densities of the targets and backgrounds were measured with a densitometer for the purpose of computing contrasts and chromaticity coordinates. Table I presents the brightness contrasts of the twelve targets (six against each background, for each projection condition), the chromaticity and Y value of the targets, and the chromaticity and Y value of the two backgrounds.

TABLE I

TARGET CHROMATICITIES AND CONTRASTS

Background	Target No.	Color	Chromaticity x	Chromaticity y	Y	CONTRAST (%)* Y	red	green	blue	Simulated Panchro.	Comparison Panchro.
Light Background	1	Yellow	425	.410	64.4	48	45	50	28	43	48
	2	Red	.418	.373	55.1	30	41	38	44	42	39
	3	Blue	300	.362	44.1	24	28**	38	60	43	22
	4	Blue/Green	.300	.399	48.0	29	31**	46	52	41	29
	5	Green	.329	.393	59.4	44	07	54	59	51	43
	6	Orange	.455	373	52.6	36	58	29	28	34	37
Dark Background	7	Green	.313	.415	40.5	39	16**	52	58	46	38
	8	Blue	.295	.344	39.4	38	10**	48	75	55	35
	9	Orange	.509	.364	52.4	53	68	37	37	49	53
	10	Red	.407	.376	55.8	56	55	56	66	59	56
	11	Blue/Green	.293	.406	53.0	54	04**	64	72	61	52
	12	Yellow	.448	.397	69.3	65	67	64	56	62	65
	B1	Dark Bkgd	.426	.391	24.6						
	B2	Light Bkgd.	.419	.382	33.5						

*$\frac{\text{Brighter - Less Bright}}{\text{Brighter}} \times 100$

**Targets darker than background

Subjects

Six subjects were used in the study. The subjects included five males and one female who were screened for normal color vision with American Optical Pseudo-isochromatic Plates and for 20/20 Snellen acuity.

Experimental Design

The experimental conditions consisted of six types of projection: red record, green record, blue record, simulated panchromatic, full additive color, and comparison panchromatic. The simulated panchromatic was included in order to check on the degree of similarity to actual panchromatic which was attained in the simulation. Each type of projection was used to present each of the two target matrices: one against the light background and one against the dark background. Since only two target matrices were used, negatives obtained during North and South flight headings were alternated to inhibit familiarization with target locations on any given matrix. Light and dark background conditions were randomized for the six types of projection which were presented in a counter-balanced order. The six types of projection of the two different backgrounds were presented at three different sizes, from smallest to largest, to three subjects. Three additional subjects were tested on just the intermediate size.

Procedure

The subjects were briefed on the nature of the experiment and what to expect and look for in the stimulus presentation. They were instructed to work carefully and take as much time as necessary. The subjects were seated 28 in. from the rear projection screen, limited by a forehead rest projecting from the adjacent wall. The subjects were given five minutes to adapt to room ambient illumination prior to testing. The task required the subject to point out, with the aid of a hand-held pointer, the location of artificial targets within an imaginary matrix, starting with the uppermost target and working from left to right, top to bottom. Location of the acuity breaks were reported verbally as upper left, upper right, etc. Incorrect responses and omissions were recorded by the experimenter on master data sheets.

Results

Summary results are presented in the form of percentages of total number of possible targets detected and detail resolved.

Their evaluation is directed primarily at comparing various aspects of additive color with other forms of photography. To indicate the value of viewing the three additive records separately, a composite score is compiled which represents a composition of performance on the three records viewed separately. That is, if a given target is detected or recognized on any or all of the three separation records, it is recorded only as a single correct response.

The results are summarized in Figure 1, which presents percent correct responses, detection and resolution, for each type of projection, as a function of target size. Number of correct responses per number of presentations is presented in Tables II-A, B, and C.

Discussion

All targets used in the experiment have greater brightness contrast with the background on one of the separated additive color records than under any of the other experimental conditions. That must always be the case except when target and background have exactly the same relative spectral reflectance properties. Since the results of the experiment demonstrate superior target detectability and detail resolution with the separated records, target/background contrast appears to be a major factor in determining the performance which is judged by those criteria. It appears to be especially important to the present study that

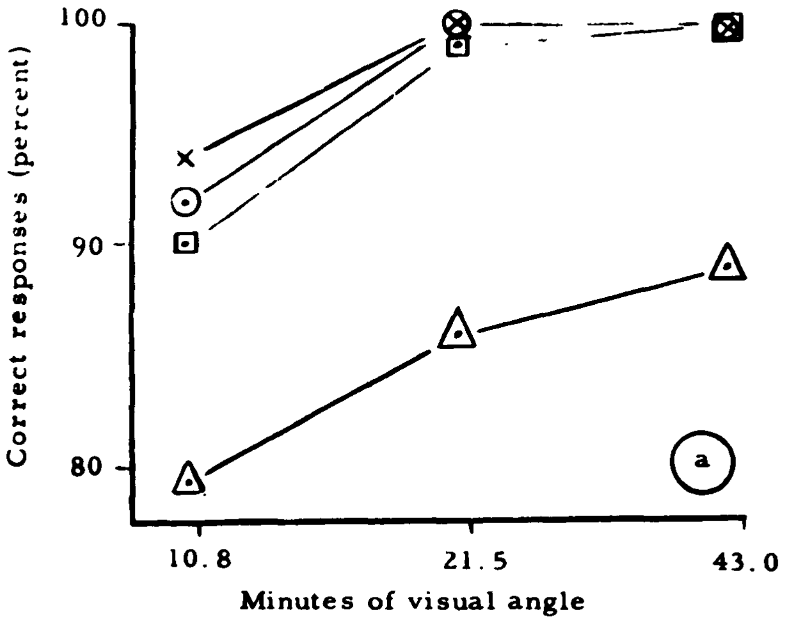


Figure 1. Percent of total targets detected (a) and detail resolved, (b) with projection of:

- △ panchromatic
- ⊡ simulated panchromatic
- ⊙ full additive color
- X separated records

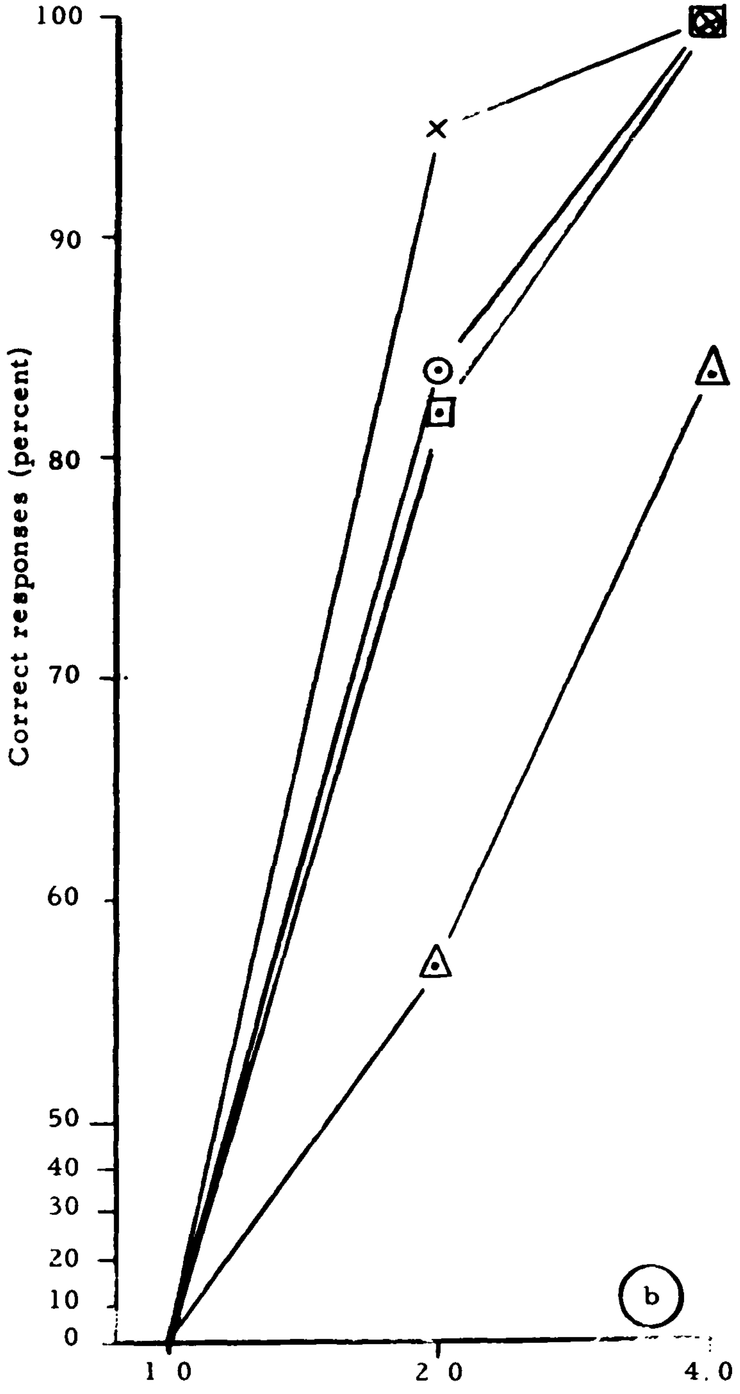


TABLE II-A

Number of targets correctly detected (D) and resolved (R) per presentation*

Target No.	Comparison Panchromatic 5000 D	R	2500 D	R	1250 D	R	Simulated Panchromatic 5000 D	R	2500 D	R	1250 D	R
1	9/9	0/9	18/18	10/18	9/9	9/9	9/9	0/9	18/18	14/18	9/9	9/9
2	6/6	0/6	12/12	6/12	6/6	6/6	6/6	0/6	12/12	10/12	6/6	6/6
3	0/9	0/9	0/18	0/18	0/9	0/9	9/9	0/9	17/18	7/18	9/9	9/9
4	6/6	0/6	12/12	2/12	6/6	6/6	3/6	0/6	12/12	11/12	6/6	6/6
5	9/9	0/9	18/18	11/18	9/9	9/9	9/9	0/9	18/18	18/18	9/9	9/9
6	6/6	0/6	12/12	8/12	6/6	5/6	6/6	0/6	12/12	8/12	6/6	6/6
7	9/9	0/9	18/18	12/18	9/9	9/9	9/9	0/9	18/18	14/18	9/9	9/9
8	0/6	0/6	2/12	1/12	5/6	1/6	6/6	0/6	12/12	12/12	6/6	6/6
9	9/9	0/9	18/18	15/18	9/9	9/9	9/9	0/9	18/18	17/18	9/9	9/9
10	3/9	0/9	18/18	14/18	9/9	9/9	3/9	0/9	18/18	14/18	9/9	9/9
11	9/9	0/9	18/18	16/18	9/9	9/9	9/9	0/9	18/18	18/18	9/9	9/9
12	6/6	0/6	12/12	10/12	6/6	6/6	6/6	0/6	12/12	11/12	6/6	6/6
# correct	72	0	158	105	83	78	84	0	185	154	93	93
Total	93	93	186	186	93	93	93	93	186	186	93	93
% correct	77	0	85	56	89	84	90	0	99	83	100	100

*Number to left of slash is number correct; number to right of slash is number presented.

TABLE II-B

Number of targets correctly detected (D) and resolved (R) per presentation*

Target No.	Composite of Additive Records 5000 D	R	2500 D	R	1250 D	R	Full Additive Color 5000 D	R	2500 D	R	1250 D	R
1	9/9	0/9	18/18	17/18	9/9	9/9	9/9	0/9	18/18	18/18	9/9	9/9
2	6/6	0/6	12/12	12/12	6/6	6/6	5/6	0/6	12/12	9/12	6/6	6/6
3	9/9	0/9	18/18	17/18	9/9	9/9	9/9	0/9	18/18	14/18	9/9	9/9
4	6/6	0/6	12/12	10/12	6/6	6/6	6/6	0/6	12/12	10/12	6/6	6/6
5	9/9	0/9	18/18	17/18	9/9	9/9	9/9	0/9	18/18	15/18	9/9	9/9
6	6/6	0/6	12/12	9/12	6/6	6/6	6/6	0/6	12/12	8/12	6/6	6/6
7	9/9	0/9	18/18	18/18	9/9	9/9	9/9	0/9	18/18	14/18	9/9	9/9
8	6/6	0/6	12/12	12/12	6/6	6/6	6/6	0/6	12/12	7/12	6/6	6/6
9	9/9	0/9	18/18	17/18	9/9	9/9	9/9	0/9	18/18	17/18	9/9	9/9
10	3/9	0/9	18/18	18/18	9/9	9/9	3/9	0/9	18/18	14/18	9/9	9/9
11	9/9	0/9	18/18	18/18	9/9	9/9	9/9	0/9	18/18	16/18	9/9	9/9
12	6/6	0/6	12/12	12/12	6/6	6/6	6/6	0/6	12/12	12/12	6/6	6/6
#correct	87	0	186	177	93	93	86	0	186	154	93	93
Total	93	93	186	186	93	93	93	93	186	186	93	93
%correct	94	0	100	95	100	100	92	0	100	84	100	100

*Number to left of slash is number correct; number to right of slash is number presented.

TABLE II-C

Number of targets correctly detected (D) and resolved (R) per presentation*

Target No	Red Record 5000 D	Red 5000 R	Red 2500 D	Red 2500 R	Red 1250 D	Red 1250 R	Green Record 5000 D	Green 5000 R	Green 2500 D	Green 2500 R	Green 1250 D	Green 1250 R	Blue Record 5000 D	Blue 5000 R	Blue 2500 D	Blue 2500 R	Blue 1250 D	Blue 1250 R
1	9/9	0/9	18/18	17/18	9/9	9/9	9/9	0/9	18/18	14/18	9/9	9/9	0/9	0/9	8/18	6/18	6/9	4/9
2	6/6	0/6	12/12	12/12	6/6	6/6	6/6	0/6	12/12	3/12	6/6	6/6	3/6	0/6	12/12	9/12	6/6	6/6
3	0/9	0/9	0/18	0/18	2/9	2/9	9/9	0/9	18/18	2/18	9/9	9/9	9/9	0/9	18/18	17/18	9/9	9/9
4	0/6	0/6	0/12	0/12	0/6	0/6	6/6	0/6	12/12	4/12	6/6	6/6	3/6	0/6	12/12	10/12	6/6	6/6
5	0/9	0/9	0/18	0/18	0/9	0/9	9/9	0/9	18/18	9/18	9/9	9/9	9/9	0/9	18/18	17/18	9/9	9/9
6	6/6	0/6	12/12	9/12	6/6	6/6	5/6	0/6	11/12	0/12	6/6	6/6	3/6	0/6	12/12	3/12	5/6	5/6
7	0/9	0/9	0/18	0/18	0/9	0/9	9/9	0/9	18/18	18/18	9/9	9/9	9/9	0/9	18/18	15/18	9/9	9/9
8	0/6	0/6	0/12	0/12	0/6	0/6	6/6	0/6	12/12	12/12	6/6	6/6	6/6	0/6	12/12	11/12	6/6	6/6
9	9/9	0/6	18/18	17/18	9/9	9/9	0/9	0/9	0/18	0/18	9/9	9/9	0/9	0/9	10/18	10/18	6/9	2/9
10	3/9	0/9	18/18	18/18	9/9	9/9	3/9	0/9	18/18	17/18	9/9	9/9	3/9	0/9	18/18	16/18	9/9	9/9
11	0/9	0/9	0/18	0/18	0/9	0/9	9/9	0/9	18/18	18/18	9/9	9/9	9/9	0/9	18/18	17/18	9/9	9/9
12	6/6	0/6	12/12	12/12	6/6	6/6	6/6	0/6	12/12	12/12	6/6	6/6	6/6	0/6	12/12	9/12	6/6	6/6
*correct	39	0	90	85	47	47	77	0	167	109	93	93	60	0	168	140	86	80
Total	93	93	186	186	93	93	93	93	186	186	93	93	93	93	186	186	93	93
%correct	42	0	48	46	51	51	83	0	90	59	100	100	65	0	90	75	92	86

*Number to left of slash is number correct; number to right of slash is number presented.

in the majority of cases maximum contrast has been achieved on the blue record. Since most aerial photographic systems use minus-blue filtering, as was used with the comparison panchromatic system in this study, that contrast was lost on the comparison films. Furthermore, since the eye is relatively insensitive to blue, full color projection lost much of the benefit of the blue component in its presentation. The chromatic contrast of the full color projection apparently compensates, to a large extent, for the loss of brightness contrast.

It is difficult to determine if the high contrast obtained on the blue record is an artifact caused by selection of the particular materials used in the study as well as the extent to which any such gains might persist at greater altitudes than those flown. Increased attenuation and scattering of the shorter wavelengths generally results in a less distinct photograph, and that appears to be true in the present case. However the increased contrast of the separated additive image has more than compensated for such an effect on performance as measured by the technique used in this study.

It would be interesting if contrast could be related precisely to detection and resolution, as in terms of thresholds, for the type of PI task simulated in this study. The experimental conditions established are far enough removed from classical detection and resolution data so that such comparison is not reasonable; that is, the background was irregularly heterogeneous, distracting elements appear in the pictures, search is required, and the like. Furtheremore, since that was not the primary purpose of the study, the stimuli were not sufficiently continuous, nor were sufficient data taken to make confident threshold statements. However, it is probably most significant to the purpose of this study and to the application of its results to observe in the target detection data presented in Figure 1.a that the top three curves of detection performance are separating as visual angle of the target is decreased and that they are substantially above the detection performance curve for panchromatic material. On the basis of that fact one might hypothesize that they would continue to separate as target size were decreased, so that separated additive color image viewing would increase it's superiority to the other forms and that different detection size thresholds would be reached at zero performance on the abscissa for targets obtained by the different photographic techniques.

The resolution performance data plotted in Figure 1.b may be entirely misleading between the two smallest target sizes--- all curves reach zero performance at 1.0' because the limit of resolution of the emulsion used in flight tests was approached due to the crudeness of camera mounting, lightness of aircraft and related factors (negative images much smaller had been resolved with the additive system in the laboratory).

If the results of the resolution size threshold experiment suggested above were hypothesized and the results of the laboratory study (2) were considered, one might infer that the resolution performance curves dropping from 2.0' to zero performance would distribute themselves along the abscissa below 1.0' and that the order of threshold magnitudes might preserve the order of performance observed among the four photographic systems at 2.0', with panchromatic material resulting in the largest resolution size threshold nearest to 1.0'.

Targets appeared darker than the background only on the red separated record. Under that condition, five different targets appeared dark on light, constituting 39 possible responses on the smallest and largest sizes, and 78 possible responses at the intermediate size. Those particular target projections occurred only in the low contrast range, 4-31%, and, therefore, would not be expected to have a high percentage of detection or recognition Nevertheless, the percentage of dark on light targets which were detected and resolved in that range is noticeably smaller than for the light on dark targets which were resolved in the same contrast range. One possible explanation of that effect which is of considerable interest to photo-interpretation involves the hypothesis of the importance of perceptual "set" or expectancy in a search task. It might be expected that when a search task consistently involves detection of a given category of targets, defined by the similarity of a given parameter, other possibly more significant common parameters may be overlooked.

III. CONCLUSIONS

The purpose of this study was to compare the capability of an additive color aerial photographic system with the performance of a standard system, using visual detection and resolution of critical detail of artificial targets as the criterio .

(1) The results of the study demonstrate increased target detectability and detail resolution produced by increased contrast on separated records obtained with an additive color system.

(2) The study demonstrates that results similar to those obtained with stimulus materials photographed in the laboratory (2) are also achievable with similar stimuli photographed from the air.

(3) It is also shown that the image sharpness achieved by minus-blue filtering is not accomplished without some loss of information.

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