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Evaluation of Four-Color Plan View Display Console

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June 1982

Final Report

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Appendix B Authors: G. C. Kinney and M. J. DeCicco of the MITRE Corporation, McLean, Virginia

16. Abstract

Technical and operational evaluations were conducted on Plan View Displays (PVDs) modified for both four-color and monochrome presentation. Two of six PVDs modified for color were tested and evaluated for display performance at the Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey. Data were collected on brightness and resolution, power consumption, color registration, character legibility and position accuracy, and distortion in the broadband or "TV" mode. A registration board failure analysis, a maintainability analysis, and a radio frequency radiation survey were also performed. All six color PVDs were subjectively evaluated for operational suitability at the Washington Air Route Traffic Control Center (ARTCC) in Leesburg, Virginia. Data were collected to determine controller's reactions on the operational use of multicolor PVDs from questionnaires and taped interviews. Results indicated that the color-modified PVDs provided satisfactory color performance in the technical evaluation at the FAA Technical Center. However, problems were encountered with failures of the high-voltage power supplies during the operational evaluation at the Washington ARTCC. Analyses of the questionnaires indicated that most controllers spent less than a total of 10 hours during the entire test period operating the PVDs in the multi-color mode. The subjective data obtained from controllers during the limited operational evaluations appeared inadequate as a basis for accurately determining the operational suitability of color.

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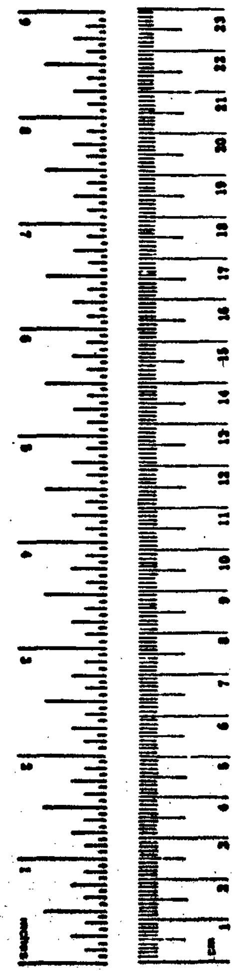
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

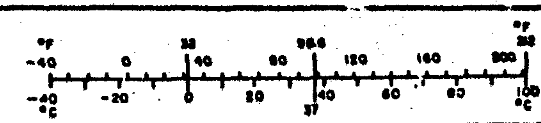
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This document describes work efforts initiated in June 1978 by 9550 Request No. AAF-610-78-006 from the Airway Facilities Service (AAF) to the Systems Research and Development Service (SRDS). SRDS was requested to provide technical and operational support for the evaluation of six Plan View Displays (PVDs) modified for both four-color and monochrome presentation. The Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey, was tasked by SRDS to test the color-modified PVDs for display performance. The PVDs were modified for color by the Raytheon Company under an AAF contract. Certification and technical operation of the color PVDs at the Washington Air Route Traffic Control Center (ARTCC) in Leesburg, Virginia was supervised by AAF.

The operational evaluation was assigned by Air Traffic Service (AAT) to the Washington ARTCC. It was conducted by AAT with SRDS providing support from the MITRE Corporation in McLean, Virginia and the FAA Technical Center.

The technical evaluation conducted at the FAA Technial Center is discussed in the main body of this document, and the operational evaluation at the Washington ARTCC is discussed in Appendix B. The report in Appendix B was prepared by the MITRE Corporation and is reprinted in its entirety for presentation herein.

The SRDS managers responsible for ensuring support to the aforementioned 9550 request were J. O'Brien, L. Douglass, and A. Kopala. Appreciation is expressed to the following organizations outside SRDS in the accomplishment of this test and evaluation effort.

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  J. W. Aschenbach, ACT-230
  R. T. Kelly, ACT-430
  L. Walker, AAF-360
- Contractor Personnel - G. C. Kinney, MITRE Corporation
  M. J. DeCicco, MITRE Corporation
  C. M. Hall, Raytheon Company
  W. Hamilton, Raytheon Company

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INTRODUCTION

PURPOSE.

This report describes the work and results of an experimental project that involved modifying Plan View Display (PVD) consoles for multi-color presentation. The main objectives were:

1. To test and evaluate the display performance of four-color data presentation.

2. To conduct a field evaluation for determining the operational suitability of the color-modified PVD console.

BACKGROUND

A prior investigation of color for air traffic control (ATC) displays was performed for SRDS in 1974 by the FAA Technical Center (formerly National Aviation Facilities Experimental Center (NAFEC)). This former study is documented in Final Report No. FAA-RD-75-39, May 1975. The color display device used during that evaluation was a Dumont 16-inch penetration-type color cathode-ray tube (CRT). It was configured in an experimental radar console, for both terminal and en route evaluation, by the Norden Division of the United Aircraft Corporation. Data was displayed in four colors: red, orange, yellow, and green. The study consisted of operational and engineering tests to evaluate both controller and display performance. The study concluded that color aided in the identification and interpretation of overlapping display symbology (e.g. aircraft data blocks), but it did not measurably improve performance of the separation function by controllers.

Display performance of the 16-inch color CRT did not match the performance requirements for monochrome. The study did recommend further testing and evaluation of color, especially under heavily cluttered or complex display conditions.

Further investigation into color by the FAA primarily included research and review of current literature on potential ATC usage and the state-of-the-art in color display technology. In 1978, the color evaluation for this subject report commenced. In this evaluation, en route Plan View Display consoles were experimentally modified for both color and monochrome presentation by the Equipment Division of the Raytheon Company. The modified PVDs were equipped with 23-inch Penetration-type four-color CRTs supplied by the Dumont Electron Tube Division (Clifton, New Jersey) of Thomson CSF, Inc. Six PVD consoles, two from the Technical Center and four from the Washington ARTCC, were modified by Raytheon. The modified PVD design was evaluated in two consecutive phases--a technical evaluation and an operational evaluation. In the technical phase, the first two color PVDs were tested and evaluated for display performance at the Technical Center. Subsequently, all six color PVDs were installed at the Washington ARTCC for a subjective evaluation of their operational usage.

ENGINEERING MODIFICATIONS FOR COLOR CONVERSION

The color-modified consoles were required to function operationally equivalent to the standard monochrome PVDs, except that color controls replaced the controls for the five-level brightness. Also, a switch was added to the System Status and Maintenance Indicator Panel that, when actuated, converted the display from color to monochrome operation. The color-modified console, in conjunction with the Display Control Vector Generator (DCVG), used the bit codes of the five-level brightness function, as received from the National Airspace System (NAS), to identify and separate data categories for display in the various colors.

Several engineering modifications were required for converting the PVD console to color and are listed below. (See Figure 1.)

1. Replacement of the standard 23-inch monochrome CRT with the penetration-type color tube.

2. Replacement of a single high-voltage supply with a new high-voltage module that includes a fixed 18 thousand volt (KV) output, and a switching 10KV to 18KV output.

3. Installation of a printed circuit board for deflection compensation.

4. Installation of a printed circuit board for monitoring color registration.

5. Modification of a printed circuit board in the Display Control Vector Generator (DCVG) to provide an automatic time-out function when changing colors.

6. Installation of console operator controls for color selection and adjustment.

The cathode-ray tube (CRT) for the color-modified PVD supplied by Dumont Corporation as specified by Raytheon is a single-gun, all-glass, 23-inch diameter type, similar to the current monochrome PVD CRT. The penetration-type tube is characterized by a unique phosphor system on the inside of its faceplate. It is the P-49 type and consists of a multi-layer combination of red and green phosphors. This allows four colors to be produced: red, orange, yellow, and green. The light emission changes color as the red and the green layers are sequentially penetrated to varying depths by the electron beam under a variable high-voltage drive.

A special split-anode design, developed and patented by Raytheon, in the CRT allows rapid changes in beam penetration depth (See Figure 2). The first anode, which encompasses most of the funnel area inside the tube, is held at 18 KV potential. The second anode, which covers the front part of the funnel area and the phosphor surface inside of the faceplate, switches to the different voltages required to produce the

PVD CONVERSION TO COLOR

PICTORIAL REPRESENTATION

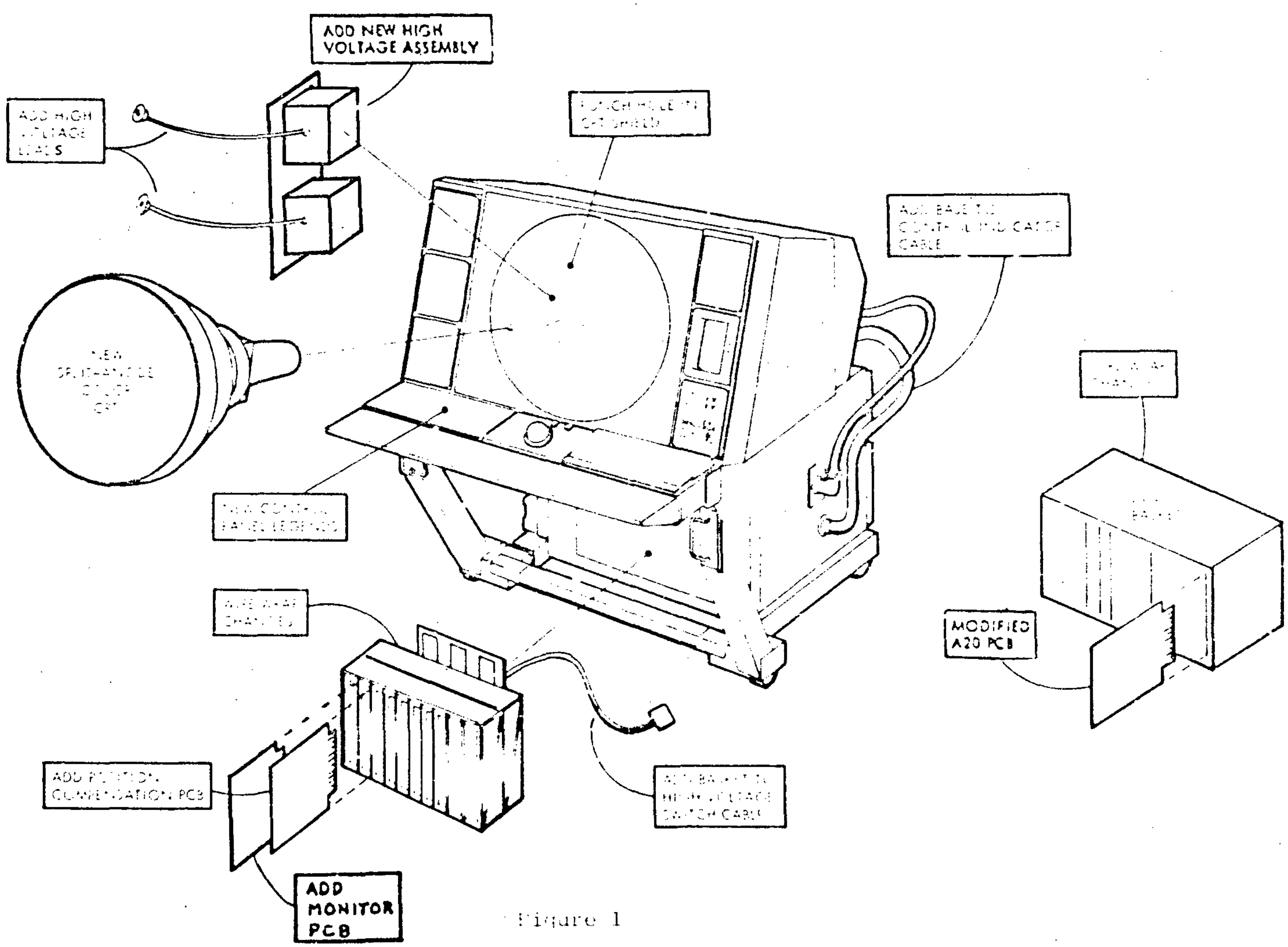


Figure 1

PENETRATION COLOR PHOSPHOR OPERATION

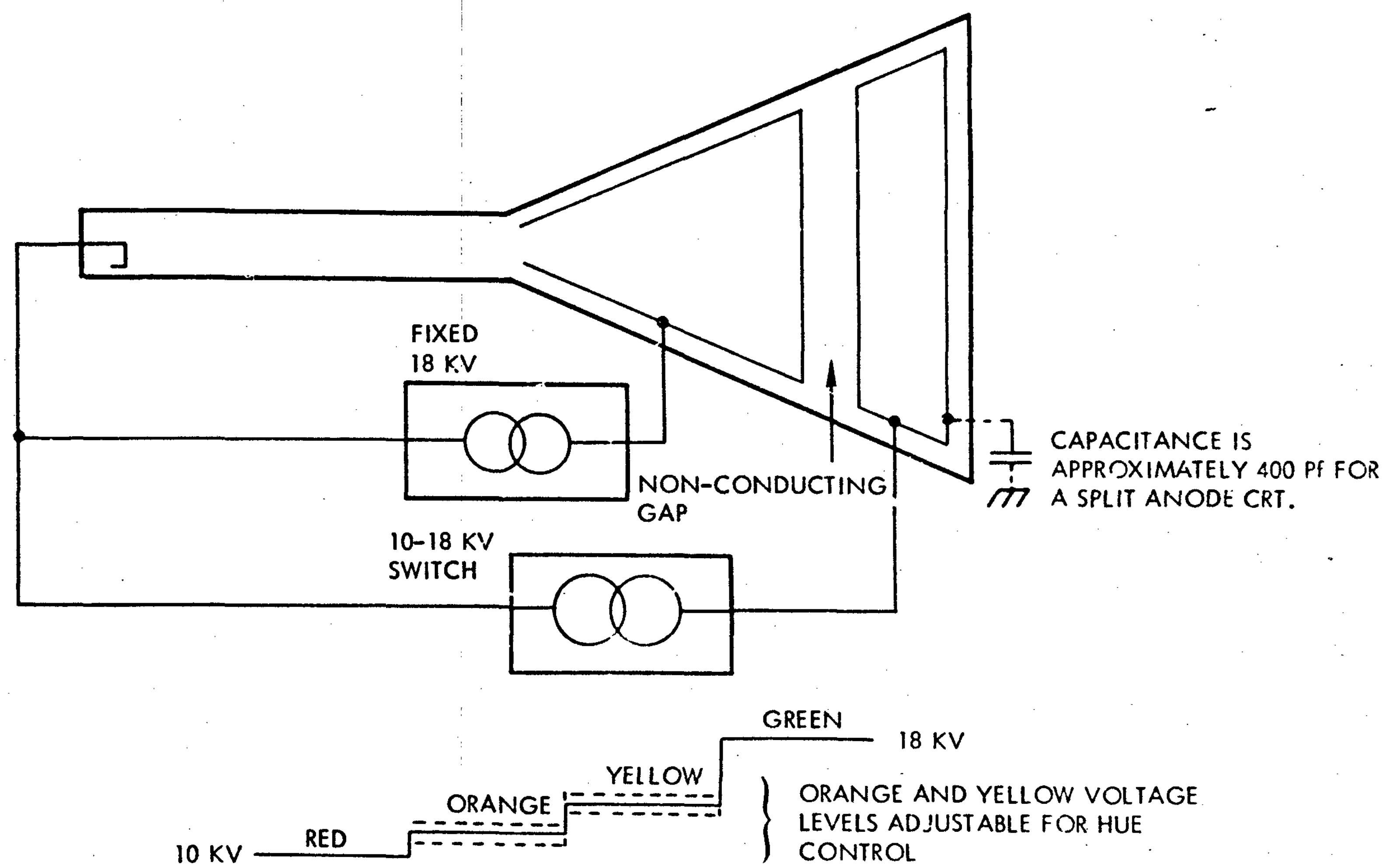


Figure 2

four colors. In actual CRT operation at 10KV, the electron beam has only sufficient energy to reach the red phosphor and a pure red emission results. At 18kV, the beam has more energy and reaches the green phosphor. This produces green light emission, and at a sufficiently brighter level to overwhelm any emission from the red phosphor. The two other colors, orange and yellow, are formed by proportioned blending of the red and the green emissions as the second anode voltage is varied in-between the 10 and 18kV levels. Thus, selection of each color, red, orange, yellow, and green, is controlled by switching corresponding discrete levels of high-voltage to the CRT second anode. The penetration phosphor system is illustrated in Figure 3.

To present a large amount of data in four colors during the display refresh period of 18.2 milliseconds, the anode voltage must switch at the minimum rate of 8kV in 100 microseconds. This limited the capacitive load of the CRT anode to be approximately 500 picofarads, substantially lower than for conventional tubes. To accomplish this, the split-anode structure was specifically designed for this tube. The design was intended to allow an adequate color switching rate without placing undue strain on the high-voltage supply assembly.

The use of the split-anode design required that the deflection current be compensated in order to correct deviations of the beam-trace in response to the switching high-voltage. The trace deviates because the deflection sensitivity of the electron beam is inversely proportional, in an approximate sense, to the square root of the anode voltage. (Deflection sensitivity is the ratio of unit distance of beam trace per unit level of deflection current.) In the case of the split-anode CRT, the amount of compensation necessary is close to, but not exactly the same amount required for a conventional CRT, because the first anode does not vary in voltage. When the second anode voltage changes to produce different colors, the deflection current must be continuously corrected during its dynamic operation. To accomplish this, a special "A1" printed circuit board designed for this corrective function was added to the lower card basket of the color-modified PVD.

Certain failure modes of the A1 board could erroneously alter the relative alignment of data elements displayed in each of the four colors. To detect these faults, another printed circuit board, an "A3" board, was added to the lower card basket of the PVD. Its function was to monitor the output deflection current of the A1 board and to revert the PVD back to the monochrome mode in the event of alignment failure. Upon failure detection, a console failure light would illuminate to alert the controller of the problem. The A3 board circuitry was used in conjunction with a minor NAS software patch to detect and indicate a fault with the A1 board, whether from component failure or thermal drift. The threshold of minimum error to be detected was a deviation of 0.040 inches for red and green data strokes intended to directly overlap at the edge of the screen.

PENETRATION LAYER PHOSPHOR

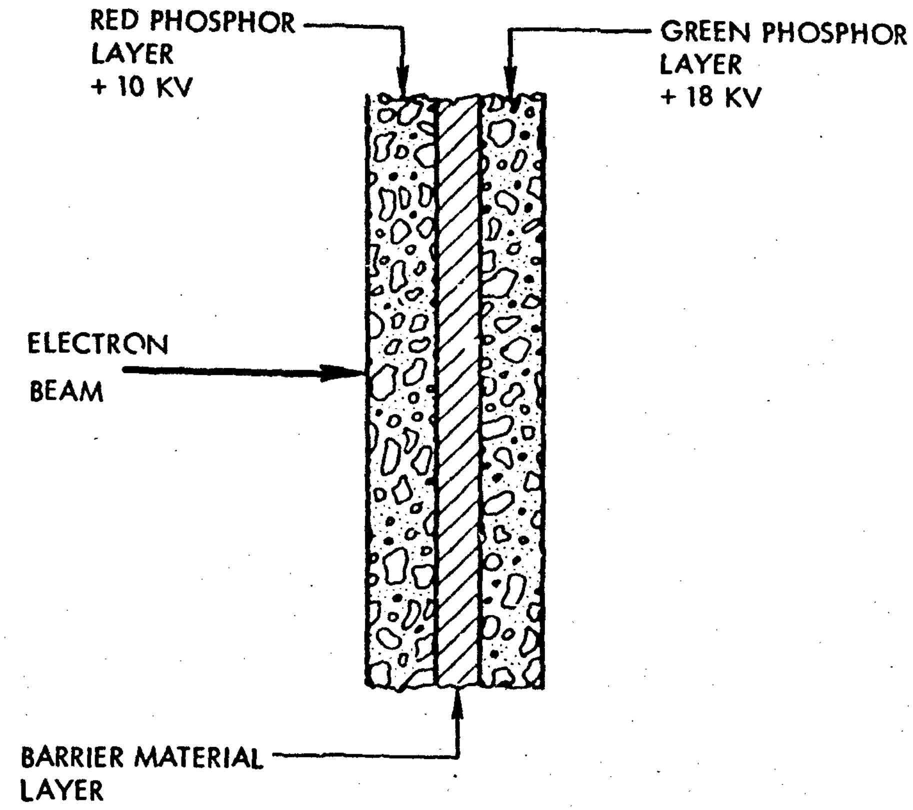


Figure 3

In the Display Control Vector Generator (DCVG), it was necessary to establish a 100 microsecond time delay for allowing adequate time for the PVD high-voltage to settle to a new value upon changing colors. This amount of time between data words of different categories is larger than that required by the standard monochrome-type PVD. Logic circuitry was added to the DCVG A20 board to recognize when data elements of a new color were ready to be presented. Upon this recognition, the circuitry delays this data. If this circuitry fails, an error message is automatically sent to re-establish the reconfiguration subsystem and the failed DCVG is automatically replaced.

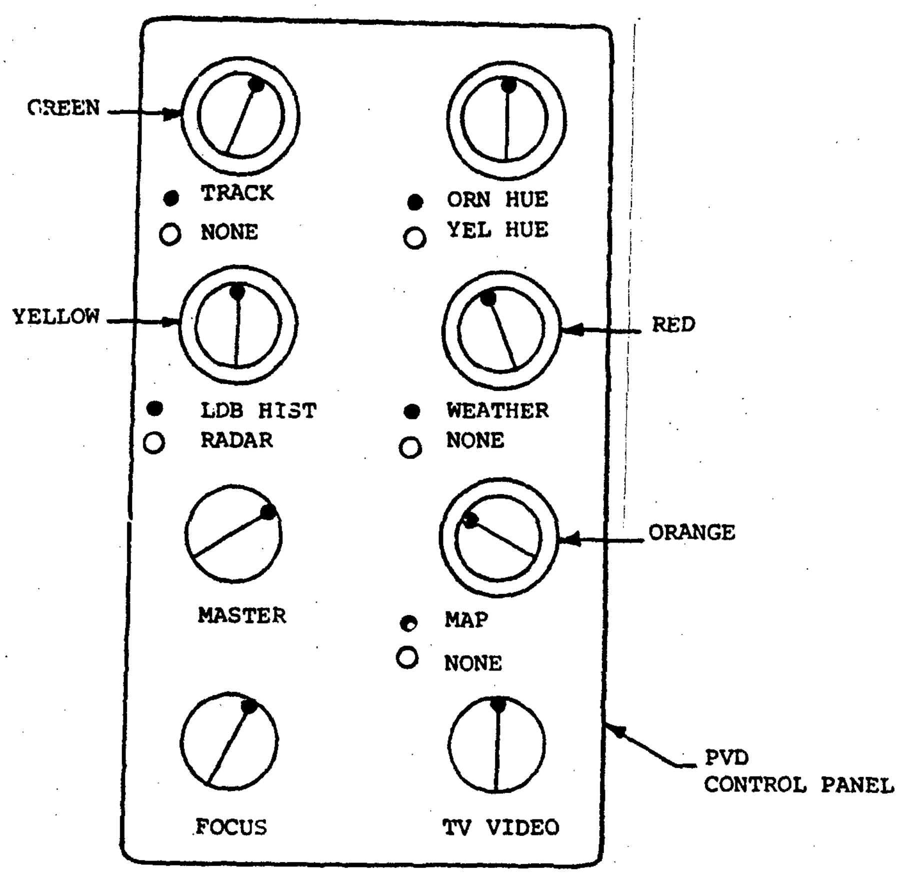
The color-modified PVD console featured brightness controls for each data type in each of the four colors and hue controls for orange and yellow.

Data Type	Color
Weather Lines and Symbols	Red*
Map Lines and Symbols	Orange*
Full Data Block, Track, Tabular, and Clock	Green
Radar and Trackball	Yellow (Bright)
Limited Data Blocks and Histories	Yellow (Dim)

*At the start of the evaluations, weather lines and symbols were displayed in red, map lines and symbols in orange; however, these color functions were reversed after several weeks because of controller comments.

These four color brightness controls were implemented as dual potentiometers on the Display Adjustment Control Panel of the PVD. They replaced the "five-level" brightness controls which are used in the unmodified monochrome PVD. A fifth dual potentiometer control was used to adjust the hue of the orange and yellow colors. This control allowed the observer to vary the data of yellow hue from mixed blends of yellow-green to yellow-orange, and the orange hue from orange-red to orange-yellow. The controls for master brightness, focus, and TV video were retained. Their respective functions were to simultaneously adjust all color brightness levels, to optimally adjust data resolution, and to adjust screen brightness in the broadband mode. There was also a failure lamp installed on the System Status and Maintenance Indicator Panel to indicate if the color data were presented out of registration, as previously described on the A3 board modification. An illustration of the color control arrangement is provided in Figure 4.

Figure 4. BRIGHTNESS AND HUE CONTROL LOCATIONS



TECHNICAL EVALUATION

The following tests were performed at the FAA Technical Center on two color-modified PVD consoles (FAA Serial Numbers 27 and 39).

1. Display brightness and resolution
2. Character legibility and position accuracy
3. Color registration
4. Broadband line distortion
5. Radio frequency radiation
6. Power consumption
7. NAS hardware/software compatibility

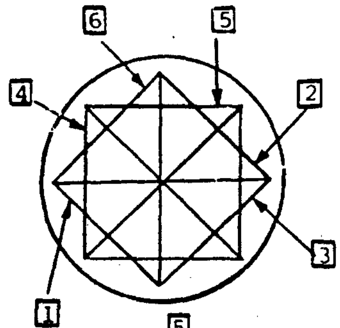
DISPLAY BRIGHTNESS AND RESOLUTION

Brightness and resolution measurements were taken on the displays both before and after their modification to color. The test data is shown in Table 1. Referring to the corresponding test patterns illustrated in Table 1, the line brightness reading in foot-lamberts (fL) for each test PVD was measured at the geometric center point of each pattern. The brightness was measured with a Gamma Scientific Model No. 700-10A photometric microscope. For these tests, linewidth was defined as the distance between the 50 percent peak-brightness points across a displayed line. Measurements are in thousandths of an inch (mils). The linewidth resolution measurements were made at the values indicated in Table 1 in foot-lamberts of average line brightness near the center of the screen. Resolution measurements were performed using a Gamma Scientific Model No. 700-10-1 microscope with a scanning-slit aperature having an effective size of approximately 1 mil by 40 mils.

For the unmodified PVD displays, Serial No. 27 and No. 39, linewidth resolution was measured at the horizontal and vertical center lines and at the six widest lines of the screen test pattern. These measurements were repeated on the same consoles after modification, using test patterns consecutively displayed in red, orange, yellow, and green.

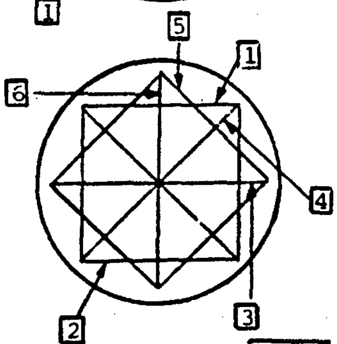
The maximum linewidth for comparing the resolution performance of the unmodified and color-modified PVDs was specified at 21.0 mils (per Computer Display Channel Revised Design Plan, May 15, 1971, Volume II, Table 4-5, p. 4-72). The resolution readings for the unmodified standard consoles were within specification except for test pattern position 1 on PVD no. 27 and for positions 1 and 2 on PVD no. 39 which were marginal. For the modified color consoles, linewidths of each color were measured to be within or very near to 21.0 mils at the horizontal and vertical center positions. The measurements at off-center positions varied up to maximum linewidths of 33.2 mils for PVD no. 27 and 30.9 mils for PVD no. 39, both on red display patterns.

Table 1. LINE RESOLUTION MEASUREMENTS IN MILS



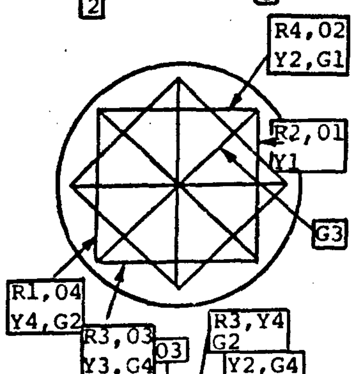
PVD No. 27 - Unmodified Monochrome @ 50 f-L

Horiz Ctr	Vert. Ctr	Maximum Linewidths 1	2	3	4	5	6
11.2	13.2	21.9	19.7	15.9	15.6	14.6	14.3



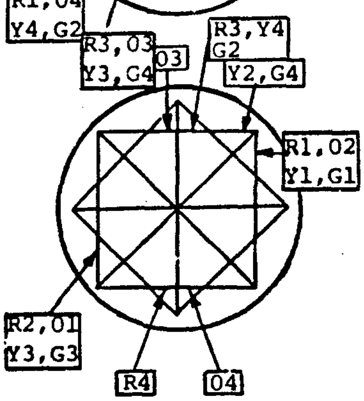
PVD No. 39 - Unmodified Monochrome @ 50 f-L

Horiz Ctr	Vert. Ctr	Maximum Linewidths 1	2	3	4	5	6
14.6	16.0	27.4	21.9	20.9	18.7	16.8	15.9



PVD No. 27 - Color Modified

Color	Horiz Ctr	Vert Ctr	Maximum Linewidths 1	2	3	4	Bright (f-L)
Red	21.7	22.6	33.2	32.8	28.9	26.7	4.0
Orn	19.3	18.6	27.1	24.4	22.8	22.4	6.0
Yel	15.5	15.8	23.2	22.8	22.2	22.0	9.0
Grn	14.7	15.3	23.6	21.3	20.7	20.2	18.0



PVD No. 39 - Color Modified

Color	Horiz Ctr	Vert Ctr	Maximum Linewidths 1	2	3	4	Bright (f-L)
Red	22.3	22.7	30.9	29.1	26.8	25.1	4.0
Orn	22.1	21.6	27.9	27.7	25.6	24.0	6.0
Yel	19.0	19.5	26.0	24.0	22.3	22.0	9.0
Grn	18.3	16.0	21.7	20.0	19.9	18.9	18.0

Also, the data indicated that the color resolution measurements increased in linewidth as the color patterns were consecutively changed from green to yellow, yellow to orange, and orange to red. This relationship could possibly be attributed to the increasing dispersion of light as it is emitted through the red phosphor layer to the green layer. The red and orange lines were probably wider due to the increased effect of electron repulsion within the beam. This can occur at the higher beam currents required by the relatively inefficient red phosphor. However, the line resolution for the color-modified consoles was considered adequate for legible presentation of data.

With reference to the line resolution data tabulated in Table 1, the worst-case readings in all four colors for both PVDs no. 27 and no. 39 were obtained primarily from the lower left and upper right quadrants of the display test pattern. Since lines displayed for each color were affected in this same manner, a common cause could be attributed to irregularities in the physical configuration of the CRT yoke windings. The differences in resolution with reference to the other two unaffected quadrants were not significant, however, and could be generally disregarded as an area of major concern.

The brightness levels used for the color measurements were lower than those specified for the monochrome display. These were the brightness levels recommended by the Raytheon contractor and are the highest possible levels without noticeably degrading line resolution. This limitation results from the P-49 color phosphor being less efficient than for the P-31 monochrome phosphor. However, the color brightness levels were adequate for use in the low ambient lighting as were observed in the Washington Center control room.

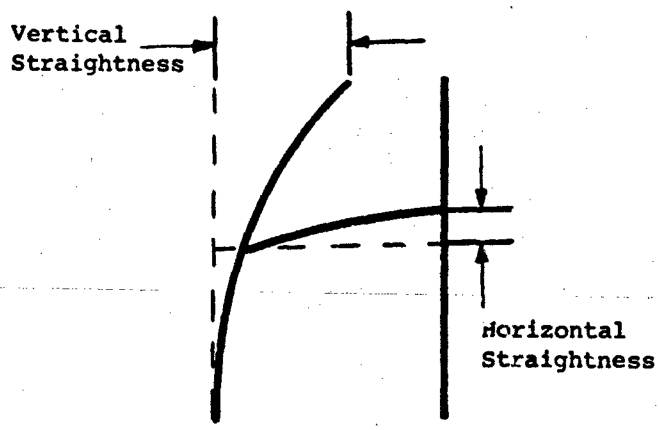
CHARACTER LEGIBILITY AND POSITION ACCURACY

Character legibility is a test parameter indicating the maximum deviation from orthagonal straightness in displaying an alphanumeric character or symbol. For the legibility tests on both the monochrome and color PVDs, the vertical and horizontal lines of the characters E, F, and H were measured and the deviations in mils are expressed in Table 2. A diagram for measuring the straightness of the letter "H" is provided in the inset of Table 2. The data showed little or no difference of character straightness before and after the color modification. Therefore, the modified color consoles no. 27 and no. 39 were considered satisfactory in character legibility.

In the position accuracy test, the performance of the electron beam in addressing a particular location on the display was checked for the standard monochrome PVD and for each color of the modified test PVDs. The position accuracy was checked by generating a pattern on the display that formed a box approximately 14 inches on a side. Vertical and horizontal lines connecting the corners of the box crossed each other at the center and the trace generated a "plus sign" at that point. If this character was displayed within 20 mils of the intersection of the two lines and all lines forming the box were square to within 20 mils, the

Table 2. CHARACTER LEGIBILITY

PVD Under Test	Vertical Straightness (mils)	Horizontal Straightness (mils)
Unmodified, No. 27	5.0	5.0
Color-Modified, No. 27	5.0	5.0
Unmodified, No. 39	12.0	10.0
Color-Modified, No. 39	10.0	10.0



positional accuracy for that particular PVD test was considered satisfactory. A special template was used to align the test pattern. Table 3 lists the worst-case measurements of the box alignment linearity, and the offset between the "plus" character and the intersection of the two lines at the center of the pattern. The test pattern, with measurement areas designated, is illustrated under Table 3.

COLOR REGISTRATION

Measurements were taken to check the registration of superimposed lines in all four colors displayed on the modified PVD. The color registration test was intended to measure the deflection compensation function of the circuitry on the A1 board; the function of the A1 board was to adjust the beam deflection current to compensate for the changing high-voltage on the phosphor surface inside the CRT. A registration pattern added to the NAS test software by AAF-360 was implemented for this test. This pattern is illustrated in Figure 5. In this software routine, the registration test pattern was written on the display four times during each refresh cycle, once in each color.

When the A1 board was adjusted so that all four colors of the pattern were superimposed, the test required that there should be no more than 40 mils between the centers of any two overwritten lines. This criteria was satisfactorily met during the color registration test since the pattern lines were adjustable to within one linewidth (approximately 20 mils) of each other.

If the circuitry of the new A1 deflection compensation board malfunctioned, this could affect the relative positions of data displayed in different colors. Because of this, a failure analysis of the A1 board was conducted. The failure analysis consisted of non-destructive procedures, using a special A1 board supplied by Raytheon, by which all major component failures could be simulated and their effects on the displayed information could be observed. Each failure mode caused the characters displayed on the test pattern of Figure 6 to shift by an individually specific distance and direction. The failure analysis was conducted separately for each display color of the modified PVD console. There was minimal change of position at the center of the screen, and increasing change with radial distance from the center. Maximum change occurred at the outer screen edge and was measured as a shift in the overall pattern up to five inches in distance.

The deviations of character position in both the red and green modes were significant in magnitude. However, their probability of occurrence was considered low based on a mathematical reliability analysis for the A1 board by the Raytheon contractor. The mean-time-between-failures (MTBF) for the A1 board was found to be 165,360 hours or approximately 7.5 years.

Table 3. POSITION ACCURACY

PVD Under Test	Line Linearity (mils)	Character Offset (mils)
Unmodified, No. 27	20.0	15.0
Color-Modified, No. 27	20.0	15.0
Unmodified, No. 39	20.0	5.0
Color-Modified, No. 39	20.0	5.0

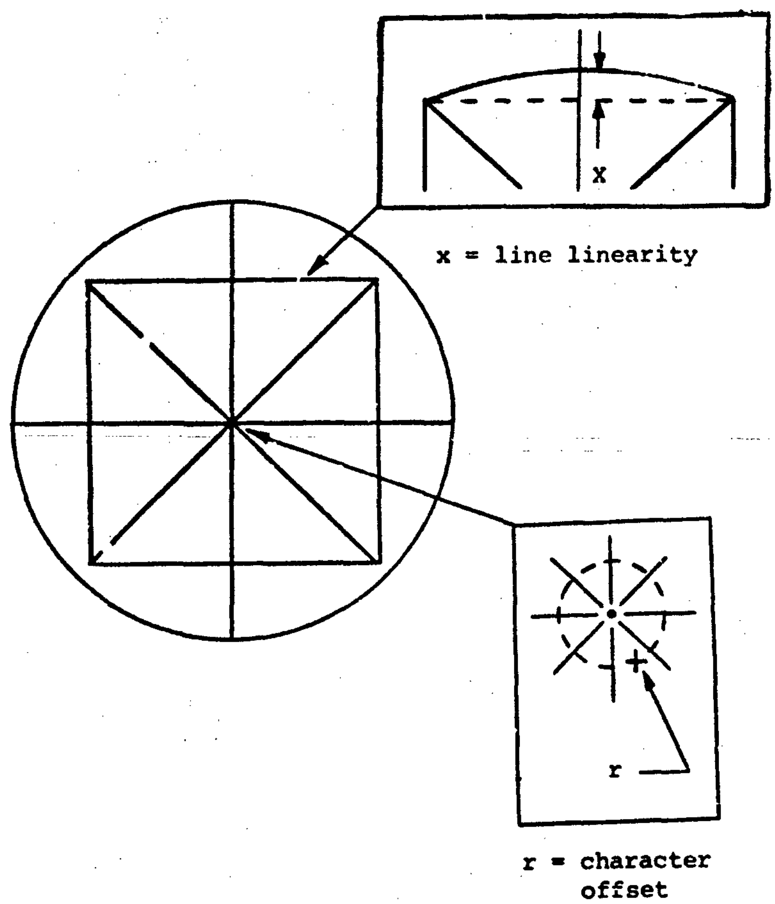


Figure 5. COLOR REGISTRATION TEST PATTERN

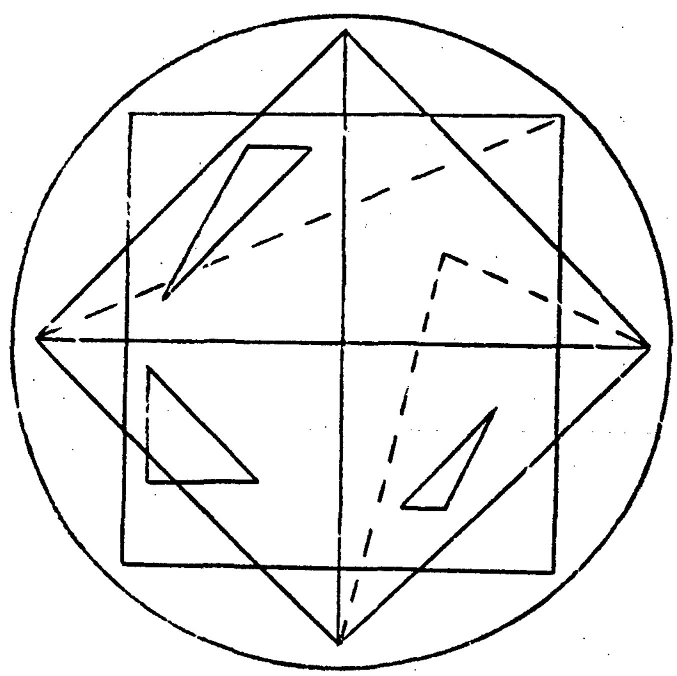
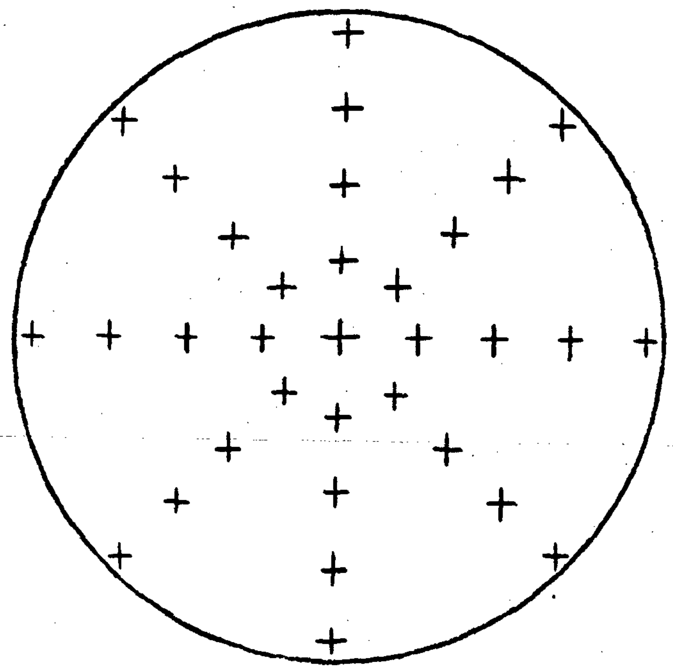


Figure 6. DEFLECTION COMPENSATION (A1) BOARD FAILURE TEST PATTERN



BROADBAND LINE DISTORTION

The color-modified PVDs were evaluated also in a broadband raster-scan display mode to check line distortion. The test equipment for checking line distortion consisted of a Cohu model DBG-2 TV crosshatch pattern signal generator, a Cohu model 2740-505 TV sync signal generator, and a special linearity template. For each color, the display raster exhibited line distortion at the left edge of the screen. This distortion was satisfactorily reduced by adjusting the horizontal TV sweep signal on the A-4 board, and the yoke bias current (-V bias) on the X-deflection amplifier. Also, the deflection amplifier power supply voltage was increased by approximately 10% and the recovery clamp zener diode was changed from 12 to 14 volts.

RADIO FREQUENCY RADIATION

While the color-modified PVDs were at the Technical Center, radiation measurements were taken by AAM-431, AAF-643, and ACT-230 to test the color-modified PVD for non-ionizing and for ionizing radiation. A Narda Model 8316B Isotropic Radiation Monitor was used to detect non-ionizing, microwave radiation in milliwatts per square centimeter (mw/cm^2) in the 0.3 to 18.0 gigahertz range. Ionizing radiation measurements were made with a Victoreen Model 440 RF/C Radiation Exposure Rate Measuring System. The Victoreen system was responsive to X-ray and gamma radiation in milliroentgens per hour (mR/hr).

The occupational exposure standard for non-ionizing radition is 10 mw/cm^2. No non-ionizing radiation from each color PVD console was detected. With the Lexan® viewing shield and its surrounding metal bezel on the PVD removed, the non-ionized radiation was measured to be only 0.8 mw/cm^2. This is significantly below the safety standard level of 10.0 mw/cm^2 for occupational exposure. For the ionizing-type of radiation, none was detected above the background level, both with and without the Lexan® bezel and PVD top. The background level was the amount of ambient radiation detected in the test area with the PVDs powered off. The value ranged from 0.18 to 0.24 mR/hr, more than ten times lower than the standard limit of 2.5 mR/hr for occupational exposure to ionizing radiation. Based on these results, the color-modified PVD satisfactorily met the safety criteria for both non-ionized and ionized types of radio frequency radiation. A detailed test report of this radiation survey is provided in Appendix A.

PVD POWER CONSUMPTION

Measurements of power consumption were made on the three-phase power input cable before and after the color modification was performed. Both versions of the PVD had been already modified for low power consumption per Electronic Equipment Modification (EEM) No. 6160.1, 12/7/78. The power measurements were taken using an Amprobe model AW50 A.C.-type wattmeter. Both color-modified PVDs, no. 27 and no. 39 respectively, consumed 1033 and 1050 watts of power. These readings showed increases in power consumption over pre-modification levels of approximately 2% and 8% respectively.

NAS COMPATIBILITY TESTING AND EVALUATION

The monitor logic circuitry for self-test color registration in the color-modified PVD required special color test vector messages to activate the circuitry at the proper time during each refresh cycle. Also, a special maintenance color test pattern was needed. Therefore, at the FAA Technical Center, tests were conducted by AAF-360 to assess the compatibility of the color-modified PVDs with respect to the hardware and software of the National Airspace System (NAS). Both monochrome and color modes of operation were exercised. The testing was conducted with test patches incorporated in the NAS Display Channel Complex (DCC) software.

In order to check out the registration monitor logic, these special software test patches were used to simulate errors in the deflection signal. In this way, the monitor circuitry was checked both for false error messages and for correct error messages when the deflection signal was outside the pre-determined limits.

The color-modified PVDs satisfactorily displayed registration test patterns with all colors superimposed as required. Also, the color PVDs properly switched from the color mode to the monochrome (all green data) mode upon receiving the simulated deflection signal error.

ENGINEERING CHANGES DURING THE OPERATIONAL EVALUATION

Six color-modified PVDs, including the two that were performance-tested at the FAA Technical Center, were installed at the Washington ARTCC in Leesburg, Virginia, for an operational evaluation by air traffic controllers. These PVDs were respectively identified by serial numbers 27, 39, 265, 285, 299, and 313. The operational evaluation is described in a detailed report prepared by the MITRE Corporation, Report No. MTR-82W37, and is located in Appendix B. During the operational evaluation, the color-modified PVDs underwent certain engineering modifications to improve equipment performance and reliability. The prominent areas requiring change included malfunctioning high-voltage power supplies and electrostatic charge build-up on the display screens.

The high-voltage switching power supplies exhibited a high failure rate during the center evaluation. "Switching," in this context, refers to the changing output levels of high-voltage that correspondingly generate the various colors on the CRT screen.

A total of eight switching high-voltage power supplies were on hand for use in the color PVDs during the operational evaluation. One power supply was allocated for each of the six color PVDs under evaluation, and two were available as spares. However, the failure rate was high enough to cause a shortage of working power supplies and thus precluded simultaneous operation of all six color PVD test positions during most of the time.

The power supply failures were generally attributed to design inadequacies in handling loads and to heat dissipation. The loading problems were manifested by failures to maintain proper color levels due to poor voltage regulation. A change in capacitance in a critical regulating circuit largely correcte this problem.

Power supply failures also occurred due to undissipated heat produced by frequent voltage switching. More voltage transitions are necessary when presenting more types of data. The additional power consumption incurred from frequent color changes produced excessive heat as evidenced by supply temperature measurements at approximately 60° Centigrade. These measurements were well above the supply manufacturer's specified temperature of 45° Centigrade. The problem was solved by increasing the ventilation of the supply enclosure to dissipate heat. This was accomplished by replacing the solid outer enclosure of each high voltage supply with a perforated case.

During the operational evaluation at the Washington ARTCC, static noise was detected by controllers in their headsets as they used the color PVDs. The static was caused by electrical interference produced by bringing the headsets in close proximity to the Lexan® panel on the PVD screen. The electrical interference was generated by the charging action of the switching high voltage on the capacitive anode surface of the PVD screen. The positively charged "plate" of this "capacitor" is the anodic area inside the faceplate; the "dielectric" is composed of the faceplate glass, the Lexan® polycarbonate panel, and the air gap between these layers. The negatively charged "plate" is any conductive surface near the Lexan® panel, e.g. controller's hand, headset cable.

To alleviate this effect, a conductive gold coating was applied to the outer surface of the color PVD Lexan® screen. The thin, transparent layer of gold became the negative "plate" of the "capacitor." By grounding the gold layer to the metal bezel surrounding it, the charge was dissipated to PVD chassis ground. Thus, charge was prevented from building up on the display surface. However, the gold coating made light reflections more noticeable on the display screen.

The maintenance workload for the PVD console is increased by the modifications for providing the four-color display capability. The additional work mainly consists of alignment and adjustment procedures for the A1 deflection compensation board and A3 registration monitor board. During an alignment, technicians are required to adjust up to eleven different potentiometers on the A1 board, and up to six potentiometers on the A3 board.

During the operational evaluation, maintenance personnel found that false failure reports from the A3 monitor circuitry occurred occasionally after performing the complete alignment procedures. This required re-alignment of the A3 board and thus increased the technician's workload. This situation was attributed to the sensitivity of the A3 board to voltage level drifts monitored from the A1 deflection compensation board. These voltages from the A1 board must not deviate outside very narrow tolerance windows, otherwise, a registration failure would be falsely reported.

During the early part of the evaluation at the Washington Center, faults with the color time-out error-reporting circuitry on the DCVG A20 board caused false error messages to unintentionally reconfigure the modified DCVG. This fault was corrected and no problems of this type ensued throughout the remainder of the evaluation.

CONCLUSIONS

Based on the findings and results of the technical evaluation described herein, and on the Mitre Report No. MTR-82W37 of the operational evaluation documented in Appendix B, it is concluded that:

1. The color-modified PVDs provided satisfactory display performance in the technical evaluation at the FAA Technical Center. However, the modified PVDs exhibited lower brightness and resolution than established by the criteria for the standard monochrome version.

2. The reliability of the color PVD equipment was degraded by intermittent failures of the switching high voltage power supplies.

3. The subjective data obtained from the participating controllers during the limited operational evaluation were inadequate to serve as a statistically valid basis for determining the suitability of color for field usage. Disparities in the various responses to the surveys apparently occurred before, and after the controllers' strike and thus impacted the data evaluation.

REFERENCES

1. Connolly, D.W., Spanier, G., Champion, F. Color Display Evaluation For Air Traffic Control, U. S. Department of Transportation, Federal Aviation Administration, Washington, D.C., Report No. FAA-RD-75-39, May 1975.

2. Mitchell, R. H., Aschenbach, J. W., Evaluation of Cathode-Ray Tube Protection and Antireflective Surface for the Plan View Display, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., Report No. FAA-RD-78-130, January 1979.

APPENDIX A

RADIATION SURVEY OF A PROTOTYPE

FOUR-COLOR PLAN VIEW DISPLAY (PVD)

RADIATION SURVEY OF A PROTOTYPE 4-COLOR PLAN VIEW DISPLAY (PVD)

Introduction:

This report presents the results of a radiation survey of a prototype 4-color PVD. The survey was conducted by Joseph A. Sirkis, AAM-431, LeRoy Walker, AAF-643, and John Aschenbach, ANA-230, during the evening of June 20 in Building 149 at the National Aviation Facilities Experimental Center (NAFEC).

Equipment Surveyed:

The 4-color PVD surveyed is one of several prototype equipments to be evaluated by the Federal Aviation Administration (FAA) at the Washington ARTCC in Leesburg, Virginia. This equipment, manufactured by Raytheon, uses a 58.42 cm (23 inch) diameter single-gun beam penetration type Cathode Ray Tube (CRT) and displays air traffic control data in four colors (red, orange, yellow, and green). Color selection is made by changing the screen anode voltage, which in turn changes the beam energy and thus the penetration depth of the electron beam into a multilayer phosphor screen (P-49 phosphor). The split anode operates at a fixed potential of 18.5 kV (kilovolts) and a switched potential of 10 to 18.5 kV. The CRT surveyed was supplied by the DuMont Electron Tubes and Device Corportion.

Test Equipment:

A NARDA Model 8316 B Broadband Isotropic Radiation Monitor with a Model 8321 Isotropic Probe was used to detect radio frequency (RF) radiation in the microwave range of 0.3 to 18 GHz (Giga Hertz). All measurements with this instrument were made 5 cm from every accessible surface. The active elements in the probe are enclosed in a foam sphere which insures that the 5 cm spacing is maintained for all measurements.

Ionizing radiation measurements were made with a Victoreen Model 440 RF/C Radiation Exposure Rate Measuring System. This system is entirely nonresponsive to electrostatic magnetic and electromagnetic fields, but is responsive to x-ray and gamma radiation over the energy range of 6 keV (kiloelectron volts) to 1.2 MeV (megaelectron volts) with field intensities as low as 0.1 mR/hr (milli Roentgens per hour).

Test Methods:

The brightness of the 4-color PVD was adjusted to an optimal viewing level and the screen was filled with simulated targets and associated flight data generated by a computer test program. This display was "frozen" and used for all tests. The equipment was surveyed for both nonionizing and ionizing radiation.

The NARDA Broadband Isotropic Radiation Monitor was used for non-ionizing (microwave) detection. The probe was traversed over all accessible surfaces (screen, top, sides, front and back) using the most sensitive scale (.2 mW/cm^2 full scale) on the monitor. No nonionizing radiation was detected.

The Victoreen Model 440 RF/C was activated and the background ionizing radiation level was monitored between 7:36 pm and 8:51 pm and found to be in the range of .18 to .24 mR/hr.

The instrument was traversed over all accessible surfaces using the most sensitive scale (1 mR/hr full scale). No ionizing radiation was detected above the background level.

The LEXAN bezel was removed from the front of the console and the metal cover on top of the equipment was removed and the survey was repeated. No nonionizing radiation was detected except for a reading of 0.8 mW/cm^2 at the center of the CRT face. No ionizing radiation was detected above the background level.

Conclusions:

The maximum detected level of nonionizing radiation was found to be 0.8 mW/cm^2 at the center of the CRT screen with the LEXAN bezel removed. The occupational exposure standard for nonionizing radiation is 10 mW/cm^2 per Threshold Limit Values (TLV) for Physical Agents adopted by ACGIH for 1978.

The Occupational Exposure Standard for ionizing radiation based on the annual dose limit of 5000 mR divided by 2000 working hours per year is 2.5 mR/hr. No ionizing radiation was detected above the background level.

It can be concluded, that based on the observations made, the 4-color PVD does not produce nor radiate nonionizing or ionizing radiation with the LEXAN bezel in place. With the bezel removed nonionizing radiation from the front surface of the CRT can be detected but at a level more than a factor of 10 below the occupational exposure standard.

Joseph A. Sirkis

JOSEPH A. SIRKIS, P.E.
June 26, 1979

APPENDIX B

MITRE REPORT NO. MTR-82W37

DISCUSSION OF TRIALS OF FOUR-COLOR PLAN VIEW DISPLAYS
AT WASHINGTON AIR ROUTE TRAFFIC CONTROL CENTER

Discussion of Trials of Four-Color Plan-View Displays at Washington Air Route Traffic Control Center

Dr. Glenn C. Kinney
Mary J. DeCicco

April 1982

MTR-82W37

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ABSTRACT

Operational trials of Raytheon Penetron multi-color Plan-View Displays (PVDs) were conducted, by the Federal Aviation Administration, at Washington Air Route Traffic Control Center from August 1979 to September 1981. Questionnaires and taped interviews provided information on controller reactions, and information was sought for further work on color applications. In general, the controllers rated the four-color display as equal to or poorer than their current display which has all data in green; some favorable responses were received. The distribution of color vision capabilities and deficiencies among controllers should be considered in the application of multi-color displays at radar positions. Recommendations are made for further work.

PREFACE

The operational trials of the multi-color displays discussed in this paper were done at the request of the Air Traffic Service (ATS) of the Federal Aviation Administration (FAA). The trials were arranged and conducted in a joint effort involving ATS Headquarters, Eastern Region Headquarters, Washington Center (Air Traffic and Airways Facilities), the FAA Technical Center (Atlantic City, New Jersey), the Systems Research and Development Service (SRDS) of the FAA, and the Raytheon Company (Sudbury, Massachusetts). MITRE participated in human factors aspects of the trials at the request of the Air Traffic Service and under the direction of the SRDS.

MITRE's part consisted of suggestions for the format and wording of the FAA-generated questionnaire in Appendix A of this report; these suggestions were adopted. MITRE contributed a second questionnaire described in Appendix B of this report. MITRE gave pre-trial briefings to participating controllers on relevant topics in color vision and visual perception. MITRE attended most of the interview sessions of the first set of interviews of controllers, and all of the second set, asking questions, offering explanations and information, and taking notes.

The interviews were conducted by Robert C. Wainwright (ATS), Raymond T. Kelly (Technical Center), and staff personnel of Washington Center. Mr. Charles Hall of the Raytheon Company attended the interviews and briefings, offering technical information on the displays and associated equipment.

Controllers' participation in the trials was wholly voluntary. An electrical switch was provided on the display console so that a controller could quickly change the displayed data from the multicolor mode to an all-green mode. (The data on the regular displays were all in green.) Operation in the all-green mode was identical to the operation of the regular displays. At all times, the displays met operational requirements when in use, and installation and removal of the displays were under the regular jurisdiction of the Facility Chief.

At the conclusion of the trials, MITRE prepared this report on relevant technical human factors. The report includes an appendix on color vision in the Air Traffic Service as background for design decisions involving visual displays for such a population of users. For further discussion, see Glenn C. Kinney and L. G. Culhane, <u>Color in Air Traffic Control Displays: Review of the Literature and Design Considerations</u>, MITRE Technical Report MTR-7728, The MITRE Corporation, McLean, Virginia, March 1978.

ACKNOWLEDGEMENTS

In addition to those mentioned in the Preface, several other people helped in this work. The work was encouraged and supported by many persons in the FAA's System Research and Development Service. Among these were Mr. J. O'Brien and Mr. Robert P. Pringle. Recent participants include Mr. Lauren Douglass and Mr. A. Kopala. In MITRE, helpful criticism and support were provided by Mr. Lawrence G. Culhane, Dr. Richard M. Harris, and Mr. John A. Varela. Dr. Glennis L. Bell and Mr. Martin A. Ditmore provided editorial and technical assistance. Mrs. Christina M. Davis did the Wang word processing.

EXECUTIVE SUMMARY

Operational trials of multi-color Plan-View Displays (PVDs) were conducted at Washington Air Route Traffic Control Center in Leesburg, Virginia, from August 1979 to September 1981. The trials were conducted by various offices of the FAA; MITRE participated and prepared this report. In the trials, from two to six Raytheon Penetron cathode-ray tubes were installed in operating radar positions so that controllers could obtain experience with the colors while controlling live traffic. The controller could select either all data in green (all-green mode), similar to the current PVD, or data in up to four colors in the multi-color mode. Colors were initially assigned with full data blocks in green, radar data and limited data blocks in yellow, maps with sector boundaries and geographic data in red, and weather displays in orange. Near the end of the trials the colors for the map and weather data were reversed. All colors had brightness controls, and yellow and orange had hue controls. All controls were available to the controller under a small panel in the console work shelf. A switch on the console face allowed a quick change of modes.

Information on controller reactions was obtained from a questionnaire and taped interviews. A second questionnaire asked controllers about a specific assignment of color to data blocks which was not tested. Controllers were also asked about the desirability of personally selected colors and color assignments. Guidelines were sought on issues and questions for further work on color applications. No attempt was made to collect quantitative data on job performance with either an all-green or multi-color display.

Technical problems intermittently required either removal of the multi-color displays or their operation in all green. The delays prolonged the test period and the technical troubles altered the colors. Also, when the eyes were moved rapidly to and from points on the PVD and its surrounding area, numerous flashes of small line segments in red were seen. Tubes of more recent manufacture reportedly do not show this effect, but were not used in these trials.

Most of the 50 participating controllers spent an average of less than ten hours operating the PVDs in the four-color mode. In general, controllers considered the four-color mode to be worse than or at best equal to the all-green mode for most of the items on the questionnaire. Some comments favoring the four-color mode were received. Low color saturation and lack of distinctness of colors were reported by several controllers.

Many controllers reported that the red was "hard to work with." This experience may be related to normal optical difficulties in focusing

the eyes on the long wavelength phosphor coupled with the perception of the red symbols as lying farther from the eye than the other colors. It may also be related to the low luminance of the red (a nominal 4 Foot-lamberts).

Many controllers reported that the orange and yellow were not distinctly different. This report may be related to voltage control of the display tubes, ineffective adjustments of the hues, or individual differences in color perception among the viewers.

A gold-tinted coating, which was installed on the outer display surface to reduce static interference with radio communications, reflected images of lighted surfaces located behind the display viewer. The coating and reflections were reported to affect the color and contrast of displayed symbols.

Identification of the technical causes of the controllers' reports is not possible because of unknown factors including

1) the relevant visual capabilities of the viewers,

2) the spectral energy distributions of the involved "colors,"

3) the specific environmental viewing conditions,

4) the specific operating characteristics of the individual PVDs, and

5) the brightnesses and hues associated with the particular adjustments of the PVDs.

In view of these factors, a technical or quantitative description of controllers' reports and their causes is deemed infeasible beyond speculation.

Participants disagreed on the settings of hue and brightness when viewing the PVDs individually or together. The basis for this disagreement is not known.

The four categories of display data to which separate colors were assigned corresponded exactly to the data categories established in the computer system with which controllers have extensive experience. Thus, in the four-color mode, data in the four categories were clearly different in size, shape, brightness, and color, simultaneously. The participants found it difficult to separate the effects of color from the simultaneous effects of the other redundantly coded visible differences. The exact correspondence of these visual information codes prevents isolation of the effects attributable to color alone.

Controllers reacted favorably to the color assignment scheme suggested in the second questionnaire and unfavorably to having each controller select his own colors and color assignments.

The trials and data collection occurred before and after the controller strike on August 3, 1981. Associated events may account for the low use of the multi-color mode and may have been responsible for some of the reported negativism toward color. The reactions obtained were not based on prolonged use of the multi-color PVDs.

The results of these trials should not be used to specify color for advanced displays in air traffic control.

No specific topics for further work on multi-color PVDs were identified from these trials or from work associated with the trials.

The trials provided an occasion to draw attention to the variability in human color vision, including normal vision, and to FAA policies on hiring color-deficient personnel.

Further work initiated by other considerations would need more thorough planning, better preparation, better monitoring, better human engineering, improved maintenance, and more effective assignments of colors to categories of information. Such work would need a thorough review of human color perception and an experimental validation of the operational usefulness of color. Determination of viewer abilities to use color would require experimental measurements which could provide the basis for selecting a common color capability. The measurement process could be used to screen personnel for employment.

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1. INTRODUCTION

1.1 Background and Purpose

Between August 1979 and September 1981, the FAA installed Raytheon Penetron four-color Plan-View Displays (PVDs) in selected radar control positions at Washington Air Route Traffic Control Center, Leesburg, Virginia, to allow controllers to evaluate multi-colored radar displays based on operational experience. The FAA ran these trials; MITRE participated and prepared this report.

The specific purposes of the evaluation trials were to determine controllers' reactions and to obtain information on issues to be examined by further research on the operational uses of multicolor displays. The controllers' reactions and attitudes toward the displays were obtained by asking controllers to fill out questionnaires and participate in interviews.

No attempt was made to obtain experimental data on the effects of the multi-color display on controllers' job performance, but controllers' opinions on this matter were obtained in the questionnaires (Appendices A and B) and interviews.

Details of colors and operation of the displays are in Appendix C. An electrical switch was provided so that a controller could quickly change the display from the four-color mode to the regular mode with all data in green (all-green mode), or vice versa.

1.2 Test Subjects

Controllers at Washington ARTCC voluntarily participated in the evaluation trials as test subjects. The test subjects were divided into two categories, the Control Group and the Non-Control Group. The purpose of separating the groups was to allow subjects to use the color displays regularly in the Control Group and randomly in the Non-Control Group in order to determine whether or not reactions to using the displays were affected by the level of experience with them.

Since initial reactions might be changed with more prolonged experience, the Control Group's reactions were planned to show such an effect, if it occurred, in order to provide better guidance for additional work. Before the trials began, four groups of subjects in both the Control and Non-Control Groups were given a one-hour briefing on the operating and visual features of the displays and related aspects of human vision.

The participating controllers were given no specific instructions on what to look for, but were asked to use the multi-color mode, with their own adjustments, in an open-minded manner.

1.3 Test Schedule and Procedure

1.3.1 First Trial Period

The First Trial Period took place from August 1979 to May 1981. During this period, test team personnel were selected, equipment was installed, and test subjects were given a facility briefing on the purpose of the study, how to use the displays, and other pertinent information. Interviews with subjects were conducted at the end of this period, and questionnaires were distributed and collected. The questionnaires are in Appendix A and Appendix B. Duration of the interviews ranged from 30 minutes to an hour and a half.

During this period, there were several problems with the displays (see 1.5 below). There were long periods of time when one or more of the displays were not being used. Most subjects in both Groups did not use the displays on a regular basis. Average use was less than 10 hours; no controller used the multi-color mode more than 40 hours.

The distinction between the Groups is retained in this paper in order to facilitate comparison with Federal Aviation Administration data collected on these trials.

1.3.2 Second Trial Period

The Second Trial Period was held between May and September 1981. Interviews were conducted with durations as in the First Trial Period, and each subject was asked to answer the questions on the two questionnaires.

During this time, the subjects continued to have problems with the equipment (see 1.5 below). Displays were used intermittently by subjects in both the Control and the Non-Control Groups. On average, subjects in the Control Group had less experience than subjects in the Non-Control Group. Eleven of the seventeen controllers used the multi-color mode less than 40 hours.

Personnel in the control facility requested a specific description of how to operate and set up the displays correctly in the multi-color mode. A Checklist was prepared and distributed to the subjects in July (see 1.4.3 below).

This trial period ended with extensive interview and debriefing sessions. The two questionnaires were handed out and later collected. During this Trial Period, there was much general, unrelated discontent for many of the controllers. Many of the subjects participating in the color study were unavailable after the controllers' strike in August 1981. After the controllers' strike, the Center had fewer controllers working, and fewer subjects were available to use the displays in the multi-color mode and to participate in the interviews and complete the questionnaires.

1.3.3 Color Assignments to Data Categories

In deference to controllers' complaints about the color red, the assignment of colors to different data categories was changed in the Second Trial Period. Since the map category is used continuously, and the weather category infrequently, the orange and red were reassigned in order to reduce the frequency of viewing the red. The subjects thus used one or both of the color assignments shown just below.

	Color Assignment 1	Color Assignment 2
Weather	Orange	Red
Map	Red	Orange
Limited Data Blocks, History	Yellow	Yellow
Full Data Blocks, Beacons	Green	Green

All subjects had experience with color Assignment 1, but only a few had experience with Color Assignment 2. Plans to try other assignments late in the trials were abandoned because of the conditions prevailing at the time.

1.4 Documents

1.4.1 Questionnaire A

Questionnaire A (see Appendix A) was used as a basis for the interviews and group discussions with the subjects during each evaluation period. This questionnaire dealt with specific issues in detail. In general, the overall theme of the questionnaire was to ask the subject whether or not using the multi-color display helped performance on the job. One question asked whether or not the color display enhanced job satisfaction. Blank areas on the questionnaire were provided for subjects' explanations, comments, and suggestions.

1.4.2 Questionnaire B

This second questionnaire (Appendix B) addressed specific issues that had been raised earlier in the trials. For example, "dynamic color selection" is the process allowing controllers to set up their own assignment of color to data categories. The questionnaire asked whether or not "dynamic color selection" should be used in various situations, and asked for comments and reasons why or why not. The questionnaire was also intended to collect opinions on specific ways in which color might aid controllers' performance of a specific task.

1.4.3 Color Display Checklist

The Color Display Checklist in Appendix C was intended to help subjects set up and operate the displays correctly. The checklist was requested by the FAA because of reports of subjects having difficulty using the displays in the multi-color mode. Many subjects apparently had been using the displays without knowing completely how to set up the four colors, or to detect improper operation of the PVDs in the four-color mode. This systematic way to set up and operate the displays was distributed to subjects in July 1981.

1.4.4 Interview Tape Recordings and Notes

The purpose of the interview tape recordings and notes was to give the controllers a forum, and to supplement the questionnaires with more detailed explanations and descriptions of experience from the subjects.

1.5 Technical Problems

Technical problems with the displays were encountered with symbol registration, voltage switching, electrostatic effects, and other installation features which intermittently required either removal of the multi-color displays or their operation in the all-green mode. The resulting delays prolonged the test period beyond initial plans, and the technical troubles produced alterations in color generation and hue control. Numerous flashes of small line segments in red appeared when the eyes were moved rapidly to and from points on the PVD and its surrounding area. It is understood that this does not occur on newer display tubes; the newer tubes were not used in these trials.

During the Second Trial Period, an electrically conducting coating of gold-colored, glossy appearance was added to the outside surface of the display in order to reduce electrostatic interference with radio communications. The spectral transmittance and reflectance of this coating are not known, but the specular reflectance of tŀ front surface was increased by the coating. No measurements were made.

2. RESULTS

2.1 Taped Interviews

The number of participants in the first interviews (42) was greater than the number in the second interviews (18). This happened because the interviews for the First Trial Period were conducted before the controller strike, and the interviews for the Second Trial Period were conducted before and after the strike. The Center had fewer resources, participants, and time to support the PVD evaluation trials after the strike.

2.1.1 Subjects' Favorable Responses

In summary, subjects who had favorable responses reported that the four colors were easier to work with than "harsh" green. Some reported that the colors aided in the detection of data blocks through weather and other symbology. Others claimed that the colors may have been helpful as an alerting device.

2.1.2 Subjects' Unfavorable Responses

The subjects who disliked using the PVDs in the four-color mode complained that the colors were "too bright" and "extremely fatiguing to use." Others claimed that the displays gave them headaches and nausea. Some subjects claimed that the difference between red and orange and the difference between orange and yellow were too small for easy recognition or discrimination. There were also complaints about the color assignments, desaturation of colors, and the illegibility of limited data blocks when overlapped by full data blocks which often were brighter.

Most of the participating controllers reported that the red was "hard to work with."

Some controllers reported that the colors seemed to "drop out" after a few minutes' use (see 3.3 below).

It was reported that the gold-colored coating produced shifts in hue of the four colors, and surface reflectance was higher than it was in the First Trial Period, and it was reported that the reflections and the gold coating reduced chromatic contrasts and symbol-background contrasts in brightness.

2.1.3 Subjects' Mixed Responses

Many subjects felt that using the four-color mode had advantages, but they did not know whether the advantages would outweigh the difficulties. Many of the subjects enjoyed using the colors, but did not see how it affected their performance on the job. Many subjects claimed that they may have liked the color had the equipment been working well.

The subjects were often unable to determine what they were being asked to evaluate. Their responses ranged from very favorable to very unfavorable toward "color." Many of their feelings were based on hopes or anxieties of experiences they would have in the future. These included fears of physiological harm to vision, possible radiation exposure, and the possible purchase of color displays instead of other more desirable system components.

2.2 Questionnaire A

The numbers of responses obtained for each item on Questionnaire A are in Tables D-1 through D-14 for the First Trial Period, and Tables D-15 through D-28 for the Second Trial Period, in Appendix D. Six questionnaires are reported separately from the two groups because there was no way to determine which group they were from; see Tables D-29 through D-42 (these Tables are not discussed further).

Item 5 was largely blank probably because respondents chose not to respond. Item 5 is not included in the Tables. Item 12 on Questionnaire A contained only a few responses, because Item 11 was answered primarily in the negative. Item 12 responses were as discussed in 2.1 above. Item 12 is not included in the Tables.

For many items in the questionnaires, the sums of answers do not add up to the number of subjects participating, because not all subjects answered every item.

The statements in 2.2.1 and 2.2.2 below do not imply significant statistical differences. Statistical tests are considered inappropriate because of

1. the small number of subjects' responses,

2. the lack of independence of the responses, and

3. subjects in both groups did not answer all items.

2.2.1 Comparison of Control Group with Non-Control Group in the First Trial Period

The following is an item-by-item summary of responses made by the subjects to Questionnaire A (Appendix A).

Item 1a. The majority of subjects in both the Control Group and the Non-Control Group operated the displays in full-color mode less than ten hours. No controller used the multi-color mode for 40 hours or more. See Table D-1.

Item 1b. The majority of subjects in both the Control Group and the Non-Control Group operated the displays in the all-green mode less than ten hours also. See Table D-1.

Item 2. The majority of subjects in both groups during the First Trial Period used the multi-color displays in moderate to light traffic most of the time. See Table D-2.

Item 3a. The Control Group felt that the multi-color display was the same or better than the all-green display. The Non-Control Group reported that for distinguishing among data categories, the multi-color display was the same or poorer than the all-green display. See Table D-3, and Discussion below.

Item 3b. Both groups reported that the multi-color display was the same or poorer for detecting the occurrence of flashing data or symbols than was the all-green display. See Table D-3.

Item 3c. The majority of the subjects in the Control Group reported that the multi-color display was the same as the all-green display for locating data blocks. The subjects in the Non-Control Group reported that the multi-color display was poorer than the all-green display as an aid for locating data blocks. See Table D-3.

Item 3d. Subjects in the Control Group were slightly more favorable than subjects in the Non-Control Group toward the multi-color display for reading symbols under light or moderate traffic volumes. See Table D-3.

Item 3e. Both groups reacted unfavorably toward the multi-color display for reading symbols under heavy traffic loads or with cluttered displays. See Table D-3.

Item 3f. Subjects in the Control Group reacted slightly more favorably than did subjects in the Non-Control Group in reporting that the multi-color display better aided reading one color printed over another. See Table D-3.

Item 3g. Both groups reported that the multi-color display was the same as the all-green display in aiding controllers to retain data after it left the display. See Table D-3.

Item 3h. Subjects in the Non-Control Group reacted slightly less favorably than did subjects in the Control Group regarding the multi-color display in aiding controllers to avoid preoccupation or overlooking data. See Table D-3.

Item 3i. The Control Group reported that the multi-color display was the same or poorer than the all-green display for avoiding eye fatigue. Subjects in the Non-Control Group reported that the multi-color display was poorer for avoiding eye fatigue than was the all-green display. See Table D-3.

Item 4a. Subjects from both groups reported that the color green, as assigned for this evaluation, was generally satisfactory. See Table D-4.

Item 4b. Subjects in the Control Group reacted slightly more favorably toward the assignment of the color yellow than did the Non-Control Group. See Table D-4.

Item 4c. Half of both groups responded favorably to the way the color red was assigned, and half of both groups disliked the way red was assigned. See Table D-4.

Item 4d. Subjects in the Control Group reacted slightly more favorably to the assignment of the color orange than did subjects in the Non-Control Group. See Table D-4.

Item 6. Subjects in both groups responded that color should not be used to call attention to special conditions. See Table D-5.

Item 7. Most of the subjects in both the Control and Non-Control Groups had no operational or equipment problems when transitioning between multi-color and all-green modes of operating the displays. See Table D-6.

Item 8. The majority of subjects in both groups had no problems operating alongside an all-green PVD while they operated their own PVD in the multi-color mode. See Table D-7.

Item 9a. A little over half the subjects from both groups had an opportunity to observe the weather in color (either in red or orange). The subjects in both groups who saw weather displayed reported that weather in the multi-color mode was the same as or equal to weather in the all-green mode. See Table D-8.

Item 10. Subjects in both groups responded that color as assigned in this study should not be a requirement in the ATC system. See Table D-9.

Item 11. Subjects in both groups responded that color used in some way other than in this study should not be a requirement in the ATC system. See Table D-9.

Item 13. The majority of the subjects in both groups reported that color did not enhance job satisfaction. See Table D-10.

Item 14a. Subjects in the Control Group rated the color brightness range for green "good" to "fair." Subjects in the Non-Control Group rated the color brightness range for green "fair." See Table D-11.

Item 14b. Subjects in both groups rated the brightness of the red equally. Their responses were equally distributed among "good," "fair," and "poor." See Table D-11.

Item 14c. Subjects in both groups rated the color brightness range for orange as "fair" to "poor." See Table D-11.

Item 14d. Subjects in the Control Group rated the color brightness range for yellow as "fair." Subjects' responses in the Non-Control group were equally distributed among all categories. See Table D-11.

Item 15a. Subjects in the Control Group rated the hue variance control for orange "fair." Subjects in the Non-Control Group rated the hue variance control for orange "fair" to "poor." See Table D-12.

Item 15b. Subjects in the Control group rated the hue variance control for yellow slightly more unfavorably than did subjects in the Non-Control Group. See Table D-12.

Item 16. Subjects in the Control group rated the dual-level operation of the yellow brightness control slightly more unfavorably than did the Non-Control Group. See Table D-12.

Item 17. Subjects in the Control Group switched from the multicolor mode to the all-green mode slightly more frequently than did subjects in the Non-Control Group. See Table D-14.

2.2.2 Comparison of Control Group and Non Control Group in the Second Trial Period

The following is an item-by-item summary of responses made by the subjects to Questionnaire A in The Second Trial Period.

Item 1a. A larger number of subjects in the Control Group had fewer hours of experience using the multi-color mode than was the case in the Non-Control Group. Of the 17 subjects in both Groups, 11 used the multi-color mode less than 40 hours, and 6 less than 10 hours. See Table D-15.

Item 1b. A larger number of subjects in the Control Group had fewer hours of experience using the all-green mode than did the Non-Control Group. See Table D-15.

Item 2. The majority of subjects in both groups used the multi-color displays in moderate traffic most of the time. See Table D-16.

Item 3a. Subjects in both groups reported that for distinguishing among data categories, the multi-color display was the same as the all-green display. See Table D-17.

Item 3b. Subjects in both groups also reported that the multi-color display was the same as the all-green display for detecting the occurrence of flashing symbols. See Table D-17.

Item 3c. Subjects in the Control Group reported that the multi-color display was the same or better than the all-green display for locating symbol blocks. Subjects in the Non-Control Group reported that using the multi-color display was the same or poorer for locating symbol blocks. See Table D-17.

Item 3d. Subjects in the Control Group reported that the multi-color display was the same as the all-green display for reading symbols under light or moderate traffic loads. Subjects in the Non-Control Group rated the multi-color display as the same or poorer than the all-green display for reading symbols under light or moderate traffic loads. See Table D-17.

Item 3e. Subjects in the Control Group rated the multi-color display slightly more favorably than did the Non-Control Group for reading symbols under heavy traffic loads or with cluttered displays. See Table D-17.

Item 3f. Subjects in the Control Group rated the multi-color display slightly more favorably than did subjects in the Non-Control Group for reading one color printed over another. See Table D-17.

Item 3g. Subjects in both groups rated the multi-color display the same as the all-green display for remembering data after the data are cleared from the display. See Table D-17.

Item 3h. Subjects in both groups rated the multi-color display the same as the all-green display for helping controllers avoid preoccupation or overlooking data. See Table D-17.

Item 3i. Both groups rated the multi-color display as poorer than the all-green display for avoiding fatigue from using the display. See Table D-17.

Item 4a. Subjects in both groups rated the color assignment for green satisfactory. See Table D-18.

Item 4b. Subjects in the Control Group rated the color assignment for yellow satisfactory, while subjects in the Non-Control Group rated it unsatisfactory. See Table D-18.

Item 4c. Subjects in the Control Group rated the color assignment for red satisfactory, while subjects in the Non-Control Group rated it unsatisfactory. See Table D-18.

Item 4d. Subjects in the Control Group rated the color assignment for orange satisfactory, while subjects in the Non-Control Group rated it unsatisfactory. See Table D-18.

Item 6. Subjects from both groups responded that color should not be used to call attention to special conditions. See Table D-19.

Item 7. The majority of the subjects in both groups had no operational or equipment problems when transitioning between the multi-color and all-green modes of operation of the display. See Table D-20.

Item 8. The majority of the subjects in both groups had no problems operating alongside an all-green PVD while using the multi-color mode themselves. See Table D-21.

Item 9a. The majority of the subjects in both groups had a fair opportunity to observe the weather display in color. Of these people, the subjects in the Control Group rated the weather in red or orange better or equal to all-green, while subjects in the Non-Control Group rated the weather in red or orange equal to that of the all-green display. See Table D-22.

Item 10. Subjects in both groups responded that color, as used in this study, should not be a requirement in the ATC system. See Table D-23.

Item 11. Subjects in both groups responded that color, used in some way other than in this study, should not be a requirement in the ATC system. See Table D-23.

Item 13. Subjects in the Control Group reacted slightly less favorably toward the multi-color display enhancing their job satisfaction than did the Non-Control Group. See Table D-24.

Item 14. Subjects in both groups rated the color brightness range for the color green satisfactory. See Table D-24.

Item 14b. Subjects in the Control Group rated the color brightness range for red satisfactory, but subjects in the Non-Control Group rated the color brightness range for red unsatisfactory. See Table D-25.

Item 14c. Subjects in the Control Group rated the color brightness range for orange satisfactory, while subjects in the Non-Control Group rated the color brightness range for orange unsatisfactory. See Table D-25.

Item 15a. Subjects in both groups rated the hue variance control for orange "poor" to "fair." See Table D-26.

Item 16. Subjects in both groups rated the yellow brightness controls as "poor" to "fair." See Table D-27.

Item 17. Subjects in the Control Group switched from the multicolor mode to the all-green mode more frequently than did subjects in the Non-Control Group. See Table D-28.

2.3 Questionnaire B

Questionnaire B was distributed to the controllers during the interviews after both Trial Periods. Thirteen completed forms were received from both Trial Periods. The results are described here without regard to the separate Groups of controllers. (See Appendix B for each item.)

2.3.1 Item 1

On Item 1, there were 7 "yes," 3 "no," and 2 "no response." Two controllers said that Point-Outs should be in their own color. One "yes" excluded Part (c), and one "yes" excluded Parts (b) and (c). One controller said that tracked and non-tracked aircraft should have different colors. One of the "no-responses" was a general anti-color response, and one voted for self-discipline as the required answer to the problem.

2.3.2 Item 2

For Item 2, there were 12 "yes" and 1 "no response." One "yes" excluded Part (a), and one was for Parts (a) and (d) only. The "no response" was a general anti-color response.

2.3.3 Item 3

Item 3 consists of two questions. For the first question, there were 9 "yes," zero "no," and 5 indeterminant responses (3 marked "yes," but not indicating which question, one unmarked, and 1 general anti-color response). For the second question, there were zero "yes," 5 "no," 1 "no response," and 6 indeterminate responses. Of the indeterminate responses, 3 were marked "yes," but not indicating which question. There were one general anti-color response and 2 "no-response."

3. DISCUSSION

3.1 Reactions in Interviews and on Questionnaire A

Specific identification of the technical causes for the subjects' reactions reported above is not possible because

1. the relevant visual characteristics of the viewers are not known (passing the color vision test is not sufficiently diagnostic),

2. the spectral energy distributions of the involved "colors" are unknown,

3. the specific viewing conditions in the operating environment are not quantitatively describable,

4. the specific operating characteristics of the PVD at the time of the reported experiences are not known, and

5. the particular adjustments of the PVD are not quantitatively or qualitatively specifiable for any time (these adjustments were judged subjectively by each adjuster).

For these reasons, further description of these reported reactions for identifying their causes is deemed infeasible beyond open speculation. For example, the report that red was "hard to work with" may be related to normal optical difficulties in focusing on the long wavelength phosphor coupled with the perception of the red symbols as lying farther from the eye than the other colors (also called "depth effect"). It may also be related to the low luminance of the red (a nominal 4 Foot-lamberts), and to the images of lighted surfaces located behind the viewer being reflected from the gold-tinted coating on the outer display surface. Also, the report that yellow and orange were not distinctly different may be related to operating troubles with voltage control of the displays, to the controllers' not effectively adjusting the hues, or to normal individual differences among the color sensitivities of the viewers (all but one, apparently, have passed the color vision test in their medical examinations). It could also be related to the shifts in hue accompanying variations in brightness settings. Further discussion requires data not available from the trials.

Participants generally disagreed on the settings of hue and luminance when viewing the PVDs individually or together. Such disagreement may arise from differences in personal preferences. Differences in preference could occur in the presence of common or similar perceptions. Experimental evidence in the literature shows wide individual differences in color responses, and therefore presumably in the perceptions, of "color normal" viewers. The relative contributions of preference or perception to this disagreement are not identifiable in this instance.

3.2 Subject Groups

The Tables are reported separately for the Groups of subjects for the reasons given earlier. No attempt is made in this paper to attach significance to differences between the Groups. Also, the responses in Tables D-35 through D-42 for the Unspecified Group are not discussed.

3.3 Isolation of Color Effects

The four categories of display data to which separate colors were assigned corresponded exactly to the data categories established in the Center's computer system with which the controllers had extensive experience. Full data blocks, commonly adjusted to be brighter than other data categories, were green. Limited data blocks (fewer symbols) and radar returns, commonly adjusted to be dimmer than full data blocks, were yellow. Map displays, commonly equal in brightness to, or dimmer than, limited data blocks, were red at first and orange later. Weather lines, commonly the dimmest category, were orange at first and red later. Thus, the four categories of data were clearly different in size, shape, brightness, and color, simultaneously. In these circumstances, the participants may understandably have found it difficult to separate the effects of "color" from the simultaneously occurring effects of the other redundantly coded visible differences. The confounding (exact correspondence) of these visual information codes makes it logically impossible to isolate the effects attributable to color alone.

3.4 Questionnaire B

3.4.1 Item 1

The controllers' responses generally favored the scheme described in the Item. The basis for the "no" responses is not known. It is noted that the scheme suggested here needs some thought, especially since the information on which a controller is communicating with an aircraft would require a keyboard input to the computer. In general, this scheme for "tailoring" the color to indicate that some control responsibility was attached to the aircraft is an example of supporting a controller's tasks by color coding tracks uniquely for this case.

3.4.2 Item 2

The responses seem to reject "dynamic color selection," although the reasons for doing so differ slightly.

3.4.3 Item 3

The responses to the first question support the indication in Item 2, and the responses to the second question also seem supportive. The "no-response" category was large probably because the item's two questions should have had separate spaces for the 3 response categories, which renders a single "yes" response ambiguous.

3.5 Other Factors

The results were probably influenced by events associated with the controllers' strike, which may account partly for the low amount of time spent using the multi-color mode. The low rate of use in the available calendar time was due largely to the maintenance and operational difficulties discussed in 1.5 above. These resulted in long delays to isolate and solve the unforeseen problems, and probably contributed to the confusion among participating controllers about the purpose of the trials and the operating features of the displays. These factors could have been responsible for some of the observed negativism on the usefulness of color as presented.

4. FOLLOW-ON WORK

4.1 General

The results of these trials provide no basis for specifying the characteristics of advanced multi-color displays in air traffic control, or for identifying issues or problems for further work.

Information bearing on further work was made uncertain by the need for more thorough planning, better preparation and monitoring of the participating personnel, better human engineering of design and color generation, better maintenance to provide consistently proper operation of the equipment, and more careful consideration of color assignments to display items and categories of information, especially in regard to the support of specific controller tasks to be provided by color coding. While opinions and reactions were obtained, they were not based on prolonged use of the multi-color PVDs operating properly in the multi-color mode independently of other coding dimensions.

4.2 Summary

The results of the trials might have contributed more to guide further work if there had been the opportunity to try different ways in which color assignments supported specific controller tasks requiring display use. Questionnaire B contains an example of such a color assignment procedure. Unfortunately, controllers do not follow common, standardized work habits or techniques on which such a color assignment code could be based. Any one scheme would yield results varying with different work habits and control techniques, and would be based in some unknown way on interactions among working methods and color-coding schemes.

Any selection of "colors" requires a quantitative description of the spectral energy distributions (SEDs) of all light sources involved. Colorimetric coefficients, Munsell descriptors, and other color specifications are inadequate. This is so because many different SEDs can have the same values in a given color system, but will have different effects on different viewers. A selection of SEDs suitable for a population of viewers must evoke visual responses of color sensation which are predictable in that population. At the least, this procedure requires relevant data on the color capabilities in the entire using population. Appendix E discusses some general aspects of this problem; such data in the present case probably can not be obtained.

As described in a previous report* (and in numerous other preceding sources, some discussed in that report, others available in the literature), the visual response of color in an individual can not be calculated from the SED and measurements of individual visual characteristics by available methods. Thus, a selection of "colors" must, at present, rely on individual control of SEDs by subjective adjustment of appropriate controls. The report discusses problems which raise serious doubts about the usefulness of such "dynamic color selection" in the air traffic control situation.

4.3 Recommendations

Since no specific issues or topics for further work on the application of more than one color in PVDs emerged from the trials reported in this paper, no recommendations are made in this regard. Appendix E discusses other factors to consider, and offers additional information.

It is recommended that consideration of further work on color applications be based on a comprehensive review of the pertinent aspects of human color vision and its control by selection of stimulus properties. Such a review should undertake evaluation of all aspects of color application including, but not confined to, the issue of color use to improve the job performance of air traffic controllers based on documented requirements for the operational use of color perception in air traffic control. In the absence of such a review, further work could not be justified by technical or experimental data, or by a reliable basis in experience consistent with the current state of the art in displays and information coding for a given population of viewers.

Glenn C. Kinney

Dr. Glenn C. Kinney

Mary J. DeCicco

Mary J. DeCicco

* MTR-7728, see Preface.

APPENDIX A

QUESTIONNAIRE A

QUESTIONNAIRE FOR COLOR PVD FIELD STUDY

NAME (Optional) ______________________________ DATE: ______________

1. As of the above date, estimated total number of hours operating
   (a) in full-color mode
   Less than 10 ☐ More than 10, less than 40 ☐ More than 40 ☐
   (b) in one-color mode
   Less than 10 ☐ More than 10, less than 40 ☐ More than 40 ☐
2. Traffic level(s) encountered most of the time: Light ☐ Moderate ☐ Heavy ☐
3. Comparing the multi-color mode to the one-color mode for each item

	Multi-color was				
As an aid in each of the following:	MUCH BETTER	BETTER	THE SAME	POORER	MUCH POORER
(a) Distinguishing among data categories					
(b) Detecting occurrence of flashing displays					
(c) Locating symbol blocks					
(d) Reading symbols under light or moderate loads					
(e) Reading symbols under heavy loads, or cluttered					
(f) Reading one color when printed over another					
(g) Retention of data after it leaves the display					
(h) Display scanning to avoid preoccupation or overlooking data					
(i) Avoiding fatigue from using the visual display					

4. Were the color categories, as assigned for this evaluation, satisfactory?

	Yes	No
GREEN	☐	☐
YELLOW	☐	☐
RED	☐	☐
ORANGE	☐	☐

5. If you answered NO to any of the colors in question #4, please explain how you would assign color categories differently. ____________

____

____

____

____

6. Should color be used to call attention to special conditions? Yes ☐ No ☐

If yes, please explain how: ____________

____

____

____

____

7. Were there any operational or equipment problems in transitioning between the color and monochrome modes of operation? Yes ☐ No ☐

If yes, please explain how: ____________

____

____

____

____

8. Did you have any problems operating alongside a monochrome PVD while operating in the multi-color mode? Yes ☐ No ☐

If yes, please explain: ____________

____

____

____

____

9. Did you have a fair opportunity to observe the weather display in color? Yes ☐ No ☐

If so, was weather in color ☐ better ☐ about equal ☐ inferior to monochrome?

10. Do you believe that color, as used in this field study, is a requirement for the ATC system? Yes ☐ No ☐

11. Do you believe that color used in some ways other than in this field study is a requirement for the ATC system? Yes ☐ No ☐

12. If you answered question 11 YES, please explain how: ______________________

____

____

____

____

13. Did use of color enhance your job satisfaction? Much ☐ Little ☐ None ☐

	EXC	GOOD	FAIR	POOR	UNSAT
14. Rate the color brightness range for					
GREEN	☐	☐	☐	☐	☐
RED	☐	☐	☐	☐	☐
ORANGE	☐	☐	☐	☐	☐
YELLOW	☐	☐	☐	☐	☐
15. Rate the range of the Hue Variance control for					
ORANGE	☐	☐	☐	☐	☐
YELLOW	☐	☐	☐	☐	☐
16. Rate the dual level operation of the yellow brightness controls.	☐	☐	☐	☐	☐

17. How often did you switch from color mode to monochrome for any reason?

Frequently ☐ Occasionally ☐ Seldom ☐ Never ☐

If you switched, please explain why (failure, preference, etc.): ______________

____

____

____

____

18. Do you have a medical waiver for color vision deficiency? Yes ☐ No ☐

If yes, what is the deficiency? ______________________

____

____

____

____

****

APPENDIX B

QUESTIONNAIRE B

QUESTIONS FOR CONTROLLER INTERVIEWS

1. There is a problem called "data-block fixation" in which some controllers show a tendency to disregard, neglect, or forget an aircraft not being shown with a full data block. Less-than-full data blocks occur sometimes with early handoffs or pointouts when the aircraft is in the controller's airspace. The controller is thus led to pay less than full attention to all of the aircraft he should be monitoring.

   This fixation might also occur if the data blocks of only those aircraft for which the controller has computer, or track, control were shown in their own color, in the present case, green. The green color, by being associated with full data blocks, could worsen the fixation. A fixation could also occur if green (or any one color) was used only for aircraft in a controller's airspace, regardless of the size of the data block; this would be a green-color fixation.

   Question: Do you believe that "data block fixation" and "color fixation" would be partly overcome if one color (say green) was used to show symbology and radar data for all aircraft which meet one or more of these criteria?

   (a) The aircraft is in the controller's airspace.

   (b) The aircraft is under the controller's track control.

   (c) The aircraft is in voice communication with the controller.

   YES________________ NO________________ NO RESPONSE________________

   Comments or Reasons

2. Color preferences differ among controllers; some want green for one thing, yellow for another, and some want green and yellow to be used in other ways. One suggestion is to allow the controller to set up his own color scheme; this is called "dynamic color selection".

Question: Do you believe that dynamic color selection would make things difficult for controllers in the following situations?

(a) During position relief briefings.

(b) While working alongside someone whose color scheme is different from yours.

(c) When working a given sector with decombined positions when the two controllers (radar and handoff) prefer different schemes.

(d) When working as a D or R man with an R or D man whose color scheme is different from yours.

YES________________ NO________________ NO RESPONSE________________

Comments or Reasons

3. "Dynamic color selection" is intended to overcome controller objections to any fixed color scheme. At the same time, no one color scheme has been selected to please the majority; perhaps no single scheme is preferred by a majority of controllers. One approach to this problem is to select a good working scheme and ask all controllers to use it. Brightness control of each color would be provided.

Questions: Do you believe that controllers would adapt to a single, good scheme and perform better than they now do with one color?

Or, do you believe that color preferences are so strongly related to performance that "dynamic color selection" is an operational requirement?

YES________________ NO________________ NO RESPONSE________________

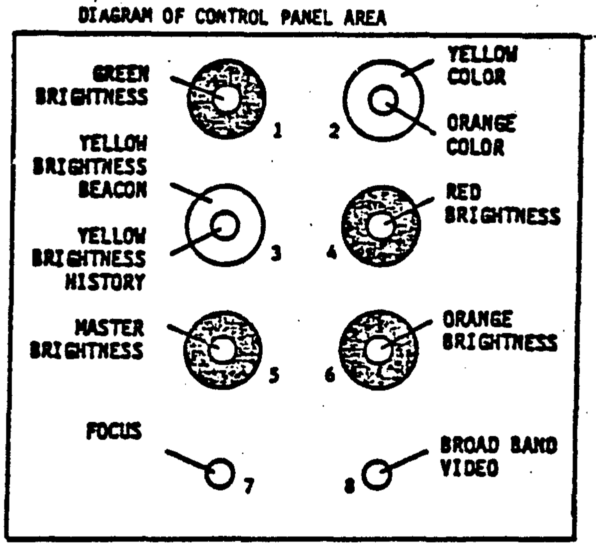
Comments or Reasons

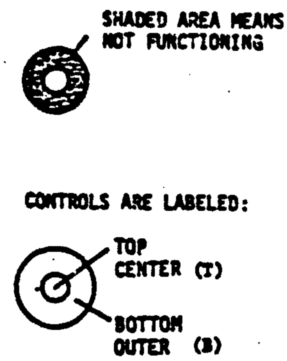
APPENDIX C

COLOR DISPLAY CHECKLIST

COLOR PVD CHECKOUT

DIAGRAM OF CONTROL PANEL AREA





1. ADJUST MASTER BRIGHTNESS 5T (HALFWAY IF STARTING WITH BLANK DISPLAY).
2. MAP
   - SELECT HIGH/LOW ALTITUDE
   - ADJUST ORANGE BRIGHTNESS 6T
   - ADJUST ORANGE COLOR 2T
3. ADJUST FOCUS 7
4. FULL DATA BLOCKS
   - SELECT FULL DATA BLOCKS
   - ADJUST GREEN BRIGHTNESS 1T
5. LIMITED DATA BLOCKS
   - SELECT LIMITED DATA BLOCKS
   - ADJUST YELLOW (HISTORY) BRIGHTNESS 3T
   - ADJUST YELLOW (BEACON) BRIGHTNESS 3B
   - ADJUST COLOR TO YELLOW 2B
6. WEATHER
   - SELECT WEATHER 1, 2, OR BOTH
   - ADJUST RED BRIGHTNESS 4T
7. ADJUST MASTER BRIGHTNESS 5T
8. ADJUST FOCUS 7

COLOR DISPLAY CHECKLIST (Concluded)

CATEGORIES

ORANGE - Map
- sector/center boundaries
- special areas
- airways
- single symbol - geographic

YELLOW - Radar, LDB
- history
- normal LDB
- selected LDB
- inbound list
- hold list
- departure list
- trackball cursor
- radar 1, 2, 3 and 4

GREEN - Track
- alert tabular data
- clock
- requested route display lines
- FDEs, target position symbols

RED - Weather
- lines
- strobe
- single symbols

ADJUSTING

EACH PERSON HAS TO MAKE HIS/HER OWN ADJUSTMENTS OF THE BRIGHTNESS CONTROLS, THE ORANGE-RED CONTROL (2 TOP) AND THE YELLOW-ORANGE CONTROL (2 BOTTOM) TO GET THINGS SET FOR THE INDIVIDUAL'S EYES. YOU SHOULD BE ABLE TO GET ALL OF THESE -

- FOUR CLEARLY DIFFERENT COLORS
- BEACON BRIGHTER THAN HISTORY
- OVERALL BRIGHTNESS SATISFACTORY
- GOOD FOCUS OVERALL

IF THESE CAN NOT BE ACHIEVED, EQUIPMENT MAY NEED ATTENTION.

NOTES

THE "RED FLASH" OCCURS BECAUSE THERE ARE ONLY TWO PHOSPHORS, RED AND GREEN. RED PLUS A DIM GREEN LOOKS ORANGE. RED PLUS A BRIGHTER GREEN LOOKS YELLOW. LOTS OF GREEN LOOKS GREEN. WHEN THE ELECTRON BEAM HITS THE RED AND GREEN PHOSPHORS AT THE SAME TIME, THE RED RESPONDS SOONER AND LASTS LONGER THAN THE GREEN. AS YOU MOVE YOUR EYES ACROSS THE SCOPE, SOMETIMES YOU MOVE THEM JUST AFTER THE GREEN HAS FADED, BUT THE RED IS STILL THERE. WHAT YOU SEE ARE THE RED LEFT-OVERS. THIS "FLASH" IS <u>ALWAYS THERE</u> WITH YELLOW, ORANGE, AND GREEN, BUT YOU DON'T SEE IT UNTIL YOUR EYES MOVE. IT IS HARMLESS. NEWER DESIGNS HAVE DIFFERENT PHOSPHORS AND NO RED FLASH.

TO REDUCE OR ELIMINATE THE RED FLASH, TURN DOWN THE BRIGHTNESS ON YELLOW, ORANGE, AND GREEN AS FAR AS YOU CAN TOLERATE IT.

APPENDIX D

TABLES

TABLE D-1
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD)
ON THE NUMBER OF HOURS OPERATING THE DISPLAYS

1. As above date, estimated total number of hours operating

(a) in full-color mode

	Less than 10	More than 10 Less than 40	More than 40	Sums
Control	16	5	0	21
Non-Control	15	4	0	19
Total	31	9	0	40

(b) in one-color mode

	Less than 10	More than 10 Less than 40	More than 40	Sums
Control	13	1	4	18
Non-Control	6	0	4	10
Total	19	1	8	28

TABLE D-2
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP
SUBJECTS (FIRST TRIAL PERIOD) ON THE TRAFFIC LEVEL ENCOUNTERED
MOST OF THE TIME WHILE OPERATING THE MULTI-COLOR DISPLAY

2. Traffic level(s) encountered most of the time.

	Light	Moderate	Heavy	Sums
Control	8	13	0	21
Non-Control	6	10	2	18
Total	14	23	2	39

TABLE D-3
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD) FOR THE MULTI-COLOR DISPLAY AIDING SPECIFIC TASKS

3. Comparing the multi-color mode to the one-color mode for each item as an aid for each of the following:

	Better	Same	Poorer	Sums
a. Distinguishing among data categories				
Control	8	7	5	20
Non-Control	3	9	8	20
Total	11	16	13	40
b. Detecting the occurrence of flashing displays				
Control	1	14	6	21
Non-Control	1	13	5	19
Total	2	27	11	40
c. Locating symbol blocks				
Control	2	12	5	19
Non-Control	2	7	10	19
Total	4	19	15	38
d. Reading symbols under light or moderate loads				
Control	6	9	6	21
Non-Control	2	7	11	20
Total	8	16	17	41
e. Reading symbols under heavy loads or with cluttered display				
Control	3	7	9	19
Non-Control	2	5	9	16
Total	5	12	18	35
f. Reading one color, when printed over another				
Control	8	7	6	21
Non-Control	2	6	8	16
Total	10	13	14	37

TABLE D-3
(Concluded)

	Better	Same	Poorer	Sums
g. Retention of data after it leaves the display				
Control	1	17	3	21
Non-Control	0	11	4	15
Total	1	28	7	36
h. Display scanning to avoid preoccupation or overlooking data				
Control	4	10	6	20
Non-Control	1	9	9	19
Total	5	19	15	39
i. Avoid fatigue from using the visual display				
Control	2	10	8	20
Non-Control	0	4	14	18
Total	2	14	22	38

TABLE D-4
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUF SUBJECTS (FIRST TRIAL PERIOD)
FOR COLORS AS ASSIGNED FOR THIS STUDY

4. Were the color categories, as assigned for this evaluation, satisfactory?

a. Green	Yes	No	Sums
Control	14	6	20
Non-Control	11	9	20
Total	25	15	40

b. Yellow	Yes	No	Sums
Control	12	8	20
Non-Control	9	10	19
Total	21	18	

c. Red	Yes	No	Sums
Control	10	10	20
Non-Control	9	10	19
Total	19	20	39

d. Orange	Yes	No	Sums
Control	12	8	20
Non-Control	9	11	20
Total	21	19	40

TABLE D-5
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD)
FOR COLORS CALLING ATTENTION TO SPECIAL CONDITIONS

6. Should color call attention to special conditions?

	Yes	No	Sums
Control	5	14	19
Non-Control	2	17	19
Total	7	31	38

TABLE D-6
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD) FOR PROBLEMS
TRANSITIONING BETWEEN ONE-COLOR AND MULTI-COLOR MODES

7. Were there any operational or equipment problems transitioning between the color and the monochrome modes of operation?

	Yes	No	Sums
Control	7	15	22
Non-Control	8	11	19
Total	15	26	41

TABLE D-7
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD) FOR
PROBLEMS OPERATING ALONGSIDE AN ALL-GREEN PVD

8. Did you have problems operating alongside a monochrome PVD while operating in the multi-color mode?

	Yes	No	Sums
Control	7	14	21
Non-Control	6	12	18
Total	13	26	39

TABLE D-8
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD)
FOR WEATHER DISPLAY IN COLOR

9a. Did you have fair opportunity to observe the weather display in color?

	Yes	No	Sums
Control	13	8	21
Non-Control	11	8	19
Total	24	16	40

9b. If so, was weather in color better, equal, or inferior to monochrome?

	Better	Equal	Inferior	Sums
Control	5	4	4	13
Non-Control	2	6	2	10
Total	7	10	6	23

TABLE D-9
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD)
FOR COLOR BEING AN ATC REQUIREMENT

10. Do you believe that color, as used in this field study, is a requirement for the ATC system?

	Yes	No	Sums
Control	2	18	20
Non-Control	2	18	21
Total	4	36	41

11. Do you believe that color as used in some ways other than in this field study is a requirement for the ATC system?

	Yes	No	Sums
Control	2	18	20
Non-Control	2	16	18
Total	4	34	38

TABLE D-10
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD) FOR COLOR ENHANCING JOB SATISFACTION

13. Did use of color enhance your job satisfaction?

	Much	Little	None	Sums
Control	1	5	16	22
Non-Control	1	1	18	20
Total	2	6	34	42

TABLE D-11
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD) FOR BRIGHTNESS RANGES OF COLORS

14. Rate the color brightness range for

	Excellent & Good	Fair	Poor & Unsat	Sums
a. Green				
Control	6	10	4	20
Non-Control	5	7	5	17
Total	11	17	9	37
b. Red				
Control	6	7	7	20
Non-Control	6	4	6	16
Total	12	11	13	36
c. Orange				
Control	2	11	7	20
Non-Control	4	5	8	17
Total	6	16	15	37
d. Yellow				
Control	3	13	4	20
Non-Control	5	6	6	17
Total	8	19	10	37

TABLE D-12
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD)
FOR HUE VARIANCE CONTROL

15. Rate the hue variance control for

	Excellent & Good	Fair	Poor & Unsat	Sums
a. Orange				
Control	5	8	5	18
Non-Control	2	7	6	15
Total	7	15	11	33
b. Yellow				
Control	3	6	9	18
Non-Control	4	6	6	16
Total	7	12	15	34

TABLE D-13
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP (FIRST TRIAL PERIOD) FOR
OPERATION OF YELLOW BRIGHTNESS CONTROLS

16. Rate the dual-level operation of the yellow brightness controls

	Excellent & Good	Fair	Poor & Unsat	Sums
Control	3	7	7	17
Non-Control	6	7	3	16
Total	9	14	10	33

TABLE D-14
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (FIRST TRIAL PERIOD) ON
THE FREQUENCY OF SWITCHING FROM COLOR TO ALL-GREEN MODE

17. How often did you switch from color mode to monochrome mode for any reason?

	Freq.	Occas.	Seldom	Never	Sums
Control	2	7	5	7	21
Non-Control	3	2	6	9	20
Total	5	9	11	16	41

TABLE D-15
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) IN
THE NUMBER OF HOURS OPERATING THE DISPLAYS

1. As above date, estimated total number of hours operating

a. in full-color mode

	Less Than 10	More than 10, Less than 40	More Than 40	Sums
Control	5	3	2	10
Non-Control	1	2	4	7
Total	6	5	6	17

b. in one-color mode

Control	4	3	2	9
Non-Control	2	1	3	6
Total	6	4	5	15

TABLE D-16
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL
GROUP SUBJECTS (SECOND TRIAL PERIOD) IN THE TRAFFIC LEVEL
ENCOUNTERED MOST OF THE TIME WHILE OPERATING A COLOR DISPLAY

2. Traffic level(s) encountered most of the time

	Light	Moderate	Heavy	Sums
Control	1	9	0	10
Non-Control	0	8	0	8
Total	1	17	0	18

TABLE D-17
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) FOR MULTI-COLOR DISPLAYS AIDING SPECIFIC TASKS

3. Comparing the multi-color mode to the one-color mode for each item as an aid for each of the following:

	Better	Same	Poorer	Sums
a. Distinguishing among data categories				
Control	3	6	1	10
Non-Control	2	4	2	8
Total	5	10	3	18
b. Detecting the occurrence of flashing displays				
Control	2	6	2	10
Non-Control	0	6	2	8
Total	2	12	4	18
c. Locating symbol blocks				
Control	3	6	1	10
Non-Control	2	3	3	8
Total	5	9	4	18
d. Reading symbols under light or moderate loads				
Control	3	5	2	10
Non-Control	1	3	4	8
Total	4	8	6	18
e. Reading symbols under heavy loads or with cluttered display				
Control	4	2	4	10
Non-Control	1	4	3	8
Total	5	6	7	18
f. Reading one color when printed over another				
Control	5	2	3	10
Non-Control	2	4	2	8
Total	7	6	5	18

TABLE D-17
(Concluded)

	Better	Same	Poorer	Sums
g. Retention of data after it leaves the display				
Control	0	8	1	9
Non-Control	0	6	1	7
Total	0	14	2	16
h. Display scanning to avoid preoccupation or overlooking data				
Control	2	6	2	10
Non-Control	1	4	3	8
Total	3	10	5	18
i. Avoid fatigue from using the display				
Control	2	3	5	10
Non-Control	0	2	6	8
Total	2	5	11	18
Grand Total	33	80	47	

TABLE D-18
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD)
FOR EVALUATING COLORS

4. Were the color categories, as assigned for this evaluation, satisfactory?

	Yes	No	Sums		Yes	No	Sums
a. Green				b. Yellow			
Control	9	1	10	Control	8	2	10
Non-Control	5	3	8	Non-Control	3	5	8
Total	14	4	18	Total	11	7	18
c. Red				d. Orange			
Control	8	2	10	Control	7	3	10
Non-Control	0	8	8	Non-Control	2	6	8
Total	8	10	18	Total	9	9	18

TABLE D-19
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) FOR
COLORS CALLING ATTENTION TO SPECIAL CONDITIONS

6. Should color call attention to special conditions?

	Yes	No	Sums
Control	3	7	10
Non-Control	1	6	7
Total	4	13	17

TABLE D-20
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) FOR PROBLEMS
TRANSITIONING BETWEEN ONE-COLOR AND MULTI-COLOR MODES

7. Were there any operational or equipment problems transitioning between the color and the monochrome modes of operation?

	Yes	No	Sums
Control	2	8	10
Non-Control	0	8	8
Total	2	16	18

TABLE D-21
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) FOR
PROBLEMS OPERATING ALONGSIDE AN ALL-GREEN PVD

8. Did you have problems operating alongside a monochrome PVD while operating in the multi-color mode?

	Yes	No	Sums
Control	1	9	10
Non-Control	2	6	8
Total	3	15	18

TABLE D-22
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) FOR WEATHER DISPLAY IN COLOR

9a. Did you have fair opportunity to observe the weather display in color?

	Yes	No	Sums
Control	9	1	10
Non-Control	8	0	8
Total	17	1	18

b. If so, was weather in color better, equal, or inferior to monochrome?

	Better	About Equal	Inferior	Sums
Control	4	3	2	9
Non-Control	2	4	1	7
Total	6	7	3	16

TABLE D-23
NUMBER OF RESPONSES OF CONTROL GROUP AND NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) FOR COLOR BEING AN ATC REQUIREMENT

10. Do you believe that color, as used in this field study, is a requirement for the ATC system?

	Yes	No	Sums
Control	1	8	9
Non-Control	0	8	8
Total	1	16	17

11. Do you believe that color as used in some ways other than in this field study is a requirement for the ATC system?

	Yes	No	Sums
Control	1	8	9
Non-Control	1	7	8
Total	2	15	17

TABLE D-24
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD)
FOR COLOR ENHANCING JOB SATISFACTION

13. Did use of color enhance your job satisfaction?

	Much	Little	None	Sums
Control	1	5	4	10
Non-Control	1	0	6	7
Total	2	5	10	17

TABLE D-25
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD)
FOR BRIGHTNESS RANGES OF COLORS

14. Rate the color brightness range for

	Excellent & Good	Fair	Poor & Unsat	Sums
a. Green				
Control	6	2	2	10
Non-Control	4	1	2	7
Total	10	3	4	17
b. Red				
Control	7	0	3	10
Non-Control	1	2	5	8
Total	8	2	8	18
c. Orange				
Control	4	1	5	10
Non-Control	1	2	5	8
Total	5	3	10	18
d. Yellow				
Control	4	2	4	10
Non-Control	2	2	4	8
Total	6	4	8	18

TABLE D-26
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD)
FOR HUE VARIANCE CONTROL

15. Rate the hue variance control for

	Excellent & Good	Fair	Poor & Unsat	Sums
a. Orange				
Control	1	3	6	10
Non-Control	0	3	4	7
Total	1	6	10	17
b. Yellow				
Control	1	2	7	10
Non-Control	0	3	4	7
Total	1	5	11	17

TABLE D-27
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP (SECOND TRIAL PERIOD) FOR
OPERATION OF YELLOW BRIGHTNESS CONTROLS

16. Rate the dual-level operation of the yellow brightness controls

	Excellent & Good	Fair	Poor & Unsat	Sums
Control	1	2	4	7
Non-Control	1	2	3	6
Total	2	4	7	13

TABLE D-28
NUMBER OF RESPONSES OF CONTROL GROUP AND
NON-CONTROL GROUP SUBJECTS (SECOND TRIAL PERIOD) ON
THE FREQUENCY OF SWITCHING FROM COLOR TO ALL-GREEN MODE

17. How often did you switch from color mode to monochrome mode for any reason?

	Freq.	Occas.	Seldom	Never	Sums
Control	1	3	3	3	10
Non-Control	0	3	1	4	8
Total	1	6	4	7	18

TABLE D-29
NUMBER OF RESPONSES OF SUBJECTS IN THE
UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS IN
THE NUMBER OF HOURS OPERATING THE DISPLAYS

1. As above date, estimated total number of hours operating

	Less Than 10	More than 10, Less than 40	More Than 40	Sums
a. in full-color mode	2	4	1	7
b. in one-color mode	3	1	2	6

TABLE D-30
NUMBER OF RESPONSES OF SUBJECTS IN THE UNSPECIFIED GROUP
FOR BOTH TRIAL PERIODS ON THE TRAFFIC LEVEL ENCOUNTERED
MOST OF THE TIME WHILE OPERATING A MULTI-COLOR DISPLAY

2. Traffic level(s) encountered most of the time

Light	Moderate	Heavy	Sums
3	3	0	6

TABLE D-31
NUMBER OF RESPONSES FOR SUBJECTS OF THE UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR MULTI-COLOR DISPLAYS AIDING SPECIFIC TASKS

3. Comparing the multi-color mode to the one-color mode for each item as an aid for each of the following:

	Better	Same	Poorer	Sums
a. Distinguishing among data categories				
	1	0	5	6
b. Detecting the occurrence of flashing displays				
	0	2	5	7
c. Locating symbol blocks				
	1	3	3	7
d. Reading symbols under light or moderate loads				
	1	2	4	7
e. Reading symbols under heavy loads or with cluttered display				
	0	1	5	6
f. Reading one color when printed over another				
	2	1	4	7
g. Retention of data after it leaves the display				
	1	2	3	6
h. Display scanning to avoid preoccupation or overlooking data				
	1	1	5	7
i. Avoid fatigue from using the visual display				
	0	1	5	6
Total	7	13	39	59

TABLE D-32
NUMBER OF RESPONSES FOR SUBJECTS OF THE UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR COLORS AS ASSIGNED FOR THIS STUDY

4. Were the color categories, as assigned for this evaluation, satisfactory?

	Yes	No	Sums		Yes	No	Sums
a. Green	6	1	7	b. Yellow	2	4	6
c. Red	3	3	6	d. Orange	2	5	7

TABLE D-33
NUMBER OF RESPONSES OF SUBJECTS IN UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR COLORS CALLING ATTENTION TO SPECIAL CONDITIONS

6. Should color call attention to special conditions?

Yes	No	Sums
1	6	7

TABLE D-34
NUMBER OF RESPONSES OF SUBJECTS IN UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR PROBLEMS TRANSITIONING BETWEEN ONE-COLOR AND MULTI-COLOR MODES

7. Were there any operational or equipment problems transitioning between the color and the monochrome modes of operation?

Yes	No	Sums
3	3	6

TABLE D-35
NUMBER OF RESPONSES OF SUBJECTS IN UNSPECIFIED GROUP (SECOND TRIAL PERIOD) FOR PROBLEMS OPERATING ALONGSIDE AN ALL-GREEN PVD

8. Did you have problems operating alongside a monochrome PVD while operating in the multi-color mode?

Yes	No	Sums
3	4	7

TABLE D-36
NUMBER OF RESPONSES OF SUBJECTS IN UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR WEATHER DISPLAY IN COLOR

9a. Did you have fair opportunity to observe the weather display in color?

Yes	No	Sums
5	2	7

b. If so, was weather in color better, equal, or inferior to monochrome?

Better	About Equal	Inferior	Sums
1	2	1	4

TABLE D-37
NUMBER OF RESPONSES OF SUBJECTS IN THE UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR COLOR BEING AN ATC REQUIREMENT

10. Do you believe that color, as used in this field study, is a requirement for the ATC system?

Yes	No	Sums
0	6	6

11. Do you believe that color as used in some ways other than in this field study is a requirement for the ATC system?

Yes	No	Sums
0	7	7

TABLE D-38
NUMBER OF RESPONSES OF SUBJECTS IN THE UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR ENHANCING JOB SATISFACTION

13. Did use of color enhance your job satisfaction?

Much	Little	None	Sums
0	2	5	7

TABLE D-39
NUMBER OF RESPONSES OF SUBJECTS IN
UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS
FOR COLOR BRIGHTNESS RANGES OF COLORS

14. Rate the color brightness range for

	Excellent & Good	Fair	Poor & Unsat	Sums
a. Green				
	4	2	1	7
b. Red				
	1	2	4	7
c. Orange				
	1	1	4	6
d. Yellow				
	0	2	4	6
Total	6	7	13	26

TABLE D-40
NUMBER OF RESPONSES OF SUBJECTS IN
UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS
FOR HUE VARIANCE CONTROL

15. Rate the hue variance control for

	Excellent & Good	Fair	Poor & Unsat	Sums
a. Orange				
	1	1	4	6
b. Yellow				
	1	1	4	6
Total	2	2	8	12

TABLE D-41
NUMBER OF RESPONSES OF SUBJECTS IN THE UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS FOR OPERATION OF YELLOW BRIGHTNESS CONTROLS

16. Rate the dual-level operation of the yellow brightness controls

Excellent & Good	Fair	Poor & Unsat	Sums
2	2	2	6

TABLE D-42
NUMBER OF RESPONSES OF SUBJECTS IN THE UNSPECIFIED GROUP FOR BOTH TRIAL PERIODS ON THE FREQUENCY OF SWITCHING FROM COLOR TO ALL-GREEN MODE

17. How often did you switch from color mode to monochrome mode for any reason?

Freq.	Occas.	Seldom	Never	Sums
0	3	3	1	7

APPENDIX E

COLOR VISION IN THE AIR TRAFFIC SERVICE

About two years ago, MITRE inquired of Dr. H. L. Reighard, Federal Air Surgeon, about the occurrence of color deficiencies among air traffic control specialists in the center and terminal options. To his knowledge (he has more than 20 years' service in the aeromedical branch) there are no statistical data available on the topic. He speculated that there were approximately 220 specialists with unspecified color deficiencies in the center option.

The FAA medical policy on requiring normal color vision was adopted in 1965. Dr. Reighard pointed out that there may be some specialists still in the service who joined before then and who have some color deficiency. Since then, there may have been new entries with color deficiency which, in the opinion of the examining physician, were not disqualifying; these cases could occur in either of the specialist options. No formal requirement exists for the physician to record or report such cases. Thus, data would be in the medical records at regional headquarters; the data would not be in standard form, and would exist for reported cases only. The work required to answer our question, insofar as these incomplete and probably ambiguous records are involved, would be prohibitively expensive and time-consuming. In Dr. Reighard's opinion, there is no reason for conducting such a search in view of the current medical requirements, the length of their application (15 years), the absence of related problems reported from the field, and the complexity of deciding which color deficiencies would be relevant.

The authors comment here that the complexity of this decision arises from the nature of color vision and of testing for color deficiencies. Two of the main problems are that the methods of medical examiners (physicians) for testing color vision are not controllable with sufficient precision, and second, the art of color testing at best is imprecise and has not been validated against job performance. The imprecision is inherent in present methods for testing human color vision -- people with normal color vision as determined by these clinical tests comprise a population with wide individual differences in color responses.

Dr. Reighard asked if controls could be provided on the display to allow the viewer to adjust the relative brightnesses of the colors so that visual discrimination could be based on brightness if not on color. In our opinion, this question poses the thought that, if brightness differences alone are sufficient, what does color add? Also, this approach probably could not meet two criteria: First, that all color-normal and color-deficient viewers be reliable in identification of each "color" (or brightness) when the other "colors" (or brightnesses) are not visually adjacent for comparison,* and second, that arranging the display so that two viewers with different requirements for display appearance could adjust it satisfactorily for both to use simultaneously.

The latter case occurs whenever (a) an operational position is operated by a Radar Controller and a helper such as a Handoff Controller, (b) a Radar Controller is working with another Radar Controller on adjacent displays, (c) a Radar Controller and the "D Controller" simultaneously refer to the same display, and (d) during position relief. Since all four of these circumstances occur frequently and regularly, the design solution for a multi-color display must meet a very wide variety of criteria. The data available for such design decisions are not now with us, and are obtainable only with careful attention to technical detail and at appreciable cost.

MITRE contacted Dr. George A. Smith who had moved from the office under Dr. Reighard to the Office of Personnel Management. Dr. Smith's office submitted a statement of policy position to the FAA on color vision requirements for FAA employees, including Radar Controllers. In brief, the position is that if the medical screening of an applicant shows a color deficiency that will not progress with age, or in the work environment, or as a result of work activities, then the applicant becomes a candidate for a practical test to be administered by the employing agency. Thus, applicants are not to be medically rejected for such color deficiencies. Applicants can be job-rejected only on the grounds that a practical test shows inability to perform the job for which the applicant would be employed. Such a "color test" is thus an exercise for the FAA as the employer.

First, the FAA must establish the operational requirements for color capability. At the time of publication of this report, the Office of Personnel Management and FAA medical and Air Traffic Service personnel were examining the requirements for color vision among control tower operators (in the glassed-in cab atop a tower at airports). For radar operators, all of whom are PVD users, the requirement for normal color vision may be replaced by a practical test of vision with one color on the PVD; this color is presently a green.

* The reliability of repeated adjustments of colors on the display by a given controller is not estimable from available data; it would have to be determined for each type or kind of display device, and for each viewer.

Returning to the number of controllers with color deficiencies in the center option, Dr. Smith reported that a number between 200 and 300 had been estimated, more or less intuitively, two or three years before we asked our question. This number may increase if the practical test for radar controllers mentioned above replaces the standard clinical test for color vision.

NOTE:

Readers who are not workers in the field of color vision and color perception may be helped in grasping the extent of the problems cited above by the fact that the perception of a "color" in any given viewer is not reliably controllable by adjusting the physical properties of the visual stimulus (wavelength composition, for example). Color is not a property of the stimulus; it is entirely a response in the perceiving subject. Determining how a given viewer will respond to a given stimulus can not be calculated, it must be found by experimental methods with that viewer. The color response of a viewer is highly sensitive to numerous conditions in the viewing environment and in that viewer. It is unstable in a given viewer even when other conditions are held constant. Thus, any set of such findings applies only to narrow, specific conditions for a short, unpredictable period of time, and only for any one viewer.

These inconstancies and instabilities usually remain unnoticed in routine life situations involving color TV, color films, choice of clothing, interior decoration, and other common applications. In the present need for stable use in a technical field by a large population of viewers, the employment of color perception is made a different matter by the very nature of the perception itself. Thus, what works like a charm in other places is not necessarily dependable for radar operations, and may prove unsatisfactory in ways that common experience could not foresee. Our intuitions can mislead us into expecting what seems obvious, but is found to be highly complex and rather poorly understood upon critical appraisal.

SUPPLEMENTARY

INFORMATION

ERRATA

DOT/FAA/RD-82/46

AD A117 897

EVALUATION OF FOUR-COLOR

PLAN VIEW DISPLAY CONSOLE

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Replace pages iii/iv and 7/8 with the attached for technical report.

ARD-10d

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PREFACE

This document describes work efforts initiated in June 1978 by 9550 Request No. AAF-610-78-006 from the Airway Facilities Service (AAF) to the Systems Research and Development Service (SRDS). SRDS was requested to provide technical and operational support for the evaluation of six Plan View Displays (PVDs) modifi d for both four-color and monochrome presentation. The Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey, was tasked by SRDS to test the color-modified PVDs for display performance. The PVDs were modified for color by the Raytheon Company under an AAF contract. Certification and technical operation of the color PVDs at the Washington Air Route Traffic Control Center (ARTCC) in Leesburg, Virginia was supervised by AAF.

The operational evaluation was assigned by Air Traffic Service (AAT) to the Washington ARTCC. It was conducted by AAT with SRDS providing support from the MITRE Corporation in McLean, Virginia and the FAA Technical Center.

The technical evaluation conducted at the FAA Technial Center is discussed in the main body of this document, and the operational evaluation at the Washington ARTCC is discussed in Appendix B. The report in Appendix B was prepared by the MITRE Corporation and is reprinted in its entirety for presentation herein.

The SRDS managers responsible for ensuring support to the aforementioned 9550 request were J. O'Brien, L. Douglass, and A. Kopala. Appreciation is expressed to the following organizations outside SRDS in the accomplishment of this test and evaluation effort.

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In the Display Control Vector Generator (DCVG), it was necessary to establish a 100 microsecond time delay for allowing adequate time for the PVD high-voltage to settle to a new value upon changing colors. This amount of time between data words of different categories is larger than that required by the standard monochrome-type PVD. Logic circuitry was added to the DCVG A20 board to recognize when data elements of a new color were ready to be presented. Upon this recognition, the circuitry delays this data. If this circuitry fails, an error message is automatically sent to re-establish the reconfiguration subsystem and the failed DCVG is automatically replaced.

The color-modified PVD console featured brightness controls for each data type in each of the four colors and hue controls for orange and yellow.

Data Type	Color
Weather Lines and Symbols	Red*
Map Lines and Symbols	Orange*
Full Data Block, Track, Tabular, and Clock	Green
Radar and Trackball	Yellow (Bright)
Limited Data Blocks and Histories	Yellow (Dim)

*At the start of the evaluations, weather lines and symbols were displayed in orange, map lines and symbols in red; however, these color functions were reversed after several weeks because of controller comments.

These four color brightness controls were implemented as dual potentiometers on the Display Adjustment Control Panel of the PVD. They replaced the "five-level" brightness controls which are used in the unmodified monochrome PVD. A fifth dual potentiometer control was used to adjust the hue of the orange and yellow colors. This control allowed the observer to vary the data of yellow hue from mixed blends of yellow-green to yellow-orange, and the orange hue from orange-red to orange-yellow. The controls for master brightness, focus, and TV video were retained. Their respective functions were to simultaneously adjust all color brightness levels, to optimally adjust data resolution, and to adjust screen brightness in the broadband mode. There was also a failure lamp installed on the System Status and Maintenance Indicator Panel to indicate if the color data were presented out of registration, as previously described on the A3 board modification. An illustration of the color control arrangement is provided in Figure 4.

Figure 4. BRIGHTNESS AND HUE CONTROL LOCATIONS