The use of Ektacolor Paper as a pre-press color proof

Keith Erb

John Suter

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THE USE OF EKTACOLOR PAPER
AS A PRE-PRESS COLOR PROOF

BY

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and
John Suter

ROCHESTER INSTITUTE OF TECHNOLOGY
ROCHESTER, NEW YORK

5 May 1967
ABSTRACT

To test the usefulness of Ektacolor Professional Paper as a pre-press color proofing method, one set of three predictor equations for each of the four primary printing inks was derived relating additive exposures on Ektacolor to colorimetric solid ink densities. These relationships would not yield to simultaneous solution.

Chromaticity coordinates of several sets of solid inks were matched on Ektacolor with an error of 2-10 MacAdam noticeability units. Probably because of the differences in surface characteristics of Ektacolor and newsprint, a visual match was not achieved.
OBJECTIVES

1. To reproduce within 10 MacAdam noticeability units solid-ink densities of cyan, magenta, yellow and black patches on newsprint from a web offset press on Ektacolor Professional Paper.

2. To derive a relationship between the necessary additive exposures on Ektacolor Professional Paper to produce the colorimetric density matches of the cyan, magenta, yellow and black inks.
INTRODUCTION

Pre-press color proofs of halftone separation negatives are a valuable tool for the printing industry. Color proofs provide the printer with a sample for the customer and a method of color control before production begins. The many methods on the market today used for proofing color halftones do not meet the basic criteria for a pre-press color proof. A successful pre-press color proofing method must ideally satisfy three major requirements.

In order of importance these are: 1) Repeatability—the variability of the proofing method must be lower than that of the printing method to which the proof relates. 2) Optical match—ideally the proofing material should have the same surface characteristics of the printing material. 3) Tone reproduction—the ideal proofing method should be capable of duplicating the tone reproduction obtained by the printing method.

The ability to control hue, saturation and lightness of Ektacolor Professional Paper through additive printing makes this process attractive enough to be used as a pre-press color proof to match the color characteristics of printing inks.
EXPERIMENTAL PROCEDURE

A number of solid ink samples were measured on a Colormaster Differential Colorimeter with respect to a Type C illuminate and C. I. E. plots made to find the general areas in which they lay. (See Appendix, graph 1).

An additive exposure test series was made on Ektacolor paper (Emulsion #949640-41418ZDT, +10M, 130 Exp. Factor) using Wratten filters 70, 99, and 98 (red, green and blue, respectively) to find the approximate exposures necessary to colorimetrically match within 10 MacAdam's noticeability units the solid inks. (See Appendix, graphs 2-4). All exposures were made by a "point light source" which consisted of a 100 watt, 20 volt General Electric bayonet mounted bulb operated at 7.95 ±.5 volts. The bulb was contained in a bullet safelight housing with heat absorbing glass to prevent damage to the filters. (See Appendix, page 5).

Centering the exposure levels around the previously determined exposures, a 5-level, partially replicated, factorial design produced data with which a regression analysis was run to find the coefficients for a 3-input variable, second order equation. The
significance of the coefficients was tested at $\alpha = .10$.

The exposure levels used were:

To produce CYAN

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7-11 sec. w/ .5 N.D. filter</td>
<td>8-12 sec. w/ 1.0 N.D. filter</td>
<td>0-4 sec. w/ 1.0 N.D. filter</td>
</tr>
<tr>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
</tr>
</tbody>
</table>

To produce MAGENTA

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4 sec. w/ 1.0 N.D.</td>
<td>7-11 sec. w/ .50 N.D.</td>
<td>1-5 sec. w/ 1.0 N.D.</td>
</tr>
<tr>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
</tr>
</tbody>
</table>

To produce YELLOW

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5 sec. w/ 1.0 N.D.</td>
<td>2-6 sec. w/ 1.0 N.D.</td>
<td>3.5-5.5 sec. w/ 1.0 N.D.</td>
</tr>
<tr>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
<td>$@t=.5$ sec.</td>
</tr>
</tbody>
</table>

To produce BLACK

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2-6 sec. w/ no N.D.</td>
<td>3-7 sec. w/ no N.D.</td>
<td>6-10 sec. w/ 1.0 N.D.</td>
</tr>
<tr>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
<td>$@t=1.0$ sec.</td>
</tr>
</tbody>
</table>

All exposures were timed with an electronic timer with an accuracy of about $\pm .2$ seconds and made at .57 foot-candles. The Ektacolor paper was processed on a Kodak Drum Processor according to instructions.

An IBM 1620 computer was used to run the regression analysis and find the solutions to the four sets of three simultaneous equations by the Newton-Raphson Method. (See Appendix, pages 6-11)

The full mathematical model used was:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + \text{error}$$
where $Y$ is the colorimetric density of an ink and $X_1, X_2, X_3$ are log exposures of red, green and blue, respectively. An error term, calculated from the replications was associated with each equation.
RESULTS

A set of printing inks' chromaticity coordinates were matched on Ektacolor paper within 10 MacAdam non-noticeability units. With the ink sets measured, a 90° difference in orientation of the newsprint sample during measurement produced a change in response of approximately 10 MacAdam units. (See Appendix, graphs 13-22 and Table I below).

TABLE I

<table>
<thead>
<tr>
<th>G.P.I. inks</th>
<th>uncorrected ΔC</th>
<th>corrected ΔC</th>
<th>ΔA</th>
<th>See graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>3.75</td>
<td>4.75</td>
<td>4.90</td>
<td>13-14</td>
</tr>
<tr>
<td>Cyan</td>
<td>1.90</td>
<td>2.00</td>
<td>2.10</td>
<td>15-16</td>
</tr>
<tr>
<td>Magenta</td>
<td>9.50</td>
<td>10.25</td>
<td>10.50</td>
<td>17-18</td>
</tr>
<tr>
<td>Black</td>
<td>6.35</td>
<td>7.70</td>
<td>8.10</td>
<td>19-20</td>
</tr>
<tr>
<td>Direction I and II</td>
<td>9.00</td>
<td>10.00</td>
<td>10.10</td>
<td>21-22</td>
</tr>
</tbody>
</table>

where uncorrected ΔC is the number of MacAdam units, ΔC corrected is the weighted MacAdam units for differences in levels of lightness and ΔA is total color difference enabling the comparison of light colors to dark. (Reference: Union Carbide's "Rapid Graphical Computation of Small Color Differences", by Simons and Goodwin).
Due to the gloss differences in Ektacolor paper and newsprint, the colorimetrically matched samples did not appear visually equal. The low gloss characteristics of the newsprint caused the ink to appear lighter and less saturated than the relatively high gloss Ektacolor, but left the hue unchanged. (See Appendix for illustration, page 12 and Table I.)

Under similar gloss conditions, the maximum number of MacAdam units for a "just noticeable difference" on Ektacolor is tabulated below. (See illustration, page 23 in Appendix).

<table>
<thead>
<tr>
<th></th>
<th>uncorrected</th>
<th>corrected</th>
<th>4A</th>
<th>See graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>5.0</td>
<td>6.5</td>
<td>6.5</td>
<td>24-25</td>
</tr>
<tr>
<td>Cyan</td>
<td>6.5</td>
<td>7.0</td>
<td>7.5</td>
<td>26-27</td>
</tr>
<tr>
<td>Magenta</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>28-29</td>
</tr>
<tr>
<td>Black</td>
<td>5.0</td>
<td>6.0</td>
<td>6.0</td>
<td>30-31</td>
</tr>
</tbody>
</table>

The following equations relating colorimetric density to log exposures were derived from additive exposures on Ektacolor paper:

**Yellow Predictor Equations**

\[
D_r = 0.02 + 0.09R + 0.08G + 0.77B + 0.16R^2
\]

\[
s_y,x = 0.055
\]

\[
D_g = 0.16 + 0.03R - 0.07G + 0.08B + 0.17R^2 + 0.29G^2
\]

\[
s_y,x = 0.013
\]
\[ D_b = 0.50 - 0.12B + 2.24B^2 \]
\[ s_{y.x} = 0.064 \]

Cyan Predictor Equations

\[ D_r = 0.31 - 4.35R - 0.78B \]
\[ s_{y.x} = 0.098 \]

\[ D_g = 0.58 - 0.61R - 0.45G - 0.13B + 0.18B^2 \]
\[ s_{y.x} = 0.028 \]

\[ D_b = 0.35 + 1.57R - 0.26G - 0.15B + 0.96RB + 1.59B^2 \]
\[ s_{y.x} = 0.030 \]

Magenta Predictor Equations

\[ D_r = 0.33 + 0.03R + 2.09G + 0.16R^2 \]
\[ s_{y.x} = 0.021 \]

\[ D_g = 0.29 + 0.004R + 2.45G \]
\[ s_{y.x} = 0.030 \]

\[ D_b = 0.45 + 2.27G + 0.17B + 1.20B^2 \]
\[ s_{y.x} = 0.097 \]

Black Predictor Equations

\[ D_r = 1.07 + 2.66R + 0.78G + 0.36B - 1.08RG + 0.25RB - 1.97R^2 \]
\[ - 0.57G^2 \]
\[ s_{y.x} = 0.037 \]

\[ D_g = 1.02 + 1.43R + 1.22G + 0.63B - 1.23R^2 - 1.24G^2 \]
\[ s_{y.x} = 0.040 \]

\[ D_b = 0.20 + 0.26R + 0.63G + 4.37B - 2.92B^2 \]
\[ s_{y.x} = 0.063 \]

where \( D_r, D_g, D_b \) are the colorimetric densities of an ink set and \( R, G, B, \) are \( \log_{10} E \). These equations must be used with the neutral densities listed in the Experimental Procedure.
CONCLUSIONS

Ektacolor paper is capable of reproducing colorimetrically within 10 MacAdam units, the representative solid inks used.

Under similar gloss conditions the maximum number of MacAdam units tolerable for a visual match is approximately 10. All of the Ektacolor and newsprint samples fell within this range, but due to the gloss differences were far from visually matched.

Ektacolor paper does not meet the gloss characteristics of newsprint and is probably better suited for use with high gloss printing paper.

It is possible to derive a relationship between colorimetric density and additive log exposures on Ektacolor paper. The fact that the equations were not solved in no way invalidates the use of Ektacolor paper as a pre-press color proof for web offset lithography. Another form of this relationship such as percent reflectance equated to exposure might be tried.

Since variability between batches of Ektacolor paper was not tested, the equations derived in this experiment are valid only with this emulsion. Assuming a change in emulsion batches constitutes only a speed shift in individual layers, a constant could be applied to adjust these equations to other emulsions.
Plots of several solid inks

- Yellow
- Neutral
- Cyan
- Magenta
Point Light Source

Heat Absorbing Glass

99 green
70 red
98 blue

Separation

Ektacolor Paper
EXPLANATION OF THE NEWTON-RAPHSON METHOD


The Newton-Raphson Method computes the solutions to \( n \) non-linear equations with \( n \) unknowns. The following is an example of 2 equations with 2 unknowns:

\[
\begin{align*}
F_1(x, y) &= Q_1, \\
F_2(x, y) &= Q_2
\end{align*}
\]

Successively solve the sets:

\[
\begin{align*}
F'_1(x_{m-1}, y_{m-1})\Delta x_{m-1} + F'_1(y_{m-1}, y_{m-1})\Delta y_{m-1} &= -F_1(x_{m-1}, y_{m-1}) \\
F'_2(x_{m-1}, y_{m-1})\Delta x_{m-1} + F'_2(y_{m-1}, y_{m-1})\Delta y_{m-1} &= -F_2(x_{m-1}, y_{m-1})
\end{align*}
\]

The computer program:

The Newton-Raphson computer program is a modification of the "Crout" solution of \( n \) linear equations with \( n \) unknowns. The red lines on the printout indicate the additions made for the Newton-Raphson solution.

Definition of the program: \( n \)=number of equations (program is presently set up for a maximum of three equations), \( XX, YY, ZZ \)=first estimates to the solutions.

The \( C(I,J) \) matrix is made up of the "signed" coefficients of the equations to be solved. The co-
coefficients must be ordered as follows: \( b_x, b_y, b_z, b_{xy}, b_{xz}, b_{yz}, b_{x2}, b_{y2}, b_{z2} \). The \( DX(I,J) \), \( DY(I,J) \), \( DZ(I,J) \) matrices are the coefficients of the partial derivatives of \( f_1 \) with respect to \( x, y, z \) (\( Dx, Dy, Dz \), respectively). These partial derivatives are followed by the partials of \( f_2 \) \( x, y, z \) and \( f_3 \) \( x, y, z \). The coefficients must be ordered on the card to read \( b_x, b_y, b_z, b_0 \). The \( B(L) \) term is the evaluation of each function at the estimated values. The \( A(I,1-3) \) matrix is the evaluation of the partial derivatives.

From this point on the program is "Crout" which is explained in the I. B. M. manual.

The equations have been solved when the previous \( XX, YY, ZZ \) values compare with the new \( XX, YY, ZZ \) within \( \pm 0.0005 \). If no solution is found after 30 iterations the program terminates. (See sample printout).
NEUMANN - RAPHSON SOLUTION OF 3 EQUATIONS 3 UNKNOWNS

DIMENSION A(3,3), B(3), X(3), Z(3,3), C(3,10), DX(3,4), DZ(3,4)
READ 99,N
PRINT 99,N
99 FORMAT(12)
1  READ 306,XX, YY, ZZ
PRINT 306,XX, YY, ZZ
DO 307 I=1,N
READ 308, (C(I,J),J=1,10)
307 PRINT 308, (C(I,J),J=1,10)
DO 309 J=1,N
READ 309, (DX(I,J),J=1,4)
READ 309, (DY(I,J),J=1,4)
READ 309, (DZ(I,J),J=1,4)
PRINT 309, (DX(I,J),J=1,4)
PRINT 309, (DY(I,J),J=1,4)
PRINT 309, (DZ(I,J),J=1,4)
XTEST=30.
300 XTEST=XTEST-1.0
J=1
DO 310 L=1,N
B(L)=-(C(L, J)+XX+C(L, J+1)+Y+C(L, J+2)+ZZ+C(L, J+3)+XX*YY
+1+C(L, J+4)+XX+ZZ+C(L, J+5)+YY+ZZ+C(L, J+6)+XX+ZZ+C(L, J+7)+YY+YY+
2C(L, J+8)+ZZ+XX+C(L, J+9))
310 PRINT 308, B(L)
DO 311 I=1,N
A(I,1)=DX(I, J)+XX+DX(I, J+1)*YY+DX(I, J+2)*ZZ+DX(I, J+3)
A(I,2)=DY(I, J)+XX+DY(I, J+1)*YY+DY(I, J+2)*ZZ+DY(I, J+3)
A(I,3)=DZ(I, J)+XX+DX(I, J+1)*YY+DZ(I, J+2)*ZZ+DZ(I, J+3)
311 A(I,1)=DX(I, J)+XX+DX(I, J+1)*YY+DX(I, J+2)*ZZ+DX(I, J+3)
DO 108 I=1,N
DO 108 J=1,N
108 Z(I, J)=A(I, J)
NMI=N-1
DO 10 J=1,N
JP1=J+1
JMI=J-1
DO 6 I=J,N
ASUM=0
IF (J-1)=6,6,7
7 DO 9 K=1,JM1
8 ASUM=ASUM+A(I, K)*A(K, J)
6 A(I, J)=A(I, J)-ASUM
A(MAX)=A(I, J)
IMAX=J
IF (JP1-JM1)=20,20,21
20 DO 1 I=JP1,N
1 IF(ABSF(A(MAX))-ABSF(A(I, J)))/3,1,1
3 IMAX=A(I, J)
21 IF(ABSF(A(MAX))-1.E-30)=504,504,4
4 DO 5 K=1,IMAX
4 ASAVE=A(IMAX, K)
A(IMAX, K)=A(J, K)
5 A(J, K)=ASAVE
ASAVE=B(IMAX)
B(J)=B(J)
I1=J
J1=JP1
IF (JP1=N)Z2,23,22
22 DO 8 J2=JP1,N
ASUM=0.
8 IF (JH1)8,8,11
11 DO 12 K=1,JH1
12 ASUM=ASUM+A(I1,K)*A(K,J2)
8 A(I1,J2)=(A(I1,J2)-ASUM)/A(I1,I1)
23 ASUM=0.
IF (JH1)2,2,13
13 DO 14 K=1,JH1
14 ASUM=ASUM+A(I1,K)*B(K)
8 B(I1)=(B(I1)-ASUM)/A(I1,I1)
DO 15 J=1,N
11=N-J+1
I=I1+1
ASUM=0.
8 IF (I1-I,N)17,15,15
17 DO 16 K=1,N
16 ASUM=ASUM+A(I1,K)*X(K)
15 X(I1)=B(I1)-ASUM
501 DET=1.0
DO 502 I=1,N
499 PRINT 498,I,J,Z(I,J),A(I1,I)
502 DET=DET*A(I1,I)
600 PRINT 503,DET
IF (ABS(DET)>.0001)504,504,120
120 DO 103 I=1,N
103 PRINT 104,I,X(I1)

PXX=XX
PYY=YY
PZZ=ZZ
XX=X(1)+XX
YY=X(2)+YY
ZZ=X(3)+ZZ
PRINT 200,XX
200 FORMAT(11X,8H NEWXX= ,E14.8)
PRINT 201,YY
201 FORMAT(11X,8H NEWYY= ,E14.8)
PRINT 202,ZZ
202 FORMAT(11X,8H NEWZZ= ,E14.8)
DO 109 I=1,N
109 SUM=0.
DO 110 J=1,N
110 SUM=SUM+Z(I,J)*X(J)
109 PRINT 111,I,SUM
GO TO 306
504 PRINT 105
306 IF (ABS(PXX-XX)>.0005) 301,301,299
301 IF (ABS(PYY-YY)>.0005) 302,302,299
302 IF (ABS(PZZ-ZZ)>.0005) 303,303,299
299 IF (XTEST) 304,304,300
304 PRINT 305
305 FORMAT (5X,15H NEED MORE RUNS)
303 CALL EXIT
104 FORMAT(12H X(12,5H), E14.8)
105 FORMAT(7X, 22H THE MATRIX IS SINGULAR/)
111 FORMAT(3X, 9H CONSTANT(12,5H), E14.8)
198 FORMAT(27X, ZE20.8)
503 FORMAT(7X, 14H DETERMINANT =, E15.377)
309 FORMAT (10F0.5)
END
<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Orginal guesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>39000</td>
<td>0.08000</td>
<td>0.43821</td>
<td></td>
</tr>
<tr>
<td>0.08</td>
<td>0.048</td>
<td>0.76213</td>
<td></td>
</tr>
<tr>
<td>0.07060</td>
<td>0.0395</td>
<td>0.00000</td>
<td></td>
</tr>
<tr>
<td>0.0000</td>
<td>0.00000</td>
<td>0.00000</td>
<td></td>
</tr>
<tr>
<td>3.502</td>
<td>0.00000</td>
<td>0.00000</td>
<td></td>
</tr>
<tr>
<td>3.4666</td>
<td>0.00000</td>
<td>0.00000</td>
<td></td>
</tr>
<tr>
<td>3.0000</td>
<td>0.00000</td>
<td>0.00000</td>
<td></td>
</tr>
<tr>
<td>2.0000</td>
<td>0.00000</td>
<td>0.00000</td>
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</tr>
<tr>
<td>1.0000</td>
<td>0.00000</td>
<td>0.00000</td>
<td></td>
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</tbody>
</table>

Matrix:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>2</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>3</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

Determinant = -0.37315747E+01

Value larger than one means valid solution

Delta value added to estimates

Solutions to equations

As a test program solves for B(L)

Repeats itself with NEW XX, YY; ZZ as new estimates

Determinant = 0.72810561E+01

X(1) = -0.62853800E+01
X(2) = 0.14038411E+01
X(3) = 0.48579173E+01
## Control Sample

<table>
<thead>
<tr>
<th>Color</th>
<th>X Value</th>
<th>Y Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>0.505</td>
<td>0.418</td>
</tr>
<tr>
<td>Magenta</td>
<td>0.423</td>
<td>0.207</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.110</td>
<td>0.277</td>
</tr>
<tr>
<td>Black</td>
<td>0.288</td>
<td>0.313</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control</th>
<th>X Value</th>
<th>Y Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>0.499</td>
<td>0.421</td>
</tr>
<tr>
<td>Magenta</td>
<td>0.411</td>
<td>0.207</td>
</tr>
<tr>
<td>Cyan</td>
<td>0.108</td>
<td>0.268</td>
</tr>
<tr>
<td>Black</td>
<td>0.293</td>
<td>0.310</td>
</tr>
</tbody>
</table>
FROM TABLE 2

MAGENTA

COLOR DIFFERENCE CALCULATING CHART
CHART K
Y = 0.160 TO 0.230

ΔC = 7.5 (CORRECTED)

0.160 0.165 0.170 0.175 0.180 0.185 0.190 0.195 0.200 0.205 0.210 0.215 0.220 0.225 0.230

Union Carbide Corporation