EFFECT OF LABORATORY PROOFING METHODS ON PRINT COLOR

NPIRI Task Force on Color Proofing*

ABSTRACT

Color measurements of laboratory prepared proof samples were made for sheetfed paste inks and Type C gravure liquid inks under carefully controlled conditions. Using the same ink, the same paper, and the same procedures, significant differences were found between laboratories in L*,a*,b* and Delta E* colorimetric values. Significant differences were also observed in sequential proof samples made at the same laboratory by the same operator. Color differences between laboratories were minimized when nine replicate samples were averaged.

Color measurement of proof samples made with two commercial papers recommended by SWOP and produced to the same specifications (Paper A and Paper B) also showed significant differences. Variation within a given paper was less for Paper B than Paper A. Photomicrographs showed Paper B to have a smoother surface than Paper A. These results attest to the critical importance of using paper from the same manufacturer, and preferably from the same roll, when comparing color data between laboratories.

Since the same samples of ink were used in each of the laboratories, these results demonstrate that there are considerable differences in color not due to the ink, but to variations in the substrate and the method used to apply the ink. Color variation between laboratories can be minimized by using

mechanical ink applicators, the same paper substrate, and, most importantly, averaging the results of several replicate samples.

* R. W. Bassemir
A. S. Di Bernardo
J. T. Di Piazza
G. J. Johnson
C. B. Rybny
J. J. Singer
W. F. Zawacki

Introduction

The faithful reproduction of color is perhaps the most critical quality feature in determining overall print quality. The availability of portable, low cost spectrophotometers that give precise color measurement provide a tool that makes it more feasible to achieve that goal. A vital component of course, is the color of the ink. Once a given color is decided upon, it is incumbent upon the ink manufacturer to faithfully reproduce that ink color. This is normally done by comparing the color of proof samples prepared in the laboratory with those of the accepted standard ink.

It has long been suspected that the weakest link in the color measurement chain is the laboratory proof sample. The purpose of this study was to determine the magnitude of the color differences that can occur solely because of the inability to prepare reproducible proof samples. To achieve that goal, proofs were made at different laboratories with the same paste and liquid inks and two standard SWOP papers using the same laboratory proofing equipment under carefully controlled conditions.

Experimental Procedure

In this investigation, two classes of inks, paste and liquid, and two coated papers, stocks A and B were used. Two laboratory proofing techniques were used for the paste inks, the Prufbau and the Little Joe. The inks used were cyan and magenta standard quickset sheet fed offset inks.

For the liquid inks, cyan and warm red type C packaging gravure inks were selected. The same paper stocks, A and B were used with a motorized K-Coater using a wire wound rod.

To evaluate interlaboratory repeatability and reproducibility, two different laboratories made replicate proofs for each proofing method using a specified procedure. The same batches of inks and paper were used by each participating laboratory.

Ten replicate prints, made by each laboratory with each ink and stock, were measured spectophotometrically at three places on each print and averaged. Colorimetric data for each print was then calculated. The color variations within and between laboratories were calculated for each stock and ink. These data are presented as variations in overall color differences (delta E*), using the second proof as a reference. In order to evaluate the effect of using different instruments on color variation, proofs were also measured with one instrument and one operator.

Proofing Materials

Inks - Paste inks were selected from a single batch of a standard sheet fed offset ink made by one manufacturer. Cyan and magenta process colors were chosen for these tests.

The liquid inks were also selected from a single batch of type C packaging gravure ink made by one manufacturer. Cyan and warm red colors were chosen and pre-diluted to press viscosity before distribution to the testing laboratories.

The paste inks meet the following rheological specifications:

	Laray Vis	Yield Stress
	(25 C, 2500 1/sec)	(2.5 1/sec.)
Magenta	210 poise	1730 dynes/cm
Cyan	290 poise	2070 dynes/cm
Tack, 90 F, 800 rpm	12.0	

The liquid inks meet the following specifications:

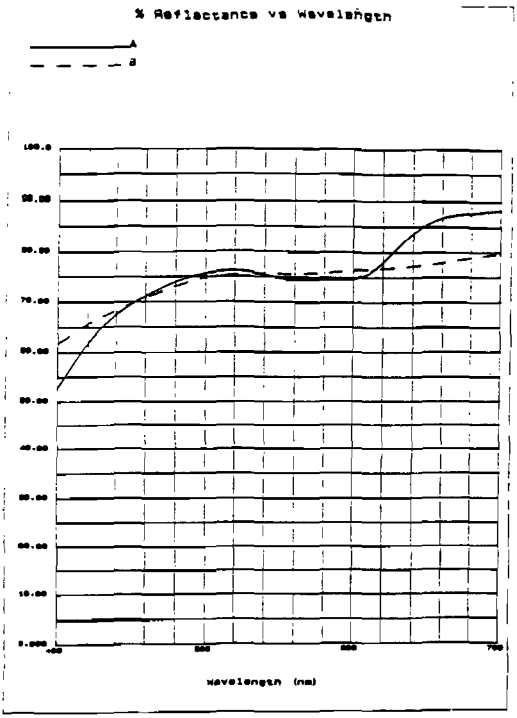
	#2 Zahn Cup Vis-secs At 25 degrees C	Density	Solids
Warm Red	20.0	8.2	29.5%
Cyan	20.0	8.2	30.1%

Stocks - Two commercial coated papers currently specified in the SWOP proofing manual were used for all tests. These are identified here as A and B. An adequate supply of these stocks was obtained from a single roll of each and distributed to the testing laboratories. Measurements were made and vendor specifications obtained on these papers.

The spectral curves of the stocks are shown in Figure 1. It is evident that stock A has a pink/yellow cast from the rise in the curve at 640 nm and the drop in the curve at 400nm.

Figure 1

Paper Stock Spectral Curves

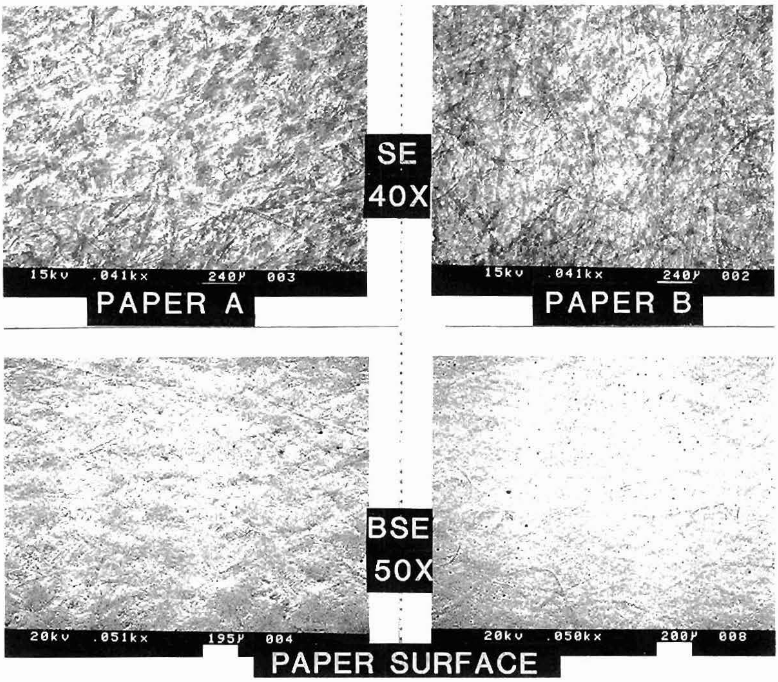


Scanning Electron Micrographs of the stocks are shown in Figure 2. Both SE (secondary emission, which gives a view slightly below the surface) and BSE (Backscattered electrons, which gives a view characteristic of the surface morphology) are shown.

Absorption patterns using a Leneta test ink indicate that stock A is somewhat more absorbent for oil based ink, but with a much smaller mottle pattern than stock B.

Figure 2

Paper Stock Electron Micrographs



Proofing Methods

Target Density - Each laboratory calibrated its densitometer to SWOP standard process magenta and cyan prints from IPA for paste ink samples. Each densitometer was first zeroed and calibrated as recommended by the manufacturer. The density reading of the SWOP standard was then recorded, and proof samples were made to match the standard reading. For the Prufbau press, stock A required about 10 percent more ink on average than stock B to achieve target density. For the K-Coater using liquid inks and a wire wound rod that applied the thinnest coating of ink, densities resulted that were higher than the target density. Each laboratory evaluating liquid inks applied exactly the same amount of ink using the same wire wound rod, pressure, and speeds.

Paste Inks - For proofing of paste inks, two techniques were used. These were the Prufbau Printability Tester and the Little Joe Color Swatcher. The Prufbau is an extremely accurate, but expensive miniature printing press capable of proofing at speeds up to 1000 fpm, at controlled pressure and temperature.

The Little Joe Color Swatcher is a commonly used, relatively inexpensive hand operated press with none of the quantitative control features of the Prufbau.

Liquid Inks - For proofing of liquid inks, there are limited choices of laboratory equipment that appear to be reproducible enough to be satisfactory for spectrophotometric measurements. For the laboratories involved in this program, the only available proofing equipment that appeared satisfactory was the motor driven K-Coater using a wire wound rod as the imaging element. This equipment is widely used in both flexographic and gravure laboratories, is moderately expensive, and does give some control of speed and pressure.

Detailed descriptions of the actual printing parameters used for both liquid and paste inks are given in the Appendix.

Color Measurements

The proofs were measured using a sphere geometry spectrophtometer with the specular component included. Each proof was measured in at least three different areas and the reflectance values averaged by the instrument. Colorimetric calculations using the CIELAB coordinates L*, a*, b* were performed and recorded along with the spectral curve for each proof. The 10 deg. observer and illuminant

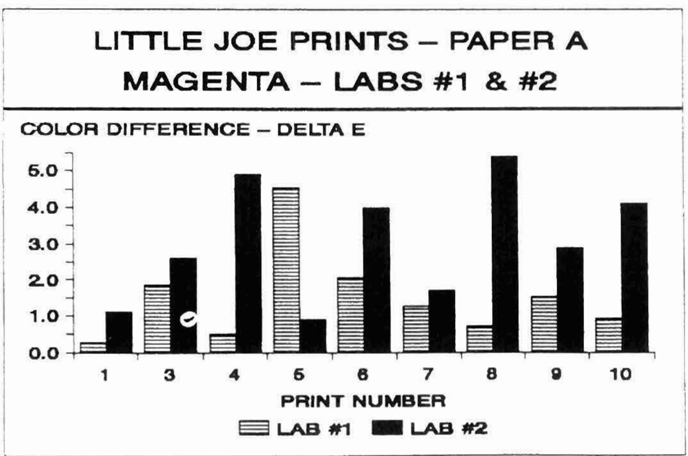
D6500 were used for these calculations. Delta E* color differences were then calculated using the second proof made as a reference. This was done in order to avoid any problems which might have occurred with the first proof made on the equipment. The color differences for each set of 10 proofs were plotted as bar charts and the standard deviation and range of values for each set was also calculated.

Density and Gloss - Each proof sample was measured for density and gloss by taking the average of five readings. Variations within a given sample, from sample to sample and between laboratories and paper stocks were recorded.

Results and Discussion

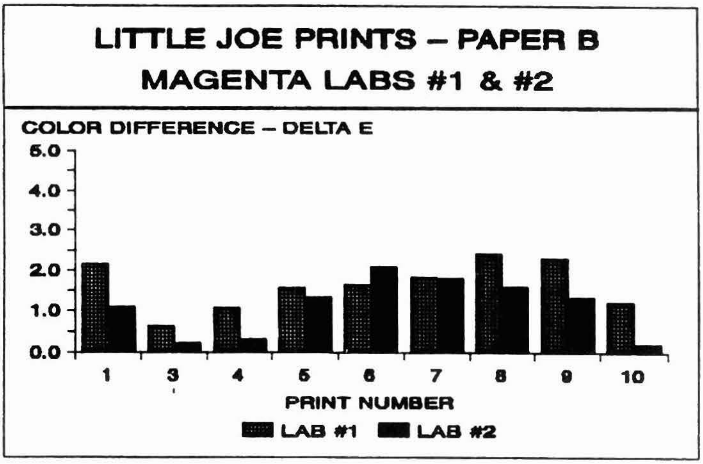
The use of laboratory prepared proofs to determine a delta E* that truly represents a given ink on a given substrate is subject to random variation. A series of proofs made sequentially by the same operator can vary significantly. Variations are magnified when results are compared between laboratories even when as in this case, the same ink, the same paper, and carefully controlled procedures were used.

Figure 3



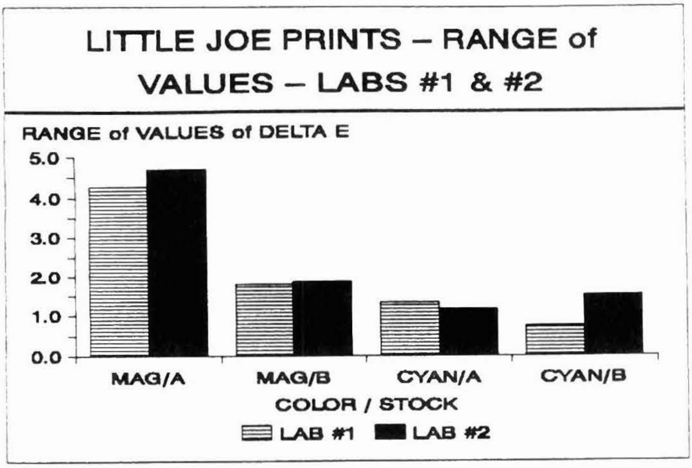
Little Joe Proofs - Bar charts in Figure 3 above show the degree of variation that can exist for ten sequential proofs, and the variation between laboratories using the #2 proof as the reference. In Figure 3, the range of dE* values is 4.6 for lab 2 magenta proofs made with paper stock A, and for lab 1 the range is 4.3. If print #8 for lab 2 is compared with print #1 for lab 1, the maximum difference between labs is 5.1. However, if print #5 for lab 2 is compared with print #10 for lab 1, the dE* difference is only 0.02. If only two prints are made (one reference) it is possible, (although not probable) for dE* to vary from 0.02 to 5.1 between laboratories. If the dE* of all nine proofs for each lab are averaged, the dE* differences between labs is 1.6. (see appendix Table 1 for complete dE* data)

Figure 4



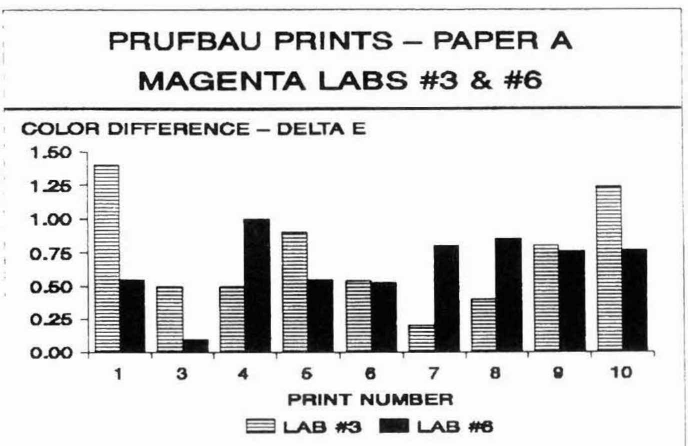
As shown in Figure 4, dE* color differences were less with paper stock B. This was generally true for all proofing methods tested. For stock B, the range of values for replicate samples was 1.9 for magenta, lab 2, and 1.8 for lab 1 using Little Joe proofs. Variation with cyan proofs was significantly less than magenta for both stocks and both laboratories. Differences between paper stocks, laboratories, and colors for the Little Joe are summarized in Figure 5.

Figure 5.



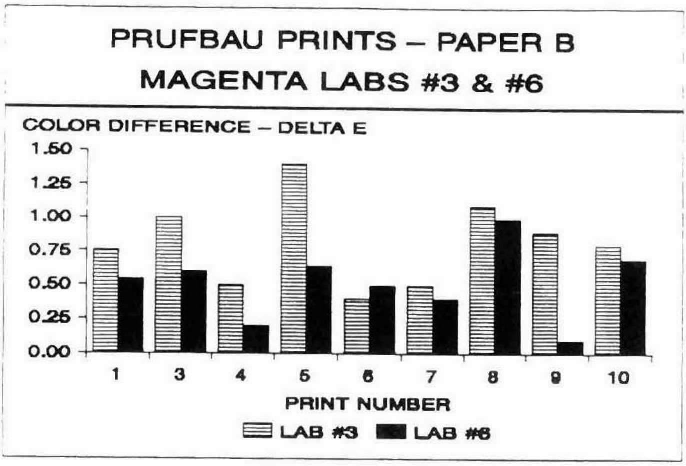
Prufbau Proofs - Color differences were much less with prints made using the Prufbau press. As shown in Figure 6, the maximum dE color range for nine sequential magenta proofs was 0.9 for lab 6, and 1.20 for lab 3 using stock A.

Figure 6



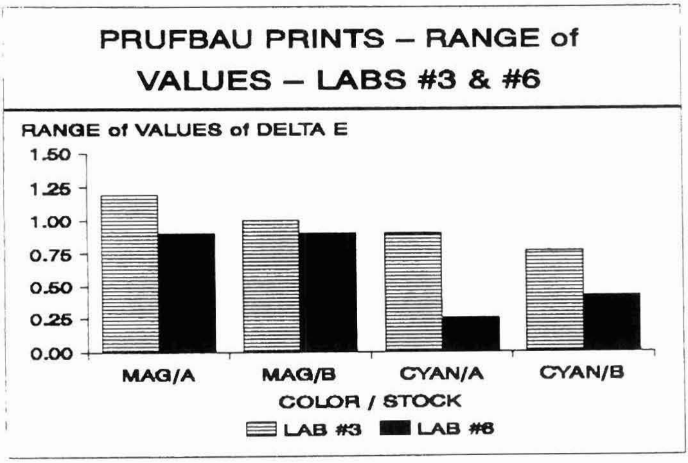
The range of values for Magenta Prufbau prints for stock B (Figure 7) was 0.9 for lab 6, and 1.0 for lab 3, a little less than stock A. Using extreme values for individual proofs, (see Appendix Table 2), the maximum color difference between labs is only 1.3 for magenta, and 0.8 for cyan.

Figure 7



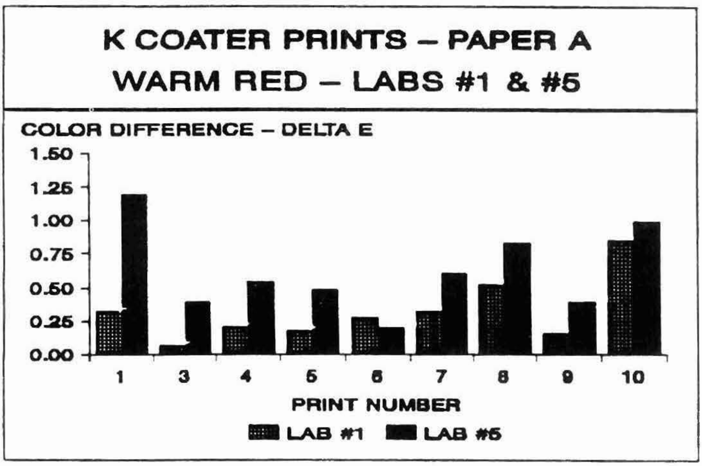
Comparing <u>average</u> color difference values for nine proofs, (App. Table 2) the variation between labs is only 0.06 for magenta/A, and 0.30 for magenta/B. Differences were slightly less for cyan proofs. The range of values by color, stock, and laboratory are summarized in Figure 8.

Figure 8



K-Coater Proofs - Liquid ink proof samples made with the K-Coater had dE* color differences similar to proofs for paste ink made with the Prufbau. The range of values for warm red (Fig. 9) was 0.8 for lab 1, and 1.0 for lab 5 using paper A.

Figure 9



For stock B (Fig 10) the range was 0.3 for lab 1 and 0.8 for lab 5. A summary of color difference values for K-Coater prints is shown in Figure 11. As was the case for paste ink samples, variation was less for cyan and stock B.

Figure 10

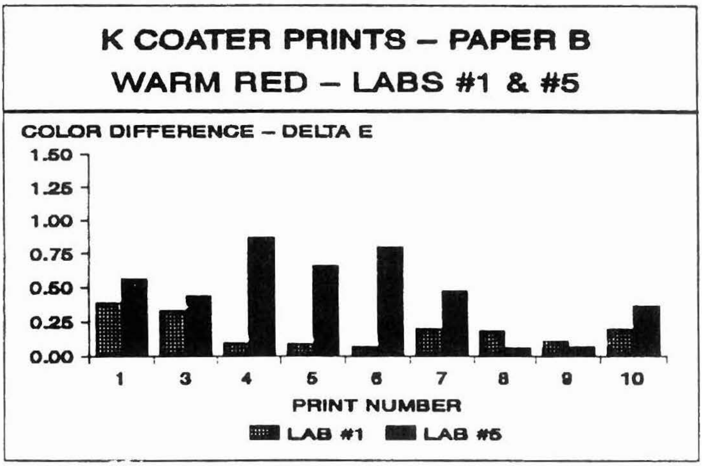


Figure 11

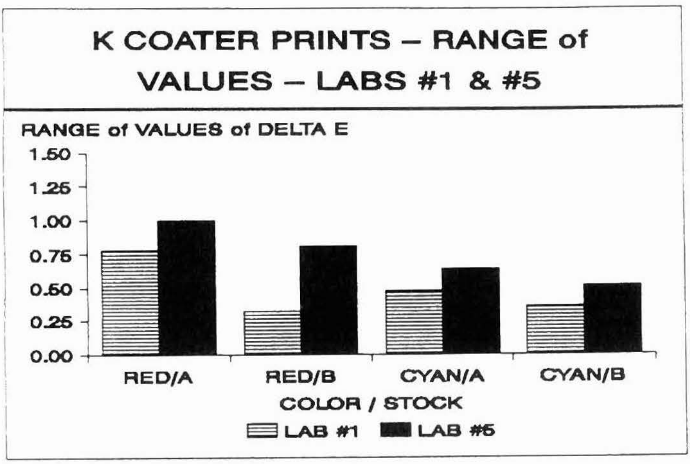


Table 1 below summarizes dE* data by proofing method. It is quite obvious that proofs made with the Little Joe have the greatest variability particularly with magenta. Average dE* differences are significantly lower for the Prufbau, and slightly lower yet for the K-Coater, perhaps because of the flow-out characteristic of liquid inks.

Table 1

dE* Color Difference by Proofing Method (1)

Method	Mag/A	Mag/B	Cyan/A	Cyan/B
Little Joe	2.30	1.38	0.85	0.63
Prufbau	0.69	0.67	0.39	0.41
K-Coater	0.48 (2)	0.34 (2)	0.29	0.28

(1) Average of 18 prints, two laboratories.

(2) Warm Red.

Data which is the average of nine proof samples can be misleading in that it represents the best possible case. What if only three proof samples are run (one reference), and what if the samples represent the extremes? Table 2 shows that if the samples happen to have dE* color values furthest from, and closest to the dE of the reference sample, recorded dE* values differ significantly, and can also be misleading.

Table 2

dE* Color Difference - Extreme Cases

Proof Samples	Prufbau/Magenta (1)		Little Joe/Magenta (2)	
(Stocks)	A	B	A	B
Two Closest	0.30	0.20	0.39	0.85
Two Furthest	0.93	0.82	3.30	2.37
Nine Samples	0.66	0.52	1.51	1.65

(1) Laboratory No. 6.

(2) Laboratory No. 1.

If one accepts the average of nine samples as being the "true" dE* value, dE* for three samples (one reference) can also lead to significant error.

Table 3 compares the color difference obtained when the average of all the Prufbau and Little Joe proofs for a given stock are compared. This data shows that a significant color difference can be obtained with the same ink and same paper when different proofers are used. When comparing results between laboratories, it is most important that the same proofer be used to establish color tolerances and to control subsequent batches of ink.

Table 3

delta E* Color Differences

Prufbau versus Little Joe

	Stock A	Stock B
Magenta	1.83	3.04
Cyan	1.07	2.53

L* a* b* Analysis - Figure 12 below is a plot of all L* a* b* data for paste ink on paper A. The larger scatter pattern for the Little Joe proofs as well as the differences in position in color space are evident.

Figure 12

COLOR DATA FOR REPLICATE
CYAN PRINTS ON PAPER "A"

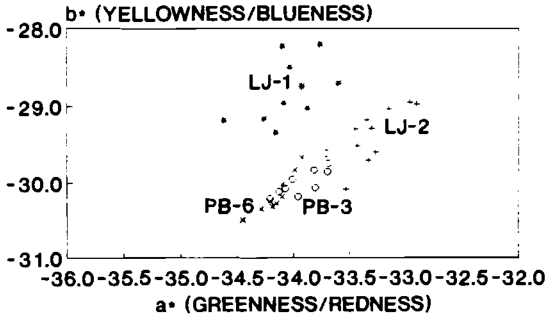
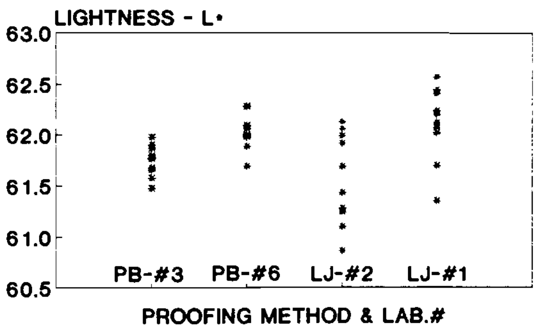


Figure 13 shows a plot of L* data for cyan prints. Again the larger variation in lightness for the Little Joe prints is obvious.

Figure 13

CYAN LIGHTNESS VALUES
REPLICATE PROOFS-PAPER A



Density Measurements

Density measurements are summarized in Table 4 below. Each laboratory calibrated its densitometer against the same SWOP color standard. Densities for the paste ink samples were then matched to the standard. Liquid ink samples were made at the same speed and pressure.

Table 4

Density Measurements (1)

Lab	Proof Method	Cyan Stock A	Cyan Stock B	Magenta Stock A	Magenta Stock B
#1	Little Joe	1.29±.04	1.27±.05	1.50±.07	1.45±.05
#2	Little Joe	1.30±.04	1.27±.04	1.47±.13	1.42±.05
#3	Prufbau	1.33±.01	1.33±.01	1.35±.01	1.36±.01
#6	Prufbau	1.31±.01	1.31±.01	1.35±.01	1.36±.01
		Cyan		Warm Red	
#5	K-Coater	1.88±.03	1.98±.02	1.55±.05	1.62±.03
#1	K-Coater	1.61±.06	1.69±.08	1.22±.07	1.24±.06

(1) Average of ten proof samples, five measurements per sample.

Density of ten samples made with the Prufbau tester were quite uniform. Variations were somewhat greater with the Little Joe press. Densities of liquid ink samples made with the K-Coater showed more variation between labs, possibly due to small differences in the wire wound rods.

Gloss Measurements

Gloss measurements were made of each paper stock and each proof sample using a Byk-Gardner Gloss Gard II glossmeter at 75 degrees. The data for proof samples shown in Table 5 represent the average of ten samples with 5 readings averaged per sample. Gloss data for the two paper stocks are the average of five readings per sheet.

Table 5

Unprinted Paper Stock 75° Gloss

	Stock A	Stock B
Average	56.3	55.6
Range	7.6	3.1

Although the average gloss reading for stock A is slightly higher than stock B, there is more variation with stock A than stock B.

Proof Samples, 75° Gloss

Lab	Proof Method	Cyan Stock A	Cyan Stock B	Magenta Stock A	Magenta Stock B
#1	Little Joe	64	64	61	61
#2	Little Joe	66	67	63	58
#3	Prufbau	67	82	68	83
#6	Prufbau	65	82	66	82
#5	K-Coater	70	76	75	80
#1	K-Coater	71	66	76	70

Gloss data shows fairly good agreement between laboratories. The one exception is the K-Coater proof sample for stock B where there is a ten unit spread between laboratories.

Instrument/Operator Comparison - In order to determine the effect if any, of color measuring instrument-operator variables, the same Little Joe, Prufbau, and K-Coater proof samples were measured with one spectrophotometer, and one operator (lab #4). Results, summarized in Table 6 below show that there are no significant differences. This indicates good correlation in the color measuring procedures used in the various laboratories.

Table 6

dE* Measurement of Same Prints

at Different Laboratories

Color	Magenta		Cyan	
Paper Stock	A	B	A	B
	Little Joe			
Laboratory #1	1.5	1.7	0.8	0.5
Laboratory #4	1.3	1.8	0.7	0.5
	Prufbau			
Laboratory #3	0.7	0.8	0.4	0.3
Laboratory #4	0.6	0.6	0.4	0.2
	K-Coater			
Laboratory #5	0.6	0.5	0.3	0.3
Laboratory #4	0.6	0.5	0.3	0.2

Conclusions

1. Realistic color tolerances for inks using printed proofs can only be set after determining the normal level of variations that can arise from the proofing method, stock, and operator, using a single batch of ink.

2. Replicate proofs are essential if the reliability of measurements is to be improved. Making only a single proof can lead to large differences from the true average color, as established from a significant number of replicates.

3. Variations in colorimetry of proofs printed to equivalent densities with the same ink and stock can be significant.

4. Differences in the micro distribution of the same ink on print surfaces, can produce differences in color due to local film thickness variations, and paper showing through the ink film.

5. For reliable results, it is essential to take several color measurements in different spots in each print and average them in the spectrophotometer.

6. Because of the inherent non-uniformity of the ink distribution on proofs, the largest area of view available on the spectrophotometer is recommended to minimize sampling errors.

7. As expected, of the two paste ink proofing methods, the Little Joe shows a much larger variation in the mean color difference of proofs than the Prufbau. Standard deviations for the Little Joe vary from .22 to 1.58, while those for the Prufbau were from .09 to .38 units. (See Appendix Table 1)

8. The total range of Delta E* values for 10 replicate proofs varied from as low as 0.25 units to as much as 5.4 units, depending on the proofing method, ink color and paper used.

9. The variation in mean color difference for paste inks is appreciably greater with stock A and with the magenta inks. In general, the cyan inks and stock B gave less variation in mean color difference.

10. The K-Coater gave reasonably reproducible results for liquid ink proofing. The magnitude of variations in mean Delta E* and standard deviation were of the same order as those obtained using the Prufbau with paste inks. There was less variation observed for differences in ink color and stock with the liquid inks.

11. Measuring the same proofs with a different brand of spectrophotometer, but having the same optical geometry, and a different operator showed no significant differences in delta E*.

APPENDIX TABLE 1

DELTA E MEASUREMENTS ON REPLICATE PROOFS -

LABORATORY CODE	2	2	2	2	1	1	1	1
Paste or Liquid	P	P	P	P	P	P	P	P
PROOFING METHOD	LJ	LJ	LJ	LJ	LJ	LJ	LJ	LJ
INK COLOR	M	M	C	C	M	M	C	C
PAPER CODE	A	B	A	B	A	B	A	B
PROOF NUMBER								
1	1.10	1.10	1.54	0.38	0.27	2.15	0.25	0.49
3	2.60	0.23	0.36	0.74	1.86	0.63	1.01	0.08
4	4.90	0.32	0.63	0.32	0.50	1.08	1.08	0.33
5	0.90	1.33	0.95	1.83	4.54	1.58	0.57	0.73
6	4.00	2.10	1.34	0.35	2.05	1.65	0.74	0.83
7	1.70	1.80	0.86	0.30	1.25	1.84	0.51	0.68
8	5.60	1.60	0.70	0.33	0.71	2.43	0.43	0.53
9	2.90	1.33	0.73	1.49	1.52	2.30	0.90	0.46
10	4.10	0.22	1.10	0.69	0.92	1.21	1.59	0.73
MEAN of VALUES	3.09	1.11	0.91	0.71	1.51	1.65	0.79	0.54
VALUE RANGE	4.70	1.88	1.18	1.53	4.27	1.80	1.34	0.75
STD. DEVIATION	1.58	0.67	0.35	0.53	1.21	0.57	0.39	0.22

PROOFING METHODS: LITTLE JOE=LJ

INK COLORS: MAGENTA=M CYAN=C

APPENDIX TABLE 2

DELTA E MEASUREMENTS ON REPLICATE PROOFS -

LABORATORY CODE	6	6	6	6	3	3	3	3
Paste or Liquid	P	P	P	P	P	P	P	P
PROOFING METHOD	PB	PB	PB	PB	PB	PB	PB	PB
INK COLOR	M	M	C	C	M	M	C	C
PAPER CODE	A	B	A	B	A	B	A	B
PROOF NUMBER								
1	0.55	0.54	0.50	0.27	1.40	0.75	0.70	0.34
3	0.10	0.60	0.25	0.14	0.50	1.00	0.40	0.80
4	1.00	0.20	0.40	0.30	0.50	0.50	0.20	0.10
5	0.55	0.64	0.40	0.50	0.90	1.40	1.00	0.15
6	0.33	0.50	0.30	0.23	0.54	0.40	0.10	0.10
7	0.80	0.40	0.50	0.33	0.20	0.50	0.20	0.03
8	0.85	1.00	0.30	0.56	0.40	1.10	0.40	0.60
9	0.76	0.10	0.40	0.50	0.80	0.90	0.20	0.10
10	0.77	0.70	0.30	0.40	1.24	0.80	0.38	0.10
MEAN of VALUES	0.66	0.52	0.37	0.36	0.72	0.82	0.40	0.26
VALUE RANGE	0.90	0.90	0.25	0.42	1.20	1.00	0.90	0.77
STD. DEVIATION	0.25	0.25	0.09	0.13	0.38	0.31	0.27	0.25

PROOFING METHODS: PRUFBAU=PB

INK COLORS: MAGENTA=M CYAN=C

APPENDIX TABLE 3

DELTA E MEASUREMENTS ON REPLICATE PROOFS

LABORATORY CODE	1	1	1	1	5	5	5	5
Paste or Liquid	L	L	L	L	L	L	L	L
PROOFING METHOD	KC	KC	KC	KC	KC	KC	KC	KC
INK COLOR	R	R	C	C	R	R	C	C
PAPER CODE	A	B	A	B	A	B	A	B
PROOF NUMBER								
1	0.33	0.39	0.28	0.00	1.20	0.56	0.60	0.20
3	0.07	0.34	0.15	0.00	0.40	0.44	0.30	0.50
4	0.21	0.10	0.14	0.00	0.55	0.87	0.70	0.23
5	0.18	0.09	0.26	0.00	0.49	0.66	0.12	0.44
6	0.28	0.07	0.08	0.00	0.20	0.80	0.06	0.41
7	0.33	0.20	0.33	0.15	0.61	0.48	0.12	0.12
8	0.53	0.19	0.56	0.00	0.83	0.06	0.17	0.63
9	0.16	0.11	0.21	0.18	0.40	0.07	0.31	0.21
10	0.85	0.20	0.32	0.36	0.99	0.37	0.53	0.20
MEAN of VALUES	0.33	0.19	0.26	0.23	0.63	0.48	0.32	0.33
VALUE RANGE	0.78	0.32	0.48	0.36	1.00	0.81	0.64	0.51
STD. DEVIATION	0.22	0.11	0.13	0.09	0.30	0.27	0.22	0.16

PROOFING METHODS: MOTORIZED K COATER=KC

INK COLORS: CYAN=C WARM RED=R

APPENDIX TABLE 4

Preparation of Little Joe Proof Samples

1. Via roller, meter .4cc (2 I.P.I notches) of ink to distribution plate.
2. Distribute evenly with roller.
3. Use high type solid plate.
4. Ink plate with 12 passes (up and back = 2 passes).
5. Ink blanket with 6 passes (up and back = 2 passes).
6. Re-ink roller with 12 passes.
7. Re-ink plate with 12 passes.
8. Ink blanket 3 passes; on third pass, continue through and pull first print.
9. Repeat steps 4-8.
10. Select prints in target density range.
11. Clean up and repeat entire procedure until enough prints in density range are made.

APPENDIX TABLE 5

Preparation of Prufbau Proof Samples

- Target Density - 1.30
- Print Pressure - 100 kp
- Print Speed - 3 m/s
- Temperature - 75 degrees F
- Ink Distribution - 1 min
- Blanketed Roller

APPENDIX TABLE 6

OPERATING SPECIFICATION FOR K-COATER APPLICATION OF FLUID INKS

TESTING EQUIPMENT

K-Coater: Model KCC101 with variable speed drive
Manufactured by R-K Print-Coat Instruments, Ltd.
Distributed by Testing Machines, Inc., Amityville, NY.

OPERATING SPECIFICATIONS

Wire wound rod: R-K Industries KCC Bar #1 (weight 218.4 grams)
Rod Pressure: 300 grams per side
Application Speed: 17cm/second at dial setting of 12 (6.7 inches/speed).
Paper Support: Mellinex Pad of 1/8 inch thickness and free of contamination.

APPLICATION SPECIFICATIONS

Time lapse between ink application by pipette to substrate and activation of application: 2 - 2.5 seconds.
Forced air drying of ink for 3 seconds at 120 degrees Fahrenheit.