EFFECT OF LABORATORY PROOFING METHODS ON PRINT COLOR, PART II

NPIRI Task Force on Color Proofing*

ABSTRACT

Color measurements of laboratory prepared proof samples were made for heatset paste inks and water base flexo liquid inks under carefully controlled conditions. Using the same ink, the same paper, and the same procedures, differences were found between laboratories in L*, a*, b* and Delta E* colorimetric values. 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.

Since the same samples of ink were used in each of the laboratories, these results demonstrate that there are differences in color not due to the ink, but to variations in the substrate and the method used to apply the ink. Color variations can be minimized by using mechanical ink applicators, the same paper substrate, and, most importantly, averaging the results of several replicate samples. Delta E* values measured on the same spot with spectrophotometers having 0/45 geometry were slightly higher but comparable with spectrophotometers having integrating sphere geometry. However, significant differences in absolute L* a* b* color values were observed.

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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, sequential proofs were made at different laboratories with the same paste and liquid inks and the same papers using the same laboratory proofing equipment under carefully specified conditions. This study is a continuation of the work that was reported previously for sheetfed and gravure inks.(1)

EXPERIMENTAL PROCEDURE

In this investigation, two classes of inks, paste and liquid were used. Two coated papers, stocks A and B, and two laboratory proofing methods were used for the paste inks, the Prufbrau and the Little Joe. The paste inks were magenta and cyan standard heatset offset inks.

For the liquid inks, water base flexo cyan and calcium lithol red were selected. Cup stock and liner board were the substrates used with the liquid inks. Prints were prepared using a motorized K-Coater using a wire-wound rod, and two new proofers, the Flexo Proofer and the EZ

Flex Proofer which both use motorized anilox rollers that have controlled pressure and speed. A hand held anilox proofer was also used.

To evaluate repeatability and reproducibility, two laboratories made replicate prints for each proofing method using the same specified procedure. The same sample of ink and paper stocks were split and used by each laboratory.

Ten replicate prints made by each laboratory and each stock were made as nearly possible to the same density so that comparisons between laboratories were made with prints having equivalent density. These prints were then measured spectrophotometrically at three places on each print and averaged. Colorimetric data for each print was then calculated using the second print as the reference. The color variations within and between laboratories were calculated for each stock and ink and are presented as variations of overall color differences (Delta E*).

In order to determine color differences between hand held spectrophotometers using 0/45 geometry and lab instruments using integrating sphere geometry, the same spots on the same proofs were measured and compared.

PROOFING MATERIALS

Inks - Paste inks were selected from a single batch of a standard heatset 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 water base flexographic ink made by one manufacturer. Cyan and calcium lithol 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. (25C 2500 1/sec)	Yield Stress (2.5 1/sec)	Tack, 90 F (1200 rpm)
Magenta	164	3070	13.0
Cyan	175	2960	12.3

The liquid inks meet the following specifications:

	Viscosity, Secs No. 2 Zahn Cup, C	Density lbs/gal	Solids, %
Red	24.0	8.2	41.8
Cyan	24.0	8.2	42.9

<u>Stocks</u> - Two commercial coated papers currently specified in the SWOP proofing manual were used for all prints made with the heatset inks. 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.

Cup stock and liner board were used for all prints made with the water base flexographic inks. They are identified here as stocks C and L.

Physical and optical inspections for the paper stocks are shown in Table 1.

Table I

PROFILOMETRY: SURFACE ROUGHNESS PROFILE IN MICRONS

STOCK	R(max)	R(z)	R(a)
A	22.0	16.5	2.7
B	18.0	13.5	2.1
C	50.0	44.0	6.3
L	29.0	21.5	4.8

where,

R(max)= maximum roughness value in microns
R(z)= average roughness value in microns
R(a)= average standard deviation

OPTICAL PROPERTIES: TECHNIBRITE MICRO TB-1C

PROPERTY	STOCK IDENTIFICATION			
	A	B	C	L
Brightness, ISO	67.92	68.28	81.86	77.38
Opacity, ISO	96.93	94.40	---	---
TRISTIMULUS VALUES				
X	71.61	71.57	84.14	71.86
Y	73.09	73.62	86.23	73.84
Z	79.55	80.37	96.43	91.25
CIE STARLAB				
L*	85.50	85.80	92.86	85.93
a*	-0.10	-1.28	-0.77	-1.12
b*	4.68	4.53	3.44	-2.80
ASTM Whiteness	50.15	51.54	67.90	87.50
ASTM Yellowness	7.86	7.50	5.32	3.82

Profilometry data show that Stock B is slightly smoother than Stock A, and, cup stock is much rougher than liner board.

The optical properties for Stocks A and B are similar. As expected, the optical properties for cup stock and liner board are quite different.

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 liquid inks, reference standards were made for each ink using the EZ Flex Proofer. Print samples were then made to match the reference standard.

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 conditions for making Prufbau prints are given in Appendix Table 2.

The Little Joe Color Swatcher is a commonly used, relatively inexpensive hand operated press with none of the quantitative control features of the Prufbau. The procedure for making Little Joe prints is given in Appendix Table 1.

Liquid Inks - For proofing of liquid inks, several methods were used. The motor driven K-Coater uses 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. The Flexo Proofer and EZ Flex Proofer are newly developed mechanized proofers that can be used with a variety of anilox cylinders. Prints were also made with a hand held anilox proofer which is commonly used by many laboratories. Descriptions of the liquid proofers and procedures are given in Appendix Tables 3 & 4.

COLOR MEASUREMENTS

Colorimetric - The proofs were measured using a sphere geometry spectrophotometer with the specular component included. Prufbau prints were also measured with a 0/45 spectrophotometric using exactly the same spot. 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. 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 - Each proof sample was measured for density 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

Density Measurement - Great care was exercised to prepare prints having the same density so that colorimetry measurements were compared between laboratories at equivalent density. Color references were supplied to each lab using the same densitometer. An example of the agreement between laboratories and the degree of variation in a sequential series of ten prints is shown in Table 2. Differences in the average density reflects the slight difference that can be obtained with different densitometers.

TABLE 2

Average Density and Variation
Ten Prufbau Prints Each Laboratory

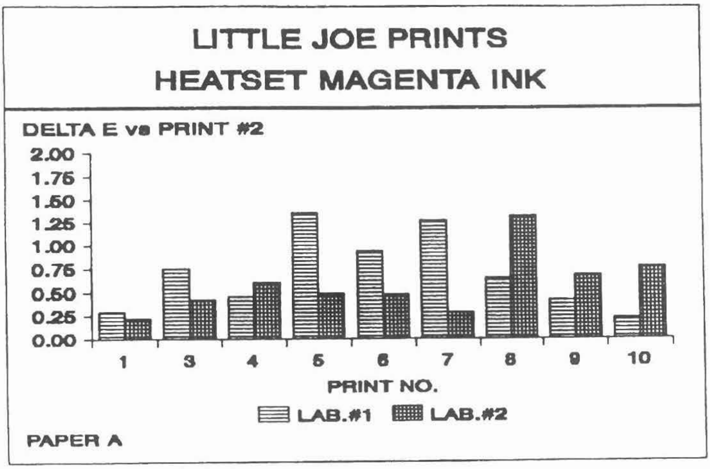
	Magenta		Cyan	
Stock	A	B	A	B
LAB #3	1.38+/-.01	1.38+/-.01	1.31+/-.01	1.32+/-.01
LAB #6	1.35+/-.02	1.35+/-.02	1.31+/-.01	1.31+/-.02

Complete density measurements for all prints are given in Appendix Table 5. The maximum difference in density for replicate prints was +/- 0.06 for the Little Joe series of prints. Maximum variations in density for the Prufbau prints was +/- 0.02. With the exception of K-Coater prints made by laboratory No. 6, the maximum variation in density for replicate liquid prints made with mechanical proofers was +/-0.05.

Colorimetric Measurements - 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 replicate prints made 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.

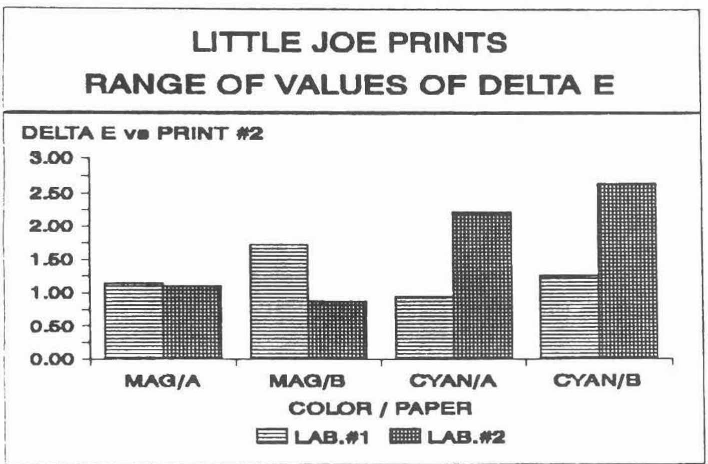
Little Joe Proofs - Bar charts in Figure 1 show the degree of variation that can exist for ten sequential proofs, and the variations between laboratories using the #2 proof as the reference. In Figure 1, the range of dE* values is 1.1 for lab 2 magenta proofs made with paper stock A, and for lab 1 the range is also 1.1. If print #1 for lab 2 is compared with print #5 for lab 1, the maximum difference between labs is 1.1. However, if print #1 for lab 2 is compared with print #10 for lab 1, the dE* difference is zero. If only two prints are made (one reference) it is possible, although not probable, for dE* to vary from 0.00 to 1.1 between laboratories. If the dE* of all nine proofs for each lab are averaged, the dE* differences between labs is only 0.17.

Figure 1



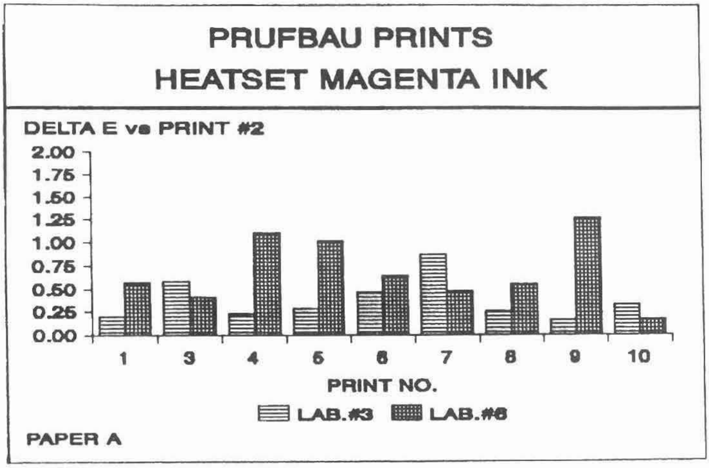
Differences between paper stocks, laboratories and colors for the Little Joe are summarized in Figure 2. The Delta E* in Figure 2 show the variation that can occur for replicate proofs using the Little Joe Color Swatcher. There was less variation in dE* between laboratories in this study than was observed in the previous (1) study, perhaps due to a different procedure used to make prints. However, dE* varied from 0.8 to 2.7 for ten replicate prints.

Figure 2



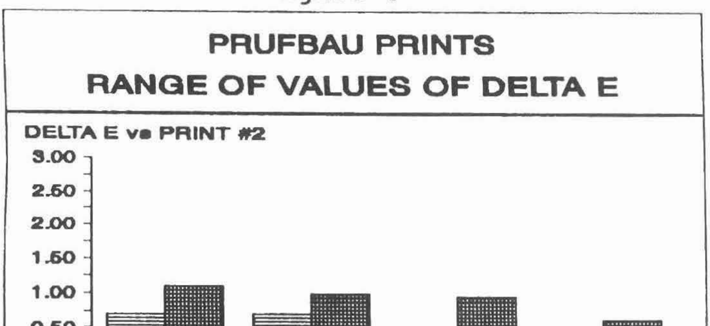
Prufbau Proofs - Color differences were less with prints made using the Prufbau press. As shown in Figure 3, the maximum dE* color range for nine replicate magenta proofs was 1.1 for lab 6, and 0.71 for lab 3 using stock A.

Figure 3



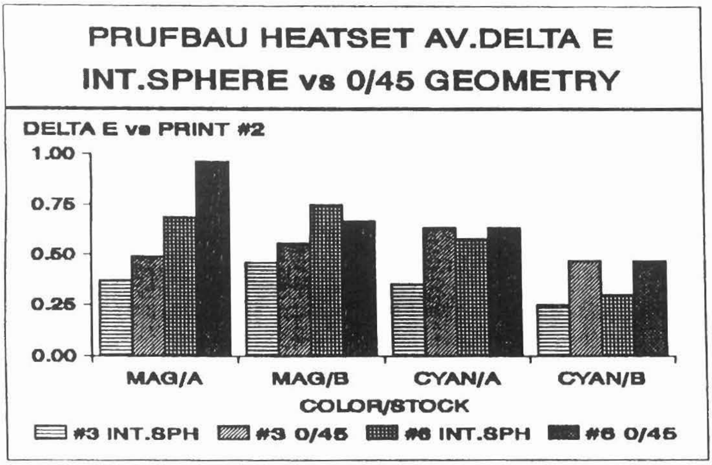
In Figure 4, the maximum range of 1.1 is shown for magenta prints, stock A, and the minimum is 0.25 for cyan with stock A. This is an acceptable range of dE* values which is the result of better uniformity possible with mechanical proofers.

Figure 4



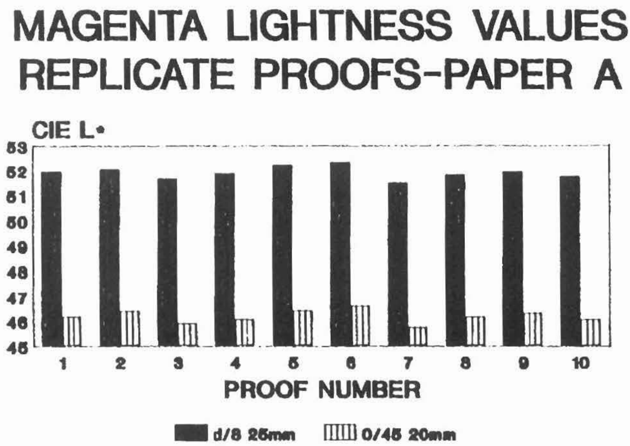
Integrating Sphere-0/45 Comparison - Delta E* values were determined for the same three spots on each of nine Prufbau prints using integrating sphere and 0/45 geometries. Delta E* values in Figure 5 which are the average of nine prints, show that 0/45 geometry is higher than integrating sphere geometry for each laboratory, each paper, and each color ink with the exception of magenta/B for lab No. 6.

Figure 5



The relatively good agreement between 0/45 and integrating sphere geometries can be misleading, however, in terms of absolute color

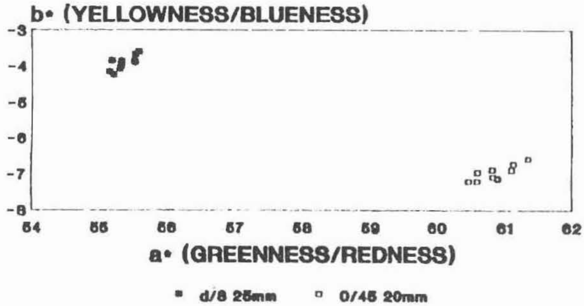
Figure 6



values. L* values in Figure 6 show a big difference in lightness for magenta heatset ink prints measured with integrating sphere and 0/45 geometries. A plot of a* versus b* for the two geometries in Figure 7 show a low level of variation for a given geometry, but again there is a wide difference in absolute values for the two geometries.

Figure 7

COLOR DATA FOR REPLICATE MAGENTA PRINTS ON PAPER B



L* values in Figure 8 show less of a difference for cyan prints than was observed for magenta. The a* b* values for cyan also agree more closely than magenta (Figure 9) but are still quite different.

Figure 8

CYAN LIGHTNESS VALUES REPLICATE PROOFS-PAPER B

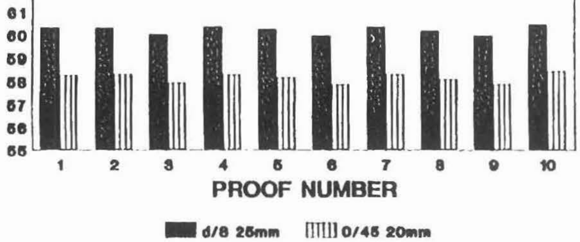
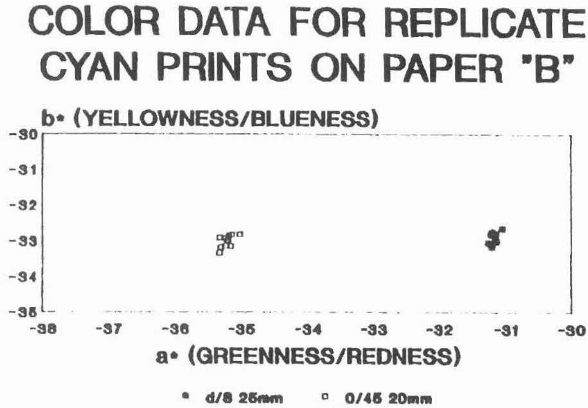
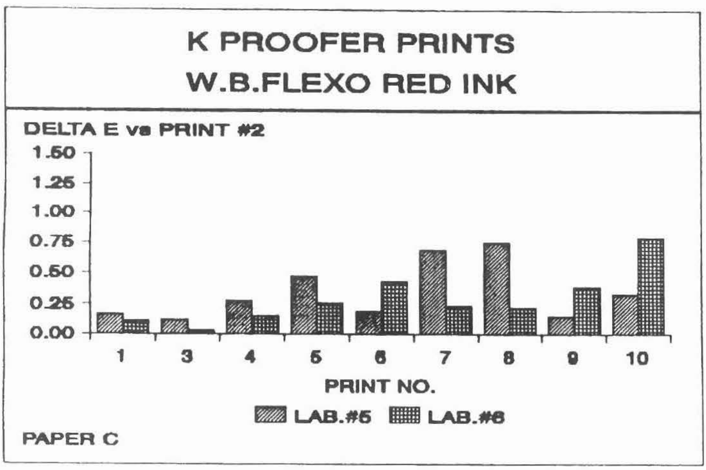


Figure 9



These results show that there is a fundamental difference in the absolute color values reported by 0/45 and integrating sphere geometries. Also, the differences in absolute readings are not the same from color to color which means that a constant factor cannot be applied to reconcile these differences. In general, CIE L* readings for 0/45 are darker than sphere measurements. For magenta, the CIE a*b* results show that 0/45 plots are bluer-redder than the sphere plots. For cyan, the 0/45 a*b* readings are greener than the sphere plots. The Task Force plans a more comprehensive study of

Figure 10

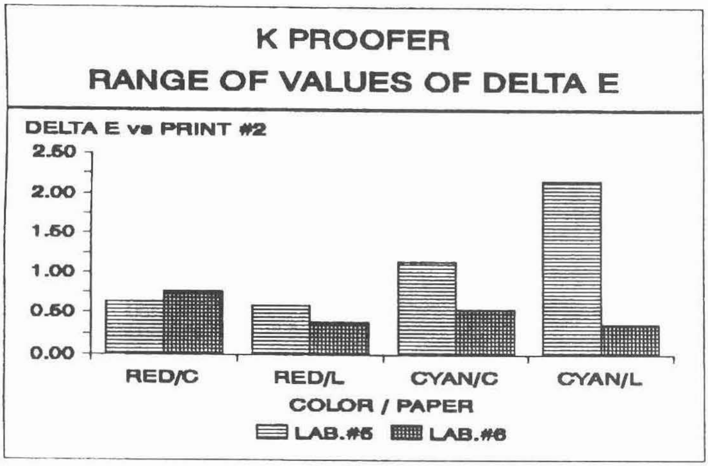


the differences between 0/45 and sphere geometries over a wide variety of colors and surface gloss.

<u>K-Coater Proofs</u> - Liquid ink proof samples made with the K-Coater had dE* color differences that were uniformly low (Figure 10). This is perhaps due to the inherent spreading characteristic of liquid inks leading to uniform prints. The maximum dE* value for 18 prints made in two laboratories is only 0.79.

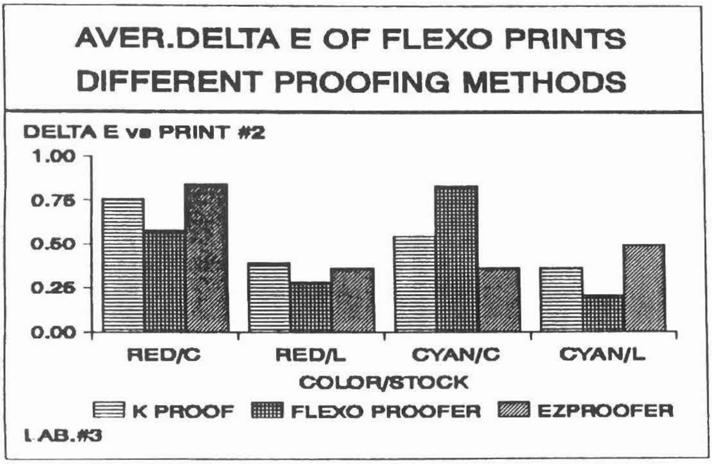
The range of dE* values for K-Coater prints are shown in Figure 11. With the exception of cyan ink samples for lab #5, the range is quite low. The higher values for the cyan prints made by lab #5 are unexplained.

Figure 11



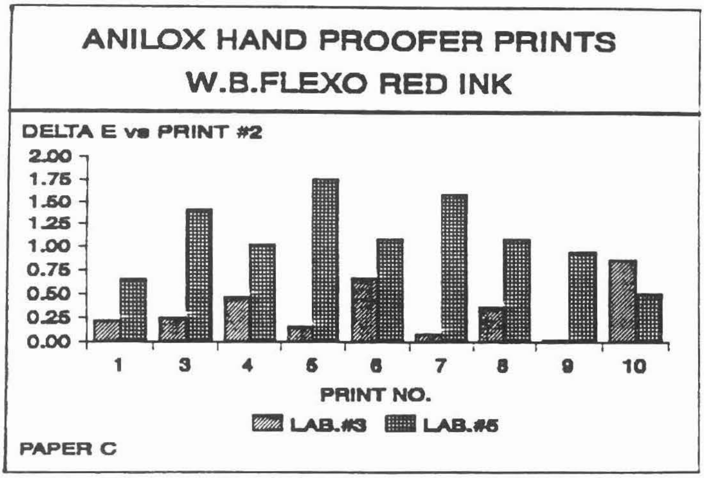
<u>EZ Flex and Flexo Proofers</u> - Two developmental liquid ink lab proofers were evaluated, the EZ Flex and Flexo Proofer machines. Descriptions of these new proofers as well as the K-Coater are given in Appendix Tables 3 & 4. The average dE* values for nine replicate prints given in Figure 12 show that all three mechanical liquid proofers had a variation substantially below 1.0, and are comparable in their ability to make a series of uniform prints.

Figure 12



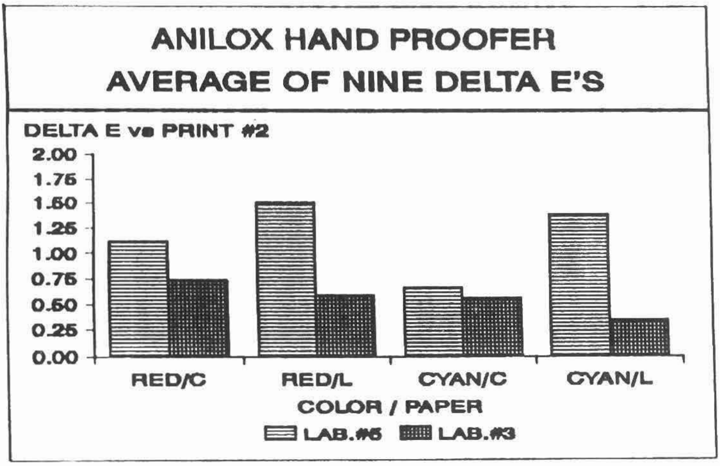
Hand Held Anilox Proofer - The hand held anilox proofer is widely used for color matching because it is quick and inexpensive. However, it is subject to significant variation from print to print and between laboratories. The variation shown in Figure 13 is that caused by the operator alone since the same anilox proofer was used at both laboratories. Even under these ideal conditions (same ink, same paper, same anilox proofer), dE* can vary by as much as 1.49 (for print No. 7) between labs, and as little as 0.01 if print number 1 from lab 5 and print number 6 from lab 3 are compared. This assumes of course that only two prints are made (one reference) which is often the case.

Figure 13



The average dE* values for nine anilox hand proofer prints are shown in Figure 14. When nine prints are averaged the agreement between labs is better, particularly for the cyan prints made with stock C.

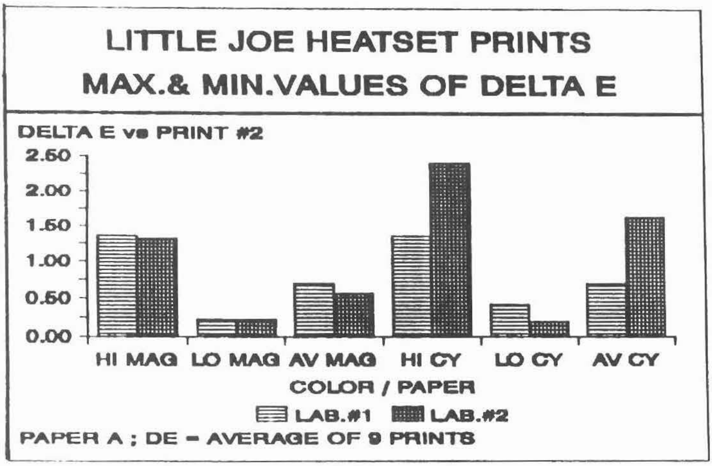
Figure 14



<u>dE* Values, Extreme Cases</u> - The results of this study confirm results of an earlier study (1) which demonstrated that even under carefully controlled conditions where the same ink, the same paper, and the same proofing procedures were used, the dE* value of replicate prints can vary significantly from print to print. The degree of variation depends upon the proofing procedure and the paper stock.

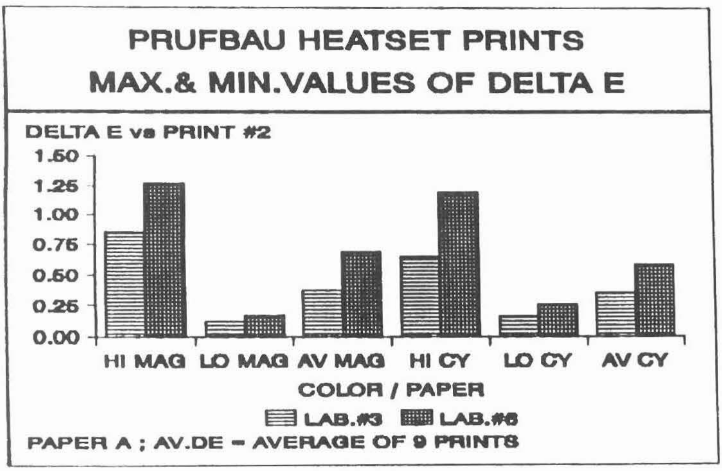
The next series of charts (Figures 15-18) show the extremes in dE* values that can occur if the prints having the two highest and two lowest dE* are compared. For reference, the average of nine prints, which may be considered the "true" dE* for the proofing method used is also given. Figure 15 shows the maximum and minimum dE* values that can occur for a series of nine replicate proofs using the Little Joe Color Swatcher. If the magenta print having the lowest dE* value (0.22 for Lab. 2) is compared with the magenta print from lab 1 having the highest dE* value (1.36) the difference is 1.14. However, if the averages of nine prints are compared, the difference is only 0.13. dE* differences were greater for the cyan prints.

Figure 15



dE* values for the Prufbau proofer are lower and show less variation between the highest and lowest print values (Figure 16). The agreement between laboratories when nine prints are averaged is understandably quite good, with differences of 0.32 dE* for magenta, and 0.23 for cyan.

Figure 16



Results with the K-Coater, a mechanical proofer used for liquid inks, are comparable to those obtained with the Prufbau, which is a mechanical proofer used for paste inks. dE* values in Figure 17 are all less than 1.0 with the exception of highest value cyan print made by lab 5. When the average of nine replicate prints are compared, the dE* difference between labs is only 0.06 for the red ink, and 0.14 for cyan.

Figure 17

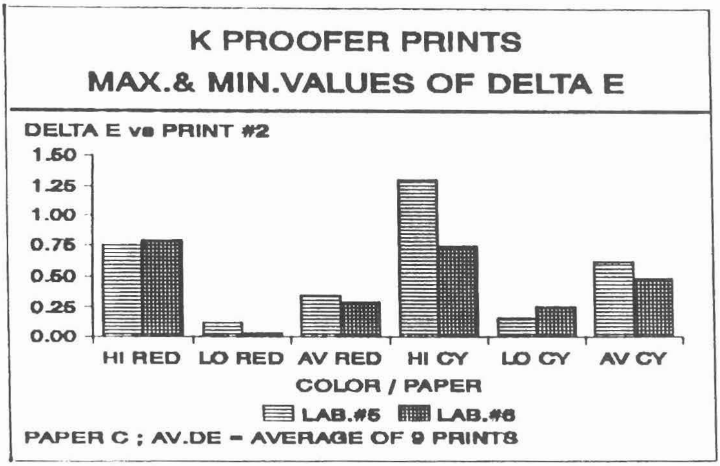
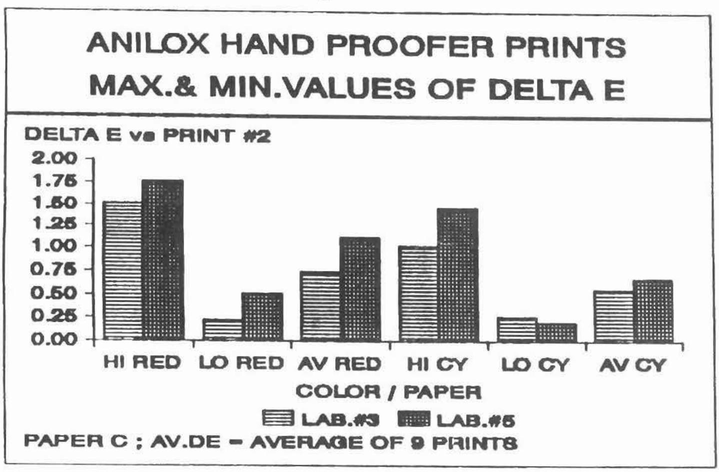


Figure 18



dE* values for prints made with the hand operated anilox proofer shown in Figure 18 are high, as might be expected. There is also evidence that the lab technician for laboratory 3 had more experience or skill since the dE* values for lab 3 are lower than for lab 5. The same anilox proofer was used at both laboratories, removing the anilox as a source of error. If the two low prints for lab 3 are compared with the two high prints for lab 5, the dE* difference is 1.41. Comparing the average of nine prints, the difference is only 0.38.

CONCLUSIONS

1. Realistic color specifications for inks using printed proofs can be set only after determining the normal variation that can occur from the proofing method, stock, and operator, using the same sample of ink.

2. Replicate proofs are needed to improve the reliability of measurements. Making a single proof can lead to large differences from the true color, as established from a significant number of replicates.

3. Variations in colorimetry of a sequential series of proofs printed to equivalent densities using the same ink and stock can be significant. The range in dE* color difference for 10 replicate prints varied from 0.20 to 2.7 depending upon the proofing method, type of ink, and paper stock used.

4. In addition to averaging the results of a significant number of replicate proofs, it is essential to make at least three color measurements in different spots in each print and average them in the spectrophotometer.

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

6. Of the two paste ink proofing methods, the hand operated Little Joe demonstrated a larger variation in mean color difference than the mechanical Prufbau. The maximum range in Delta E* for nine replicate prints for the Little Joe was 2.64 versus 1.1 for the Prufbau.

7. There was no significant difference in average mean color difference for prints made with papers A and B and for magenta and cyan paste inks.

8. Delta E* values for liquid ink prints made with the K-Coater, EZ Flex and Flexo mechanical proofers were uniformly low, and comparable to those obtained with the Prufbau for paste inks.

9. Delta E* values obtained with the hand held anilox proofer were significantly higher than the mechanical liquid proofers, and showed greater variability.

10. Delta E* values for cup stock, which has a rougher surface, were significantly higher than liner board.

11. There was no significant difference in mean delta E* for calcium lithol red and cyan water base flexographic inks for the same substrate.

12. Although mean delta E* values for 0/45 and integrating sphere geometries were comparable, significant differences were observed for absolute L* a* b* color values when the same spots on the same prints were measured.

References

1. NPIRI Task Force on Color Proofing "The Effect of Laboratory Proofing Methods on Print Color" Proceedings, Technical Association of the Graphic Arts, pp. 490-512 1991.

Appendix Table I

Little Joe Heatset Ink Proofing Technique

Materials: Little Joe proofer with clean blanket, metal plate, stock, balance accurate to 0.01 grams, ink, lint free wipers, solvent for clean-up, Sinvatrol oven.

Preparation: Set impression stripe of Little Joe to approximately 3/8" on plate and on print stock.

Sinvatrol oven set to 350 degrees F and 20 ft. per min. belt speed.

Proofing: 1. Evenly distribute 0.45-0.70g of ink with distribution roller on ink distribution plate.

2. Ink plate for a blanket wetting pass with 3 sets of 3 double passes (up and back = 1 double pass) in the following manner: 2 sets of 3 double passes (re-ink distribution roller between sets) then roll blanket over plate for 1st "bump". Disengage impression and roll back to initial position. Ink plate with 3rd set of 3 double passes, then roll blanket over plate for 2nd "bump" and continue on to make a print. Disregard this print; plate and blanket are now ready to make usable proofs.

3. Ink plate with 2 sets of 3 double passes.

4. Single bump blanket and roll out proof. This 2nd overall proof could be "a keeper". Pass thru oven and record density. Approximately 10-15 sec. from proofing to oven.

5. Repeat Steps 3 to 5 until density of print drops below target range. Approximately 3-4 prints.

6. At that point, clean up proofer, plate, roller etc. and repeat from Step 1.

7. Continue until 10 proofs of satisfactory density have been made discarding any proofs not at proper density.

Appendix Table 2

Preparation of Prufbau Proof Samples

- Target Density - Cyan 1.31, magenta 1.38
- Print Pressure - 100 kp
- Print Speed - 5 m/s
- Temperature - 25 C
- Ink Distribution - 15 sec. dist., 15 sec. print form
- Blanketed Roller
- Sinvatrol - 350 degrees F, 20 fpm belt speed

Appendix Table 3

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.

Appendix Table IV
<u>Liquid Ink Proofers</u>

<u>FLEXO PROOFER</u>

Dimensions - 20"W X 40"L X 12"H
Max. Substrate Size - 5"W X 21"L
Min. Substrate Size - 1"W X 21"L
Max. Print Area - 3 1/2"W X 20"L
Printing Speed - 50 to 175 fpm
Weight - 40 lbs.

<u>EZ FLEX PROOFER</u>

Dimensions - 13"W x 36"L x 10"H
Max. Substrate Size - 8 1/2"W X 15"L
Max. Print Area - 8 1/2"W X 15"L
(typical 2 3/4" X 15")
Printing Speed - 30 to 120 fpm
Weight - 40 lbs.
Speed - 70 fpm
Rubber Print Roller - 55 Durom. Shore A

<u>ANILOX HAND PROOFER</u>

Dimension, Anilox Roll - 4"W
Print Width - 2 3/4"
Anilox - 165 Line Pyramid (Approx. 9.4 billion cubic microns/square inch)
Rubber Roller - 55 durometer

Appendix Table 5

Density Measurements

Lab	Proof Method	Magenta Stock A	Magenta Stock B	Cyan Stock A	Cyan Stock B
# 1	Little Joe	1.38+/-.03	1.38+/-.04	1.38+/-.04	1.32+/-.05
# 2	Little Joe	1.37+/-.04	1.34+/-.06	1.31+/-.04	1.33+/-.03
# 3	Prufbau	1.38+/-.01	1.38+/-.01	1.31+/-.01	1.32+/-.01
# 6	Prufbau	1.35+/-.02	1.35+/-.02	1.31+/-.01	1.31+/-.02

Lab	Proof Method	Red Stock C	Red Stock L	Cyan Stock C	Cyan Stock L
# 5	K-Coater	1.50+/-.03	1.87+/-.01	1.48+/-.02	1.98+/-.02
# 6	K-Coater	1.40+/-.08	1.80+/-.05	1.55+/-.06	1.85+/-.06
# 3	EZ Flex	1.14+/-.01	1.49+/-.01	1.15+/-.01	1.50+/-.02
# 6	Flexo Proofer	1.24+/-.04	1.64+/-.05	1.29+/-.03	1.63+/-.05
# 3	Anilox	1.12+/-.02	1.46+/-.04	1.15+/-.02	1.47+/-.04
# 5	Anilox	1.12+/-.03	1.44+/-.04	1.14+/-.04	1.44+/-.08