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Determining the effect of printing ink sequence for process colors on color gamut and print quality in flexography

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Determining the Effect of Printing Ink Sequence for Process Colors on Color Gamut and Print Quality in Flexography

By

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Certificate of Approval

Determining the Effect of Printing Ink Sequence for Process Color
On Color Gamut and Print Quality in Flexography

This is to certify that the Master's Thesis of

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for the thesis requirement for the Master of Science degree
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Abstract

The effect of printing ink sequence for process colors on color gamut and image quality was studied, to determine if there was an optimum printing ink sequence for flexographic printing. The results of using four process color inks (Cyan, Magenta, Yellow, and Black) in various sequences in flexography were analyzed in this research. White oriented polypropylene (OPP) film was printed with UV inks on a Mark Andy LP3000 flexo press. The sequences were analyzed based on differences in the color gamut, their volume, ability of the sequence to reproduce better-looking images, and rendering of maximum ink coverage.

The results suggest there was no one particular sequence that was proved to be optimum. Among the five sequences (YMCK, MYCK, CMYK, KYMC, and KCMY) tested, only one (KCMY) printed well without producing any moiré-like pattern. The other four sequences (CMYK, YMCK, MYCK, and KYMC) did produce a moiré-like pattern in the heavy ink coverage or shadow regions of the print. However, the sequences showing the moiré-like pattern exhibited bigger color gamuts compared to the one that does not produce a moiré-like pattern. The actual cause for the moiré-like pattern formations is unknown. It may not be due to faulty screen angles. Instead it is suspected that it is related to the wetability of the CMY inks underneath the Black. Further research is needed to find the real reason for the formations of these moiré-like patterns.

Thus, it will be difficult to have one optimum ink sequence for flexography, as one sequence may be preferable for obtaining a bigger gamut for a given hue angle, while some other sequence may produce better-looking images without any moiré-like printing artifacts appearing in the prints. If the image to be printed has more colors (requiring a bigger gamut) and limited or no shadow regions,

it is recommended to print in the order of CMYK. If the image to be printed has more shadow regions, and less colors (can be printed with a smaller gamut), it is suggested to print with the KCMY sequence.

Chapter 1 – Introduction

Introduction and Problem Statement

Flexography, originally known as Aniline printing, is a relief printing process similar to letterpress. This process is widely used in the packaging and publishing industry. One of the most important design features of the packaging industry is the use of a wide variety of colors in their printed products, for which spot colors are used rather than process colors. This is due to the limitation of color gamut for process colors.

In process-color printing, color is produced by overprinting different amounts of Cyan, Magenta, Yellow, and Black consecutively. Printing with different sequences can produce different gamut volume. Thus, it becomes important to determine a sequence with the largest color gamut, along with rendering good color reproduction and density. This research attempted to determine the optimum sequence among commonly used sequences within the printing industry. There are number of reasons for selecting a particular sequence. For example, to gain better registration control, to obtain a good color gamut, as well as to obtain high density by printing with low total ink coverage.

Reasons for Interest

The researcher has been interested in the flexographic printing process since the beginning of her academic career in the School of Print Media at Rochester Institute of Technology. In particular, she has been keen on learning the flexographic process as a printing process for its widespread use in the packaging industry around the globe. The researcher believes that by determining the effect of printing ink sequence for process colors in flexography, she may be able to determine one more method for improving image quality.

Chapter 2 - Theoretical Basis

Process Colors

Process Colors are the combination of three primary colors (Cyan, Magenta and Yellow), along with Black. When mixed in various quantities, these colors are capable of reproducing a large color gamut suitable for reproduction of color images. During the printing process, Cyan, Magenta, Yellow, and Black are mixed on the press to create different colors (Fraser, 2005). These process colors must be transparent to allow light to penetrate through the ink when printed. The transparency of inks filters the light as it is reflected off the substrate rather than on the ink surface. By doing this, only certain wavelengths of light are permitted to reach the eyes. Thus, the transparency of inks is required to achieve different colors when the three process inks (Cyan, Magenta, and Yellow) are printed on top of each other. The use of Black ink is not for creating any specific color, but mainly for achieving dark densities as well as to print type.

Theoretically, the full presence of Cyan, Magenta, and Yellow results in Black. In practice, however, when 100% of these three inks are laid down on paper, the resulting color is a muddy brown. This is due to the impurities in the inks. A perfect printing ink absorbs one-third component of the spectrum and reflects two thirds component of the spectrum as shown in Figure 1 (FFTA, 2002 & Giammatteo, 1975). Ideally, Cyan ink absorbs only the Red light and reflects Green and Blue

light; Magenta ink only absorbs Green light and reflects Red and Blue light; and Yellow ink absorbs Blue light and reflects Red and Green light.

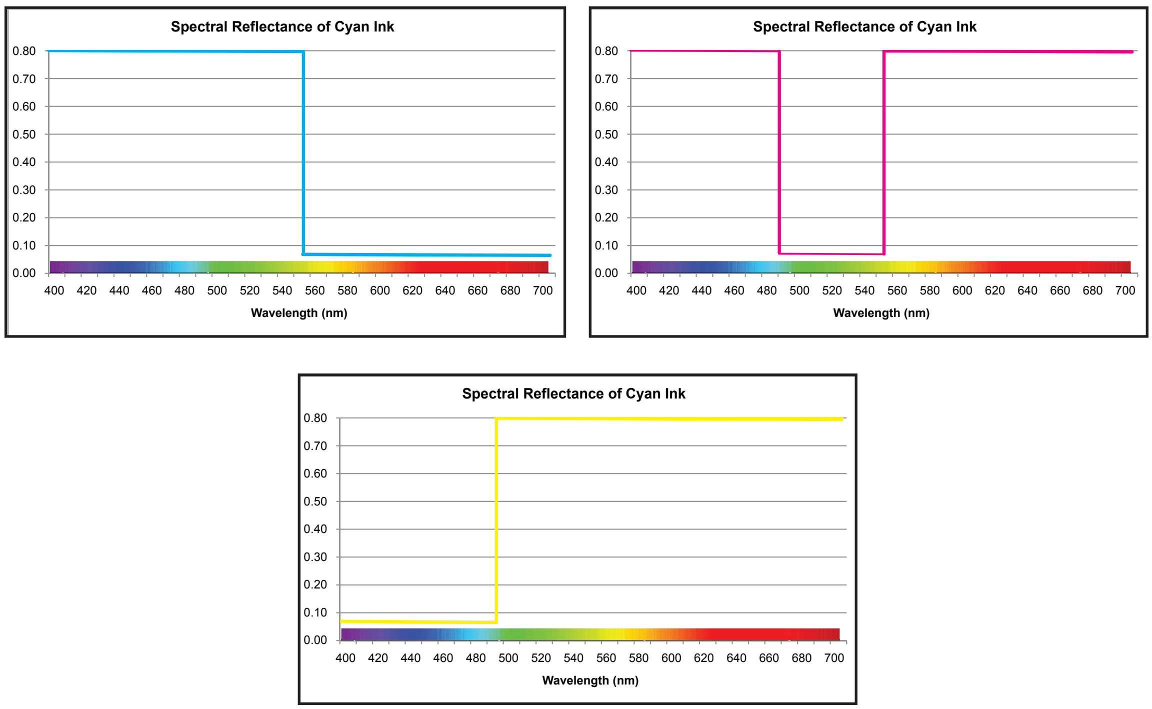

Figure 1: Spectral Reflectance Curves of Theoretically Perfect Process Inks

In reality Cyan ink not only absorbs Red but also some amount of Blue and a little Green light, Magenta absorbs more amounts of Blue and very little Red light along with Green, but Yellow absorbs Blue light but reflects almost all of Red and Green light. The spectral curves in Figure 2 show the reflectance of actual printing inks that are used to print the test forms. In other words, it can be said that Magenta is contaminated with Yellow; Cyan is contaminated with both Magenta and Yellow, but comparatively Yellow is purest as it is not contaminated strongly with any other color.

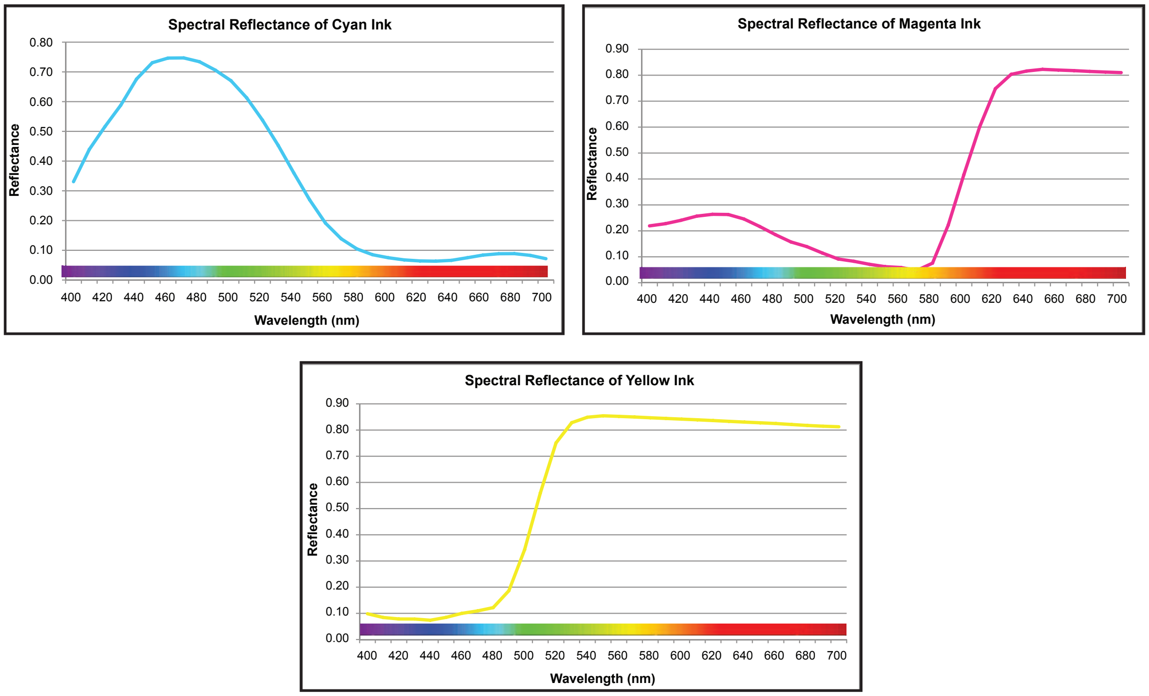

Figure 2: Spectral Reflectance Curves of Actual Process Inks Used for Printing

Ink Sequence

Ink Sequence is the order in which the process color inks are printed consecutively in the four-color printing process. It is also referred to as the *Ink Laydown Sequence*. While CMYK and KCMY are the standardized sequences for offset lithography, there is no such standard sequence determined for flexography. Malikhao, in his thesis research about the "Application of CIE Lab to Study Trapping Efficiency", tests various sequences by printing them on web offset. He determined that by changing the sequence of ink laydown, changes occur in the hue and chroma, thereby resulting in a different color gamut (Malikhao, 1988). Unlike web offset, flexography is a wet-on-dry ink trapping technique, which may reproduce color in a different manner when the sequences are changed. Wet-on-dry printing takes place when the ink is laid down directly on the substrate, or when the ink

on the substrate is dried before laying down the next ink in the sequence. When printing wet-on-wet ink, the color printed last (on top) in a sequence, dominates the overall hue of the reproduced color. For example, a better Green is obtained when Yellow is printed over Cyan as opposed to Cyan being printed over Yellow (Giammatteo, 1975).

Color Gamut

Color Gamut is a measure volume of possible colors for a color system (Anderson, 1997). In terms of colorimetry, it is defined as a range of different colors, which can be interpreted by a profile generated by a particular device (X-Rite, 1996). It describes the range of colors limited by the primaries and the substrate used, as well as by the dynamic range; that is, the range of brightness levels from the darkest Black to the brightest White of the device (Fraser, 2005). For a printing device, the three process colors (Cyan, Magenta, and Yellow), along with its two color overprints (Red, Green, and Blue) mark the six corners of its reproducible color gamut. In CIELAB color space, a color gamut is represented in a three-dimensional diagram, where two dimensions are its color coordinates a* and b* while the third dimension is the luminance L* (as shown in Figure 3). The other way of representing a color gamut is in a two-dimensional plot, showing the chrominance information at a single L*. A three-dimensional diagram, however, better represents the gamut as compared with a two-dimensional plot as the two-dimensional plot loses the luminance aspect.

A three-dimensional plot also assists in evaluating the difference between different color gamuts by viewing the profiles in Chromix ColorThink Pro as shown in Figure 3.

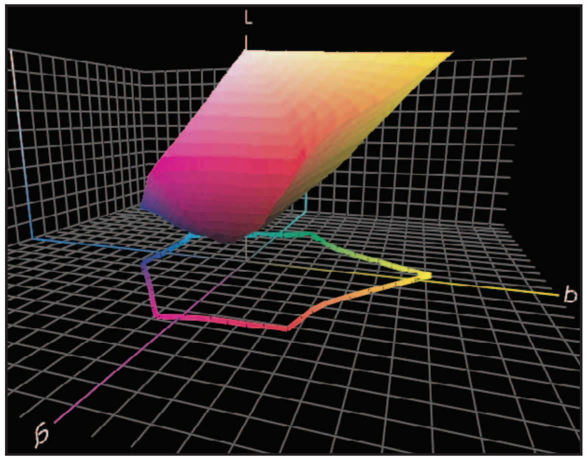

Figure 3: Three-Dimensional Representation of a Color Gamut

Densitometry

Densitometry is a method of measuring solid ink density and tone values on the printed sheet. *Density* is the log to the base 10 of inverse of the reflected light off the paper. There are two types of densities: transmittance and reflectance. *Transmittance density* measures transparent materials such as film while *reflectance density* measures light reflected from the paper surface. With reflection densitometry, the color to be measured is illuminated by a light source, whereby the light penetrates the translucent ink film on the paper, and the paper scattering the remaining light. Some of this scattered light is reflected back, passing through the ink film then reaching a sensor within the densitometer, thereby converting it to an electric signal. The *optical density* is obtained by taking the log (to the base 10) of the inverse of reflectance. Optical density is an important measure for process control in printing and is denoted as a **D**.

$$D = \log_{10}\left(\frac{1}{R}\right)$$

Where, D = optical density and R = reflectance (Sigg, 2006)

A *densitometer*, which is a device designed to measure chromatic colors, has Red, Green, and Blue filters placed in front of the sensor (Heidelberg, 2006). For example, when measuring a Magenta patch, a Green filter is used to absorb Red and Blue light; thus, allowing only Green light to pass. The printed ink density on paper depends on the type of pigment and the concentration used in the ink. Density measured on a solid printed area is known as *Solid Ink Density (SID)*, while density measured on a halftone area is known as *Tint Density* . Optical density monitors and maintains uniform ink film thickness across the sheet and throughout the press run.

A densitometer is a device measuring the amount of light absorption in a specific region of the visible spectrum. When measuring a color patch on a printed sheet, an increase in density value indicates an increase in the amount of colorant on the sheet. Thus, the use of densitometers during the printing process is an effective process control approach for monitoring the application of inks (Binder, 2008). *Densitometry* describes a measure of the ink film thickness, but does not indicate the color of the ink as perceived by the human eye. Thus, to predict the visual perception or appearance of color, colorimetry is used (Heidelberg, 2006).

Colorimetry

Colorimetry is the science of measuring color with a goal of estimating what an observer sees. A *colorimeter* or a *spectrophotometer* is a device used to measure

color depending upon the required indices. While a colorimeter obtains tristimulus values (XYZ), a spectrophotometer obtains spectral reflectance and transmittance values (from about 360nm to 830nm). Most color measurement instruments are designed for one CIE standard illuminant and observer pair (Berns, 2000). The Graphic Arts industry prefers an instrument with a combination of illuminant D50 and 2° observer.

Colorimeter

To measure a printed patch, a light source illuminates a small area on the patch. The substrate absorbs some of the light while the remaining light is reflected back. With a colorimeter, this reflected light is filtered by passing it through three color filters, which together with the spectral sensitivity of the light sensor, have a spectral response similar to the color matching functions of a specified CIE standard observer (also similar to the cone receptors of the eye). The measurement data received from a colorimeter is in the form of tristimulus values (X, Y, and, Z).

Spectrophotometer

A spectrophotometer measures spectral data, which is the amount of light reflected from an object along the visible spectrum at many small wavelength intervals. By performing calculations, the spectral data can be translated into colorimetric or densitometric data. Tristimulus values are not visually uniform; thus, a non-linear transformation is performed to obtain opponent-type coordinates, usually L* a* b* (Berns, 2000). These Lab values can further define the color gamut as well as compute color difference values for process optimization.

A colorimeter is typically used for characterizing the colors of luminous displays like CRT, LCD, OLED, etc.. Spectrophotometers are typically used for

characterizing colors of materials; providing information about consistency of raw materials; identifying problems regarding metamerism; and calculating colorimetric data from spectral power distribution (Berns, 2000). Hence, in this experiment, a spectrophotometer was used to measure color patches.

UV Flexo Inks and Transparency

Transparency is the ability of an ink to transmit and absorb light without scattering (ISO 2846-5, 2004). For printing test forms in this experiment, UV-curable inks were used. These inks need to be cured (using a UV lamp) at the end of each printing unit. This type of printing process is called *wet-on-dry* as the ink on the substrate is already dry before the next ink is laid down. To obtain good color appearance and bigger gamut, the ink must be able to trap well and must be transparent. By using UV inks, there is no need to worry about *ink trapping*; that is, the ability of the printed ink to transfer to a previously-printed ink. However, opacity of these inks can range from being translucent to very transparent. The very transparent inks produce a cleaner and bigger color gamut, making them suitable for four-color process printing. Transparency can be an issue when inks are not cured properly. During the curing process, if excessive radiation is applied, then the next color may not adhere properly, with the ink film becoming brittle and peel off. If less radiation is applied, then the inks fail to cure. This causes the ink to offset in rewound roll, pick up on idle rolls, and track through the press. If uncured ink tracks through the press, then the rest of the ink becomes contaminated or dirty with the printed image having a hue cast of the ink that is printed last.

UV inks are also able to deliver higher quality by producing better density and less dot gain. Unlike water-based inks, UV inks are able to print a 100% solid

dot area as it does not contain any solvent that evaporate at the time of curing. Also water-based and solvent-based inks dry down during the inking, which clogs the anilox cells and limits 100% transfer of ink from the cell to the substrate. UV inks, however, do not dry down or clog the cells; thus, allowing transfer of all the ink contained in the cell onto the substrate. This results in a constant high density.

Standard Print Density

Density is a measurement representing the amount of light reflected from a printed sheet. It is very important to maintain the same density throughout the press run. In real world printing, the densities and their tolerances are pre-determined in a process called *Fingerprinting*. The optimized densities are then used as standard print density for all the jobs done.

Table 1: SID specifications as per FIRST

Solid Ink Density					
		C	M	Y	K
Wide Web:	Paper	1.25	1.25	1	1.5
	Film	1.25	1.2	1	1.4
Narrow Web:	Paper	1.35	1.25	1	1.5
	Film	1.25	1.2	1	1.4

It is also recommended to use specifications made by ISO or FTA for print density. In this experiment, the specifications and tolerances mentioned in FIRST (Flexographic Image Reproduction Specification and Tolerances) are followed, as shown in Table 1 (FIRST, 2003).

Total Area Coverage

Total Area Coverage (TAC) is the total sum of Cyan, Magenta, and Yellow in the darkest area of the printed image, which theoretically could be a sum of up to 400%. A heavy coverage of ink on the substrate may cause problems in four-color process printing; specifically, causing the ink not to cure properly and resulting in a bad print. Thus, when preparing the plates, use pre-determined specifications. The value of the TAC is specified in the FIRST, as shown in Table 2 (FIRST, 2003).

Table 2: TAC specifications as per FIRST

Total Area Coverage		
	Wide Web	Narrow Web
Corrugated	270% - 300%	-
Paper	290% - 320%	290% - 320%
Film	300% - 340%	300% - 340%

The value of the TAC is specified based on the type of process, substrate, and web size. It is assigned when preparing the plates and is also used when making the profile out of the printed profiling target. Use of 400% of total ink coverage in its shadow areas is not recommended for flexographic printing.

Chapter 3 - Literature Review

Introduction

The literature studies reviewed for the purpose of understanding the subject matter of this thesis research are summarized in this chapter. In the beginning, this review process provides a brief overview of flexographic printing process, its history, and its scope. As not much information was obtained about ink sequences for flexography the author looks into other researches done in the field of flexography in the next section. The last part of the review describes previously performed research work, where researchers tried to optimize print quality by testing different printing ink sequences for offset, screen, and gravure printing processes.

Flexography

The flexographic printing process was originally derived from letterpress. The main difference between letterpress and flexography is that letterpress uses raised type made up of metal plate for printing, while flexography uses synthetic rubber plates for printing (FTA, 1980). In the first few decades of the 20th century, aniline dyes derived from coal tar were used; hence, the process was known as *Aniline Printing* (Gomez, 2000). In the middle of the 20th century, the Food and Drug Administration (FDA) declared these inks toxic. As a result, formulations of these inks were changed, along with its name from Aniline Printing to *Flexographic*

Printing (Crouch, 1998).

Traditionally, *flexography* is defined as “a method of direct rotary printing using resilient raised image printing plates, affixed to variable repeat plate cylinders, inked by a doctor blade wiped engraved metal roll, carrying fluid or paste-type inks to virtually any substrate” (FTA, 1980). In flexography, the plates are flexible, made of rubber with raised image areas. Inks used for printing are less viscous and dry quickly as compared to inks used in lithography (Foundation of Flexographic Technical Association, 1991). An anilox roll is used for transferring the ink from the ink fountain roll to the rubber plate. The anilox roller, made of either chromed metal or ceramic roll, is evenly screened with cells (about 200 to 600 lines/cm) carrying ink. Unlike lithography, the plate comes in direct contact with the substrate (Kipphan, 2001). There is a drying or curing unit after each color unit in a flexo press; thus, the ink on the substrate always dries before the next ink is laid. Due to printing with soft, flexible plates and low-viscosity inks, flexography is capable of printing on a wide variety of absorbent and non-absorbent substrates. For example, thin, solid, and flexible polymer films; different kinds of paper; foil; thick cardboard; fabrics; coarse-surfaced packaging materials, etc. (Anthony, 1972)

Other Researches related to Flexography

There was not much information found regarding the standardized sequence used for printing with flexography. Also, the researcher did not find any data about research related to printing with different sequences and observing its effect for flexography. Though a considerable amount of study has been done on other topics related to flexography. One of the researches done in the field of flexography was examining colorimetric characterization of flexographic process utilizing analytical

models, which was done by Arturo Aguirre in 2002. In this research he analyzed the colorimetric performance of different dot-gain models in the characterization of the flexographic process. Barry Allen Lee in 1998 conducted a study about design characteristics unique to the flexographic printing process, where he explored the unique considerations that were required to be addressed while designing graphics for flexographic printing. Some of the other researches done in the field of flexography that were done were related to printing on corrugated board with flexography, hybrid halftoning in flexography, use of UV vs. water-based inks for printing with flexography, and many more.

Previous Research Work

In 1975, Phill Giammatteo, did a similar kind of study as this thesis experiment in which he determined the effect of color sequence on the ink's hue and saturation characteristics for web offset. As a result of performing an initial survey of literature, he suggested there were no specific rules for selecting a particular color sequence as there were many variables present (i.e., ink, substrate, press, and type of job). He learned in the first few years of process work that the most commonly-used sequence was Yellow, Magenta, Cyan, and Black. It was believed that good color reproduction was dependent on the selection of ink sequence, ink film thickness, and ink tack. Hence, he attempted to determine the effects of color sequence on hue and saturation for a specific set of process inks using the GATF method of evaluating process inks. He performed this experiment by printing different sequences using the IGT printability tester, which attempted to simulate web offset. He ensured the repeatability of the process as well as evaluated the density and color for each test run to obtain test results. Giammatteo concluded that Cyan,

Magenta, and Yellow inks must be printed in a sequence. Black ink may be printed before Cyan, Magenta, and Yellow, or after to obtain better hue and saturation of color (Giammatteo, 1975).

Aristotelis Bougas performed a similar study in 1993 for the screen-printing process. When conducting thesis research, he looked at the influence of ink sequence on color's hue and saturation in four color halftone screen printing. In his study, all variables (i.e., ink, paper, and press) remained constant. The only variable was the sequence of printing. He created a test target called, Nucleus Sequence Pattern Originator (NSPO), with an image, 36 patches of single color, and possible overprints (two-color, three-color, and four-color overprints), which included solid area and tints of 50% and 80%. The NSPO was printed on a five-color web screen printer using UV inks on a clear polymer film. Eight different sequences were printed and evaluated with the help of densitometry. For each sequence tested, the density value taken was an average of five sheets. This density data was plotted on the GATF Hexagon Hue and used a Saturation Color Chart for evaluating the sequences. This evaluation involved the observation of changes in the hue and saturation of each sequence. Spectral data was also extracted from the printed NSPO using a MINOLTA spectrophotometer for viewing the result in the CIE L*a*b* system and for deriving the color differences (ΔE) for analyzing changes in hue, saturation, and lightness. To obtain experiment results, some analyses were performed for all eight sequences. This included ink analysis using densitometric readings, hexagon diagram analysis, colorimetric graph and chart analysis, as well as visual analysis. From this analysis, the sequence of MCYK showed better image and good color reproduction. However, overall, the KMCY sequence was proved to be the best when compared with a particular proof. In addition, a number of methods were used to evaluate results, with colorimetry

proving to be the most efficient way of analysis compared to densitometry and GATF method (Bougas, 1993).

In his TAGA paper of 1983, Gary Field investigated the effect of color sequence in four-color offset printing from the perspective of changes in the color gamut due to the opacity of individual printed inks. As a conclusion, he recommended either YMCK or CMYK. In addition, he recommended printing Black on top of Yellow. As this experiment was based on dry ink trapping, there was a need to redo it in 1987 by printing wet on wet inks. This time he recommended only one ink sequence, CMYK, as the optimum ink sequence for offset printing.

In their TAGA research paper on the Gravure Process Color Optimization, Professors Robert Chung and Fred Hsu were able to increase color gamut and improve the color progression by simply changing ink sequence and tone reproduction curves for the gravure process. Improvements in the gamut size were observed by changing the ink down sequence. The ink sequence chosen for gamut optimization in this experiment was MCYK. The authors suggest that during color gamut optimization for flexographic process, it is advisable to follow the methodology of gravure process when printing with solvent-based ink and to follow the methodology of offset when using UV inks (Chung, 2006).

Chapter 4 - Research Statement

The basic research interest was to determine the effect of printing ink sequence for process colors in flexography. Five-ink laydown sequence combinations were tested to observe the effect on print quality. Whether or not a sequence is optimal was based on good color reproduction, gamut volume, and total area coverage, all examined with the help of densitometry and colorimetry.

LIMITATION

The experiment was done using UV curable inks printed on OPP substrate on a narrow web, Mark Andy flexo press. When conducting this research, the type of ink, substrate, and press conditions remained constant. The only variable was the printing sequence of process inks. There are 24 possible combinations of sequences for four-process inks; only five of them were tested in this thesis research. It is very important to check the repeatability of the process and to record the noise in the system. To aptly evaluate the difference between the tested sequences and to ensure differences are significant, an ANOVA (ANalysis Of VAriance) test should be performed. This, however, requires replication of printing sequences. Due to limitations of resources, however, the sequences were tested only once. Thus, only the sheet-to-sheet variability as a measure of partial noise was calculated and was used for evaluating the significance of the gamut differences.

Chapter 5 – Methodology

Test Form

A test form containing the following targets was constructed for analysis.

- **IT8.7-3 Printer Profiling Target** – used for making a profile and for determining color gamut size.
- **Total Area Coverage Chart** – used for observing the maximum density of different combinations of CMYK ink coverage.
- **Step Wedges** – added to the test form with two- or three-color overprints. This shows how the change in sequence changes the color of the overprints.
- **Bearer Bars** – used for adjusting even pressure over the plate when printing.
- **Doubling Bars** – used when checking for gear streaks while printing.
- **Registration Target** – used in aiding registration.
- **Pictorial Images** – used for evaluating memory colors such as skin tones and two-color overprints such as Red, Green or Blue flowers.

Determining the Variables

A six-color Mark Andy LP3000 press was used to make print runs on white OPP film (substrate code #160LL302, donated by Exxon Mobil), using Ultra Violet (UV)-curable process inks, for this research. These UV curable process inks were

manufactured by Water Ink Technologies, which were identified by Pharmaflex Process Cyan (#RPL300838), Pharmaflex Process Magenta (#RPN200749), Pharmaflex Process Yellow (#RPN100728), and Pharmaflex Process Black (#RPL40065). Flexographic Technical Association (FTA) had determined a set of standard print densities for printing on both film and paper that are discussed in the theoretical basis of this thesis document. During the press run, the print densities that were followed were the standard print density determined by FTA for film. Variables affecting ink density in flexography are anilox roller (most important variable), pressure, and the plate surface. Thus it was important that the density for all the individual process colors remained same for all the five sequences (YMCK, MYCK, CMYK, KYMC, and KCMY) tested, within FTA specified tolerances.

Printing the Test Form with Different Sequences

Theoretically, by using four process colors (Cyan, Magenta, Yellow, and Black), 24 different ink sequences are possible. In this research, five of these 24 sequences were tested. Five to Six industry experts were asked about the sequence predominantly used by them for printing process colors. The next two sequences were selected based on this informal survey; they are YMCK and MYCK. The other two sequences (CMYK and KCMY) were selected because they are the standard sequences for offset lithography; hence, they were selected to make a comparison between the two processes. The fifth sequence, KYMC, was selected, as it was one of the two sequences suggested by FIRST, the other was YMCK. The order in which the press run was performed was YMCK, MYCK, CMYK, KCMY, and KYMC, with the printing units interchanged to change the sequence of inks.

For each sequence, desired densities were tried to obtain by verifying that

the values were within tolerance (±0.07); registration was verified to be accurate; and 20 samples were collected for measurement. The reason for selecting 20 samples even though only two samples were used for measurement was to assess short-term and sheet-to-sheet variability. Short-term variability helps to estimate system noise, which then determines whether a given gamut differences between two ink sequences are significant.

Measuring and Evaluating the Test Charts

Densitometry and colorimetry were used for measuring and evaluating the printed test sheets. When performing the measurements, only two samples were measured (Sheet #3 and Sheet #17), which were selected randomly out of the 20 samples taken. While it would have been better to have a longer press run and to collect more samples to account for sheet-to-sheet variability, only a limited quantity of substrate was available. As a result, the assumption was made that 20 samples would be sufficient. Still, it was important to measure and classify the variability in the printing process to determine the degree in which the process was repeatable.

Repeatability of the Process

In this experiment, the critical element was to categorize the difference between any two printing ink sequences, which can be termed as in this context. is the variability in a process. In this experiment noise may be caused by gear streaks, inking variability, or inking difference from the aim point. In other words, noise is related to within-sheet and sheet-to-sheet variability in a single process, while signal is the difference obtained by changing the sequences of ink laydown.

Noise can be random or periodic and may often vary in magnitude. It was very important to check whether the printing process was repeatable and to record the noise in the system. The ideal way to do this would be to make the pressruns to test all sequences more than once. The data from these multiple pressruns can be used to do an ANOVA (ANalysis Of VAriance) test. This test will be useful to determine the significance of gamut differences. The above-mentioned method would give a true measure of experimental noise and variability of this ink sequence test.

However, it was not possible to make more pressruns for this research due to limitations of material. Thus, an alternative method was required to be established for obtaining an estimate of system noise. System noise consists of a number of different components, which can be categorized by spatial variability (i.e. within-sheet variability), temporal variability (within-run or sheet-to-sheet variability). There was very limited data for within-sheet variability in terms of solid and tint patches in the four corners of the press sheet. A better measure for within-sheet variability could be obtained by printing two IT8.3 targets on the same sheet; one horizontally and the other vertically placed. However, there was not sufficient space on the press sheet to print two IT8.3 for this experiment. Also, the between-jobs variability could not be measured, as the replication of the whole process was not done.

Nevertheless, we did have data for between-sheet variability. Thus, we had a partial measure of noise and could estimate the total noise by multiplying the between-sheet noise by a scaling factor. If the selected factor was too small, then we could run the risk of accepting a gamut difference as real, while in reality it could have been only noise. If, however, the factor was too big, then we would run the risk of rejecting gamut differences as noise while in reality they were true differences. The magnitude of that factor will be discussed in the results section.

To obtain an estimate of color gamut noise (in terms of differences in the L*C* areas) L*C* Charts were needed for comparing Sheet #3 and Sheet #17 for the eight different hue angles for each sequence. First, the IT8.7/3 printer-profiling target was read using the GretagMacbeth Eye-One ISis Spectrophotometer for all the sample sheets taken (both the Sheets #3 and Sheet #17 for all the five sequences). The obtained L*a*b* data was then used for making a profile of each sheet and for calculating the average of Sheet #3 and Sheet #17 using ProfileMaker (Appendix A). These profiles were used to create L* C* (luminance vs. chrominance) charts and 2D gamut plots using a methodology developed by Professor Franz Sigg (Sigg, n.d.).

Secondly, the densities of the step wedges (repeated around the test target) were measured. A single-color solid along with one of the tint patches of each color at four corners were measured and recorded on a Microsoft Excel spreadsheet. These measurements were taken for both Sheet #3 and Sheet #17 for all five sequences tested, with a total of 4 corners x 4 colors x 2 sheets x 5 sequences = 160 samples. Their standard deviation was calculated to observe the difference in density for each color printed in each sequence. This investigation provided a quantitative measure of inking variability, which will be helpful to appropriately evaluate the sequences during comparing their gamuts. When comparing the gamuts of two sequences, if for a given hue angle their difference in L*C* area was more than noise and if the inking variation did not explain the difference in area of the corresponding L*C* chart, then we would assume that this area difference was a real gamut difference.

Total Area Coverage (TAC) Chart

A Total Area Coverage (TAC) Chart shows how the reproduction of shadow areas are affected by a change in sequence. The TAC contains 49 patches having different percentages of process inks. The sum of the tone values of these four process inks is the total ink coverage. This sum serves as a guide when determining the total ink limit for a particular sequence. In the TAC target, the Cyan, Magenta, and Yellow values increase for each column, while the Black values increment for each row.

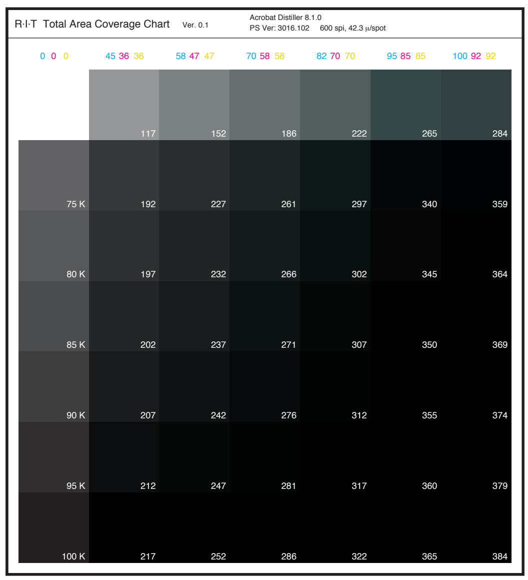

Figure 4: RIT Total Area Coverage (TAC) Chart

As shown in Figure 4, the TAC target has numbers on the top of each column representing the percentage of Cyan, Magenta, and Yellow inks, and the Black percentage value in the lower right corner of the patch in the first column patches representing the Black percentage for each row. The number in the lower right corner of each patch represents the total ink coverage of that patch. The first row is no Black and the first column is only Black. The visual filter density was measured

for all the patches of the TAC Charts for each sequence using the GretagMacbeth SpectroScan. The measured density data of TAC Chart was evaluated by making Microsoft Excel Charts and comparing their results.

Procedure of Determining Color Gamut Differences

The profiles were made using the average L*a*b* data from Sheet #3 and Sheet #17 for each sequence as shown in Appendix A. The gamuts of these profiles were viewed and compared using two different methods; one using ColorThink Pro and the other generated by Professor Franz Sigg (Sigg, n.d.).

A visually-effective way of evaluating gamut is using ColorThink Pro 3.0 because it can display a three-dimensional rendering of the gamut colors. It calculates the color gamut volume as a single number. The gamut differences at various hue angles can be observed by rotating the three-dimensional plot. All profile gamuts for the five sequences can be viewed and compared at the same time. However, the single number representing the gamut volume can be misleading. When comparing the different gamuts, one gamut can be bigger in a particular color region and smaller in another color region; however, both may be having almost the same total volume. Thus, the number does not suggest anything about the hue differences in the gamut.

The second method, which compares the areas of L*C* slices for eight hue angles, was developed by Professor Franz Sigg. Two sets of ink sequences were displayed on each chart. Two sets of charts were created, one using CMYK and KCMY (standard sequence for offset) as a reference and the other using YMCK (specification by FTA for flexography) as the reference. The other sequences were considered as sample, with each one compared against the two references. The

output of this method was in the form of a PDF file containing all these charts along with numeric gamut area details for all the L*C* slices. In particular, it also numerically evaluates the area of each L*C* slice of the sample profile against that of the reference profile.

Chapter 6 – Results and Discussion

Introduction

In this section, the measurements from the printed test forms are analyzed for the five different sequences. As a first step, experimental noise was determined, which was required to evaluate significance of gamut differences between the ink sequences. Then, the TAC for each sequence was evaluated based on density as a function of TAC, and moiré. Finally, color gamut was compared between sequences by analyzing three-dimensional gamut plots from ColorThink and by comparing the areas of L*C* slices at different hue angles.

Determination of Noise

<u>Average Density:</u>

The process by which the density data was extracted from the step-wedges has been discussed in the Methodology. These densities were averaged out for the four patches on each sheet as well as for Sheet #3 and Sheet #17, resulting in a single number representing average inking for a given ink sequence as shown in Table 3.

Table 3 shows that there were some variations in the solid ink densities (SIDs) for Cyan and Magenta. The SIDs of Yellow deviated from the aim point of 1.00 to about 0.88, but was constant. All sequences, with the exception of KYMC

Table 3: Average Density, of Four Corners of the Two Sample Sheets, for the Five Sequences

	CYAN		MAGENTA		YELLOW		BLACK	
	Solid	**Tint**	**Solid**	**Tint**	**Solid**	**Tint**	**Solid**	**Tint**
Aim	1.25	-	1.20	-	1.00	-	1.40	-
Tolerence	0.07	-	0.07	-	0.05	-	0.07	-
YMCK	1.20	0.27	1.18	0.27	0.87	0.26	1.44	0.30
MYCK	1.24	0.28	1.19	0.26	0.88	0.25	1.43	0.31
CMYK	1.31	0.29	1.20	0.30	0.89	0.27	1.49	0.34
KCMY	1.21	0.29	1.26	0.32	0.89	0.27	1.47	0.31
KYMC	1.27	0.30	1.29	0.31	0.88	0.27	1.46	0.31

(difference of 0.09), have the Black SID within tolerance. The variable inking of Cyan, Magenta, and Black may cause an increase or decrease in the actual gamut size. This data suggests use of inking variability as a factor when determining whether the difference in gamut was actually caused by change in printing sequence or inconsistency in ink density.

Assessing Noise:

The gamut comparisons using Prof. Franz Sigg's method includes a table comparing the sample L*C* area with the reference L*C* area for each hue angle. Here, Sheet #3 was treated as a sample and Sheet #17 was treated as a reference. The sample and the reference gamut were compared by dividing the area of each hue slice of the sample by the reference. The value obtained was the percent of match between both, where the reference gamut remains a constant to 100%. Table 4 lists the percent of match between the gamut area slices of the two sheets for each sequence.

If the percentage value of the sample/reference was less than 100%, means that the particular gamut slice area of the sample (Sheet #3) was less than the gamut slice area of the reference (Sheet #17), but if it is greater than 100% it

*Table 4: L*C* Area Comparison, for Different Hue Angles Between Two Sheets*

Ratio of Sample vs. Reference L*C* Area (Sheet #3 vs. Sheet #17)					
Color	**YMCK**	**MYCK**	**CMYK**	**KCMY**	**KYMC**
Yellow	99%	100%	98%	103%	97%
Red	103%	98%	97%	100%	99%
Magenta	107%	97%	100%	99%	98%
Purple	100%	101%	100%	97%	99%
Blue	96%	100%	100%	98%	100%
Cyan	99%	101%	100%	100%	99%
Emerald	113%	95%	97%	99%	100%
Green	99%	100%	97%	101%	100%
Total *	102%	99%	98%	100%	99%

**Total - The total is the percentage ration of the sums of L*C* area for the eight hue angles for the two sheets.*

means that the particular gamut slice area of the sample (Sheet #3) was more than the gamut slice area of the reference (Sheet #17). The total of the gamut area comparison was the percentage ration of the sum of L*C* area for the eight hue angles. The total percentages were very similar for all sequences because a larger L*C* area in one hue angle was compensated by a smaller hue angle in another area. Appendix B includes files that contain the tables with gamut area details comparing the two sheets printed with the same sequence, for all the sequences tested.

The short-term variability of the L*C* area differences of the eight hue angles between the two sheets was calculated. Also, their standard deviation was calculated as it serves as a measure of sheet-to-sheet noise in the process.

The histogram in Figure 5 shows the percentage difference between two sheets (#3 and #17) for eight hue angles for all the five sequences. In theory there should be no difference between the two sheets and should match 100%. Thus all the samples should line up at 0% difference. But due to variability of the process

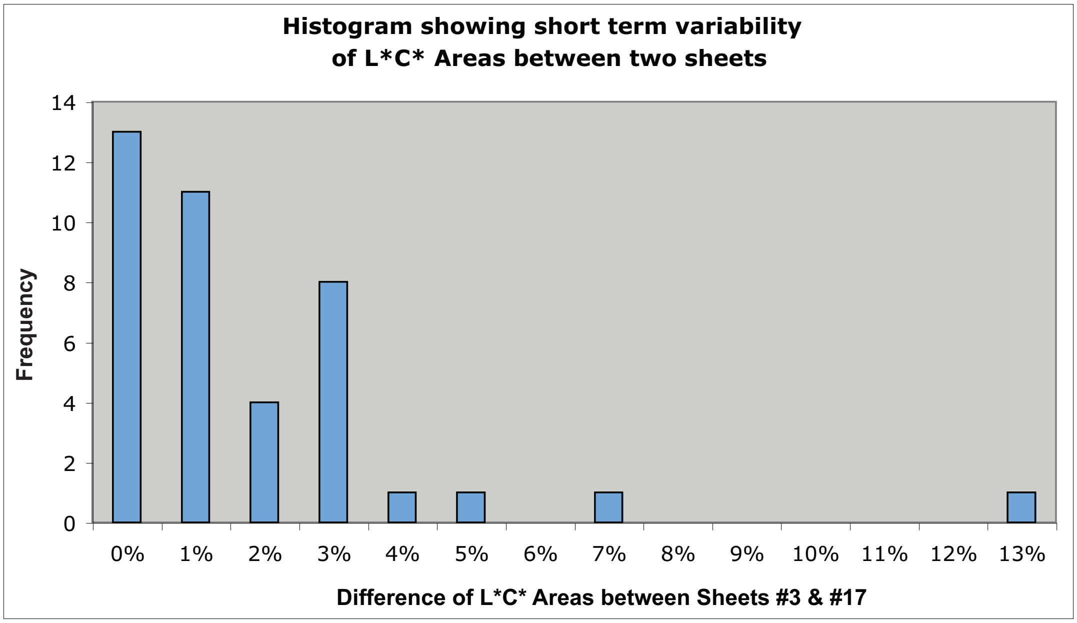

Figure 5: Histogram Showing Percentage Difference in Gamut Area for Eight Hue Angles Between Sheet #3 and Sheet #17 for the Five Sequences

there is noise. All the difference in the gamut between the two sheets is noise. The difference between the gamuts of any two sequences should be definitely more than noise. As this is only a partial measure of noise, its factor should be magnified when evaluating the significance of the difference between the sequences i.e. whether the difference between the two sequences is caused by the change of printing order or due to experimental noise.

Total Area Coverage

To evaluate the sequences based on total area coverage (TAC), the densities (visual filter) for all the patches of the TAC Chart were measured for Sheet #3 and Sheet #17 and were averaged for each sequence. The densities indicate the darkest patch within the target and without subject to how much percent of ink has been laid down in the patch. Figure 6 shows the TAC chart and the maximum

densities achieved respective to the total ink coverage for all the sequences. The highest density is not necessarily achieved by higher TACs, even with lower TACs high densities are achievable. To evaluate TAC based on density, line graphs were prepared representing TAC, where density was plotted against Black tone values. The numeric values displayed on the points are the TAC values corresponding to their densities. In these graphs, only the higher range of tone values and density

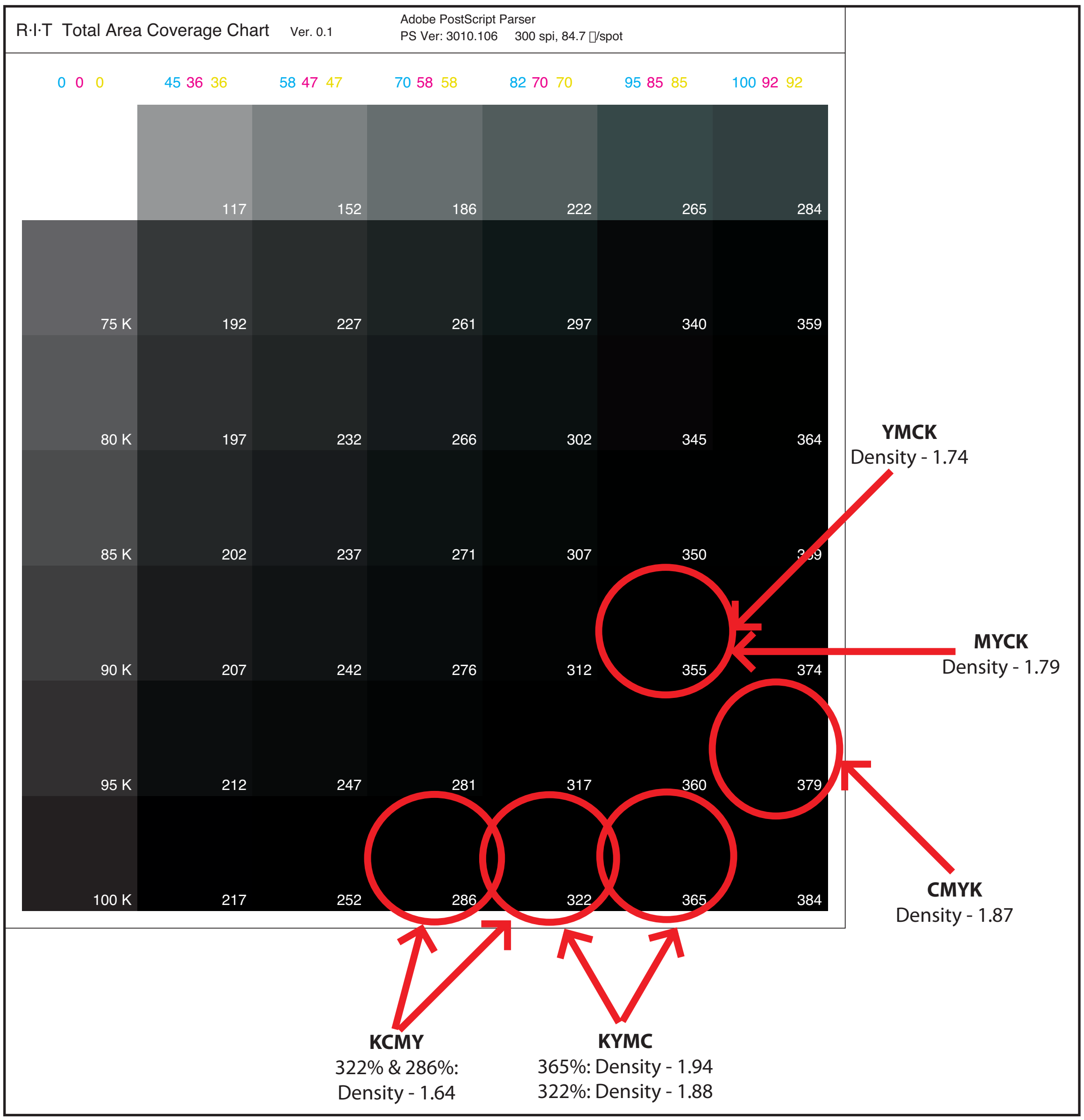

Figure 6: TAC Chart Showing the Chosen Optimum TAC Patches for Each Ink Sequence

are shown.

The overall hue of the chart differs for all ink sequences; it is not, however, necessary for it to be neutral. When selecting a particular sequence an important factor to be considered is its ability to print maximum dark color with as little dot area as possible.

YMCK:

The TAC Chart printed with sequence YMCK had an overall reddish tint to it. One of the major issues observed in this chart was that a very strong moiré pattern formed in the patches of the bottom two rows. Figure 7 shows a scanned image of the last two rows of the printed TAC Chart. In addition, four color over-print patches of the last row appear lighter compared to the two rows above it, indicating this sequence is not able to print with heavy ink coverage (about 95% – 100%).

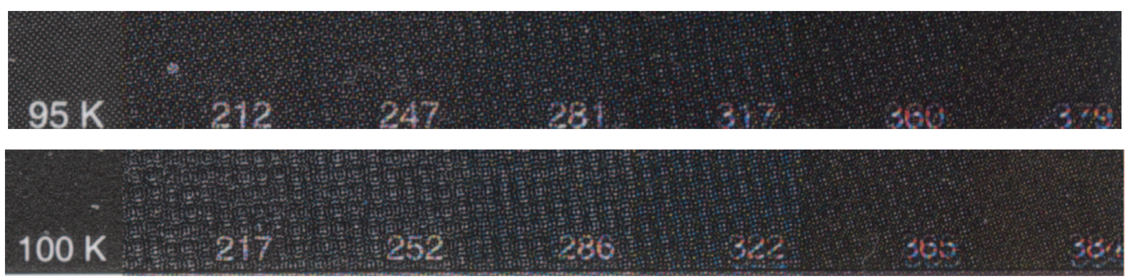

Figure 7: Last Two Rows of the TAC Chart with 100% and 90% Black, Forming a Moiré Pattern

Visually, the darkest patches are in the rows with 90% and 85% Black in the last two columns. This can be seen in Figure 8, representing maximum density achieved by relatively lower TAC. The highest density for YMCK is 1.74 with the TAC of 90% Black and 265% CMY (TAC = 355%).

However, it must be noted that the obtained maximum density is limited by

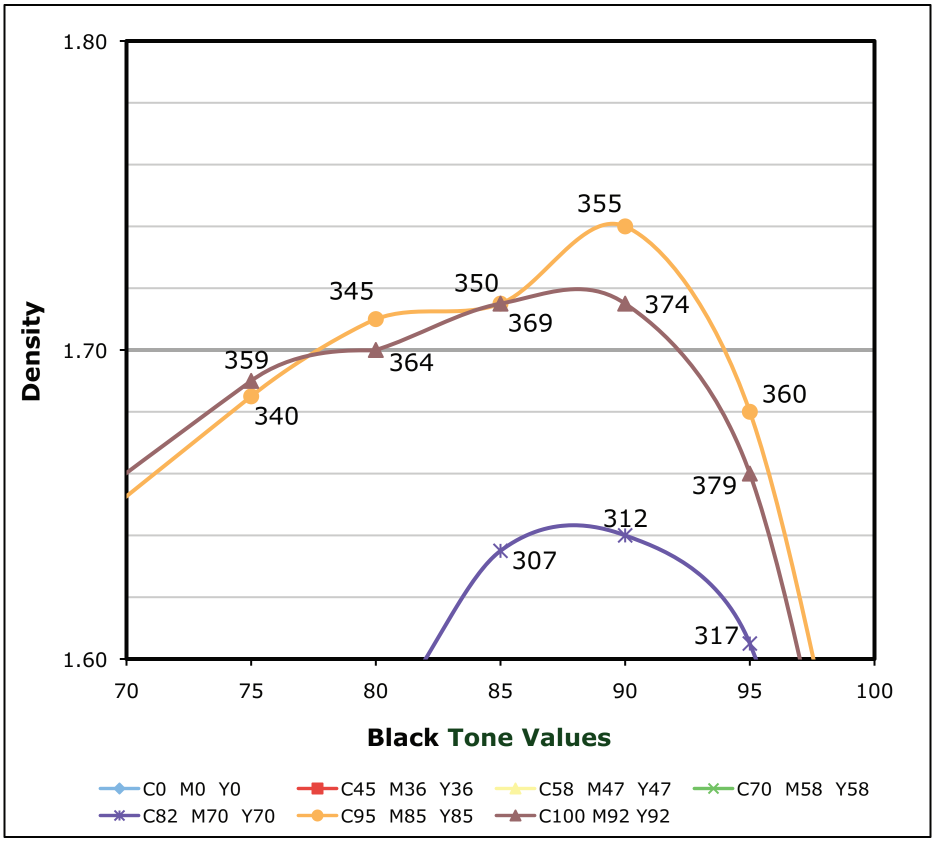

Figure 8: Graph for Seeking Highest Density for Low TAC for YMCK

the white dots forming the “moiré”-like artifact. The ink density between the white dots is higher than the measured average patch density.

MYCK:

The TAC Chart printed with MYCK sequence had an overall neutral hue. Also, the overall density of this chart appears to be more than that of the chart printed with YMCK sequence. Like the previously-discussed sequence, YMCK, this chart also has a very similar moiré in the patches with four-color overprints of rows with 95% and 100% Black.

The patches in the last two columns from 75% Black to 95% Black visually

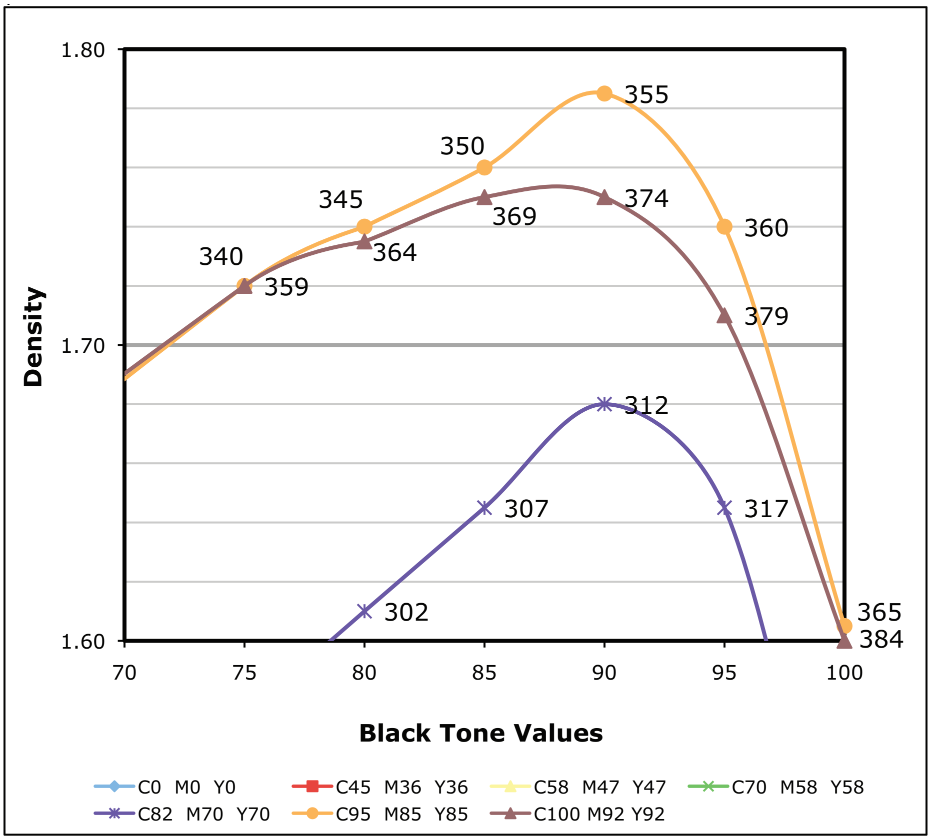

Figure 9: Graph for Seeking Highest Density for Low TAC for MYCK

seem darker than the patches with 100% Black. Figure 9 indicates that at 90%K, 90%C, 85%M, and 85%Y (355% TAC), the highest density (1.79) was achieved.

CMYK:

The TAC Chart printed with CMYK sequence had an overall hue with a little bluish (Cyan) tint. Similar to the above two sequences, this sequence also has a prominent moiré being formed in its last two rows. The common element in all the three sequences discussed until now is that Black was printed last in the order. The overall density of the printed target seems to be very good. Visually, the last two columns from 75% K to 95%K have really dark patches, which suggest high

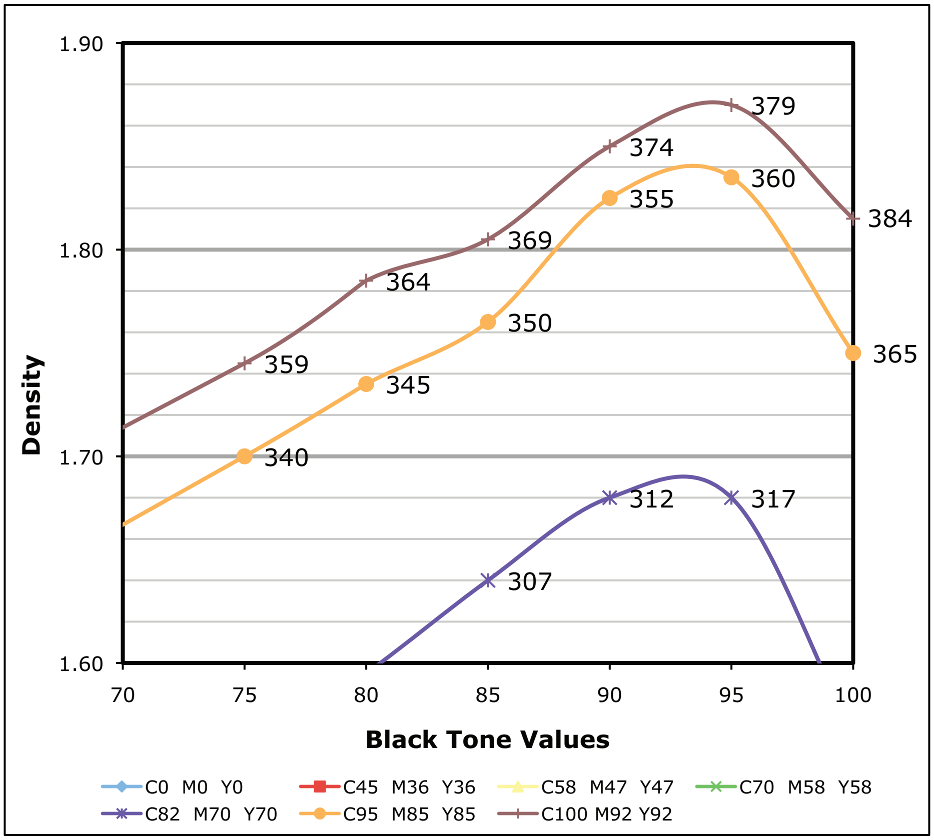

Figure 10: Graph for Seeking Highest Density for Low TAC for CMYK

TAC. The patch having the highest density of 1.87 for this sequence is at 95% Black and 284% CMY (TAC = 379%) as shown in Figure 10, which is higher than the previously-discussed sequences.

KCMY:

The TAC Chart printed with the KCMY sequence had an overall Magenta cast to it. Unlike the previously-discussed sequences, this sequence does not have any moiré formations in its heavy ink coverage areas. Figure 11 shows the scanned image of the last two rows of the TAC Chart without any moiré pattern formation.

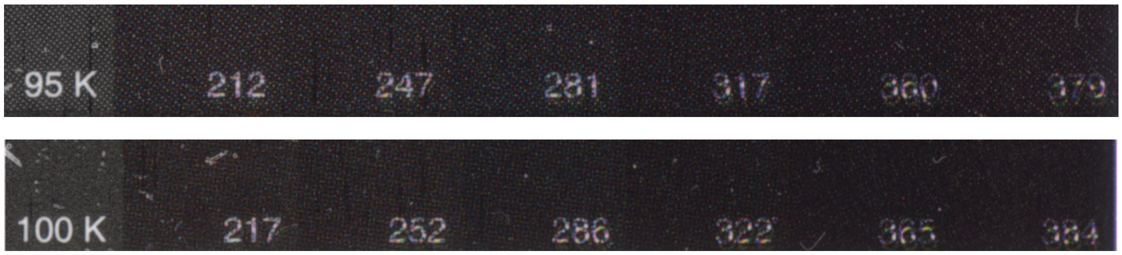

Figure 11: Last Two Rows of the TAC Chart with 100% and 90% Black That Do Not Form a Moiré Pattern

In this chart, the last row is not printed light as it is 100% Black. Rather, it is the last column with 100C, 92M, and 92Y that prints lighter than its former columns. Visually, all patches with the exception of the first and the last patches of the last row seem to have a heavy ink coverage and high density. The patches with TAC of 286% (100% K and 186% CMY), and 322% (100% K and 222% CMY) have

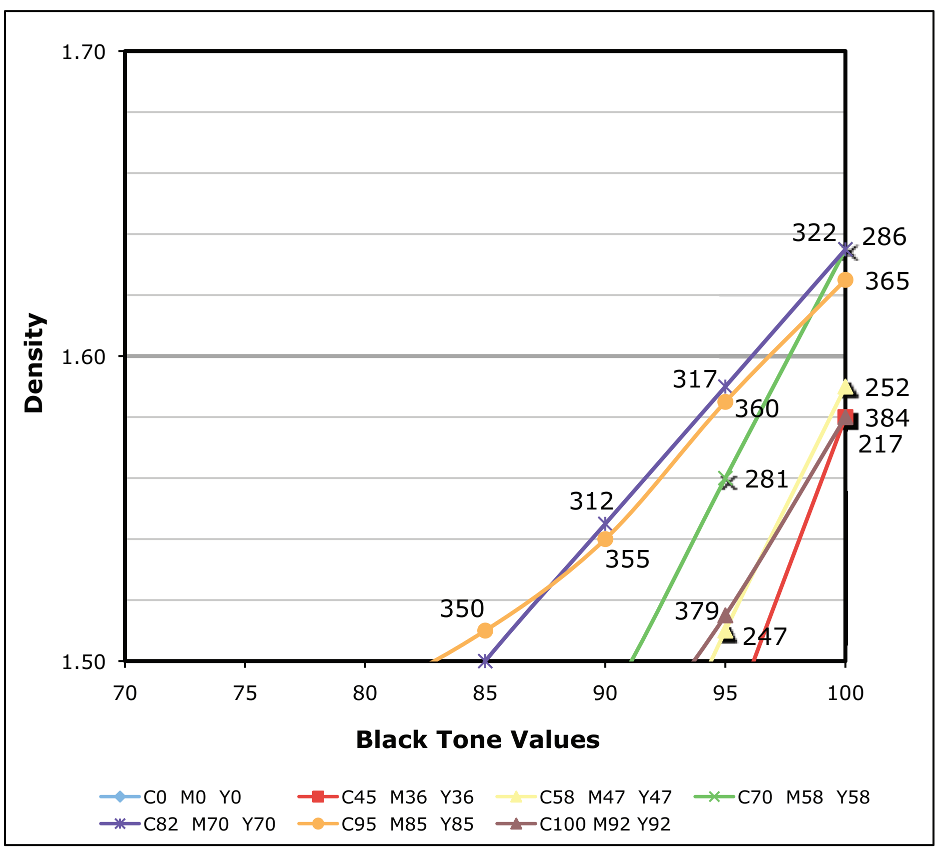

Figure 12: Graph for Seeking Highest Density for Low TAC for KCMY

the highest density of 1.64. Thus, even with the low TAC of 286%, essentially the same density is achieved as with TAC of 322% and with TAC of 365% as shown in Figure 12.

By observing the printed TAC Chart and the filter densities, it can be said that KCMY can achieve better trap, and considerable density with low TAC of only 286%, without any moiré formations in the dark shadows. The reason for no moiré in the shadows could be that Black is printed first in the sequence. Until now, the only drawback is of producing warm neutrals.

KYMC:

The TAC Chart printed with KYMC sequence on the whole had a slight reddish hue cast. This sequence also prints Black as first ink down, resulting in no moiré pattern being formed in the heavy ink coverage patches. Like the KCMY sequence, the last column appears to be lighter than the preceding columns. The density and the print quality of the TAC Chart printed with KYMC appears to be the best among all the five sequences tested in terms of trap, density and print quality. Visually, the last row looks as if it has the highest density. As shown in Figure 13, the highest density is of the patch with 365% TAC (100% K and 265% CMY), which is 1.94. Almost the same density can be achieved by printing with less percentage of ink as a density of 1.88 can be achieved with a TAC of only 322%. The measured density of this chart is the highest among all the other sequences. The result obtained by observing the TAC Chart printed by KYMC is better than that of all the other sequences discussed previously in all aspects.

In terms of total area coverage, KYMC has proved to be the best sequence when looking at density and formation of moiré-like artifacts, and TAC itself.

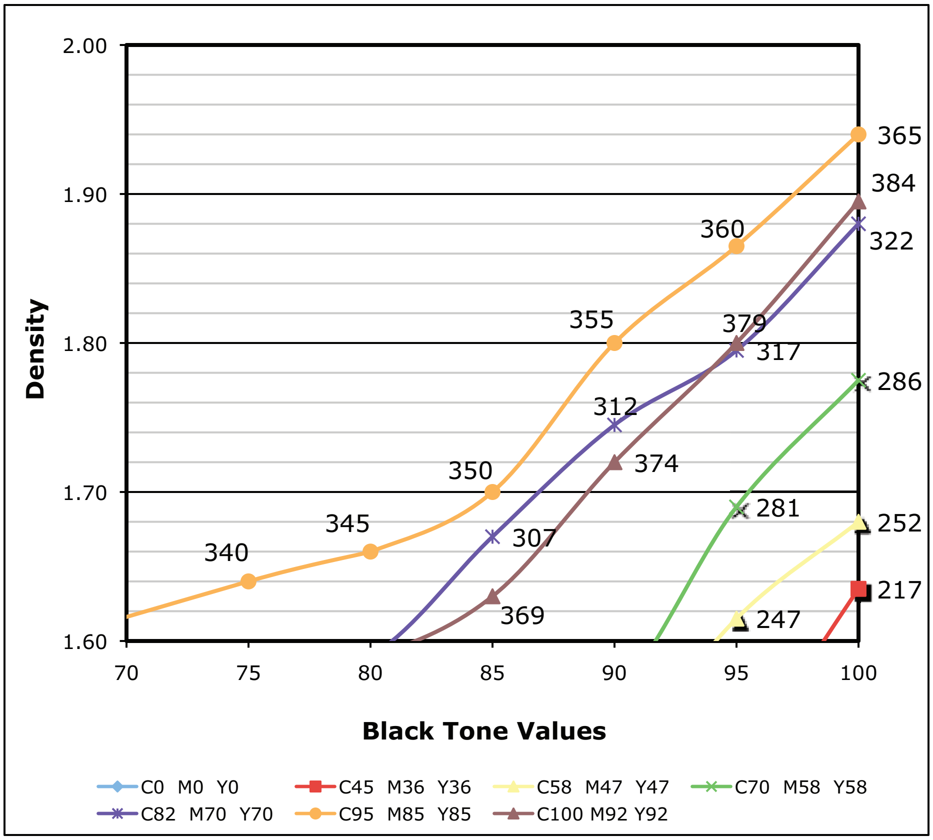

Figure 13: Graph for Seeking Highest Density for Low TAC for KYMC

Printing Artifact

Although the moiré-like patterns were first observed with a TAC Chart, noting that there were no moiré-like patterns when Black was printed first, similar artifacts were also observed with Cyan. For instance, moiré-like patterns were seen in the image of the three musicians and in the Blue robe of the Chinese women of the test form when Cyan printed after Magenta. If Cyan and Black are printed before Magenta and Yellow, then moiré-like patterns do not appear.

By printing with YMCK and MYCK sequences, moiré-like patterns are formed for both Cyan and Black, while KYMC (Black first but Cyan last) only forms a moiré-like pattern with Cyan and CMYK (Cyan first but Black last) only forms

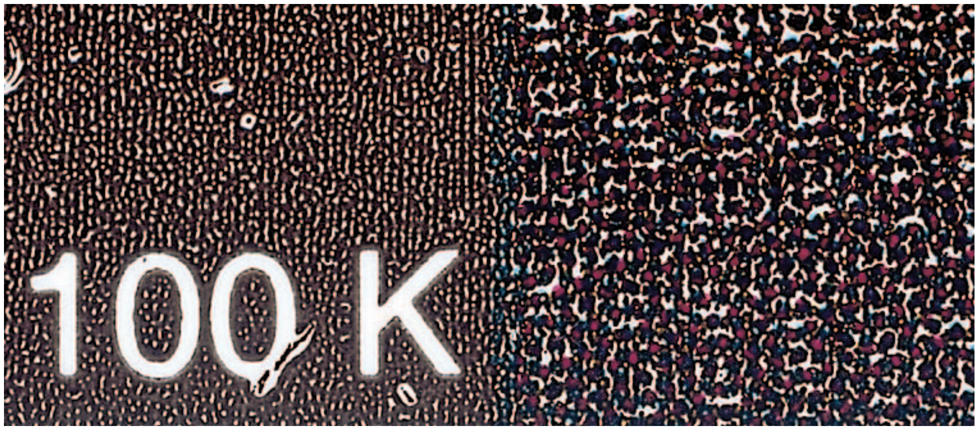

Figure 14: Magnified Image of Solid Black and Four Color Overprint of a TAC Chart Showing Moiré-Like Patterns. The Image on the Left is Black Only and the one on Right is CMYK.

a moiré-like pattern with Black. The only sequence that did not form any kind of artifacts was KCMY as Black was the first and Cyan was the second ink down sequence. By printing Cyan and Black last, moiré-like artifacts are formed in the regions containing the two inks.

Theoretically, a moiré pattern is an inference pattern created when two grids are overlaid at an inappropriate angle. To minimize the moirés, Cyan, Magenta and Black screen angles should be 30º apart from each other, and Yellow 15º apart from any of the other three colors. The angles in the flexo plate used for this experiment had Cyan at 7.5º, Black at 37.5º, Magenta at 67.5º, and Yellow at 82.5º (the angles for flexo printing are shifted by 7.5º from the nominal angles, to avoid moirés with the cell pattern of the anilox roller). These screen angles conform to the rule of keeping the main colors 30º apart, therefore the moiré-like pattern is not caused by wrong screen angles.

When observing printed test sheets with a microscope, it seems that for Black, wetability is different on the substrate by itself, and the substrate covered by CMY. Figure 14 shows the scanned and magnified image of a CMYK TAC chart (of a print with moiré-like pattern) showing the patches with 100% Black and 217%

TAC. For both patches, Black is not a coherent solid. The 100% Black-only has a very fine structure to it, while the Black printed over the other three colors, has a much coarser structure. It looks like the Black ink film, when printed over other inks, contracts into larger droplets, because apparently, it does not wet the surface very well. This might be the reason for more spots of White substrate being seen, instead of the area being completely covered with ink. Further research is needed to investigate the real cause for these moiré-like patterns.

Gamut Comparison

The gamut comparison of the five sequences was done by two methods; one by comparing the total gamut volume of the profiles of each sequence and the other by evaluating the gamut area of eight hue slices obtained by the method of Prof. Franz Sigg. The files generated by the second method contained eight L*C* slice comparison graphs and eight L*C* slice area values and ratios in a table. These files are displayed in Appendix C. As mentioned in the Methodology, there are two sets of comparisons; one using CMYK as a reference for the other colors and the other using YMCK as a reference.

The gamut differences may be caused not by the change in sequence, but also by the noise in the process or inking variability. The measure for noise, determined in the earlier section, set the tolerance values for evaluating the significance of the gamut differences. For instance, if Magenta was printed at a higher density in one sequence as compared to another, then the sequence with heavy Magenta may have an increased color gamut in the Red, Purple, Blue and Magenta regions as compared to the sequence printed with Magenta at a lower density. Thus, it was important to evaluate the gamut by considering the inking

variability of the sequences.

First the comparison is between the two reference sequences as it gives an estimate of which of the two sequences is better in terms of color gamut. Later on, each sequence is discussed individually.

CMYK – YMCK:

In this comparison, the sequence CMYK was treated as the sample and YMCK as the reference. Figure 15 shows the gamut volume comparison using ColorThink Pro, where it can be seen that the YMCK (solid) gamut is bigger in the Green and Orange regions, but in all other regions (Cyan, Blue, Purple, and Magenta) the CMYK gamut is bigger.

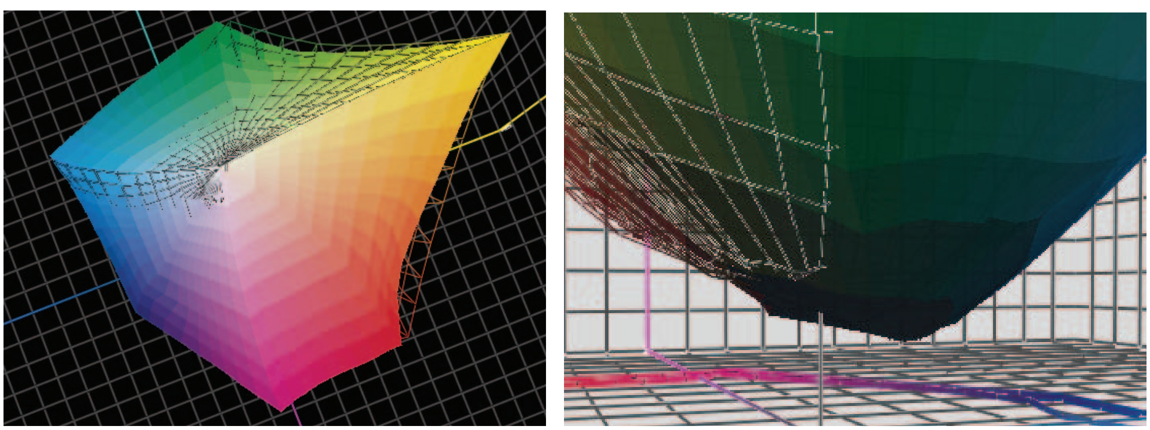

Figure 15: Gamut Volume Comparison of CMYK vs. YMCK. Only if the wireframe gamut is bigger than the solid gamut, it is visible. When the solid gamut is bigger than the wireframe, than it is not seen.

In Figure 15, the second image shows the same gamut is zoomed to focus at darker colors and Black. It appears that by printing with the CMYK sequence, darker shadows can be produced than with the YMCK sequence. The total gamut

volume (as calculated by ColorThink) of CMYK is 314,141, while that of YMCK is 297,385; thus clearly CMYK has a bigger gamut than YMCK. To evaluate gamut differences for different hue angles, single slice comparisons obtained by Professor Franz Sigg's method are observed, which are included in Appendix C. The L*C* slice comparisons for CMYK vs. YMCK also suggest the same differences observed in the gamut volume comparison.

Even though both of these methods imply the CMYK gamut is bigger, it is necessary to check whether the difference between the two gamuts obtained is significant. This means checking whether the gamut differences are more than just due to the noise of inking variability. To determine the significance of the gamut differences, the gamut area ratio for each hue angle (listed in Table 5) for CMYK vs. YMCK have been formatted based on the tolerances set by noise.

The noise was determined as the standard deviation of the gamut area differences between two press sheets of the same sequence, for all five sequences. Since this number only represents between-sheet variability, it was necessary to increase this estimate of noise to more than ±3 standard deviations (Six Sigma), as there were other sources of noise in the process for which there was no estimate. Thus, the factor of noise tolerance was set at ±5 standard deviations of the sheet-to-sheet variability. The values in the table formatted with Red color are the ones, which are outside this estimate of noise; thus, they are assumed to be significant

*Table 5: Comparision of L*C* Area Ratios for YMCK (Sample) vs. CMYK (Reference)*

	Color	Samp / Ref	Solid Ratio	Area/Solid
YMCK / CMYK	Yellow	114%	98%	116%
	Red	113%	98%	115%
	Magenta	97%	98%	99%
	Purple	91%	95%	96%
	Blue	76%	95%	80%
	Cyan	81%	92%	88%
	Emerald	75%	94%	80%
	Green	118%	95%	124%

due to ink sequence, rather than to noise.

The first column in Table 5 is the name of the eight hues angles. The second column is the L*C* slice area ratio for CMYK vs. YMCK (sample vs. reference). The third column is the solid density ratio that compares the average density of two sheets for one sequence with the average of two sheets of the other sequence. In other words, it's a measure of how much alike the solid densities are between the two ink sequences. If the values are outside the tolerance of ±0.05 density units, then they are marked Red in the table, indicating that the inking difference has to be specially considered when evaluating the gamut differences. The densities for Yellow, Magenta, and Cyan are obtained directly. The densities of Red, Purple, Blue, Emerald, and Green, however, are obtained by taking an average of the primaries (CMY) used to form each color. For instance, to form the Green hue angle requires mixing of about 80% Cyan and 100% Yellow; thus, to obtain its density, 80% density of Cyan is added to 100% density of Yellow and divided by 1.8. The reason why a ratio of 80% to 100% is chosen is because the Green hue angle is a little closer to Yellow than to Cyan. The fourth column contains a ratio obtained by dividing area ratio (column 2) with solid ratio (column 3). This column shows the effect of ink sequence on gamut slice, corrected by possible differences in inking levels. Values shown in Red color are taken to be significant, eliminating the differences caused by noise as well as inking variability.

Thus, from Table 5 it can be said that the Blue and Emerald regions of CMYK are significantly bigger than YMCK (means due to change of printing ink sequence), and the Green region of YMCK is significantly bigger than CMYK. The differences of the other hue angles are less than what could be caused by noise, or might actually be due to differences in level of inking.

*Tables 5 - 11: Comparison of L*C* area Ratios*

Gamut Area and Soild Ink Density Ratios for Each Sequence Relative to Two References

Table 6 — MYCK / CMYK

Color	L*C* Slice Area Ratio: Samp / Ref	SID Ratio: Solid Ratio	Corrected Area Ratio: Area/Solid
Yellow	104%	98%	106%
Red	101%	98%	103%
Magenta	93%	99%	94%
Purple	89%	97%	92%
Blue	78%	97%	81%
Cyan	86%	95%	90%
Emerald	84%	96%	88%
Green	113%	97%	117%

Table 7 — MYCK / YMCK

Color	L*C* Slice Area Ratio: Samp / Ref	SID Ratio: Solid Ratio	Corrected Area Ratio: Area/Solid
Yellow	91%	100%	91%
Red	89%	100%	89%
Magenta	96%	101%	95%
Purple	97%	102%	95%
Blue	103%	102%	101%
Cyan	107%	103%	103%
Emerald	113%	103%	110%
Green	96%	102%	94%

Table 8 — KYMC / CMYK

Color	Samp / Ref	Solid Ratio	Area/Solid
Yellow	105%	99%	106%
Red	106%	104%	102%
Magenta	96%	107%	90%
Purple	92%	102%	90%
Blue	80%	101%	79%
Cyan	86%	97%	89%
Emerald	85%	97%	87%
Green	113%	98%	116%

Table 9 — KYMC / YMCK

Color	Samp / Ref	Solid Ratio	Area/Solid
Yellow	92%	101%	91%
Red	93%	106%	88%
Magenta	98%	109%	90%
Purple	101%	107%	94%
Blue	105%	107%	98%
Cyan	107%	105%	102%
Emerald	113%	104%	108%
Green	95%	103%	92%

Table 10 — KCMY / CMYK

Color	Samp / Ref	Solid Ratio	Area/Solid
Yellow	96%	100%	96%
Red	92%	103%	90%
Magenta	88%	104%	84%
Purple	89%	99%	90%
Blue	86%	98%	88%
Cyan	87%	92%	94%
Emerald	86%	94%	91%
Green	99%	96%	103%

Table 11 — KCMY / YMCK

Color	Samp / Ref	Solid Ratio	Area/Solid
Yellow	84%	102%	82%
Red	81%	105%	77%
Magenta	91%	107%	85%
Purple	98%	104%	94%
Blue	114%	103%	110%
Cyan	108%	101%	107%
Emerald	115%	101%	114%
Green	84%	101%	83%

- The 2nd column of these tables are the L*C* slice ratios for sample vs. refernce.

- The Third column is a ratio of the SIDs suggesting how much alike the SIDs are between the two ink sequences.

- The 3rd column is a ratio of 1st and 2nd colunm, showing the effect of ink sequence, corrected by possible differences in inking levels

Table 5 — YMCK / CMYK

Color	Samp / Ref	Solid Ratio	Area/Solid
Yellow	114%	98%	116%
Red	113%	98%	115%
Magenta	97%	98%	99%
Purple	91%	95%	96%
Blue	76%	95%	80%
Cyan	81%	92%	88%
Emerald	75%	94%	80%
Green	118%	95%	124%

- The area/soild ratios in red are the ones where the sample is smaller than the reference, while the one in greens are the ones where the sample is bigger than the reference.

- The sequences marked with blue text do not produce a moire while printing shadows, and the squences marked with orange text do produce moire.

MYCK:

In this section, the MYCK sample is compared with the two reference sequences, CMYK and YMCK, one at a time. Figure 16 displays the gamut volume comparison between MYCK and CMYK, where it is observed that the gamut of MYCK (solid) is slightly bigger in the Green hue region, while the CMYK (wireframe) gamut is bigger in the Magenta, Purple, Blue, and Emerald hue regions. Both the gamuts are almost the same in the Red and Yellow hue regions.

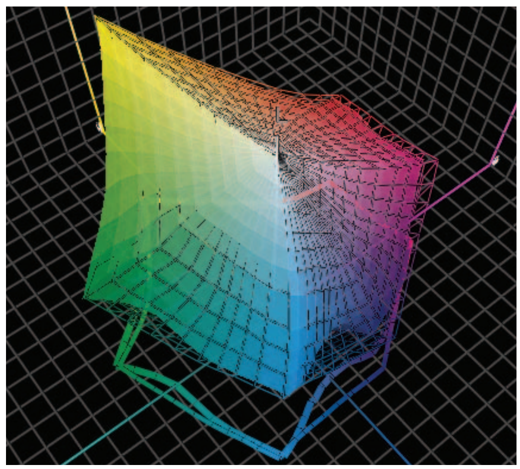

Figure 16: Gamut Volume Comparision of MYCK vs. CMYK

Figure 17 shows the gamut volume comparison of MYCK (solid) vs. CMYK (wireframe) at a lower luminance level, where the reproduction of dark colors by printing with CMYK sequence is more compared to MYCK sequence.

When the L*C* slices area are compared for MYCK vs. CMYK (refer to Appendix C for MYCK vs. CMYK and Table 6), the result is similar to that obtained by the first method using ColorThink Pro. Table 6, shown below, indicates that Green was significantly bigger in MYCK, while Magenta, Purple, Blue, Cyan, and Emerald regions had a bigger gamut for CMYK sequence. Only the Blue region proved to be significantly different.

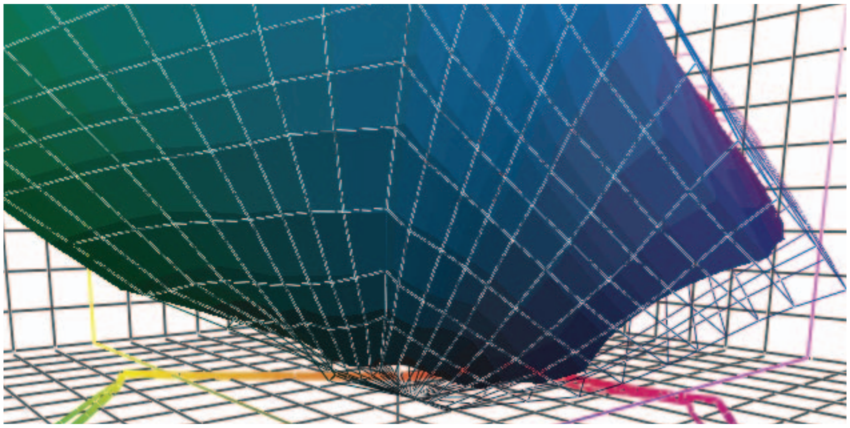

Figure 17: Gamut Volume Comparision at Lower L of MYCK vs. CMYK*

Subsequently, MYCK is compared with the other reference sequence YMCK, where only the first two down inks were switched with the last two remaining the same. The gamut plot in Figure 18 indicates that, the Red and Yellow regions

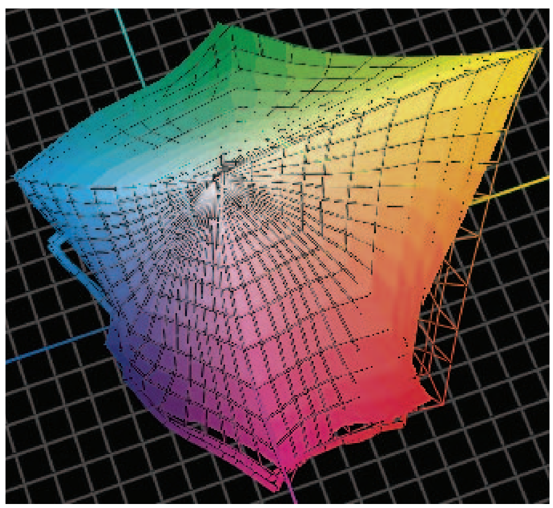

Figure 18: Gamut Volume Comparision of MYCK vs. YMCK

were bigger in YMCK gamut, but MYCK had an increased gamut in the Cyan and Emerald hue regions. The Black point of MYCK and YMCK is almost the same. Hence, there is not much difference in dark color regions of both gamuts.

While comparing these two sequences by the eight hue angle L*C* slices

(refer to Appendix C for MYCK vs. YMCK), the difference was only seen in the lower L* region; mostly for Yellow, Red, Emerald and Green color regions. Between MYCK and YMCK, only Magenta and Yellow inks were interchanged, which could be the reason for only having a difference in the lower L* regions. Surprisingly, Table 7 indicates that even though there were color differences between the two sequences, none were significant with the chosen tolerances of system noise.

The total gamut volume obtained from ColorThink Pro suggests the gamut formed by printing MYCK (284,572) is smaller than both CMYK (314,141) and YMCK (297,385). Only the Blue hue region was significantly bigger in CMYK (19%) while the Green hue region was bigger in MYCK (17%).

<u>KCMY:</u>

The comparison of KCMY with CMYK and YMCK are interesting. With KCMY vs. CMYK, only the sequence of Black is changed from last to first. In KCMY vs. YMCK, the entire sequence is reversed. First, the KCMY sequence is evaluated against the reference sequence CMYK. The L*C* Charts in Appendix C, which evaluate both the sequences based on eight different hue angles, show that both

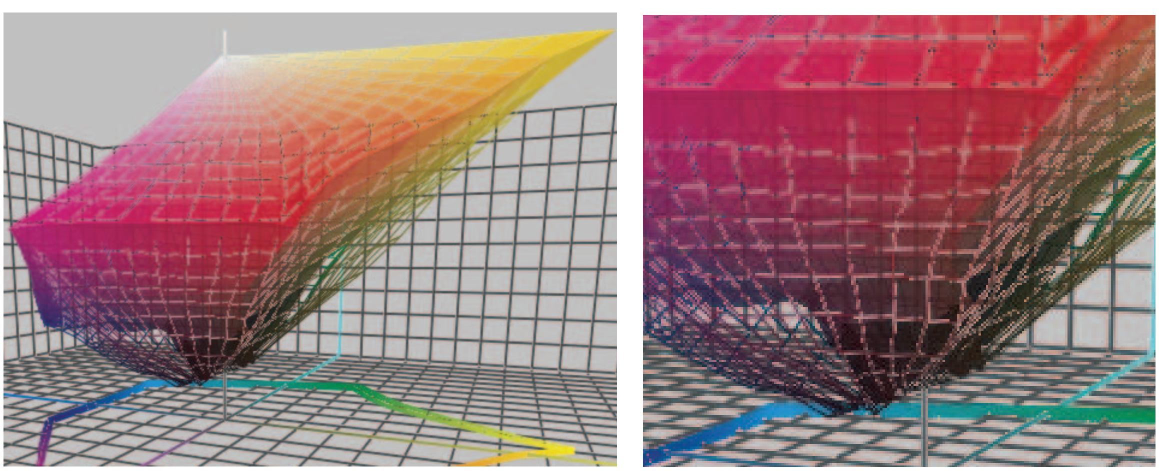

Figure 19: Gamut Volume Comparison of KCMY vs. CMYK

sequences produce almost the same colors at higher L*. They differ, however, as the L* reduces. Figure 19 shows the gamut volume comparison for KCMY (solid) vs. CMYK (wireframe), which implies that by printing Black as the last ink down sequence, CMYK can produce more range of darker colors compared to KCMY.

The total gamut volume of KCMY (245,397) is much smaller than that of CMYK (314,141). The L*C* slice area values shown in Table 10 states that CMYK is bigger in all the hue regions compared to KCMY. When observing the effect of ink sequence on the compensated L*C* areas, it seems that the differences in only the Magenta hue region are barely significant.

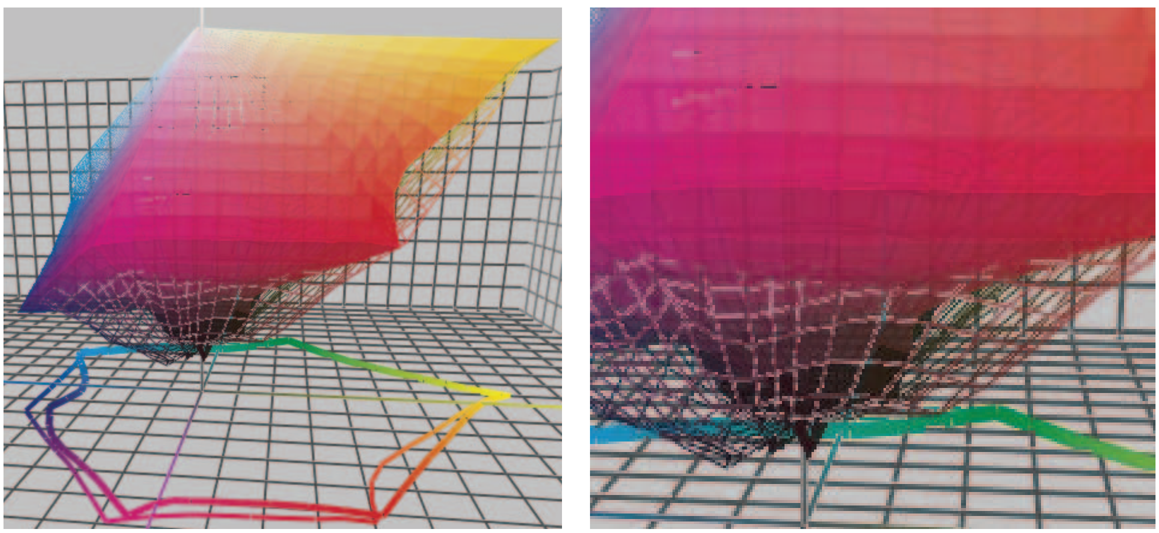

Figure 20: Gamut Volume Comparison of KCMY vs. YMCK

When comparing KCMY against YMCK by the gamut volume using Color Think Pro, it is observed that KCMY is not able to produce darker shades in almost all hue regions. It can, however, produce more chromatic colors in Emerald, Blue, Cyan, and Magenta hues when compared to YMCK. On the other hand, YMCK can produce more chromatic colors in the Red hue region and also darker colors in all hue regions as shown in Figure 20.

The L*C* Charts shows that both KCMY and YMCK reproduce lighter shade colors similarly in the Yellow, Red, Magenta, Purple, and Green hue regions, but YMCK can produce more dark colors in these hue regions. KCMY can produce more chromatic colors for Blue and Emerald hues, as well as for some lighter shades of Cyan as compared to YMCK. The solid ink density ratio in Table 11 indicates a difference in print density in Magenta. The corrected area by solid ratio indicates that only the differences in slice area for hue regions Yellow, Red, and Green are significant.

KYMC:

KYMC is first compared against CMYK, which is an inverse of it. In terms of gamut volume, KCMY can produce more chromatic colors in the hue regions of Purple, Magenta, Red and Green as compared to CMYK, while CMYK can produce more chromatic colors in the Blue region. CMYK can produce darker shades for almost all the hue regions and small number of lighter shades for Yellow, Cyan, Purple, Magenta, and Red, when compared to KYMC. Figure 21 shows, the Dmax

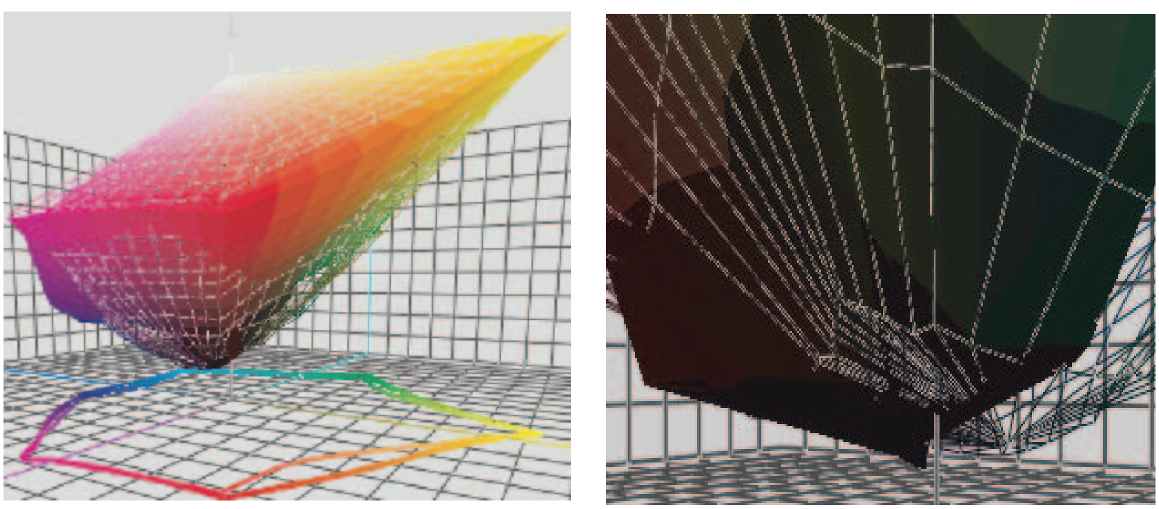

Figure 21: Gamut Volume Comparison of KYMC vs. CMYK

(darkest Black) are a little higher for KYMC than CMYK.

Overall, the gamut volume of CMYK (314,141) is much bigger than that of KYMC (265,589). Table 8 shows that the difference in density or inking between both the sequences is more than normal for Magenta; the rest of the colors have small differences in density. The L*C* hue slice area rectified by likely inking

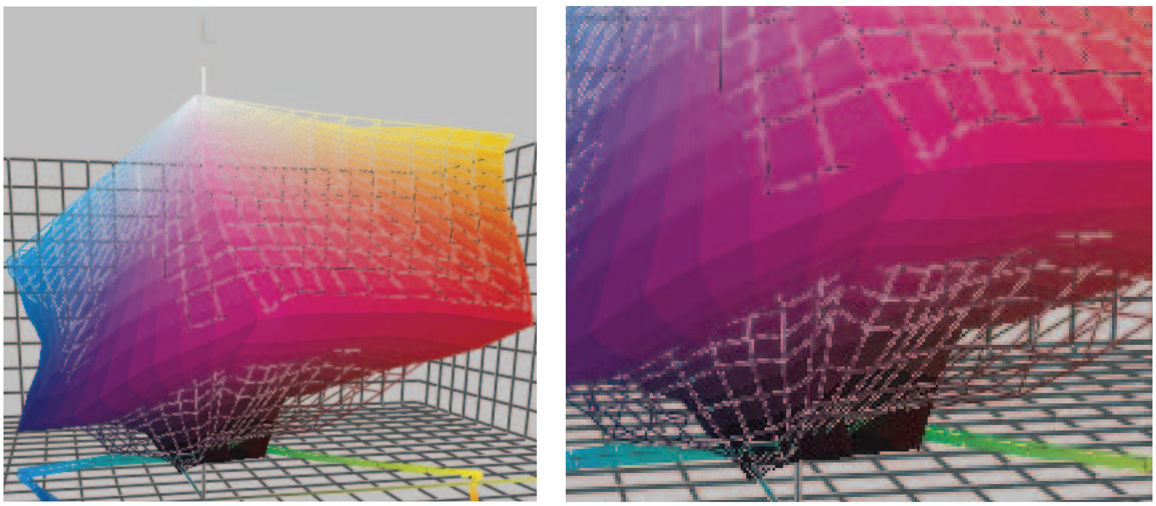

Figure 22: Gamut Volume Comparison of KYMC vs. YMCK

differences, indicates that out of all the differences in the L*C* slice area between the two sequences, the differences only in the Blue region where CMYK is bigger and in the Green region where KYMC is bigger are evaluated to be significant.

Now KYMC is compared with the second reference YMCK. Only the position of Black has changed from first to last in these two sequences. As seen in Figure 22, the gamut of KYMC (solid) is able to produce more chromatic colors in the hue regions of Green, Emerald, Cyan, Blue, Magenta, and Red, than YMCK (wireframe).

The gamut of YMCK, however, is bigger in the darker (lower L*) regions of the almost all the hues, and also a little more in the lighter regions of Cyan,

Magenta and Yellow. Figure 22 also shows the gamut of KYMC has a higher Dmax compared to YMCK. Table 11 indicates that the inking difference of KYMC was unusually more than that found for YMCK for Red, Magenta, Purple, Blue, and Cyan. This variation in solid print density may be one of the factors resulting in none of the hue angle differences to be significant for the corrected L*C* area.

Chapter 7 - Summary and Conclusion

The basic research interest was to determine the effect of printing ink sequence for process colors in flexography. Out of the five sequences that were tested, no one sequence was better than another in all respects. These five sequences were compared in a way where four sample sequences were evaluated against one of the two reference sequences (CMYK and YMCK) at a time, in terms of TAC and color gamut.

Out of the five sequences, four sequences (CMYK, YMCK, KYMC, and MYCK) produced moiré-like patterns in the shadow or heavy ink coverage regions that uses Black and Cyan inks, while KCMY was the only sequence that trapped well and did not produce any moiré-like patterns. However, this sequence has a smaller gamut compared to others. KYMC gives the highest density of 1.88 at a TAC as low as 322%. While it does not produce any moiré-like pattern with Black, it does produce a moiré-like pattern with Cyan (which was printed last). The common factor among the four sequences showing moiré-like patterns is that they print either Black or Cyan as last ink down. Sequences showing a moiré are not acceptable, even if they have a bigger gamut as compared to the one with no moiré-like pattern, unless the images to be printed do not contain shadows or dark neutrals, Greens, and Blues.

The actual cause for the moiré-like pattern formations is unknown. It may not be due to faulty screen angles. Instead it is suspected that it is related to the

wetability of the CMY inks underneath the Black. Further research is needed to find the real reason for the formations of these moiré-like patterns.

One of the objectives of this research was to find out if there were differences in the color gamut, that were greater than experimental noise, between any two of the five sequences tested. After evaluating the results, there were differences obtained in the color gamut, which were greater than noise between some pairs of the five sequences tested. There was no sequence with a bigger overall gamut than the others. However, there are differences for specific hue angles. Therefore, if a specific ink sequence needs to be chosen to obtain a larger gamut, then it would only be relative to the colors used predominantly in a given job. For instance, if a job containing more images of plants and trees, and having no heavy coverage shadow regions is to be printed, any one of YMCK, MYCK, or KYMC sequences can be used as they have significantly increased gamut in the Green region. Likewise, CMYK has a significantly increased gamut in the Magenta, Blue and Emerald regions; YMCK has a significantly increased gamut in Yellow, Red, and Green regions; KYMC and MYCK have a significantly increased gamut in the Green regions. The above-mentioned gamut differences are proven to be significant when using the criteria established in chapter 5 - Methodology.

Recommendations for Further Studies

A valuable study would be to repeat this experiment under different set of conditions and investigate the issue of formation of moiré-like pattern for certain sequences.

It would also be interesting to repeat the experiment idyllically by making more than one press runs to ensure repeatability. This can be followed by an ANNOVA (ANalysis Of VAriance) test for obtaining a better estimate of experimental error and to determine if the gamut differences are truly significant.

The other 19 combinations of sequence out of the total 24 that were not tested in this thesis research could also be tested.

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Appendix A

Making the Profile

Two different types of profiles were made. One was for single Sheet #3 and Sheet #7 individually for the five sequences. The second type was by averaging the L*a*b* data of both Sheet #3 and Sheet #17 using the GretagMacbeth Measure Tool. This averaged data was taken in GretagMacbeth ProfileMaker to make the profile for each sequence. The profile settings were the same for both the type of profiles.

Figure 23 shows the reference and the measurement data selected and also profile making settings like profile size, perceptual rendering intent and gamut

Figure 23: Printer Profiling in ProfileMaker 5.0

mapping technique and light source, which were set to default. The separation key allows us to make custom settings for Separation method, specify maximum Black, maximum CMYK, Black width and also lets us define the Black point. The separation method is the chromatic composition procedure, which lets us choose among UCR (Under-color Removal), GCR 1-4 (Gray Component Replacement), NoK (no Black), MaxK (Maximum Black). GRC-3 was selected for making these

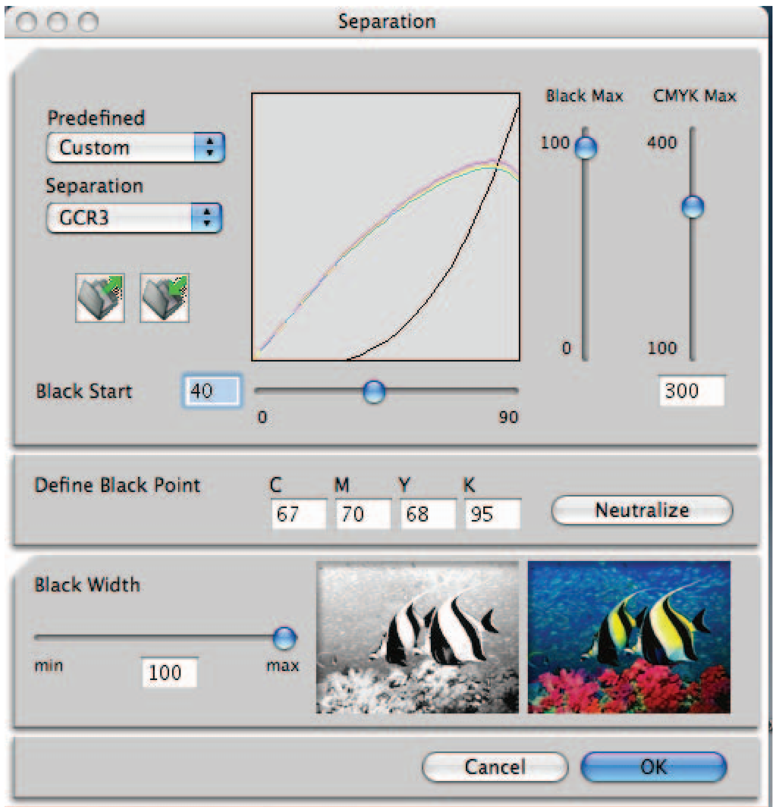


Figure 24: Separation Window in ProfileMaker

profiles. The Black Max is to specify the maximum Black coverage. In this case it was set at 95% Black, which means, a maximum of 95% Black will be used in the color separations. The CMYK Max setting is to specify maximum total ink coverage.

The type of substrate and printing process used also determines the setting

selection. Based on the FIRST specification the TAC of flexo print on narrow web film should range from 300% to 340%. Thus approximately maximum CMYK was set to 300. The CMYK separation shown was based on the Black Max and CMYK Max. The curve diagram in the separation window shows the relation of Cyan, Magenta, Yellow and Black.

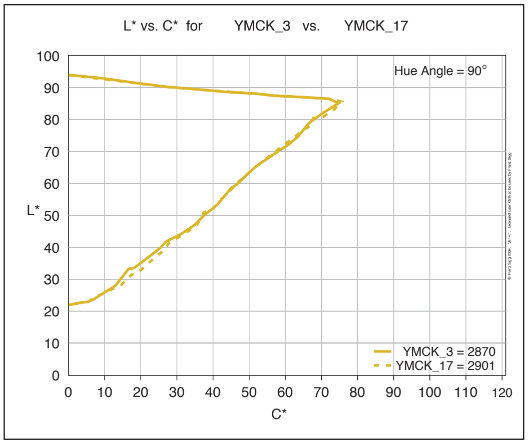
Appendix B

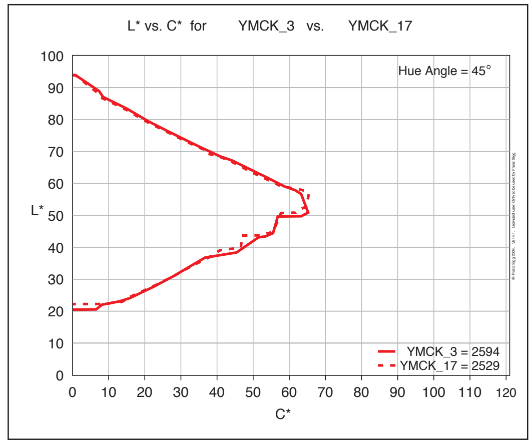
Sheet-to-Sheet L*C* Area Comparison

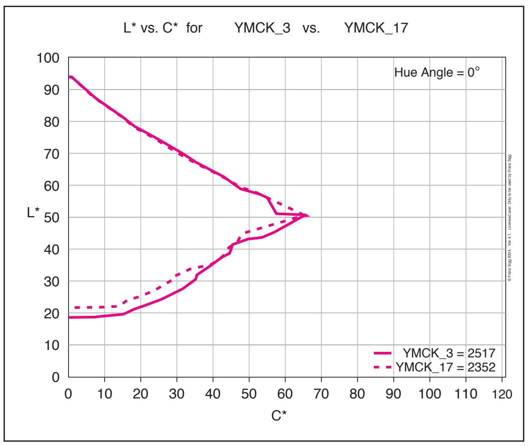
The L*C* area comparison done by the method developed by Prof. Franz Sigg outputs PDF files showing the difference in eight hue angles of a gamut with the help of L*C* slices, an a*b* diagram, and a table containing area values and their ratios. This exercise was done to observe sheet-to-sheet variability for the five sequences tested by evaluating Sheet #3 and Sheet #17 out of the 20 sheets printed for each sequence. Here, Sheet #3 is treated as the sample and Sheet #17 as the reference.

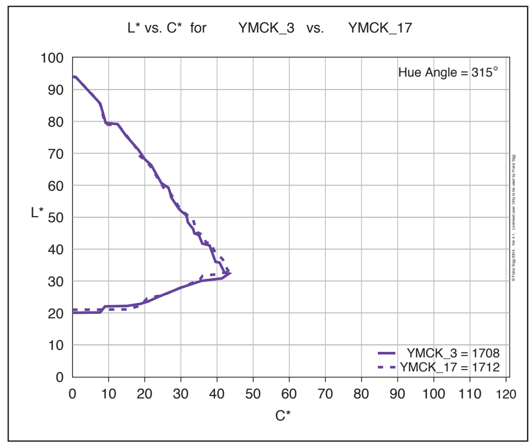
Flexo Ink Sequence, YMCK_3 vs. YMCK_17

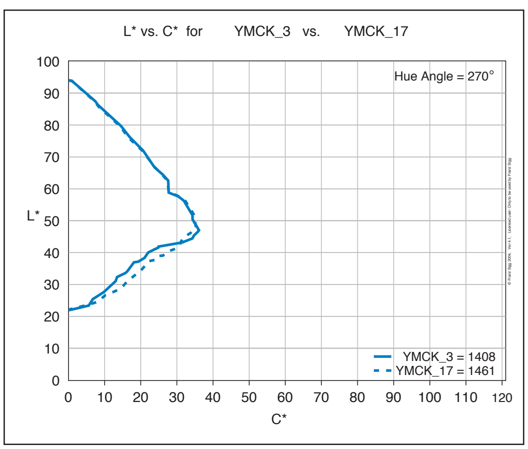
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

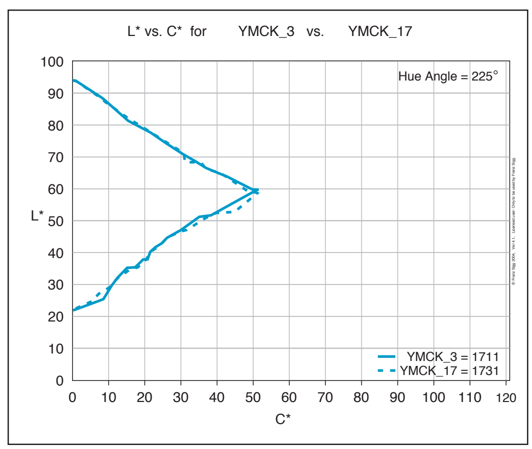


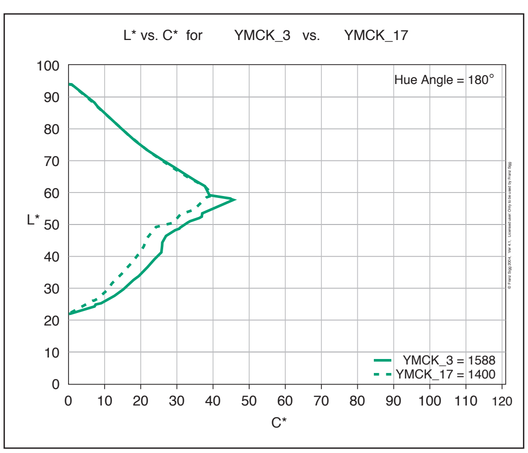


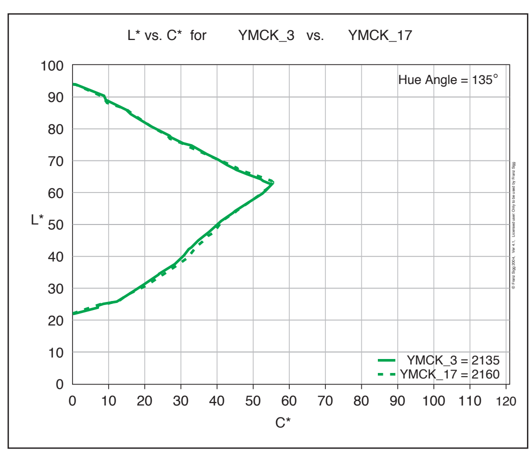


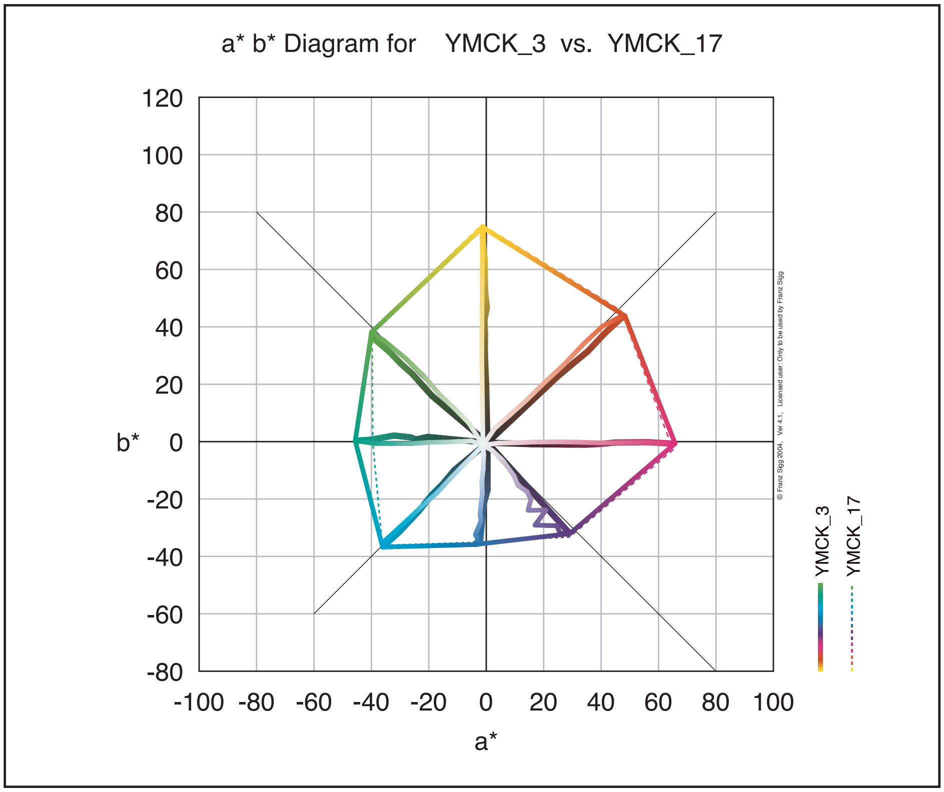












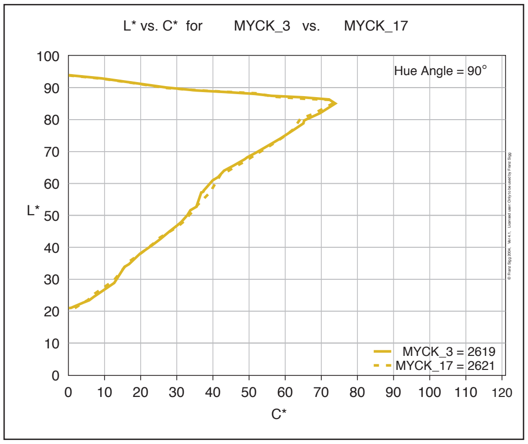
Gamut areas for the 8 L*C* slices:

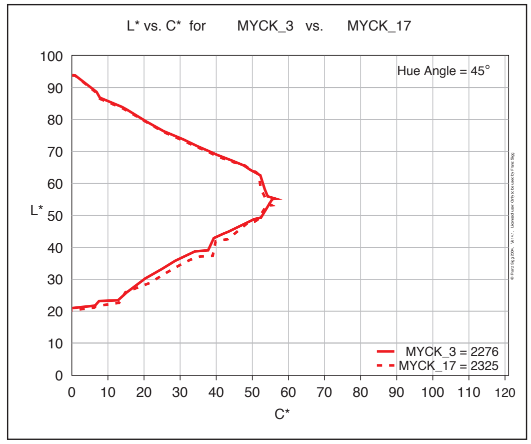
Color	Hue_Angle	YMCK_3 Sample	YMCK_17 Reference	Samp / Ref
Yellow	90	2870	2901	99 %
Red	45	2594	2529	103%
Magenta	0	2517	2352	107%
Purple	315	1708	1712	100%
Blue	270	1408	1461	96 %
Cyan	225	1711	1731	99 %
Emerald	180	1588	1400	113%
Green	135	2135	2160	99 %
Total		16531	16246	102%

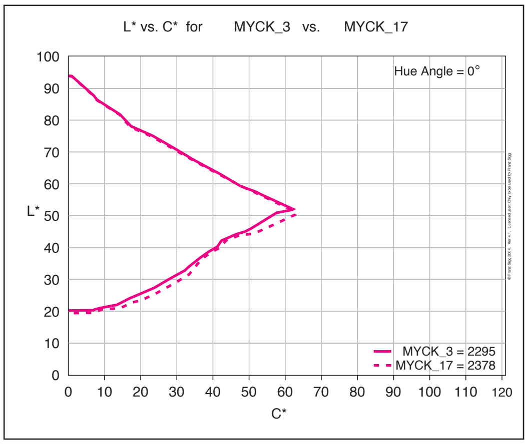
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

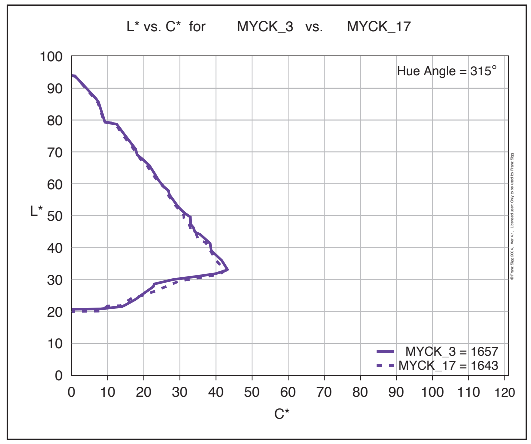
Flexo Ink Sequence, MYCK_3 vs. MYCK_17

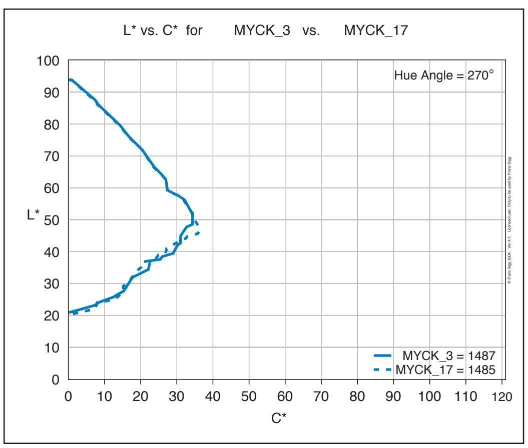
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

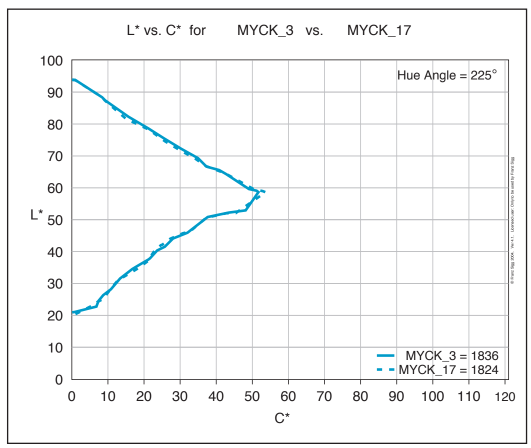


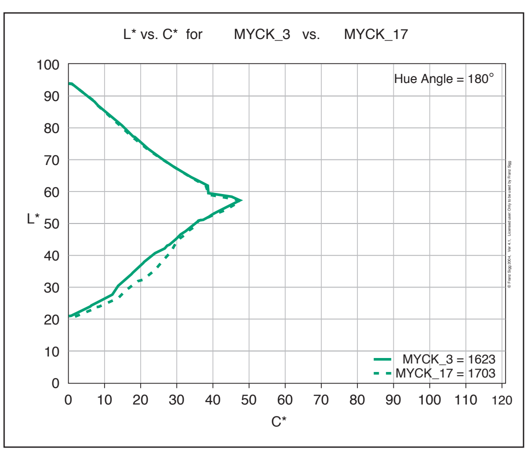


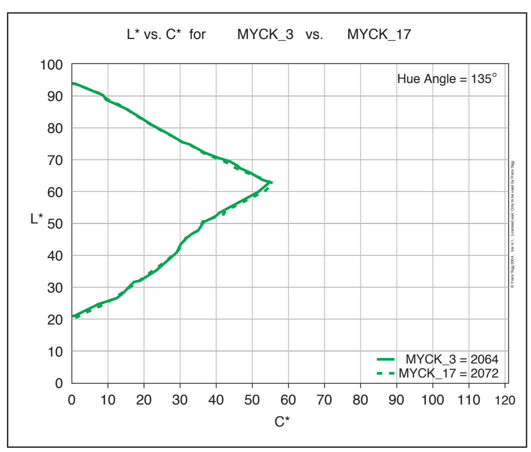


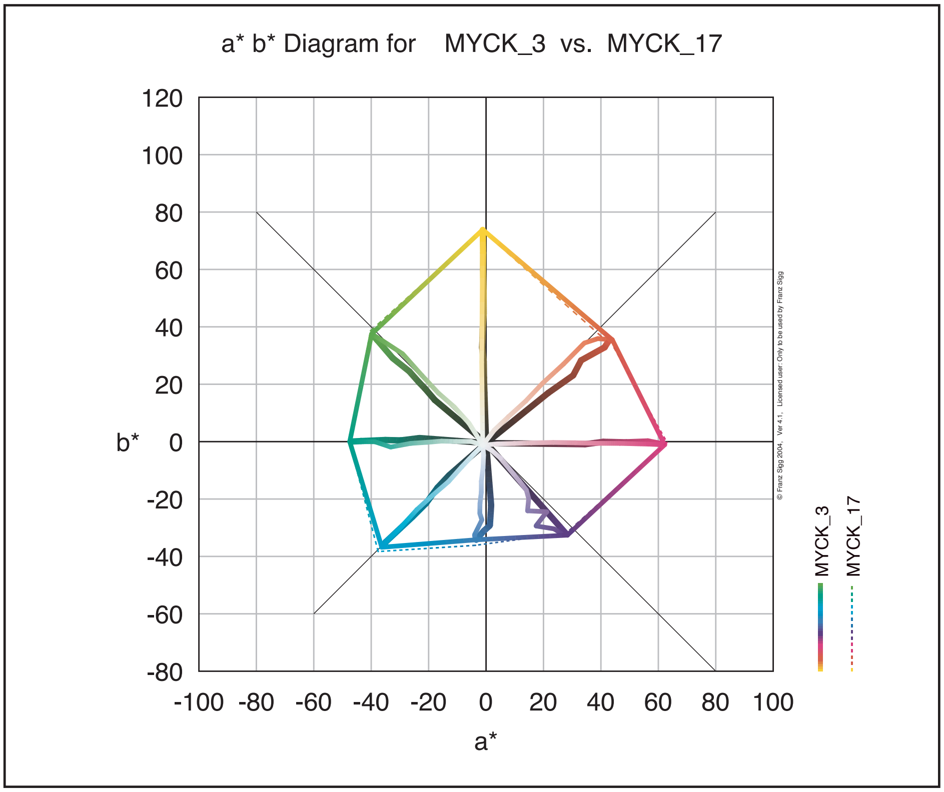












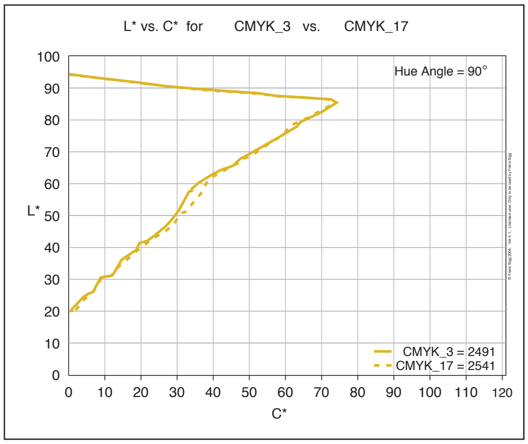
Gamut areas for the 8 L*C* slices:

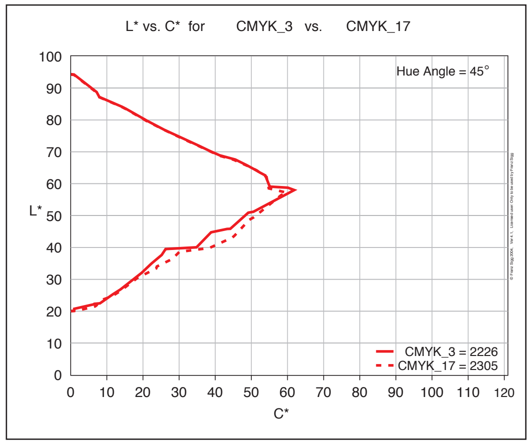
Color	Hue_Angle	MYCK_3 Sample	MYCK_17 Reference	Samp / Ref
Yellow	90	2619	2621	100%
Red	45	2276	2325	98 %
Magenta	0	2295	2378	97 %
Purple	315	1657	1643	101%
Blue	270	1487	1485	100%
Cyan	225	1836	1824	101%
Emerald	180	1623	1703	95 %
Green	135	2064	2072	100%
Total		15857	16051	99 %

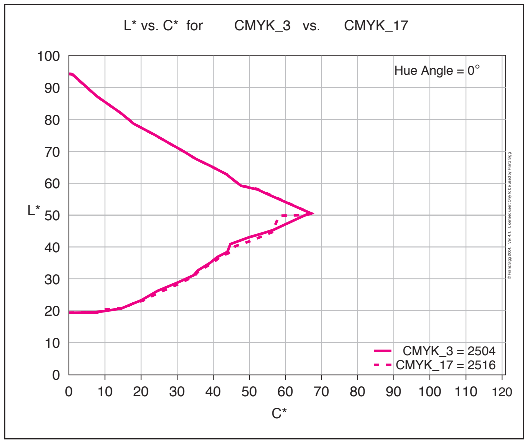
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

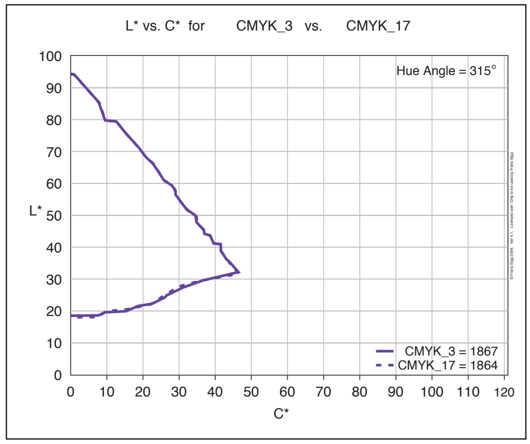
Flexo Ink Sequence, CMYK_3 vs. CMYK_17

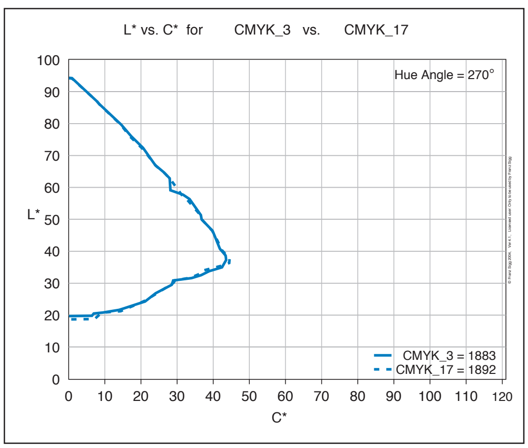
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

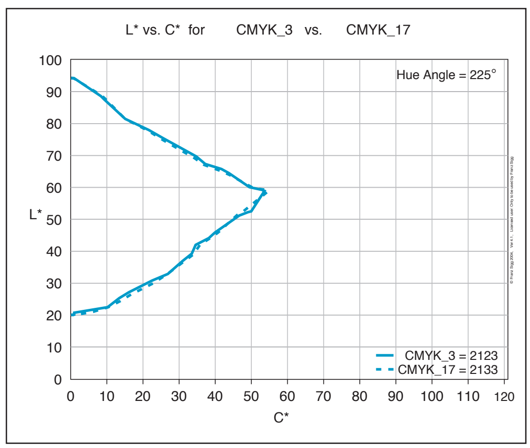


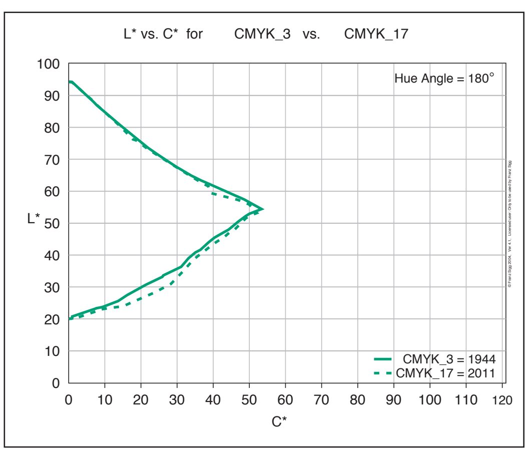


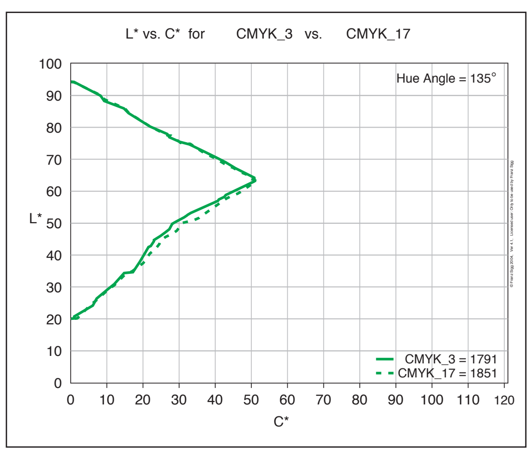


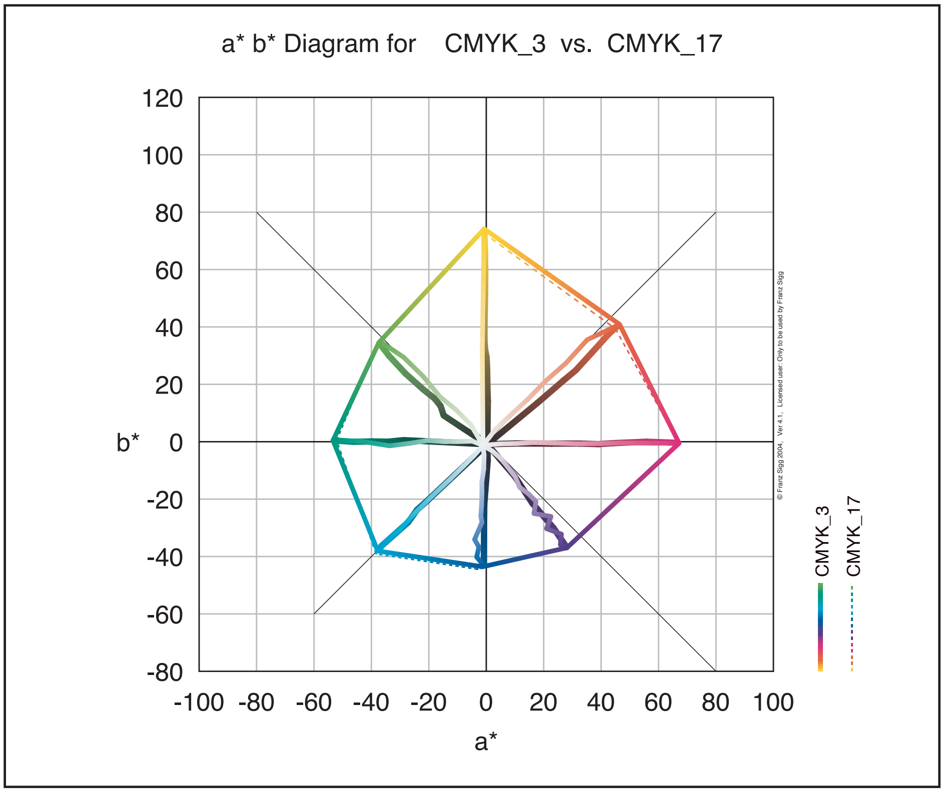












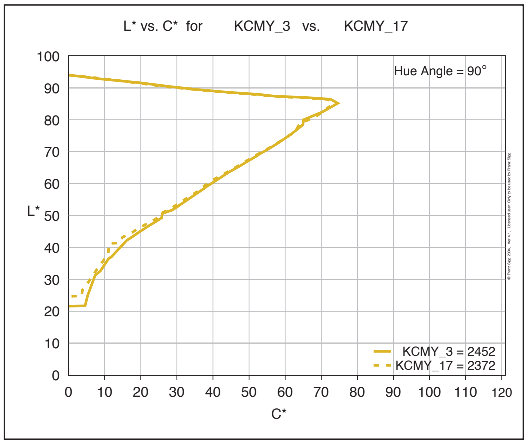
Gamut areas for the 8 L*C* slices:

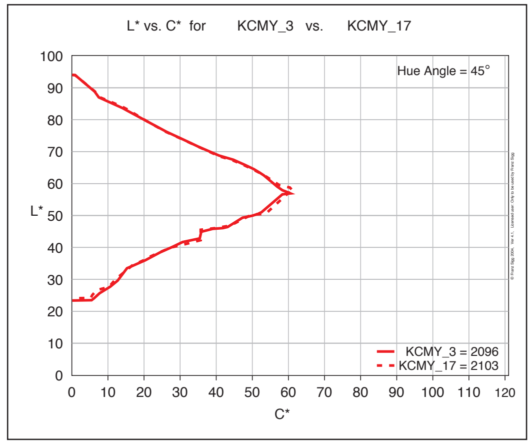
Color	Hue_Angle	CMYK_3 Sample	CMYK_17 Reference	Samp / Ref
Yellow	90	2491	2541	98 %
Red	45	2226	2305	97 %
Magenta	0	2504	2516	100%
Purple	315	1867	1864	100%
Blue	270	1883	1892	100%
Cyan	225	2123	2133	100%
Emerald	180	1944	2011	97 %
Green	135	1791	1851	97 %
Total		16829	17113	98 %

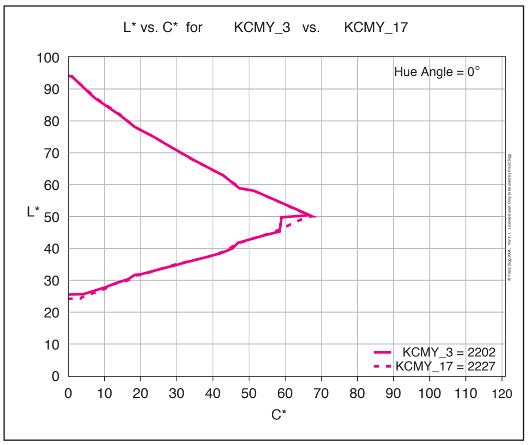
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

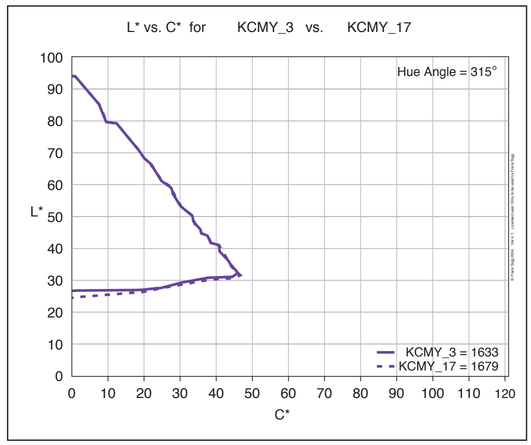
Flexo Ink Sequence, KCMY_3 vs. KCMY_17

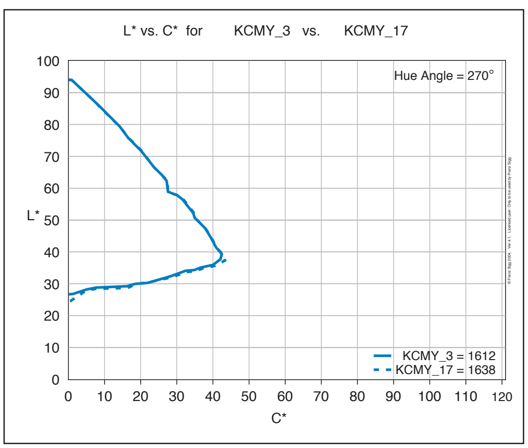
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

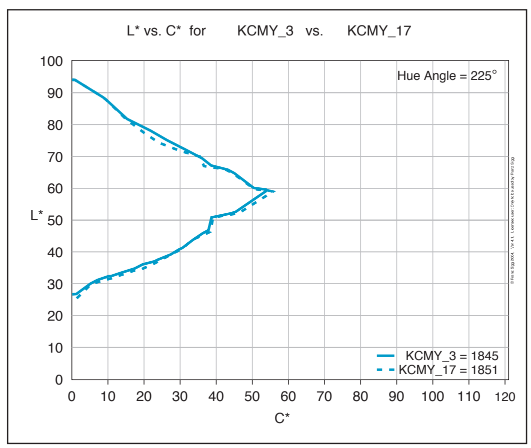


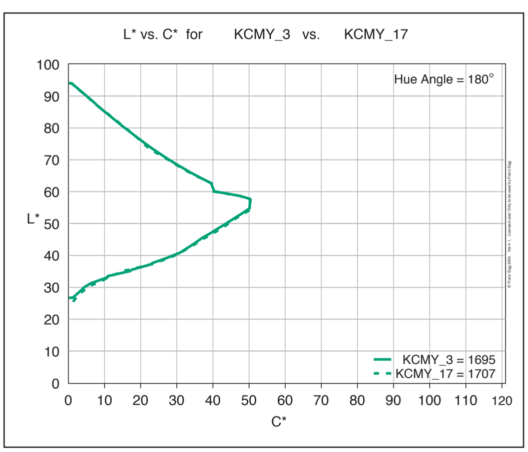


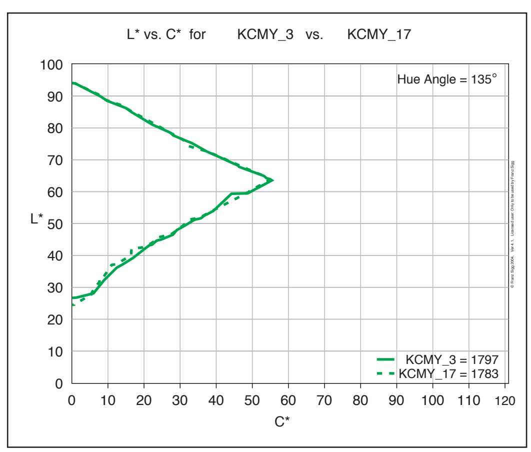


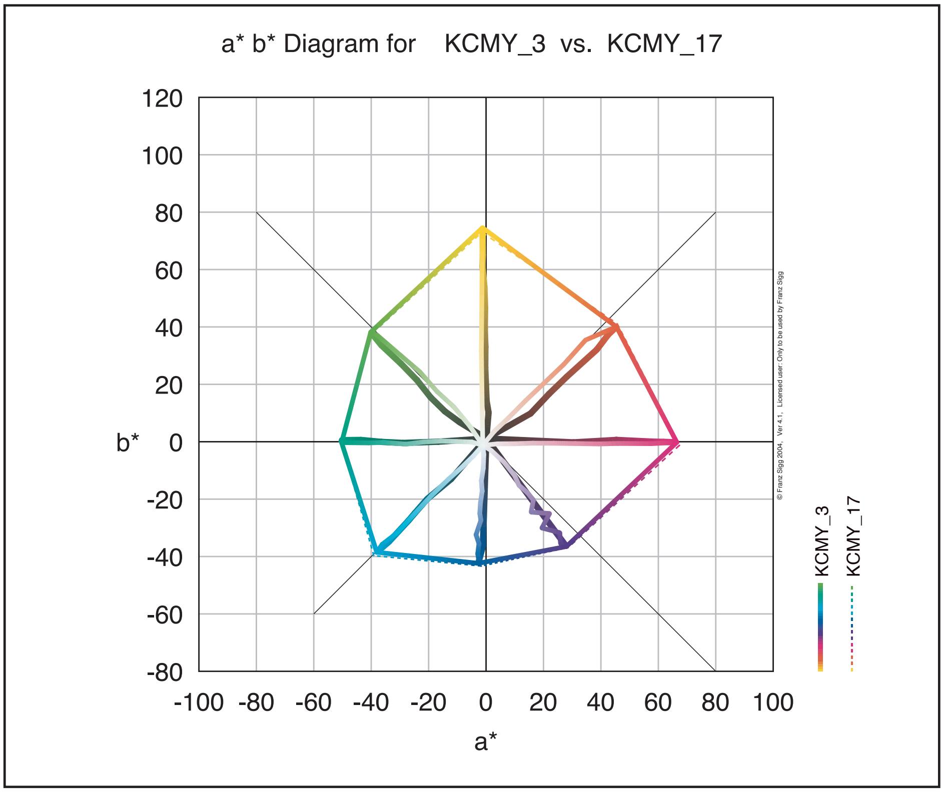












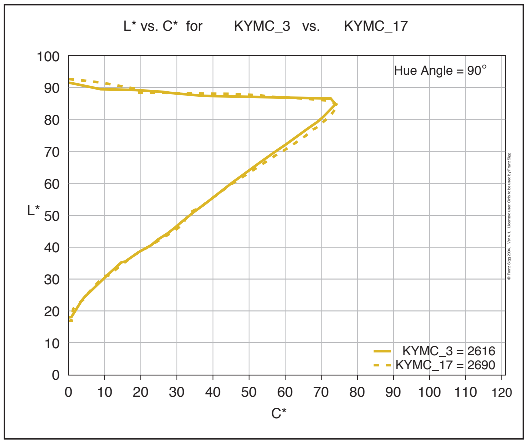
Gamut areas for the 8 L*C* slices:

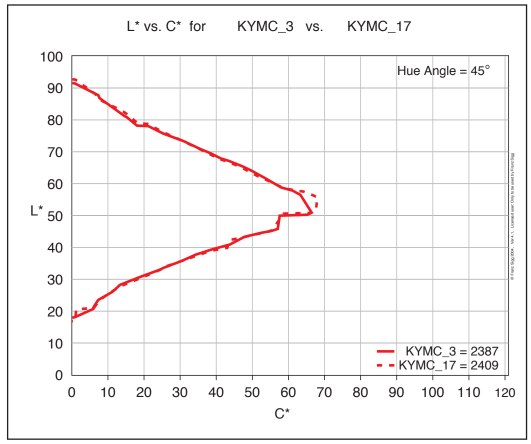
Color	Hue_Angle	KCMY_3 Sample	KCMY_17 Reference	Samp / Ref
Yellow	90	2452	2372	103%
Red	45	2096	2103	100%
Magenta	0	2202	2227	99 %
Purple	315	1633	1679	97 %
Blue	270	1612	1638	98 %
Cyan	225	1845	1851	100%
Emerald	180	1695	1707	99 %
Green	135	1797	1783	101%
Total		15332	15360	100%

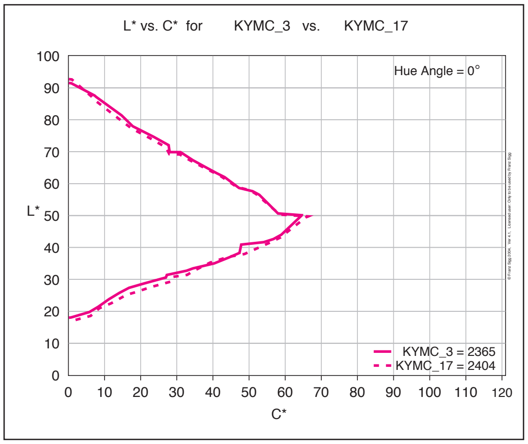
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

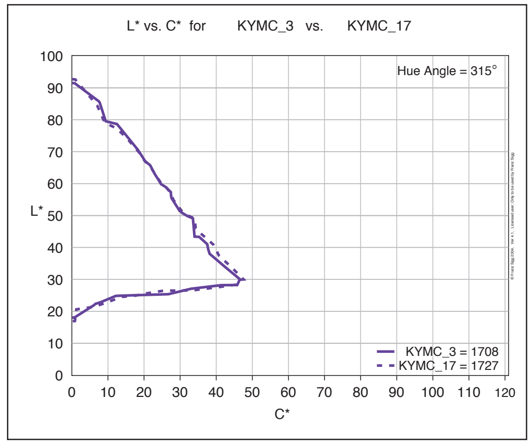
Flexo Ink Sequence, KYMC_3 vs. KYMC_17

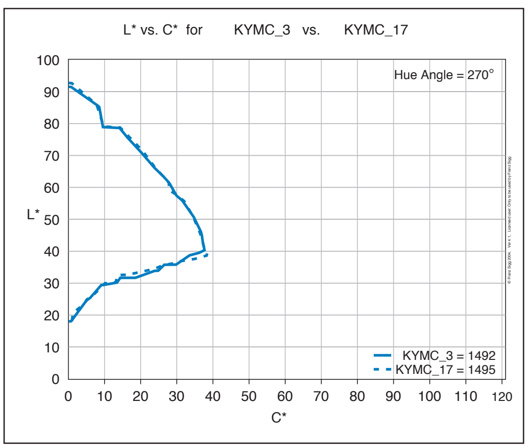
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

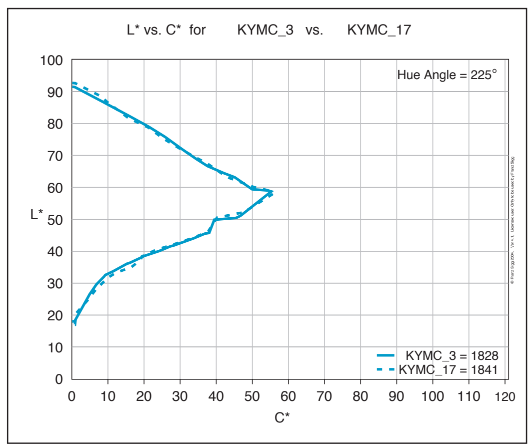


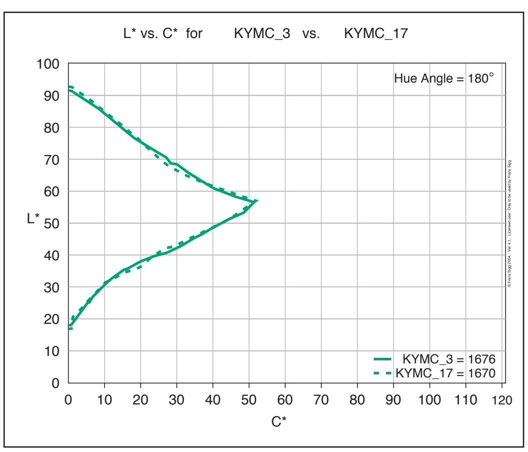


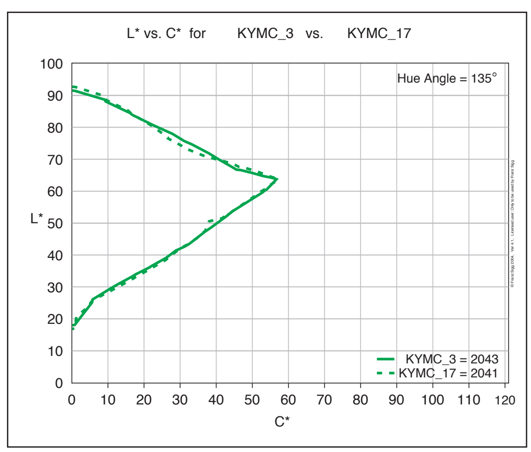


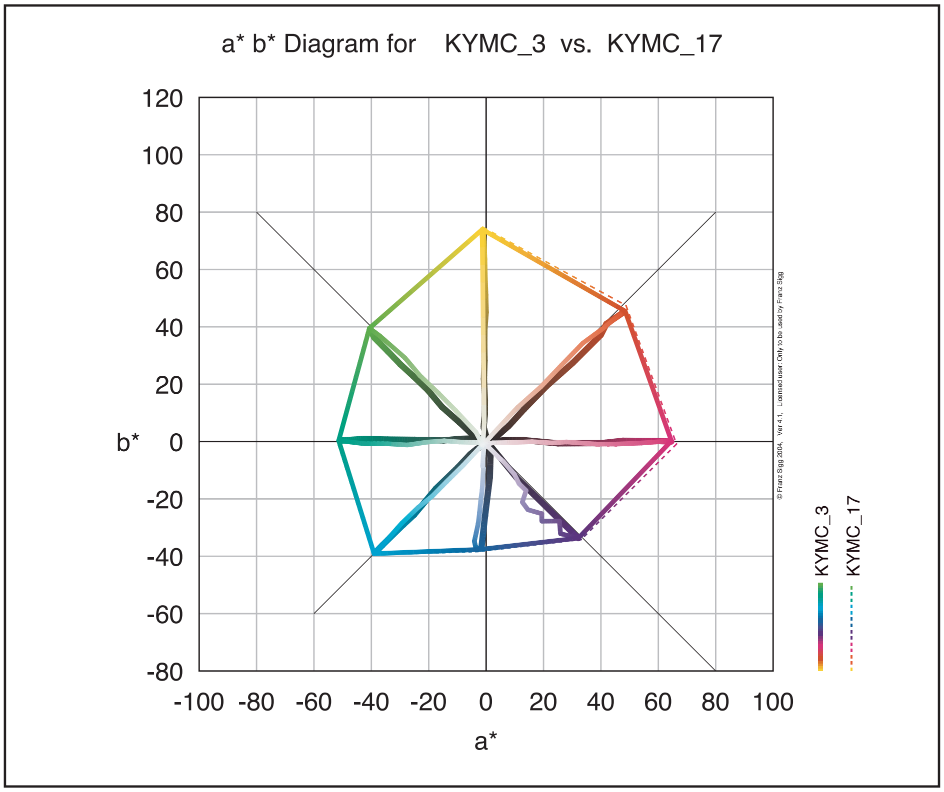












Gamut areas for the 8 L*C* slices:

Color	Hue_Angle	KYMC_3 Sample	KYMC_17 Reference	Samp / Ref
Yellow	90	2616	2690	97 %
Red	45	2387	2409	99 %
Magenta	0	2365	2404	98 %
Purple	315	1708	1727	99 %
Blue	270	1492	1495	100%
Cyan	225	1828	1841	99 %
Emerald	180	1676	1670	100%
Green	135	2043	2041	100%
Total		16115	16277	99 %

Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

Appendix C

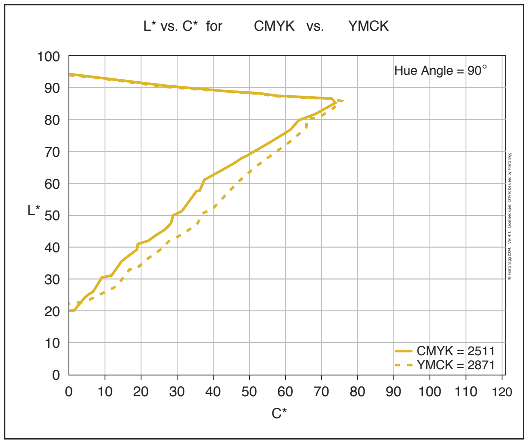
L*C* Area Comparison for Each Sample Sequences vs. One of the Two Reference Sequences

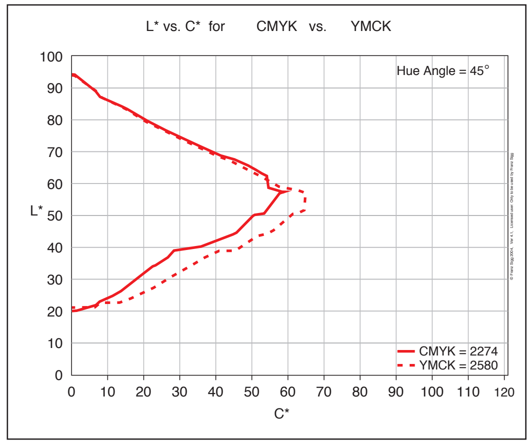
This appendix contains the PDF files generated for evaluating the five sequences tested using the method generated by Prof. Franz Sigg. Two sequences are compared at a time, where the first is the sample and the second is the reference. There are two reference sequences CMYK and YMCK. The sequence comparison files will be in the following order.

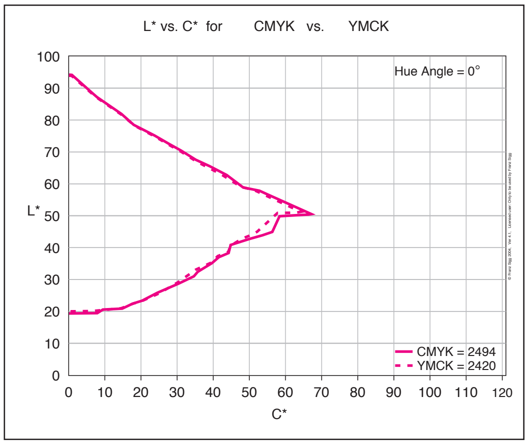
1. CMYK vs. YMCK (two reference sequences compared against each other, considering CMYK as sample and YMCK as Reference)
2. MYCK vs. CMYK
3. MYCK vs. YMCK
4. KCMY vs. CMYK
5. KCMY vs. YMCK
6. KYMC vs. CMYK
7. KYMC vs. YMCK

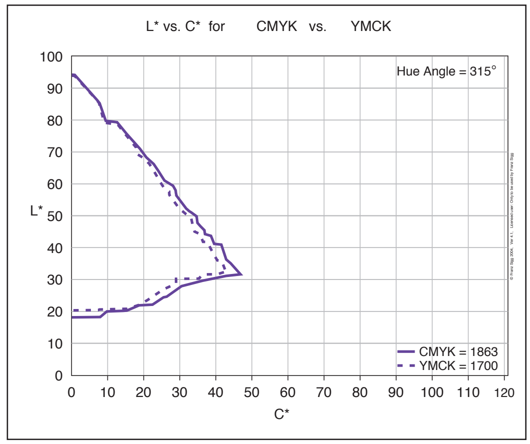
Flexo Ink Sequence, CMYK vs. YMCK

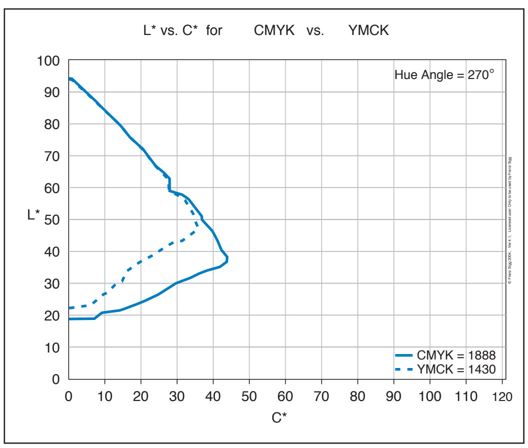
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

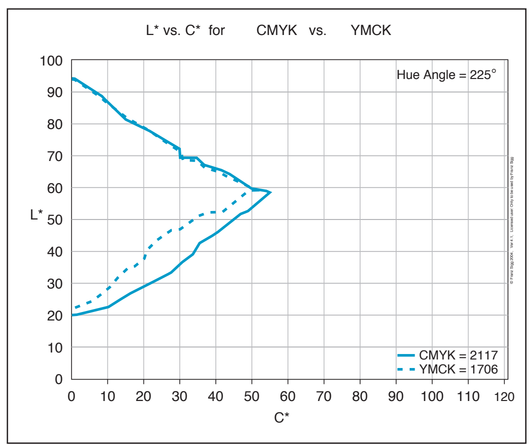


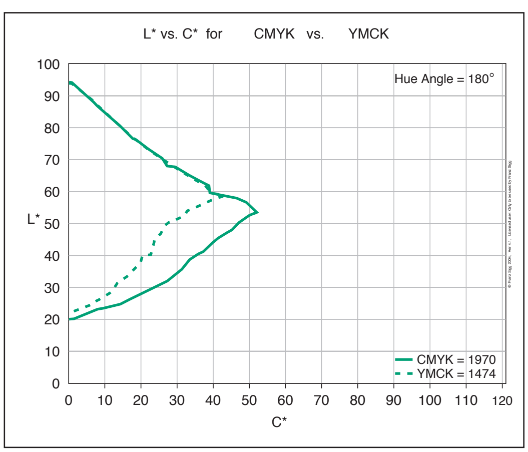


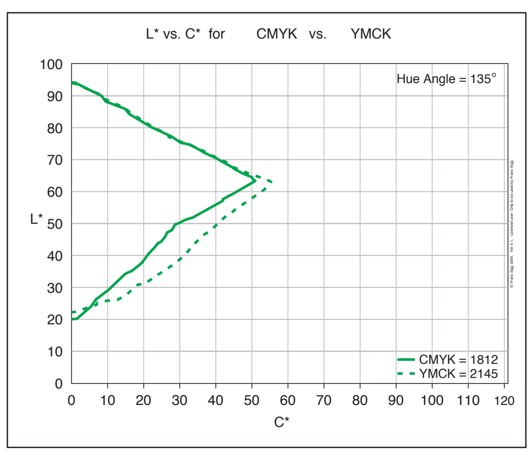


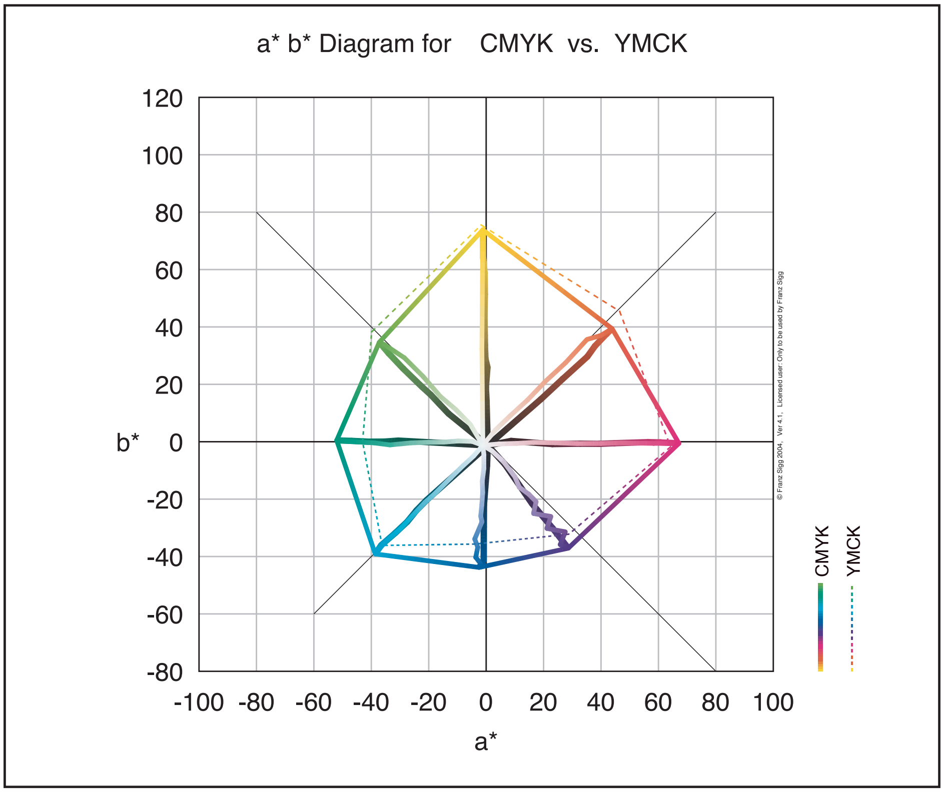












CIELab for special patches

Patch		CMYK L*	CMYK a*	CMYK b*	YMCK L*	YMCK a*	YMCK b*
Paper		94.56	-0.99	-1.23	94.45	-1.22	-1.42
400%	solid	11.3	-2.61	-5.54	16.6	-0.2	4.06
K	solid	20.1	1.2	2.06	20.97	0.87	1.55
C	solid	58.94	-35.55	-47.3	59.53	-32.75	-46.65
C+Y	solid	52.16	-60.99	20.38	53.22	-58.78	24.44
Y	solid	91.09	-7.71	83.5	90.82	-7.88	83.45
M+Y	solid	49.71	63.99	38.32	49.34	62.2	41.53
M	solid	49.48	70.11	-7.62	49.39	68.32	-4.59
C+M	solid	26.27	18.86	-44.52	27.2	18.31	-38.41

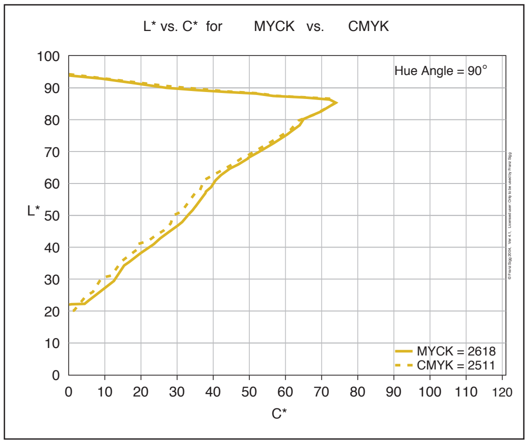
Gamut areas for the 8 L*C* slices:

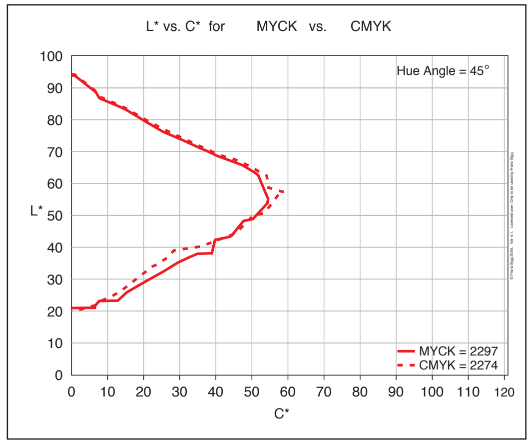
Color	Hue_Angle	CMYK Sample	YMCK Reference	Samp / Ref
Yellow	90	2511	2871	87 %
Red	45	2274	2580	88 %
Magenta	0	2494	2420	103%
Purple	315	1863	1700	110%
Blue	270	1888	1430	132%
Cyan	225	2117	1706	124%
Emerald	180	1970	1474	134%
Green	135	1812	2145	84 %
Total		16929	16326	104%

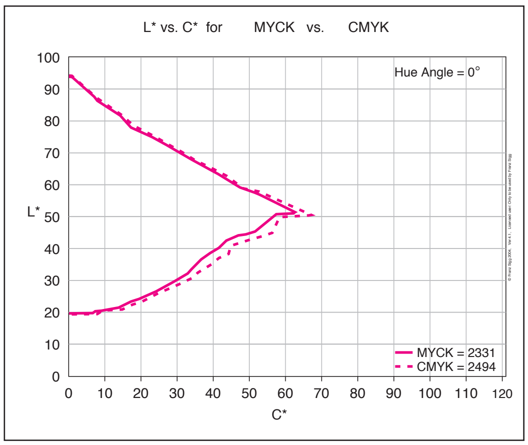
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

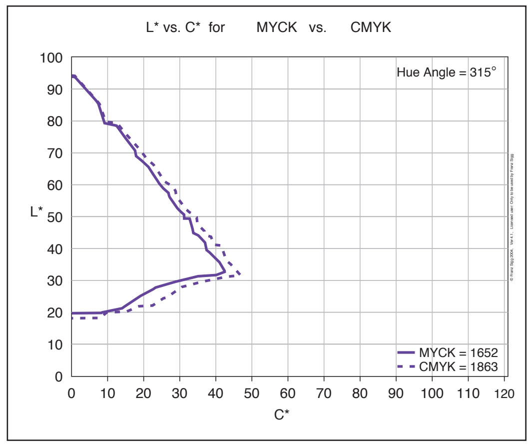
Flexo Ink Sequence, MYCK vs. CMYK

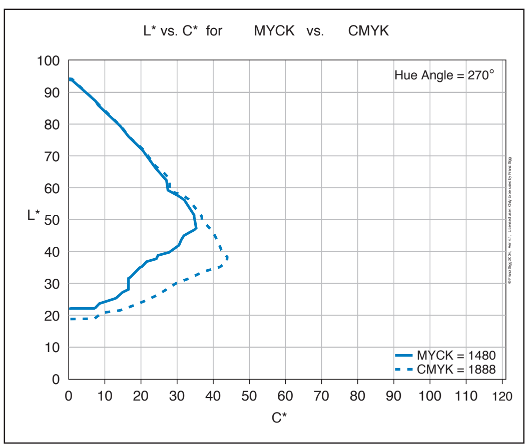
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

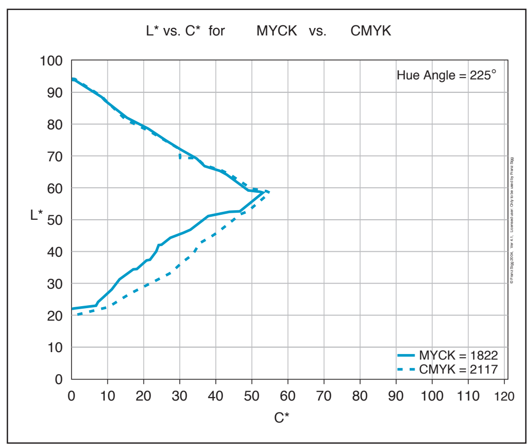


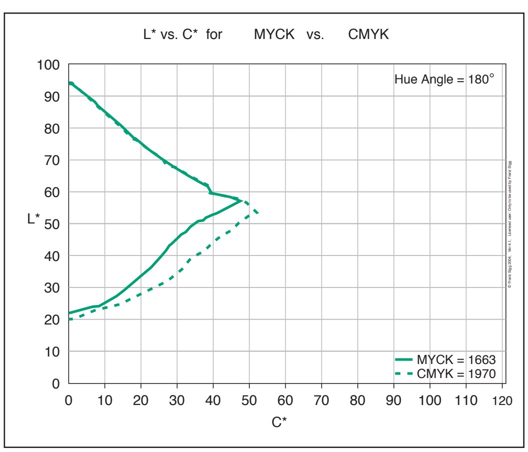


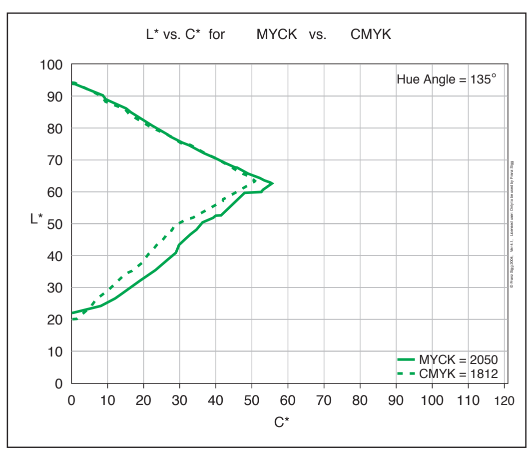


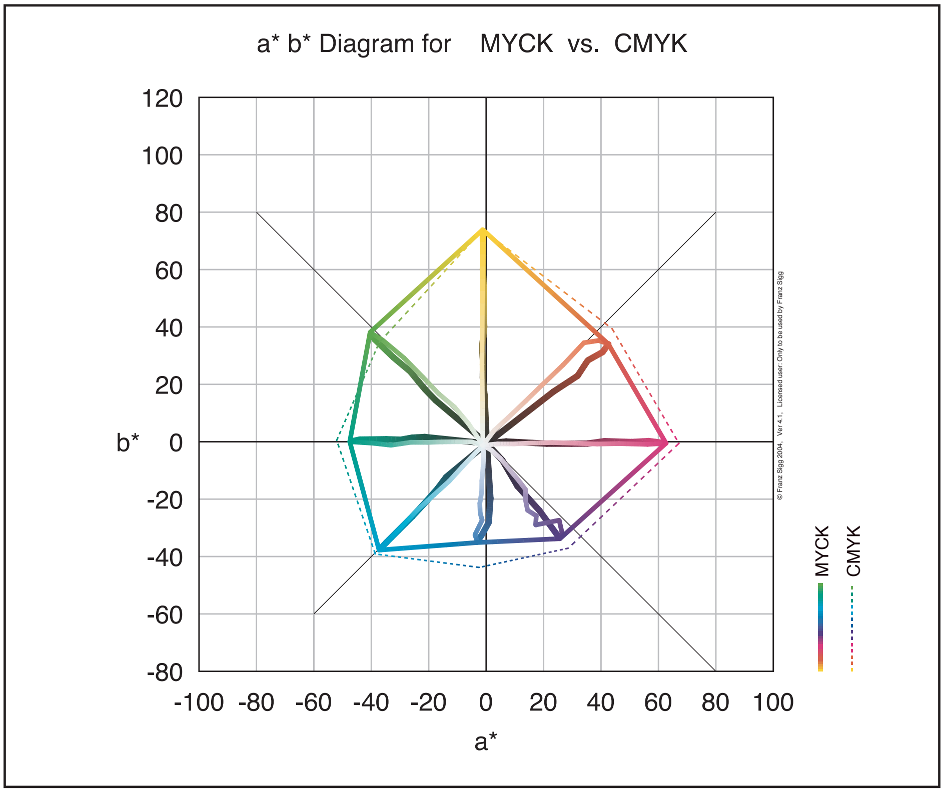












CIELab for special patches

Patch	MYCK L*	MYCK a*	MYCK b*	CMYK L*	CMYK a*	CMYK b*
Paper	94.34	-1.24	-1.42	94.56	-0.99	-1.23
400% solid	14.27	0.6	-0.64	11.3	-2.61	-5.54
K solid	20.56	0.77	1.54	20.1	1.2	2.06
C solid	58.88	-33.74	-47.71	58.94	-35.55	-47.3
C+Y solid	51.77	-61.8	21.28	52.16	-60.99	20.38
Y solid	91.04	-7.8	82.11	91.09	-7.71	83.5
M+Y solid	50.89	59.89	39.06	49.71	63.99	38.32
M solid	51.92	64.03	-5.59	49.48	70.11	-7.62
C+M solid	29.34	11.77	-40	26.27	18.86	-44.52

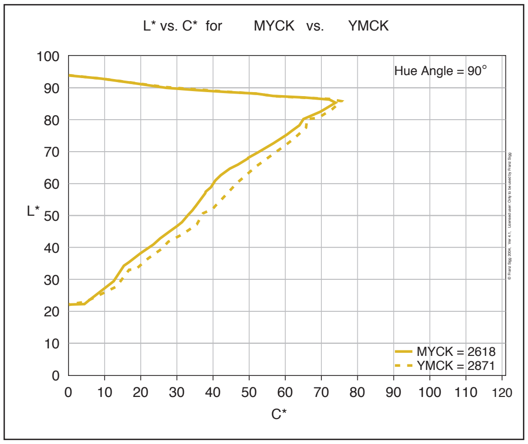
Gamut areas for the 8 L*C* slices:

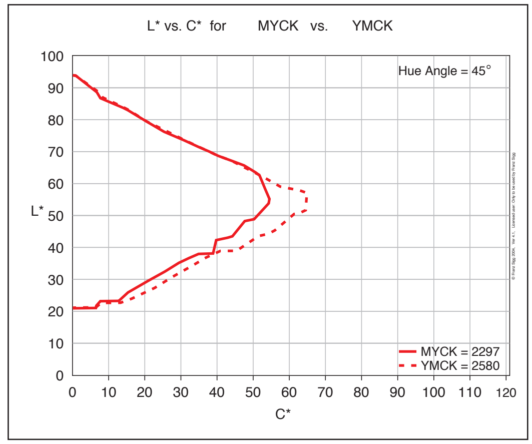
Color	Hue_Angle	MYCK Sample	CMYK Reference	Samp / Ref
Yellow	90	2618	2511	104%
Red	45	2297	2274	101%
Magenta	0	2331	2494	93 %
Purple	315	1652	1863	89 %
Blue	270	1480	1888	78 %
Cyan	225	1822	2117	86 %
Emerald	180	1663	1970	84 %
Green	135	2050	1812	113%
Total		15913	16929	94 %

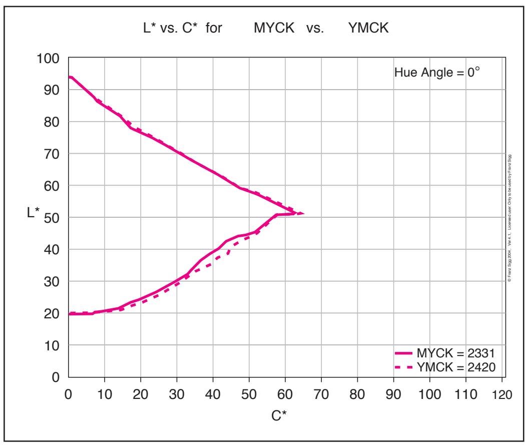
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

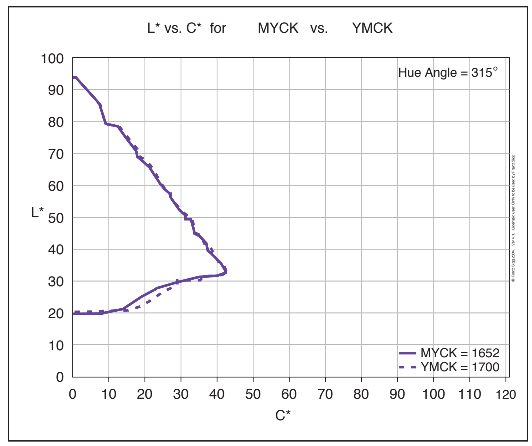
Flexo Ink Sequence, MYCK vs. YMCK

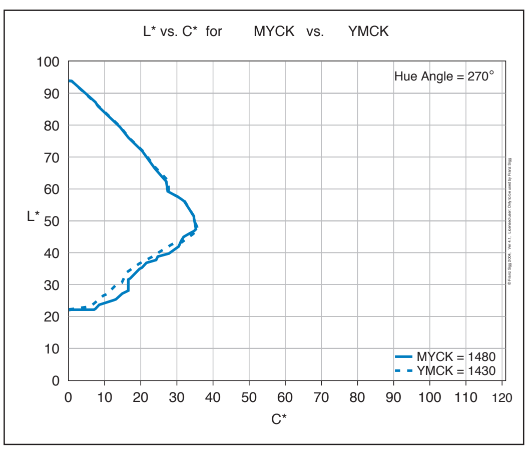
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

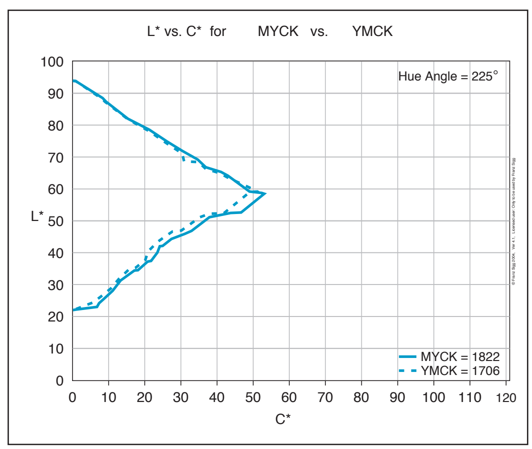


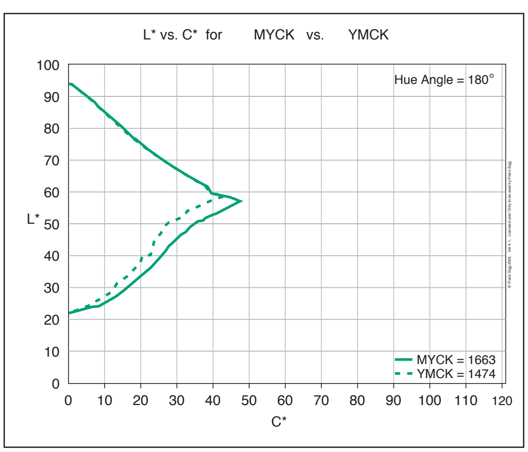


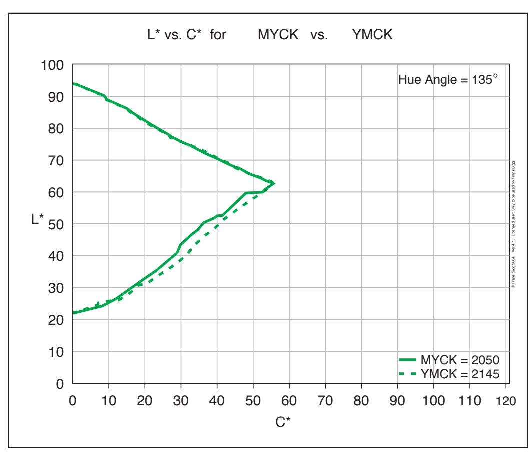


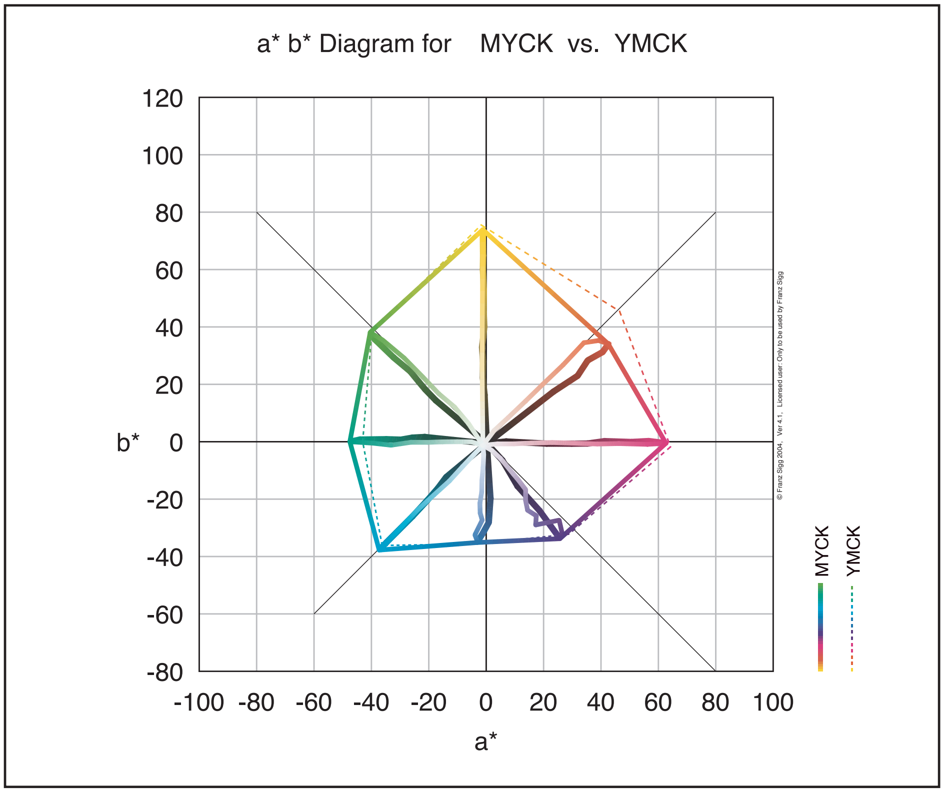












CIELab for special patches

Patch	MYCK L*	MYCK a*	MYCK b*	YMCK L*	YMCK a*	YMCK b*
Paper	94.34	-1.24	-1.42	94.45	-1.22	-1.42
400% solid	14.27	0.6	-0.64	16.6	-0.2	4.06
K solid	20.56	0.77	1.54	20.97	0.87	1.55
C solid	58.88	-33.74	-47.71	59.53	-32.75	-46.65
C+Y solid	51.77	-61.8	21.28	53.22	-58.78	24.44
Y solid	91.04	-7.8	82.11	90.82	-7.88	83.45
M+Y solid	50.89	59.89	39.06	49.34	62.2	41.53
M solid	51.92	64.03	-5.59	49.39	68.32	-4.59
C+M solid	29.34	11.77	-40	27.2	18.31	-38.41

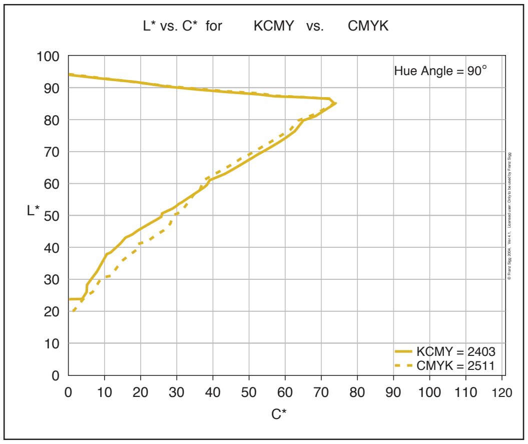
Gamut areas for the 8 L*C* slices:

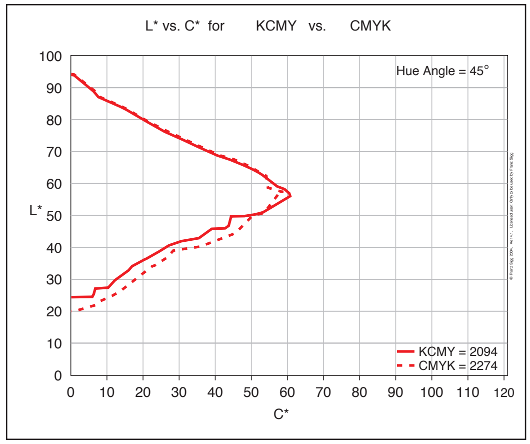
Color	Hue_Angle	MYCK Sample	YMCK Reference	Samp / Ref
Yellow	90	2618	2871	91 %
Red	45	2297	2580	89 %
Magenta	0	2331	2420	96 %
Purple	315	1652	1700	97 %
Blue	270	1480	1430	103%
Cyan	225	1822	1706	107%
Emerald	180	1663	1474	113%
Green	135	2050	2145	96 %
Total		15913	16326	97 %

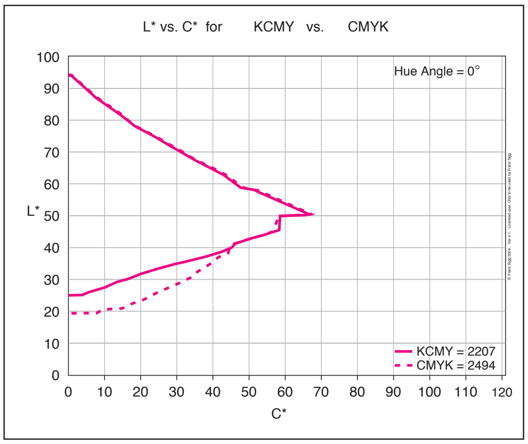
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

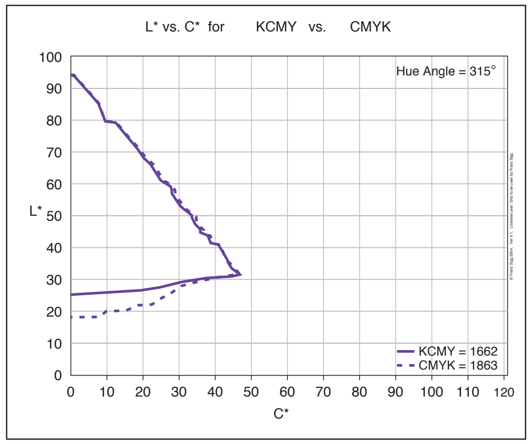
Flexo Ink Sequence, KCMY vs. CMYK

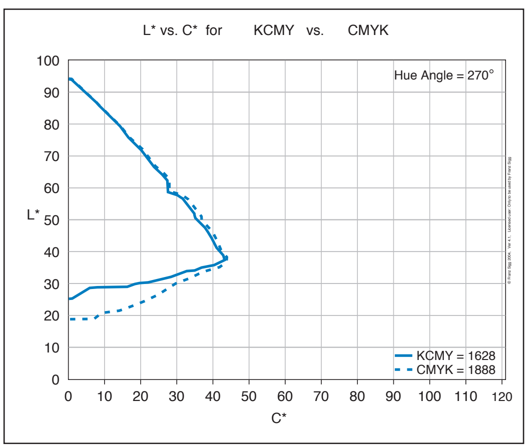
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

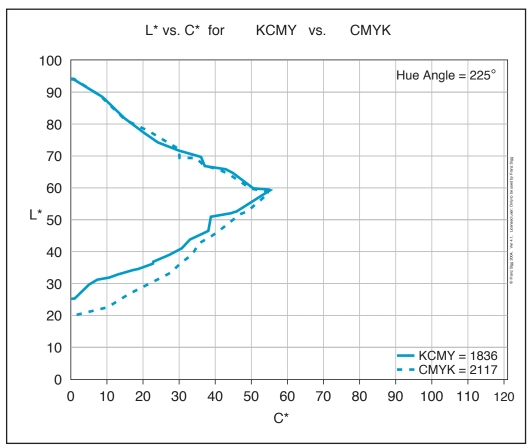


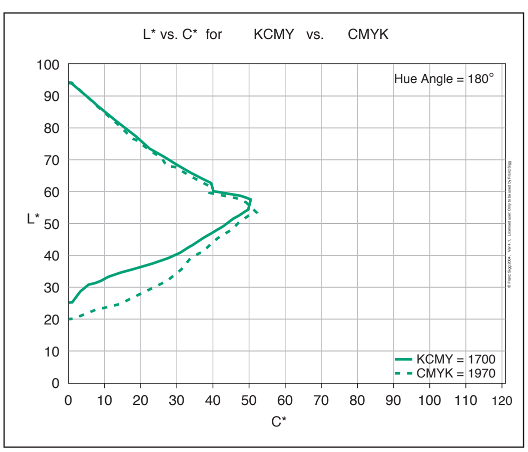


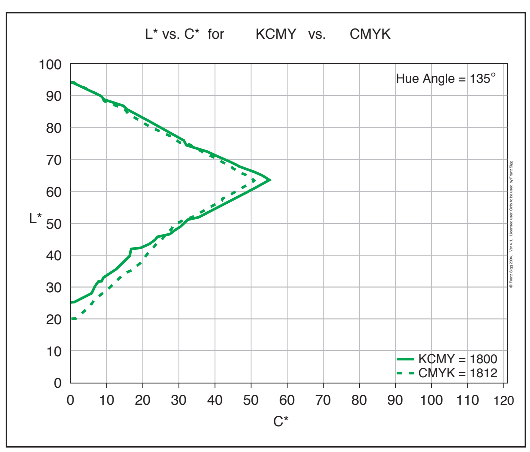


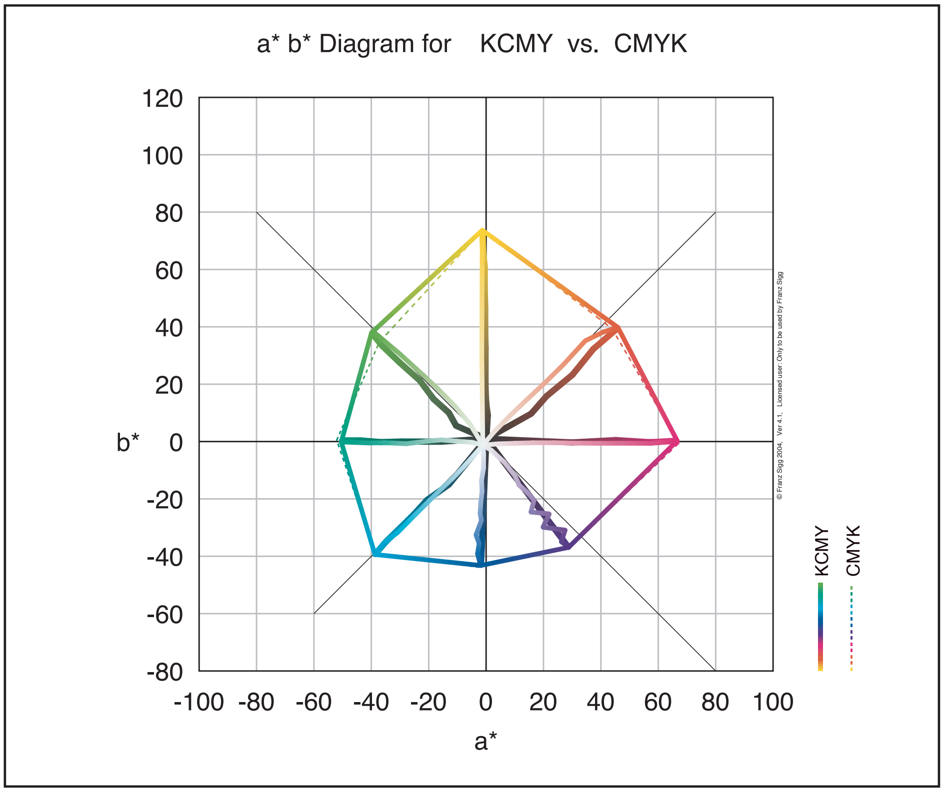












CIELab for special patches

Patch	KCMY L*	KCMY a*	KCMY b*	CMYK L*	CMYK a*	CMYK b*
Paper	94.36	-1.01	-1.23	94.56	-0.99	-1.23
400% solid	18.31	0.97	5.33	11.3	-2.61	-5.54
K solid	21.12	1.09	2.3	20.1	1.2	2.06
C solid	60.2	-35.6	-46.07	58.94	-35.55	-47.3
C+Y solid	53.69	-59.41	24.59	52.16	-60.99	20.38
Y solid	90.97	-7.76	85.89	91.09	-7.71	83.5
M+Y solid	48.72	64.52	40.21	49.71	63.99	38.32
M solid	49.03	70.69	-7.8	49.48	70.11	-7.62
C+M solid	26.29	21.2	-43.63	26.27	18.86	-44.52

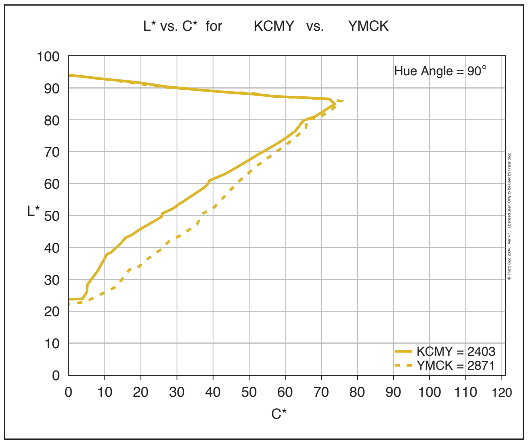
Gamut areas for the 8 L*C* slices:

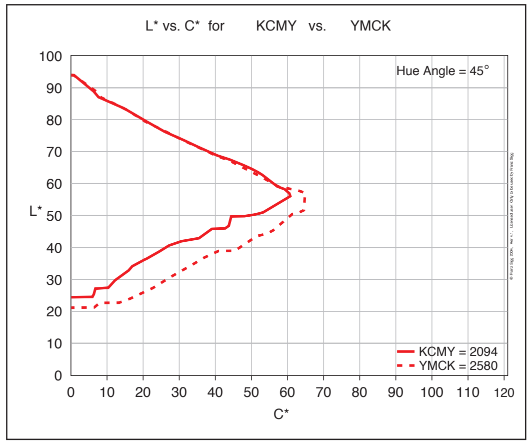
Color	Hue_Angle	KCMY Sample	CMYK Reference	Samp / Ref
Yellow	90	2403	2511	96 %
Red	45	2094	2274	92 %
Magenta	0	2207	2494	88 %
Purple	315	1662	1863	89 %
Blue	270	1628	1888	86 %
Cyan	225	1836	2117	87 %
Emerald	180	1700	1970	86 %
Green	135	1800	1812	99 %
Total		15330	16929	91 %

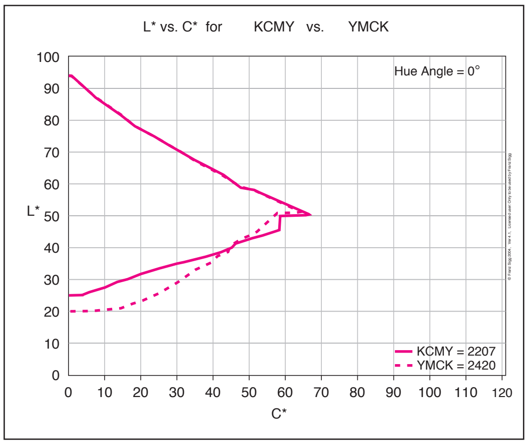
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

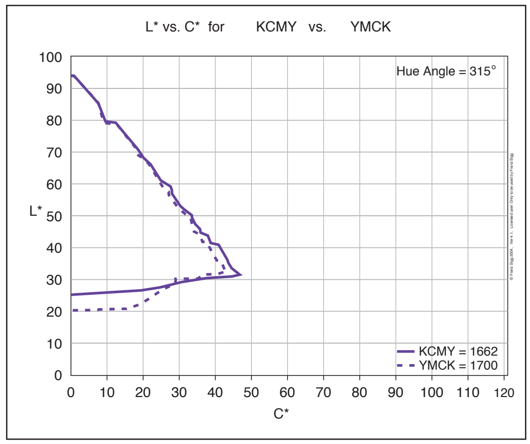
Flexo Ink Sequence, KCMY vs. YMCK

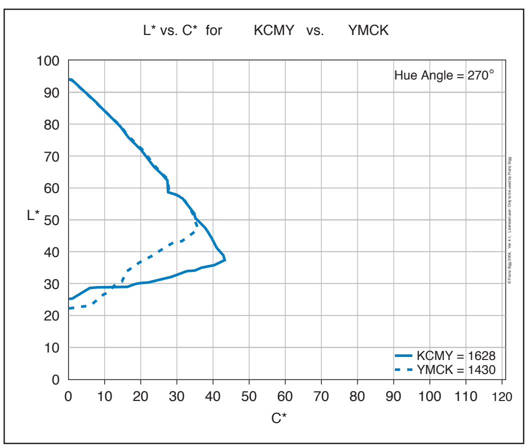
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

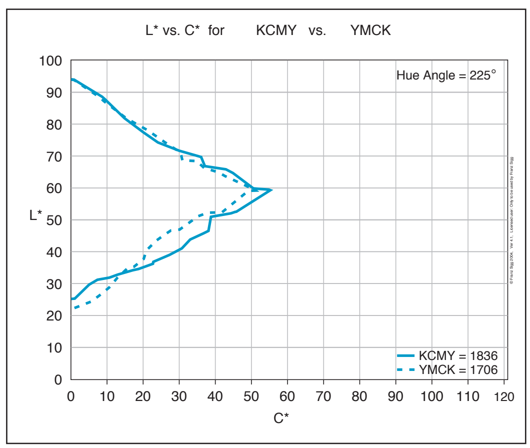


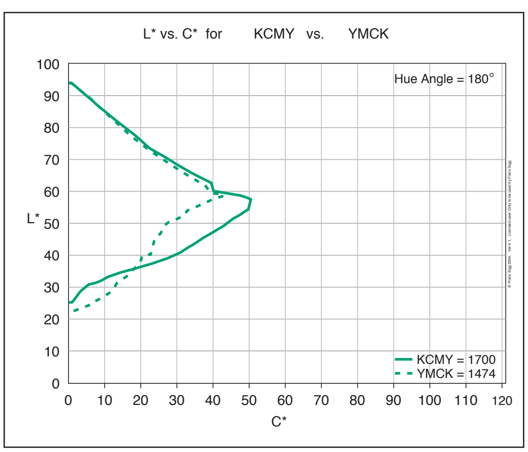


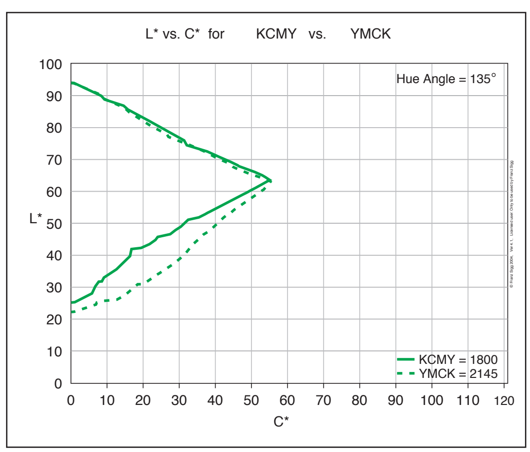


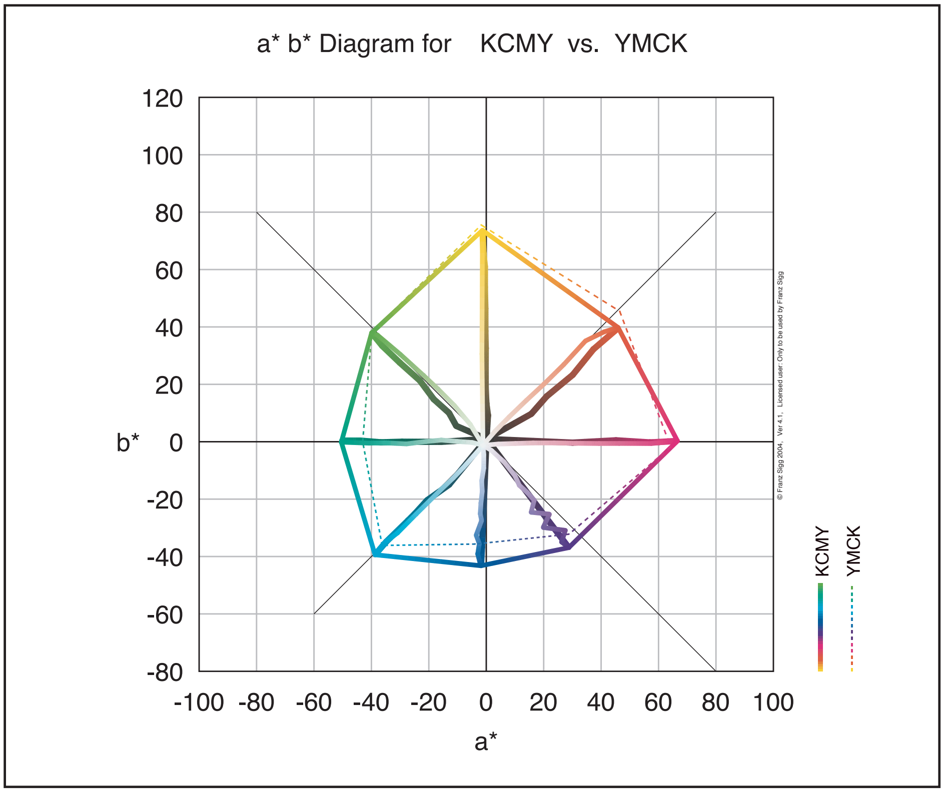












CIELab for special patches

Patch	KCMY L*	KCMY a*	KCMY b*	YMCK L*	YMCK a*	YMCK b*
Paper	94.36	-1.01	-1.23	94.45	-1.22	-1.42
400% solid	18.31	0.97	5.33	16.6	-0.2	4.06
K solid	21.12	1.09	2.3	20.97	0.87	1.55
C solid	60.2	-35.6	-46.07	59.53	-32.75	-46.65
C+Y solid	53.69	-59.41	24.59	53.22	-58.78	24.44
Y solid	90.97	-7.76	85.89	90.82	-7.88	83.45
M+Y solid	48.72	64.52	40.21	49.34	62.2	41.53
M solid	49.03	70.69	-7.8	49.39	68.32	-4.59
C+M solid	26.29	21.2	-43.63	27.2	18.31	-38.41

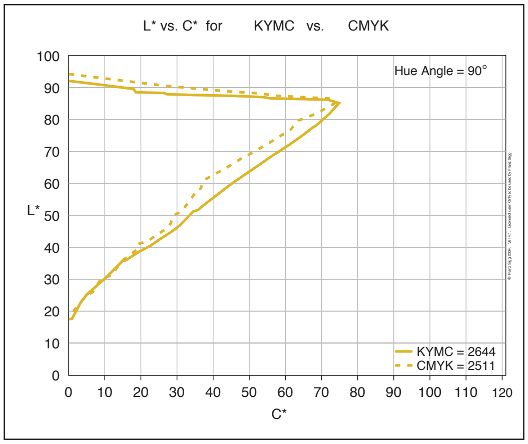
Gamut areas for the 8 L*C* slices:

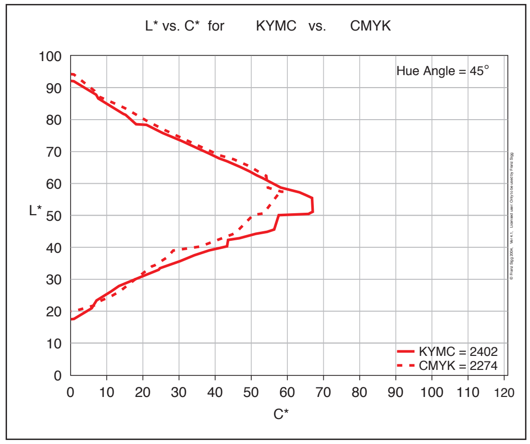
Color	Hue_Angle	KCMY Sample	YMCK Reference	Samp / Ref
Yellow	90	2403	2871	84 %
Red	45	2094	2580	81 %
Magenta	0	2207	2420	91 %
Purple	315	1662	1700	98 %
Blue	270	1628	1430	114%
Cyan	225	1836	1706	108%
Emerald	180	1700	1474	115%
Green	135	1800	2145	84 %
Total		15330	16326	94 %

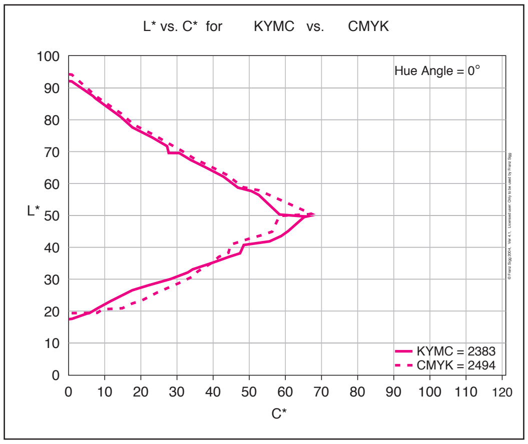
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

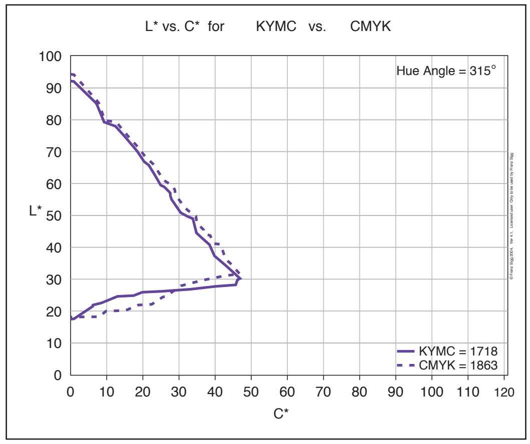
Flexo Ink Sequence, KYMC vs. CMYK

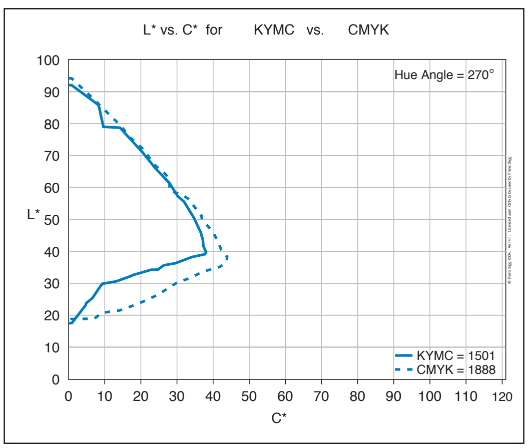
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

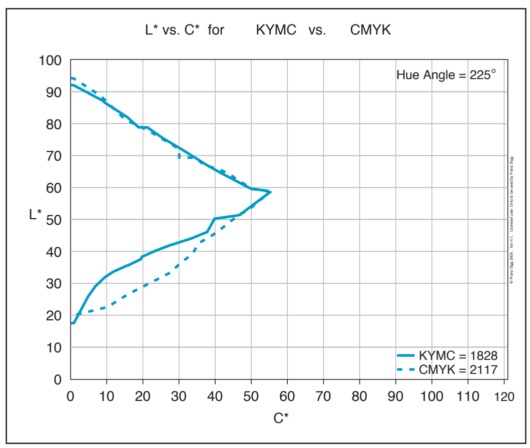


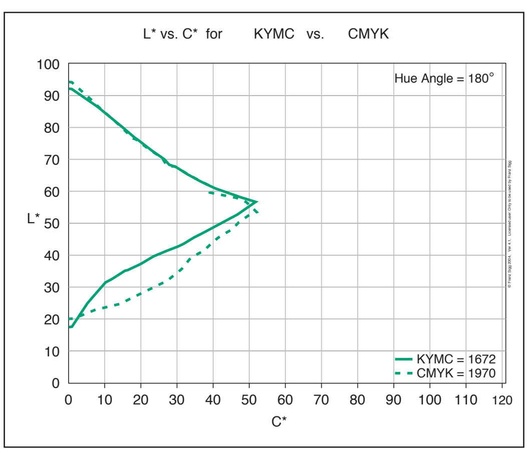


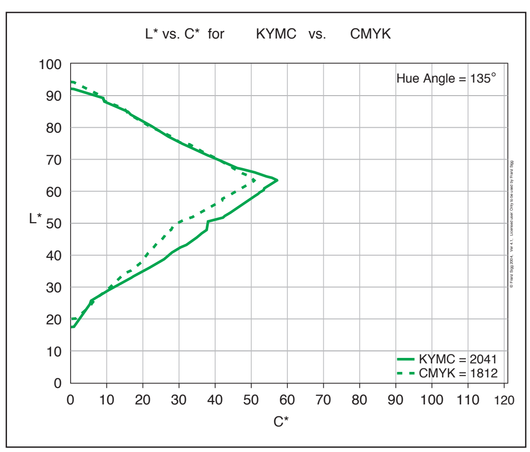


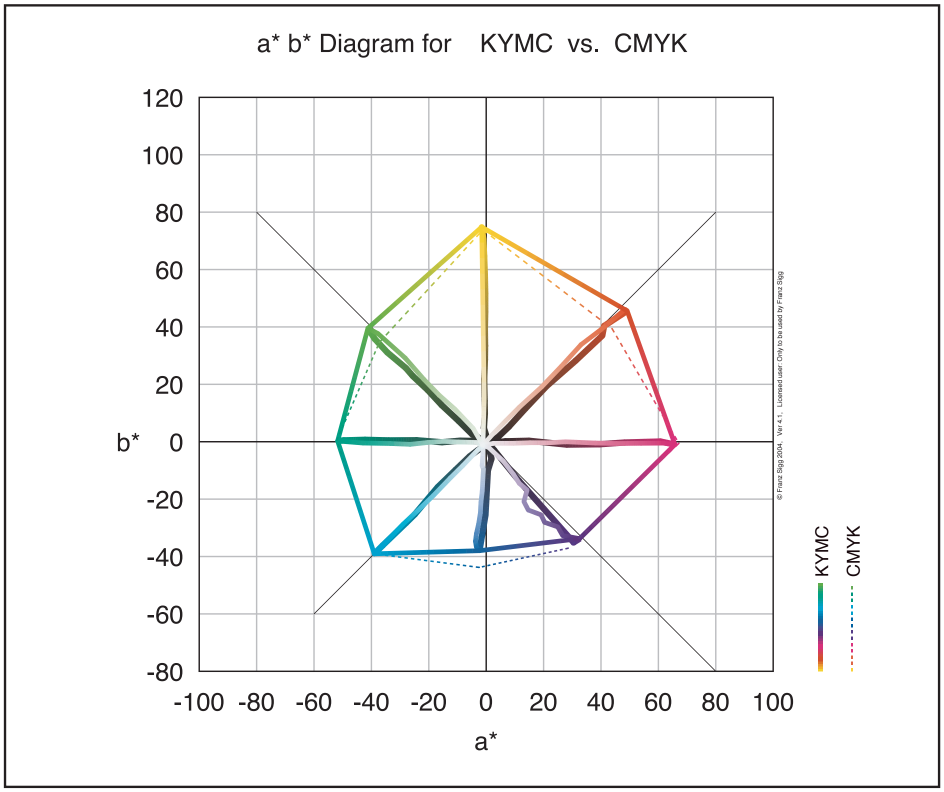












CIELab for special patches

Patch		KYMC L*	KYMC a*	KYMC b*	CMYK L*	CMYK a*	CMYK b*
Paper		92.41	-1.26	-1.02	94.56	-0.99	-1.23
400%	solid	10.62	3.89	-1.15	11.3	-2.61	-5.54
K	solid	20.6	0.99	2.31	20.1	1.2	2.06
C	solid	59.14	-36.43	-47.37	58.94	-35.55	-47.3
C+Y	solid	52.39	-64.3	21.67	52.16	-60.99	20.38
Y	solid	90.12	-7.82	82.05	91.09	-7.71	83.5
M+Y	solid	46.84	65.69	40.21	49.71	63.99	38.32
M	solid	48.33	70.76	-6.79	49.48	70.11	-7.62
C+M	solid	23.62	19.8	-43.39	26.27	18.86	-44.52

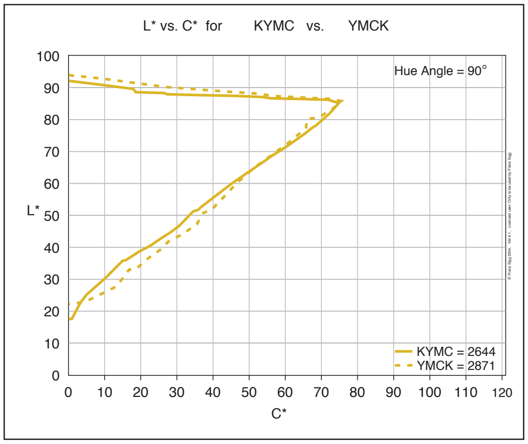
Gamut areas for the 8 L*C* slices:

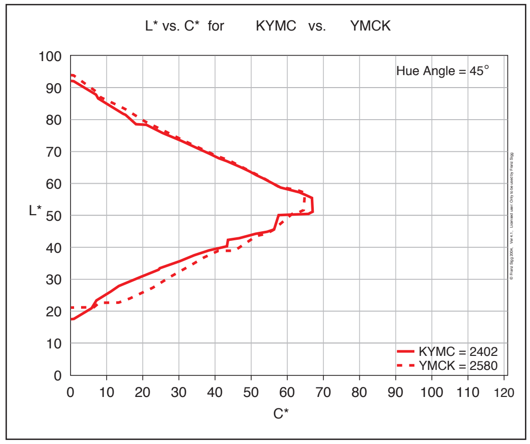
Color	Hue_Angle	KYMC Sample	CMYK Reference	Samp / Ref
Yellow	90	2644	2511	105%
Red	45	2402	2274	106%
Magenta	0	2383	2494	96 %
Purple	315	1718	1863	92 %
Blue	270	1501	1888	80 %
Cyan	225	1828	2117	86 %
Emerald	180	1672	1970	85 %
Green	135	2041	1812	113%
Total		16189	16929	96 %

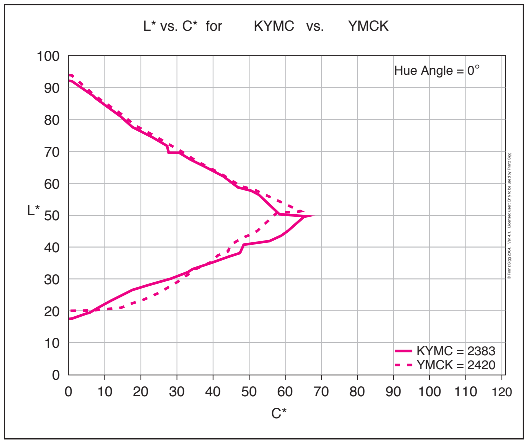
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only.
CIELab is not visually equidistant. The totals numbers are therfore to be used with great caution.
Real World colors are all the colors that might have to be reproduced as specified by ISO 12640-3.4 draft.

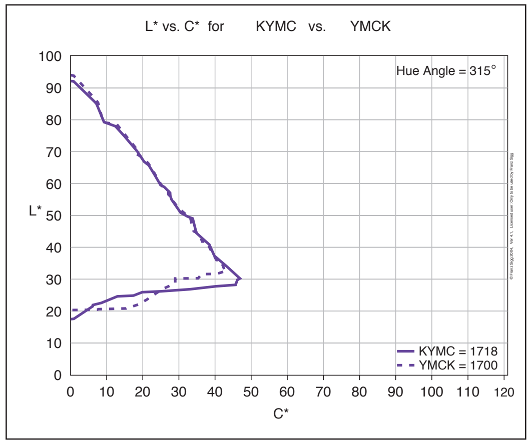
Flexo Ink Sequence, KYMC vs. YMCK

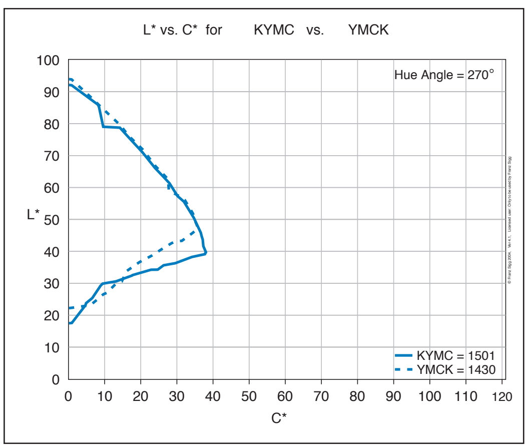
Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
Gamut comparisons in CIELab should therefore be limited to comparing same hue angles only. CIELab is not visually equidistant.

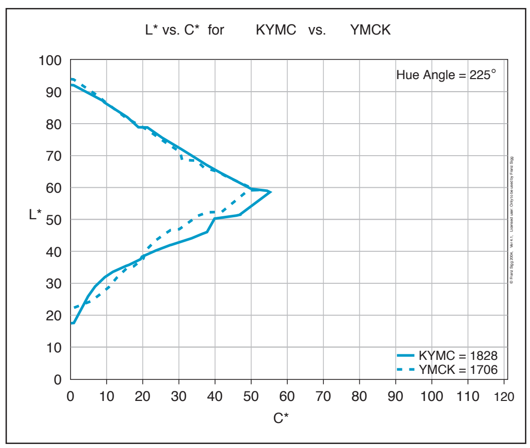


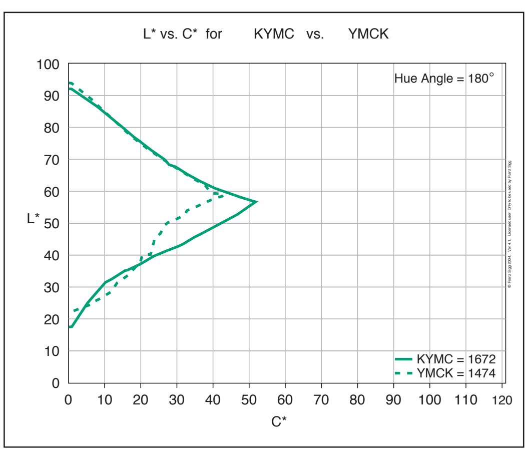


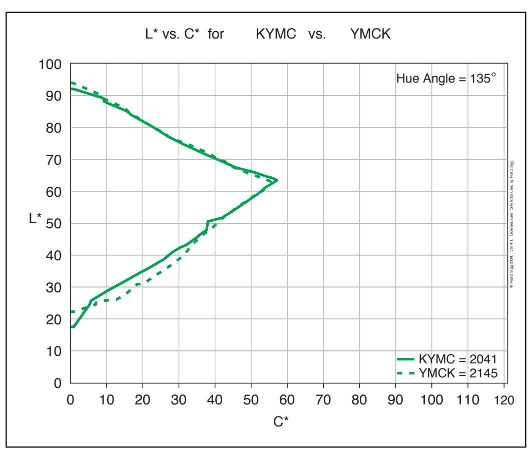


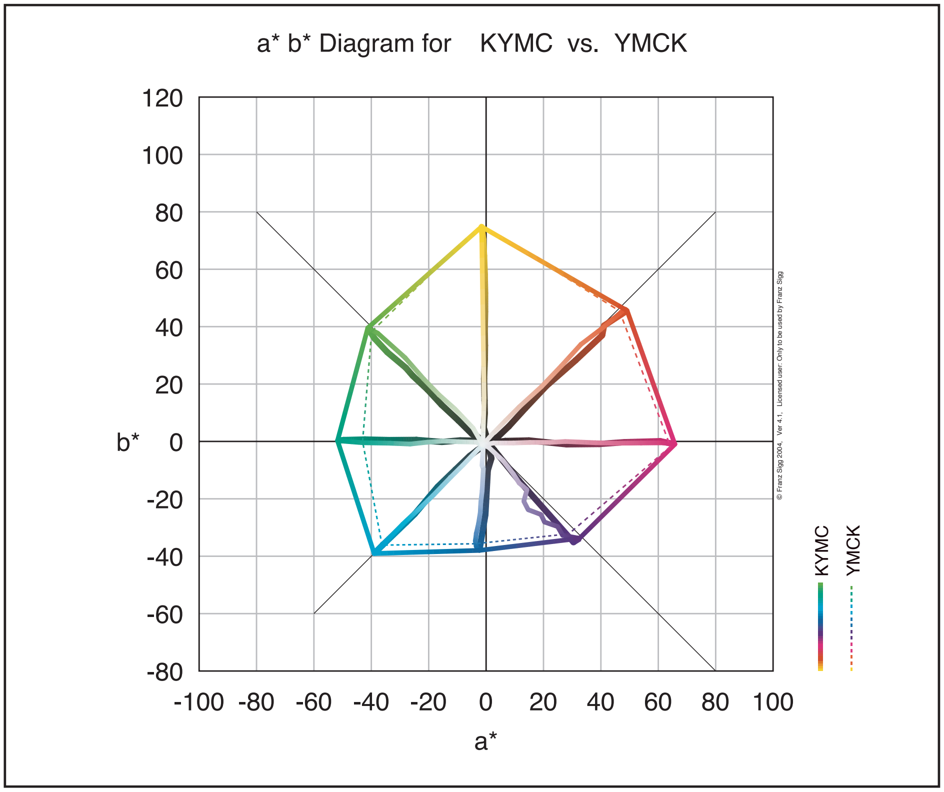












CIELab for special patches

Patch	KYMC L*	KYMC a*	KYMC b*	YMCK L*	YMCK a*	YMCK b*
Paper	92.41	-1.26	-1.02	94.45	-1.22	-1.42
400% solid	10.62	3.89	-1.15	16.6	-0.2	4.06
K solid	20.6	0.99	2.31	20.97	0.87	1.55
C solid	59.14	-36.43	-47.37	59.53	-32.75	-46.65
C+Y solid	52.39	-64.3	21.67	53.22	-58.78	24.44
Y solid	90.12	-7.82	82.05	90.82	-7.88	83.45
M+Y solid	46.84	65.69	40.21	49.34	62.2	41.53
M solid	48.33	70.76	-6.79	49.39	68.32	-4.59
C+M solid	23.62	19.8	-43.39	27.2	18.31	-38.41

Gamut areas for the 8 L*C* slices:

Color	Hue_Angle	KYMC Sample	YMCK Reference	Samp / Ref
Yellow	90	2644	2871	92 %
Red	45	2402	2580	93 %
Magenta	0	2383	2420	98 %
Purple	315	1718	1700	101%
Blue	270	1501	1430	105%
Cyan	225	1828	1706	107%
Emerald	180	1672	1474	113%
Green	135	2041	2145	95 %
Total		16189	16326	99 %

Note: It is well known that a step difference in yellow is visually less significant than a step difference in blue.
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