REPORT NO. PE-68-10

COPY #7

CONFIDENTIAL

E. I. DU PONT DE NEMOURS & COMPANY, INC.
FABRICS AND FINISHES DEPARTMENT
RESEARCH DIVISION
DIVISIONAL PROCESS ENGINEERING GROUP
COLOR OPERATIONS SECTION

C-3

CHARACTERIZATION OF COLORANTS FOR METALLIC FINISHES

By: W. S. Armstrong

Date Issued: December 1968

Project: 41-0029, Instrumental Color Technology

ABSTRACT

This report describes the development of a practical system for characterizing colorants for metallic products so that dual-angle color vectors can be

TABLE OF CONTENTS

I - SUMMARY

INTRODUCTION

Vector shading of metallic colors has been successfully carried out by C.O.S. for some four years by using dual-angle color measurements to account for the marked directional behavior of metallics. Unfortunately existing color theory did not cover the metallic field, so it was necessary to laboriously prepare and measure dual-angle vector panels for each colorant in a formula before it could be computer-shaded. This routine is time-consuming (requiring about one man-day per formula) and often inaccurate because of the weighing of very small quantities of colorant. Manual vector preparation then effectively limited instrumental shading to a few large volume products whose repetitive manufacture could justify the cost of vector preparation. To make routine instrumental shading of metallics practical it was necessary to develop a technique whereby reliable dual-angle vectors could be rapidly computed while retaining compatibility with the existing methods of measuring and shading.

The objective of this study was the development of technology and equipment necessary to rapidly predict dual-angle vectors for metallic colors from formula composition.

The bulk of the development work was carried out between October 1964 and June 1966.

RESULTS AND CONCLUSIONS

Over 30 colorants in each of two mill base lines (901 and 913) were characterized in metallic products using different techniques. These characterization data were then used to generate computed dual-angle color vectors on a variety of 867 and 945 line formulas covering a wide color range. Correlation of these computed vectors with manually derived ones is good with the final system. A comparison of computed and manual vectors is given in Appendices B, C and D.

The soundest overall approach was determined to be:

1. Characterize the colorants in aluminum at two separate illumination and viewing conditions approximating those used on the "Colormaster" equipped with an Angular Viewing Device.

2. Determine the statistical relationship between tristimulus readings developed from the dual-angle spectral curves and those on the "Colormaster."

3. Compute formula and vector tristimulus values (using characterization data from step 1) for the "Flat" case and convert to equivalent "Colormaster" tristimulus values (using relationships from step 2) before converting to ΔL, Δa, Δb.

4. Repeat step 3 for the "High Angle" case.

Actual plant shading experience on 945-line at Parlin using this approach with experimental characterization data showed that the computed vectors were equal to or better than manual vectors in required hits/batch.

The characterization and vector computer programs have been modified to handle the system outlined above and are fully operational.

CONTINUING WORK

Experience gained during the experimental work with the prototype Dual-Angle Reflectance Attachment has been utilized in the design and fabrication of an improved unit for permanent use. The improved unit is being used for the routine dual-angle characterization of all metallic lines. The 847, 867, 927, and 945 lines are shaded using computed vectors. (This system is being extended into the "Dulux" metallic lines and data will be available for essentially all metallic products within the next year.) Technical work is continuing on improving the absolute accuracy of characterization data.

The second phase of the metallic program will be to utilize the dual-angle characterization data in the computer formulation of metallic colors.

ACKNOWLEDGMENT

The Parlin Plant Laboratory greatly helped the 913-line characterization work by letting down all the required bases to 944-line single pigment quality.

PREPARED BY: W. S. Armstrong
W. S. ARMSTRONG

APPROVED BY: R. H. Vining
R. H. VINING

APPROVED BY: W. H. Edwards
W. H. EDWARDS

WSA:IL

II - DISCUSSION

BACKGROUND

Metallic colors have been successfully vector-shaded on a commercial basis by C.O.S. since August 1964 (Ref. 1). The technique that made metallic vector shading possible was the dual angle color difference measurement. For non-metallic (solid) colors the color difference between batch and standard is measured on the colorimeter at a single viewing angle normal to the panel surface. For metallic colors the color difference between batch and standard is measured at the normal (flat) angle and also at a fixed grazing angle (high-angle) to account for the highly directional effect of the metallic pigment. Therefore two sets of vectors, flat and high-angle, are required to shade a metallic color to match the standard at all angles.

The principal deterrent to generating metallic vectors via computer was the inability to predict the high angle effects. Flat vectors for metallic colors could be calculated with fair accuracy by characterizing the colorants in the same manner as solid colors, substituting aluminum in place of white as the reference colorant, but there was no established technology for calculating the high angle data.

References 4, 5, and 6 indicate there are no satisfactory solutions to the metallic color problems in the literature to date. In fact reference 6 makes the following statement in a preface: "There is no current theory whatsoever for the color of metalized paint films; any progress here represents a step into the unknown." The work described in this report was aimed at a practical solution to the problem by adapting existing theory to the metallic case rather than attempting to evolve a new theory.

One of the restrictions on the use of the Kubelka-Munk equation is that it assumes essentially perfect diffusion of light flux within the colorant layer. This has been interpreted to mean that the pigment particles must be randomly oriented and that therefore metallic flakes (which would tend to be mostly horizontal) would fall outside the scope of this equation (Ref. 3). Some limited experiments showed that the Kubelka-Munk equation seemed to work fairly well with simple metallic colors. Therefore it was logical to assume that the Kubelka-Munk equation would be adequate at least for vectors where we are interested in relatively small composition and color differences.

Two approaches were taken to the problem of high angle characterization. The first was to make the flat characterization as with solid colors and then calculate what hypothetical K and S values would be required for the aluminum to give the measured high angle effects. This method was tried first because it required no equipment modifications. The second approach was to characterize the colorants at two different viewing angles. This method required design and fabrication of a special viewing attachment for the spectrophotometer.

GENERAL METHOD OF CHARACTERIZATION

The following is a brief description of the mathematics involved to determine the color characterization data for a mill base.

Nomenclature used in the equations:

K = Absorption Coefficient
S = Scattering Coefficient
R = Reflectance at Complete Hiding
W = Weight Fraction of a Component in a Mixture
Subscript c - refers to colorant (base) being characterized
" r - refers to reference colorant
" n - refers to mixture n
" m - refers to mixture m

At complete hiding the Kubelka-Munk equation gives the relationship (Ref. 2, p. 389):

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \qquad (1).$$

The absorption coefficient (K) and the scattering coefficient (S) of a mixture are the weighted sums of the component coefficients. Therefore the K/S ratio of a mixture of a reference colorant and another colorant can be written:

$$\frac{K}{S} = \frac{W_r K_r + W_c K_c}{W_r S_r + W_c S_c} \qquad (2).$$

For a two-component mixture we can eliminate one of the weight fractions, since $W_r = 1-W_c$. If we have two mixtures of the two colorants we can use equation (2). to solve explicitly for K_c and S_c in terms of K_r and S_r. If W_n and W_m are the weight fractions of a colorant in two different mixtures with the reference, then the equations for S_c and K_c become:

$$S_c = \frac{[(1-W_n)/W_n) \quad (S_r\,[K/S]_n - K_r)] - [(1-W_m)/W_m) \quad (S_r\,[K/S]_m - K_r)]}{[K/S]_m - [K/S]_n} \qquad (3).$$

$$K_c = (1-W_m/\,W_m) \quad (S_r\,[K/S]_m - K_r) + S_c\,[K/S]_m \qquad (4).$$

If we make two different mixtures of a colorant and reference and measure their reflectances (R_n and R_m), we can calculate $[K/S]_n$ and $[K/S]_m$ from equation (1). Assuming we know K_r and S_r, we can then calculate S_c and K_c from equations (3) and (4).

R is a function of wavelength, so we may have a different value of K_c and S_c at each wavelength across the spectrum. We have found that it is sufficiently accurate to pick reflectances every 10 nanometers across the visible spectrum from 400 to 700 nanometers inclusive. This gives a total of 31 points at which S_c and K_c are calculated for each colorant.

The values K_r and S_r for the reference may be determined absolutely by methods outlined by Judd (Ref. 2.). However, all these methods are dependent upon the accuracy of film thickness measurements on thin films. If we are interested only in color, and not hiding power, we do not need the absolute values for K_r and S_r, as shown by Edwards and Vining in 1961.

If we assume values for S_r, the corresponding values of K_r are determined from the spectral curve of the reference and equation (1). The S_c and K_c values which we calculate for each colorant using equation (4) are then actually relative to the reference values. This is a mathematically sound approach so long as all the colorant K and S values used in a particular composition are relative to the same reference.

A white dispersion is used as reference for solid colors because white has a fairly uniform spectral curve which is markedly affected by any colorant which is added and because white is common to most formulas. The value of S_r for the white reference was assumed equal to 1.0 at all wavelengths.

Theoretically we could use any two compositions of colorant and reference to determine S_c and K_c, but there are several practical limitations to consider. Since equations (3) and (4) are dealing with differences between spectral curves (in terms of K/S) then accuracy is improved by making these differences as large as possible. Also we find that K_c and S_c values calculated from two different pairs of mixtures do not agree exactly. This disparity is probably due to the combined effects of experimental error in make-up and measuring and to limitations in the theory. To get good compromise values for K_c and S_c across the full composition range for solid colors, we standardized on three compositions 10/90 and 40/60 colorant/reference, and masstone (100%) colorant. S_c and K_c are calculated for the 10/90 - masstone pair and then from the 40/60 - masstone pair and averaged. The desirability of using masstone whenever possible was shown by Edwards and Vining in 1961 and demonstrated mathematically by Nickols and Orchard (Ref. 3.).

Because of the difference in dispersion and flocculation properties of different vehicle systems, individual pigments must be characterized as mill bases in each particular system where they are used. For example W-224 would be characterized separately as 42-224 for use in alkyds, as 901-224 for use in acrylic lacquers, etc. Once the K and S values for each dispersion required for a particular formula have been calculated, these data may then be used to compute the color vectors for the formula from its composition.

RELATIONSHIP OF FLAT AND HIGH-ANGLE COLOR MEASUREMENTS

The principal appearance difference between metallic and non-metallic colors is the effect of viewing angle. The appearance of metallics can change markedly with viewing angle, while most solid colors appear essentially unchanged at different angles. The constancy of a solid color with viewing angle can be explained, at least for a perfectly diffuse surface, by Lambert's law:

$$I_a = I_n \operatorname{Cos}(A)$$

where I_a = intensity of reflection at an angle A to the normal and I_n = intensity of reflection normal to the surface.

If we replace I_n by the tri-stimulus values G_n, R_n and B_n of the surface measured on the normal, we can write:

$$G_a = G_n \operatorname{Cos}(A)$$
$$R_a = R_n \operatorname{Cos}(A)$$
$$B_a = B_n \operatorname{Cos}(A)$$

Substituting in the cube-root equation for modified Adams coordinates and solving in terms of L_n, a_n and b_n we get:

$$L_a = (\operatorname{Cos}A)^{1/2} \quad (L_n) \quad - \quad (1-(\operatorname{Cos}A)^{1/2}) \quad (18.38)$$

$$a_a = (\operatorname{Cos}A)^{1/2} \quad (a_n)$$

$$b_a = (\operatorname{Cos}A)^{1/2} \quad (b_n)$$

If we can put any credence in the second term of the L equation, it indicates that L would be affected more by viewing angle than a or b. There will be a change in saturation with viewing angle, but since both a and b change proportionately, there will be no change in hue. The coordinates change slowly with viewing angle as can be seen by the following values of $(\operatorname{Cos}A)^{1/2}$.

Angle A	$(\operatorname{Cos}A)^{1/2}$
0°	1.0
45°	0.9
83°	0.5
89°	0.25

The diagram in Appendix A shows the illumination and viewing angles involved in the Angular Viewing Device for the "Colormaster" colorimeter. The 45°, 0° illuminating, viewing angles of the "flat" position are the same as those used for solid colors. The "high-angle" position is obtained by rotating the panel 70° about the center line of the illuminated area. Note that this changes both the illuminating and viewing angles, since they are measured from the normal to the panel. We can calculate what the "high-angle" reflectance of a Lambertian (perfect diffusing) surface should be in relation to its "flat" reflectance on this device. The change in illuminating angle will have no effect on the results as long as the photo cell "sees" the entire illuminated area in both cases. Therefore for the Lambertian surface:

$$G_h = G_f \operatorname{Cos}(70°) = 0.342\ G_f$$
$$R_h = R_f \operatorname{Cos}(70°) = 0.342\ R_f$$
$$B_h = B_f \operatorname{Cos}(70°) = 0.342\ B_f$$

Thus the ratio of the high-angle to flat tristimulus values should be 0.342 for a perfect diffuser on the Angular Viewing Device.

Table I below shows actual measured values of the high-angle/flat tri-stimulus ratios and the flat and high-angle L, a, b values for a series of solid colors. These panels were actually gloss enamels and therefore did not approach the perfect diffusing surface. However, we can see that the high-angle/flat tri-stimulus ratio is fairly constant from panel to panel and averages 0.376

for all readings. The ratios falling furthest from the average are for the black, dark blue, and dark green where extremely low reflectances had to be measured for the high-angle case. This deviation may be due to minor inaccuracies in these low reflectance measurements. These data indicate that the high-angle/flat reflectance ratio is constant for solid color panels of the same gloss level regardless of hue or saturation.

The last column in Table I marked "Hue Angle" is arctan (b/a) expressed in degrees with the +a axis taken as zero degrees. For example, a pure red would have a hue angle of 0°, a pure yellow 90°, a pure green 180°, etc. If we ignore the first four panels, which are achromatic, we see that for solid color panels with significant saturation the hue angle is independent of viewing angle, which is what was predicted for the perfect diffusing surface.

Table II shows the same measurements made on a series of metallic panels, most of them current automotive colors. We see that for the metallic panels the high-angle/flat ratios are much lower and more variable than the solid panel ratios. The average variation in flat to high-angle hue angle is six times as great for the metallic colors as for the solid colors. There is also a much larger variation among the metallic colors. The Copper shows a shift of only 0.1° from flat to high-angle hue, but the Bright Blue shifts 24.8° with the other colors falling between these two extremes.

These results, tabulated on the next two pages, show that there is no simple geometrical relationship between flat and high-angle reflectance for metallic colors as there is for solid colors. In fact the relationship appears to be composition dependent. This means that the high-angle reflectance cannot be calculated from the flat data for metallic colors, and that some new technology would be required to predict the high-angle behavior of a metallic composition.

Two separate approaches were taken to the high-angle problem. The first was to find some property of the aluminum flake alone which would account for the angular effects of all metallic colors. The second was to treat the flat and high-angle properties of a colorant mixture as two separate mixtures. The investigations were done in the chronological order given here because the first could be started with existing instrumentation, while the second required instrument design modifications.

TABLE I

COLOR	VIEW ANGLE	G	R	B	G_h/G_f	R_h/R_f	B_h/B_f	L	a	b	HUE ANGLE (°)
White	Flat High	89.32 36.00	90.44 35.92	88.09 35.31	.403	.397	.401	94.67 65.13	+1.15 -0.66	+0.87 +0.90	37.1 126.3
Light Gray	Flat High	43.29 16.78	43.12 16.49	45.30 17.46	.388	.382	.385	70.42 46.37	+0.76 -0.52	-2.27 -1.44	288.5 250.1
Med. Gray	Flat High	18.39 7.26	18.17 7.06	19.43 7.81	.395	.389	.402	48.37 30.59	+0.16 -0.47	-2.07 -2.02	274.4 256.9
Black	Flat High	0.35 0.09	0.34 0.12	0.40 0.13	.257	.353	.325	-0.55 -7.05	+0.14 +5.07	-1.36 -2.47	275.9 334.0
Lt. Blue	Flat High	33.58 13.13	22.00 8.57	71.07 28.11	.391	.390	.396	63.21 41.28	-6.10 -4.21	-38.78 -28.85	261.1 261.7
Med. Blue	Flat High	14.15 5.58	6.28 2.44	48.49 18.74	.394	.389	.386	42.79 26.48	+3.41 +1.34	-51.99 -37.36	273.8 272.1
Dk. Blue	Flat High	0.43 0.12	0.51 0.14	1.78 0.66	.279	.275	.371	0.71 -5.91	+16.90 +13.95	-19.36 -15.98	311.0 311.0
Lt. Green	Flat High	48.98 19.27	32.90 12.75	56.09 22.03	.393	.388	.393	74.15 49.42	-32.91 -25.07	-7.16 -5.18	192.4 191.9
Med. Green	Flat High	26.39 10.35	12.58 4.94	30.79 11.95	.392	.393	.388	56.91 36.73	-47.25 -34.80	-6.65 -4.53	188.0 187.4
Dk. Green	Flat High	0.69 0.22	0.41 0.13	1.39 0.51	.319	.317	.367	3.98 -3.11	-3.97 -1.39	-9.84 -8.27	248.0 260.5
Pale Yellow	Flat High	77.50 30.99	90.83 36.02	25.73 10.11	.400	.397	.393	89.44 61.05	+0.60 -0.55	+55.52 +41.44	89.4 90.8
Med. Yellow	Flat High	68.94 27.38	88.03 34.88	8.30 3.37	.397	.396	.406	85.32 57.84	+6.50 +4.59	+87.80 +64.13	85.8 85.9
Pink	Flat High	47.01 18.25	64.17 24.88	53.51 20.74	.388	.388	.388	72.89 48.20	+37.06 +26.90	-6.74 -4.86	349.7 349.7
Red	Flat High	4.47 1.75	10.52 4.14	0.96 0.35	.391	.394	.365	23.28 12.10	+42.63 +31.37	+27.98 +21.18	33.4 33.8

DUP030002693

TABLE II

COLOR	VIEW ANGLE	G	R	B	G_h/G_f	R_h/R_f	B_h/B_f	L	a	b	HUE ANGLE (°)
0100	Flat	34.89	35.01	37.26	0.156	0.151	0.154	64.26	+1.87	-3.06	328.6
	High	5.45	5.27	5.72				26.13	-1.03	-1.21	229.6
105	Flat	31.71	31.80	34.10	0.161	0.157	0.159	61.67	+1.93	-3.29	295.5
	High	5.12	4.99	5.39				25.28	-0.60	-1.26	244.5
99206	Flat	7.69	9.62	4.15	0.142	0.141	0.154	31.54	+7.32	+15.53	64.8
	High	1.09	1.36	0.64				7.65	+4.05	+7.09	60.3
97635 Gray	Flat	9.54	9.31	10.80	0.122	0.122	0.127	35.26	+0.53	-3.79	278.0
	High	1.17	1.14	1.39				8.27	+0.63	-2.64	283.4
99313 Copper	Flat	8.87	15.61	2.71	0.209	0.220	0.173	33.97	+30.01	+28.61	43.6
	High	1.85	3.43	0.47				12.67	+19.95	+19.06	43.7
99020 Verdure Green	Flat	6.55	6.80	3.23	0.136	0.140	0.158	28.94	-4.80	+16.63	106.1
	High	0.89	0.95	0.51				5.95	-1.08	+6.90	98.9
99073 Bright Blue	Flat	8.48	4.29	21.11	0.126	0.142	0.170	33.19	-7.26	-30.68	256.7
	High	1.07	0.61	3.58				7.49	+4.35	-21.46	281.5
98931 Med. Green	Flat	22.03	19.39	20.21	0.158	0.145	0.159	52.52	-11.58	+3.36	163.8
	High	3.49	2.82	3.21				19.98	-9.66	+1.77	169.6
98879 Turquoise	Flat	13.00	8.84	19.61	0.134	0.126	0.160	41.49	-13.54	-14.62	227.2
	High	1.74	1.11	3.13				12.04	-5.78	-11.01	242.3
98843 Blue	Flat	18.90	14.83	29.92	0.147	0.133	0.175	48.99	-5.34	-18.66	254.0
	High	2.77	1.97	5.25				17.14	-2.63	-14.12	259.5
98847 Ivory Gold	Flat	31.57	33.14	22.45	0.139	0.134	0.118	61.55	-2.02	+14.37	98.0
	High	4.40	4.46	2.64				23.06	-4.10	+10.86	110.7

DIRECTIONAL SCATTERING OF ALUMINUM METHOD

Since the only difference between solid and metallic colors is the aluminum, it seems reasonable to assume that the variation in the high angle reflectance of the metallics described above could be accounted for by some property of the aluminum alone. We evaluated the hypothesis that the aluminum flakes would have different effective scattering coefficients at different angles and that the dual angle effects of metallic colors could be calculated by merely using one set of aluminum scattering coefficients for the flat case and a different set for the high-angle case.

Characterization data were calculated on a series of 901-line colorants to test out this hypothesis. The characterization for the flat case was handled the same as solid colors except aluminum was used as the reference with an assumed S = 1.0 at all wavelengths. The characterization panels were then measured on the Dual Angle "Colormaster" and the high-angle/flat reflectance ratio calculated for each one. The flat K and S data were then used on the Model II Color Formulating Computer (Ref. 7.) to determine what the quasi high-angle S value for aluminum would have to be to yield the measured high-angle/flat reflectance ratio for each characterization panel.

The Color Formulating Computer has the capability of computing spectral curves and tristimulus values for any composition of up to six colorants. Each of the six input stations accepts the 31 pairs of K and S values for an individual colorant. A concentration dial connected to each input station makes it possible to independently vary the concentration of any colorant in the mixture. The technique used on the computer was to enter the colorant K and S data in the normal manner, but to enter the aluminum K and the aluminum S values as two separate colorants on different input stations. This made it possible to vary the effective S value of the aluminum independently. The concentration dials were initially set to the composition of the panel being analyzed and the flat G, R, and B values were determined on the computer. Then the concentration dial for the aluminum S values was adjusted until the largest of the tristimulus values was equal to its flat value multiplied by the measured high/flat ratio for that panel.

For example, for the 10/90 868-750/867-100 panel the largest tristimulus reading was B, which had a measured high/flat ratio of 0.125 on the "Colormaster." The concentration dial for 868-750 was set at 10, the 867-100 K and the 867-100 S concentration dials were both set at 90 on the Color Formulating Computer, and the computed B value of 40.1 was recorded. Next the 867-100 S dial was decreased until the computer B value was equal to 0.125 x 40.1 or 5.01. At this point the S concentration (3.97 in this case) was recorded. The high-angle quasi S of aluminum can then be calculated: (3.97/90) x 1.0 = 0.0441.

The high-angle aluminum S value calculated for 867-100 alone was 0.0434 and the average of the values calculated from all 20 characterization panels was 0.0433. The 10% colorant panels averaged .0439 and the 40% colorant panels averaged .0426.

Vectors were calculated for nine 1965 - 867-line products and compared with the manually prepared vectors for these products. The results are tabulated in Appendix B. The majority of the computed vectors compared fairly well with the manual ones. Dark saturated colors such as 867-97213 (Maroon) and 867-97224 (Dark Green) showed the poorest correlation between computed and manual results. Suitable K and S data were not available for white at the time.

Three pigments: W-458, W-652 and W-855 showed the largest high angle deviations.

One weakness of the directional S approach was that the quasi high-angle S value had to be a compromise figure. The three high/flat tristimulus ratios for a panel were not equal, so one had to be selected to calculate the S value. The S value chosen would not give the correct high/flat ratio for the other two tristimulus values. This difference is small for unsaturated colors, but can be quite significant as saturation is increased. A possible cause stems from the lumping of two effects into the high angle S value, the normal lowering of reflectance at a grazing angle (which would be experienced even with solid colors) and the additional lowering of reflectance at the grazing angle due to the directional effect of the aluminum alone. It might be possible to improve the range and accuracy of this method by handling the two effects separately.

Further work along these lines was stopped at this point because the prototype dual-angle reflectance head for the spectrophotometer was completed. We decided to evaluate it and pursue the more basic two-angle characterization approach because it was less speculative in nature.

DUAL-ANGLE CHARACTERIZATION METHOD

The most direct approach to the dual angle vector problem is to characterize all the necessary colorants in aluminum at the same two sets of illumination and viewing conditions that are used on the Colorimeter Angular Viewing Device. The flat and high-angle colors can then be treated as two separate entities, eliminating the need to find any mathematical relationship between them.

The standard spectrophotometer reflectance attachment utilizes an integrating sphere to collect the reflected light coming off the panel in all directions, whereas the colorimeter measures the light reflected at essentially one angle only. There is no commercially available equipment which could satisfactorily match the colorimeter illumination and viewing conditions on the spectrophotometer, so a special unit had to be designed and built. This initial unit was built as an experimental prototype to determine the feasibility of such a system and replaces the standard integrating sphere reflectance attachment on the Bausch & Lomb Spectronic 505 spectrophotometer. The Dual Angle Reflectance Attachment duplicated as well as possible the illuminating-viewing geometry of the colorimeter equipped with the Angular Viewing Device. (See Appendix A.) Exact duplication could not be attained because the spectrophotometer uses a single phototube to view both reference and sample while the colorimeter uses two separate phototubes. The reference and sample in the spectral Dual Angle Reflectance attachment are situated so that they are illuminated with 45° incident light as in the colorimeter. The phototube is located at the intersection of the normals to the reference and sample (flat position) and the axis of the tube is along the bisector of the angle between the normals. We can say that the geometry of the two instruments is similar although not congruent.

Some difficulties encountered during the Directional Scattering work indicated that the standard 10/90 - 40/60 masstone mixtures used for solid colors in white were not adequate for metallic characterization. One of the problems was that the 10/90 reflectance curve was often so close to the aluminum curve

DUP030002696

that slight measuring errors caused the equations to yield negative values for S. In some cases with the very transparent pigments it was almost impossible to get complete hiding with the masstone and still have a usable panel. There was also some evidence, that since true masstone was never reached in metallics, using masstone data could distort the results. A new set of standard concentrations was used: 20/80, 50/50, 80/20, and 98/2 color/aluminum. Only three of these were used for any particular colorant, but the selection of which three to use depended on the properties of the particular colorant. Masstones were also used where they could be attained with a reasonable number of coats and where there was a good chance the colorant would be used in saturated colors approaching the masstone of the colorant. The digital computer characterization program was modified to make it completely general so it could handle any concentration. All panels used were half black and half white primed so that hiding could be checked instrumentally on the spectrophotometer.

Two colorants, N-124 and W-630, showed anomalous behavior in aluminum and are discussed in a separate section. All other colorants characterized behaved normally in the flat position. In the high angle position many of the reds and yellows showed reflectances higher than the aluminum in the region of their dominant wavelength. This is no problem as long as the data are consistent; i.e., the reflectance curve for a mixture of two colorants should fall between the curves of the two colorants themselves. It can be shown mathematically (Appendix E) that if the spectral curves of two colorants intersect, the curves for all mixtures of the two must intersect at the same point. In most cases due to small measuring errors the spectral curves did not all intersect at a common point, so minor adjustments had to be made to make the data consistent.

Figure I shows flat and high angle curves typical of blue and green organic pigments. Increasing the colorant concentration lowers all points on the spectral curve of the mixture. Figure II shows typical behavior of reds and yellows which have higher reflectance than aluminum in their dominant region in the high-angle position but not in the flat.

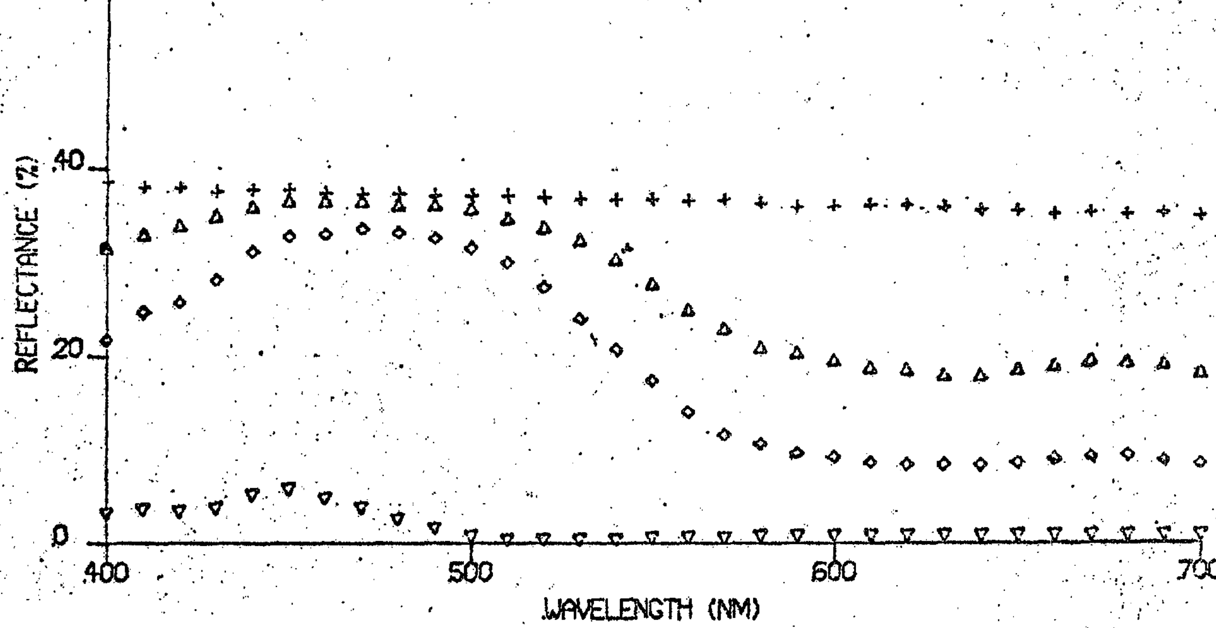
CORRELATION WITH COLORIMETERS

During the early stages of characterization work we found that there was a marked offset between the spectral curve of a panel run on the standard integrating sphere reflectance attachment and the curve of the same panel run on the Dual Angle Reflectance Attachment in the flat position. There had been fairly good correlation between colorimeter readings and standard spectrophotometer readings (using the integrating sphere) on solid colors. A reasonably good correlation between the two instruments is necessary for accurate color work. A statistical correlation was made between the spectral curves of all panels run on the Dual Angle Reflectance Attachment and these same panels measured on the Dual Angle "Colormaster" colorimeter. A linear correlation was computed with the following results:

$$\text{Colorimeter Value} = \alpha + (\beta)(\text{Spectral Value})$$

	α	β	Correlation Coeff.
Flat	-0.02	1.11	.98
High Angle	+0.40	0.591	.97

DUP030002697



HIGH-ANGLE VIEWING

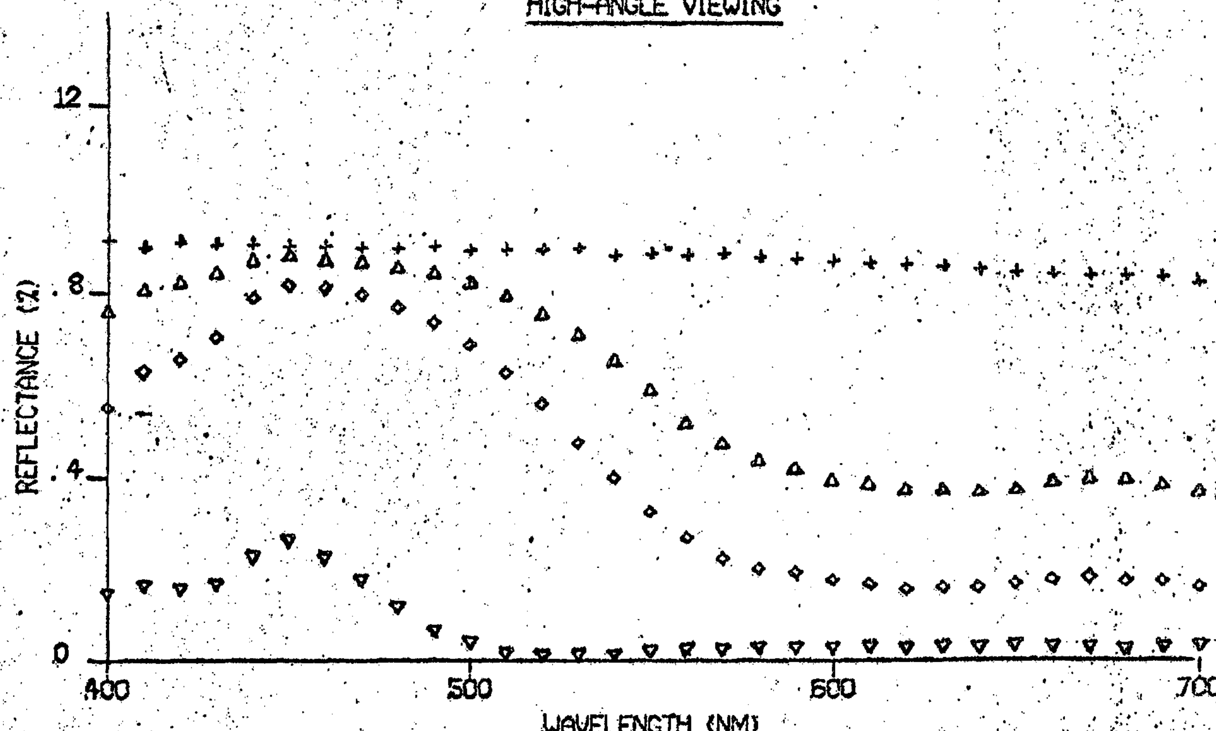
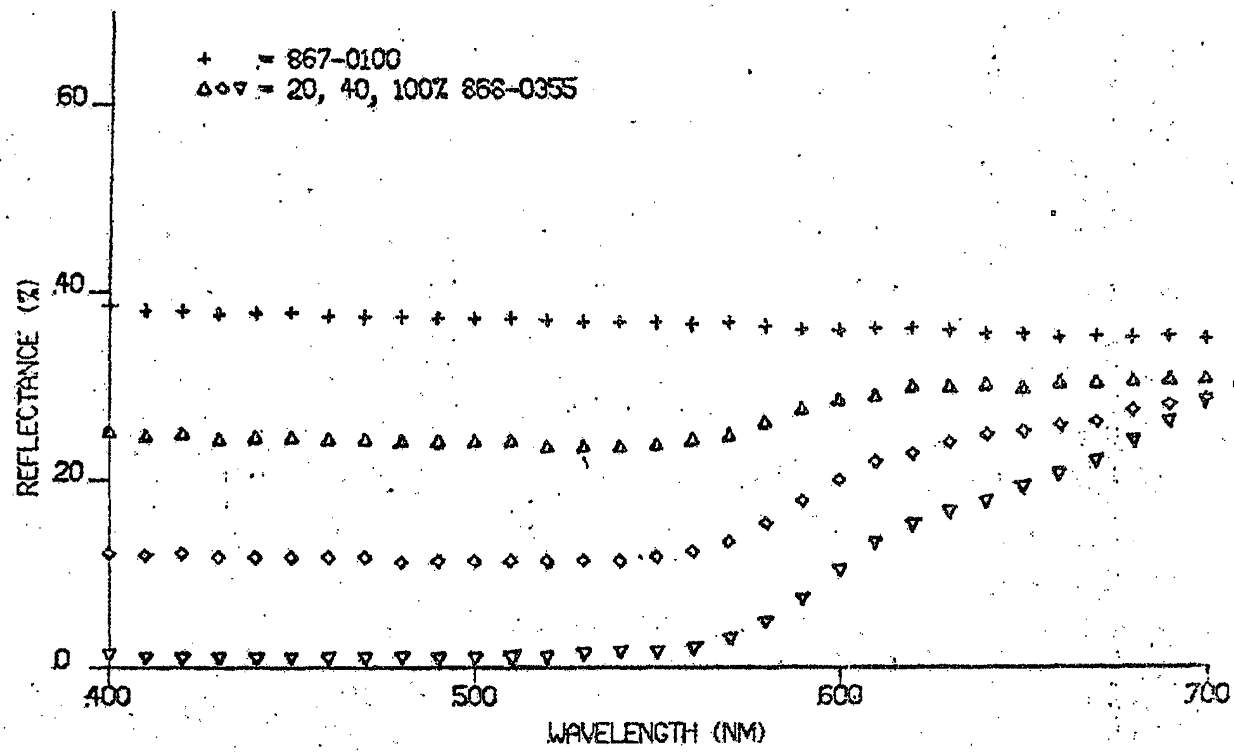
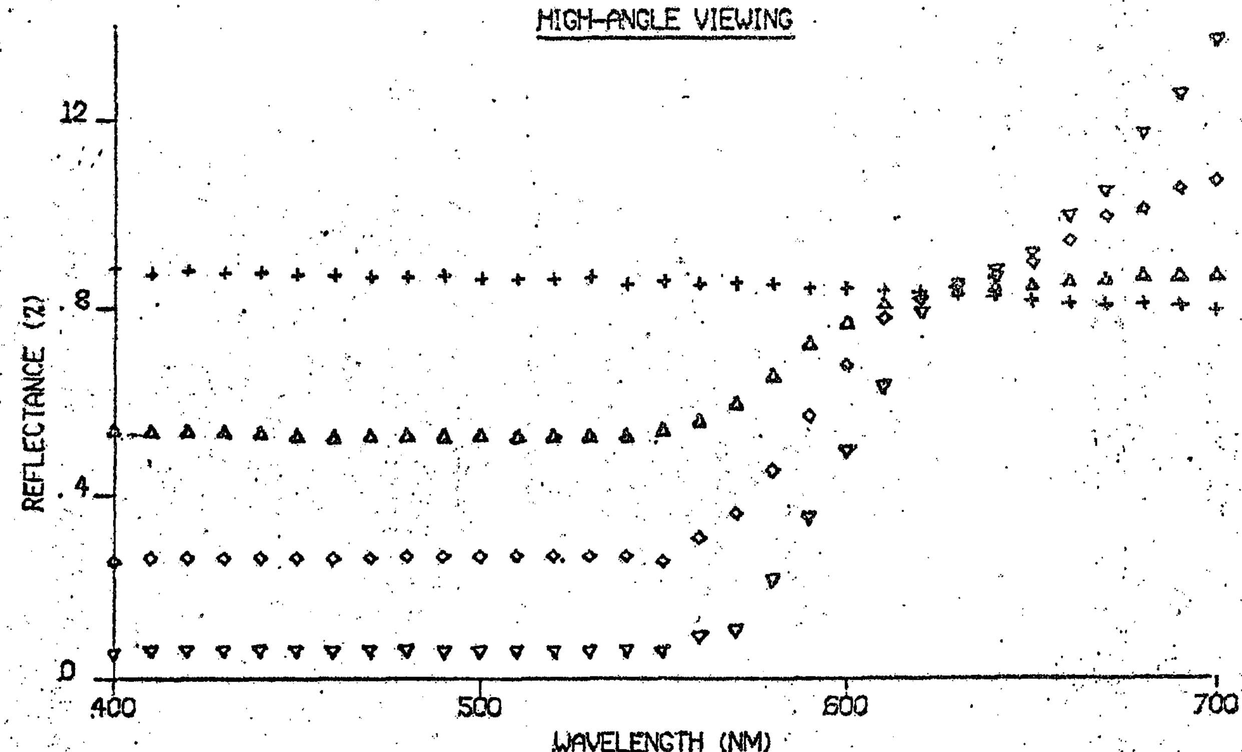


FIGURE II
IRON OXIDE RED METALLIC MIXTURES

NORMAL VIEWING



HIGH-ANGLE VIEWING



The correlation constants were then used to adjust each point on the Dual Angle spectral curves so that their computed tristimulus values would then coincide with the values measured on the colorimeter. Then the K and S values were computed for the colorants using the adjusted spectral curves.

This technique was used to characterize 39 - 901-line colorants and the results used to compute flat and high angle vectors for 26 - 867-line formulas. A comparison of the computed and manual vectors for these formulas is given in Appendix C.

The statistical correlation mentioned above was a composite of G, R, and B values and therefore gave a compromise adjustment of the reflectance curve across the entire spectrum. If G, R, and B values are correlated separately, there is a significant difference between the constants obtained. This indicated that it might be more accurate to make individual adjustments to the computed tristimulus values during the vector calculations than to use a bulked correction factor on the reflectance curves. This second technique was used in the dual-angle characterization of 36 - 913-line colorants. Reflectance curves for the metallic characterization panels were run on the Dual Angle Reflectance Attachment and a separate statistical correlation was made for G, R, and B between the spectral data and the colorimeter. K and S values were calculated for the colorants from the original reflectance data. The correlation constants for each tristimulus value were built into the vector program so that after the tristimulus values of a formula were computed, they were individually adjusted to coincide with the colorimeter data.

Vectors have been computed for approximately 125 - 945-line formulas using the 913-line metallic characterization data. A comparison of computed and manual vectors on those formulas which had manual vectors prepared is shown in Appendix D. In most cases where the computed vectors do not compare well with the manual ones, we know why. For the two silvers 97397 and 97786 the manual 913-1121 Flat ΔL movement is much larger than the computed. This is because the formula purposely loads light for these colors. If the vectors were computed on the final composition, the ΔL would be larger. The manual vectors for 97473, 97547, 97797 and 97814 show +ΔL Flat movements for white. White will darken metallic colors in this lightness range, which the computed vectors show. The computed data for 97788 is inaccurate because the characterization data for 913-2664 did not include masstone data and there is very little aluminum (0.52%) in this formula. The computed and manual vectors for 97805 do not compare well, but shading experience using the computed data has been good.

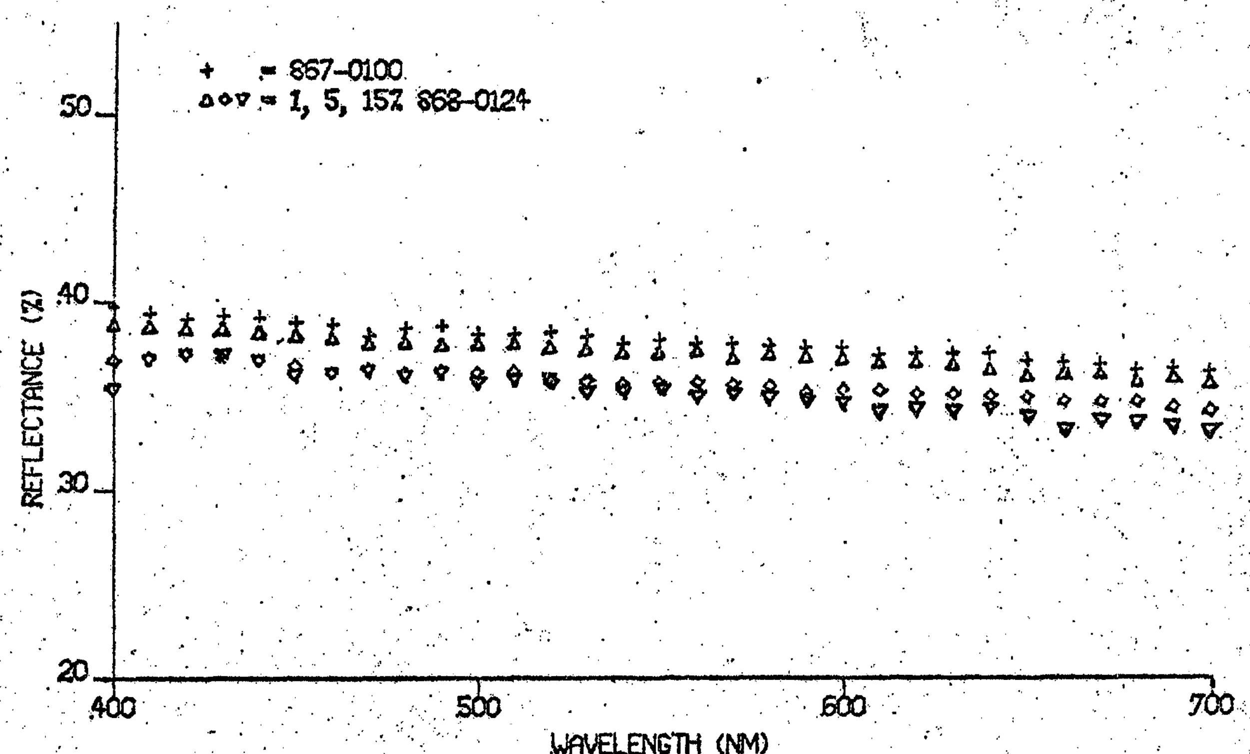
BEHAVIOR OF HIGH SCATTER PIGMENTS SUCH AS W-124 AND W-630

Certain pigments behave abnormally enough in metallics to make them extremely difficult to handle mathematically. Fortunately there are very few of these pigments which are used in metallic formulas. White and W-630 are two such pigments presently being used in metallic formulas which show extreme deviation.

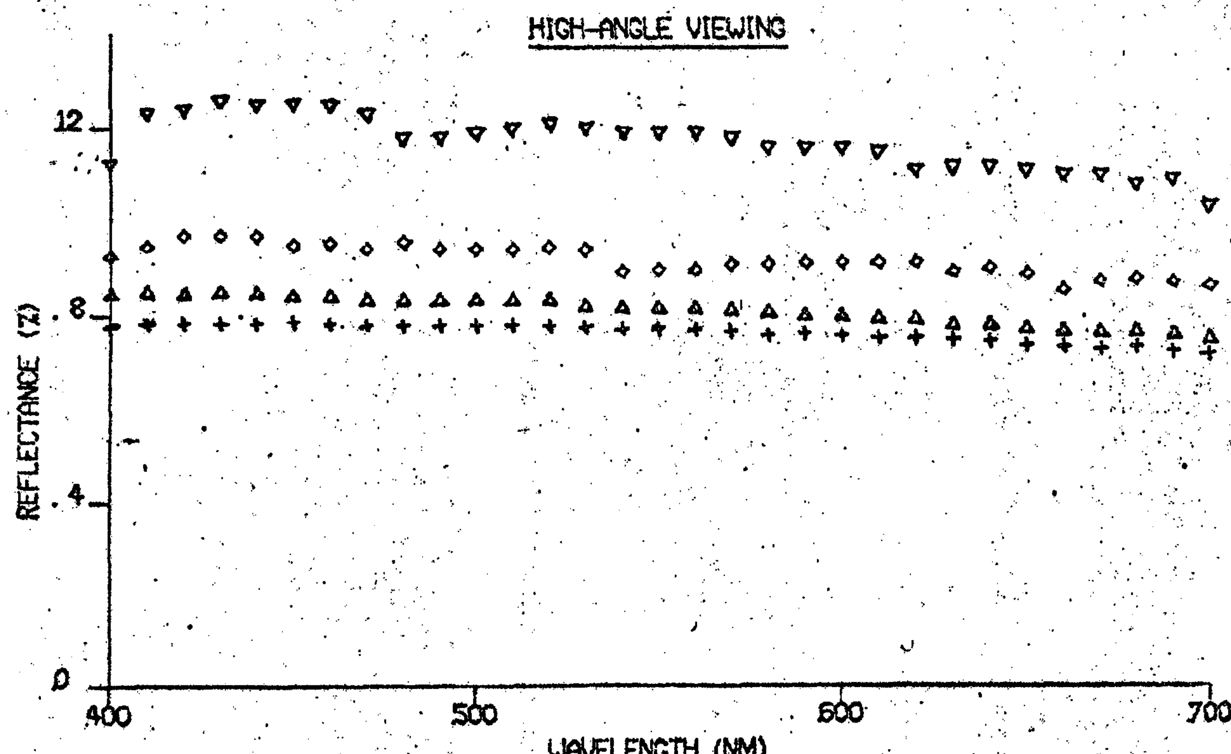
Figure III shows spectral curves of several white/aluminum mixtures in the flat and high angle positions. In the flat position the reflectance initially decreases as the white concentration increases, then the trend reverses and reflectance increases with increasing white concentration. In the high-angle position white in all proportions increases the reflectance. Figure IV shows reflectance versus white content at a single wavelength.

FIGURE III
WHITE METALLIC MIXTURES

NORMAL VIEWING



HIGH-ANGLE VIEWING



DUP030002701

FIGURE IV
EFFECT OF ADDING WHITE TO ALUMINUM
(WAVELENGTH = 550 NM)

NORMAL VIEWING

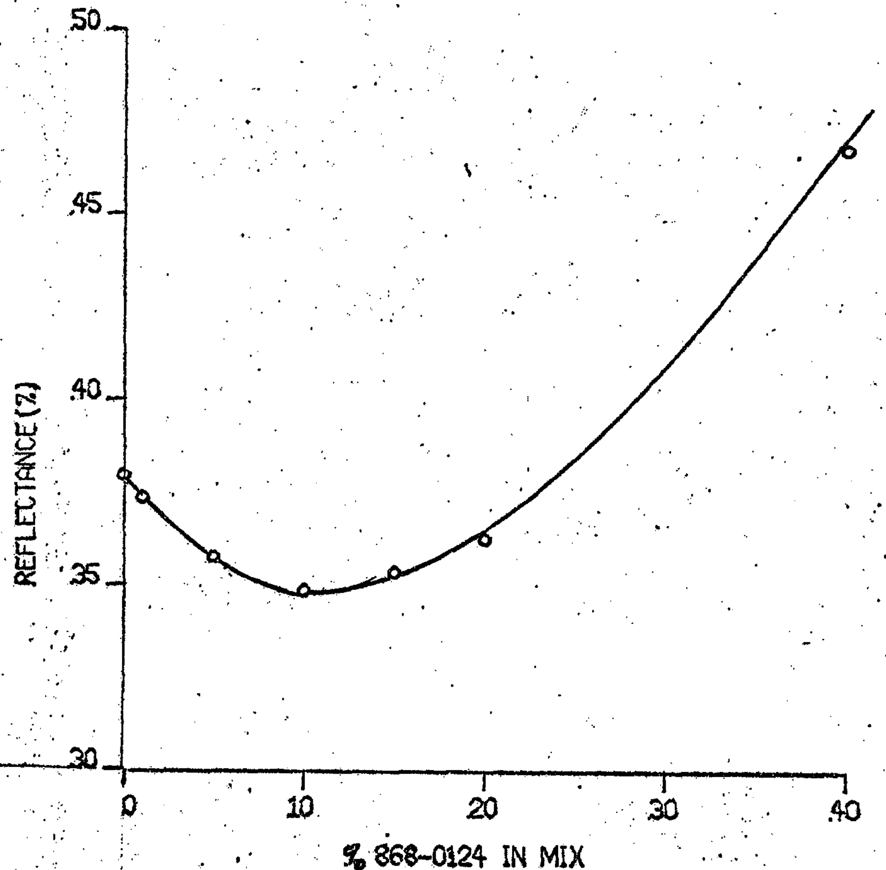
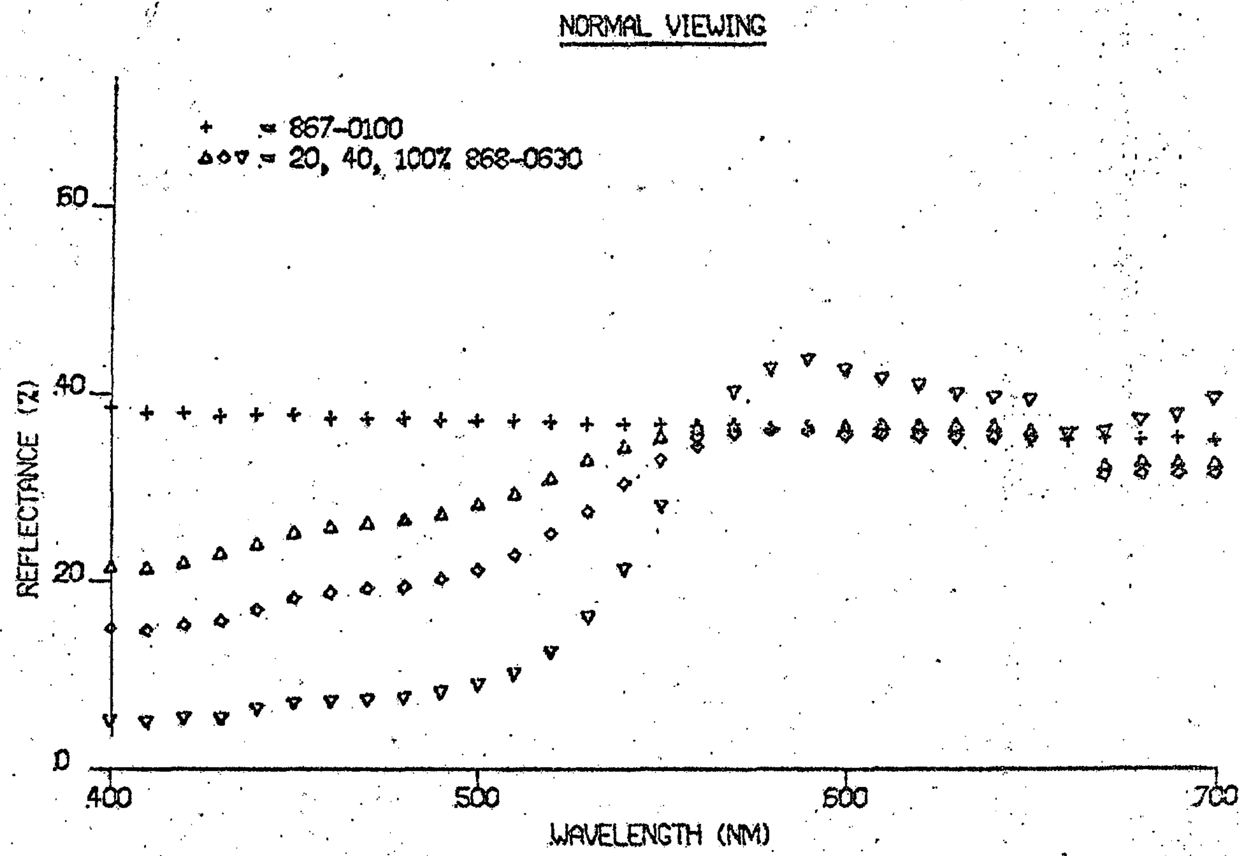
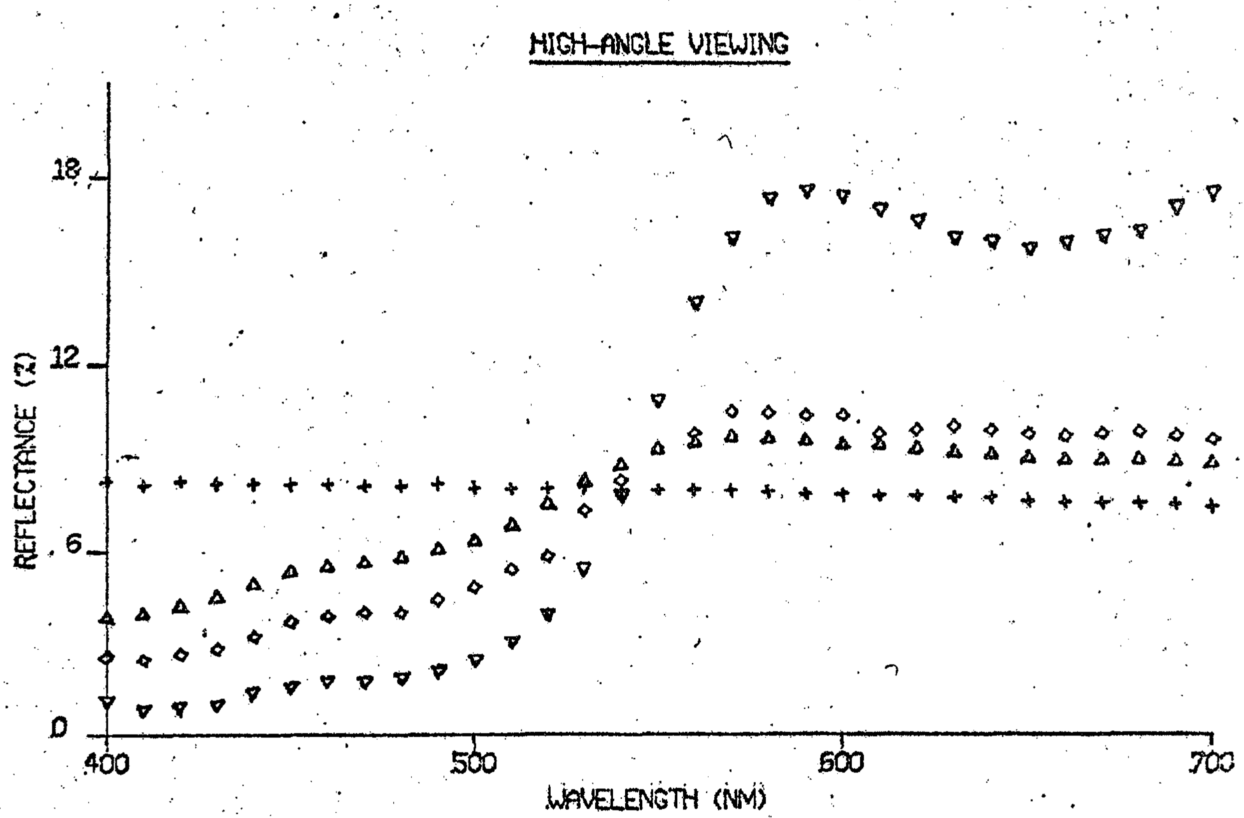


FIGURE V
FERRITE YELLOW METALLIC MIXTURES





This is a real phenomenon and not some quirk of a particular measuring instrument. The effect is quite obvious visually and on the "Colormaster" and a variety of spectrophotometers. The phenomenon can be explained, but cannot be handled mathematically by the Kubelka-Munk equation.

The formulating range for white in metallics is in the decreasing reflectance region. With higher concentrations the colors take on a milky look. This is fortunate in that we do not have to mathematically simulate the reversal of the reflectance trend line in our vector calculations. It appears then that we could calculate an effective set of K and S values for white from two sets of reflectance curves in the decreasing reflectance region. K and S values calculated this way gave good vector movements in the light colors, but very inaccurate ones in dark colors.

Examination of the manual vector data showed that the flat white vectors darkened colors with L values above 40 and lightened colors with L values below 30. The white behaved in the flat position as though it had a masstone with an L value somewhere between 30 and 40. For the 901-line characterization this quasi masstone reflectance curve was assumed parallel to the aluminum reflectance curve and having an L value of 35. These quasi-masstone data were then used to calculate K and S values for 901-124 in aluminum. White vectors computed using these data correlated much better with the manual ones.

When the 913-line bases were characterized another method was tried to determine the quasi masstone of the white. A series of mixtures composed of black and aluminum in the proper lightness range was prepared and a small amount of white added to each. When a point was reached where the white did not change the lightness (L = 32), this was taken as the quasi masstone of the white.

Figure V shows the spectral curves of several mixtures of 868-0630 and 867-0100. The curves are normal in the blue end of the spectrum, but behave abnormally in the red end. We would expect the mixture curves to fall between the two masstone curves, but the flat curves of all mixtures below 50% 868-0630 fall below both masstone curves. Fortunately we can get around this serious problem by characterizing W-630 at concentrations below 50% 868-0630 where we have psuedo-normal behavior. Any formula with higher than 50/50 868-0630/867-0100 ratio is closer to a solid color than to a metallic.

PRODUCTION SHADING EXPERIENCE WITH COMPUTED VECTORS

Shading performance at Parlin on the 945-line using computed dual-angle vectors has been good. Analysis of the data on 41 batches shaded by computed vectors and 48 batches shaded with manual vectors showed an average of 3.3 hits/batch using computed vectors and 3.6 hits/batch using manual vectors. On eight colors which were shaded by both manual and computed vectors, the computed data averaged 3.1 hits/batch while the manual vectors averaged 4.1 hits/batch. Therefore, the computed vectors appear to be slightly better than the manual ones.

Computed vectors were generated for all new 1967 model year 867-line colors starting in June 1966 and have been used for shading all of the 867 and 927 line products ever since that time. Overall shading performance on the automotive lacquers has been equal to or better than with the manually prepared vectors.

CONCLUSIONS

The relatively good comparison between the computed and manual vectors for most colors and the good production experience with the computed vectors indicate that the dual-angle characterization approach is sound. The prototype reflectance head was built to provide sufficient data to determine the feasibility of this technique and to determine what refinements would be necessary for a permanent working model. Experience gained with the prototype has been used in the design of a precisely fabricated working model. Characterization panels for all 901 and 913 line bases have been remeasured on the new model as have the majority of the 42-line and 330-line mill bases.

The spectral data punch system, K,S calculation program, and color vector calculation program have all been modified to handle the dual-angle characterization system.

The initial phase of the metallic characterization program has been completed. We now have a working system by which we can routinely characterize colorants in any line for the generation of shading vectors. The second phase, which has been started and will continue indefinitely, is the development of techniques to improve the accuracy of the characterization data. A third phase is the application of the dual-angle characterization data to pigment identification and color formulation. The Mark II Color Formulating Computer has been modified to accept two reference curves (flat and high-angle) for this purpose.

REFERENCES

1. Vining, R. H., Process Engineering Report PE-65-5, "Instrumental Shading of Metallics."

2. Judd, D. B. and Wyszecki, G., "Color in Business, Science, and Industry," 2d. Ed. 1963, Wiley.

3. Nickols, D. G. and Orchard, S. E., J. Opt. Soc. Am., 55, 162 (Feb. 1965).

4. Davidson, H. R., Color Engineering, 3, 22, (Jan.-Feb. 1965).

5. Davidson, H. R. and Hemmendinger, H., Color Engineering, 4, 13 (May-June 1966).

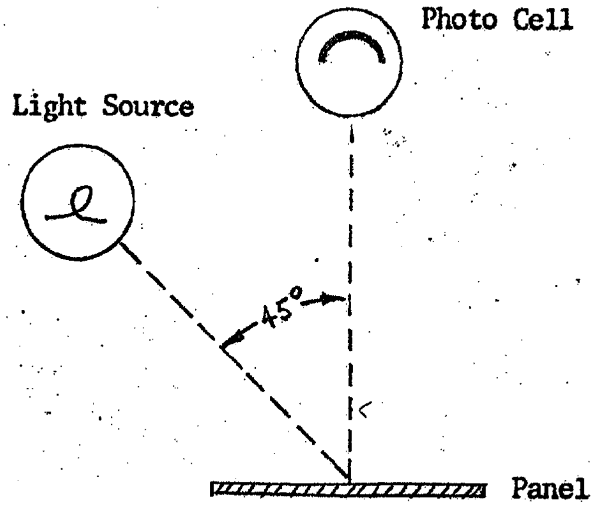
6. Billmeyer, et al., J. Paint Tech., 40, 143 (1968).

7. Faulhaber, M. E., Engineering Department Report EPL-65-7, "Mark II Colorant Formulation Computer Instruction Manual" (June 1965).

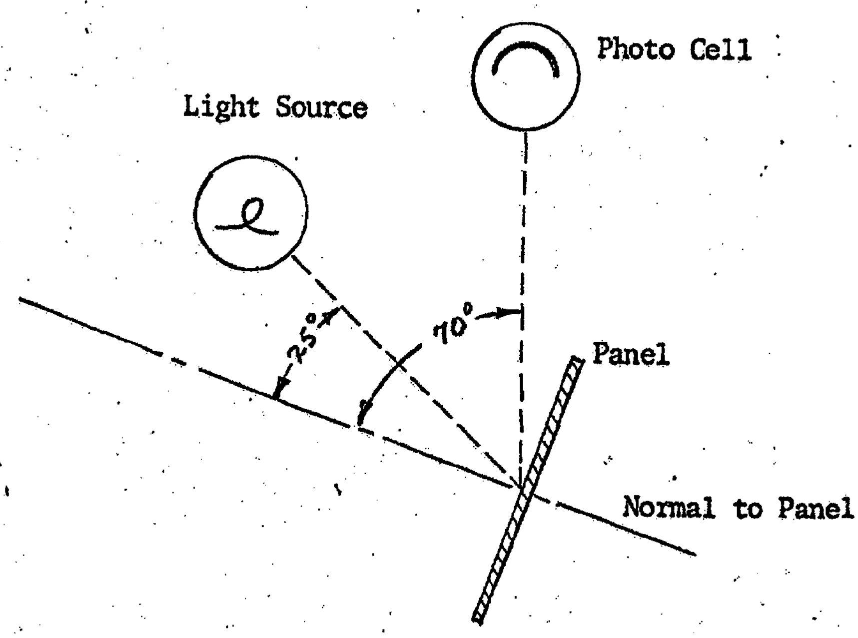
APPENDIX A

COLORIMETER VIEWING GEOMETRY

NORMAL VIEWING (45°,0°)



HIGH-ANGLE VIEWING (25°,70°)



APPENDIX B

COMPARISON OF 867-LINE COMPUTED AND MANUAL VECTORS

(Directional Scatter of Aluminum Method)

Manual vector movements are shown in red

Computed " " " " " blue

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97215	100	+2.86	-1.22	-1.50	+0.80	-0.75	-0.88
Saddle		+3.58	-1.52	-2.38	+0.30	-1.80	-1.37
	458	-1.19	+0.50	+1.71	-0.56	+0.59	+0.89
		-2.02	-.002	+2.01	-0.60	+0.03	+0.37
	855	-0.86	+1.10	+0.52	-0.10	+1.15	+0.66
		-1.12	+1.21	+0.12	+0.39	+1.29	+0.67
	253	-1.84	-1.23	-1.78	-1.57	-1.17	-1.62
		-3.31	-1.07	-1.49	-2.28	-1.70	-1.83
867-97216	105	+0.75	-0.24	-2.34	+1.03	-0.52	-1.10
Fawn		+1.26	-0.18	-2.95	+0.47	-0.74	-1.39
	100	+1.04	-0.14	-0.97	+0.72	-0.16	-0.47
		+2.23	-0.16	-2.36	+0.81	-0.61	-0.91
	458	-1.10	+0.17	+2.42	-0.40	-0.03	+1.38
		-1.95	+0.39	+2.70	-0.55	+0.86	+1.04
	253	-3.00	-0.83	-0.72	-1.44	-0.80	-0.82
		-4.30	-0.03	-0.83	-2.79	-0.35	-1.26
	855	-2.82	+2.53	+3.17	-0.14	+1.43	+2.62
		-2.13	+2.69	+0.56	+0.60	+3.44	+1.51
867-97217	105	+1.28	+2.31	+0.54	+1.50	+1.16	+0.49
Turquoise		+1.96	+3.03	-0.24	+0.70	+0.60	+0.43
	100	+1.27	+1.16	+0.24	+0.82	+0.58	+0.35
		+2.60	+2.36	-0.19	+0.85	+0.19	+0.35
	750	-1.32	-2.06	+0.45	-0.50	-0.89	+0.23
		-0.88	-1.29	+0.55	-0.21	-0.27	-0.01
	557	-1.80	-0.97	-1.86	-1.19	-0.15	-1.06
		-1.25	-0.52	-1.58	-0.53	+0.36	-0.94
	253	-1.69	+1.06	+0.62	-0.97	+1.29	+1.09
		-2.05	+1.66	+0.84	-1.29	+1.39	+0.71
867-97220	582	-2.83	-0.41	+3.02			
Dark Blue		-2.30	+1.46	+0.60	-0.33	+0.36	-1.07
	588	-0.40	+2.02	-0.34			
		+0.05	+1.80	-0.58	+0.78	+1.36	-1.48
	253	-0.32	-0.69	+1.74			
		-0.41	-0.50	+1.91	-0.11	-0.29	+0.88
	100	+0.86	-0.08	-1.12			
		+1.00	-0.44	-1.10	+0.05	-0.04	-0.08

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97221 Orchid	100	+3.43	-1.00	+0.06	+0.80	-0.63	+0.20
		+2.98	-1.43	+0.16	+0.80	-1.33	-0.56
	105	+2.52	-1.70	+0.32	+1.48	-1.06	+0.17
		+2.25	-1.79	+0.22	+0.59	-1.79	-0.62
	253	-1.37	-0.79	+0.63	-0.89	-0.67	+0.40
		-2.26	-1.20	+1.55	-1.41	-1.34	+0.94
	658	-1.66	+3.34	+2.86	-0.90	+1.95	+2.56
		-2.60	+4.16	+2.97	+1.45	+5.72	+3.40
	559	-2.00	+1.44	-2.56	-1.44	+0.70	-1.46
		-2.48	+1.38	-3.30	-1.20	+0.09	-1.57
867-97223 Light Green	105	+2.70	+0.94	-0.79	+1.78	+0.67	-0.17
		+3.80	+1.35	-1.07	+1.45	-0.17	+0.07
	750	-0.77	-2.37	-0.17	-0.57	-1.54	-0.29
		-1.08	-2.11	-0.20	-0.17	-0.51	-0.57
	253	-1.00	+0.46	+0.08	-0.70	+0.25	+0.11
		-1.97	+0.88	+0.07	-0.94	+0.46	+0.04
	458	-1.24	-0.10	+2.72	-0.10	-0.11	+1.65
		-1.03	+0.44	+1.91	-0.06	+0.48	+0.83
867-97224 Dark Green	750	-0.47	-1.33	+0.68	-0.18	-0.28	-0.58
		+0.13	-0.31	-0.98	+0.64	-0.12	-0.93
	253	-0.94	+1.91	-0.18	-0.39	+0.36	+0.15
		-0.57	+0.45	+0.03	-0.30	+0.14	+0.22
	105	+2.64	-1.63	+0.31	+0.52	-0.28	+0.01
		+3.39	-1.93	+1.07	+0.19	-0.12	+0.09
	612	+0.33	-1.55	+1.52	+0.26	-0.51	+0.44
		+2.37	-4.01	+3.69	+3.11	-5.23	+4.37

APPENDIX C

COMPARISON OF 867-LINE COMPUTED AND MANUAL VECTORS
(Dual Angle System)

Manual vector movements are shown in red.
Computed vector movements are shown in blue.

The cube root color coordinates measured from the standard panel and those computed by the vector program are shown at the bottom of the data for each formula.

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97211 Gunmetal	100	+1.65	+0.43	-0.50	+0.25	+0.06	-0.11
		+1.49	-0.64	-0.54	+0.57	-0.26	+0.02
	664	+0.16	-0.76	+1.10	+0.18	-0.42	+0.14
		+1.60	-0.43	+1.09	+0.49	1.45	+1.99
	6253	-0.75	+0.54	+0.74	-0.12	-0.50	+0.24
		-1.44	+0.78	+1.46	-0.19	+0.15	+0.56
	552	-1.45	-0.95	-2.10	-0.22	0	-0.55
		+1.77	+1.92	+0.97	-1.17	-1.01	-1.69
	588	-3.22	-0.70	-4.57	-0.42	+1.07	-2.26
		-3.16	+0.76	-3.55	-1.80	+1.39	-2.56
	COORD	24.16	+0.84	-5.79	15.38	+2.07	-2.20
		27.05	-2.27	-5.00	12.26	-2.06	-5.75
867-97212 Blue Gray	6551	-2.05	-1.46	-2.61	-0.77	-0.78	-1.49
		-2.69	-1.95	-2.84	-1.80	-2.02	-1.73
	1804	-2.26	+1.77	-0.60	-0.52	+1.39	-0.24
		-1.96	+2.64	-1.12	-1.22	+2.91	+0.40
	6253	-2.83	-0.69	+1.52	-0.74	-0.26	+1.17
		-2.83	+0.25	+1.85	-1.89	-2.39	+3.18
	105	+1.76	+0.89	+1.39	+1.40	+0.66	+0.86
		+1.73	+0.77	+1.81	+1.45	+0.83	+1.34
	124	-1.18	0	+0.74	+1.70	+0.61	-0.80
		-1.26	+0.24	+0.44	+2.63	+4.03	-0.84
	COORD	56.32	+0.44	-8.17	27.21	-0.26	-5.34
		58.53	-3.47	-7.30	26.00	-6.70	-9.73
867-97213 Maroon	4804	-0.62	+0.84	-0.55	-0.09	+0.72	-0.15
		+0.07	+0.45	-0.13	+0.28	-0.50	-0.06
	820	-1.23	-2.85	-1.46	-0.52	-1.76	-0.68
		-1.16	-0.98	-0.95	-0.88	-0.09	-0.65
	355	+2.76	+4.17	+2.59	+1.12	+3.01	+1.63
		+0.69	+1.08	+1.85	+0.62	+2.16	+0.86
	100	+1.10	+1.65	+0.22	+0.15	+0.24	-0.02
		+1.75	+0.36	-0.31	+0.22	+0.12	-0.20
	6253	-0.56	-1.87	-0.89	-0.27	-1.66	-0.55
		-0.23	-0.71	-0.26	-0.11	-0.32	-0.13
	124	+1.11	+1.72	+0.11	+0.75	+1.34	+0.15
	COORD	22.05	+17.81	+5.31	16.74	+9.32	+1.88
		22.25	+22.26	+5.05	17.07	+8.68	+3.86

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97215	100	+2.54	[illegible]	-1.59	+0.77	-0.54	[illegible]
Saddle		+3.50	-1.64	-2.59	+1.57	-1.45	-1.57
	458	-0.83	+0.64	+0.92	-0.60	[illegible]	+0.02
		-2.03	+0.86	+1.96	-0.91	+0.51	+0.60
	6253	-2.08	-1.45	-2.36	-1.12	-1.65	-1.51
		-2.44	0.42	-1.77	-1.53	-0.11	-1.41
	834	-1.02	+1.41	+0.02	-0.02	+0.82	+0.36
		-0.85	+0.98	-0.35	-0.50	+1.20	+0.62
	124	-0.20	+0.44	-0.61	+1.02	+0.98	[illegible]
		-1.06	-0.38	-1.30	+1.38	-0.55	+0.01
	COORD	52.44	+7.18	+17.08	27.39	+3.95	+8.98
		55.53	+3.54	+16.47	27.35	+3.18	+9.28
867-97216	855	-2.37	+2.50	+2.94	-0.42	+2.26	+1.76
Fawn		-3.49	+3.64	+2.14	-1.29	+2.21	+1.46
	6253	-2.00	-0.45	-0.75	-1.30	-0.34	-0.80
		-3.30	+0.15	-1.39	-2.38	-0.30	-1.54
	100	+1.06	+0.48	-0.94	+0.45	+0.47	-0.40
		+2.29	-0.36	-2.72	+1.12	+0.20	-1.71
	458	-0.86	+0.23	+2.03	-0.19	+0.29	+0.86
		-2.22	+0.83	+3.31	-1.20	+0.49	+1.46
	6750	-0.18	-1.15	-0.62	-0.40	-1.32	-0.52
		-0.38	-1.02	-0.25	-0.38	-0.94	-0.43
	105	+0.85	-0.04	-2.15	+0.65	+0.12	-0.85
		+0.85	-0.50	-3.93	+0.66	-0.75	-1.71
	COORD	58.54	+1.52	+8.81	28.76	-0.22	+4.79
		61.19	-0.67	+11.11	30.15	-1.56	+5.84
867-97217	6750	-1.34	-1.59	+0.40	0	-0.67	+0.09
Turquoise		-0.76	-1.61	+0.59	-0.46	-0.91	+0.37
	6253	-1.43	+1.20	+0.78	-0.79	+1.12	+0.42
		-1.63	+1.05	+0.47	-0.95	+0.41	+0.34
	6557	-1.85	-0.61	-1.60	-0.13	-0.19	-1.00
		-1.58	-1.16	-1.95	-0.94	-0.19	-1.38
	105	+1.10	+2.21	+0.55	+1.38	+0.86	+0.37
		+1.16	+3.20	+0.17	+0.64	+0.71	-0.06
	100	+1.08	+1.02	+0.26	+0.97	+0.23	+0.15
		+2.19	+2.26	+0.12	+1.51	+2.30	+0.35
	124	-1.42	-0.01	-0.60	+3.92	-2.60	-0.82
		-3.75	+2.97	-0.16	+4.44	+1.75	-0.64
	COORD	54.34	-11.32	-6.47	25.01	-5.69	-4.60
		59.07	-13.37	-3.09	27.34	-11.14	-4.18

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97218	6750	-0.98	-3.56	+1.80	-0.12	-0.43	+0.20
Dk. Turquoise		-1.24	-2.44	+2.43	-0.54	-1.86	+0.87
	6253	-1.02	+0.45	+1.40	-0.28	+0.46	+0.54
		-1.99	+1.62	+1.78	-0.34	+0.37	+1.01
	6551	-1.20	+0.67	-1.62	-0.20	+0.57	-0.61
		-2.08	+1.19	-1.96	-1.22	+1.00	-1.85
	124	+1.24	+0.82	-1.26	+1.93	-0.65	-1.89
		+0.59	+0.20	-0.26	+5.35	-2.05	-0.63
	100	+1.92	+0.20	-0.49	+0.44	-0.10	-0.33
		+3.10	-1.23	-0.48	+1.23	-0.44	+0.17
	COORD	28.17	-4.80	-8.49	16.52	+0.77	-4.20
		28.87	-5.93	-7.14	12.51	-2.89	-7.64
867-97219	6804	-1.96	+1.97	-0.31	-0.33	+1.24	+0.03
Lt. Blue		-2.27	+3.54	-0.90	-1.47	+3.13	+0.14
	6551	-1.80	-0.23	-1.58	-0.32	+0.07	-0.97
		-2.48	-1.04	-2.14	-1.49	-0.82	-1.37
	6253	-1.66	+0.06	+2.43	-0.74	-0.12	+1.92
		-2.08	+0.55	+2.09	-1.27	-0.79	+2.21
	100	+2.05	-0.19	+1.26	+1.06	-0.10	+0.57
		+3.80	+1.13	+2.45	+2.70	+1.92	+2.57
	124	-0.87	+0.39	-0.29	+1.79	-0.50	-1.38
		-1.99	+0.88	+1.46	+3.18	+2.10	-1.05
	COORD	57.85	-1.78	-14.10	25.29	-0.59	-9.16
		55.86	-6.67	-12.36	25.70	-5.07	-10.81
867-97221	6253	-1.50	-1.30	+0.64	-1.19	-1.32	+0.44
Orchid		-1.33	-0.76	+0.69	-0.99	-1.17	+0.26
	658	-2.31	+2.53	+2.82	-1.22	+1.18	+2.14
		-1.57	+2.27	+1.71	-0.83	+1.23	+1.57
	100	+1.90	-0.54	+0.18	+0.08	-0.51	+0.14
		+3.06	-1.33	+0.41	+1.54	+0.02	+0.22
	124	-0.91	-0.12	+0.04	+2.21	+1.65	-0.70
		-1.29	-0.88	+0.14	+2.06	+1.40	-0.28
	559	-2.10	+0.89	-2.37	-1.08	+0.12	-1.29
		-1.69	+0.83	-2.12	-1.14	-0.16	-1.36
	105	+1.72	-1.46	+0.32	+0.64	-0.75	+0.16
		+2.36	-2.27	+0.69	+0.98	-1.44	+0.06
	COORD	56.02	+7.83	-3.97	27.26	+3.72	-2.14
		55.18	+8.08	-4.86	27.21	+3.11	-3.42

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97223 Lt. Green	100	+2.69	-0.02	-0.29	+1.09	+0.37	-0.13
		+2.59	+1.18	-0.81	+2.03	+3.21	-0.15
	458	-0.92	-0.25	+2.37	-0.22	+0.03	+1.06
		-1.48	+0.42	+3.70	-0.70	+0.70	+2.27
	105	+2.21	+0.56	-0.58	+1.57	+0.15	-0.10
		+1.39	+1.54	-1.19	+0.88	+0.85	-0.55
	6750	-1.11	-2.28	-0.27	-0.37	-1.36	-0.32
		-1.13	-2.60	+0.04	-1.07	-2.33	-0.39
	6253	-1.28	+0.56	-0.04	-0.62	+0.16	-0.13
		-1.94	+0.60	+0.03	-1.53	-0.09	-0.35
	124	-1.01	-0.13	-0.31	+3.61	-1.53	+0.14
		-4.41	+1.57	-1.52	+6.66	+4.28	+0.26
	COORD	54.81	-4.20	+0.86	26.45	-2.97	-0.08
		59.52	-6.04	+2.18	28.23	-8.46	-0.18
867-97224 Green	105	+2.85	-2.09	+0.85	+0.54	-0.40	+0.01
		+3.41	-2.24	+0.87	+0.68	-1.28	+0.13
	6253	-0.83	+1.58	-0.25	-0.17	+0.20	+0.05
		-0.94	+0.84	-0.07	-0.09	+0.51	+0.06
	6750	-0.82	-0.26	-1.23	-0.07	-0.12	-0.50
		+0.11	-0.86	-1.32	-0.69	-1.78	-1.18
	124	+2.41	-1.69	-0.55	+1.66	-1.50	-0.30
		+4.91	-2.55	-1.12	+10.99	-4.19	+1.63
	612	+0.44	-0.84	+0.88	+0.27	-0.41	+0.23
		+0.67	-1.22	+1.32	+0.92	+2.05	+1.29
	6557	-0.03	+0.66	-0.81	0	+0.74	-0.30
		-0.40	+0.92	-1.10	-0.24	+0.20	-0.65
	COORD	21.53	-2.59	-2.08	15.38	+0.55	-1.98
		19.91	-2.07	-1.00	11.62	-3.51	-3.50

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97343	6253	-0.54	-2.17	-0.90	-0.33	-1.65	-0.55
Maroon		-0.34	-0.79	-0.39	-0.14	-0.47	-0.27
	355	+0.96	+2.23	+1.34	+0.84	+2.27	+1.14
		-0.33	+0.67	+0.58	+0.81	+1.98	+0.46
	100	+2.95	+2.62	+1.19	+0.40	+0.14	+0.26
		+2.94	+0.65	+0.75	+0.55	+0.19	-0.37
	860	-0.22	+0.61	+0.53	-0.03	+0.05	+0.11
		+4.84	-1.07	-0.43	-1.26	+3.52	+2.52
	3804	-0.65	-0.67	-0.90	-0.20	-0.36	-0.36
		-1.41	+1.42	-2.19	+1.06	-2.32	-0.48
	1393	-0.92	-2.20	-0.66	-0.70	-0.93	-0.49
					-0.73	+0.17	-1.59
	COORD	23.18	+20.65	+7.78	16.92	+10.34	+2.64
					15.89	+11.09	+6.86
867-97344	6253	-0.42	+0.08	+1.22	-0.24	+0.16	+0.97
Nassau Blue		-1.09	+0.46	+1.70	-0.49	-0.03	+1.27
	6557	-0.93	+0.20	-0.92	-0.32	+0.95	-0.43
		-1.68	-0.21	-0.78	-0.04	+0.34	-0.37
	6551	-1.22	+0.79	-1.08	-0.42	+1.00	-0.56
		-1.62	+0.61	-0.66	-0.57	+0.47	-0.19
	100	+2.09	-0.22	+0.54	+0.64	-0.25	+0.22
		+3.62	-0.26	+1.51	+1.22	-0.73	+0.65
	124	-0.32	+1.12	-0.15	+1.63	-0.63	-2.10
		-1.00	+0.84	+1.73	+2.03	-0.90	-1.11
	COORD	43.59	-5.34	-24.72	20.87	+0.64	-13.37
		44.15	-11.70	-22.39	20.75	-2.69	-15.36

C-1

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97561 Dk. Turquoise	105	+3.48	-1.65	-0.56	+1.05	-1.02	-0.58
		+4.34	-2.93	+0.67	+1.05	-2.08	+0.19
	124	+0.56	+0.68	-1.10	+1.00	-1.12	-0.86
		+0.53	+0.42	+0.07	+3.06	-1.87	-0.71
	6557	-1.24	+1.80	-1.18	-0.30	+1.06	-0.46
		-0.94	+0.91	-2.20	0	+1.16	-1.15
	6253	-1.44	+1.86	+0.95	-0.89	+0.80	+0.54
		-1.35	+2.00	+0.83	-0.45	+0.77	+0.53
	6804	-0.67	+1.94	-0.12	-0.20	+0.78	+0.06
		-0.64	+2.01	-0.36	+0.39	+0.38	+0.73
	6750	-1.18	-0.44	+1.35	-0.17	-0.06	+0.40
		-0.67	-0.45	+1.85	-0.47	-0.78	+0.78
	100	+1.37	-0.66	-0.33	+0.26	-0.08	-0.25
		+2.04	-1.39	+ .23	+0.45	-0.23	0
	COORD	26.50	-9.58	-8.28	17.00	-0.76	-4.97
		27.23	-11.64	-9.88	14.61	-6.72	-7.56
867-97589 Bright Blue	6551	-2.98	+1.76	-1.62	-0.40	+0.72	-0.81
		-2.81	+1.06	-1.23	-1.43	+0.88	-0.97
	100	+4.22	-1.75	+3.15	+1.53	-1.21	+1.42
		+4.00	+0.21	+1.89	+1.96	-0.73	+1.17
	6253	-2.00	+0.46	+3.08	-0.36	-0.63	+1.76
		-1.72	+0.90	+2.35	-0.83	+0.17	+1.71
	6557	-2.21	+0.14	-1.67	-0.41	+0.42	-1.06
		-1.99	-0.33	-1.21	-0.86	+0.44	-0.74
	124	-0.94	+1.58	-0.09	+2.67	-1.18	-2.71
		-1.68	+1.53	+2.25	+8.37	-1.33	-1.18
	6804	-1.18	+2.84	+0.48	-0.12	+0.84	+0.64
		-1.84	+3.49	-0.34	-0.72	+2.15	+0.63
	COORD	43.75	-6.02	-21.98	21.05	+6.99	-2.19
		47.07	-12.62	-19.48	21.36	-3.79	-13.88

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97590 Plum	105	+2.45	+1.17	-0.65	+0.45	+0.63	-0.35
		+2.35	-0.77	-0.95	+0.19	-0.18	-0.29
	6253	-0.87	-1.17	+0.21	-0.22	-0.33	+0.04
		-1.01	-1.70	+0.28	-0.48	-0.60	+0.08
	124	+0.57	+0.72	-0.68	+0.45	+0.78	-0.63
		+0.39	-0.56	-0.61	+0.58	+0.66	-0.96
	6551	-0.44	-0.49	-0.83	-0.08	-0.06	-0.33
		-0.55	-1.57	-0.95	-0.32	-0.60	-0.51
	4804	-0.55	+1.38	0	-0.05	+0.76	0
		-0.15	+2.04	-0.23	+0.26	+0.51	-0.05
	458	+0.05	+0.17	+1.20	+0.15	+0.46	+0.23
		+0.68	+0.41	+2.87	+0.13	+0.60	+0.97
	COORD	21.05	+5.26	-1.53	15.48	+1.25	-0.31
		23.33	+13.12	+0.18	17.99	+1.80	+1.14
867-97591 Fawn	612	+0.02	-0.43	+1.35	+0.02	-0.26	+0.84
		-0.23	-0.56	+1.69	+0.13	-0.08	+0.73
	105	+2.02	-1.11	-3.10	+1.00	-0.05	-1.89
		+1.87	-1.42	-4.51	+1.14	-1.87	-1.35
	1482	-1.25	+0.45	+1.90	-0.63	+0.29	+0.53
		+1.64	+1.08	+1.94	-1.06	+0.76	+0.02
	6253	-1.66	-0.33	-1.04	-1.05	-0.82	-1.02
		-1.90	-0.29	-1.38	-0.99	+0.11	-0.92
	834	-1.87	+2.76	+0.72	-0.34	+1.65	+0.70
		-2.00	+2.29	-0.73	-0.92	+2.25	+1.05
	100	+2.80	-1.18	-1.44	+0.93	-0.53	-0.60
		+2.99	-0.90	-2.98	+1.62	-0.69	-1.16
	COORD	56.18	+7.52	+12.85	28.17	+1.48	+6.92
		57.85	+0.86	+16.92	27.22	+0.34	+8.62

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97592 Bronze	1816	-1.61	+0.58	-2.42	-0.31	+0.15	-0.52
		+1.89	-1.17	+0.57	-1.29	+5.04	-1.40
	460	-1.83	-2.33	-0.75	-0.42	-1.13	-0.55
		+1.30	-1.14	-1.77	-1.03	-0.49	+4.21
	1393	-2.48	-2.16	-2.30	-0.40	-1.01	-0.43
		-3.07	+0.03	-0.19	+0.20	-1.99	-1.89
	6253	-0.78	-1.95	-1.23	-0.41	-1.06	-0.72
		-0.52	-1.14	-0.63	-0.20	-0.70	-0.49
	105	+2.43	+0.71	+1.43	+0.54	+0.55	+0.39
		+1.21	-0.09	+0.29	+0.40	-0.66	-0.34
	100	+2.14	+1.11	+1.50	+0.46	+0.77	+0.38
		+1.20	+0.49	+0.58	+0.59	+0.10	+0.15
	COORD	29.60	+23.46	+13.14	17.72	+9.91	+3.44
		35.01	+19.14	+8.79	12.06	+19.02	+6.56
867-97593 Silver	105	+ .96	+ .34	+0.59	+0.39	+0.30	+0.51
		+ .77	+ .25	+0.60	+0.14	+0.26	+1.03
	6551	-1.55	-0.90	-2.37	-1.20	-0.54	-1.07
		-2.14	-1.93	-2.56	-3.02	-3.60	-3.92
	6557	-1.29	-1.73	-2.19	-1.07	-1.12	-1.52
		-2.76	+0.24	-3.34	-2.72	-3.98	-3.71
	6253	-2.12	+0.26	+0.79	-1.34	+0.01	+0.50
		-2.67	-0.02	+1.00	-3.62	-4.27	+1.09
	100	+1.36	+0.03	+0.39	+0.63	+0.23	+0.22
		+1.42	+0.50	+0.65	+0.72	+0.71	+0.79
	124	-0.48	-0.05	-0.22	+2.13	-0.30	-0.51
		-3.38	+0.13	+0.08	+6.48	+7.27	+0.98
	COORD	59.86	+0.70	-3.89	30.47	-0.72	-2.70
		61.68	-1.45	-3.25	31.88	-2.16	-4.99

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97692 Champagne	654	-0.66 -0.58	+0.13 +0.09	+2.39 +1.50	+0.31 +0.30	-0.13 +0.04	+1.24 +2.08
	100	+1.71 +1.53	-0.62 -0.48	-1.54 -1.90	+0.46 +0.52	-0.27 -0.46	-0.49 -2.64
	6253	-1.61 -1.85	+0.10 +0.03	-1.13 -0.91	-1.04 -1.15	+0.03 +0.01	-0.81 -0.76
	834	-1.31 -1.21	+1.84 +1.33	+0.71 +0.17	-0.41 -0.60	+1.13 +1.30	+0.65 +0.88
	460	-0.75 -0.58	+0.87 +0.53	+1.62 +1.06	-0.47 -0.62	+0.55 +0.64	+0.69 +1.42
	124	-0.91 -4.43	+0.21 -0.11	-0.14 -3.53	+4.30 +3.69	-0.86 -0.65	+1.79 -1.89
	COORD	60.33 62.48	+1.59 -0.08	+9.81 +10.43	30.43 31.47	-0.22 -0.30	+5.51 +11.40
867-97841 Gold	458	-1.10 -4.02	+2.00 +2.43	+2.54 +2.79	-0.12 -1.60	+0.94 +1.51	+0.91 +1.04
	6253	-1.82 -1.48	-0.35 -0.10	-1.54 -1.17	-0.84 -0.85	-0.50 +0.13	-1.11 -0.76
	612	-0.32 -0.09	+0.03 -0.25	+0.71 +0.75	+0.20 +0.11	-0.54 -0.04	+0.33 +0.47
	100	+1.67 +2.12	-1.03 -0.93	-1.00 -1.62	+0.92 +0.93	-0.92 -0.73	-0.06 -0.71
	834	-0.87 -0.47	+1.15 +0.61	-0.02 -0.28	-0.05 -0.26	+0.64 +0.67	+0.24 +0.29
	124	-0.94 -1.79	+0.25 -0.41	-0.99 -2.30	+2.75 +2.22	-0.05 -1.03	+1.99 +0.07
	COORD	54.60 55.51	+4.08 2.00	+17.68 18.56	25.96 27.13	+1.86 +1.67	+7.41 +8.76

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97842 Silver	6253	-0.72	+0.41	-0.22	-0.55	+0.03	-0.23
	458	-0.88	+0.34	+3.43	-0.38	+0.17	+2.02
		-1.96	+0.50	+4.21	-1.23	+0.02	+2.53
	6750	-0.43	-1.63	-0.39	-0.42	-1.38	-0.45
		-0.86	-2.13	-0.21	-0.81	-1.90	-0.39
	100	+1.38	+0.80	-1.02	+0.10	+0.11	-0.60
		+2.42	+0.57	-1.61	+0.43	+1.01	-1.75
	105	+0.86	+1.02	-1.50	+0.03	+0.32	-0.93
		+0.79	+0.72	-2.32	+0.01	+0.45	-1.27
	124	-0.21	-0.20	+0.07	+2.90	-0.40	+0.06
		-3.31	+0.60	-1.57	+2.84	+1.01	-0.60
	COORD	60.72	-0.66	+1.87	30.27	-2.08	+1.23
		61.59	-3.05	+4.72	32.51	-3.36	+3.29
867-97844 Dk. Blue	124	+ .70	+0.09	-0.94	+0.52	+0.06	-0.89
		+ .70	-0.13	-0.74	+2.09	-1.06	-0.36
	6750	-0.06	-0.66	+0.59	+0.10	-0.34	+0.02
		+0.11	-0.48	+0.19	-0.18	-1.09	+0.40
	100	+3.98	-2.47	-1.73	+0.65	-0.20	-0.59
		+3.40	-0.06	-2.09	+1.10	-0.56	+0.08
	6253	-1.02	+0.20	+1.86	-0.17	+0.02	+0.79
		-0.64	-0.56	+1.67	-0.04	-0.14	+1.07
	6557	-0.42	+1.18	-1.35	0	+0.35	-0.72
		-0.21	+0.83	-1.41	-0.48	+0.78	-1.40
	COORD	20.05	+0.63	-6.47	14.95	+1.92	-2.78
		18.55	+2.17	-5.85	11.12	-0.98	-7.33

PRODUCT	BASE	FLAT ΔL	FLAT Δa	FLAT Δb	HIGH ANGLE ΔL	HIGH ANGLE Δa	HIGH ANGLE Δb
867-97846 Blue	105	+2.33	+0.55	+1.67	+0.67	+0.39	+1.26
		+1.54	-0.16	+1.80	+0.77	+0.78	+0.95
	6750	-0.49	-1.55	+0.37	-0.75	-1.00	+0.37
		0.43	-1.32	+0.44	0.49	-1.59	+0.72
	6253	-1.54	+0.65	+1.27	-0.97	+0.23	+6.00
		-1.44	-0.15	+1.14	-1.35	-1.19	+1.71
	6557	-1.85	-1.40	-2.77	-1.20	-0.72	-1.73
		-2.76	+0.56	-3.07	-1.51	-1.44	-1.79
	100	+2.14	+0.38	+1.36	+0.97	+0.53	+0.85
		+2.41	+0.03	+1.20	+2.15	+3.26	+2.27
	124	-0.33	-0.13	-0.61	+2.54	-0.95	-0.98
		-1.78	-0.05	+0.78	+4.29	+3.78	+1.60
	COORD	56.17	-2.73	-8.20	28.08	-2.28	-5.75
		58.16	-0.64	-8.28	28.00	-7.71	-8.28
867-97847 Green	6750	-1.65	-3.91	-0.53	-0.95	-2.28	-0.63
		-1.36	-3.23	+0.14	-1.59	-3.31	-0.67
	2612	-0.27	-1.43	+3.46	+0.18	-0.84	+1.84
		-0.16	-0.67	+1.87	+0.23	+0.58	+1.76
	105	+1.27	+1.67	-1.08	+0.68	+1.39	-0.60
		+0.74	+1.62	-1.07	+0.92	+1.66	-0.66
	6253	-0.82	+0.60	-0.11	-0.70	+0.58	-0.18
		-0.96	+0.23	+0.07	-0.97	-0.25	-0.32
	1482	-0.58	+0.33	+1.66	-0.24	+0.20	+0.88
		-0.52	+0.05	+1.60	-0.51	+0.41	+1.28
	124	-0.75	-0.42	-0.17	+3.56	-1.94	+0.21
		-2.93	+0.88	-0.79	+5.45	+5.07	+0.88
	COORD	57.66	-3.40	+0.17	28.13	-3.14	0
		61.52	-5.49	+1.34	28.89	-9.43	-0.20
867-98106 Blue	100	+2.66	-1.54	+0.26	+0.65	-0.02	0
		+3.56	-1.38	-0.35	+1.87	-0.99	+0.34
	6253	-0.74	-0.78	+3.17	-0.24	-0.60	+2.06
		-1.43	+0.12	+3.23	-0.51	-0.83	+2.61
	124	-0.18	+0.94	-0.12	+0.84	+0.32	-1.86
		-0.16	0	+0.90	+2.14	-0.65	-1.17
	6551	-4.05	+1.65	-0.42	-0.84	+0.82	-0.15
		-5.25	+2.06	+1.35	-2.87	+1.72	-0.58
	818	-2.28	+1.87	+3.62	-0.45	+0.28	+2.22
		-0.99	+1.35	+0.62	-0.16	+0.27	+0.72
	COORD	31.90	+2.85	-26.03	17.26	+4.72	-12.18
		34.26	-4.57	-21.38	14.04	+0.86	-17.19

APPENDIX D

COMPARISON OF 945-LINE COMPUTED AND MANUAL VECTORS

(Dual Angle System)

Manual vector movements shown in red

Computed " " " " blue

The cube root color coordinates measured from the standard panel and those computed by the vector program are shown at the bottom of the data for each formula.

COMPUTED VS. MANUAL VECTORS

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-95603		- 1.25	+ 2.11	- 1.96	- 0.37	+ 1.12	- 0.95
Aqua	551	- 1.49	+ 2.61	- 1.12	- 0.44	+ 0.96	- 0.57
		- 0.68	- 0.03	+ 2.45	- 0.22	- 0.27	+ 1.30
	253	- 0.68	- 0.37	+ 2.84	- 0.27	- 0.57	+ 2.19
		- 0.14	- 1.68	+ 1.00	- 0.04	- 0.09	+ 0.29
	750	- 0.21	- 1.85	+ 2.73	- 0.05	- 0.80	+ 1.31
		+ 2.96	- 1.68	- 1.35	+ 0.42	+ 0.35	- 0.78
	110	+ 2.88	- 1.98	- 2.54	+ 0.50	- 0.13	- 1.08
		+ 2.20	- 0.93	- 2.50	+ 1.32	- 0.07	- 2.47
	124	+ 1.13	- 1.46	+ 0.90	+ 2.32	- 0.81	- 3.84
		21.59	- 0.28	-11.99	15.14	+ 0.75	- 7.04
	COORD.	21.73	+ 1.28	-13.91	15.96	+ 1.24	- 6.44
945-95604		+ 3.68	- 0.25	+ 2.25	+ 1.37	- 0.06	+ 1.30
Blue	110	+ 3.77	+ 0.25	+ 2.34	+ 1.04	- 0.36	+ 2.01
		- 3.32	+ 0.04	- 3.37	- 1.60	+ 0.71	- 1.76
	551	- 3.41	+ 0.13	- 3.38	- 1.59	+ 1.04	- 2.13
		- 2.32	+ 0.15	+ 3.68	- 0.91	+ 0.36	+ 2.64
	253	- 1.28	+ 0.32	+ 2.12	- 0.79	- 0.11	+ 2.16
		- 0.62	+ 0.50	- 0.60	+ 2.33	- 0.45	- 1.82
	124	- 1.38	+ 0.82	+ 2.44	+ 2.85	- 0.68	- 1.64
		48.48	- 4.04	-18.82	24.07	- 1.95	-12.52
	COORD.	48.20	- 7.82	-17.99	25.10	- 2.07	-12.08
945-97397		+ 2.52	+ 0.21	- 1.10	0	+ 0.21	- 0.50
Silver	121	+ 0.56	+ 0.23	- 0.86	- 0.14	+ 0.10	- 0.27
		- 1.35	- 1.05	- 2.14	- 1.25	- 0.88	- 1.62
	551	- 1.85	- 1.75	- 2.72	- 1.02	- 0.73	- 1.63
		- 0.83	+ 0.69	+ 2.08	- 0.56	+ 0.54	+ 1.44
	834	- 1.01	+ 0.66	+ 2.69	- 0.24	+ 0.35	+ 1.59
		61.57	+ 1.36	- 0.14	31.32	- 1.53	- 0.38
	COORD.	64.08	- 1.08	+ 0.60	31.33	- 0.48	+ 0.18

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-97473 Lt. Beige	121	+ 4.16 + 0.99	- 0.05 - 0.14	- 3.97 - 2.55	+ 0.46 + 0.20	- 0.06 - 0.09	- 2.08 - 0.99
	654	+ 0.10 - 0.52	- 0.08 - 0.19	+ 2.29 + 3.43	+ 0.25 + 0.30	- 0.11 - 0.13	+ 1.26 + 1.38
	253	- 1.02 - 2.43	+ 0.34 + 0.60	- 3.35 - 0.48	- 2.78 - 1.60	+ 0.16 + 0.10	- 2.87 - 0.27
	658	- 0.69 - 1.12	+ 3.54 + 2.25	- 0.05 + 0.16	- 0.90 - 0.55	+ 2.56 + 1.31	- 0.02 + 0.44
	124	+ 2.66 - 3.33	- 0.62 + 0.74	- 1.90 - 1.68	+ 3.76 + 3.93	- 0.11 - 0.34	+ 0.05 - 0.19
	COORD.	59.39 61.74	+ 1.39 - 1.23	+ 9.46 + 9.62	31.18 30.28	- 1.51 - 0.20	+ 4.46 + 3.55
945-97547 Blue	110	+ 3.01 + 2.64	+ 0.22 + 0.13	+ 2.32 + 0.87	+ 1.09 + 0.67	+ 0.09 - 0.06	+ 1.64 + 0.78
	551	- 1.68 - 0.99	- 0.66 - 0.32	- 2.12 - 1.19	- 0.70 - 0.50	+ 0.13 - 0.07	- 1.29 - 0.74
	253	- 1.36 - 0.38	+ 0.18 + 0.10	+ 1.56 + 0.53	- 0.57 - 0.24	+ 0.07 + 0.01	+ 1.27 + 0.51
	124	+ 0.11 - 0.41	+ 0.33 + 0.25	+ 0.28 + 0.59	+ 1.74 + 0.94	- 0.25 - 0.19	- 0.67 - 0.48
	818	- 2.12 - 0.89	+ 2.92 + 1.16	- 0.19 - 0.26	- 1.25 - 0.42	+ 2.05 + 0.76	+ 0.14 - 0.07
	750	- 0.06 - 0.39	- 2.61 - 1.21	+ 1.69 + 0173	- 0.23 - 0.18	- 1.50 - 0.69	+ 1.11 + 0.41
	105	+ 2.67 + 2.28	+ 0.70 + 0.21	+ 2.97 + 0.94	+ 1.15 + 0.97	+ 0.21 - 0.11	+ 2.11 + 0.84
	COORD.	51.37 47.35	- 2.26 - 6.09	-13.72 -13.29	25.26 25.31	- 0.28 - 2.03	-10.01 - 8.82

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-97771		- 1.14	0	+ 0.59	- 0.30	- 0.21	+ 0.15
Dark Gray	253	+ 2.38	- 0.93	+ 3.35	- 0.60	- 0.32	+ 0.92
		- 0.14	- 0.92	- 0.07	- 0.02	- 0.18	- 0.12
	750	- 0.37	- 1.26	+ 0.30	- 0.09	- 0.27	- 0.04
		- 1.04	+ 1.35	- 0.98	- 0.25	+ 0.50	- 0.16
	559	- 1.20	+ 1.22	- 1.11	- 0.24	+ 0.27	- 0.17
		+ 3.96	+ 0.07	- 0.85	+ 0.92	+ 0.62	- 0.44
	105	+ 4.47	+ 0.37	- 1.39	+ 1.28	+ 0.25	- 0.70
		+ 2.75	+ 0.17	- 0.68	- 0.42	+ 0.41	- 0.29
	110	+ 3.34	+ 0.32	- 1.05	+ 0.67	+ 0.14	- 0.39
		+ 0.27	+ 0.18	- 0.48	+ 0.85	+ 0.41	- 0.92
	124	+ 0.60	- 0.09	+ 0.52	+ 2.37	+ 0.46	- 1.81
		27.52	+ 2.93	- 6.19	15.66	+ 2.52	- 4.09
	COORD.	26.69	+ 1.67	- 5.94	16.61	+ 0.42	- 1.30
945-97772		+ 1.56	- 0.04	- 0.31	+ 0.45	- 0.04	- 0.10
Silver	110	+ 0.82	- 0.03	- 0.15	+ 0.01	+ 0.01	- 0.07
		- 2.75	- 0.05	+ 0.75	- 1.82	- 0.13	+ 0.46
	253	- 1.93	+ 0.03	+ 0.57	- 1.26	+ 0.05	+ 0.36
		- 0.41	+ 0.10	- 0.05	+ 1.42	+ 0.17	- 0.10
	124	- 1.17	+ 0.07	- 0.04	+ 1.18	- 0.07	- 0.11
		- 2.99	+ 2.38	- 2.77	- 1.55	+ 1.94	- 2.00
	818	- 2.59	+ 2.22	- 2.22	- 1.33	+ 1.68	- 1.33
		62.32	+ 0.95	- 1.99	29.01	+ 0.28	- 1.58
	COORD.	63.73	- 0.39	- 0.76	31.41	- 0.36	- 0.36
945-97774		- 1.36	+ 0.88	- 2.28	- 0.42	+ 0.72	- 0.66
Blue	576	- 1.52	+ 0.94	- 0.93	- 0.37	+ 0.38	- 0.17
		+ 3.77	- 1.29	+ 0.45	+ 1.36	- 0.70	- 0.30
	110	+ 5.40	- 1.98	- 0.42	+ 1.46	- 0.66	- 1.37
		- 0.94	- 0.14	+ 2.85	- 0.32	- 0.20	+ 1.76
	253	- 0.96	- 0.27	+ 2.75	- 0.24	- 0.33	+ 1.47
		- 0.93	+ 2.18	+ 0.55	- 0.20	+ 0.69	+ 0.42
	819	- 1.50	+ 2.92	+ 1.29	- 0.17	+ 0.67	+ 0.67
		- 0.26	+ 0.22	+ 0.74	+ 1.70	- 0.70	- 2.54
	124	- 0.35	- 0.39	+ 3.13	+ 3.12	- 0.49	- 5.53
		35.72	- 2.87	-23.01	17.64	+ 2.73	-11.25
	COORD.	33.49	- 3.59	-22.94	17.38	+ 0.62	- 8.48

Rx Code	Base	ΔL_P	Δa_P	Δb_P	ΔL_H	Δa_H	Δb_H
945-97778		+ 0.48	- 0.06	- 0.92	+ 0.05	- 0.12	- 0.48
Lt. Beige	110	+ 0.35	- 0.18	- 0.93	+ 0.05	- 0.11	- 0.49
		- 0.05	- 0.09	+ 0.57	- 0.07	- 0.09	+ 0.12
	654	- 0.35	- 0.35	+ 2.04	+ 0.15	- 0.10	+ 0.77
		- 0.74	+ 1.22	+ 0.98	- 0.38	+ 0.62	+ 0.58
	834	- 1.38	+ 1.43	+ 2.58	- 0.30	+ 0.76	+ 1.68
		- 4.02	- 0.33	- 1.63	- 2.84	- 0.88	- 1.73
	253	- 2.04	+ 0.12	- 0.42	- 1.35	+ 0.11	- 0.35
		- 0.70	+ 0.25	- 0.12	+ 2.64	+ 0.39	+ 0.70
	124	- 3.70	+ 0.11	- 1.82	+ 3.97	- 0.55	- 0.13
		+ 0.30	- 0.28	- 1.55	+ 0.09	- 0.20	- 0.77
	105	+ 0.05	- 0.26	- 1.51	+ 0.31	- 0.19	- 0.77
		60.94	+ 2.63	+ 9.15	30.79	+ 0.78	+ 5.51
	COORD.	63.29	+ 0.21	+ 8.29	31.00	+ 0.27	+ 4.19
945-97783		+ 0.64	- 0.43	- 0.19	+ 0.45	- 0.43	- 0.10
Rose	110	+ 2.29	- 1.18	- 1.02	+ 0.53	- 0.46	+ 0.41
		- 0.91	+ 1.09	+ 0.45	- 0.76	+ 0.47	+ 0.25
	807	- 3.57	+ 4.07	+ 1.38	- 1.42	+ 2.16	+ 0.81
		- 0.60	- 0.28	+ 0.18	- 0.32	- 0.59	+ 0.01
	253	- 1.25	- 0.34	+ 0.01	- 0.84	- 0.19	- 0.11
		- 0.63	+ .03	+ 0.12	+ 1.34	+ 0.20	+ 0.01
	124	- 3.10	- 1.02	- 0.95	+ 4.37	- 0.14	- 0.02
		59.13	+ 6.14	+ 2.51	28.55	+ 3.66	+ 1.95
	COORD.	57.56	+ 4.33	+ 3.51	29.04	+ 1.94	+ 2.42
945-97786		+ 4.35	- 0.10	+ 0.34	+ 1.59	+ 0.13	+ 0.38
Silver	121	+ 1.78	+ 0.21	+ 0.05	+ 0.58	- 0.02	+ 0.12
		- 1.92	- 2.75	- 3.32	- 1.26	- 1.48	- 2.32
	557	- 2.80	- 3.60	- 3.94	- 1.54	- 1.54	- 2.46
		- 2.50	+ 2.57	- 2.43	- 1.46	+ 2.02	- 1.61
	818	- 2.77	+ 2.50	- 2.27	- 1.27	+ 1.71	- 1.22
		- 1.54	+ 1.14	+ 4.43	- 0.22	+ 0.65	+ 3.00
	834	- 2.22	+ 1.41	+ 6.07	- 0.43	+ 0.87	+ 3.40
		- 0.15	- 0.03	- 0.03	+ 1.22	- 0.21	- 0.22
	124	- 1.26	+ 0.11	+ 0.02	+ 1.34	- 0.14	- 0.17
		- 2.32	+ 0.34	+ 1.00	- 1.55	+ 0.01	+ 0.78
	253	- 2.10	+ 0.08	+ 0.71	- 1.23	+ 0.09	+ 0.43
		61.61	+ 1.46	- 3.79	28.13	+ 0.95	- 2.74
	COORD.	62.33	- 0.85	- 1.57	30.00	- 0.22	- 0.67

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-97788		- 0.45	+ 0.85	- 0.76	- 0.12	+ 0.59	- 0.43
Aqua	551	- 1.03	+ 0.46	- 1.89	- 0.19	+ 0.42	- 0.34
		+ 0.75	- 1.31	+ 1.60	+ 0.33	- 0.37	+ 0.60
	664	+ 4.77	- 2.29	+ 8.87	+ 1.14	- 2.61	+ 1.56
		- 0.63	+ 1.19	+ 0.77	- 0.14	+ 0.91	+ 0.27
	253	- 0.46	+ 0.76	+ 0.14	- 0.17	+ 0.35	+ 0.14
		+ 3.41	- 2.12	- 0.91	+ 0.56	- 0.10	- 0.47
	121	+ 1.47	- 0.63	- 3.49	+ 0.41	- 0.08	- 0.73
		+ 1.58	- 0.97	- 1.21	+ 1.14	- 0.39	- 1.21
	124	+ 0.16	+ 0.30	- 0.97	+ 1.73	- 0.73	- 2.95
		- 0.29	+ 0.42	- 0.74	- 0.06	+ 0.32	- 0.36
	557	+ 0.61	+ 0.02	- 1.17	+ 0.12	+ 0.22	- 0.23
		21.99	- 2.10	- 7.41	15.48	+ 4.09	- 5.46
	COORD.	30.18	- 8.55	+10.77	16.74	- 3.92	+ 0.07
945-97789		+ 0.67	- 0.05	+ 0.83	+ 3.09	- 0.28	+ 1.04
Blue	121	+ 1.22	- 0.01	+ 0.64	+ 0.53	- 0.08	+ 0.16
		- 1.00	+ 0.07	+ 1.93	- 1.02	+ 0.14	+ 1.41
	253	- 1.07	+ 0.01	+ 1.35	- 0.43	+ 0.06	+ 0.78
		- 0.34	- 0.17	- 0.45	+ 2.00	- 0.08	- 0.94
	124	+ 1.23	+ 0.24	+ 1.43	+ 2.31	- 0.26	- 1.12
		- 2.36	- 1.56	- 3.32	- 1.20	- 0.26	- 1.88
	551	- 3.09	- 1.58	- 3.83	- 1.05	- 0.19	- 1.59
		- 2.86	+ 3.42	- 1.32	- 0.91	+ 2.35	- 0.74
	818	- 2.54	+ 2.64	- 0.98	- 0.72	+ 1.26	- 0.29
		49.39	+ 0.57	-11.24	23.71	+ 1.24	- 8.01
	COORD.	51.19	- 2.62	-12.04	23.45	- 0.24	- 5.56
945-97790		- 1.30	+ 0.28	- 2.40	- 0.41	+ 0.72	- 0.84
Blue	576	- 2.08	- 0.72	- 2.73	- 0.67	- 0.22	- 0.97
		- 0.27	+ 1.42	+ 0.03	- 0.03	+ 0.80	- 0.12
	819	- 0.65	+ 2.10	+ 0.47	+ 0.01	+ 0.80	+ 0.27
		- 0.75	- 0.32	+ 2.39	- 0.24	+ 0.03	+ 1.21
	253	- 0.83	- 0.20	+ 1.71	- 0.24	- 0.18	+ 0.80
		+ 1.63	+ 0.04	- 0.52	+ 0.26	+ 0.19	- 0.30
	121	+ 1.48	- 0.28	- 0.53	+ 0.31	- 0.06	- 0.26
		+ 0.10	- 0.44	- 0.02	+ 0.02	- 0.20	+ 0.10
	750	- 0.23	- 0.88	+ 0.51	- 0.06	+ 0.25	+ 0.11
		+ 0.90	+ 1.40	- 1.71	+ 1.16	+ 0.27	- 1.97
	124	+ 0.41	- 0.28	+ 0.93	+ 2.52	- 0.34	- 2.77
		25.06	+ 3.22	-11.42	16.03	+ 4.29	- 6.50
	COORD.	29.19	+ 1.18	- 9.36	17.41	+ 1.30	- 3.26

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-97795 Mauve	110	+ 4.34 + 2.56	- 1.72 - 1.79	+ 0.68 + 1.06	+ 0.90 + 1.17	- 0.85 - 1.17	+ 0.50 + 0.46
	818	- 3.02 - 1.87	+ 2.22 + 1.77	- 1.70 - 1.13	- 2.00 - 0.76	+ 1.77 + 1.15	- 0.59 - 0.53
	253	- 2.90 - 1.59	- 0.82 - 0.62	+ 1.69 + 1.02	- 2.43 - 0.90	- 0.32 - 0.52	+ 0.87 + 0.69
	124	- 0.88 - 1.33	+ 0.22 - 0.60	- 0.09 + 0.43	+ 1.24 + 1.86	+ 0.31 + 0.06	- 0.48 - 0.45
	COORD.	54.72 57.86	+ 4.96 + 5.48	- 5.49 - 5.61	25.93 27.39	+ 3.78 + 3.73	- 3.63 - 2.79
945-97797 Samoa Gold	121	+ 2.13 + 1.81	- 0.23 - 0.82	- 0.63 - 1.54	+ 0.57 + 0.01	- 0.30 - 0.24	- 0.45 - 0.86
	654	+ 0.00 + 0.09	+ 0.10 + 0.17	+ 0.65 + 1.44	+ 0.10 + 0.15	- 0.17 - 0.04	+ 0.17 + 0.57
	253	- 1.50 - 1.02	- 0.10 + 0.09	- 1.08 - 0.44	- 1.11 - 0.87	- 0.46 + 0.03	- 1.08 - 0.46
	124	+ 0.26 - 1.26	- 0.08 - 0.04	- 0.21 - 1.05	+ 1.44 + 2.04	- 0.23 - 0.33	+ 0.27 + 0.09
	834	- 0.41 - 0.54	+ 0.70 + 0.74	+ 0.69 + 0.87	- 0.13 - 0.15	+ 0.47 + 0.48	+ 0.32 + 0.73
	COORD.	53.44 53.41	+ 2.44 + 2.09	+10.20 +13.27	28.93 30.81	+ 2.11 + 0.66	+ 5.23 + 6.66
945-97798 Caballero Tan	110	+ 2.21 + 2.00	- 0.39 - 1.15	- 0.11 - 0.86	+ 0.66 + 0.43	- 0.06 - 0.43	+ 0.08 - 0.29
	253	- 2.78 - 1.40	- 1.43 - 0.28	- 2.35 - 1.08	- 1.45 - 0.93	- 1.11 - 0.31	- 1.66 - 0.93
	654	+ 0.09 + 0.91	+ 0.12 + 0.72	+ 0.70 + 2.71	+ 0.34 + 0.60	+ 0.30 - 0.13	+ 0.21 + 0.93
	834	- 0.58 - 0.48	+ 0.89 + 0.75	+ 0.46 + 0.55	- 0.06 + 0.06	+ 0.58 + 0.57	+ 0.30 + 0.46
	124	+ 0.24 - 0.77	- 0.03 - 0.47	- 0.32 - 1.03	+ 1.27 + 1.83	+ 0.44 - 0.34	+ 0.60 + 0.59
	362	- 0.94 - 0.27	+ 1.28 + 6.05	- 0.23 + 1.13	+ 0.07 + 0.62	+ 1.29 + 2.21	+ 0.38 + 0.66
	COORD.	45.36 47.44	+ 5.53 + 6.56	+14.36 +17.33	24.57 26.26	+ 3.15 + 3.38	+ 5.26 + 8.60

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-97800		- 0.46	- 0.41	+ 2.63	- 0.11	+ 0.54	+ 0.64
Dk. Blue	253	- 0.45	- 0.52	+ 2.20	- 0.10	- 0.13	+ 0.57
		- 0.62	+ 1.48	+ 0.80	0	+ 0.48	+ 0.44
	559	- 1.14	+ 1.55	+ 0.85	- 0.18	+ 0.25	+ 0.32
		+ 1.53	+ 0.06	- 1.90	+ 0.23	+ 0.54	- 0.70
	110	+ 1.52	+ 0.00	- 2.28	+ 0.21	+ 0.01	- 0.46
		+ 0.43	+ 0.61	- 0.86	+ 0.35	+ 0.98	- 1.07
	124	+ 0.31	- 0.12	- 0.13	+ 0.60	+ 0.08	- 1.48
		19.23	+ 2.73	- 9.67	14.51	+ 0.87	- 4.94
	COORD.	20.29	+ 0.01	- 7.36	15.40	+ 0.06	- 1.53
945-97801		+ 2.25	+ 0.75	+ 2.02	+ 1.32	+ 0.81	+ 1.23
Pale Blue	121	+ 2.22	+ 1.24	+ 2.89	+ 1.05	+ 0.26	+ 1.62
		- 3.72	- 1.57	- 4.58	- 1.37	- 0.06	- 2.57
	551	- 4.61	- 1.59	- 5.51	- 2.06	+ 0.09	- 3.08
		- 3.02	+ 2.65	- 1.17	- 0.89	+ 2.17	- 0.57
	818	- 2.22	+ 2.59	- 0.89	- 0.91	+ 1.53	- 0.42
		- 3.26	+ 0.42	+ 2.71	- 1.11	+ 0.50	+ 2.16
	253	- 1.79	+ 0.45	+ 2.00	- 0.96	+ 0.19	+ 1.39
		- 1.30	- 0.06	- 0.38	+ 3.49	- 0.84	- 1.75
	124	- 2.31	+ 1.07	+ 2.02	+ 3.14	- 0.56	- 1.02
		59.22	- 2.04	-11.49	25.00	- 0.36	- 7.89
	COORD.	57.32	- 6.46	-12.55	27.04	- 2.13	- 6.67
945-97805		+ 1.73	+ 1.09	- 2.02	+ 0.17	+ 0.88	- 1.06
Lt.Green	110	+ 0.49	- 0.13	- 2.47	+ 0.05	+ 0.41	- 1.16
		- 0.16	+ 0.23	+ 1.43	+ 0.03	+ 0.06	+ 0.71
	654	- 0.33	+ 0.11	+ 2.13	+ 0.24	+ 0.07	+ 1.13
		- 1.30	- 2.96	- 1.29	- 0.78	- 1.85	- 1.00
	750	- 0.36	- 0.54	+ 0.07	- 0.62	- 1.34	- 0.63
		- 0.85	+ 0.73	+ 2.94	+ 0.48	+ 0.72	+ 2.64
	630	+ 0.08	+ 0.77	+ 2.14	+ 0.92	+ 1.31	+ 3.34
		- 1.88	- 1.87	- 2.96	- 1.34	- 1.13	- 2.10
	557	- 0.46	- 0.14	- 0.65	- 0.87	- 0.70	- 1.41
		- 0.18	- 0.33	- 0.34	+ 1.71	- 0.06	+ 0.71
	124	- 0.86	+ 1.04	- 0.16	+ 2.24	- 0.79	- 0.48
		57.21	- 5.95	+13.10	31.64	- 5.24	+ 6.88
	COORD.	61.46	- 2.94	+17.98	31.19	- 3.69	+ 7.12

Rx Code	Base	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
945-97806		+ 2.32	+ 0.60	- 2.46	+ 0.29	+ 0.06	- 1.24
Gold	121	+ 1.49	- 0.41	- 2.72	+ 0.20	- 0.10	- 1.37
		- 0.85	+ 1.84	+ 1.55	- 0.78	+ 0.92	+ 0.82
	484	- 1.61	+ 1.41	+ 1.88	- 0.56	+ 0.71	+ 0.87
		- 0.70	- 1.94	- 1.17	- 0.51	- 1.80	- 0.86
	750	- 0.65	- 1.62	- 0.91	- 0.44	- 1.10	- 0.59
		58.02	- 0.23	+12.99	30.96	- 1.92	+ 6.56
	COORD.	58.70	- 1.46	+15.52	30.01	- 0.97	+ 8.15
945-97814		+ 2.43	- 0.80	- 2.47	+ 0.15	- 0.34	- 1.45
Pale Gold	121	+ 1.94	- 0.84	- 3.06	+ 0.62	- 0.52	- 1.39
		- 0.29	- 0.06	+ 2.14	- 0.14	- 0.03	+ 0.75
	674	- 0.33	+ 0.21	+ 2.57	- 0.45	+ 0.24	+ 1.12
		- 2.14	+ 2.83	+ 3.99	- 1.61	+ 2.18	+ 1.51
	484	- 4.01	+ 2.58	+ 3.94	- 1.19	+ 1.52	+ 1.44
		- 3.54	- 0.48	- 2.66	- 2.90	- 0.55	- 2.68
	253	- 2.40	- 0.13	- 1.41	- 1.47	- 0.11	- 1.25
		+ 0.16	+ 0.15	+ 0.12	+ 2.13	- 0.13	+ 0.86
	124	- 2.21	- 0.31	- 1.98	+ 2.93	- 0.26	+ 0.89
		58.57	+ 2.03	+12.81	30.88	+ 1.13	+ 7.28
	COORD.	58.37	+ 0.71	+14.66	28.67	+ 0.48	+ 7.88
945-97816		- 2.61	- 0.24	+ 0.19	- 0.75	+ 0.66	- 0.10
Charcoal	253	+ 2.70	+ 0.01	- 0.09	- 0.72	- 0.02	- 0.09
		+ 2.71	+ 0.07	+ 0.02	+ 0.69	+ 0.55	+ 0.07
	121	+ 3.38	- 0.02	+ 0.03	+ 1.00	+ 0.03	+ 0.10
		+ 0.38	- 0.37	- 0.55	+ 1.87	- 0.09	- 0.26
	124	- 0.19	+ 0.04	- 0.05	+ 4.19	- 0.15	+ 0.15
		- 0.98	+ 0.70	- 1.12	- 0.16	+ 0.58	- 0.42
	818	- 1.26	+ 1.28	- 1.35	- 0.17	+ 0.61	- 0.27
		- 0.40	- 1.71	- 0.39	- 0.12	- 0.66	- 0.24
	750	- 0.79	- 2.10	- 0.47	- 0.19	- 0.51	- 0.22
		35.85	+ 2.16	- 0.44	18.01	+ 0.67	- 2.60
	COORD.	36.25	- 0.13	+ 2.28	18.36	- 0.01	+ 0.70

APPENDIX B

Intersection of Characterization Curves

Assume a mixture of two pigments, a colorant and a reference, then:

$$\frac{[K]}{[S]}_{mix} = \frac{(1-c)K_r + CK_c}{(1-c)S_r + CS_c} = \frac{\left(\frac{1-c}{c}\right) K_r + K_c}{\left(\frac{1-c}{c}\right) S_r + S_c} \quad (1).$$

1. If the masstone spectral curves of the two pigments do not intersect, is it possible for the spectral curve of any mixture of the two to intersect either masstone curve?

   At any wavelength we can find the ratio of the two absorption and scattering coefficients:

   Let $\frac{(K_c)}{(K_r)} = m$ and $\frac{(S_c)}{(S_r)} = n$

   Then at a specific wavelength $$\frac{[K]}{[S]}_{mix} = \frac{K_r \; [(1-c)/_c + m]}{S_r \; [(1-c)/_c + n]} \quad (2).$$

   At the point of intersection of a mixture with a masstone curve, either:

   $$\frac{[K]}{[S]}_{mix} = \frac{K_r}{S_r} \quad \text{or} \quad \frac{[K]}{[S]}_{mix} = \frac{K_r}{S_c}$$

   From Equation 2 we can see that either of these conditions can occur only if n = m.

   But, if n = m, then $\frac{K_r}{S_r} = \frac{K_c}{S_c}$, which means the two masstone curves intersect.

   Therefore, we have shown that mixture curves will intersect masstone curves only if the masstone curves themselves intersect.

2. If the masstone spectral curves of two pigments intersect, do curves of all mixtures of the two pigments intersect at the same point?

At point of intersection of masstones:

$$\frac{K_c}{S_c} = \frac{K_r}{S_r}$$

Therefore $$\frac{K_c}{K_r} = \frac{S_c}{S_r} = m$$

$$K_c = m\,K_r \quad \text{and} \quad S_c = m\,S_r$$

Then:

$$\left[\frac{K}{S}\right]_{mix} = \frac{\frac{(1-c)}{c} K_r + mK_r}{\frac{(1-c)}{c} S_r + mS_r} = \frac{K_r[(1-c)/c + m]}{S_r[(1-c)/c + m]} = \frac{K_r}{S_r}$$

Therefore all mixtures regardless of concentration (c) will have a K/S = K/S of the reference and hence all mixture spectral curves will intersect at the point of intersection of the masstone curves.

APPENDIX F

STATISTICAL CORRELATION OF TRISTIMULUS VALUES

Linear Regression: $Y = \alpha + \beta X$

867 Line data X = "Colormaster," Y = Spectrophotometer

945 Line data X = Spectrophotometer, Y = "Colormaster"

DATA	α	β	r^2	N
867 Flat G, R, B 80/20	0.09	1.0299	.976	57
" " " 50/50	-0.130	1.1243	.974	60
" " " " + Al	-0.970	1.1768	.976	63
" " " 20/80	0.80	1.1387	.974	60
" " " " + Al	-0.03	1.1726	.974	63
" " G All	-1.51	1.2292	.985	60
" " G 80/20	-0.12	1.0614	.968	19
" " G 80/20 & 50/50	-0.700	1.1541	.974	39
" High Angle G,R,B 80/20	3.87	0.5806	.960	57
" " " " 50/50	3.93	0.5933	.970	60
" " " " 20/80	4.21	0.5748	.923	60
20/80 + Al	4.08	0.5986	.926	63
945 Flat G	2.82	0.6619	.912	67
" " R	2.98	0.6983	.941	67
" " B	2.10	0.6889	.973	67
" " R'	3.29	0.6779	.956	67
" High Angle G	-2.37	1.8635	.970	67
" " " R	-2.33	1.6604	.903	67
" " " B	-1.74	1.8338	.958	67
" " " R'	-2.21	1.8011	.904	67

Note:

r^2 = (correlation coefficient)^2

N = Number of samples

DISTRIBUTION

		Copy No.
C. W. THEOBALD	- WILM. F&F	1
J. O. GRAVES	- " "	2
C. W. STAHL	- " "	3
R. J. KNAKE	- " "	4
P. J. GRAHAM	- EXP. STA., F. & F.	5
O. H. BULLITT, JR.	- MARSHALL LAB.	6
G. E. LEWIS	- " "	7
G. I. MULHOLLAND	- FLINT DEV. LAB.	8
N. PAPPAS	- MARSHALL LAB.	9
Q. E. LENGEL	- MECHELEN	10
F. W. TROMBLEY	- AJAX	11
R. H. VINING	- PHILA.	12
W. H. EDWARDS	- "	13
W. S. ARMSTRONG	- "	14
P. E. (C.O.S.) FILE		15-16