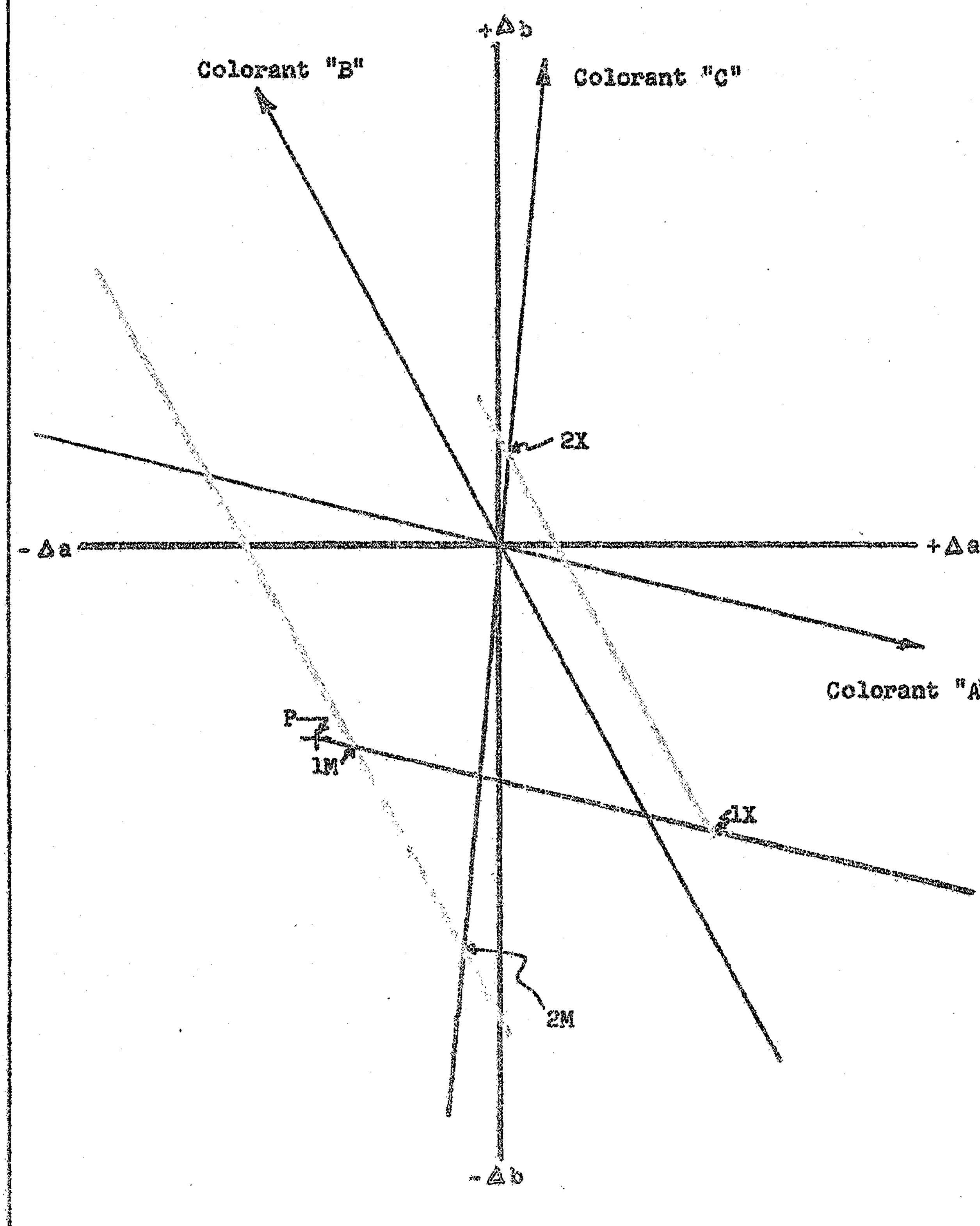
The (2M) intercept in this situation is achieved by **reversing** the direction of the (1M)-Colorant B line and extending **that line** until it intersects the Colorant C vector. This intersection is (2M). (Note Figure XXII.)

Figure XXII



Consider further the problem of selecting the proper Colorant C. Most of the Color Effect Chart will contain vectors representing the three-dimensional color effects of four or five individual colorants. If two of these are selected as Colorants A and B, this leaves only two or three colorants which could be Colorant C. While the third Δ plot (i.e., the one not used to determine points (1M) and (1X) in step 2) will normally give a clear definition of Colorant C, it is possible that the construction of step 3 will show that all of these colorants are intersected in this third Δ plot and should be considered as Colorant C. In this case reference must then be made to the other two Δ plots to determine which of these colorants will produce the desired movement toward the origin in all three Δ plots.

If upon completion of the construction as detailed in steps 1 through 5, any of the colorant adds are found to represent Negative quantities of one of the colorants, the cause usually can be traced to the improper selection of Colorant C. The first move would be to inspect the construction to determine if another Colorant C is feasible. If not, then either some error has been made in the selection of Colorants A and B or a major construction error has occurred.

ONE AND TWO COLORANT CORRECTIONS

While the nature of color adjustment requires a three-color correction at least 99% of the time, it is hypothetically possible in certain cases to have a situation which will require the use of only one or two colorants to adjust the color of the batch to that of the standard. However, these situations are easily identified.

1) One Colorant Correction - will always be required if the batch (Point P) lies on the same colorant vector in all three Δ plots in such a position that the addition of the colorant to point (P) will move the color to the origin of the Δ plot.

2) Two Colorant Correction - will always be required if points (1M) and (1X) of step 2 lie on the Colorant B vector in all three Δ plots in such a position that the addition of Colorant B will move the color to the origin of the Δ plots. Alternately, a two-colorant correction will always be required if point (I) of step 4 lies on the origin of the three Δ plots.

METALLIC COLORS

Metallic colors differ from non-metallic colors in their pigmentation, which is usually composed of transparent colored pigment dispersions and a metallic flake, which acts as a series of small mirrors embedded in the film, reflecting the light entering the film with a high degree of directional intensity. This directional reflectance of the light entering the film produces the phenomenon of "two-tone" which is associated with metallic finishes. "Two-tone" is nothing more than the change in the intensity of light reflected from the film with a change in viewing angle. A modification of the J-3 Glossmeter has been developed to measure two-tone as the intensity difference between light reflected at the angles of maximum and minimum intensity. The use of this instrument to define two-tone in numerical terms is an integral part of the Colorimeter-Chart Color Adjustment System procedure for handling metallic colors. Because of the construction of this instrument, it measures "two-tone" as a function of Lightness (L).

The control of "two-tone" (hereafter referred to as TT) is achieved by adjusting the light scattering power of the film, thereby adjusting the reflectance of the minimum reflectance angle. This control of light-scattering is achieved through the use of a highly light-scattering pigment dispersion, such as Titanium Dioxide white, to compensate for the lot to lot scattering power of the colorants used in the manufacture of the formulation. Color Control of metallic-type finishes means the control of ΔL, Δa and Δb and ΔTT. Basically this is achieved in the same manner previously outlined for controlling ΔL, Δa and Δb for non-metallic colors, with minor system modifications necessary for ΔTT control.

For purposes of instrumental control, there are two separate types of metallic finish. The first type is the conventional metallic color, containing small quantities of white. "Lucite"* Copper metallic (887-93579) is a typical example of this type. The second type of metallic color is a recent innovation of the formulators. In reality, it is a cross-breed between non-metallic formulations and the conventional metallic formulation and is used to obtain an increased saturation over that which can be obtained in conventional metallics. It is unique in that it contains a considerable amount of light-scattering Titanium Dioxide white pigment in the film in order to achieve a degree of saturation which cannot be achieved with conventional metallic films. "Lucite"* Turquoise metallic (887-93946) is a typical example of this type of finish, which is known as a high white-content metallic.

I - HIGH WHITE-CONTENT METALLICS

A: Chart Preparation

The color effect charts used in the color adjustment of high white-content metallics are obtained by the preparation of specific colorant add panels in the same manner previously detailed for non-metallic colors. A typical color of this type is composed of five colorants; i.e., 2 colors, white, black and aluminum and requires the preparation of the following six vector panels plus the standard panel.

(*) Du Pont Registered Trademark

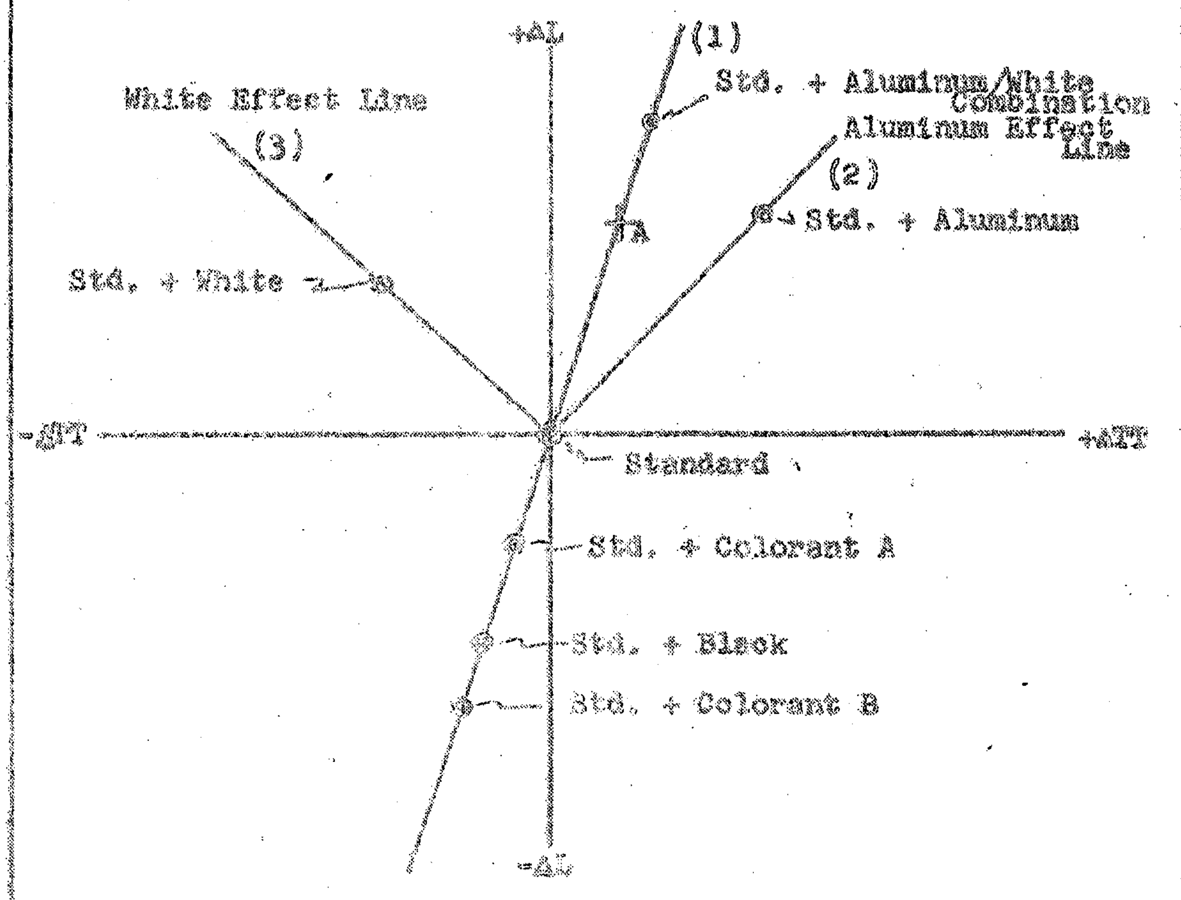
1) Standard plus Colorant A
2) Standard plus Colorant B
3) Standard plus black
4) Standard plus white
5) Standard plus aluminum
6) Standard plus aluminum/white combination found in formula

These panels are read for G, R, B (using the rotating top colorimeter) and π (using the average of 4 readings at 90°, 180°, 270° and 360°.) The π readings should be made first as the panel clips on the colorimeter spinning attachment will mar the panel surface. Calculations are made in terms of ΔL, Δa, Δb and $\Delta \pi$ from standard.

Using the ΔL, Δa, Δb and $\Delta \pi$ information obtained above, the color effect chart is constructed. Four plots are made; namely, $\Delta a \Delta b$, $\Delta L \Delta a$, ΔL Δb and $\Delta \pi L$. Since the first three plots are similar to those obtained in non-metallic colors, the remainder of the discussion will be devoted to the preparation of the ΔL $\Delta \pi$ chart.

FIGURE XXIII

$\Delta\pi\Delta L$ Chart for High White-Content Metallic



The $\Delta\pi\Delta L$ chart is prepared as shown in Figure XXIII. Note that the $\Delta\pi\Delta L$ effect for all panels except the standard plus aluminum and the standard plus white is essentially a straight line. This particular line (1) shows the relationship between lightness and π for this color. In other words, if a given batch is at the $\Delta\pi\Delta L$ point shown by (A), the adjustment of this color to match the standard, using the colorants whose points define the slope of this line, will result in a π match to standard as well as a ΔL, Δa and Δb match.

A second line (2) may be drawn from the $\Delta\pi=0$, $\Delta L=0$ (standard) point through the $\Delta\pi$, ΔL point representing the standard plus aluminum panel. This line, known as the "aluminum effect line" represents the real increase in π which can be obtained in these high white-content metallics by increasing the amount of aluminum in the color without a proportionate increase in the white content.

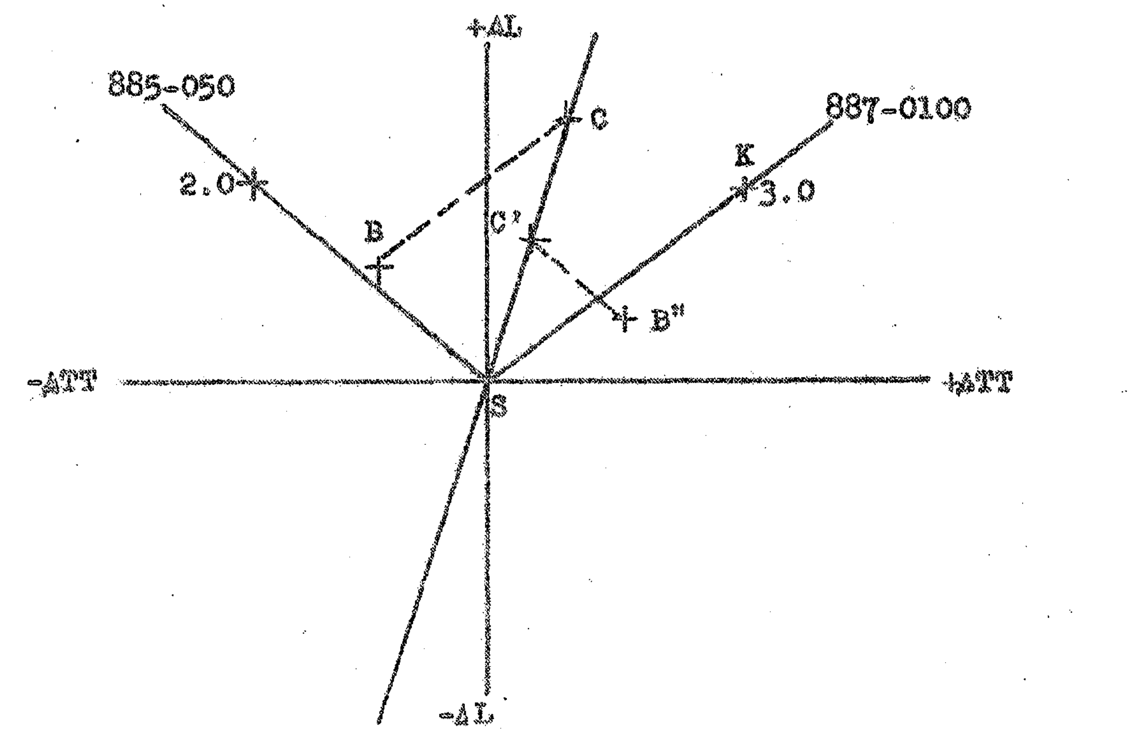
A third line (3) can be drawn from the standard point through the $\Delta\pi$, ΔL point representing the standard plus white panel. This line is known as the "white effect line" and represents the real decrease in π which can be obtained in high white-content metallics by increasing the white content of the color without a proportionate increase in the aluminum content.

B: Chart Use

In high white-content metallics, the π adjustment is made as an integral part of the overall color correction. (Note Figure XXIV.)

FIGURE XXIV

Use of $\Delta\pi\Delta L$ Color Effect Chart For High White-Content Metallics



For example, assume that a batch of this high white-content metallic varied from standard in ΔL, Δa, Δb and ΔT and had a ΔT ΔL value corresponding to point B of Figure XXIV. The following sequence should then be followed:

Step 1: Plot the batch points on the $\Delta a \Delta b$, $\Delta L \Delta a$, $\Delta L \Delta b$ and $\Delta T \Delta L$ plots. This gives the batch point (B) prior to correction.

Step 2: Since point (B) lies on the minus ΔT side of the ΔT, ΔL line for this color, aluminum tinting (887-0100) will be required to increase the ΔT to the level shown by the ΔT ΔL line for the color. Draw a line from point (B) parallel to and in the direction of the aluminum effect line (887-0100) until it intersects the ΔT ΔL line for the color at point (C). (Note red construction in Figure XXIV.)

Step 3: Using the variable spring scale of the Colorimeter-Chart Plotting Device, set the scale to measure 1.00 units (10 on scale) between the standard point (ΔT =0, ΔL=0) and the calibration point (3.0) on the 887-0100 line. Measure the length of the line from (B) to (C) as a decimal portion of the scale calibration (i.e., distance BC = 0.75 of distance SK).

Step 4: In the $\Delta a \Delta b$, $\Delta L \Delta a$ and $\Delta L \Delta b$ plots, draw a line from point (B) parallel to and in the direction of the 887-0100 vector. In each of these plots set the variable spring scale to read 1.00 units at full vector calibration of the 887-0100 vector and lay off a distance on the line drawn from point (B) equivalent to the distance found in step 3 (i.e., 0.75 of the length of the 887-0100 vector calibration in this case). Label this point (B').

Step 5: From point (B') established in step 4, construct a normal color correction plot, using the same procedures outlined for non-metallic color correction. DO NOT USE EITHER THE WHITE (885-050) OR THE ALUMINUM (887-0100) VECTORS IN THIS STEP. USE THE COMBINATION ALUMINUM/WHITE COMBINATION VECTOR WHERE NECESSARY. The aluminum and white vectors are shown in the $\Delta a \Delta b$, $\Delta L \Delta a$ and $\Delta L \Delta b$ plots merely for shifting the batch (B) point for the T correction (i.e., from B to B').

Using the above technique, it is obvious that the overall color adjustment for this type of color will be composed of four colorants, either aluminum or white will be for the purpose of ΔT adjustment and the other three for color adjustment. If the combination aluminum/white colorant combination is used for color correction, it must, of course, be split into its individual components for colorant tinting strength correction and actual addition to the batch.

In the specific case just detailed, the batch was, at (B) in Figure XXIV, i.e., low in TT. If it had been at (B") it would have been high in TT and would then have required a white (885-050) adjustment from (B") to (C') to reduce the TT prior to the color adjustment.

II - LOW WHITE-CONTENT METALLICS

A: Chart Preparation

Hypothetically, there should be no difference in the type of color effect chart prepared for high white-content metallics and those prepared for low white-content metallics. In actual practice, however, there is a difference, due primarily to the effect of the small amounts of white on the color. Small amounts of white tend to obscure the mirror effect of the metallic flake more rapidly through scattering the light than it will raise the lightness of the color. The resultant color change is a decrease in lightness brought about by a reduction in the directional intensity of the light reflected from the film because the light is now partially diffused. Because of this effect, there is no consistent color direction for white addition to a low white-content metallic and the system described earlier for high white-content metallics is not feasible.

On this basis, the color effect chart is prepared from the following panels plus the standard panel.

1) Standard plus Colorant A
2) Standard plus Colorant B
3) Standard plus black
4) Standard plus aluminum
5) Standard plus white (2 levels)

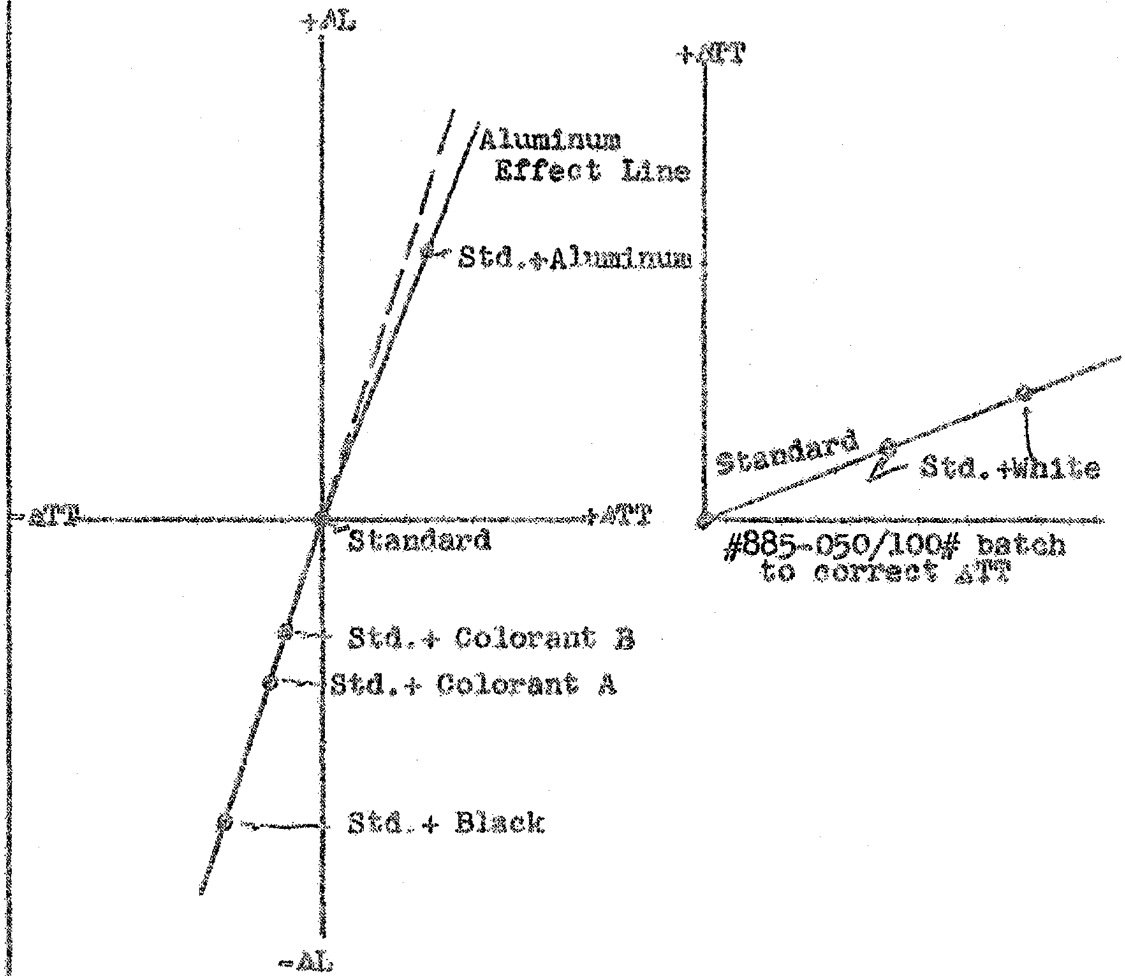
Of the above panels, panels number 5 violate the rule on the extent of colorant add. The amount of white used in preparing these panels is equivalent to the amount of white in the formula and half that amount.

These panels are read for G, R and B using the rotating colorimeter attachment and for TT using the average of 4 TT measurements made at 90°, 180°, 270° and 360°. The white add panels are read only for TT.

Using the ΔL, Δa, Δb and ΔTT information thus obtained, the Δa Δb, ΔL Δa, ΔL Δb and a special ΔTT chart are prepared. The white data is only used for the ΔTT chart which is constructed as shown in Figure XXV.

FIGURE XXV

ΔTTΔL Chart for Low White-Content Metallic Color



In the case of low white-content metallics the aluminum effect line lies very close to the slope of the ΔTTΔL line produced by the ΔTT,ΔL points obtained with the standard and the standard plus colorant (except aluminum) panels. In many formulations the aluminum effect line may actually coincide with this other line, particularly if the formulation calls for very little white. In any case, the proximity of the aluminum effect line shows clearly that it is extremely difficult to increase the real TT of a low white-content metallic.

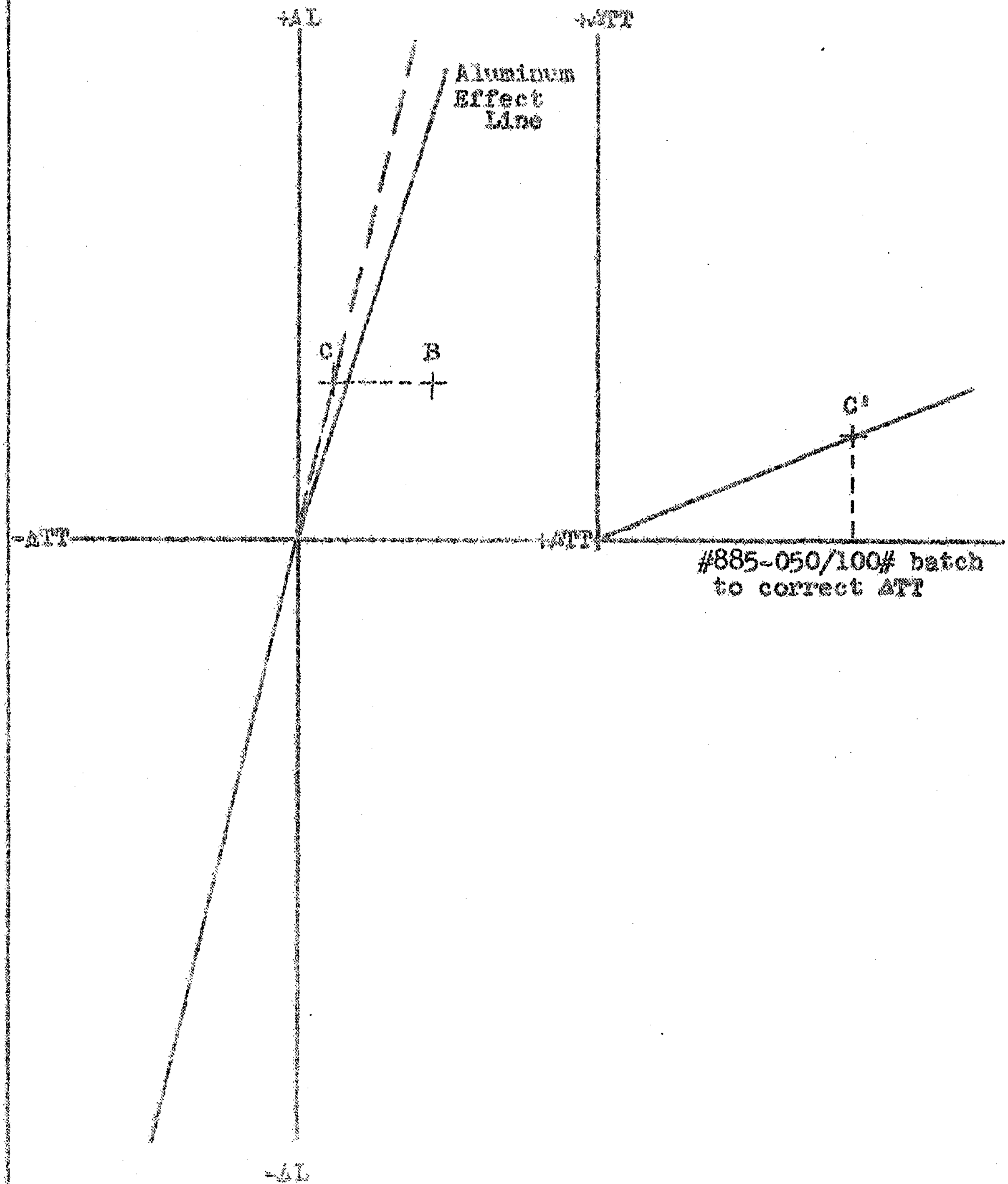
B: Chart Use

The use of the color effect chart in the adjustment of low white-content metallics varies somewhat from the technique previously described for high white-content metallics, primarily because of the differences in the ΔTT plots. The procedure involved is detailed below:

Step 1: Plot the batch (B) in terms of the Δa Δb, ΔL Δa, ΔL Δb and ΔTTΔL plots. (Note Figure XXVI for plot of ΔTTΔL.)

Use of ΔTTΔL Chart
Low White-Content Metallic Colors

FIGURE XXVI



Step 2: Using the ΔTTΔL plot, determine the ΔTT distance from point (B) to point (C) which is on the ΔTT vs. ΔL line for this color at the lightness (ΔL) of the batch. If point (B) is on the negative ΔTT side of this line, the batch must be reworked as outlined in the section on rework procedures.

Step 3: Using the ΔTT distance determined in step 2, and the ΔTT vs. white portion of the ΔTT plot, determine the amount of white necessary to adjust the ΔTT of the batch to zero.

Step 4: Starting at the batch point originally plotted (B), adjust the color difference between the batch and standard in the conventional manner previously detailed for non-metallic colors. Note that in most cases no adjustment is made of the original batch point (B) to compensate for the addition of the ΔTT white correction. This is primarily because the white does not have a predictable effect on the ΔL, Δa and Δb directions. This shortcoming is overcome by using a loading formula which contains a reasonable proportion of the white in the formula. This loading formula should hold out sufficient white to put the batch charge on the right side of the ΔTTΔL line. Loading a batch in this manner will insure that the ΔTT white correction will be relatively small and thus limit its effect on the ΔL, Δa and Δb of the batch while correcting its ΔTT deficiency.

Step 5: As in the case of the high white-content metallic colors discussed earlier, the overall color correction of a low white-content metallic involves a four color component adjustment; white, for ΔTT correction plus the three colorants involved in the color correction.

BATCH MANUFACTURE TECHNIQUES FOR OPTIMUM RESULTS

The use of the Colorimeter-Chart Color Adjustment System will result in increased color adjustment productivity and increased plant capacity due to more rapid mixer turnover when compared to current visual color adjustment techniques. These advantages can be further enhanced through plant operation on a fixed formulation basis, eliminating the individual batch preformulation inherent in certain phases of our industry. Even greater advantage can be attained if the fixed formulation considers all of the colorimetric factors inherent in the effective operation of the system. Foremost of the factors which must be considered is the lot to lot variation inherent in the manufacture of standardized single pigment colorants.

The effectiveness of any color adjustment system is measured by its rate of productivity and the amount of rework it creates. The basic problem in the manufacture of blended colors resolves into two incompatible criteria.

1) Manufacture of the greatest percentage of initially "O.K. on Load" batches.

2) The amount of the colorants used to adjust the color of a batch to that of the standard must be kept to a minimum to avoid rework.

These two criteria are basically incompatible since, under most conditions, emphasis on one will result in the violation of the other criteria. To illustrate this point, consider the case of a light and saturated color containing over 90% white. Manufacture of this color on a fixed formulation designed to match the color standard with standard colorants will produce a number of "O.K. on Load" batches, the percentage being dependent upon the reproducibility of the individual colorants and the tightness of the allowable color tolerance. However, there will be an inherent number of off-color batches requiring color adjustment to the standard. Some of these off-color batches will be darker than standard. Such a batch will require the addition of several hundred parts of white per 100 parts of the charged batch to adjust the lightness of the batch to that of the standard and will create a considerable volume of rework.

How then can these opposite objectives be reconciled and still result in production operation on a fixed formulation basis? The answer is found in a consideration of the colorant formulation and the basic commercial color tolerance of the specific color. If the commercial color tolerance is relatively tight, as in the case of automotive finishes, and the color formulation contains a preponderance of one of the colorants, the emphasis should be on <u>adjusting the color of each batch to standard</u> with a minimum quantity of colorants.

This effect can be achieved, on a fixed formulation basis, by using a fixed formulation which is deliberately off-color from the standard in the specific direction which will allow the color of the batch to be adjusted to standard with a minimum colorant volume add. This formulation will normally contain a slight excess of the predominant colorant and at the same time be "short" on the black colorant.

Certain color formulations are not critical with respect to any of the colorants involved in the blend, i.e., a slight overcharge of any one of the colorants can be readily rectified with small quantities of the remaining colorants. These colors should be blended on a fixed formulation designed to give a direct color match to the standard.

Some blended color lines are manufactured to a commercial color tolerance which is rather broad by comparison with automotive color tolerances for the same color. If this range of color tolerance for the color exceeds the lot to lot color variation inherent in the manufacture of the individual colorants making up the color blend, the color may be loaded on a colorant formulation designed to match the color standard with standard lots of the colorants. Under this system, the bulk of the batches will be within an acceptable color variation of the standard and require no color adjustment. However, there is always the inherent risk of an occasional batch of a critical formulation being outside the acceptable color variation and requiring an extensive amount of the colorants for color adjustment.

HANDLING EXCESS "TRACE" COLORANTS

As long as the color formulations which are to be graphically color controlled contain only four pigments (including white) for a non-metallic color and five pigments (including white and aluminum) for a metallic color, there is no danger of obtaining a metameric color match. However, a considerable number of our current color offerings contain one or more extraneous pigments, usually in trace quantities. To avoid the possibility of a metameric color match, it is necessary to have these trace pigments present in each batch. In order to do this, the proper amount of the trace colorants should be charged in the fixed batch formulation prior to any color adjustment.

Many formulas will contain the minimum number of pigments as defined above with one or more of the colorants in trace quantities. In this case, these "trace" colorants are not extraneous. The fixed formulation used for charging the batch, under these conditions, will not include any of the non-extraneous "trace" colorants but will use them for color adjustment.

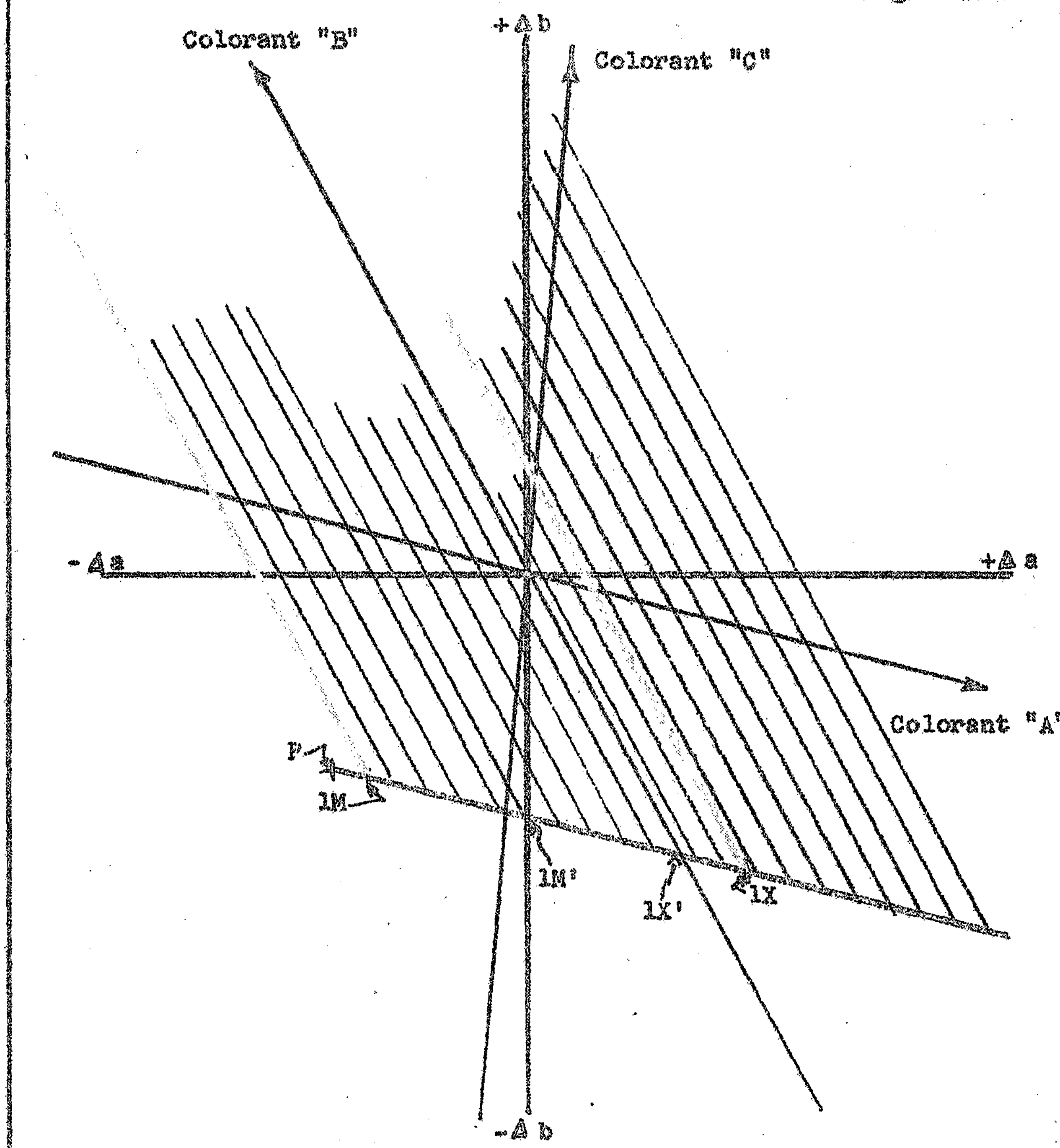
TABLE II

N_c	N	N_c	N	N_c	N	N_c	N
0.00	0.000	0.50	0.399	1.00	0.744	1.50	1.058
0.01	0.008	0.51	0.406	1.01	0.751	1.51	1.064
0.02	0.015	0.52	0.412	1.02	0.757	1.52	1.070
0.03	0.023	0.53	0.419	1.03	0.764	1.53	1.076
0.04	0.032	0.54	0.426	1.04	0.771	1.54	1.081
0.05	0.041	0.55	0.434	1.05	0.778	1.55	1.087
0.06	0.049	0.56	0.441	1.06	0.784	1.56	1.093
0.07	0.058	0.57	0.448	1.07	0.791	1.57	1.099
0.08	0.066	0.58	0.455	1.08	0.798	1.58	1.105
0.09	0.075	0.59	0.463	1.09	0.805	1.59	1.111
0.10	0.083	0.60	0.470	1.10	0.811	1.60	1.116
0.11	0.092	0.61	0.477	1.11	0.818	1.61	1.122
0.12	0.100	0.62	0.484	1.12	0.824	1.62	1.127
0.13	0.108	0.63	0.492	1.13	0.831	1.63	1.133
0.14	0.116	0.64	0.499	1.14	0.837	1.64	1.138
0.15	0.124	0.65	0.506	1.15	0.844	1.65	1.144
0.16	0.132	0.66	0.513	1.16	0.850	1.66	1.149
0.17	0.140	0.67	0.520	1.17	0.856	1.67	1.155
0.18	0.148	0.68	0.527	1.18	0.862	1.68	1.161
0.19	0.156	0.69	0.534	1.19	0.869	1.69	1.167
0.20	0.164	0.70	0.541	1.20	0.875	1.70	1.172
0.21	0.172	0.71	0.548	1.21	0.882	1.71	1.178
0.22	0.180	0.72	0.555	1.22	0.888	1.72	1.184
0.23	0.189	0.73	0.563	1.23	0.894	1.73	1.190
0.24	0.197	0.74	0.570	1.24	0.900	1.74	1.196
0.25	0.205	0.75	0.577	1.25	0.907	1.75	1.202
0.26	0.213	0.76	0.584	1.26	0.913	1.76	1.207
0.27	0.221	0.77	0.591	1.27	0.920	1.77	1.213
0.28	0.229	0.78	0.598	1.28	0.926	1.78	1.218
0.29	0.237	0.79	0.605	1.29	0.932	1.79	1.224
0.30	0.245	0.80	0.612	1.30	0.938	1.80	1.229
0.31	0.253	0.81	0.619	1.31	0.945	1.81	1.235
0.32	0.260	0.82	0.626	1.32	0.951	1.82	1.240
0.33	0.268	0.83	0.633	1.33	0.957	1.83	1.246
0.34	0.276	0.84	0.640	1.34	0.962	1.84	1.252
0.35	0.284	0.85	0.647	1.35	0.968	1.85	1.258
0.36	0.291	0.86	0.653	1.36	0.974	1.86	1.263
0.37	0.299	0.87	0.659	1.37	0.980	1.87	1.269
0.38	0.307	0.88	0.665	1.38	0.985	1.88	1.274
0.39	0.315	0.89	0.672	1.39	0.991	1.89	1.280
0.40	0.322	0.90	0.678	1.40	0.997	1.90	1.285
0.41	0.330	0.91	0.684	1.41	1.004	1.91	1.291
0.42	0.337	0.92	0.692	1.42	1.010	1.92	1.297
0.43	0.345	0.93	0.698	1.43	1.016	1.93	1.303
0.44	0.353	0.94	0.704	1.44	1.022	1.94	1.308
0.45	0.361	0.95	0.711	1.45	1.028	1.95	1.314
0.46	0.368	0.96	0.718	1.46	1.034	1.96	1.319
0.47	0.376	0.97	0.725	1.47	1.040	1.97	1.324
0.48	0.383	0.98	0.731	1.48	1.046	1.98	1.329
0.49	0.391	0.99	0.738	1.49	1.052	1.99	1.335
0.50	0.399	1.00	0.744	1.50	1.058	2.00	1.340

N_c	N	N_c	N	N_c	N	N_c	N
2.00	1.340	2.50	1.599	3.00	1.838	3.50	2.057
2.01	1.346	2.51	1.604	3.01	1.843	3.51	2.062
2.02	1.352	2.52	1.609	3.02	1.848	3.52	2.066
2.03	1.358	2.53	1.615	3.03	1.852	3.53	2.070
2.04	1.364	2.54	1.620	3.04	1.857	3.54	2.074
2.05	1.369	2.55	1.625	3.05	1.862	3.55	2.079
2.06	1.375	2.56	1.630	3.06	1.867	3.56	2.083
2.07	1.381	2.57	1.635	3.07	1.871	3.57	2.087
2.08	1.386	2.58	1.640	3.08	1.877	3.58	2.091
2.09	1.391	2.59	1.645	3.09	1.881	3.59	2.096
2.10	1.396	2.60	1.649	3.10	1.886	3.60	2.100
2.11	1.401	2.61	1.654	3.11	1.890	3.61	2.104
2.12	1.406	2.62	1.659	3.12	1.894	3.62	2.109
2.13	1.411	2.63	1.664	3.13	1.899	3.63	2.113
2.14	1.416	2.64	1.668	3.14	1.903	3.64	2.118
2.15	1.421	2.65	1.673	3.15	1.908	3.65	2.122
2.16	1.427	2.66	1.678	3.16	1.912	3.66	2.127
2.17	1.432	2.67	1.682	3.17	1.916	3.67	2.131
2.18	1.437	2.68	1.687	3.18	1.921	3.68	2.135
2.19	1.442	2.69	1.692	3.19	1.925	3.69	2.139
2.20	1.448	2.70	1.696	3.20	1.930	3.70	2.143
2.21	1.453	2.71	1.701	3.21	1.934	3.71	2.148
2.22	1.458	2.72	1.706	3.22	1.938	3.72	2.152
2.23	1.463	2.73	1.711	3.23	1.942	3.73	2.156
2.24	1.468	2.74	1.716	3.24	1.946	3.74	2.160
2.25	1.473	2.75	1.720	3.25	1.950	3.75	2.164
2.26	1.478	2.76	1.725	3.26	1.954	3.76	2.168
2.27	1.483	2.77	1.730	3.27	1.959	3.77	2.172
2.28	1.488	2.78	1.735	3.28	1.963	3.78	2.176
2.29	1.493	2.79	1.739	3.29	1.967	3.79	2.180
2.30	1.498	2.80	1.744	3.30	1.971	3.80	2.184
2.31	1.503	2.81	1.749	3.31	1.976	3.81	2.188
2.32	1.508	2.82	1.754	3.32	1.980	3.82	2.192
2.33	1.513	2.83	1.759	3.33	1.984	3.83	2.196
2.34	1.518	2.84	1.764	3.34	1.989	3.84	2.199
2.35	1.523	2.85	1.769	3.35	1.993	3.85	2.203
2.36	1.528	2.86	1.773	3.36	1.998	3.86	2.207
2.37	1.533	2.87	1.778	3.37	2.002	3.87	2.211
2.38	1.538	2.88	1.782	3.38	2.006	3.88	2.215
2.39	1.543	2.89	1.787	3.39	2.011	3.89	2.219
2.40	1.548	2.90	1.792	3.40	2.015	3.90	2.223
2.41	1.553	2.91	1.797	3.41	2.019	3.91	2.227
2.42	1.558	2.92	1.802	3.42	2.023	3.92	2.231
2.43	1.563	2.93	1.806	3.43	2.028	3.93	2.235
2.44	1.568	2.94	1.811	3.44	2.032	3.94	2.239
2.45	1.573	2.95	1.815	3.45	2.036	3.95	2.243
2.46	1.578	2.96	1.820	3.46	2.040	3.96	2.247
2.47	1.583	2.97	1.824	3.47	2.044	3.97	2.251
2.48	1.589	2.98	1.829	3.48	2.049	3.98	2.255
2.49	1.594	2.99	1.833	3.49	2.053	3.99	2.300
2.50	1.599	3.00	1.838	3.50	2.057	4.00	2.304

DUP030002532

Figure XXI



Since points (1M') and (1X') are not directly available from the construction of steps 1 through 3, it is necessary to obtain the two intersections on the Colorant C line by other means. In the specific case shown in Figure XXI, the (1X)-Colorant B line intersects the Colorant C vector on the wrong side of the origin. In view of the infinite number of parallel lines which could exist, this may be considered as a valid (2X) intersection. The line from point (1M) parallel to and in the direction of the Colorant B does not intersect Colorant C at any point. How then can a suitable (2M) intercept be achieved?

FIGURE XX

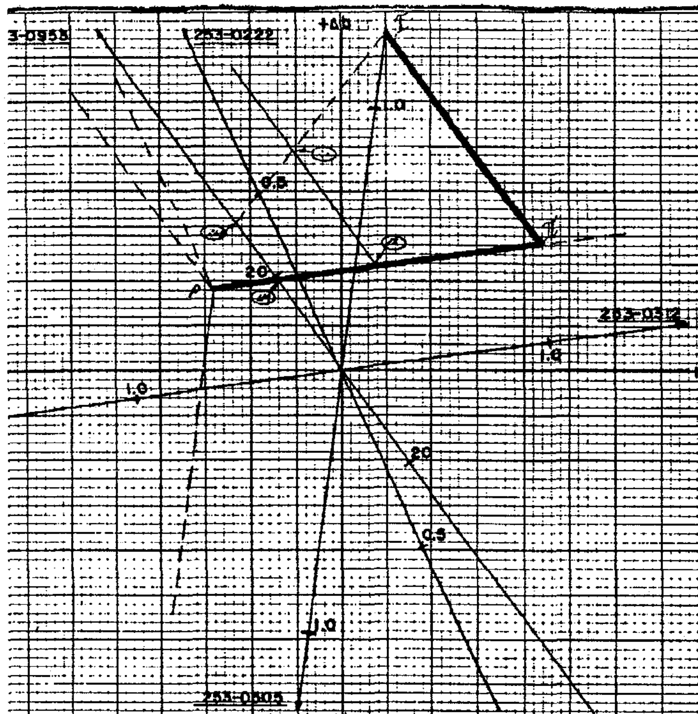
253-100000

CODE	%	ΔL	Δa	Δb
253-0953	20	+ 2.56	− 0.74	+ .04
253-0505	1	+ 2.25	− 0.38	−2.91
253-0312	1	− 2.01	+ 2.28	+0.33
253-0222	0.5	− 1.00	− 0.90	+ .97

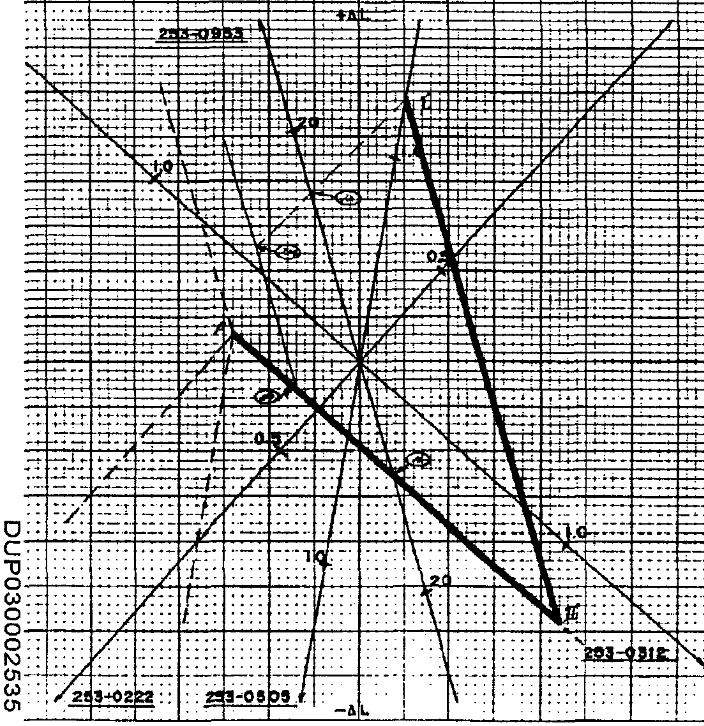
STANDARD

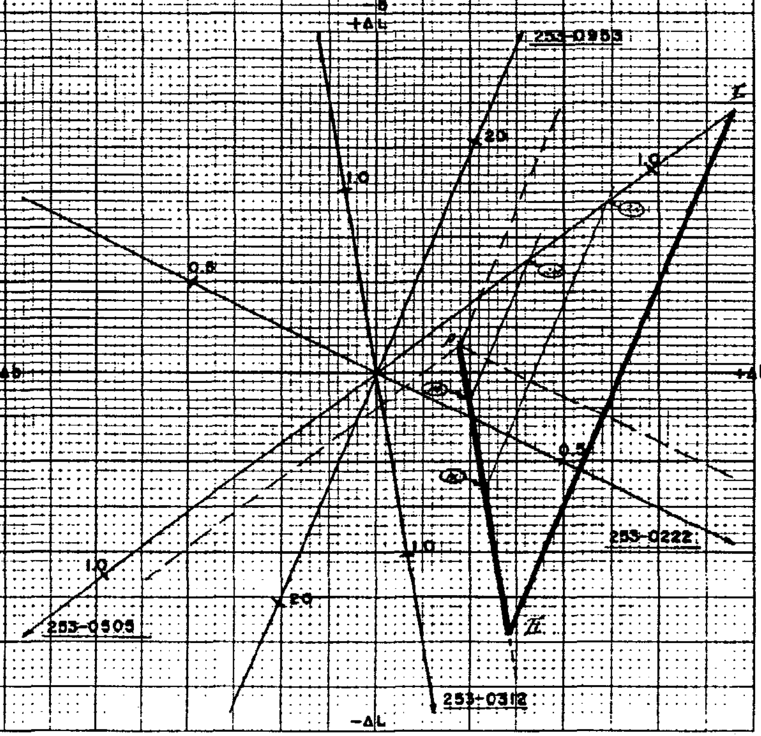
G=20.98 R=18.38 B=41.94

SCALE : 1 inch (10 divisions) = 1 NBS UNIT



30 STD (L=51.32)





Inspection of this tabulation indicates two situations exist:

1) No useable color vectors are crossed by the same colorant effect line in each of two Δplots.

2) One of the four colorant effect lines (253-0222) does not cross any useable colorant vector in any of the Δ plots. In turn, its colorant vector is not crossed in the useable position by any of the other colorant vectors.

The significance of the second situation is by far the most important. When one of the component colorants is not involved in any way in the table of useable colorant vectors, it means that this specific colorant (253-0222) will not be utilized in the color adjustment. This, in turn, means that the remaining three colorants (253-0953, 253-0312, and 253-0505) are colorants A, B and C, the order depending on which one we use to start with.

In this specific case, 253-0312 was arbitrarily chosen as colorant A and the graphical construction was started on the ΔL Δa plot. From the table of useable colorants (Figure XIX) it can be seen that this approach fixes 253-0953 as colorant B, leaving 253-0505 as colorant C. Lines are drawn in all three Δplots parallel to and in the direction of the Colorant A vector. (Note red line in Figure XX.) This line in the Δa Δb plot also crosses the colorant B (253-0953) vector but on the wrong side of the origin of the plot to be picked up in the table of useable colorant vectors (Figure XIX). This point is marked (1M) and used just as if it had been a useable intercept. The remaining graphical construction procedure is carried out as per steps 1 through 6. (Figure XX)

SELECTION OF COLORANT C

The bulk of the difficulties inherent in the use of the Colorimeter-Chart Color Adjustment System result from the improper selection of Colorant C in step 3 (note page IV-28). This improper selection usually results from an unusual circumstance of construction which does not provide a positive intersection of the (1M)-Colorant B or (1X)-Colorant B line with the Colorant C vector when the mechanics of step 3 are followed. In any consideration of the selection of Colorant C, it must be remembered that the lines drawn, in step 3, from points (1M) and (1X) parallel to and in the direction of the vector representing Colorant B are only two of an infinite number of lines which could be drawn from the Colorant A line. (Note Figure XXI.) If all of these lines are drawn, it can then be seen that the lines parallel to the Colorant B vector will intersect the Colorant C vector on the right side of the origin only if they originate on the Colorant A line at a point intermediate between points (1M') and (1X').

FIGURE XVII

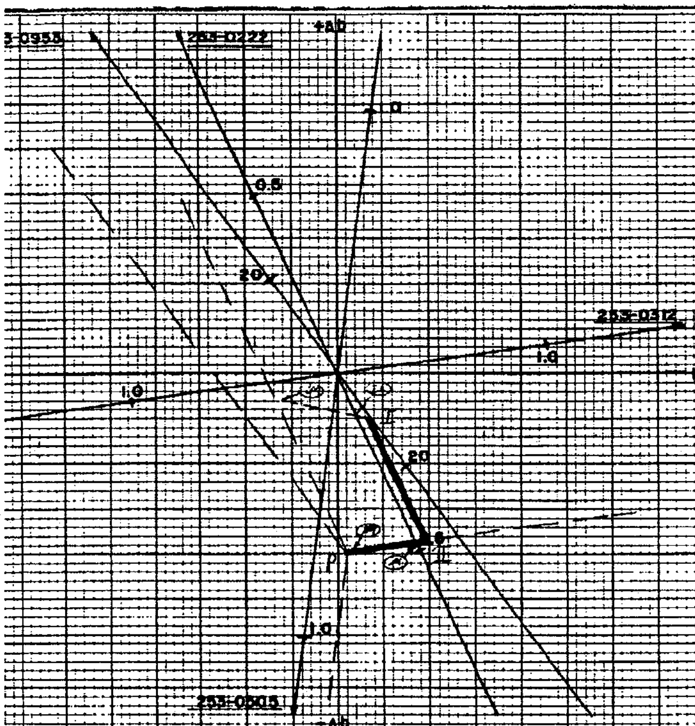
253-100000

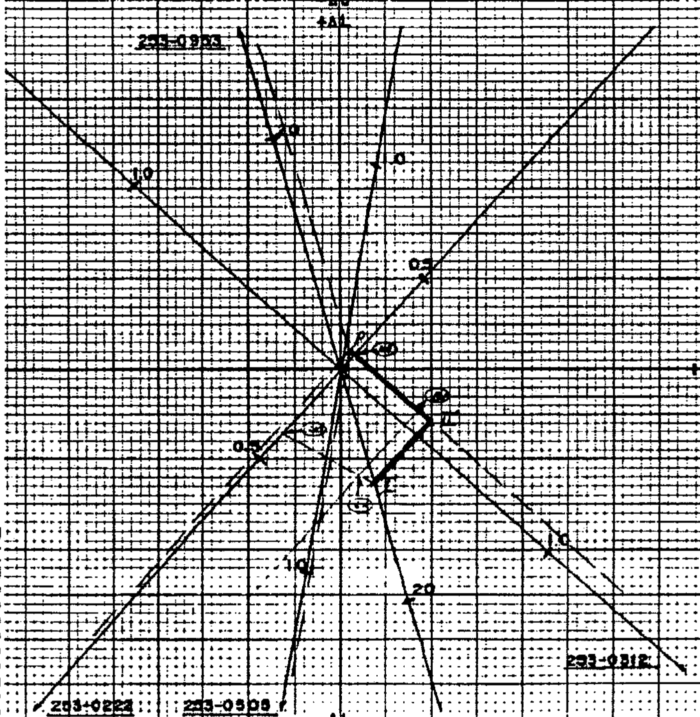
CODE	%	ΔL	Δa	Δb
253-0953	2.0	+ 2.56	- 0.74	+ 1.04
253-0505	1	+ 2.25	- 0.38	- 2.91
253-0312	1	- 2.01	+ 2.28	+ 0.33
253-0222	0.5	- 1.00	- 0.90	+ 1.97

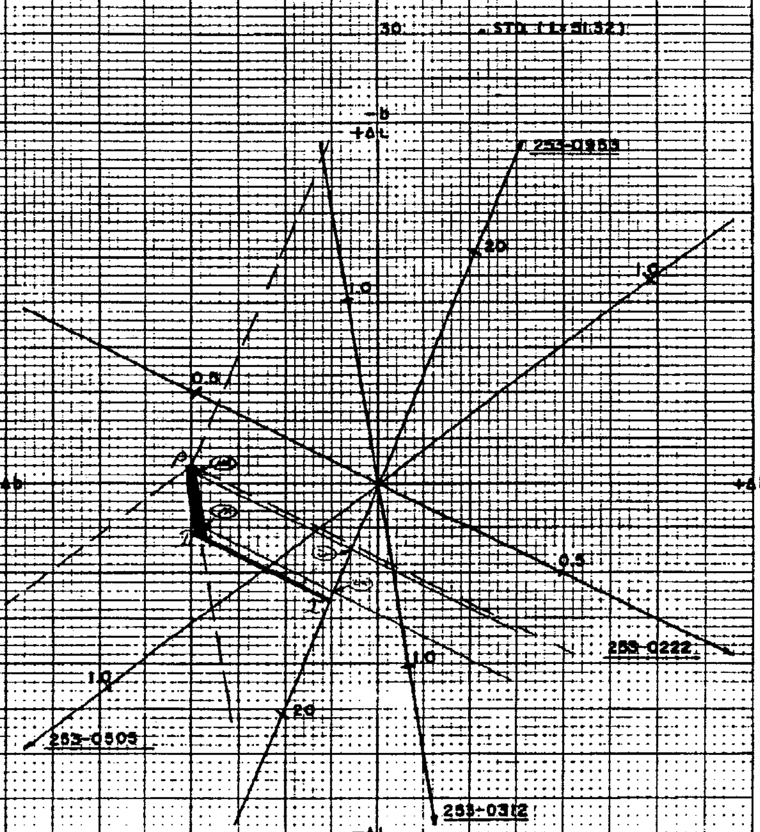
STANDARD

G = 20.98　R = 18.38　B = 41.94

SCALE : 1 inch (10 divisions) = 1 NBS UNIT



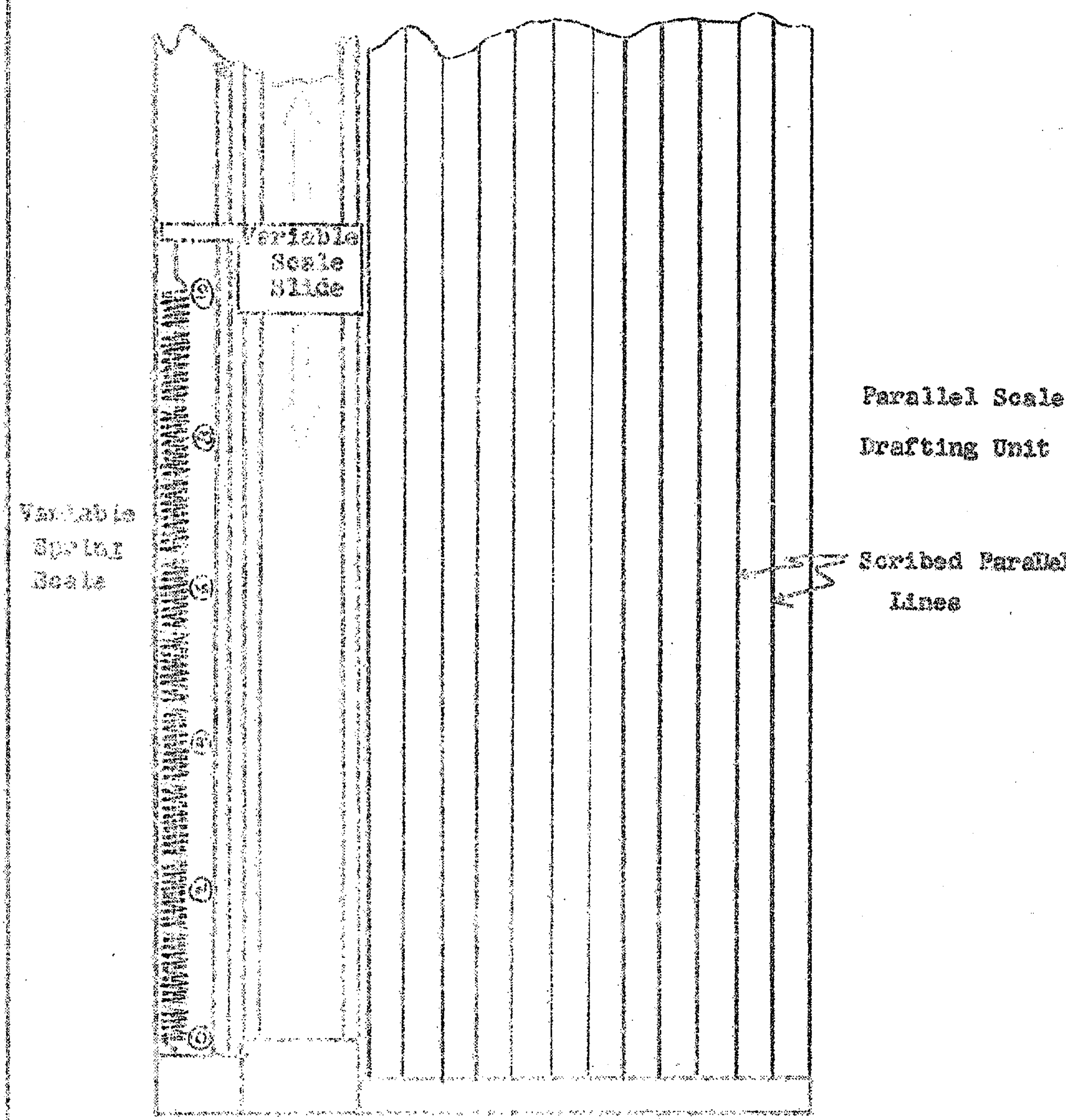




DUP030002538

Figure XII

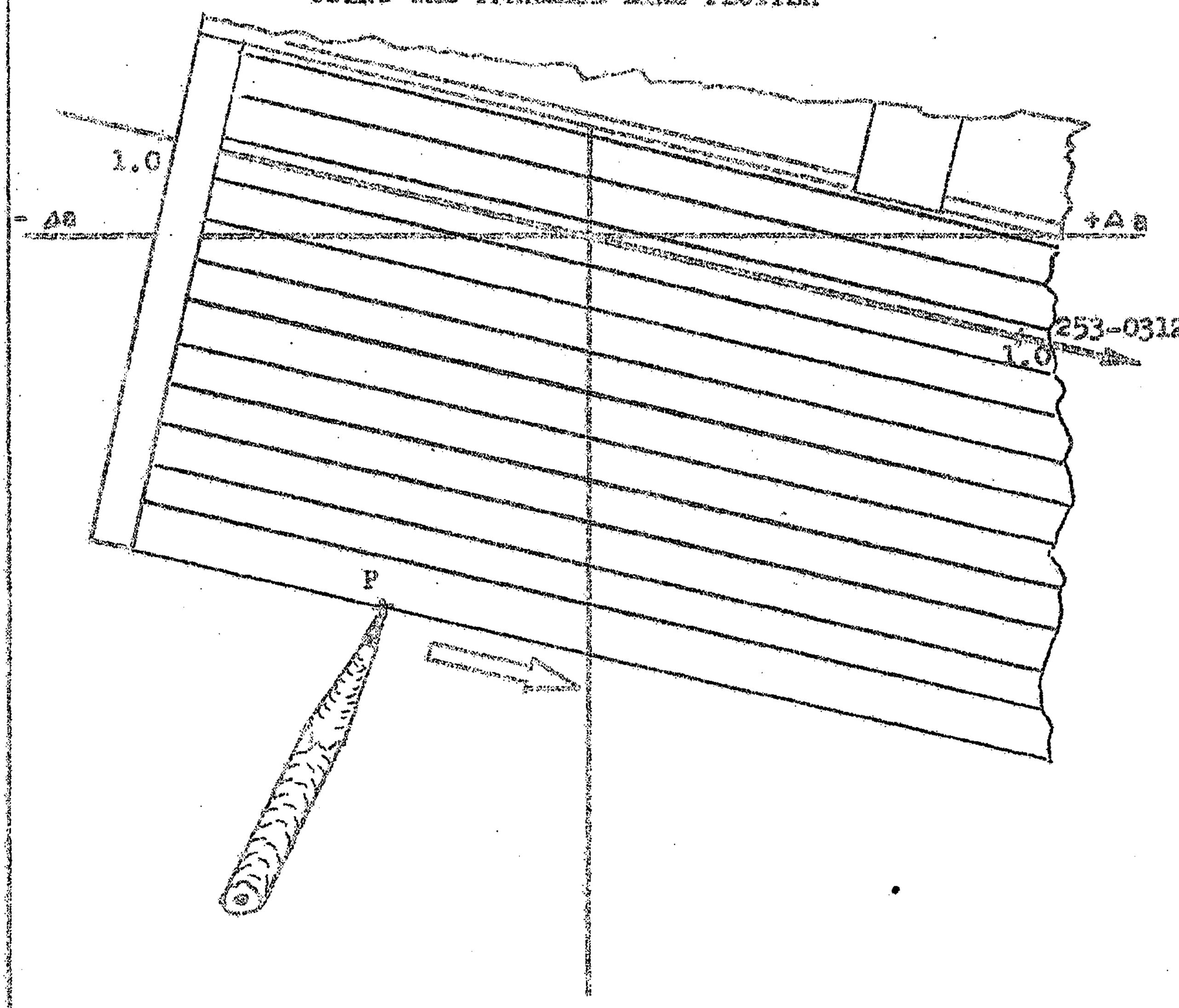
THE [illegible] CHART PLOTTING DEVICE



The use of the device in drawing parallel lines is very simple. Assume that from point (P), it is desired to draw a line parallel to the vector representing Colorant A (Red line in Figure XIII). Place a pencil on point (P) and slide the plotting device so that the drawing edge is against the pencil point. Rotate the plotting device until the Colorant A vector is aligned between and visually parallel to two of the scribed lines on the plotting device. The desired line can then be drawn by moving the pencil along the drawing edge. (Note Figure XIII)

Figure XIII

USING THE PARALLEL LINE PLOTTER



Occasionally the distance between point (P) and the Colorant A vector is so great that the vector cannot be lined up between two of the lines scribed on the plotting device. In this specific case the following procedure is followed: Place the plotting device on the chart so that one of the scribed lines furtherest from the drawing edge coincides with the colorant vector. Then draw a line along the plotting edge which is parallel to the original colorant vector. Repeat this procedure using the parallel line just drawn until the parallel line approaches the location of point (P) closely enough that the previously described technique can be utilized.

The variable scale of the plotting device is used to measure the length of a line in relation to the length of a calibrated vector. There are two separate methods for using this scale:

1) Calibrated vector longer than line to be measured. Place the scale side of the plotting device closely alongside of the Colorant A vector (Red line in Figure XIV) so that the scale is parallel to the vector. Place the zero (0) end of the scale on the intersection of the coordinate axis and, using the scale slide, extend the variable scale until the full scale indicator (10) is equivalent to the calibration marking on the vector (1.0 in the specific case of Figure XIV). Since full scale then equals 1.0 parts of the colorant per 100 parts of the batch, each increment of this scale will represent 0.01 parts of the colorant per 100 parts of the batch.

When the scale has been set to the calibration of the vector, the next step is to measure the length of the line which is to be defined in terms of the colorant calibration. To do this, place the plotting device without adjusting the scale so that the zero end of the variable scale coincides with one end of the line and the scale is parallel to the line. Read the increment of the scale corresponding to the other end of the line. In the specific case of Figure XIV, the length of the line corresponds to 71 increments. Since full scale or 100 increments is, in this case, equal to 1.0 parts of colorant A per 100 parts of the batch, the length of the line corresponds to:

$$C = L\left(\frac{V_c}{S_v}\right) = L \times \frac{V_c}{S_v} \quad \ldots\ldots \text{(IV-8)}$$

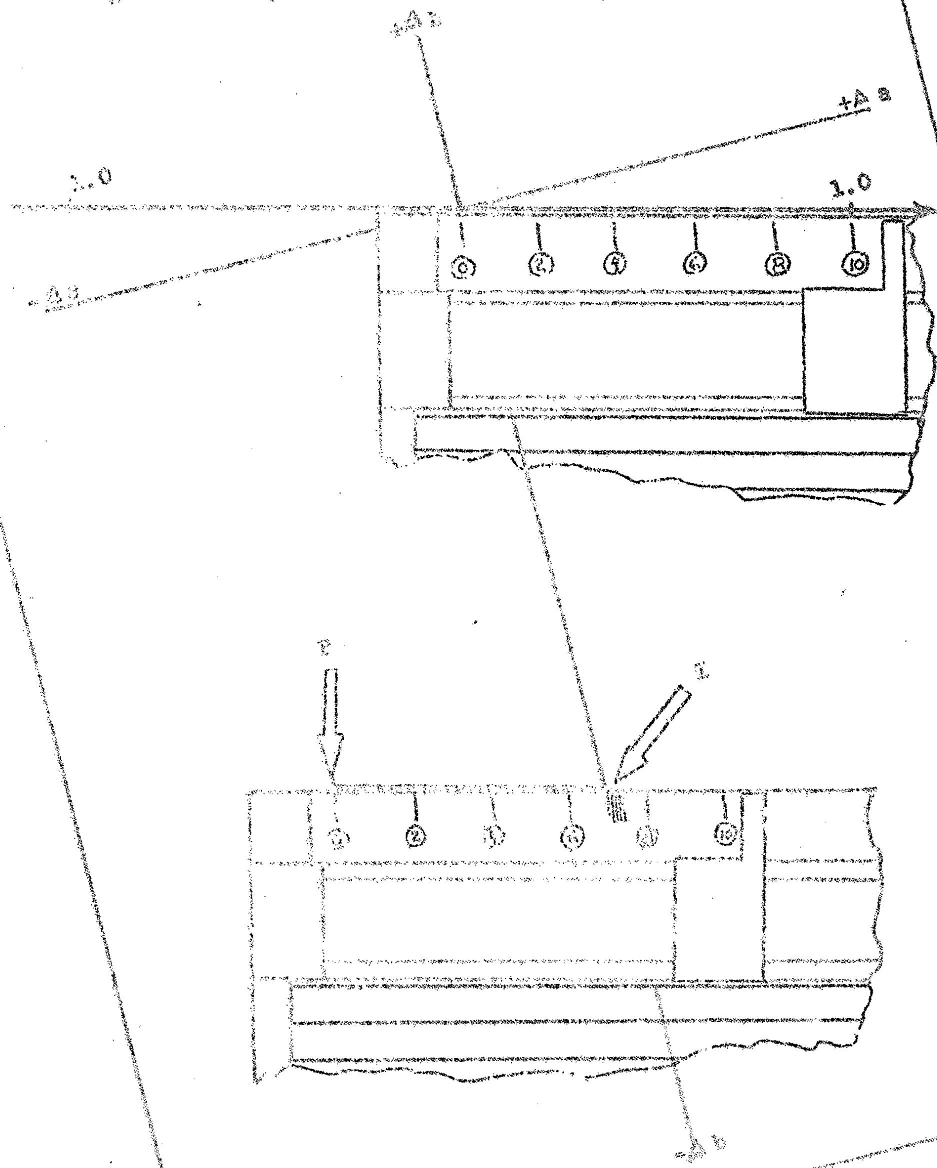
$$C = 71\left(\frac{1.0}{100}\right) = 0.71 \text{ parts of colorant per 100 parts of batch}$$

Where:

L = Length of line in scale increments
V_c = Calibration of vector in parts colorant/100 parts batch
S_v = Scale reading equivalent to calibration of vector
C = parts of colorant per 100 parts of batch

Figure XIV

MEASURING [illegible] CALIBRATION OF [illegible] VECTOR



2) <u>Calibrated vector shorter than vector to be measured.</u> Occasionally, a line will be longer than the length of the calibrated vector. This problem is handled by extending the variable scale so that the length of the calibrated vector is represented not by 100 increments but by some lesser amount. The set point of the vector calibration is usually determined by the extent to which the vector calibration must be multiplied to encompass the length of the line it is desired to measure. The following tabulation is given as a handy guide:

To expand Vector Scale by:	Use Index of:
2.0	50
2.5	40
4.0	25
5.0	20
10.0	10

For example, if the length of the line to be measured is between one and two times the length of the calibrated vector, the 50 increment line of the scale would be set equivalent to the length of the calibrated vector. (Note Figure IV)

The procedure for measuring the length of the line in terms of the colorant calibration remains the same. Without adjusting the scale of the plotting device, place the zero point (0) at one end of the line and measure the length of the line in terms of the scale increments. For example, assume the line measures 85 increments long. The length of this line, expressed in terms of parts of colorant per 100 parts of batch as calculated from equation IV-8 would be:

$$C = 85\left(\frac{1.0}{50}\right) = 1.70 \text{ parts of colorant/100 parts of batch}$$

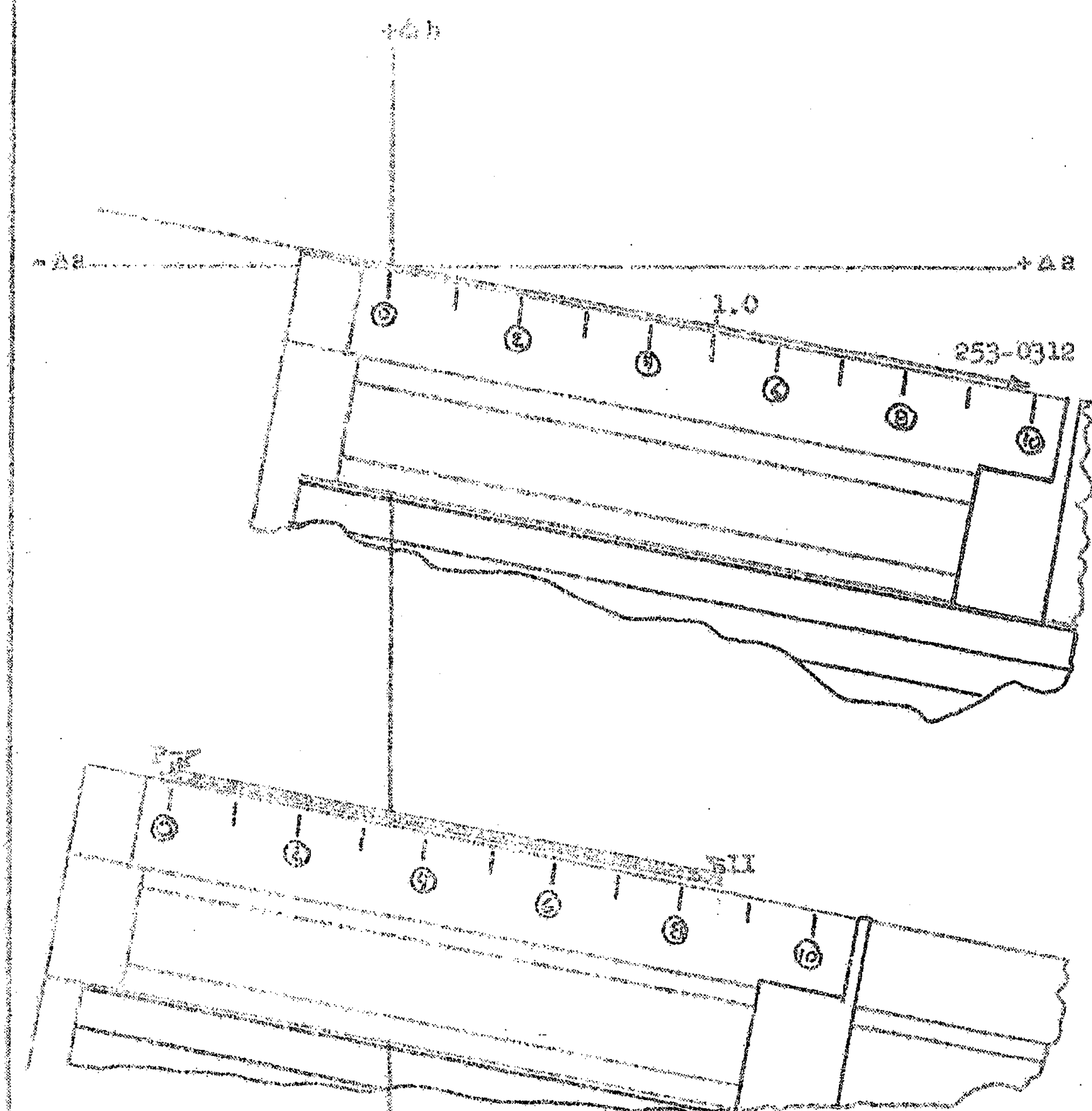
<u>COLOR ADJUSTMENT GRAPHICAL TECHNIQUE</u>

The basic objective of the Colorimeter-Chart Color Adjustment System is the adjustment of color differences existing between a batch and a standard on a routine production basis. The basic advantage of the system lies in the fact that instrumental color measurements and the Color Effect Chart can completely replace, at an improved efficiency, the experience and skill now required for production color adjustment.

The use of the Colorimeter-Chart Color Adjustment System is based upon a specific technique of graphical construction detailed in this section. Like all graphical techniques, it is subject to certain inherent errors which serve to restrict the accuracy of any color adjustment made on the basis of the graphically derived results.

FIGURE XV

MEASURING LINE LONGER THAN VECTOR CALIBRATION



For accurate results, it is necessary to use the cross-checking procedures detailed in the basic method to resolve any discrepancies which may occur in the three plots. If this is done and the prerequisites of the system are met, the results will be consistently within the tightest commercial color tolerances after the first color adjustment.

The system described below will cover 90-95% of the cases found in production color adjustment. There are occasional cases which, because of their specific location in color space in relation to the standard, cannot be worked by the procedure as detailed below. These cases can be classified into five basic classes each of which is readily recognizable and requires only slight modification of the detailed system.

The basic graphical technique is detailed in the following steps:

<u>Step 1</u>: Plot the ΔL, Δa, and Δb values of the batch (ΔL = +0.20, Δa = +0.10, Δb + -2.00) on the Δa Δb, ΔL Δa and ΔL Δb plots. Label these points (P). Using the parallel line plotter of the Colorimeter-Chart Plotting Device, draw a light line from point (P) parallel to and in the direction of the color effect vectors for each of the component colorants. Prepare a table (Figure XVI), listing for each of the Δ plots the colorant vectors which head toward the origin from the point where they are crossed by these lines from point (P). For example, in Figure XVII these lines are shown as dashed red lines and the line from point (P) in the Δa Δb plot, which corresponds to the effect of white (253-0953), crosses the 253-0312 line in such a position that the addition of 253-0312 from the crossing point will move the color in the direction of the origin. The (P)-253-0953 line also crosses the 253-0505 line, but in such a position that the addition of 253-0505 will move the color away from the origin. Thus, the intersection with 253-0312 is listed for 253-0953 in the Δa Δb plot but the intersection with 253-0505 is not. The list of intersections should include even those which fall beyond the scope of the chart. The list of intersections is for our specific example as tabulated below.

FIGURE XVI

<u>USEABLE COLORANT VECTORS CROSSED BY COMPONENT COLORANTS</u>

Plot	Component Colorants from Point (P) 253-0953	253-0222	253-0312	253-0505
Δa Δb	253-0312	253-0312	253-0953 253-0222	-
ΔL Δa	253-0505	253-0312 253-0505	253-0222	253-0222 253-0953
ΔL Δb	253-0222 253-0312	253-0953	253-0953	-

This tabulation should be inspected to determine which of the color vector lines leading from the batch (P) will intersect the <u>same color vector leading toward the origin</u> in at least two different Δ plots. (If this does not happen, refer to discussion on page IV-30.) The initial color vector from the batch (P) is called Colorant A and the intersected vector represents Colorant B. In the specific case of our example, there is a variety of colorant A and B combinations to choose from. 253-0953 could be selected as colorant A since it intersects the 253-0312 vector in both the $\Delta a \Delta b$ and $\Delta L \Delta b$ plots. 253-0222 could be selected as colorant A because it intersects 253-0312 vectors in both the $\Delta a \Delta b$ and $\Delta L \Delta a$ plots. 253-0312 could be selected as colorant A because it intersects 253-0953 vectors in the $\Delta a \Delta b$ and $\Delta L \Delta b$ plots and 253-0222 vectors in the $\Delta a \Delta b$ and $\Delta L \Delta a$ plots.

When such a variety of choices is available, the selection is usually based upon plotting and scaling considerations. The selection should be made to provide the greatest scale-up of the plot in order to provide the maximum accuracy. Trace colorant vectors should not be used unless it is absolutely necessary to a satisfactory graphical color adjustment. In the specific case of our example, 253-0312 was arbitrarily selected as colorant A and 253-0222 as colorant B.

<u>Step 2:</u> Using the parallel line plotter of the Colorimeter-Chart Plotting Device and with the batch (P) as a starting point, draw a line parallel to and in the direction of the vector of the colorant A selected in step 1 and extend it until it intersects with the vector representing the colorant B selected in step 1. Since this intersection will normally occur in only two of the three Δ plots (it may occur in all three Δ plots), the line should be extended far enough to be useable in the following operations.

Label the first intercept of the drawn colorant A line with the colorant B vector as point (1M). (Note - point (1M) should be the closest point to (P) in all three plots.) The furtherest intercept of the colorant A line from the batch (P) with the colorant B vector will be in a second Δ plot and should be labeled (1X).

The next operation is to transpose accurately these (1M) and (1X) points to the batch (P) - Colorant A line in each of the Δ plots. (Note the red lines and lettering in Figure XVII for the construction covered by step 2.) The drawn colorant A line represents the direction in which the addition of an undetermined amount of colorant A will colorimetrically move batch (P).

<u>Step 3:</u> Using the parallel line plotter of the Colorimeter-Chart Plotting Device, draw lines from points (1M) and (1X) in all three Δ plots parallel to and in the direction of the colorant B vector as chosen in step 1. Using the Δ plot which has not previously been used to determine either point (1M) or (1X) (i.e., the $\Delta L \Delta b$ plot in our specific example), the colorant B lines from points (1M) and (1X) should intersect with a third colorant vector moving back toward the origin. This colorant vector is identified as colorant C. The intersection of the (1M)-colorant B line with the vector representing colorant C is identified as point (2M). The intersection of the (1X)-colorant B line with the vector representing colorant C is identified as point (2X).

Occasionally more than one suitable vector is intersected by the colorant B line drawn from points (1M) and (1X). In this case, both vectors must be individually considered as colorant C and the remaining steps carried out until one of the vectors is proven false. In very rare cases both vectors may be suitable as colorant C. In this specific case, the composition of the finish must be considered and the colorant representing the greatest proportion of the formulation used to prevent or limit any possible metameric effects.

In certain cases, only one line (usually the (1X) - colorant B line) will intersect with a suitable colorant C vector. This case is covered in the expanded discussion on page IV-32.

Transpose point (2M) to the (1M)-colorant B line in each of the other Δ plots. Transpose point (2X) to the (1X) - colorant B line in each of the other Δ plots. (Note the green lines and lettering in Figure XVII for the construction covered by step 3.)

Step 4: Draw a line through points (2M) and (2X) in the Δ plots which were not used to fix points (2M) and (2X) (i.e., the ΔaΔb and ΔLΔb plots in the case of our specific example. Note Figure XVII for blue lines representing the construction of step 4). Extend this line until it intersects the colorant C vector. This intersection is labeled point I and represents the endpoint of the colorant B addition. Point I should be on the colorant C vector in such a position that the addition of colorant C to the color represented by point I will move the color to the origin of the Δ plot. If this is not the case, then the wrong colorant C has been used. Transpose point I to the third Δ plot.

Before going any further, the position of point I should be carefully checked between the three Δ plots to insure the accuracy of the plotting technique. Any errors at this point should be resolved and corrected before proceeding any further.

The significance of point I is often overlooked amid the maze of graphical construction which is taking place. To correct the batch color (P) to the standard color (origin of the Δ plots), we have added an unknown amount of colorants A, B, and C to the batch (P). Point I on the colorant C line now fixes the amount of colorant C used and thus represents not only the start of the colorant C add, but also the end point of the colorant B add.

Since point I in each Δ plot represents the end point of the colorant B add, the colorant B effect must be reversed starting from point I to obtain the starting point for the colorant B add. This step is achieved graphically by drawing, from point I, a line which is parallel to and in the reverse direction of the vector representing colorant B. This line is extended until it intersects the batch (P)-colorant A line at a point which is labeled point II. If this cannot be done, a mistake has been made either in plotting or in the selection of Colorant C. Point II in each Δplot should be carefully checked between plots to insure the accuracy of the graphical construction. Any variations greater than 0.10 NBS unit between plots should be resolved and corrected.

The overall colorant add then becomes:

Colorant A from point (P) to point II
Colorant B from point II to point I
Colorant C from point I to the origin

Step 5: Using the variable scale portion of the Colorimeter-Chart Plotting Device, measure the amounts of Colorants A, B and C required to adjust the batch color to that of the standard. Use the calibration of the Color Effect Chart plus any expansion or reduction of scale required to keep the construction on the chart to make this measurement. Because of minor unresolvable inaccuracies in plotting, it is necessary to measure the amount of Colorants A, B, and C in at least two of the Δplots and average them. These measurements should be made as a percentage of the full-scale calibration by setting the full scale of the plotting device to the calibration of the vector and directly measuring the proportional part of full scale. This value is called (N_c). If the plotting scale has been expanded or reduced for plotting purposes, the suitable factor should be applied at this point to get (N_c) in terms of vector calibration.

Step 6: Using the table of non-linear calibration, look up the value of (N_c) and determine the value of (N). This step represents a transformation to a non-linear calibration. It will be noted that this table does not show full calibration at 1.00 of calibration. This is because the area of useage is on the negative side of the standard and the calibration is on the positive side and by our color law of diminishing returns the color effect on the positive side of the standard will be less than that on the negative side.

FIGURE XVIII

COLOR CORRECTION FOR BATCH (P)

Colorant	N_c	N	Cal	C_n	Sb	Cb	St	C
A (253-0312)	0.38	0.307	1.0	0.307	.90	0.276	1.10	0.304 ~~3.036~~
B (253-0222)	0.70	0.541	0.5	0.270	.90	0.243	.90	0.219
C (253-0953)	0.48	0.383	20	7.66	.90	6.894	1.00	6.894

Step 7: Correct the non-linear calibration (N) for the calibration of the vector (C) by multiplying (N) times (C) to obtain (C_n) which represents the amount of colorant to be added per 100 pounds of batch if no strength correction is required for the batch.

Step 8: Rarely does a batch have the same overall color strength as the standard. The strength of a batch results from the individual tinting strengths of the component colorants. Since the standard and the batch have different compositions (or the color would be the same), the batch rarely has the same tinting strength as the standard. If the batch is weaker than the standard, each colorant will have a greater effect than predicted. The batch strength (S_b) in one specific case is 10% weak or 90% of standard. Therefore, the (S_b) factor used is 0.90. The correction is made by multiplying (S_b) times (C_n) to obtain (C_b). If the batch was 10% strong the (S_b) factor would have been 1.10.

Step 9: The Color Effect Charts are prepared from standardized colorants adjusted to standard strength. In reality, plant batches of colorants rarely match standard strength. It is necessary to adjust the colorant add for the strength of the specific colorant lots used. In this case it should be remembered that more of a weak colorant lot is required to provide the same color effect. Similarly, it is necessary to use less of a strong colorant lot. Thus, in our specific example the 253-0312 is 10% weak and therefore requires 1.10 times the amount of colorant to achieve the proper color effect. Since 253-0222 is 10% strong in our example only 0.90 times the standard strength amount of 253-0222 is required to achieve the proper color effect. Since the 253-0953 is at 0% strength, no correction is required. The tinting strength (S_t) is multiplied by the non-corrected amount of colorant (C_b) to obtain the actual amount of colorant (C) used in the color adjustment of the batch.

Note: The above system may be modified slightly for metallic-type colors. These modifications are covered later in this handbook.

HANDLING DEVIATIONS FROM THE BASIC RULES OF PLOTTING

The Colorimeter-Chart Color Adjustment System will have specific cases, which on the surface, appear to violate the general construction rules as defined on pages IV-26 through IV-30-A. To reconcile these apparent violations with the overall system, it is necessary to study in more detail, the fundamental basis of the graphical construction. In general, step 1 automatically selects Colorants A and B and step 3 automatically selects Colorant C. However, in certain cases the selection of all three colorants is carried out in step 1. When this occurs, considerable leeway is given in the remaining aspects of the graphical construction process as detailed in some of the following examples.

SAME COLOR VECTOR NOT INTERSECTED IN TWO Δ PLOTS

This case is apparently a violation of step 1 of the basic graphical technique in that none of the lines from point P which are parallel to, and in the direction of, the colorant vectors will intersect the same color vector leading toward the origin in at least two different Δ plots. How then can Colorants A and B be selected?

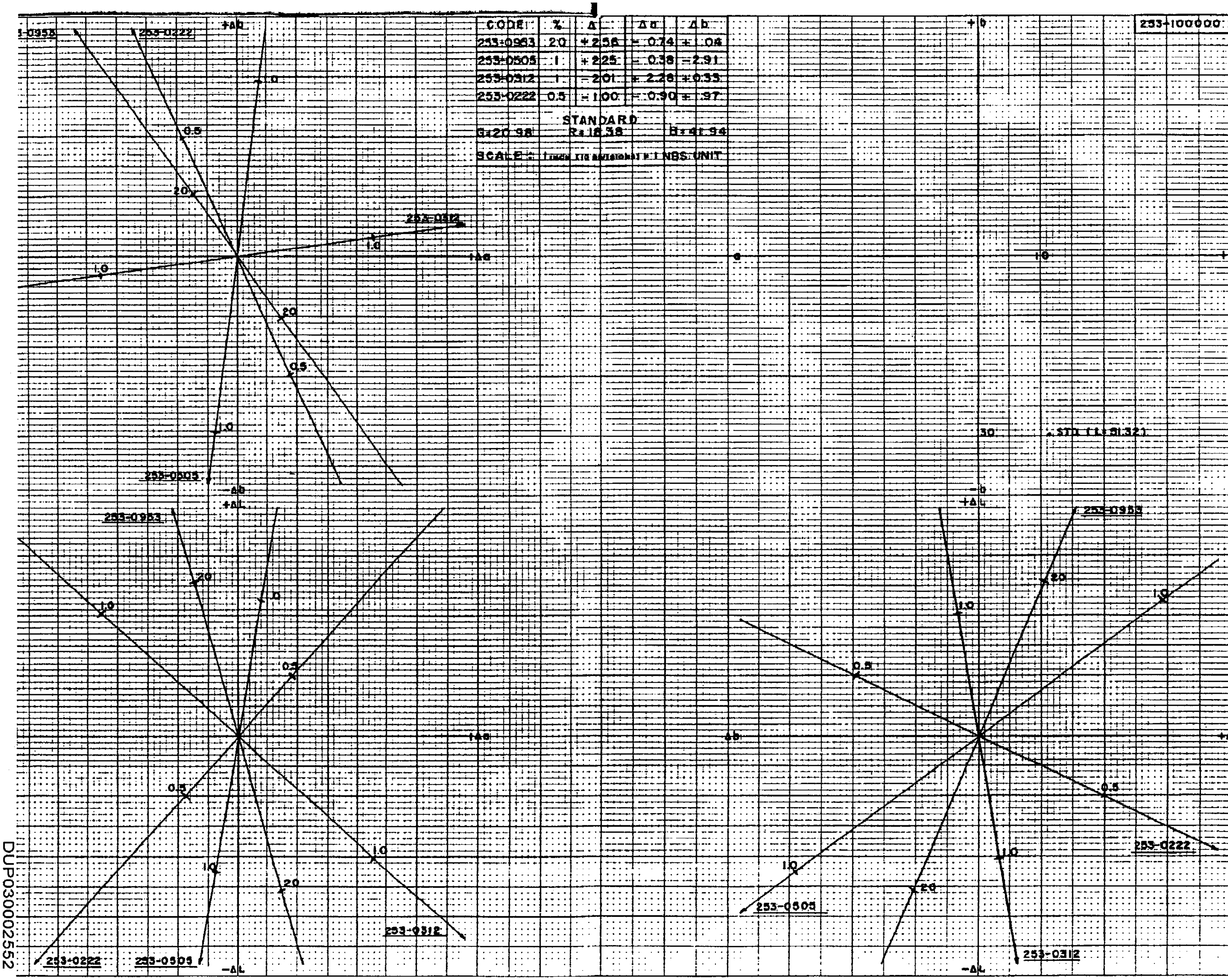
Let us take a specific example as the basis for discussion. Assume that batch point (P) is located at $\Delta L = +0.30$, $\Delta a = -1.40$ and $\Delta b = +0.90$. (Note Figure XX.) The graphical operation of step 1 is carried out by drawing the dashed lines (red) to represent the effect of adding each colorant individually to batch (P). The table of useable colorant vectors is then prepared as shown in Figure XIX.

FIGURE XIX

USEABLE COLORANT VECTORS CROSSED BY COMPONENT COLORANTS

	Component Colorants from Point (P)			
Plot	253-0953	253-0222	253-0312	253-0505
ΔaΔb	-	-	253-0505	253-0312
ΔLΔa	253-0312	-	253-0953	-
ΔLΔb	253-0505	-	-	253-0953

FIGURE XI



CODE	%	Δ	Δa	Δb
253-0963	2.0	+ 2.56	- 0.74	+ .04
253-0505	1	+ 2.25	- 0.38	- 2.91
253-0312	1	- 2.01	+ 2.28	+ 0.35
253-0222	0.5	- 1.00	- 0.90	+ .97

STANDARD

G=20.98 R=18.38 B=41.94

SCALE: 1 inch (10 divisions) = 1 NBS UNIT

DUP030002552

IV - THE COLORIMETER-CHART COLOR ADJUSTMENT SYSTEM

INTRODUCTION

The production of blended colors to within a commercially acceptable color tolerance is the basic objective of the finishes industry. This objective can be achieved only if techniques are available for the simple and rapid adjustment of the color blend formulation for the lot to lot color variation inherent in the manufacture of the color blend. Historically, these color adjustments have been made by highly trained specialists who depended upon a combination of visual color perception and experience.

The efficiency of this historical color adjustment system is controlled by the inherent limitations of visual color perception and judgment. A new color is usually a color problem in production until sufficient visual color experience has been built up to allow the estimation of the amount and type of colorant necessary to adjust a given color difference. Batches which fall outside the area of color experience remain a color matching problem.

Recent experimentation in the field of color has led to the development of a system which eliminates the need for visual judgment and extensive color experience. This system, known as the Colorimeter-Chart Color Adjustment System, replaces visual color perception with instrumentation and color experience with a calibrated chart. The system does not require an extensive technical or practical background in the field of color and thus is readily applicable to large scale rapid application to any finishes line meeting the basic prerequisites required for the system.

BASIS OF THE COLORIMETER-CHART COLOR ADJUSTMENT SYSTEM

The Colorimeter-Chart Color Adjustment System is based upon the fact that visual color coordinate systems, such as the Modified Adams' Coordinate System, despite their inherent non-linear pigmentation characteristics, are virtually linear over the relatively short distances usually encountered in production color adjustment. It is also theorized that if a variety of batches having essentially the same composition and are within a reasonable color difference of the standard, the addition of a fixed amount of a given colorant to each of these batches will result in a color movement which is essentially the same in both magnitude and direction.

Since the control charts are established with given lots of standardized colorants, the question is often asked, "What happens when different lots of these colorants are used?" These colorants will admittedly vary from lot to lot in color; the effect of these variations is shown most strongly in the adjustments in the preformulation of the blended colors required to get a close match to standard. However, these lot to lot color differences are normally relatively small with respect to the overall dimensions of color space. An analogy can be drawn with respect to firing a rifle at a target.

If the size of this target is considered as the area of acceptable color variation from the standard, it may be seen that in long-range shooting (which is analogous to the formulation or preformulation of the color) a relatively small deviation in the angle of the rifle barrel (which represents the lot to lot variation of the colorants) will cause the bullet to miss the target. Conversely, in the process of color adjustment, we are firing the rifle virtually point-blank at the target and it would require a much greater aiming deviation to miss the target.

The Colorimeter-Chart Color Adjustment System is actually based upon a graphical construction technique found in the science of Descriptive Geometry. This graphical construction is most frequently used in the construction of mine shafts or tunnels. If we have two tunnels, one starting at a given point (batch) and heading in a given direction, the other arriving at a given point (standard) from another direction, and wish to connect these two tunnels with a third tunnel which moves in a fixed direction, there is only one point in the first tunnel (Colorant A) where we can dig the connecting tunnel (Colorant B) and intersect the third tunnel (Colorant C). (Note Figure I)

The Colorimeter-Chart Color Adjustment System, like any system, has its limitations. Its single adjustment effectiveness is limited to a maximum of 4 to 5 NBS units from standard. However, even with batches of greater deviation, the system has the inherent advantage of always moving the batch color toward the standard.

PREREQUISITES OF THE COLORIMETER-CHART COLOR ADJUSTMENT SYSTEM

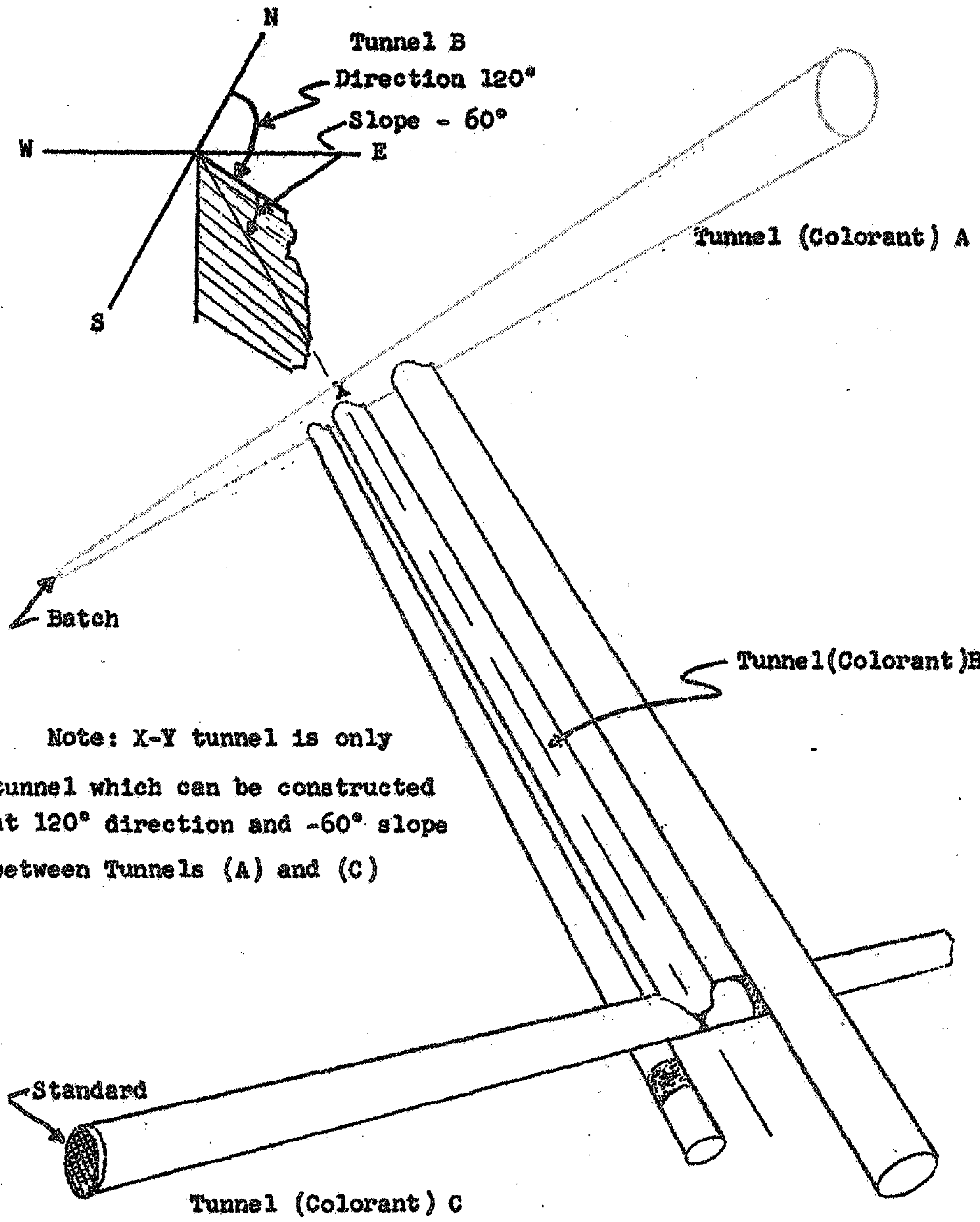
The Colorimeter-Chart Color Adjustment System like any other system, is based upon certain conditions or prerequisites which serve to rigorously define the limitations under which it can be used. The prerequisites of the Colorimeter-Chart Color Adjustment System are:

1) Standardization of Colorants. The system is dependent upon the calibration of its charts. This calibration is mainly dependent upon the strength of the colorants used in the preparation of these charts. Therefore, strength standardization of these colorants must be reasonably accurate since variations in this strength standardization will directly affect the accuracy of the color adjustment.

2) The color to be controlled must not have any color drift from the time it is sampled until the completion of the color adjustment. Any color drift due to agitation, flocculation or deflocculation of the pigment system will be directly reflected as a color deviation from standard after the color adjustment has been made. For this reason, batch samples should not be taken until the color of the batch has reached equilibrium.

FIGURE I

ANALOGY BETWEEN COLOR ADJUSTMENT AND
TUNNEL SHAFT LAYOUT



Note: X-Y tunnel is only tunnel which can be constructed at 120° direction and -60° slope between Tunnels (A) and (C)

3) The reproducibility of panel preparation and instrumental color measurement must be significantly less than the required color tolerances. There is no sense in attempting to control a color to a narrow tolerance unless it can be reproducibly measured to within this tolerance.

4) The color must be measured and controlled under conditions which insure that the differences in measurement are directly correlatable to differences in pigmentation. This means, for example, that gloss differences between the batch and the standard must be adjusted prior to reflectance measurement. It also means that products which are normally controlled at incomplete hiding must be evaluated at complete hiding to avoid the effect of differences in the intensity of the substrate color on the reflectance measurements of the batch and standard.

INSTRUMENTATION OF THE COLORIMETER-CHART COLOR ADJUSTMENT SYSTEM

The Colorimeter-Chart Color Adjustment System is based upon the replacement of visual color perception with instrumental color measurement. There are three instruments which are recommended for the commercialization of this system. They are:

1) "Colormaster" Differential Colorimeter - Model 4 - manufactured by Manufacturers Engineering and Equipment Corporation, Hatboro, Pennsylvania.

This is the basic color measuring instrument for the Colorimeter-Chart Color Adjustment System. It provides Green, Red and Blue reflectance measurements on a color panel or wet sample which can be converted into a coordinate system which precisely locates the color of the panel in a color solid (note discussion of color coordinate system starting on page (IV-6).

This instrument should be purchased with certain auxiliary equipment.

a) A screen multiplier available from MECCO. This unit is used to increase the sensitivity and accuracy of the Colormaster on reflectance values below 10%.

b) A metallic panel measuring head - currently under development and to be available from MECCO. This unit is required for reproducible color measurements on metallic-type finishes, where the orientation of the metallic particles can affect the reflectance values obtained by the "Colormaster".

2) A "two-tone" measuring instrument. This unit may be built into the J-3 Glossmeter at a cost of $100-200. Orders for conversion of existing units may be placed through:

> J. G. Schreckendgust - Marshall Laboratory
> E. I. du Pont de Nemours & Co., Inc.
> 3500 Grays Ferry Avenue
> Philadelphia 46, Pa.

This instrument is required for the measurement of the "two-tone" characteristics of metallic colors. The "two-tone" installation can also be built into the J-4 Colorimeter and Glossmeter unit.

3) The Mark 2 Color Difference Computor is also recommended equipment for the Colorimeter-Chart Color Adjustment System. This unit calculates the ΔL, Δa and Δb difference between two sets of Green, Red, and Blue reflectance readings representing a batch color panel and a standard color panel in 30 seconds or less. A similar hand calculation would take about 10 minutes with the inherent possibility of error in reading the tables or in arithmetic operation. This unit will cost $3,500-4,000 and may be obtained by referring the order to:

> W. H. Edwards - Process Engineering
> E. I. du Pont de Nemours & Co., Inc.
> 3500 Grays Ferry Avenue
> Philadelphia 46, Pa.

COLORIMETER READING TECHNIQUES

The ultimate accuracy of the Colorimeter-Chart Color Adjustment System is dependent upon the accuracy with which the color effect panels are prepared and read. Colorimeter accuracy is obtained by a special technique designed to use the "Colormaster" differential colorimeter as a color difference unit. In order to use the colorimeter properly, the following procedure should be used. (Re: TM-142)

1) Standardize the colorimeter for Grid Bias, by turning the filter switch to the "OFF" position, pushing the "High Sensitivity" button and adjusting the meter to zero using the Grid Bias adjusting knob on the right-hand side of the case.

2) Standardize the machine to the G, R and B value of the white ceramic placque. Always approach the reading from the same dial direction.

3) Read the G, R, and B values of the standard panel using the times 10 screen for all readings below 10% reflectance. (Use steps 1-2 to obtain calibration of standard if necessary.)

4) Restandardize on the G value of the standard panel, read G of batch panel.

5) Switch to Red filter, standardize on R value of standard panel, read R of batch panel.

6) Switch to Blue filter, standardize on B value of standard panel, read B of batch panel.

This technique is more accurate than conventional techniques because the filter wheel is in precisely the same position for all panel readings on a particular filter, thus eliminating any inherent error due to minor variations in the filter position between batch and standard panels.

COLOR COORDINATE SYSTEM

The G, R, and B values obtained by colorimeter measurement of a panel represent the percentage of Green, Blue and Red light reflected from the panel. These values, while measuring the color, do not correlate directly with visual interpretation of color (i.e., what the eye sees). In order to obtain agreement with visual color interpretation, it is necessary to translate these G, R, and B values into a color coordinate system which measures visual color perception in numerical terms.

Color coordinate systems are very simple and can be compared to many things with which we are familiar. For example, a simple visualization of the color solid can be made by comparison with a spoked wheel and an axle. The axle is our "neutral axis", having one end painted pure white, the other end pure black and the remainder of the axle a gradually darker series of neutral grays ranging from pure white to pure black. This neutral axis represents the first characteristic of color known as lightness. If we call the lightness of pure white 100 and the lightness of the pure black 0, all colors can be classified as having a lightness equivalent to that of a neutral gray intermediate somewhere between pure white and pure black.

If the lightness axis is considered as an axle, the remaining color characteristics can be considered as elements of a spoked wheel which can move to any position of lightness on our neutral axis. At a given lightness position, the spoked wheel contains all colors of this lightness. The spokes of the wheel represent the various tones or hues of the color solid. In other words each spoke represents a specific hue; blue, green, yellow, red or some intervening color shade. The hue (spoke) of a color can be determined by some fixed angle with respect to one hue or spoke in much the same way that East, South and West are measured on a compass as specific angles from North.

The third color characteristic expressed by axle and wheel concept of the color solid is known as saturation. Saturation is represented by the length of the particular hue spoke which in turn is symbolic of the vividness or clarity of the particular color. Since the neutral axis and the wheel hub represent gray colors having no hue or saturation, the length of the spoke is representative of how much of this gray is mixed with our pure color. The longer the hue spoke becomes, the less gray is mixed with the pure color and the greater the saturation. Saturation is, therefore, a measure of the distance the color lies from the neutral axis.

While the original color coordinate systems were based on angles and distances, the mathematics involved in obtaining these factors from G, R, and B colorimeter values were not suitable from the standpoint of routine production use. Therefore, the form of the color coordinate system was altered to a rectilinear coordinate system.

The rectilinear color coordinate system may be visualized as nothing more than two pieces of cardboard intersecting at right angles in the form of an "X" (note Figure II). The intersection of these two pieces of cardboard is identical with our axle or "neutral axis". If we label one of the pieces of cardboard "a" and the other one "b", we have the completed color solid. A particular color can be pinpointed in this color space in terms of three numbers, L (or lightness), a and b which are components of the hue and saturation. While L must always be positive, both a and b can be either positive or negative, and serve to pinpoint the color in terms of redness (plus a), greenness (minus a), yellowness (plus b) and blueness (minus b).

The coordinate system used in the Colorimeter-Chart Color Adjustment System is known as the modified Adams' Coordinate System. This coordinate system is used because it agrees most closely with visual perception and because it is the system in which many of our color tolerances are now or will be expressed. This coordinate system is expressed by many equations. However, the preparation of tables has reduced the individual calculations to the following equations:

$$L = f\ (G) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (IV\text{-}1)$$

$$a = a_{R'} - a_G \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (IV\text{-}2)$$

$$b = b_G - b_B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (IV\text{-}3)$$

$$R' = 0.8\ (R) + 0.2\ (B) \quad \ldots\ldots\ldots\ldots (IV\text{-}4)$$

A form has been prepared (note Figure III), covering the calculation of L, a and b from G, R, and B. In any case, the use of the Tables in determining L, $a_{R'}$, a_G, b_G and b_B is necessary to avoid excessive arithmetic.

The color coordinate tables are used as follows:

Step 1 - Record the G, R and B colorimeter readings

(i.e.) G = 50.00 R = 55.00 B = 60.00

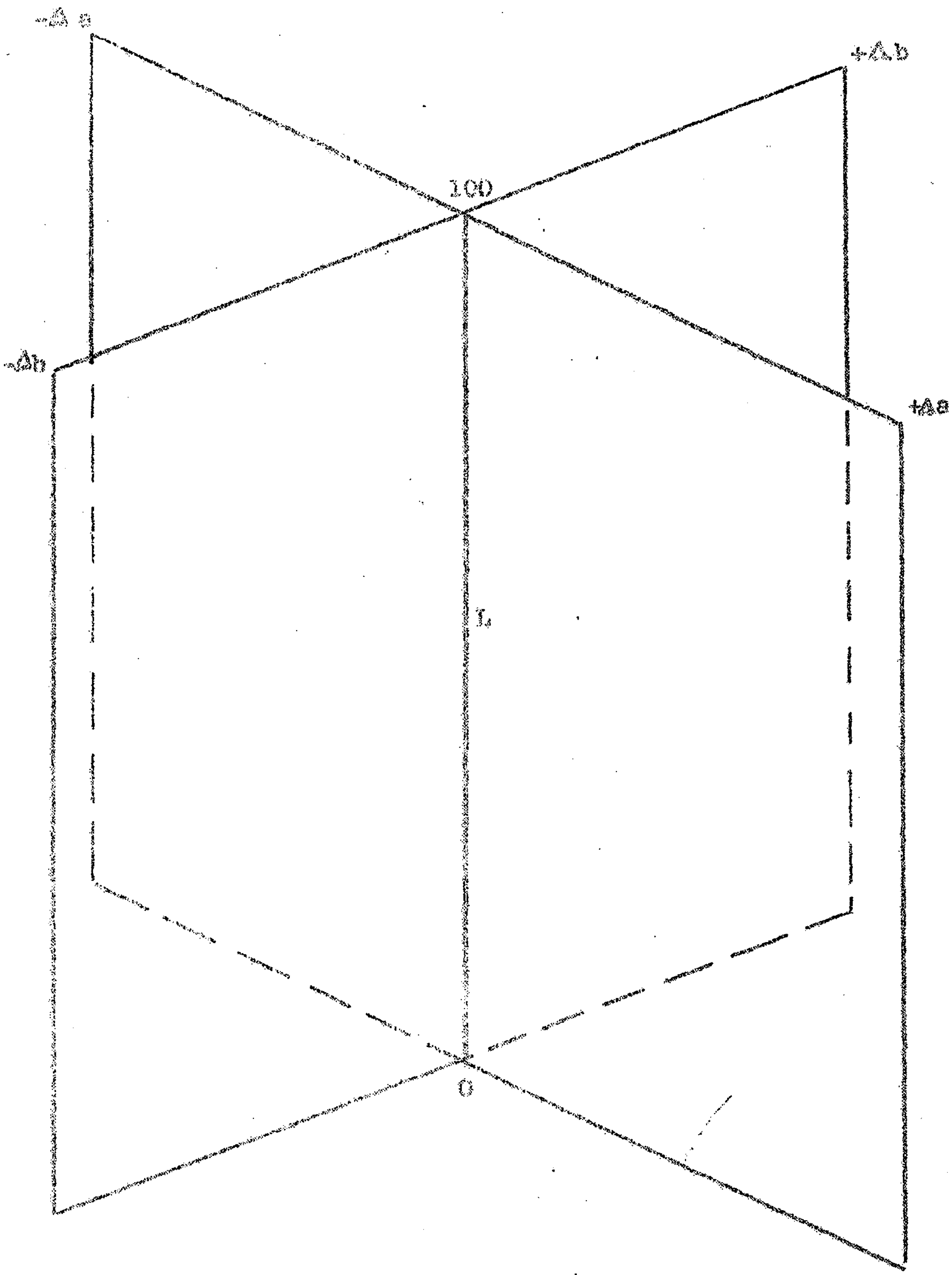
Step 2 - Calculate R' = 0.8 R + 0.2 B

R' = 0.8 (55.00) + 0.2 (60.00)

R' = 44.00 + 12.00 = 56.00

FIGURE II

THE RECTILINEAR COLOR SOLID



Step 3 - Obtain the functions of G from the tables. The table pages are identified in the upper right-hand corner by the range of G, R, and B reflectances whose functions are tabulated on that page. Since we are after functions of G when G = 50.00 we must open the tables to the page identified as 49.00-51.00. A representation of a portion of this page is given on the next page. (Note Figure IV)

FIGURE III

CODE:
BATCH NO.
MILL:
DATE:
FINENESS SPEC: ____________ FINENESS BATCH: ____________

STEP					
1	G				
2	R				
3	B				
4	0.8R				
5	0.2B				
6	(4) + (5) = R'				
7	L				
8	$^{a}R'$				
9	^{a}G				
10	^{b}G				
11	^{b}B				
12	(8) - (9) = a				
13	(10) - (11) = b				
14	Δ L				
15	Δ a				
16	Δ b				
17	E				

FIGURE IV

49.00-51.00

G	L	a_G	b_G
R'	-	$a_{R'}$	-
B	-	-	b_B
49.00	73.93	309.51	123.77
49.02	73.95	309.56	123.79
49.04	73.97	309.61	123.81
50.00	74.58	312.19	124.85
50.02	74.59	312.24	124.87
50.04	74.60	312.30	124.89

The left-hand column contains the reflectance values for G, R', and B. The remaining columns contain the functions dependent on the reflectance values for G, R' and B. The top row contains the functions L, a_G and b_G which are all determined by G. The second row contains $a_{R'}$ which is the only component dependent on the value of R' and the third row contains b_B which is the only component dependent on the value of B. To determine the value of the functions of G, we would look up G = 50.00 and record the values of L, a_G and b_G as shown below.

FIGURE V

49.00-51.00

G	L	a_G	b_G
R'	-	$a_{R'}$	-
B	-	-	b_B
49.00	73.93	309.51	123.77
49.02	73.95	309.56	123.79
49.04	73.97	309.57	123.81
50.00	74.58	312.19	124.85
50.02	74.59	312.24	124.87
50.04	74.60	312.30	124.89

Step 4 - Obtain the value of the $a_{R'}$ function of R', following the technique of step 3. Note that $a_{R'}$ is the only coordinate function depending on R'. Since R' is 55.00 we must use the page identified by 55.00-57.00 in the upper right-hand corner.

FIGURE VI

55.00-57.00

G	L	a_G	b_G	G	L	a_G	b_G
R'	-	$a_{R'}$	-	R'	-	$a_{R'}$	-
B	-	-	b_B	B	-	-	b_B
55.00	77.63	324.96	129.95	56.00	78.22	327.42	130.94
55.02	77.64	325.01	129.97	56.02	78.23	327.47	130.96
55.04	77.65	325.06	129.99	56.04	78.24	327.52	130.98

Step 5 - Obtain the value of the b_B function of B, following the technique of step 3. Note that b_B is the only coordinate function of B. Since B for our example is 60.00 we must use the table page identified by 59.00-61.00 in the upper right-hand corner.

FIGURE VII

59.00-61.00

G	L	a_G	b_G	G	L	a_G	b_G
R'	-	$a_{R'}$	-	R'	-	$a_{R'}$	-
B	-	-	b_B	B	-	-	b_B
59.00	79.94	334.64	133.82	60.00	80.50	336.98	134.76
59.02	79.95	334.69	133.84	60.02	80.52	337.03	134.78
59.04	79.97	334.74	133.86	60.04	80.53	337.08	134.80

Step 6 - Obtain L, a and b from equations (II-1), (II-2) and (II-3).

$$L = 74.58$$

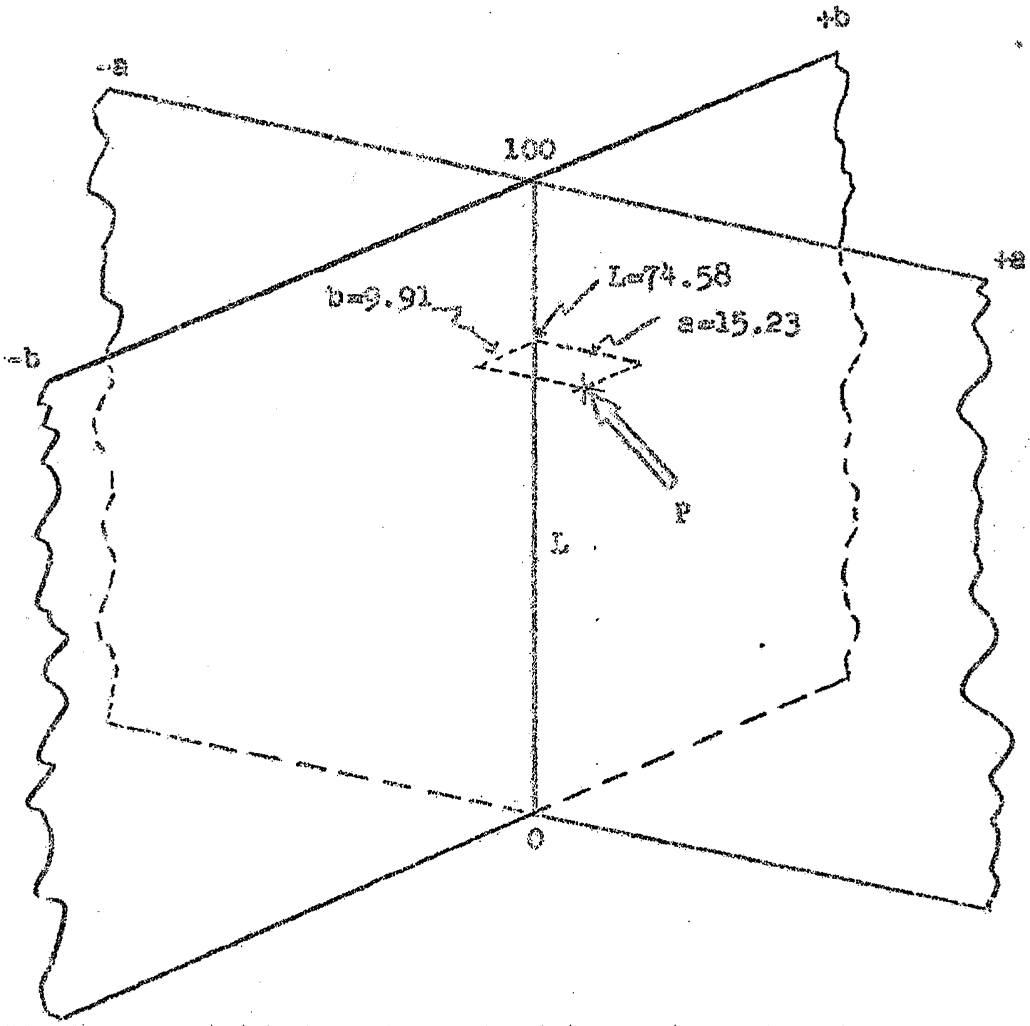
$$a = 327.42 - 312.19 = +15.23$$

$$b = 124.85 - 134.76 = -9.91$$

This color would be positioned in color space as shown in Figure VIII.

Figure VIII

LOCATING A COLOR IN RECTILINEAR COLOR SPACE



The Colorimeter-Chart Color Adjustment System is based upon the color difference existing between the standard and the batch. Since the color of the standard and the batch are represented by specific L, a and b values, the color difference existing between the standard and the batch is represented by differences in the L, a, and b values of the batch and standard. These color coordinate differences, known as ΔL, Δa, and Δb are calculated from the following formulas:

$$\Delta L = L(\text{Batch}) - L(\text{Standard}) \quad \ldots\ldots\ldots\ldots\ldots \quad (IV\text{-}5)$$

$$\Delta a = a(\text{Batch}) - a(\text{Standard}) \quad \ldots\ldots\ldots\ldots\ldots \quad (IV\text{-}6)$$

$$\Delta b = b(\text{Batch}) - b(\text{Standard}) \quad \ldots\ldots\ldots\ldots\ldots \quad (IV\text{-}7)$$

Particular care must be taken to obtain the proper sign in the calculation of Δa and Δb because a and b can be either positive or negative. Note that ΔL, Δa or Δb can be either positive or negative and depend upon the relationship in color space existing between the batch color and the standard color. The proper signs are particularly important in the Colorimeter-Chart Color Adjustment System because they control both the type and amount of the colorants added to the batch in order to match the color of the standard.

As can be seen from the preceding discussion, the calculation of ΔL, Δa and Δb is time-consuming (estimated calculation time is 10 minutes) and is subject to many possibilities of error, particularly in the mechanics of calculation. Recognizing this limitation, the F. & F. Department commissioned the Engineering Research Laboratory, in 1955, to develop and build a special purpose computer designed to compute ΔL, Δa, and Δb directly from the G, R and B reflectance data of the batch and standard panels. The computer requires about 30 seconds to make this calculation, effectively eliminates the possibility of any computation error and, in reality, makes the Colorimeter-Chart Color Adjustment System commercially feasible.

COLOR EFFECT CHARTS

The Colorimeter-Chart Color Adjustment System is based upon the use of a special chart which pictures the colorimetric effects of the individual component colorants upon the color of the standard. This chart, called the Color Effect Chart, is specific to a given color formula and replaces visual color memory and experience in the selection of the identity and the amount of the component colorants necessary to adjust the color of a batch to that of the standard. A separate Color Effect Chart is required for each color formula brought under the control of the Colorimeter-Chart Color Adjustment System.

The function of the Color Effect Chart is to present, in a useable form, all of the data required to adjust the color of the batch to that of the standard by using the Colorimeter-Chart Color Adjustment System. This data is obtained from a series of panels which illustrate the colorimetric effect obtained by adding a given amount of each of the component colorants separately to 100 parts of the color standard. The color difference between these panels and the standard is measured and the result expressed as the ΔL, Δa and Δb difference representing the colorimetric effect of a known amount of a specific component colorant upon the standard. For example, if the addition of 1.0 part of blue (253-0505) to 100 parts of color standard (S) produces a colorimetric difference (X) which is measured as $\Delta L = -2.25$, $\Delta a = -0.38$ and $\Delta b = -2.91$, the overall effect in three-dimensional color space is shown in Figure IX as black line (SX).

This overall three-dimensional color effect (SX) of the blue (253-0505) can be broken down into three two-dimensional components by projecting the (SX) line into the two-dimensional plots Δa Δb, ΔL Δa and ΔL Δb. Thus, line (SX) can be pictured in the Δa Δb (Green) plot as line (SA), in the ΔL Δa (Red) plot as line (SB) and in the ΔL Δb (Blue) plot as line (SC). While the three-dimensional effects can be adequately pictured on any two of these plots, the technique of the Colorimeter-Chart Color Adjustment System requires the use of all three Δ plots. Note that the standard is at $\Delta L = 0$, $\Delta a = 0$ and $\Delta b = 0$.

Under the concept of the Colorimeter-Chart Color Adjustment System, if line (SX) represents the color effect produced by the addition of (X) parts of a colorant to 100 parts of the standard color (S), then a directly opposite directional effect will occur if some of this colorant is removed from the color standard (S). Hypothetically, we can assume that (X) parts of the colorant can be removed even if they are not in the formulation. However, the removal of (X) parts of the colorant will not give an equal color movement in the opposite direction since the fundamental mathematics of color are essentially non-linear and follow a color law of "diminishing returns" which states that the second increment of color added will have less of a color effect than the first increment. However, when the color chart is prepared, the color effects of addition and subtraction of (X) parts of the color are assumed equal for plotting the direction of the vector. An arrowhead is used along with the vector colorant marking (253-0505) to indicate the direction of color movement resulting from the addition of the colorant. Since it is necessary to know not only which colorants are used but how much of each is required to make the necessary color adjustment, the vector must be calibrated at the ΔL, Δa, Δb values representing the color effect used in establishing the vector effect. In our specific case, this calibration would be set at 1.0.

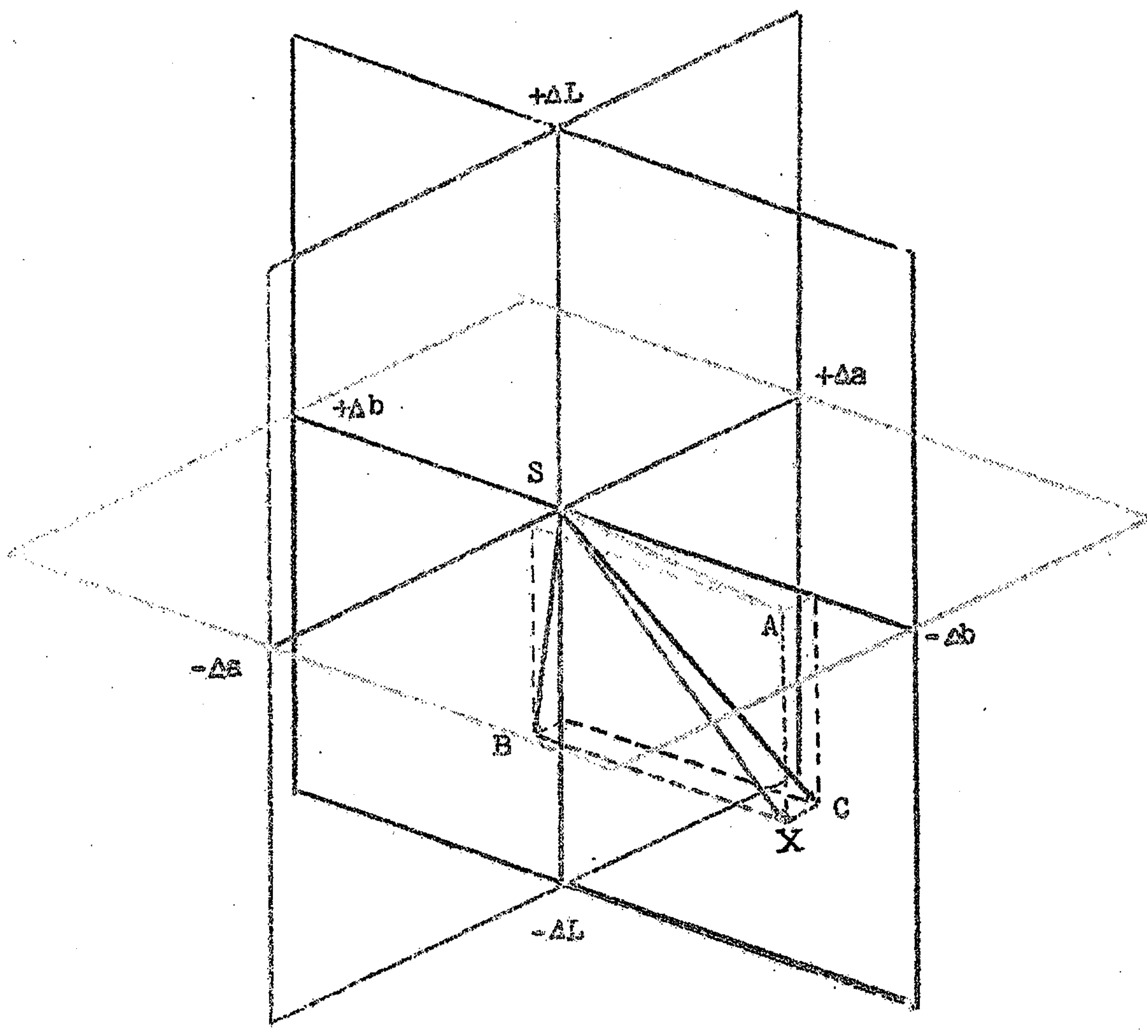
The Color Effect Chart, in addition to the Δa Δb, ΔL Δa and ΔL Δb plots, contains other information of value in the preparation and use of the charts. An a, b, chart is incorporated giving the location of the color standard in absolute color space to serve as a guide in checking the direction of the component colorant vectors for direction of color movement due to colorant addition. (For information on the relationship of pigmentation effects to color, refer to Part I of the F. & F. Color Handbook, "Introduction to Color Technology").

The Color Effect Charts for metallic colors contain a plotting area which summarizes "two-tone" data.

Figure IX

RELATIONSHIP BETWEEN THREE-DIMENSIONAL COLOR SPACE

AND $\Delta a\ \Delta b$, $\Delta L\ \Delta a$, AND $\Delta L\ \Delta b$ PLOTS



Red = $\Delta L\ \Delta a$ plot

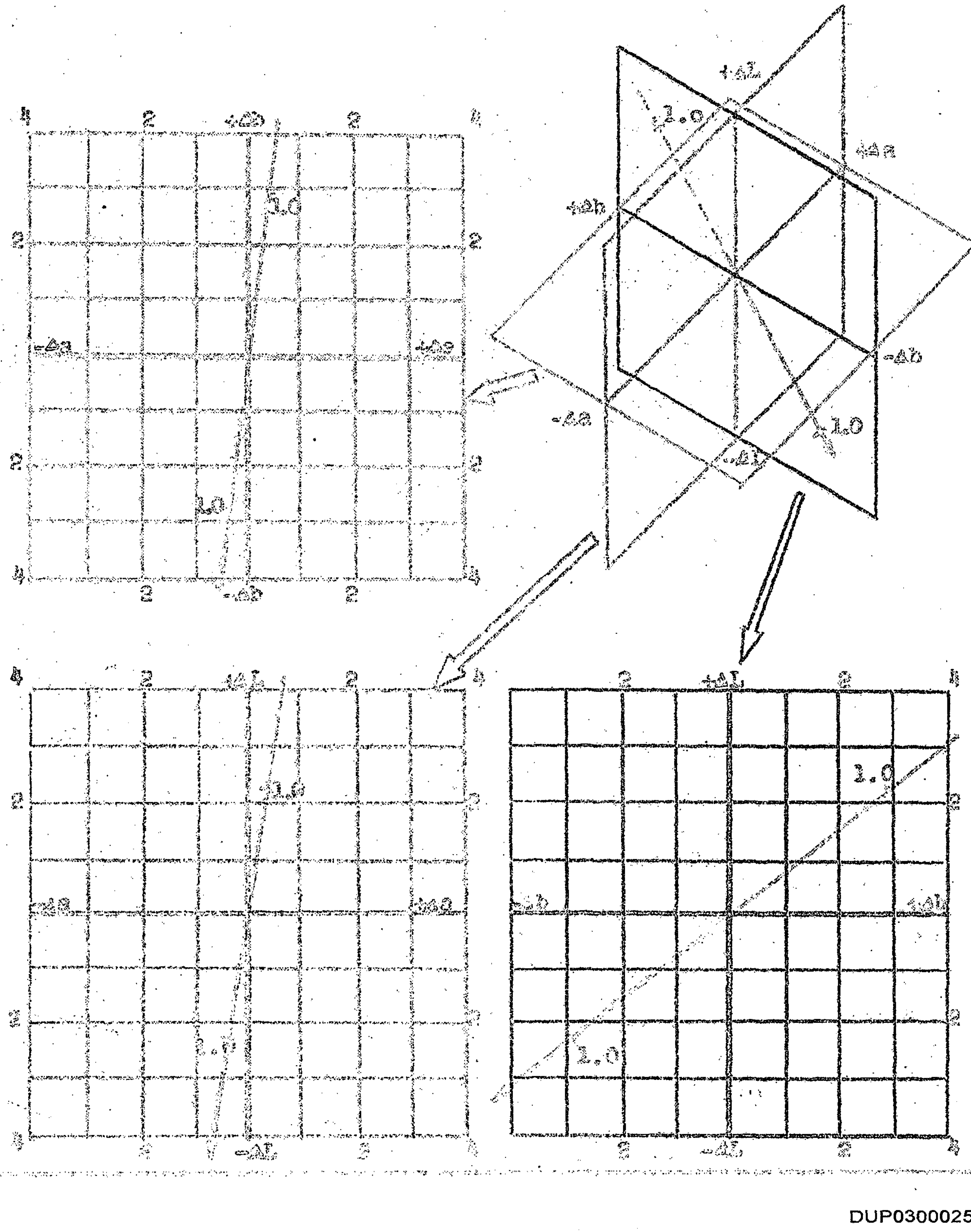
Blue = $\Delta L \Delta b$ plot

Green = $\Delta a\ \Delta b$ plot

Black = plot in three-dimensional color space

Figure I

VISUALIZATION OF THREE-DIMENSIONAL COLOR SPACE ON COLOR EFFECT CHARTS (STANDARD AT CHART ORIGIN)



The preparation of the Color Effect Chart requires the following steps:

<u>Step 1</u>: Prepare two separately weighed sets of color effect panels. These panels are normally based on wet color standard material, if it is available. Otherwise, a previously shaded acceptable batch of the same material can be used as a basis for preparing the panels. A panel of the "standard" is also prepared as a base for measuring the color differences attributable to the component colorants.

One panel is prepared for each component colorant, including all trace colorants. The amount of the component colorant used per 100 parts of the standard material will vary widely, depending both on the strength of the colorant and the area of the color solid in which it is used. A good yardstick for the amount of the colorant used per 100 parts of standard in the preparation of these panels is the ΔL, Δa and Δb color difference obtained. The color blend should be adjusted so that the maximum ΔL, Δa or Δb lies between 2 and 3 NBS units. For simplicity in the calibration of the Color Effect charts, the amount of the colorant used per 100 parts of the standard should be selected from the following listing: 0.1, 0.2, 0.5, 1.0, 2.0, 3.0, 5.0, 10.0, 20.0 or 50.0. Experience is generally the best guide to the selection of the colorant level to be used.

In our specific example, the following panels were prepared:

TABLE I

Panel No.	Colorant	Parts/100 parts standard
1	Standard	-
2	253-0505	1.0
3	253-0312	1.0
4	253-0953	20.0
5	253-0222	0.5

If the Color Effect Chart is being prepared for a metallic type color, the aluminum flake pigment will replace the white in the non-metallic color system. White colorant is used in the metallic color system primarily for the correction of two-tone differences. Therefore, a panel representing 100 parts of the metallic color standard plus sufficient white to give a reasonable two-tone difference is also prepared. Normally, the amount of white used would be equal to or less than 0.5 parts of white per 100 parts of the metallic color standard.

Step 2: The panels are coated using an approved method to complete hiding and read on the colorimeter, using the semi-absolute method given in this handbook and detailed in TM-142. The standard panel is used as the calibration standard for the colorimeter readings. The color difference is computed using either the Tables of Modified Adams Coordinates or the Color Difference Computer. Since two sets of panels are used it is necessary to reconcile any noteable deviations existing between the sets of panels.

In the specific case of the example the following readings were obtained:

TABLE II

Colorant	Calibration	ΔL	Δa	Δb
253-0505 (Blue)	1.0	-2.25	-0.38	-2.91
253-0312 (Red)	1.0	-2.01	+2.28	+0.33
253-0953 (White)	20.0	+2.56 ~~+2.26~~	-0.74	+1.04
253-0222 (Black)	0.5	-1.00	-0.90	+1.97

Note that the amount of the colorant used per 100 parts of the standard is also the calibration of the colorant vector.

Step 3: (For metallic colors only) In addition to the panels prepared under step 1, prepare a panel representing 100 parts of the standard plus sufficient white to give a reasonable reduction in the two-tone characteristics. Determine on the Two-Tone Meter, the two-tone difference existing between the standard and the standard plus the white panel.

Step 4: Using Dietzgen #332 paper or its equivalent and a scale of 1.0 NBS units per inch (i.e., a minor scale sub-division equals 0.1 NBS unit), lay out the basic Δa Δb, ΔL Δb and a,b axes as shown in Figure XI.

Step 5: Using the Δa, Δb data for each color component add, plot these points on the Δa Δb plot. Plot the reverse points (i.e., -Δa, -Δb) on the Δa Δb plot. Connect these two points and add an arrow head and colorant identification to indicate the color direction which would result from the addition of the colorant to the standard color.
Note: this line should pass through the origin of the Δa Δb plot. Calibrate the lines at the Δa, Δb point representing the addition and subtraction of the component colorant.

In our specific example 253-0505 would provide points in the Δa Δb plot at Δa = -0.38, Δb = -2.91 and Δa = +0.38, Δb = +2.91. Draw a line between these points and through the origin of the ΔaΔb plot. Extend this line beyond the points until it crosses the Δa = ± 4.0 or Δb = ± 4.0 line.

Identify the direction of color movement resulting from the addition of colorant by an arrowhead at the end of the line and identify the line with the colorant identification, i.e., 253-0505.

Certain color formulations contain an excess color pigment dispersion, usually in trace form. The colorant vectors of these excess color pigment dispersions are marked with the colorant code followed by a (T) and are used only in cases of necessity; i.e., if the 253-0505 vector represented a trace colorant it would be marked: 253-0505 (T). Black colorants, even when used in trace quantities are never considered as trace constituents. Excess colorants are also marked in this manner.

Step 6: At points Δa, Δb and $-\Delta a$, $-\Delta b$, mark the colorant vector with the calibration as determined in step 2. Repeat steps 5 and 6 for each colorant.

Step 7: Repeat steps 5 and 6 for each colorant in the $\Delta L \Delta a$ and $\Delta L \Delta b$ plots (note Figure XI).

Step 8: Plot the location of the color standard on the a,b plot. Identify the lightness value of the standard on this plot. Check the Δ plots for the proper color direction of the vectors. Record on the Color Effect Chart the G, R and B of the standard together with the commercial color tolerance of the color (if available).

Step 9: (Metallic colors only) Plot the colorant calibration on the two-tone scale at the left-hand edge of the a,b plot.

COLORIMETER-CHART PLOTTING DEVICE

The graphical technique of the Colorimeter-Chart Color Adjustment System is based upon the construction of parallel lines and the measurement of linear distances as a percentage of a calibrated distance. A special device, known as a Colorimeter-Chart Plotting Device has been designed specifically for this purpose and is available from the Gerber Scientific Instrument Company, 89 Spruce Street, Hartford, Conn., as the "C-C Plotting Device". This unit is composed of a variable spring scale and a parallel line drafting unit which is composed of clear plastic scribed with parallel lines at one-quarter inch intervals. (Note Figure XII.) The variable spring scale is a triangular spring, which when stretched, expands uniformly throughout its length. Each of the 100 increments of the spring scale is painted white with the exception of the fifth increments which are green and the tenth increments which are red. One end of the scale is in a fixed position and the other end is attached to a slide which, when moved, expands or contracts the scale. The fixed end of the scale is marked (0) zero and the remaining increments are marked 2, 4, 6, 8, and 10 at intervals of twenty units with the 10 marking representing the full 100 increments.