Philadelphia Plant # PE-65-11 - Restricted
Company Confi

CONFIDENTIAL

DU PONT

PE-65-11

A STUDY OF METALLIC COLOR TOLERANCES

PROJECT: P-58

R. H. VINING - 10/15/65

PROCESS ENGINEERING - PHILADELPHIA

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
FABRICS & FINISHES DEPARTMENT
PRODUCTION DIVISION
WILMINGTON, DELAWARE

REPORT NO. PE-65-11

RESTRICTED - COMPANY CONFIDENTIAL

COPY NO.: 1

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

A STUDY OF METALLIC COLOR TOLERANCES

BY: R. H. VINING

DATE ISSUED: OCTOBER 15, 1965

PROJECT: P-58, INSTRUMENTAL COLOR TECHNOLOGY

ABSTRACT

An analysis of the factors influencing metallic color control and customer acceptance patterns are presented together with a summary of the results of the 1964-1965 model years. Based on the data analyzed, instrumental color tolerances are proposed for metallic colors.

A STUDY OF METALLIC COLOR TOLERANCES

TABLE OF CONTENTS

A STUDY OF METALLIC COLOR TOLERANCES

I - SUMMARY

INTRODUCTION

The successful application of color technology to the routine control of color is largely dependent on defining mathematical tolerance zones in a manner such that they define the acceptability or non-acceptability of a color match to a customer when the match is viewed visually. If metamerism is not present, there should be no conflict between visual and instrumental appraisal of a color difference.

The term "color measurement" brings to the minds of most people thoughts of certain specific types of instruments. This, however, is only correct in part. The visual examination and comparison of colored materials constitute a measurement which is qualitatively the same as the most elaborate and complex instrumental method. The success of any color measurement procedure requires a standardized procedure for the preparation of the sample which is both repeatable (by the same person in the same laboratory) and reproducible (by different people in different laboratories at different times). Should visual and instrumental assessment procedures fail to agree, then it must be determined whether the criteria of repeatable and reproducible sample preparation techniques have been fully met by both systems. With respect to metallic colors, specifically "Lucite®" Automotive colors, there is strong evidence to support the belief that such is not the case with current visual color measurement procedures based on conventional sample preparation techniques and that the instrumental approach using the sparger concept is more reliable.

Production for six colors manufactured during 1965 at four plant locations has been monitored by visual and instrumental methods. Data reported and conclusions drawn in this report are based on production batches which were visually approved using conventional panel spray procedures versus a visual conventionally sprayed standard, and then subsequently resprayed via the sparger procedure and measured using Colormasters specially modified for both normal and high angle metallic color measurement.

RESULTS

The results obtained from this study are summarized below:

1. The spray variable inherent in the preparation of conventional metallic panels is of sufficient magnitude to violate the fundamental criteria of repeatability and reproducibility and effectively "masks" color shifts existing between batch and standard. The actual, as compared with the apparent, batch-to-batch variations between conventionally sprayed metallics are not accurately defined by existing procedures nor can these actual variations be considered equal to those traditionally reserved for products requiring "exacting matches." The actual batch-to-batch variability existing between metallic colors as defined by sparger spray and instrumental measurement is several orders of magnitude greater than that applied to Automotive solid colors, yet on a visual basis, color tolerance limits for metallic colors are more restrictive. The data summarized in the body of this report clearly define the actual batch-to-batch variation that has existed regardless of the manufacturing location through the application of control predicated on conventionally sprayed panels and visual color tolerance limits.

2. A significant and not fully recognized factor in multi-plant production is the color deviation existing between production for any given time period for plants operating independently under the visual appraisal methods. Under existing approval procedures where individual preferences can significantly influence the nebulous approval zone for any given product, color deviation between individual plants can be of sufficient magnitude that it probably could not be masked by the normal spray manipulation inherent in Automotive production plants.

3. Based on data compiled during this study, there is no justification for determining or maintaining a visual offset predicated on a customer's implied or imagined preference for a given color or color family, since all evidence shows that none truly exists, assuming no basic formulation weakness. All plants, regardless of whether they are attempting to maintain a visual offset for a given color, have shipped batches over a period of one or two months that completely "bracket" the standard. Batches shipped during a given time interval, would, at another time period, be rejected visually due to unacceptable color deviations from the visual offset.

4. Evaluation of the data compiled for the product codes studied show the overall variability that existed on a Divisional basis determined from sparger panels prepared from conventionally approved batches (see Table I).

TABLE I

DIVISIONAL PRODUCT COLOR VARIABILITY
(Overall variation in NBS units)

Product	"Head-In" Color			"Side-Tone" Color		
	ΔL	Δa	Δb	ΔL	Δa	Δb
867-97212	1.5	0.7	0.8	1.3	1.0	0.6
867-97215	2.2	1.8	1.5	1.6	2.5	1.7
867-97216	2.0	0.6	1.5	1.5	1.2	0.9
867-97217	2.4	2.2	1.2	1.5	1.6	0.8
867-97219	2.5	1.5	0.8	2.3	3.3	1.2
867-97223	1.6	1.4	0.8	1.4	1.6	0.7

5. There is no evidence to indicate that there is a preferred "side-tone" color match for a metallic standard. It has been assumed that problems will result if metallic colors are shipped exhibiting a light, milky side-tone and/or are less saturated than standard. It is very evident from this accumulated data that the customer has accepted and used such batches through the 1965 model year for some of the colors evaluated. In other instances, one customer plant has received production that has been consistently on the dark, saturated side of standard, a second customer plant has received and used the same basic color on the light, less saturated side, yet no color complaints have been reported. It is apparent that in many instances troublesome batches have been a case of "much-ado-about-nothing," and the principal criteria is to maintain a reasonable level of uniformity between shipments.

CONCLUSIONS

The conclusions drawn from the data presented in this report are delineated below:

1. Visual appraisal techniques, though valid and accurate at any one time and location, are subject to psychophysical factors which result in a transient color preference for a "match" to one side or another of the standard. The net effect of these factors indicates that at any one time different manufacturing locations could produce the same product on the opposite side of standard or in a given day close color matches can be erroneously evaluated as being on opposite sides of the standard. The elimination of the highly variable conventional spray system and its replacement with the more precise sparger system will not eliminate the human variability factor.

2. The color appraisal, based on visual viewing and conventional spray techniques, is subject to many variables that are not readily controllable. There is strong evidence to support the contention that these appraisal techniques do not result in the quality of match or match reproducibility credited to the overall system. Success of the visual system has been predicated on each plant attempting to minimize batch-to-batch variation at its location and a major factor in achieving success stems from the fact that the customer for the most part restricts his purchase of any given product to one Du Pont location. If the customer were to change his procurement habits and acquire metallic finishes on a random basis from any of our four producing plants, it is highly unlikely that under the existing procedures we would escape formal color complaints. The variables inherent in application of visual color appraisal techniques are such that further refinements to the overall system are not readily obtainable, therefore, the increasing demands by industry for more uniform and exacting color matches are not likely to be achieved by visual techniques alone.

3. Color approval based on instrumental techniques will not replace visual evaluation of a color. The eye will and must remain the final arbitrator of a color match, being used primarily as the check against human error in instrumental measurement. Application of instrumental techniques to color control will make possible better interplant uniformity and batch-to-batch uniformity unattainable by current visual appraisal techniques.

4. The successful application of instrumental techniques to metallic color control is dependent on proper sparger spray procedures, minimizing human variability and applying a procedure that achieves the criteria of repeatability and reproducibility.

5. The successful application of instrumental color techniques to color control is predicated on having defined meaningful color tolerances. Color tolerances to be meaningful must be based on a customer's history pattern of acceptances for individual colors and/or color families. Acceptance pattern data are available for a large group of metallic finishes. These patterns are based on a sampling of 1964 model year colors and the 1965 model year colors reported in the body of this report

6. The practice of establishing "offsets" for metallic colors should be discontinued since data show that they have no effect on the overall acceptability pattern.

RECOMMENDATIONS

The following recommendations result from this study:

1. Metallic batches be sprayed via sparger techniques and instrumentally measured, matched and approved with an after-the-fact visual check to eliminate possible human measuring or calculating error.

2. The following instrumental color tolerances are recommended for the light to medium metallic colors - Table II.

TABLE II

RECOMMENDED COLOR TOLERANCES
(Light to Medium Metallics)

	Head-in Color (N.B.S.)	Side-Tone Color (N.B.S.)
ΔL	± 0.40	± 0.30
Δa	± 0.30	± 0.30
Δb	± 0.30	± 0.30
E	0.58	0.52

REPRESENTATIVE COLOR RANGE

867-97591	867-97223	867-97846
867-97841	867-97217	867-97219
867-97847	867-97593	867-97589
867-97692	867-97344	

3. Dark metallic colors should be approved visually to the sparger standard and instrumental measurements obtained. Feedback data must be forwarded to the Color Operations Section and numerical tolerances will be established as rapidly as sufficient feedback data are available to predicate meaningful tolerances.

4. The following overall procedures are recommended for batch shading and approval:

   a. All panels be sprayed via sparger following TM-349-P.

   b. All panels to be measured via Model V or V-A Colormaster and feedback data using FF-7746 provided to C.O.S.

   c. Batches shaded to within the above tolerances (Table II) should be considered acceptable regardless of minor visual color deviations. It should be borne in mind that the improved reproducibility of sparger spray techniques can be coupled with broader visual tolerances and still achieve greater batch-to-batch and plant-to-plant reproducibility.

d. If doubt exists as to the visual validity of an instrumental match held to within the above tolerances the sample may be sprayed conventionally at the viscosity extremes allowed by the conventional spray procedure and examined relative to the conventional standard. If the color of these two panels brackets the standard the desired color match has been achieved. It must be remembered that the inherent variability of the conventional spray (see Tables III and IV) is such that even under the above circumstances a misleading representation of the color may be obtained.

e. Care must be exercised by personnel visually examining a color match to assure elimination of personal preferences for a given color, since data on the 1965 colors clearly show that the customer has accepted and used without comment, production batches that have completely bracketed the color standard. The numerical values for these batches are in excess of the ones proposed as tolerances for color control purposes for 1966 colors.

CONTINUING ACTION

1. All plant locations must report to the Color Operations Section the numerical values at which each batch was approved, indicating whether the approval was based on numerical values, on visual assessment of the sparger panel versus the sparger standard, or on a conventional sprayout without direct reference to the sparger panels. Color tolerances at best are only guide lines for operation and though carefully established based on available data, are to some extent subject to the desires of the customer. The Color Operations Section should be advised by any plant if there are informal or formal color complaints lodged against computer-controlled batches shipped to the customer. Close and continuing liaison will be necessary in order to establish and maintain the full validity of color tolerances.

2. Accumulation and analysis of feedback data on "dark" and saturated metallic colors should be continued in order to establish valid tolerances for this color range.

3. Colors exhibiting inadequate formulation characteristics in the selection of pigmentation or aluminum may necessitate either reformulation or their Divisional approval to some numerically offset standard in order to allow Production to manufacture within an acceptable range of variability. A potential example of the problem is 867-97223 (see Figure XI).

ACKNOWLEDGMENT

This study has been made possible only through the cooperation of the various manufacturing plants who have faithfully forwarded panels, feedback data, etc. to C.O.S.

RESTRICTIONS

This report is Restricted - Company Confidential and must be limited to personnel familiar with the Instrumental Shading System.

PREPARED BY: R. H. Vining
R. H. VINING
COLOR OPERATIONS SECTION

APPROVED BY: W. H. Edwards
W. H. EDWARDS
DIVISIONAL PROCESS ENGINEERING SUPERVISOR

RHV:IL

II - DISCUSSION

BACKGROUND

Rarely, if ever, does the manufacture of a batch achieve a perfect color match relative to a given standard. This is especially true in the field of metallic finishes where a compromise match between head-in and side-tone color must usually be accepted. Industry has, by necessity, relied on visual appraisal techniques by highly trained and competent specialists who have spent years developing their ability to correlate visual color differences with differences that they feel are acceptable to a customer. Color tolerances can vary for each color and can vary for each customer; consequently, the person responsible for deciding whether a match is adequate must rely heavily on a "color sense" that can best be described as intuitive.

The success of the visual appraisal system is amply demonstrated by the volume of business enjoyed by the Finishes Division in the highly competitive Automotive field. To achieve this degree of success, the visual appraisal system has been subject to constant refinements over the years and it would appear that no significant improvements in the overall system can be anticipated in the future. The trend in industry, however, is toward ever-decreasing color tolerances resulting from an increasingly stringent market requirement. Additionally, the Finishes Division will, in the 1966 model year, depart from a manufacturing procedure that has in the past resulted in production from one Finishes plant being more or less restricted to a given Automotive plant. During the 1966 model year, production for several of the large-moving metallic finishes will be manufactured simultaneously at the Flint and the Toledo Plants, and, in turn be shipped to a common Automotive plant. This procedure will result in a direct comparison by the customer of batch-to-batch variability inherent within a plant and more importantly, plant-to-plant uniformity. This is a situation not normally encountered in the Automotive segment of our business. Experience in other segments of our business has clearly shown that the problems of batch-to-batch uniformity, though significant, may be minor to the overall problem of attaining and maintaining an acceptable level of plant-to-plant uniformity.

VISUAL APPRAISAL PROCEDURES

In order to make a visual assessment of a color, it is first necessary to prepare a representative sample, usually a panel of the batch for comparison versus the standard panel. All panel preparation procedures are subject to an inherent variability. The basic criteria of panel repeatability and reproducibility must be met as the visual examination and comparison of colored materials is analogous to the most complex and exacting analytical procedure performed in a laboratory. In assessing the quality of the match, panel position, color of the surround, and lighting are equally critical. The observer, that is, the person making the decision regarding the quality of the match, is the remaining factor involved in the visual assessment process. Light from the source illuminates the object. A part of this light is reflected either unchanged or spectrally modified by the absorption characteristics of the panel into the eye of the observer. From the response of the eye the reaction is conveyed via the optic nerve to the brain where the sensation of color is evoked. The observer then decides whether the color is or is not within some intuitive specification or tolerance. As an aid to arriving at a decision, use is sometimes made of limit standards. The usual procedure is to assign the last approved batch as a limit standard and the approval is given if the current batch falls between the limit standard and the official standard.

Visual appraisal techniques at first glance would appear to be thoroughly reliable assuming the basic conditions outlined above are adhered to. In the assessment of colors, one sometimes encounters variables and transient effects which make positive conclusions very difficult, variables which appear to shift either with time or with relative position. Physical influences such as secondary light sources may often be contributing factors. The quality of the light for visual color comparisons is too often unstandardized and may be more or less changed by reflections from sources all too commonly ignored or unsuspected. For example, extraneous laboratory lighting may influence the characteristics of the light under which the match is made and/or afternoon sunlight entering the laboratory can change the light spectral characteristics. The color response of the two eyes is not necessarily identical and a color may appear to fluctuate slightly in shade as the response of one eye or the other dominates when viewing the panel. This variable is "retinal rivalry" and the shifting response is linked with a shifting of attention, conscious or otherwise, from one eye to the other. The sensitivity of the eye for spectral hues changes with intensity of illumination, and from high to low illumination intensities the shift in response is toward colors of shorter wavelengths; e.g., greens appear bluer. This is the "PURINJE EFFECT" and is a property of all normal eyes. The intent or mood of the observer can also influence what he sees and frequently a color panel can be rejected in the morning if the observer is under some form of pressure, and yet later be considered to be acceptable due to a change in environmental conditions. Personal fatigue can influence both perceived color differences and attitudes toward acceptance.

The factors influencing visual perception and color interpretation for one observer apply to all observers. No two observers can be considered identical, as each will react differently through varying stimuli. The human eye and brain are unsurpassed as a null detector but with a barely perceptible difference between the standard and the sample, there may be considerable difference of opinion amongst trained observers as to the nature of the color difference and the overall significance relative to a given customer's requirements.

REPEATABILITY AND REPRODUCIBILITY

Under the most optimum viewing conditiong with highly trained observers, the quality and uniformity of successive matches are dependent upon a panel being representative of the color of the batch being assessed. As with all analytical procedures, all facets of the process must be reproducible. With visual appraisal procedures, the criteria of repeatability and reproducibility has been assumed but not proven to be firmly established.

Repeatability can be defined as the ability of one operator to repeat a given operation successively and obtain the same end results. Reproducibility is the ability of several operators at a given location and/or separate locations to perform the same operation using samples from a common source and achieve the same results as the original operator.

There is ample evidence to show that the fundamental precepts of repeatability and reproducibility are not achieved with metallic-type finishes, nor is the basic criteria of repeatability with a function as fundamental as the preparation of conventional standards or batch panels achieved.

E. A. Miller, as a part of the development program leading to the sparger spray procedure, undertook a separate study to determine the variability existing between conventionally sprayed metallic standards. His work indicated that the repeatability and reproducibility of these standards had declined markedly as a result of major quality changes that affected the sprayability of the finish. The data were developed for the medium Turquoise color family and encompassed standards for three model years. Data indicated that the 1963 color standards (867-line quality) differed sufficiently from one another that if one panel were selected as the prime standard, many of the standards would have to be rejected if the normal visual color tolerances used in batch assessment were maintained. The standard panels were selected at random and measured for "head-in" color using a wide aperture Colormaster. "Side-tone" color data were reported in terms of two-tone as measured on the J-5 Two-Tone meter. The variability found between panels within the sets is reported in Table III.

TABLE III

STANDARD PANEL VARIABILITY

Model Year	Quality	ΔL	Δa	Δb	ΔΠ
1961	887	0.60	0.20	0.20	3
1962	887	0.80	0.50	0.50	5
1963	867	2.00	1.20	1.20	12

Sixteen "O.K." color panels for 867-95183 were in turn measured versus a single standard panel. Similarly retain samples for ten O.K. colors were resprayed and measured against the same standard panel. The variability existing between the panels is shown in Table IV.

TABLE IV

BATCH-PANEL VARIABILITY

867-95183	ΔL	Δa	Δb	ΔΠ
"OK" Color Panels	2.20	1.50	1.50	12
Retain Resprays	2.00	1.10	0.75	6.0

The "O.K." panels were sprayed at different times, whereas, the retains were sprayed at the same time by the same operator using the same gun, thus minimizing the inherent variability of the conventional spray.

In the preparation of sparger standards, 14 panels are prepared per deck and successive "decks" are prepared until an adequate number of standards is available. All panels are measured for the G value using a Model V-A Colormaster equipped with the dual angle measuring attachment. In addition, five panels selected at random from each deck are measured for G, R, B values at both positions. These data are summarized in Table V. Through the use of the Carrousel unit, the basic requirement of repeatability and reproducibility for standards preparation has been met. A similar condition exists for the single panel production sparger unit. These standards, though developed originally for instrumental control purposes, can also be used equally as successfully for visual color assessment purposes.

The level of repeatability and reproducibility which has been achieved with the sparger spray procedure may be assessed from the variability existing between standards prepared on the "Carrousel" standards unit for 1966 model year colors as shown in Table V.

TABLE V

SPARGER PANEL VARIABILITY - 1966 COLORS

Product Code	ΔL_F	Δa_F	Δb_F	ΔL_H	Δa_H	Δb_H
867-97217	0.04	0.10	0.06	0.06	0.33	0.10
867-97589	0.36	0.10	0.21	0.06	0.07	0.06
867-97593	0.22	0.20	0.12	0.34	0.32	0.09
867-97223	0.09	0.06	0.06	0.11	0.23	0.19
867-97219	0.13	0.10	0.07	0.07	0.17	0.05
867-97844	0.11	0.35	0.16	0.02	0.20	0.07
867-97841	0.23	0.17	0.16	0.20	0.09	0.12
867-97591	0.13	0.05	0.03	0.12	0.14	0.04

COLOR TOLERANCE

A color tolerance will seldom be equal to the acceptance pattern established by a customer. In establishing this color tolerance, due regard should be paid to the acceptance pattern, since this pattern is established by actual shipments acceptable to the customer and will include the occasional "maverick" that somehow slips through all control laboratories. Acceptance patterns do serve to indicate whether the proposed tolerance is realistic and the difference existing between the assigned tolerance and the acceptance pattern can be considered as a safety factor between a complaint/no complaint situation.

Under visual assessment conditions, a color tolerance must exist in the observer's mind and is a function of his experience. The tolerance will vary and is, to a large extent, dependent on the color preference of the observer. The observer may favor the light green side of standard, the dark yellow side of standard, etc., and to him any batch not falling inside his personal preference color dimension is unacceptable. Color memory is notoriously poor, the observer is himself subject to many factors, and as a result, his preference range will shift at frequent intervals and will often reverse, accepting today what a week ago was somewhat objectionable.

Thoroughly trained observers can differ amongst themselves with respect to color preference, consequently, it is not uncommon to have at any time diametrically opposed color preferences for the same color at different manufacturing locations (Figures IV - XI). Limit standards bracking the standard color could be used as a guide in visual assessment. Limit standards would define an acceptable color tolerance in all dimensions and if the batch fell anywhere within the parameters defined by the standards the batch would be approved. Divisionally, limit standards are not employed nor feasible and reference is usually made to the last batch panel and the standard panel. A "fan-out" of passing batch panels would be more truly representative of limit standards, bearing in mind that this would constitute the acceptance pattern for the color. This procedure is seldom followed due to the demonstrably poor repeatability/reproducibility of conventional metallic spray procedures.

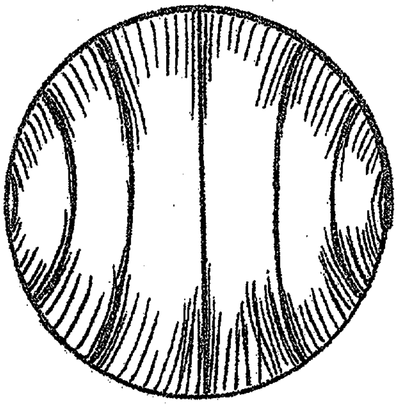
For illustrative purposes, let us assume that we have a basket ball, a volley ball and a tennis ball. Let us also assume that the volume encompassed by the basket ball is equivalent to the color tolerance for a given product; i.e., any batch falling within the basket ball would be acceptable to the customer. The three-dimensional characteristics of a color and/or color tolerance are shown in Figure I. The repeatability/reproducibility factor applicable for conventional metallic spray procedures can be represented by the volume of the volley ball; i.e., the true color location of the batch will be somewhere within this volume. Similarly, the repeatability/reproducibility factor for the sparger spray procedure can be considered equivalent to that of the tennis ball. If the volley ball were placed inside the basket ball, the overall difference between the two is extremely small (see Figure II) and represents the visual tolerance that must be maintained to insure that all batches are within the tolerance (basket ball) acceptable to the customer; whereas, if the tennis ball were placed inside the basket ball, the overall difference is considerably larger, representing the larger visual tolerance that can be used with the sparger system to achieve the same end tolerance (see Figure III). With a system where the repeatability/reproducibility factor is very poor (large) the allowable deviation permitted for a color must be small, where the repeatability/reproducibility factor is small, the allowable color deviation can be much larger.

In actual practice we have recognized that conventional spray procedures restrict the color difference between a batch and standard to a barely perceptible visual difference if we are to remain within the acceptable color tolerance zone. With a more reproducible spray procedure such as the sparger spray procedure, the color acceptance zone can be much larger visually and still be acceptable. This zone can be ascertained by preparing sparger panels from samples taken from batches that have been considered acceptable based on the conventional spray procedure and customer usage. A color tolerance zone can then be determined from these data. The batch-to-batch uniformity of the material shipped to the customer will remain within the parameters defined by his acceptance pattern based on past experience, and, from a manufacturing viewpoint, the degree of color variability that can be permitted is quantitatively defined.

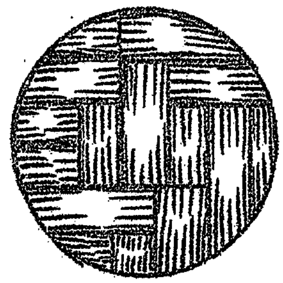
Color tolerances directly or indirectly will reflect the degree of confidence the observer has in the control system. A color tolerance can be made so restrictive that the ability to compete effectively is unduly hampered by unrealistic costs. By the same token, unrealistically broad tolerances cannot be assigned without the risk of customer complaint. Color tolerances will vary for different product lines, different end uses, and within a product line may vary with the lightness and saturation characteristics of the colors.

In addition to visual color tolerances it is possible and desirable to assign numerical color tolerances for a given color. If these numerical tolerances are properly determined, all batches falling within the tolerance parameter should be visually acceptable. The eye must be the final judge of a color match and the eye

FIGURE I



Customer Acceptance
Tolerance
(Basket Ball)



Conventional Spray
Variability
(Volley Ball)

Sparger Spray
Variability
(Tennis Ball)

DIMENSIONAL CHARACTERISTICS OF COLOR TOLERANCE

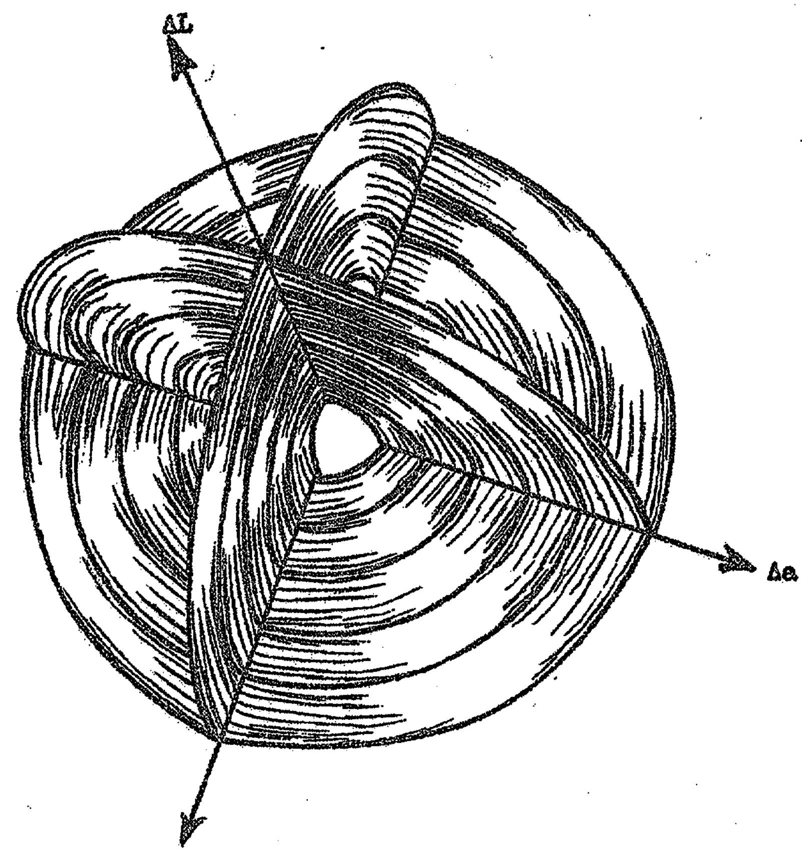


FIGURE XI

DIMENSIONAL CHARACTERISTICS OF COLOR TOLERANCE
CONVENTIONAL SPRAY PROCEDURES

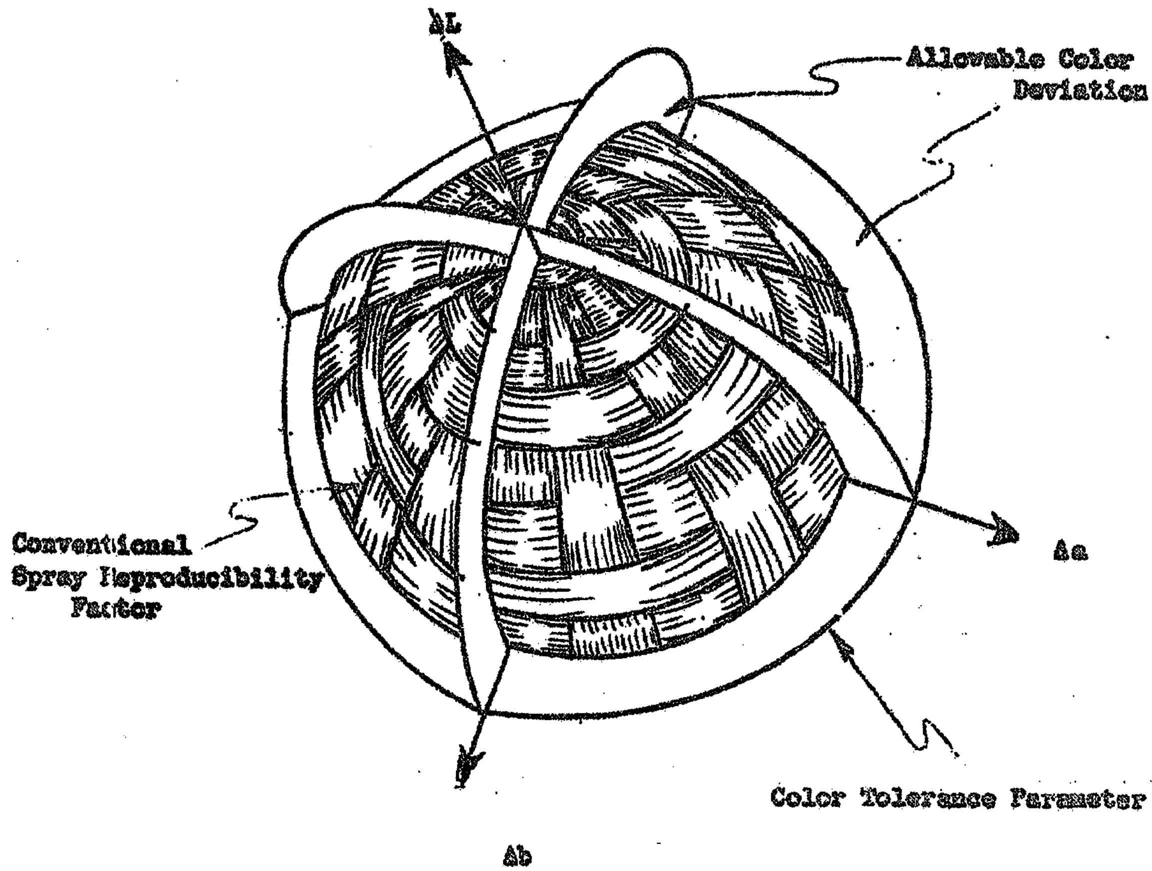
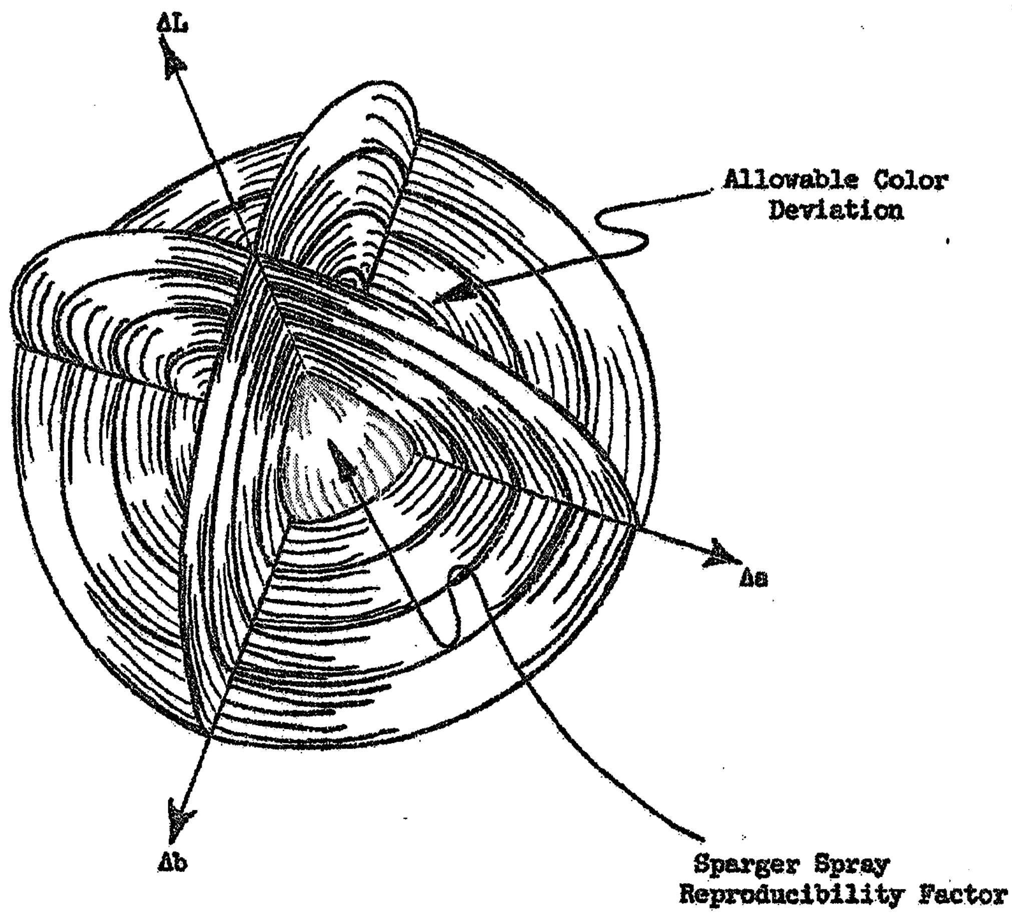


FIGURE III

DIMENSIONAL CHARACTERISTICS OF COLOR TOLERANCE

SPARGER SPRAY PROCEDURE



and the instrument must agree as to the description of the color deviation existing between the batch and standard. If disagreement exists between the eye and the colorimeter as to the magnitude of the color deviation and the instrumental values are checked and found to be correct, the visual interpretation may be in error due to factors discussed under "Visual Appraisal."

EXPERIMENTAL

The data reported below are based on metallic "Lucite*" production for four plants for the 1965 model year unless otherwise specified. All batches were approved visually based on conventional spray procedures with a sparger-type panel prepared after the visual approval was given. In many cases the sparger panels were measured both at the plant preparing the panels and at the Color Operations Section. The C.O.S. has on file color data for over 500 metallic batches, including intermediate shading data for 1964, 1965 and 1966 colors. These data are not appended to this report since their inclusion would be superfluous.

BATCH-TO-BATCH UNIFORMITY

Production batches that were visually approved following the conventional spray procedure were, after the fact, sprayed via the sparger technique. Sparger prepared panels for consecutive batches approved via visual procedures were requested from each plant location in order to determine whether a plant offset was required as a prerequisite to successful instrumental shading. The data indicate that when the variability inherent in conventional spray is eliminated, the batch-to-batch uniformity is broader than generally realized. The color differences existing between the batches when sprayed via sparger technique are, in many cases, of sufficient magnitude to result in a visual rejection of the sparger panel versus the sparger standard if the same visual tolerances used for approving visual spray were imposed. See Figures IV and V showing consecutive batches for the four locations plotted in numerical sequence.

These data not only indicate greater differences than anticipated between batch-to-batch production, but also indicate a lack of plant-to-plant uniformity. Note in Figure V (Δa, Δb chart) the quadrant grouping of each plant's production, indicating that each plant approved the same product code with different emphasis on the preferred color. The different grouping of each plant's production indicates the visual presence of a preference factor and is not indicative of a formulating weakness. The data do indicate that a Divisional problem exists with 867-97223 with respect to side-tone color control. Note that 14 out of 16 batches reported were approved on the light, milky, less glamorous side of standard, indicating the need for a brighter, coarser metallic flake if the batch is to consistently match the standard.

The data reported for 867-97217 indicate a plant preference for hue control with one plant, represented by the green numerals, approving production that is considerably redder in comparison to the Divisional approval pattern. Note also that the plant represented by the red numerals favored the yellow side of standard, with the remaining two plants randomly distributed with respect to yellow-blueness. With respect to side-tone color, the problem of lightness control is not as pronounced and an equal number of batches were approved either lighter or darker than standard. This would indicate greater formulating leeway with 867-97217 than with 867-97223.

(*) Du Pont Registered Trademark

FIGURE IV

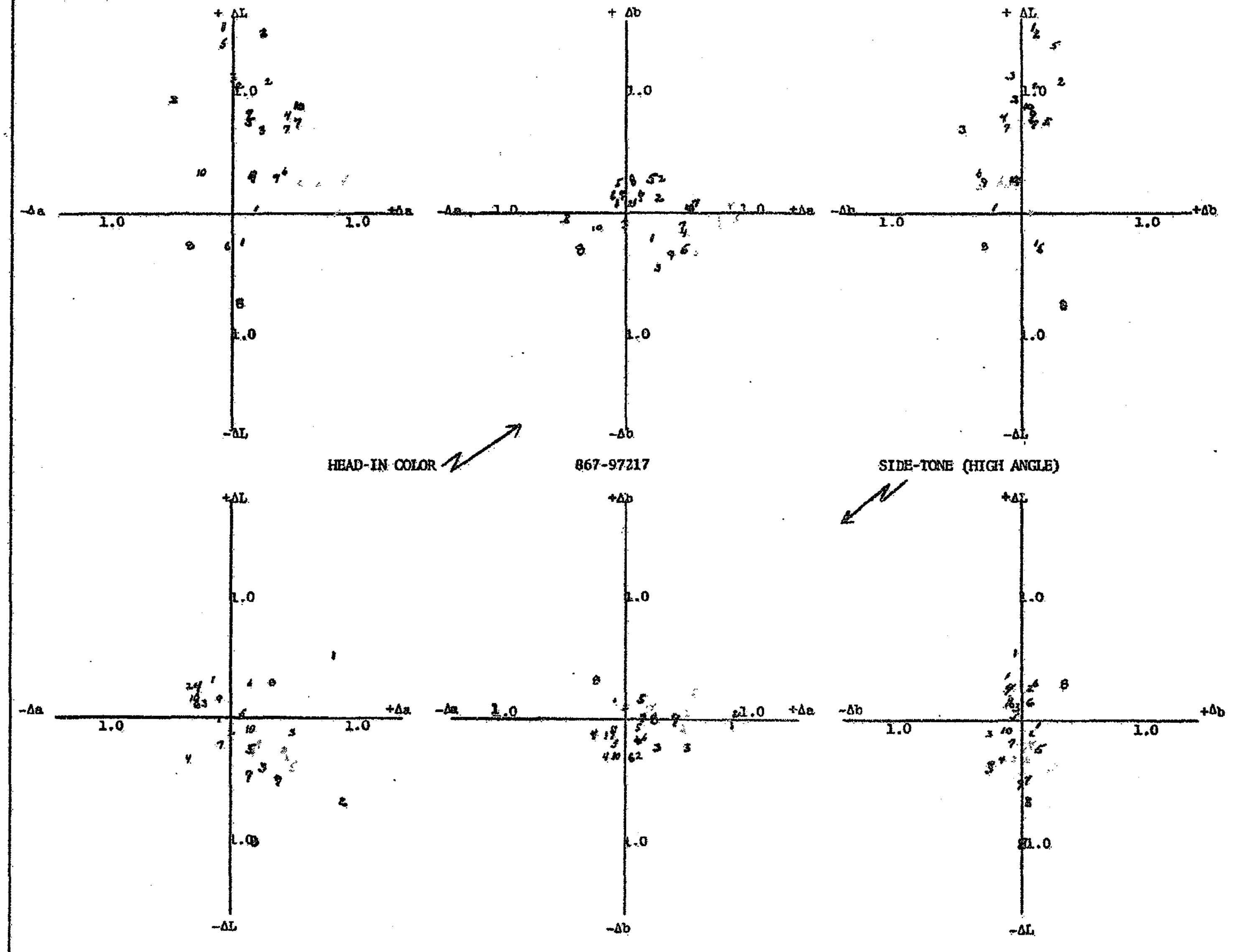
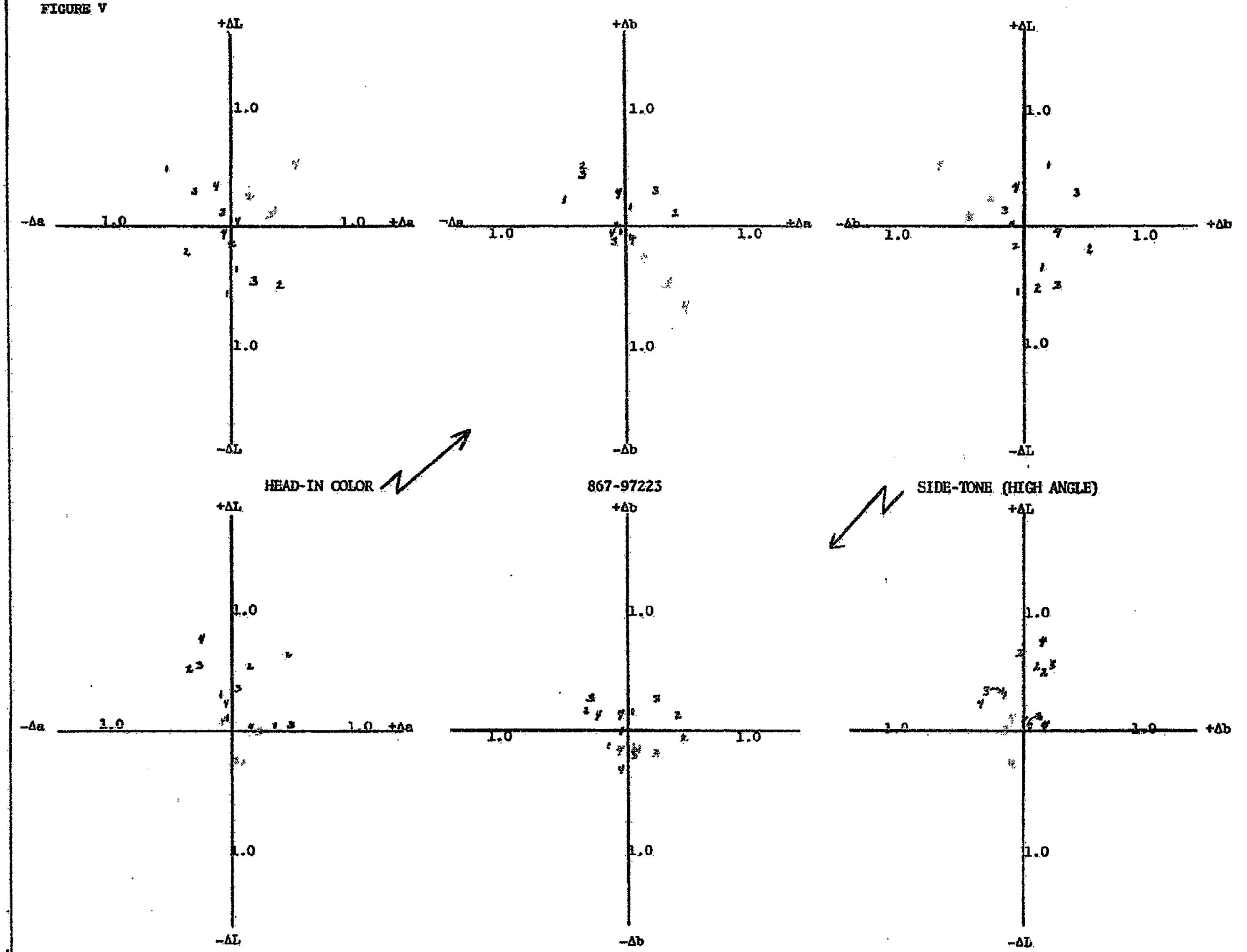

HEAD-IN COLOR
867-97217
SIDE-TONE (HIGH ANGLE)
+ ΔL
-ΔL
+Δa
-Δa
+Δb
-Δb
1.0

FIGURE V


HEAD-IN COLOR
867-97223
SIDE-TONE (HIGH ANGLE)
+ΔL
-ΔL
+Δa
-Δa
+Δb
-Δb
1.0

CUSTOMER ACCEPTANCE TOLERANCES

Data for six product codes:	867-97212	- Figure VI
	867-97215	- Figure VII
	867-97216	- Figure VIII
	867-97217	- Figure IX
	867-97219	- Figure X
	867-97223	- Figure XI

have been plotted for two or more plant locations. Data are for consecutive batches although they are not numbered as in Figures IV and V.

Color tolerances, although specific for each color within the color solid, can be generalized for the six colors studied in this report. The customer acceptance pattern indicates that a lightness deviation equal to two units in the Modified Adams' Coordinate System is acceptable. The data also indicate that the customer has accepted production, showing a greater deviation in the green-red axis than in the yellow-blue axis. The acceptance range in the Δa direction approximates one unit, in the Δb direction 0.8 units and these tolerances are shown on the transparent overlay accompanying each chart. Customer tolerances for "head-in" color can therefore be generalized to a deviation of:

$$\Delta L = \pm 1.00$$
$$\Delta a = \pm 0.50$$
$$\Delta b = \pm 0.40$$

equivalent to an E approximating 1.2 NBS units. Note that in most cases, batches have been shipped to the customer that exceed the above color tolerances, indicating an understatement of acceptance pattern.

Side-tone color exhibits approximately the same color deviation as does the head-in color. With the possible exception of 867-97219, the customer has not objected to receiving production that is on the light, milky, less glamorous side of standard. In effect, the "two-tone" characteristics of a color are not as critical as generally believed. Color tolerances for side-tone color can therefore be generalized to:

$$\Delta L = \pm 0.75$$
$$\Delta a = \pm 0.40$$
$$\Delta b = \pm 0.30$$

or an E equal to 0.9 NBS units around the mid-point of an offset centroid. Again note that the transparent overlay showing these tolerances does not include all batches, indicating a tolerance in excess of that stated above is acceptable.

COLOR TOLERANCES - CONTROL

Based on the 1965 model year data, light and medium metallic colors controlled instrumentally to:

$$\Delta L = \pm 0.40$$
$$\Delta a = \pm 0.30$$
$$\Delta b = \pm 0.30$$

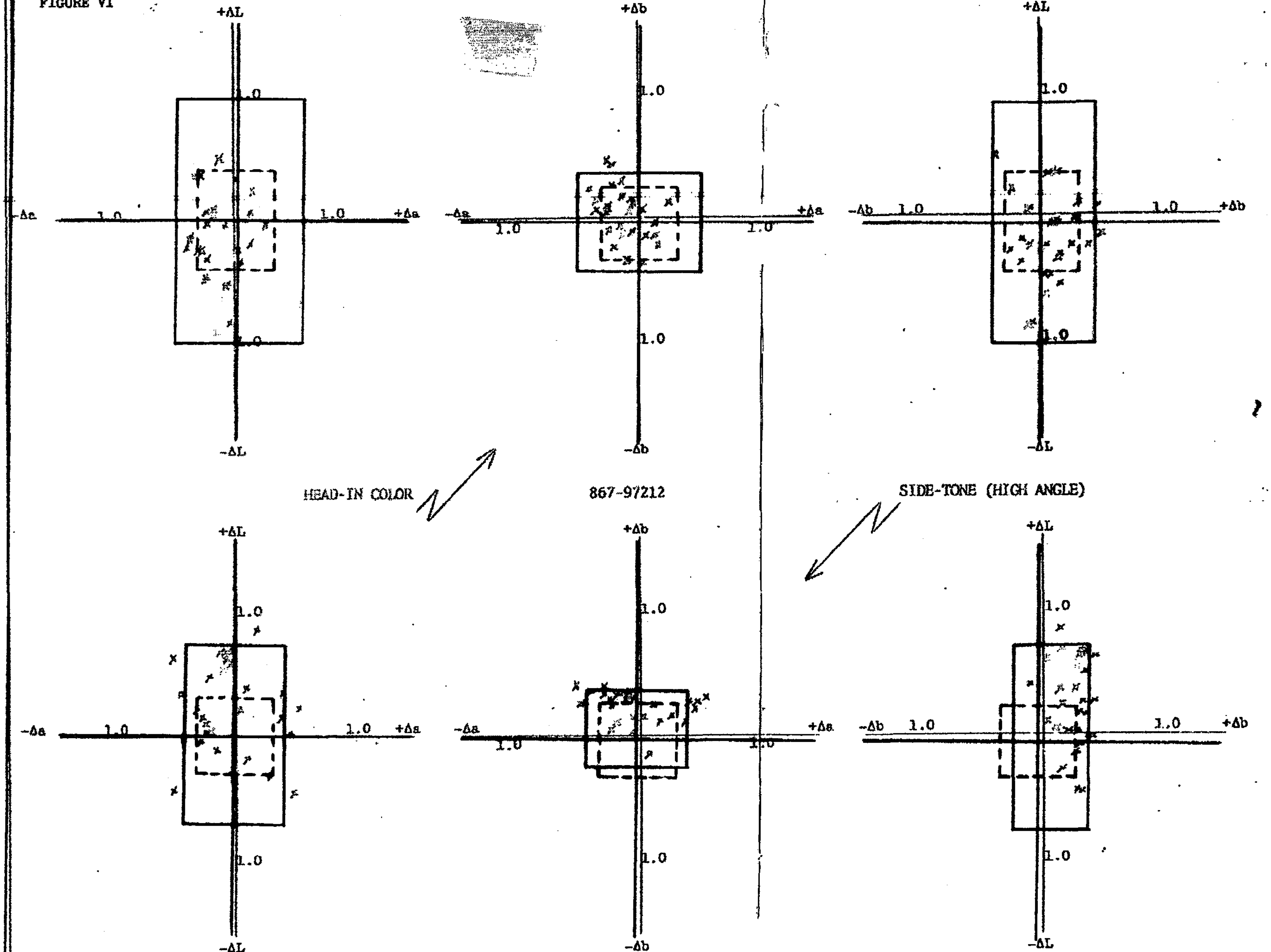
should be visually acceptable to the customer. Colors controlled to the above values would exhibit color difference (E value) of 0.58 NBS units contrasted to an E value of 1.20 NBS units established during 1965 model year.

Side-tone should similarly be controlled to:

$$\Delta L = \pm\ .30$$
$$\Delta a = \pm\ .30$$
$$\Delta b = \pm\ .30$$

or equivalent to an E of 0.52 units versus the 0.9 NBS units established for 1965. The overlays show the proposed instrumental color tolerances for the six colors involved (dashed lines) and many of the 1965 shipments would not be considered acceptable based on these new tolerances. There is sufficient formulating latitude to place the colors within these tolerance zones, assuming that no visual preferences exist. These same tolerances should be applicable to the 1966 colors that fall in the same color family and are of the same lightness range.

FIGURE VI



+ΔL
-ΔL
-Δa
+Δa
+Δb
-Δb
1.0
HEAD-IN COLOR
867-97212
SIDE-TONE (HIGH ANGLE)

FIGURE VII

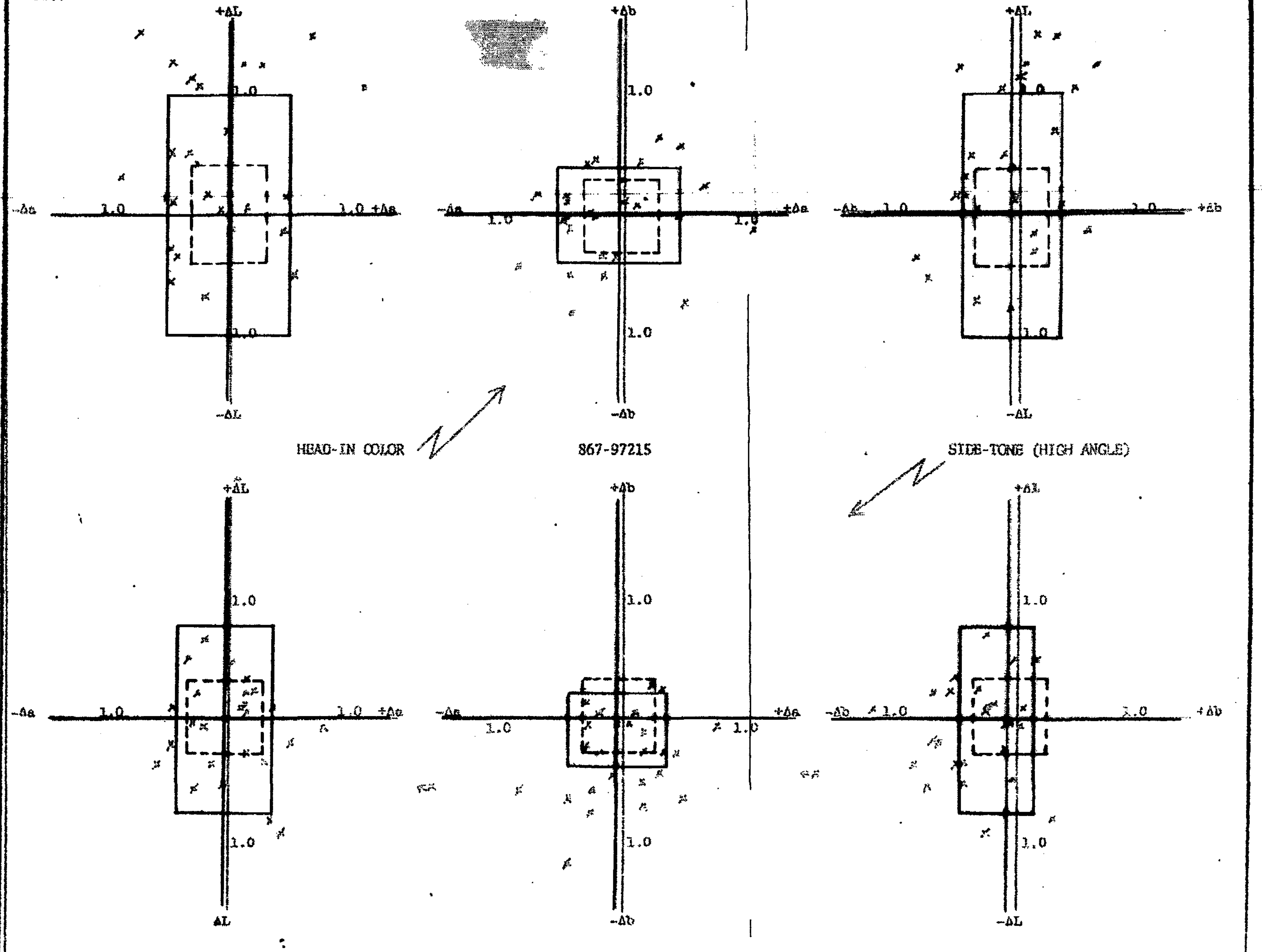
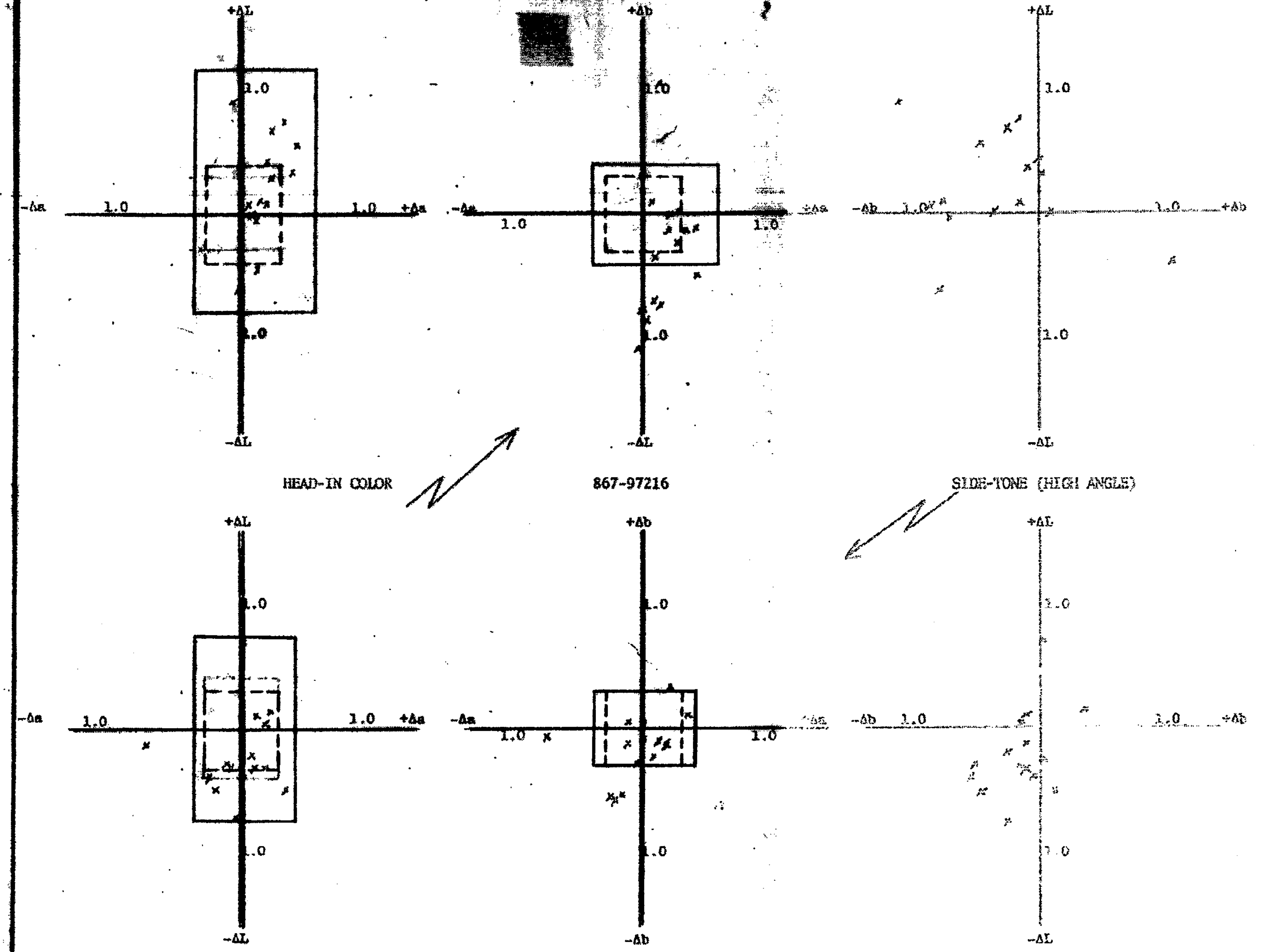

+ΔL
-ΔL
-Δa
+Δa
1.0
+Δb
-Δb
HEAD-IN COLOR
867-97215
SIDE-TONE (HIGH ANGLE)
ΔL

FIGURE VIII



HEAD-IN COLOR
867-97216
SIDE-TONE (HIGH ANGLE)
+ΔL
-ΔL
+Δb
-Δb
+Δa
-Δa
1.0

FIGURE IX

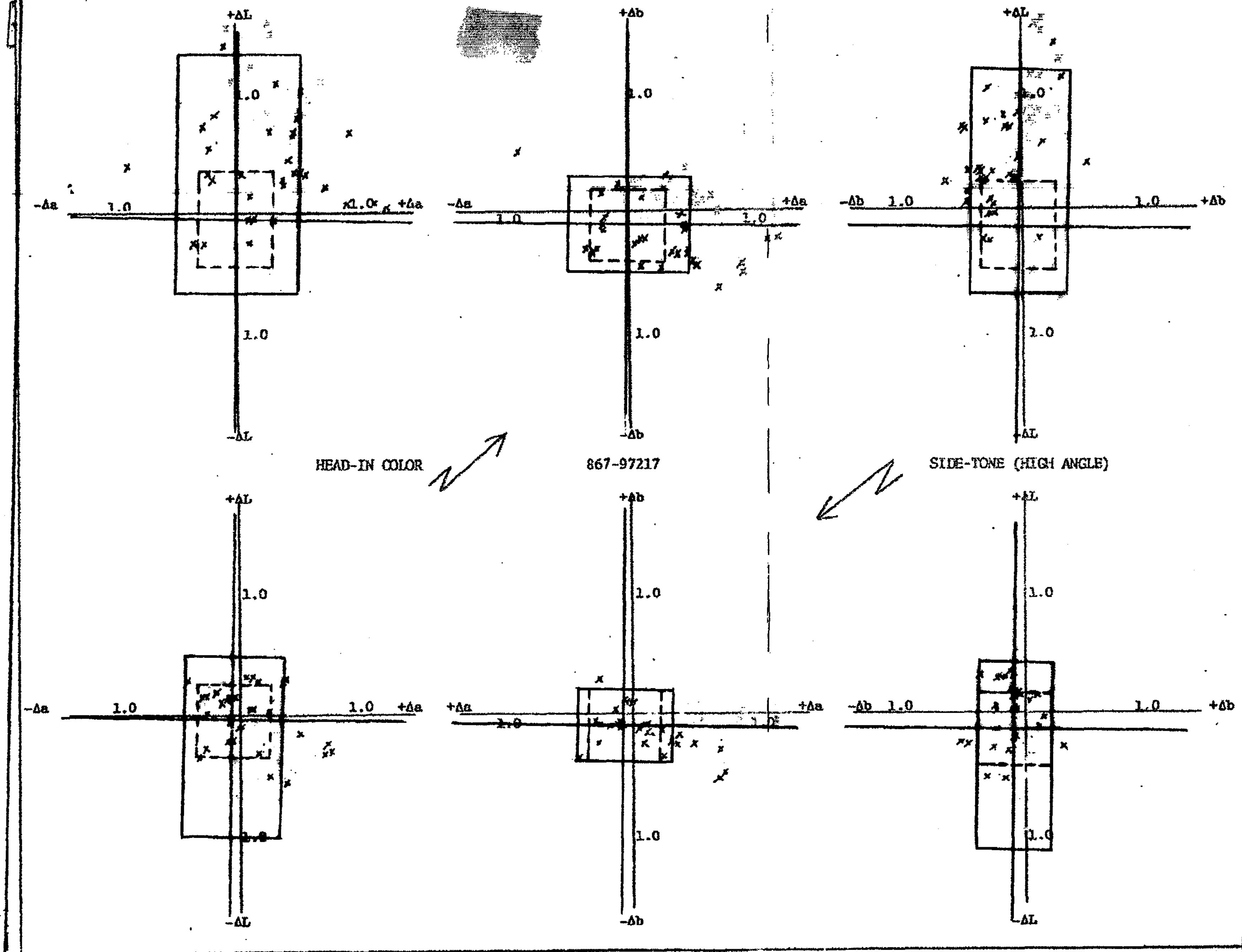
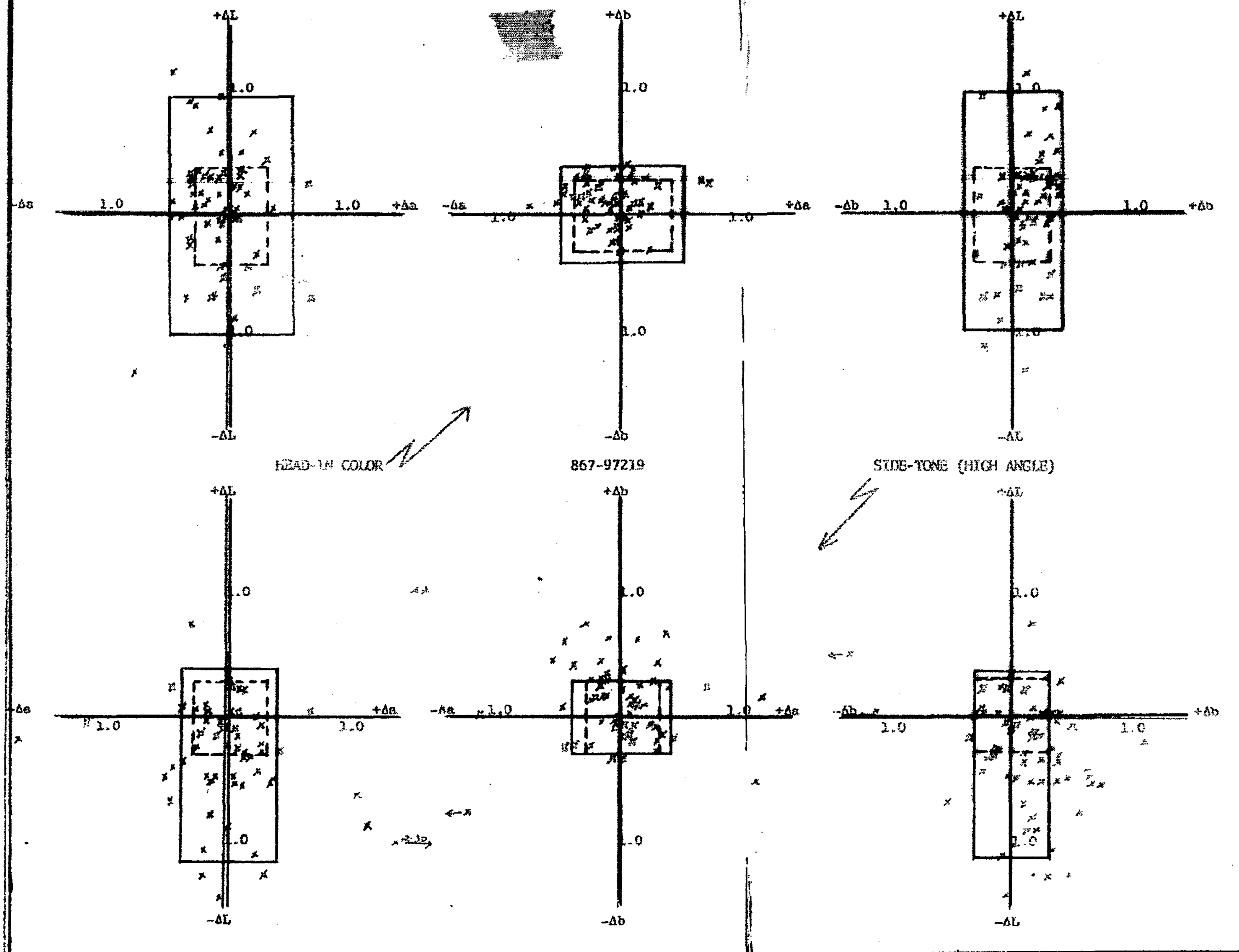
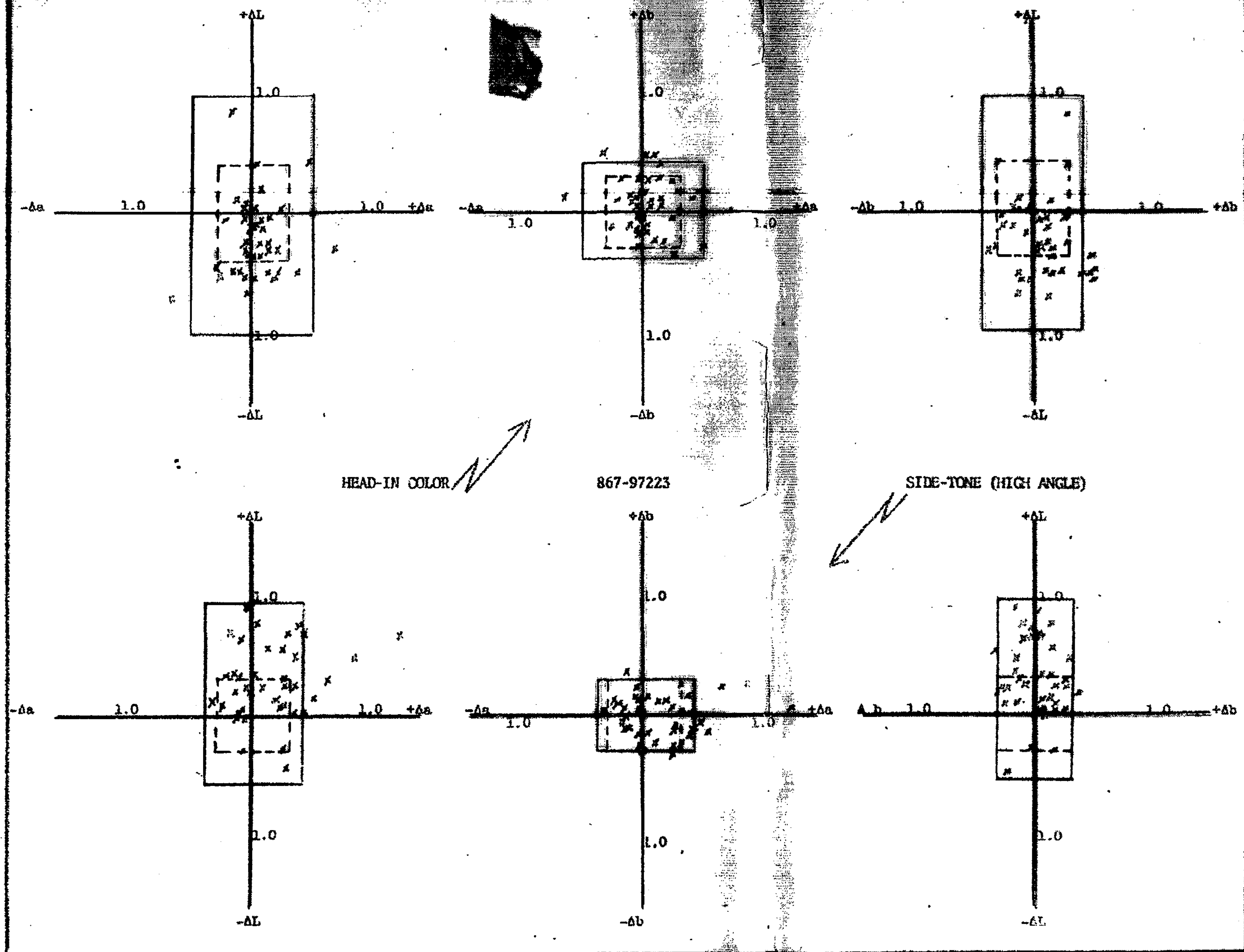

+ΔL
-ΔL
-Δa
+Δa
+Δb
-Δb
1.0
HEAD-IN COLOR
867-97217
SIDE-TONE (HIGH ANGLE)

FIGURE X



+ΔL
-ΔL
+Δa
-Δa
+Δb
-Δb
1.0
HEAD-IN COLOR
867-97219
SIDE-TONE (HIGH ANGLE)

FIGURE XI



HEAD-IN COLOR
867-97223
SIDE-TONE (HIGH ANGLE)
+ΔL
-ΔL
+Δa
-Δa
+Δb
-Δb
1.0

TUCKER PROGRAM - 1966 COLORS

At the outset of the 1966 model year, the Tucker Plant, based on their successful 1965 model year program, proposed shading the light to medium metallic colors instrumentally to tolerances of:

$$\Delta L = \pm\ 0.30$$
$$\Delta a = \pm\ 0.30$$
$$\Delta b = \pm\ 0.30$$
$$E = \ 0.52$$

for head-in and side-tone color.

The C.O.S. agreed that the proposed tolerances appeared to be realistic based on a preliminary examination of approval data available for the 1964-1965 colors, and were in favor of the Tucker proposal. It was agreed that all batches would be shaded to the above values unless it became apparent that product formulation problems precluded the attainment of the limits. This formula limitation proved to be the case for 867-97223 (Figure XII) as would be expected based on 1965 experience (Figure XI). It was further agreed that all batches would be checked visually versus the sparger standard and all colors, excluding carryover colors, would also be sprayed conventionally and checked visually versus the conventional standard as a further precautionary measure.

It became apparent that the restriction placed on ΔL for head-in color was too stringent, and based on a more thorough review of 1965 data has been increased to the basic limits proposed in this report.

The Tucker Program has demonstrated that the proposed tolerances of:

Head-In	Side-Tone
$\Delta L = \pm\ 0.40$	$\Delta L = \pm\ 0.30$
$\Delta a = \pm\ 0.30$	$\Delta a = \pm\ 0.30$
$\Delta b = \pm\ 0.30$	$\Delta b = \pm\ 0.30$

are feasible. Batches shaded to the above tolerances are good visual matches and are acceptable to the customer. The overall accuracy of the system, based on the use of the Model V-A, is more than adequate and repeatable and reproducible results can be consistently obtained.

To date some 39 batches, involving 10 - 1966 colors have been shaded successfully to color tolerances approximating the proposed tolerances without adverse effect on batch cycle time. The overall hits per batch average is 2.5, however, included in this total are a high number of alignment batches. Twenty-three batches since the initial alignment have averaged 1.5 hits for approval.

The product codes included in the Tucker Program and the number of batches shaded to date are shown in Table VI.

TABLE VI

TUCKER PLANT - 1966 COLORS

Product Code	Batches (as of 10/11/65)
867-97213	1
867-97217	6
867-97219	4
867-97223	6
867-97224	2
867-97561	4
867-97589	3
867-97591	4
867-97592	1
867-97593	8

Data, though limited, has been plotted for five colors. The colors are:

867-97223 - Figure XII
867-97217 - Figure XIII
867-97591 - Figure XIV
867-97593 - Figure XV
867-97561 - Figure XVI

The tolerances, as proposed in the subject report, are indicated in red.

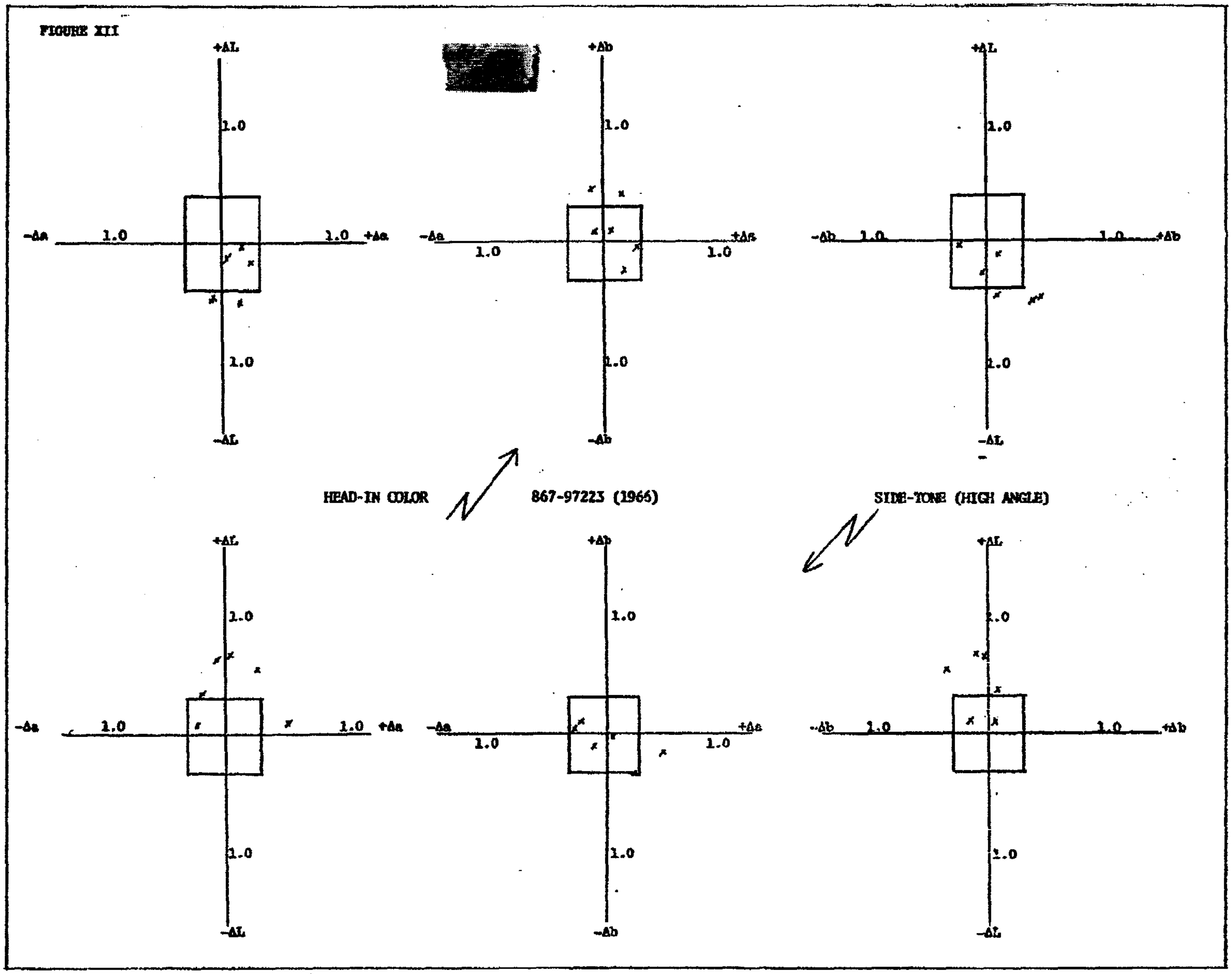


FIGURE XII
+ΔL
-ΔL
+Δa
-Δa
+Δb
-Δb
1.0
HEAD-IN COLOR
867-97223 (1966)
SIDE-TONE (HIGH ANGLE)

FIGURE XIII

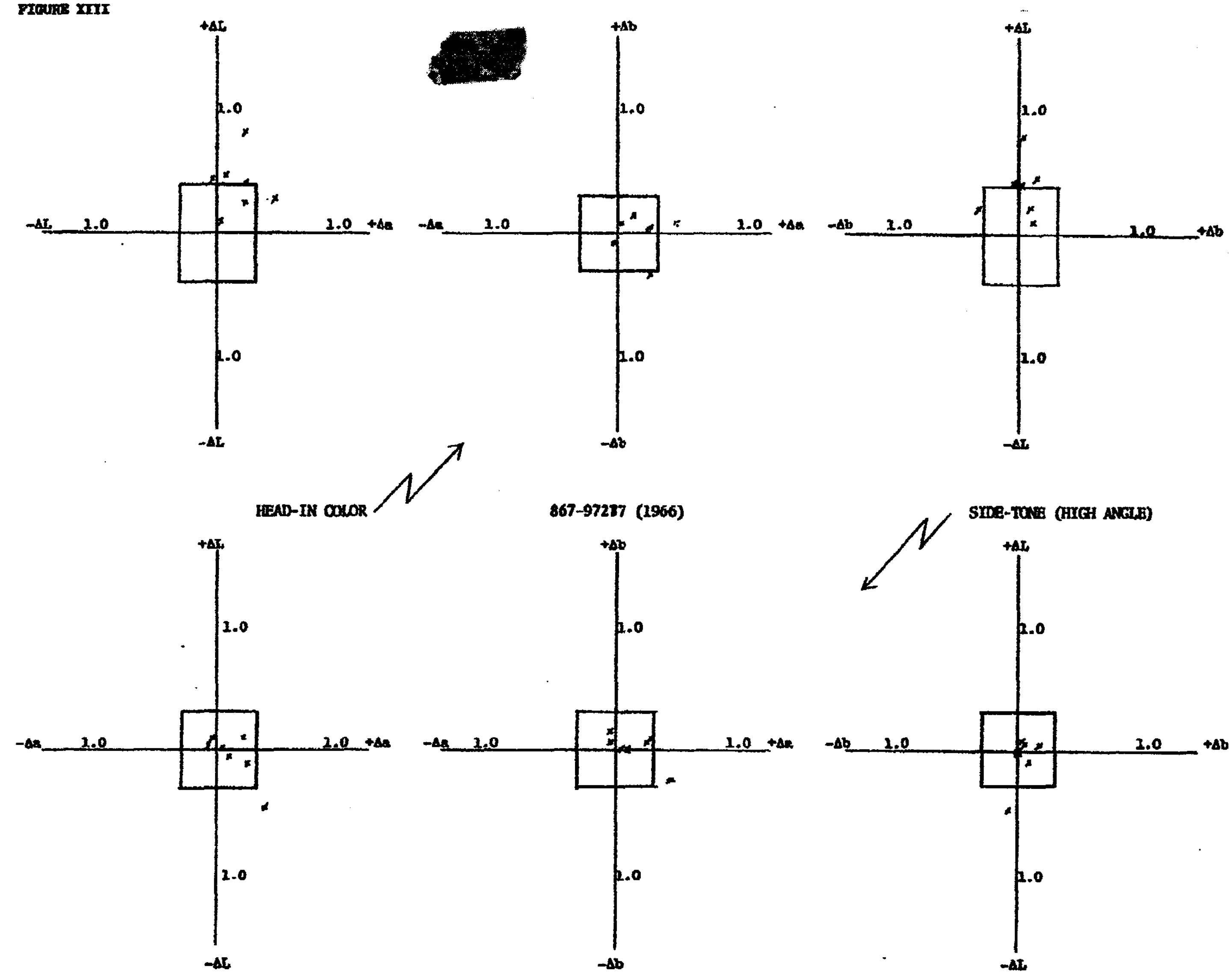
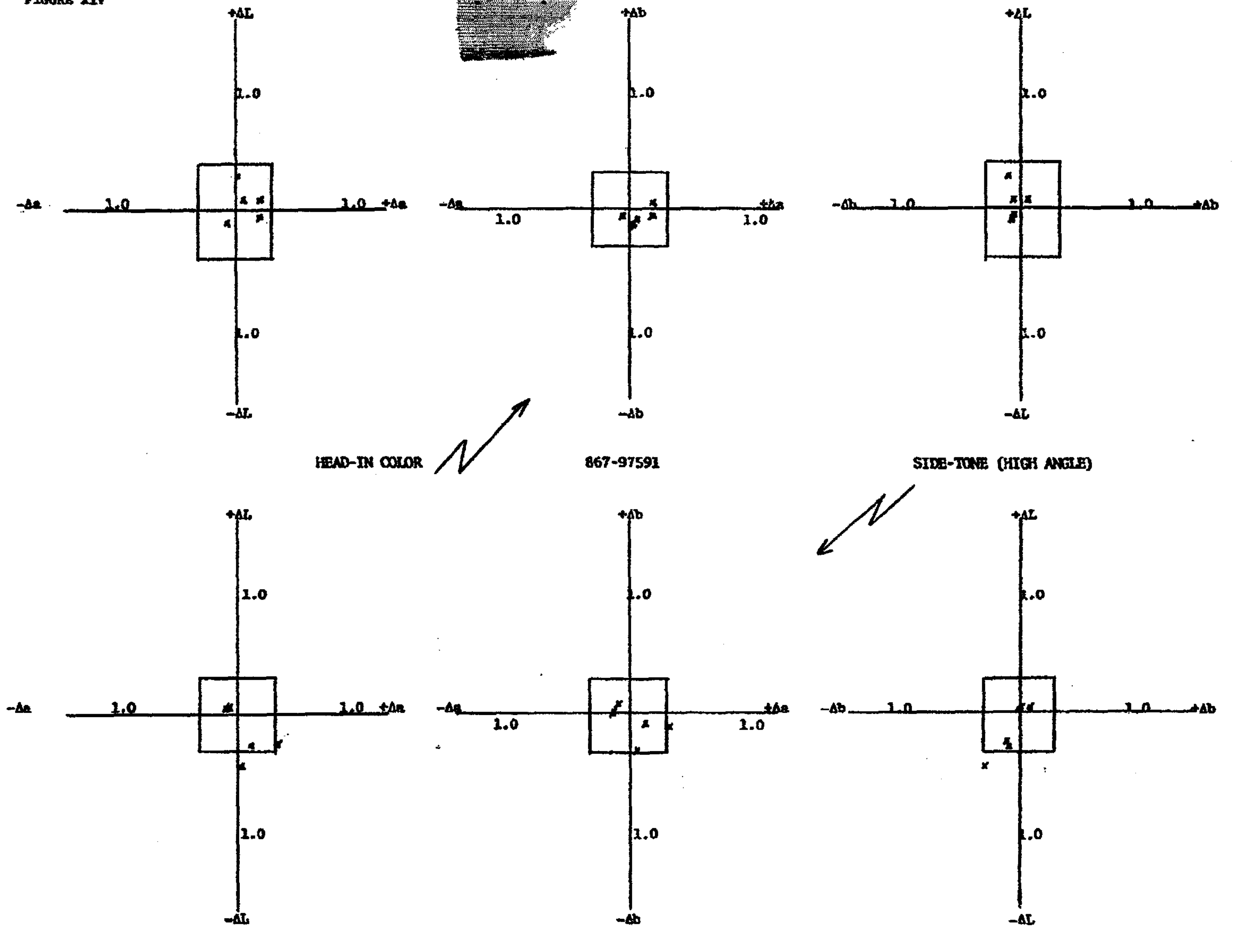

+ΔL
-ΔL
1.0
+Δa
-Δa
+Δb
-Δb
HEAD-IN COLOR
867-97237 (1966)
SIDE-TONE (HIGH ANGLE)

FIGURE XIV



DUP030002782

FIGURE XV

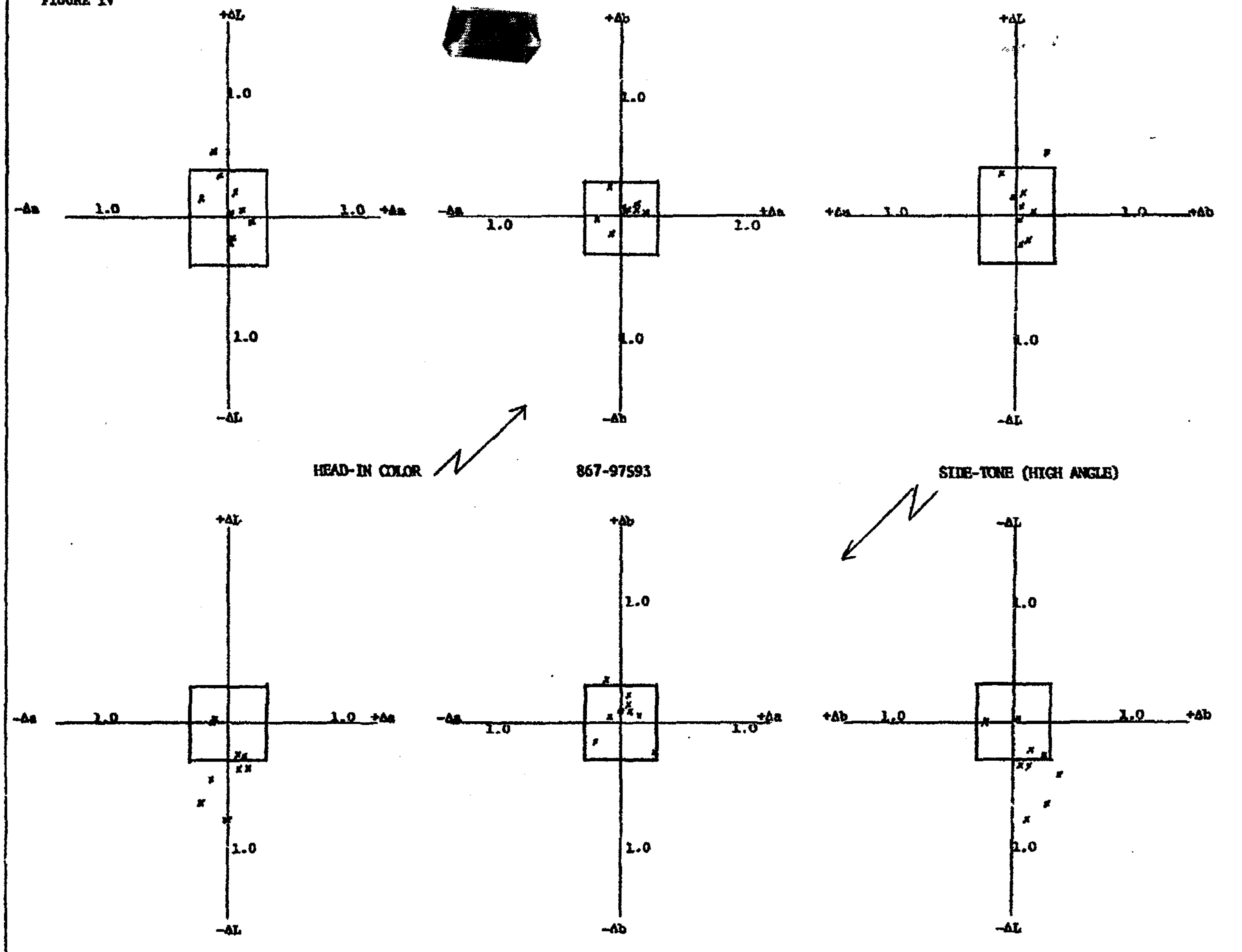
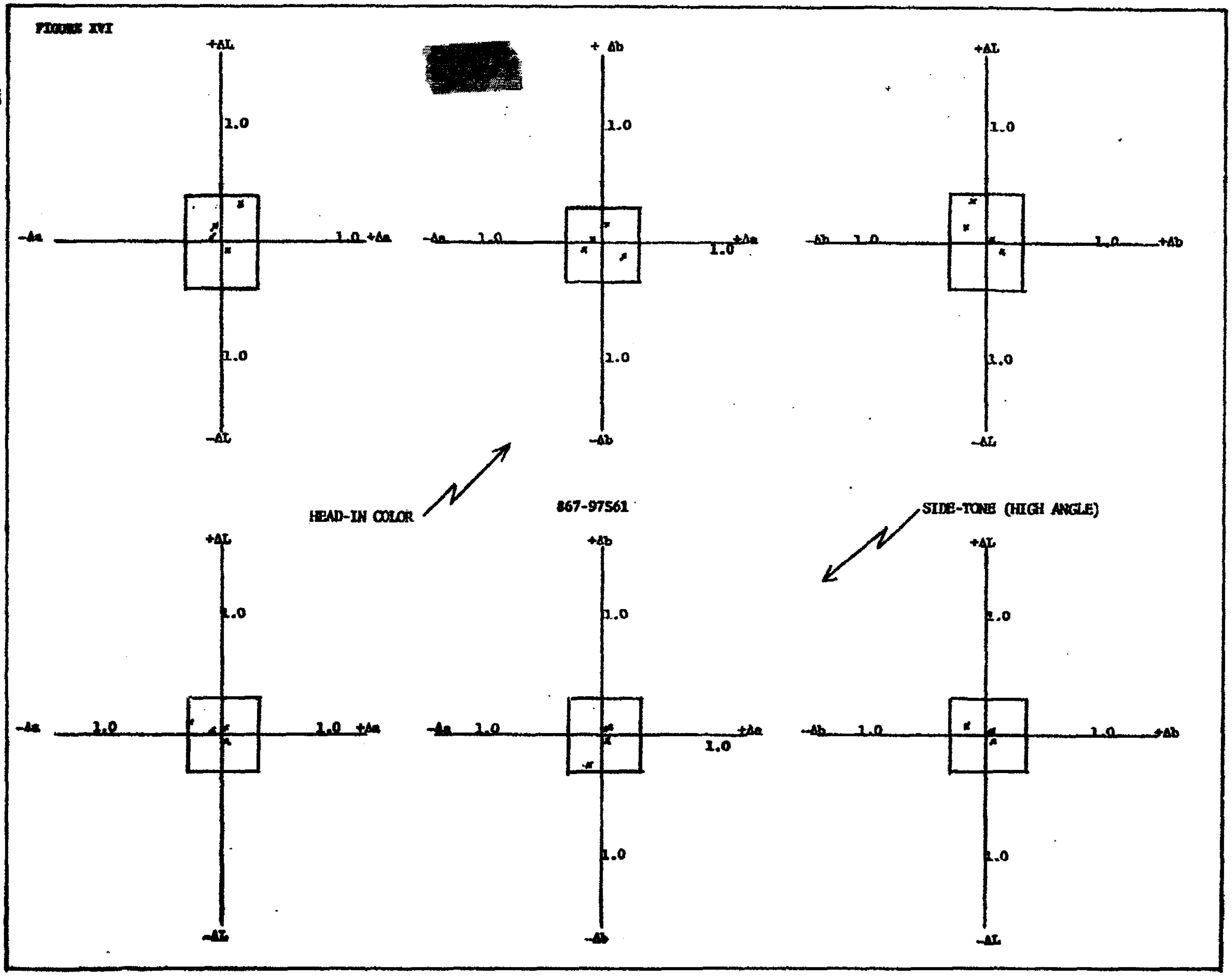

HEAD-IN COLOR
867-97593
SIDE-TONE (HIGH ANGLE)
+ΔL
-ΔL
+Δa
-Δa
+Δb
-Δb
1.0
2.0

FIGURE XVI

[redacted]



GENERAL REFERENCES:

Visual Perception

1. An Introduction to Color - Evans - John Wiley & Sons
2. The Practical Art of Color Matching - Peacock - American Cyanamid Company
3. Color and Instrumentation - E. Rhael - Sandoz, Inc.
4. Color Measurement with Eye and Other Instruments - N. Saltzman - "Dye Stuffs" Vol. 45, No. 1
5. Encyclopedia Britannica - Vol. 6
6. Encyclopedia Americana - Vol's. 7, 21, 22
7. Color Vision - National Association for the Prevention of Blindness, Inc.

Instrumental Measurements

1. Color in Business Science & Industry - Judd & Wyszecki
2. The Measurement of Color - W. D. Wright - John Wiley & Sons, MacMillan, N. Y.
3. Preparation of "Lucite*" Metallic Color Panels - E. A. Miller - 8/27/62
4. Instrumental Shading of Metallics - R. H. Vining - 5/7/65
5. Color Instrumentation in Production - R. Hansen - Official Digest - Vol. 37, No. 487
6. Color Problems in the Graphic Arts - Inter-Society Color Council, Inc.

(*) Du Pont Registered Trademark

DISTRIBUTION LIST

COPY NO.			
1	W. F. H. MATTLAGE J. W. NESTOR	- WILMINGTON F. & F.)	IN) TURN
2	F. H. BEADLES E. E. FURST	- " ")	IN) TURN
3	C. F. KALB E. T. BREUER	- " ")	IN) TURN
4	C. W. THEOBALD J. S. ALLEN	- " ")	IN) TURN
5	R. B. DAVIS	- " "	
6	C. E. CORRELL	- TOLEDO	
7	F. S. BAKER	- TUCKER	
8	R. A. DE WALL	- CHICAGO	
9	N. I. DRESS	- PHILADELPHIA	
10	R. J. KNAKE	- PARLIN	
11	P. O. PEASLEY	- SOUTH SAN FRAN.	
12	H. R. STINE	- FLINT	
13	C. H. THOMPSON	- FORT MADISON	
14	R. W. LAURRELL	- MARSHALL DEVELOPMENT LAB.	
15	G. I. MULHOLLAND	- FLINT DEVELOPMENT LAB.	
16	W. H. TOOLE	- PHILADELPHIA	
17	W. E. CRAUMER J. G. HALL	- DU PONT OF CANADA - MONTREAL) " " " - AJAX	IN) TURN
18	R. H. VINING		
19	W. H. EDWARDS		
20	PROCESS ENGINEERING GROUP FILE		