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An investigation into the interactions of certain visual attributes of a four-color reproduction produced on a sheet-fed offset lithographic printing press

Daniel Lake

AN INVESTIGATION INTO THE INTERACTIONS OF CERTAIN VISUAL ATTRIBUTES OF A FOUR-COLOR REPRODUCTION PRODUCED ON A SHEET-FED OFFSET LITHOGRAPHIC PRINTING PRESS

by

Daniel E. Lake

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
School of Printing in the College of Graphic Arts and Photography
of the Rochester Institute of Technology

March, 1978

Thesis advisor: Mr. Miles Southworth

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School of Printing
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

Daniel E. Lake

with a major in Printing Technology has been approved by the Thesis Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of June, 1976.

Thesis Committee: Miles Southworth
Thesis Advisor

Name Illegible
Director, School of Printing

Name Illegible
Graduate Advisor

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AN INVESTIGATION INTO THE INTERACTIONS OF CERTAIN VISUAL ATTRIBUTES OF A FOUR-COLOR REPRODUCTION PRODUCED ON A SHEET-FED OFFSET LITHOGRAPHIC PRINTING PRESS

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An Abstract

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ABSTRACT

The development of a closed loop press control system has been the goal of many press manufacturers in recent years. These closed loop systems are designed to collect data from sample press sheets by measuring certain process variables which are considered to be indicators of press control. The theory is that by controlling the variation of these indicator variables, it is possible to control the color variation of the halftone overprints of the reproduction. The problem in the design of these automatic control systems, however, concerns which process variables should be considered indicators of press control.

This study was undertaken to determine which process variables in sheet fed offset lithography can be considered indicators of press control in the halftone overprints of the press sheet. This thesis involves a series of correlation analyses which study the interellationships between several process variables of the reproduction. These process variables are: solid ink density of the process colors, density of screened process colors, hue and gray value of halftone overprint colors, hue and gray values of a near neutral gray halftone overprint, and hue and gray values of a critical halftone overprint color. The sample press sheets used in this thesis were taken from industrial production so that the results of the correlation studies of the process variables could be considered typical of those in industry.

The experimental results indicated that the variation of the solid ink density of the process colors at the color bars was not a true indicator of the variation which occurred in the screened process colors. It was possible for the density of the solids to remain very close to the standard while the screened process colors varied in a large amount or in the opposite direction from the solids. This indicated that the density of the screened process colors was controlled by variables other than solid ink density. The experimental results also indicated that the density of the screened process colors may vary in large amounts from the standard and continue to produce halftone overprints with hue and gray values comparable to the standard. Also, the variations of the hue and gray values of the halftones were not consistent within the same press sheet.

It may be concluded that further study is necessary which would clarify the proper indicator variables to be used in the control of the offset lithographic press. From the results of this study, it appears that proper control of the press is attainable through visually matching the halftones on the press sheet to those on the standard. Even though the process variables of this study showed a marked amount of variation, the hues and gray values of the halftone overprints remained visually stable.

If an automatic closed loop press control system is to succeed, it must be able to evaluate the hues and gray values of the halftones. Proper adjustments can then be made to the offset press to match the halftones of the press sheet to the standard.

CHAPTER I

INTRODUCTION

Increased customer demands for higher quality and improved consistency in printed products has prompted much research and development in recent years to study the problem of quality control of the press sheet. The goal of these studies has been the development of a closed loop press control system which would automatically analyze the press sheet during production and control color variation within certain customer approved tolerances. Several automated control systems have been designed which serve to measure ink film variations on the press sheet during production. The opinion of these manufacturers was that by controlling the variation of the solid ink density of the process colors at the color bars, it would be possible to control the color variation of the halftone overprints of the reproduction.[1]

The Gretag D 61 Ink Density Control System attempted this method of control through the use of a scanning head which made automatic density readings of the ink film on the press sheet during production. The Gretag system was designed to compute and monitor deviations between the median and the set value of an ink film and activate an alarm when the conditions exceeded the tolerances.[2]

While this system has shown a degree of success in the rotogravure process, it does not appear feasible for offset lithography. The high

degree of interaction among process variables and the inherent difficulties of process control makes offset lithography a much more unstable printing process than rotogravure.[3] Dampening systems in offset lithography are highly sensitive to changes in ink-water balance, plates tend to sharpen during press operations, and slur and double can occur, any of which can cause the color of the halftones to deviate from the standard during press operations.[4] The pressman's task, in the area of press control, is of major importance because he must decide which press variables should be altered to bring about the desired change in the reproduction.

GATF initiated a project in 1966 which attempted to define all of the process variables from the press infeed to the completed press sheet. In this study, a single color sheet fed offset lithographic press was used as the test instrument. The purpose of the GATF study was to give a list of problem areas in press control and to foster improvements in "press performances in terms of better reliability and print quality."[5] GATF's study set up an elaborate chart system which showed graphically the high degree of interdependence of all process variables during a press run.

In the GATF study, process variables were sub-divided into two interrelated groups referred to as inputs and intermediate inputs. The input grouping included a listing which was referred to as process variables. These were factors which the pressman could control such as ink feed and water feed. Also in this group were a list of parameters which the pressman could not modify during the press run. These would include paper type and ink type and were assumed to be relatively stable during the press run. The intermediate outputs grouping was designed to show the influence of the various inputs on the press sheet. This was done by drawing lines

from the various inputs to the appropriate output. Each line showed a press function stating the influence of an input variable on an output variable.

Linked to the intermediate input group was a listing of process outputs. These were primarily concerned with "the visual attributes of the press sheet."[6] These visual attributes included:

1. Solid ink density of the process colors
2. Density of the screened process colors
3. Hue and gray values of the halftone overprint
4. Hue and gray values of a critical halftone overprint
5. Hue and gray values of a near neutral gray halftone overprint

The GATF Press Interactions Chart possessed some limitations which made it difficult to use when linking process variables to the variations in the visual attributes of a press sheet. This was mainly due to the high degree of interaction of the lines of interdependence in the chart. For actual tracing of input and output relationships, GATF suggested the use of a grid pattern chart. In the grid pattern chart, input variables were placed on the Y axis of the grid and output variables were located on the X axis. Relationships between input and output variables were made by placing X's at the intersections which indicated dependencies bebween the input and output variables. This grid chart avoided the confusion of overlapping lines when tracing the dependencies of input and output variables.

The GATF Press Interactions Chart demonstrated that it was often a combination of variables which resulted in visual changes in the colors of a reproduction. Certainly, variation in solid ink density was a contributing factor in the variation of halftone overprint colors during a press run. But it was also possible for the solid ink densities at the

color bars to remain relatively stable while the screened overprint colors of the reproduction showed visual change. Conversely, it may be possible for the screened overprint colors to remain visually stable while the solid ink densities of the process colors at the color bars fluctuated.[7] This was due to the high degree of interaction of the process variables in offset lithography.

This study analyzes the variations of the solid ink density of the process color solids, the density of the screened process colors, the hue and gray value of a critical halftone overprint, hue error and gray value of a three color near neutral gray halftone, hue and gray value of a three color halftone overprint color, and the photometric optical density of a near neutral gray halftone. It will also analyze the interrelationships of these visual attributes to determine which of the visual attributes is the most sensitive indicator of process variation in the halftones of the reproduction.

STATEMENT OF PROBLEM

As press speeds continue to increase and customer quality demands become more stringent, it has become more important for the pressman to control color variation in the halftones to closer tolerances and to react to press variations more quickly. Moreover, the changes made in the process (ink-water balance, increase or decrease of ink feed) must be made quickly and correctly to reduce waste and control color to customer specifications.

These factors have prompted the development of several closed loop press control systems for automatic control of the offset lithographic printing press. The basic assumption of the design of these systems is that if the solid ink density of the process colors and the density of the screened process colors are controlled within certain specifications throughout the press run, the hue and gray value of the halftone overprint colors will also remain in control.[8]

The problem involved in this theory, however, is that it does not take into account the high degree of interaction of the process variables which affect hue and gray value changes in the halftones of the reproduction. Because of these interrelationships, it is possible for the solid ink density of the process colors at the color bars to be controlled within certain specifications while the hue and gray value of the halftone overprint colors show significant variations. This is possible because the screened process colors combine to form halftone overprint colors with distinct hues and gray values. If the solid ink density of the process cyan of the halftone decreases and combines with an increase in density of the process yellow, the hue of the halftone will tend to be more yellow than the standard. This can take place even though the solid ink densities of the process colors were controlled within specifications.

GATF demonstrated in its study of the Printing Press Process that interdependencies existed among the process variables in offset lithography. They also stated that present methods of press control involved "decision making in a complex system with considerable uncertainty as to the correct action."[9]

The problem of press control, therefore, is one of understanding the interrelationships of the visual attributes which relate to changes in the

hue and gray value of the halftone overprints of the reproduction. Once it has been established how these factors influence color variation in the halftones during a press run, it will be known which of the visual attributes studied in this report may be considered the best indicators of process changes in the offset lithographic process.

PURPOSE OF STUDY

The purpose of this study is to analyze the variation of certain visual attributes of an offset lithographic press run and to determine from these analyses which of the visual attributes is the best indicator of process variation in the halftones of the reproduction.

To study this question, data was drawn from sample press sheets that were gathered from a commercial press run. It was necessary for the samples to be from an industrial press run so that the data could be considered a reflection of the type of variation which would be present in a typical offset lithographic pressroom.

Certainly, the most important factor to control in a reproduction is the variation of the hues of the halftone overprint colors. The hue variation of a halftone is what the customer ultimately looks for when judging the acceptability of a press run. The printer, however, attempts to use the other visual attributes of this study as indicators of the variation which takes place in the hues of the halftones. For this reason, it must be determined how the various process variables of this study interact to affect changes in the hues of the halftones.

From the data collected from the sample press sheets, conclusions were made concerning the interrelationships which existed among these visual attributes. In this manner, it could be determined whether it was a single variable or a combination of the variables which affected t the most significant color variation in the halftones. The results of this study can then be used to indicate the process variables which were the most sensitive indicators of hue changes in the halftones of an offset lithographic reproduction.

THE HYPOTHESES

It was assumed by this author that tests of the following hypotheses would result in low correlation coefficients (r values). This would indicate that process variables which were not tested in this study were an additional source of variation in the press run. The correlation tests were performed on quantitative data taken from areas of the sample press sheets which were located in a direct line with a common set of printed solid process color bars.

However, the hypotheses for the correlation studies in this report were written to coincide with ideal conditions. The hypotheses are as follows:

1. A high positive correlation coefficient will result from a comparison of the variation of the optical densities of solid process color control bars and the variation of the optical densities of process color tints in an offset lithographic reproduction. If this occurs, it may be assumed that the solid color bars are a valid indicator of the variation of the screened process colors in an offset lithographic reproduction.

2. If a high positive correlation coefficient results from the

comparison of the variation of the optical densities of the screened process colors and the calculated hue and gray value of the halftones, then this indicates that the density variation of the screened process colors may be considered valid indicators of the variation which exists in the halftone overprint colors of an offset lithographic reproduction.

3. If a high positive correlation coefficient results from the comparison of the variation of the calculated hue and gray value of several different halftone overprint colors which lie in a line from a common set of solid process color control patches, it may be assumed that the hue and gray value of the halftone overprint colors are varying in similar directions within the same press sheet.

4. If a high positive correlation coefficient is the result of the comparison of the variation of screened process colors located in different areas of a press sheet but positioned in a line from a common set of solid color patches, it may be assumed that the screened process colors vary in the same direction from the standard within a single press sheet.

FOOTNOTES FOR CHAPTER I

[1]Rene Quirighetti, "The Automatic Ink Density Control System Gretag D 61," EPI, Volume XXI, (Dec., 1973), p. 33.

[2]Ibid., p. 34.

[3]Victor Strauss, The Printing Industry (Washington D.C.: Printing Industries of America, 1967), p. 412.

[4]Charles Shapiro, The Lithographer's Manual (Pittsburgh: Graphic Arts Technical Foundation, Inc., 1970), p. 12:28.

[5]George W. Jorgensen and Abraham Lavi, "Press Interactions Chart," (Pittsburgh: Graphic Arts Technical Foundation, Inc., 1969), p. 1.

[6]Ibid., p. 2.

[7]Miles Southworth, Color Separation Techniques, (Philadelphia, 1974) p. 116.

[8]Quirighetti, op. cit., p. 35.

[9]Jorgensen and Lavi, op. cit., p. 2.

CHAPTER II

LITERATURE REVIEW

In any manufacturing process, the ultimate goal of the production staff is to produce a product which is of consistent quality within certain manufacturing specification. In many instances product uniformity is as important as the quality level itself. In many printing applications the end use of the product is also of critical importance in determining the quality level of the press run. In package printing, if the printed product is to appear on a shelf along with similar products, variation in the color of the printed product may infer to the customer that there is corresponding variation in the product inside the package.

For this reason, a printing buyer wants the tolerances on color variation to be as tight as possible. The printer, however, wants the tolerances on color variation to be consistent with the capabilities of the printing process. It is therefore a necessity that the printer understand how to control color variation in the printing process and use this knowledge as a basis for setting the specifications on the color of the reproduction.

There are several theories in the printing industry regarding which process variables should be most closely controlled to produce a press run of consistent quality. One theory is that the most significant variations in uniformity of color are made by changes in ink film thickness.[1]

Previous studies have indicated that a high degree of ink film thickness deviation originates from variables which affect ink feed. Tapio Lehtonen suggested in his research of process variations in sheet-fed offset lithography, that the percentage was as high as 97 per cent.[2] His data indicated that ink film thickness variations should be closely controlled on the press sheet.

Robert Loekle stated in his report to the Technical Association of the Graphic Arts (TAGA) in 1972, that ink film thickness is a factor in offset lithography which demands careful control. But his report also indicated that changes in ink film thickness are most apparent in solid and near solid areas of the reproduction. Areas of the press sheet with smaller dot areas are less effected by changes in ink film thickness.[3] Loekle stated that solid color patches are beneficial in determining uniform inking but that it is possible for them to vary outside of the control limits and still deliver acceptable printing in the halftones.

The literature written on the subject of offset lithographic press variation emphasized the need for process control in offset lithographic presswork. But the various reports differed as to which variables should be considered as indicators of print quality and uniformity in the halftones of the reproduction. Most researchers agreed that solid ink density of the screened process colors should be controlled to close tolerances. However, the effects of changes in these variables on the hue and gray values of the halftone overprint colors of the reproduction was not certain. This thesis will attempt to clarify the relationships between solid ink density and the density of screened process colors and

show how these factors affect changes in the hue and gray value in the halftone overprint colors. These interrelationships can then be used to point out which of the visual attributes of a reproduction should be most closely controlled during a press run to insure a high level of quality and a minimum amount of variation in the reproduction.

FOOTNOTES FOR CHAPTER II

[1]Harry H. Hull, "Color Variations in Lithography," GATF Progress Report, (Pittsburgh: 1971), p. 145.

[2]Tapio Lehtonen, "Effect of Certain Variables in Offset Lithography on Printing Wet-on-Wet," Paper presented at 14th EUCEPA Conference, (Budapest, 1971), p. 21.

[3]Robert Loekle, "Control Charts as an Aid to Uniform Quality in Multicolor Presswork," TAGA Proceedings (1972), p. 7.

CHAPTER III

METHODOLOGY

To properly analyze the variation of the visual attributes to be studied in this thesis, data was needed which was indicative of actual industrial conditions. This necessitated the drawing of samples from a press run which was produced under normal production conditions. A controlled laboratory atmosphere would not be feasible because the data would not be considered realistic of production capabilities. Furthermore, the data would be prejudiced by the added limitations of laboratory studies.

The sample press sheets for this report were drawn from an industry production run made by an offset lithographic printing facility. The samples were four color reproductions produced on a multi-color, 25 x 38 inch Harris sheet fed offset lithographic printing press. The press run was made using Kodak LN Litho plates and standard plate and blanket packing procedures.

During production, the press sheets were matched to the customer approved O.K. sheet through visual color comparison. A reflection densitometer was only used as an aid for the pressman in determining initial inking levels on the press. The primary method of print color control during the press run was achieved through the visual comparison of the press sheets against the press O.K. sheet.

Sampling

From the 14200 total impressions in the press run, a sample was drawn every 800-900 press sheets. The total number of sample size for each experimental group was 16.

Data Retrieval

The numerical data for this study was drawn from the samples through densitometric measurements of the visual attributes. A Cosar SOS 40 reflection densitometer was used as the instrument for data collection in the laboratory. The visual attributes involved in this study were: solid ink density of the process colors, density of the screened process colors, hue error and gray value of the halftone overprint colors, hue and gray valve of a near neutral three color gray halftone overprint, and the photometric optical density of a near neutral three color gray halftone overprint.

Solid Ink Density

The solid ink density measurements were made with a reflection densitometer on the solid color bars at the tail edge of each sample sheet. These measurements were used to show the variations of the solid ink density of the process colors during the press run.

Density of Screened Process Colors

The screened process color density measurements were made with the red, green, and blue filters of the densitometer. In this press run,

screened process color control wedges were not reproduced on the press sheet. This required that the densitometric readings for the screened process colors be made directly on the halftone overprint colors. Test studies have shown that this is an acceptable method for data collection in cases where control strips were not provided.[1]

Hues of a Critical Halftone Overprint

For this study, the critical colors were three color halftone overprints which showed a high degree of variation during the press run. The hues of these halftones were determined through the use of the following mathematical formula:

$$\text{Hue} = \frac{\text{middle density} - \text{lowest density}}{\text{highest density} - \text{lowest density}}$$

Hue of a Near Neutral Three Color Gray

The hue of the near neutral three color gray halftone was measured in the same manner as the hue of the critical halftone overprint. The same mathematical formula was also used to determine the hue of the near neutral gray halftone. The hue variation of a neutral, or a near neutral gray, is an important aspect of a reproduction because it is highly sensitive to slight changes in ink density. Proper printing of neutral, or near neutral grays, indicates that correct balance of the process colors is being maintained so that the gray areas remain gray and do not show a red or blue tint.[2]

Photometric Optical Density of a Near Neutral Gray

It is common knowledge that ink film thickness varies during a press run. For this reason, it has become a practice in the printing industry to assign ± .05 control limits on solid ink density variations at the color bars during production.[3] However, the solid ink density at the color bars may be in control while there is significant color variation in the halftone overprint colors. This is because the variation in density of one screened process color may combine with the variation in another screened process color and cause an unacceptable change in the hue and gray value of the halftone. For instance, an increase in the yellow ink level may combine with a decrease in the red ink level and cause the red in the halftone to become more orange.[4]

On the other extreme, the screened process colors may vary in equal proportions which causes the hue of a reproduction to remain relatively stable. In this case, proper balance of the screened process colors was maintained while the lightness or darkness of the halftones was affected. A slight compression of the total range would be acceptable as long as the gray areas of the halftones remained neutral.

For these reasons, photometric optical densities of grays (lightness or darkness were measured. They were compared against shifts in the hues of the halftone overprints in the reproduction to determine whether the grays remained neutral or showed changes with variations in ink density of the solid or screened process colors. The visual filter of the densitometer was used for measurements of photometric optical density.

Organization of the Data

The data derived from the densitometric readings of the red, green, and blue filter densities of the halftone and the solid process colors were organized in chart form. On the Y axis of the chart was listed the impression number. The mean average of the samples ($\bar{X}$), the sample standard deviation ($\bar{s}$), and the number of samples (n) were also placed on the Y axis. On the X axis of the chart were placed the descriptions of the variables concerned with sample data listed on the Y axis.

This data was used to generate control charts of the data from the experimental groups with control limits set at $\pm$ 3 standard deviations (3 sigma). The control charts were used to show any variation during production which exceeded these tolerances. The $\pm$ 3 sigma limits, however, were theoretical and were not designed to show that production at an out of control point was not commercially acceptable.

The control charts were also used to show trends in the variation of the visual attributes. It was possible through analysis of the control charts, to judge whether several variables which were thought to be related showed similar variation during the press run. This was accomplished by analyzing the variation of the data points of one variable against the variation of the data points of another variable. In the case of solid ink density of the process colors, an increase in this test group should coincide with an increase in the density of the screened process colors in the halftones.

Hue and Gray Value Data

The hue and gray value of the halftone overprint colors were organized in chart form. On the Y axis was listed the press count, the standard (O.K.) value of the hue and gray value, the mean of the data ($\bar{X}$), the standard deviation (s), the range of the data, and the number of samples (n). On the X axis were listed the variables concerned with the numerical data listed on the Y axis.

Hue was calculated for the halftone overprint colors of each of the sixteen samples. For this study, the numerical value of the hue was a representation of the color which was made by overprinting screens of the three process colors. The hue data was used to place a numerical value on the variation of the halftone overprint colors from the standard. In this manner, the hue of the halftone overprint colors could be compared to the variation in the other visual attributes. These comparisons demonstrated that if the variation in the other visual attributes coincided with a variation in the hue of the halftones, then one of the other visual attributes could be charted during the press run as an indicator of hue variations in the halftones.

Hue was determined by making red, green, and blue filter densitometer readings of the halftones. From this data, hue was calculated by the mathematical formula:

$$\text{Hue} = \frac{\text{middle density} - \text{lowest density}}{\text{highest density} - \text{lowest density}}$$

Gray value was used as a numerical representation of the grayness or purity of the halftones. This data indicated the darkness or lightness of the halftones as compared to the standard. A low gray value

for a halftone overprint represented a halftone which was lighter or less neutral. The samples with the highest gray appeared the darkest.[6]

It is necessary to calculate both hue and gray value of a halftone overprint color to correctly define the color. The hue of the halftone indicates the deviation of the color from a hue which is produced from an ideal set of process inks. Calculating the hue and gray value of a halftone helps to define the color numerically and enables one to plot the color on the GATF Color Triangle. The location of the halftone overprint color on the triangle indicates a specific color produced from a specific set of process inks. The gray value refers to the grayness or degree of neutrality of the halftone which has been produced from a set of screened process color inks.[7]

For these reasons, it is necessary to describe a halftone overprint color in terms of a hue and as a shade of gray which is produced by the overprinting of a set of screened process color inks. During a press run it is possible to calculate the hue of a sample and find that it matches the calculated value of the hue of the standard even though the two colors do not visually appear the same. This is because the level of grayness or gray value has shifted away from the standard in the sample halftone. Likewise, the gray value of the sample may match the standard while the hue of the sample has changed from the standard.[8]

The numerical value for grayness for this study was derived from the red, green, and blue filter readings of the process colors as measured on the halftones. The mathematical formula for gray value is:

$$\text{Gray Value} = \frac{\text{lowest density}}{\text{highest density}}$$

GATF Color Triangle

The GATF Color Triangle uses hue and gray values as the coordinates for plotting of data. Its primary function is to show the gamut of colors which are possible with a given set of process inks and to predict ideal halftone overprint colors which are possible to produce with a certain set of process inks.[9]

Plots are made on the GATF Color Triangle by moving in the direction of the greatest hue error for the halftone. For example, consider a sample with a hue of .88 and a gray value of .72. The highest ink density of the screened process colors in the halftone was the red and the middle ink density reading was the process yellow. The hue would be plotted by moving 88 points from the magenta towards the yellow along the outside of the triangle. The hue moves towards the yellow because the data indicated this was the halftone's direction of error.

Plots on the GATF Color Triangle are also made up of gray value coordinates. This requires that the hue of .88 moves towards the gray area of the triangle. In this example, the hue value moves 72 points towards the center of the triangle. On the GATF Color Triangle, the closer the points are located to the center of the triangle the higher the gray value of neutrality of the halftone overprint color.

A GATF Color Triangle was shown in Appendix B as a graphical interpretation of the variation of the hue and gray value of the halftone overprint colors. Each cluster of points demonstrated the plotted position of the halftone in relation to each other on each of the sample press sheets. Another purpose of this analysis was to show whether the

halftone overprint colors varied more in gray value or hue during the press run. This variation can also be seen by comparing the standard deviations of the hue and gray value data of the halftone overprint color as shown in Table 3.

Analysis of the Data

The numerical data drawn from the samples in each of the experimental groups was compared and analyzed through the use of correlation analysis. This statistical method was used to indicate the degree of similarity between the variation of the tested process variables. Experiments which study the similarities between the variation of variables in a process yield a value which is termed a correlation coefficient. The value of r is calculated through the mathematical ratio of two terms:

$$r = \frac{\Sigma(X - \bar{X})_2(Y - \bar{Y})}{\Sigma(X - \bar{X})^2 (Y - \bar{Y})^2}$$

The r value is a numerical representation of the degree to which the variation in one experimental group is associated with the variation in another experimental group. The value of the correlation coefficient r always lies between +1 and -1. If the r value is found to be near +1, one variable increases while the other variable increases. If the value of r is near -1, one variable increases as the other decreases and if the value of r is 0, there is no interrelationship between the process variables. If an r value is encountered which is near 0, the relationship between the variation of the process variables must be attributed to either random variation or experimental error.

The r^2 value indicates the percentage of variability in the data which is a result of a relationship among the process variables. A high r^2 value indicates that the variation of one variable accounts for a high percentage of the variation in the other process variable. Correlation coefficients, however, do not specify which of the process variables is responsible for the variation in the other process variables. They are designed to show that a similarity exists between the variability of test data and do not indicate a cause and effect relationship.[10]

By performing correlation analysis on the variability of the process variables of the sample press sheets, it is possible to determine if a change in one process variable corresponds with a change in another process variable. Graphical interpretations, called scatter diagrams, are shown for each of the correlation tests of this thesis. They are interpreted by reading the direction of the slope of the line and the general arrangement of the data points on the graph. The scatter diagrams are shown in this study to help simplify the data and to show the reader at a glance the degree of interrelationship between the process variables.

FOOTNOTES FOR CHAPTER III

[1]"The Densitometer - A Standard Observer," Printing Equipment and Material, Vol. 12, (May 1975), p. 43.

[2]Miles Southworth, Color Separation Techniques, (Philadelphia: 1974), p. 116.

[3]Ibid., p. 116.

[4]Ibid., p. 116.

[5]Ibid., p. 117.

[6]Charles Shapiro, The Lithographer's Manual (Pittsburgh: Graphic Arts Technical Foundation, Inc., 1970), p. 7:13.

[7]Ibid., p. 20:26.

[8]Southworth, op. cit., p. 116.

[9]Shapiro, op. cit., p. 20:28.

[10]Albert D. Rickmers and Hollis N. Todd, Statistics: An Introduction, (New York: McGraw Hill, 1967), p. 265.

CHAPTER IV

EXPERIMENTAL RESULTS

The following analyses of the experimental results were based on the data listed in Appendix A and on the degree of correlation among the process variables. The r value, or correlation coefficient, was used as the indicator of interrelationships between the process variables. The results of the correlation studies and the scatter diagrams for each of the tests were located in Appendix D, E, F, and G.

The variations of the data derived from the process variables were compared to each other to determine if a change in one process variable coincided with a change in another process variable. It should be reiterated that the samples from which this data was drawn, were taken from an industrial production run. For this reason, the results of this thesis may be judged to be indicative of the degree of correlation which would be present under actual industry conditions.

Analysis of Control Charts

Control charts of the magenta, cyan, and yellow solid process inks and the hues of the halftone overprint colors were arranged in Appendix F. These diagrams served as a graphical analysis of the variability of the data in the process variables.

The control charts of the individual solid process colors revealed a large amount of variation through the press run. The yellow, however, was the most consistent of the process color solids having a range of .60 to .68. The data points for the yellow solid at the beginning of the press run varied up and down on the control chart. However, as the press run progressed, the yellow solid leveled off and was quite stable. The magenta process solid started out at the beginning of the press run at a low ink density and had a definite upward trend throughout the press run. The range for the magenta was 1.04 to 1.23.

The process magenta and process cyan solids appeared to be heavily affected by ink key adjustments made by the press operator. This was apparent from the lack of consistency of these process colors. If the lines of variation of the cyan and the magenta solid process inks had shown a gradual change in ink density, it would have appeared to have been caused by random process variation. However, the rate of change of the data points was in most cases very pronounced and showed the effects of operator control.

An examination of the control charts of the hue data of the halftones exhibited more gradual variations than the control charts of the solid process colors. The slope of the lines on the control charts for hues were less pronounced than the slope of the lines on the control charts for the process solids. These observations implied that it was possible for the solids of the process colors to have large amounts of variation and continue to reproduce halftones with hue and gray values comparable to those of the standard. This can be most easily seen in Figure 5. The hue

of the halftones varied only slightly on the sample press sheets even though the solids had large amounts of variation throughout the press run.

Densities of Solid Process Inks

vs.

Complimentary Filter Densities of Halftone Overprint Colors

For this set of correlation studies, the process variables were the solid ink density of the process inks as measured at the color bars and the density of the screened process as measured on the halftone overprints. The screened process color densities were derived by taking measurements on the halftones with the red, green, and blue filters of the densitometer. This was necessary because no screened control wedges were printed on the sample press sheets which could be measured and used as test objects. Because the three filter readings were taken on the halftones, the densitometric measurements of the screened process colors included the total absorption of all three process colors in the halftone overprint colors. Therefore, the green filter density of a halftone included the primary influence of the magenta ink plus added green filter density from the process yellow and process cyan inks. This also occurred when measuring the red and blue filter densities of the halftone overprint colors. This happened because each of the screened process colors contained certain amounts of impurities which caused the screened process inks to have some unwanted density.

For this reason, three filter readings were made of each of the solid process colors at the color bars on each of the sample press sheets.

This data was listed in Table 2 of Appendix A. The total density of the solid process inks was calculated by adding the green filter density of the cyan process color, the process magenta, and the process yellow solids. The same procedure was repeated for the red and blue filter densities of the halftone overprint colors. This resulted in correlation studies which compared the total red, green, or blue filter density of the solid process colors for each of the samples against the corresponding filter density of the screened process colors in the halftones.

As indicated by the test results in Tables 4, 5, 6, 7, and 8 and the scatter diagrams in Appendix D, there was a low correlation between the variation of the solid ink density of a process color at the color bars and the variation of the corresponding screened process color in the halftones. This data demonstrated that an increase or decrease in solid ink density at the color bars did not always coincide with a similar increase or decrease of the screened process colors in the halftones. This data also indicated that it was possible for the density of the screened process colors to increase or decrease even though the corresponding process color solid had remained constant in density or varied in the opposite direction. This data was quite significant because it verified the assumption that the variability of the solid ink densities at the color bars was not a true indicator of the direction or magnitude of variation of the optical densities of the screened process colors in the halftones.

Density of Screened Process Colors

vs.

Hues of Halftone Overprint Colors

Because the density variations of the solid process inks as measured at the color bars did not show a strong correlation to the variation of the density of screened process inks, it appeared that the best method of control of the hues of the halftone overprints would be through the control of the screened process colors. A series of correlation tests were made which tested the variability of the red, green, and blue filter densities of the screened process colors against the variability of the hues of the halftones.

From the red, green, and blue filter density readings of the screened process colors, hues were calculated as described in the preceeding chapter. The hue data for the halftones were assembled and listed in Table 12. The variation of the hues of the halftones were correlated to the numerical difference of the highest density reading minus the lowest density reading of the red, green, and blue filter densities of the screened process colors. This was done because it had been assumed that it would be possible for the hues of the halftones to remain relatively constant if the difference between the highest and lowest density of the screened process colors remained stable. In other words, if all the screened process colors increased or decreased in ink density in equal proportions, the hues of the halftones would remain constant. The only visual variation of the halftones would be in the lightness or darkness of the colors.

The comparisons of the variability of the screened process colors and the hues of the halftone overprints, however, did not show a strong correlation and resulted in low r values. This was because at several points the difference between the highest and the lowest density of the screened process colors demonstrated a large difference while the hues of the halftones matched the standard. The numerical data for these correlation studies can be found in Tables 9, 10, 11, 12, and 13. These tables and their corresponding scatter diagrams were presented in Appendix E.

Densities of Screened Process Colors

vs.

Gray Value of Halftone Overprints

For this series of correlation analyses, gray value was determined using the red, green, and blue filter density readings of the screened process colors and the mathematical formula given in Chapter 3. The numerical value for the gray value of each halftone overprint was listed in Table 3 of Appendix A.

The variation in gray value of the halftone overprint colors was correlated to the difference between the highest density and the lowest density of the screened process colors. These correlation tests resulted in high negative r values as were shown in Tables 15, 16, 17, 18, and 19 and the scatter diagrams located in Appendix D.

The analysis of the variations of these process variables indicated negative r values between -.83 and -.96. These r values represented a high degree of association between the variability of gray value of the halftones and the variation of the screened process colors. From the

results of these correlation tests it was shown that as the difference between the highest and lowest density readings of the screened process colors decreased, the gray value of the halftone overprint color increased.

It was assumed that if the numerical relationships between the screened process colors were controlled it would be possible to control the gray value of the halftones. Also, if the screened process colors increased or decreased in equal proportions, the gray value of the halftones would tend to match the standard. If the density of the screened process colors increased there was also a slight increase in the gray value of the halftones. Similarly, if the screened process colors decreased in density from the standard there was a slight decrease in gray value of the halftone overprint colors.

These correlation studies produced significant results because they determined a viable method of control of the gray value of halftone overprints. These tests pointed to the necessity of controlling the changes in ink density of the screened process inks in relationship to each other in order to produce consistent gray values in the halftones.

Green Filter Density of a Screened Process Color

vs.

Green Filter Density of a Near Neutral Gray Halftone

This correlation test was made to determine if the variation of the green filter density of one screened process color, as measured in one halftone, related to the variation in the green filter density of another screened process in another halftone overprint. The results of these correlation analyses indicated whether the screened process colors varied

in similar directions and proportions on the same sample press sheet. The r values from these tests showed a low correlation which indicated a high degree of variation was caused by printing variables other than ink density. Table 1 revealed that at 13100 impressions the green filter density of the near neutral gray halftone overprint was .07 above the standard. The green filter density of the three color brown halftone overprint color was .02 below the standard. This type of variability was responsible for the low correlation values as were shown in Tables 20, 21, 22, and 23 and the scatter diagrams in Appendix G.

These tests were quite interesting because they showed that the screened process colors were not constant in density variation within the same press sheet. The screened process color measurements were made in close proximity to each other and were also in a relatively straight line in the direction of ink application. This data indicated a significant amount of color variation of the screened process colors was not a product of the lay down of an ink film. However, other variables were untested in this report and remain a topic of discussion for future research in the area of control of color variation of the halftones.

Density of Solid Process Colors

vs.

Density of Screened Process Colors

Additional correlation tests were made which compared the variability of the solid process colors to the screened process colors. The process cyan solid was measured with the red filter of the densitometer at the color bars and the cyan screen was measured with the red filter on the

halftones.

This correlation test was designed to indicate whether an increase or decrease in the ink density of the solid process colors at the color bars resulted in a similar variation in the screened process colors. A study was also made of the green filter densities of the process magenta and the green filter densities of the three color red halftone overprint.

As was shown in Tables 23, 24, and 25 and the scatter diagrams in Appendix G, these tests resulted in very low r values. The data indicated that the process variables did not vary in the same direction or proportion during the press run. This would disprove the past practices of some press operators of controlling the screened process colors by controlling the variation of the solid process colors at the color bars. It had been assumed that it was possible to control the amount and direction of density variation of a screened process color in a halftone by controlling that process color's ink level at the solid color bars.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This study investigated several visual attributes of an offset lithographic reproduction to determine if a pattern of interrelationship existed between the variation of these test groups. By determining the pattern of interrelationships between the process variables, or visual attributes of this study, it would become possible to use certain variables as indicators of the variation in other process variables.

The variation of the solid ink densities of the process colors at the color bars was compared against the density variation of the screened process colors of the halftone overprint colors. It was determined through correlation analysis that solid ink density aids in holding the screened process color densities at approximate inking levels. However, as was shown in the correlation studies, the majority of the variation of the screened process colors resulted from press variables other than solid ink density. This was a significant result because it demonstrated the inability to control color variation of the screened process by controlling the variation of the solid process colors at the color bars. This data, therefore, rejected hypothesis number one regarding the control of screened process tints by solid color bars.

The density variations of the screened process colors were then correlated against the variation of the hue variations of the halftone overprint colors. It had been assumed in the second hypothesis that if the densities of the screened process colors increased or decreased in equal proportions, the hue of the halftones would remain constant. A series of correlation analyses were made which proved this hypothesis to be incorrect. The data from these tests indicated that the red, green, and blue filter densities of the screened process colors could vary in opposite directions and continue to produce hues similar to the standard.

In the samples where the differences between the highest screened process color density and the lowest screened process color density were different from the standard, gray values of the halftone overprints tended to fluctuate from the standard. This prompted a correlation study which compared the variation of the highest filter density of the screened process colors to the variation of the gray value of the halftone overprint colors. It was verified through these studies that if the three screened process colors varied in density in the same direction and similar proportions, the gray value of the halftones would remain constant. These results revealed the importance of controlling the numerical relationships of the ink densities of the screened process colors in the halftones.

It was also shown in correlation tests of gray value of the halftones and the density of the screened process colors that proper inking levels must be maintained to control the gray value of the

halftones of the sample press sheets. If the red, green, and blue filter densities of the screened process colors decreased in equal proportions, the total density of the halftone overprints would decrease even though the screened process color densities had decreased from the standard in equal proportions.

Several conclusions were made from the results of the correlation analyses of the variation of the screened process color densities and the hues of the halftones. It was found that it was necessary to control both the inking levels of the screened process color and the numerical relationships of the screened process color densities to each other in order to control the hues of the halftone overprints. The most appropriate means of hue control of the halftones appeared to be through the control of the red, green, and blue filter densities of the screened process colors in the halftones. The press operator should control the inking levels of the screened process colors and control the range of deviation of these ink densities from the standard. If the screened process color ink densities vary during the press run, they should only vary in slight amounts and their densities should all vary in equal proportions from the standard. This would be a difficult task, however, because the screened process colors would tend to vary from the standard in unequal amounts.

A series of correlation analyses were also made which compared the variation of the hues of the halftone overprints against the variation of the photometric optical density of the halftones. The photometric optical density of the halftones was derived by measuring the halftones with the visual filter of the densitometer. The goal of these studies was to de-

termine if by monitoring the halftones for changes in neutrality it would be possible to predict variation in the hues of the halftones.

These correlation studies resulted in r values which were near zero. This indicated that there was little interrelation between this variation of photometric optical density and hue variation of halftone overprint colors. These studies, however, were not conclusive because the colors which were available on the sample press sheets were not true neutral grays. Before a statement can be made concerning the use of photometric optical density as an indicator variable of hue variation in halftones, it would be best to run a series of correlation studies which involve a true neutral gray.

A series of correlation studies were also made to determine if the variation of the green filter density of one halftone overprint coincided with the variation in green filter density of another halftone overprint. Although any screened process color could have been used for these tests, only the green filter densities were used in order to limit the number of readings made with the densitometer. The low positive correlations which resulted from these tests showed that the variation of the green filter densities of the various halftone overprints did not always coincide. This would indicate that other untested variables were responsible for some of the density variation in the screened process colors of the halftones.

It had been assumed that the ink densities of the screened process colors would vary in equal proportions and the same direction from the standard with the same press sheet. The results of the correlation analyses did not indicate that this had occurred on the sample press sheets. Further testing would be necessary to determine the causes of the low correlation coefficients which resulted from the comparison of

the density variations of a screened process color of one halftone against the density variation of the same screened process color in another halftone. This further experimentation would be beneficial because it would indicate the variables which should be most closely controlled to limit the variation of the screened process colors.

In summation, the conclusions derived from the correlation studies of this thesis may be listed in the following points:

1. The density variation of the process color solids at the color bars is not a true indicator of the direction or magnitude of change of the screened process color densities in the halftones. The low correlation coefficients shown in these comparisons, therefore, reject hypothesis number one as stated on page seven of the text. It is also possible for the process color solids at the color bars to have a large amount of variation during a press run and continue to reproduce halftone overprint colors with hues comparable to the standard.

2. It is possible for the densities of the screened process colors to vary in opposite directions and unequal proportions from the standard and continue to reproduce halftone overprints with hues comparable to the standard. These results were cause to reject the second hypothesis.

3. The calculated hue error and gray value of several halftone overprint colors can vary in unequal proportions and opposite directions within the same press sheet. This occurred even though these halftone overprints lie in close proximity to each other. These results rejected hypothesis number three as stated in Chapter one.

4. A significant amount of density variation of the screened process colors is not necessarily a function of the ink density variation of the solid process colors.

5. If the density of the screened process colors increases or decreases from the standard in equal proportions, the gray value of the halftone overprints can be effectively controlled to the standard.

6. Photometric optical densities of halftone overprints are not valid indicators of the hue variations of the halftones in an offset lithographic reproduction. This assumption, however, may not be correct for all situations. Further testing of this conclusion is necessary which would compare a neutral gray against the variation of the hues of a halftone overprint color.

7. The correlation analyses of this thesis demonstrate that the density of the screened process color do not vary in equal proportions or the same direction when measured in different halftones. This occurs even though the screened process colors lie in close proximity in the printed reproduction.

The results of this thesis indicate the reasons many pressman judge the sample press sheets during production by matching the halftone overprints in the sample press sheets to the press O.K. sheet. The solid ink densities of the process colors at the color bars do not indicate the variation which is occurring in the screened process colors of the reproduction. The variation of the screened process colors does not properly indicate the variation which occurs to the hues or gray values of the halftone overprint colors. Furthermore, this thesis has shown that the variations of the hues and gray values of the halftones are not consistent within the same press sheet when the measurements are made in

close proximity to each other. This fact points to the possibility of either localized slur or double of the printing dots in the halftones which causes a change in ink density of the screened process colors.

It may be concluded, therefore, that further study is necessary which would indicate the reasons for the inconsistencies in the hue and gray values of the halftones. If the problem is an instability of the size of the printing dot of the screened process colors, then this needs clarification. After the reasons for these variations have been shown, it may be possible to control the variations of the halftone overprint colors within the reproduction. This further knowledge will then make it possible to control the variations of the hues and gray values of the halftones in an offset lithographic reproduction.

If automatic closed-loop press control systems are to succeed they must be able to evaluate the hues and gray values of the halftone overprints. The automatic systems must then compensate for variations in the halftones by making the proper adjustments to the press. It is apparent, through the results of this study, that a correct method for control of halftones is by evaluating the hues and gray values of the halftones during production. Unless some other study should find some process variables which can be used as indicators of the variation in the halftones, it appears the best indicator of variation in the halftones is the halftone itself. However, the automatic control system must also make the proper adjustments to the press to cause the correct change in the hues and gray values of the halftones. This is the part which is not fully understood

and requires more investigation before a closed loop press control system can become a reality for sheet fed offset lithographic printing.

APPENDIX A

Preliminary Data

TABLE 1

RED, GREEN, BLUE FILTER DENSITIES OF SOLIDS

IMP.	SOLID	R	G	B	IMP.	SOLID	R	G	B
13900	CYAN	1.23	.36	.14	7000	CYAN	1.26	.36	.14
	MAGENTA	.29	1.21	.66		MAGENTA	.21	1.17	.63
	YELLOW	.05	.09	.62		YELLOW	.05	.07	.64
13100	CYAN	1.24	.36	.14	6100	CYAN	1.19	.35	.12
	MAGENTA	.23	1.19	.64		MAGENTA	.23	1.17	.62
	YELLOW	.05	.09	.63		YELLOW	.04	.08	.65
12200	CYAN	1.26	.36	.13	5200	CYAN	1.22	.35	.14
	MAGENTA	.22	1.16	.62		MAGENTA	.23	1.17	.63
	YELLOW	.05	.09	.63		YELLOW	.04	.08	.68
11300	CYAN	1.22	.35	.13	4400	CYAN	1.17	.34	.12
	MAGENTA	.23	1.23	.67		MAGENTA	.20	1.10	.58
	YELLOW	.05	.08	.63		YELLOW	.03	.07	.61
10500	CYAN	1.21	.35	.13	3600	CYAN	1.24	.35	.13
	MAGENTA	.21	1.17	.63		MAGENTA	.22	1.12	.59
	YELLOW	.03	.08	.64		YELLOW	.04	.07	.65
9700	CYAN	1.24	.35	.13	2700	CYAN	1.17	.34	.12
	MAGENTA	.23	1.21	.65		MAGENTA	.20	1.07	.56
	YELLOW	.04	.07	.65		YELLOW	.02	.06	.68
8800	CYAN	1.23	.36	.15	1900	CYAN	1.17	.34	.13
	MAGENTA	.24	1.19	.64		MAGENTA	.20	1.04	.54
	YELLOW	.03	.08	.65		YELLOW	.03	.07	.64
7900	CYAN	1.21	.36	.13	1100	CYAN	1.22	.34	.12
	MAGENTA	.22	1.13	.60		MAGENTA	.20	1.12	.59
	YELLOW	.05	.09	.63		YELLOW	.03	.07	.60

TABLE 2

RED, GREEN, BLUE FILTER DENSITIES OF HALFTONE OVERPRINT COLORS

	BROWN			BLUE			RED			CRITICAL COLOR			GRAY			
IMP.	R	G	B	R	G	B	R	G	B	R	G	B	R	G	B	K
13900	.81	1.13	1.09	1.34	1.05	.68	.28	.60	.45	.38	.76	.87	.47	.63	.80	.62
13100	.82	1.14	1.11	1.30	1.05	.68	.29	.63	.46	.39	.78	.88	.52	.71	.86	.69
12200	.82	1.15	1.11	1.34	1.08	.68	.31	.65	.47	.40	.79	.90	.51	.67	.84	.67
11300	.93	1.20	1.16	1.26	1.01	.66	.28	.56	.44	.37	.75	.85	.47	.65	.82	.63
10500	.88	1.21	1.16	1.29	1.06	.68	.30	.62	.45	.40	.78	.90	.52	.68	.85	.67
9700	.88	1.19	1.15	1.27	1.04	.67	.31	.59	.45	.40	.77	.87	.47	.64	.82	.64
8800	.91	1.17	1.13	1.26	1.02	.65	.31	.61	.46	.36	.72	.83	.51	.68	.84	.70
7900	.86	1.10	1.10	1.29	.99	.64	.31	.57	.43	.37	.69	.81	.45	.62	.79	.61
7000	.87	1.19	1.14	1.34	1.08	.69	.32	.65	.48	.42	.79	.90	.47	.66	.82	.68
6100	.88	1.21	1.19	1.27	1.06	.69	.32	.62	.48	.40	.76	.90	.49	.69	.85	.65
5200	.88	1.18	1.16	1.30	1.05	.68	.32	.62	.47	.40	.77	.90	.47	.65	.85	.65
4400	.92	1.19	1.15	1.28	1.03	.65	.31	.60	.45	.41	.76	.87	.50	.64	.81	.64
3600	.89	1.13	1.12	1.30	1.04	.67	.33	.60	.44	.40	.73	.85	.52	.66	.85	.67
2700	.90	1.16	1.13	.127	1.01	.66	.31	.57	.43	.40	.73	.84	.49	.64	.81	.63
1900	.91	1.17	1.14	1.30	1.00	.65	.32	.60	.45	.41	.75	.87	.48	.62	.79	.63
1100	.85	1.09	1.08	1.27	1.05	.65	.33	.61	.46	.42	.73	.84	.51	.67	.82	.68
O.K.	.90	1.15	1.11	1.31	1.03	.67	.34	.59	.46	.40	.72	.85	.49	.64	.81	.64
$\bar{X}$	.88	1.16	1.13	1.29	1.04	.67	.31	.61	.45	.40	.75	.87	.49	.66	.83	.65
s	.04	.04	.03	.03	.03	.02	.02	.03	.02	.02	.03	.03	.02	.03	.02	.03
range	.12	.12	.11	.08	.09	.05	.05	.09	.05	.06	.10	.09	.07	.09	.07	.09
n	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16

TABLE 3

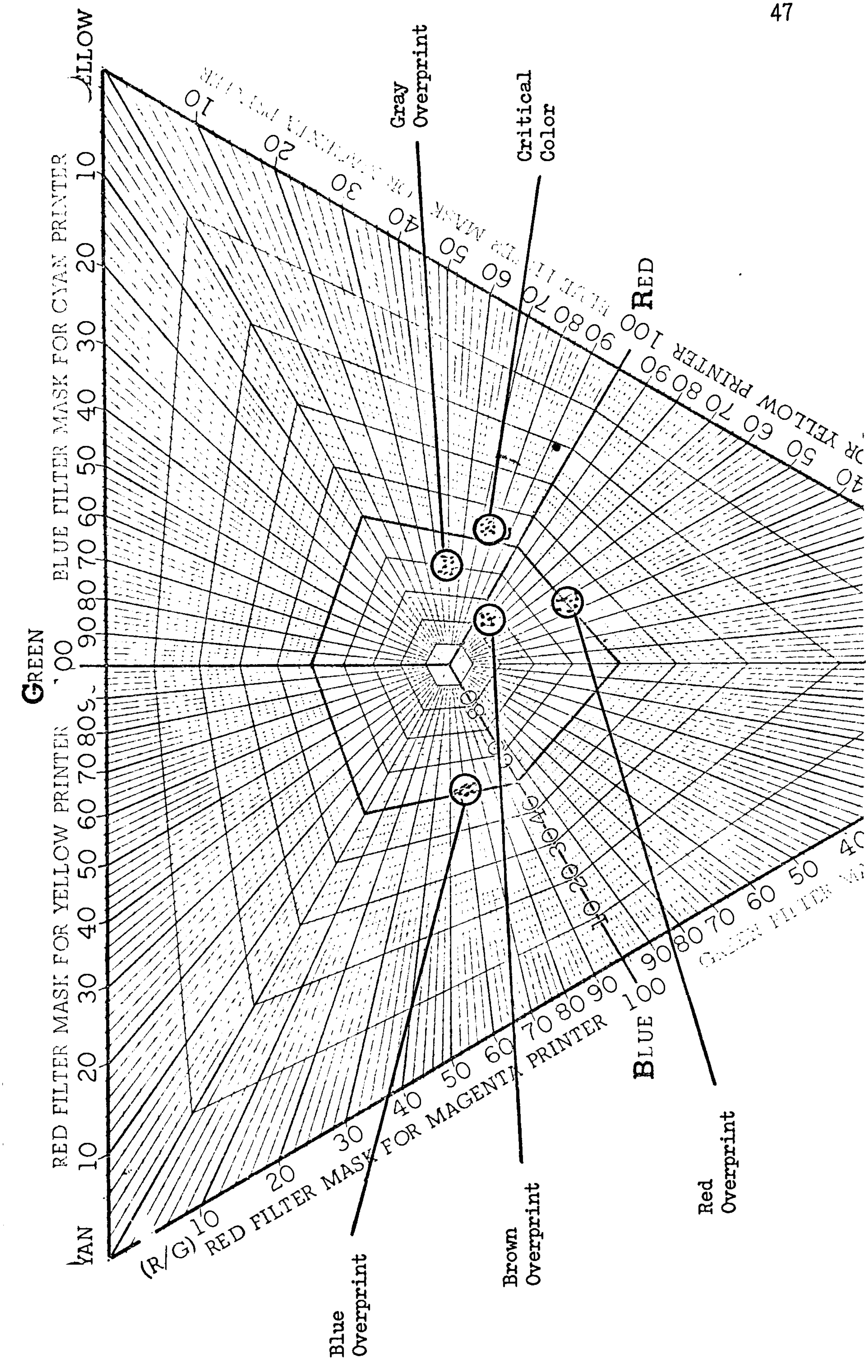
HUES AND GRAY VALUES OF HALFTONES

	BROWN		BLUE		RED		CRITICAL COLOR		GRAY	
IMP.	H	G	H	G	H	G	H	G	H	G
13900	.88	.72	.56	.51	.53	.47	.78	.44	.48	.59
13100	.91	.72	.60	.52	.50	.46	.80	.44	.56	.60
12200	.88	.71	.61	.51	.47	.48	.78	.44	.48	.61
11300	.85	.78	.57	.52	.57	.50	.79	.44	.51	.57
10500	.85	.73	.62	.53	.47	.48	.76	.44	.48	.61
9700	.87	.74	.62	.53	.50	.53	.79	.46	.49	.57
8800	.85	.77	.61	.52	.50	.51	.77	.43	.52	.61
7900	1.00	.78	.54	.50	.46	.54	.73	.46	.50	.57
7000	.84	.73	.57	.51	.48	.49	.77	.47	.54	.57
6100	.94	.73	.65	.54	.53	.52	.72	.44	.55	.58
5200	.93	.75	.60	.52	.50	.52	.74	.44	.47	.55
4400	.85	.77	.60	.51	.48	.52	.76	.47	.45	.62
3600	.96	.79	.59	.52	.41	.55	.73	.47	.42	.61
2700	.88	.78	.57	.52	.46	.54	.75	.48	.47	.60
1900	.88	.77	.54	.50	.46	.53	.78	.47	.45	.61
1100	.96	.78	.65	.51	.46	.54	.74	.50	.52	.62
O.K.	.84	.78	.56	.51	.48	.58	.71	.47	.47	.60
X	.90	.75	.59	.52	.49	.51	.76	.46	.50	.59
s	.05	.03	.03	.01	.04	.03	.02	.02	.04	.02
range	.16	.08	.11	.04	.16	.12	.08	.07	.14	.07
n	16	16	16	16	16	16	16	16	16	16

APPENDIX B

GATF Color Triangle

A Graphical Interpretation of
Hue Error and Gray Balance Data


Gray Overprint
Critical Color
GREEN
RED
BLUE
BLUE FILTER MASK FOR CYAN PRINTER
RED FILTER MASK FOR YELLOW PRINTER
(R/G) RED FILTER MASK FOR MAGENTA PRINTER
Blue Overprint
Brown Overprint
Red Overprint

APPENDIX C

Control Charts of the Ink Density Variation of the Solid Process Colors

FIGURE 2

CONTROL CHART

Cyan Solid $\bar{x}$ = 1.22 ......

Magenta Solid $\bar{x}$ = 1.15 ———

Yellow Solid $\bar{x}$ = .64 ______

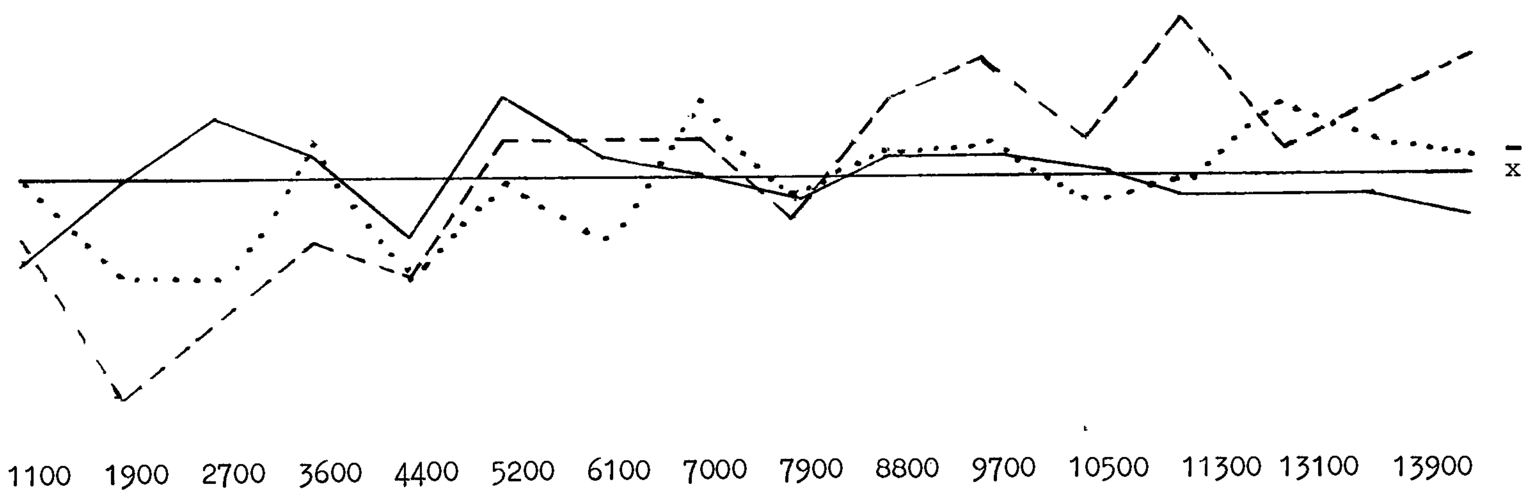


FIGURE 3

CONTROL CHART

HUE OF BLUE HALFTONE OVERPRINT

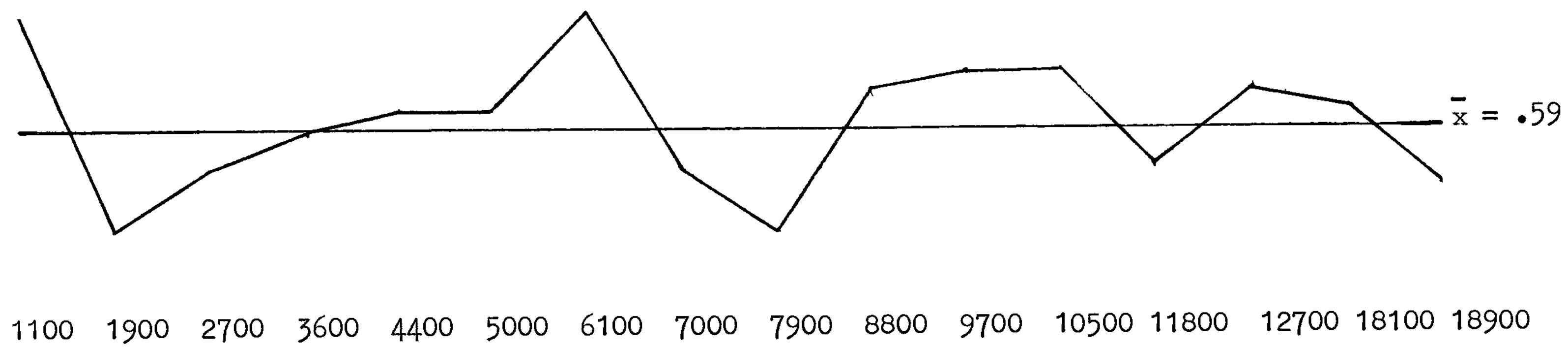


FIGURE 4

CONTROL CHART

HUE OF NEAR GRAY HALFTONE OVERPRINT

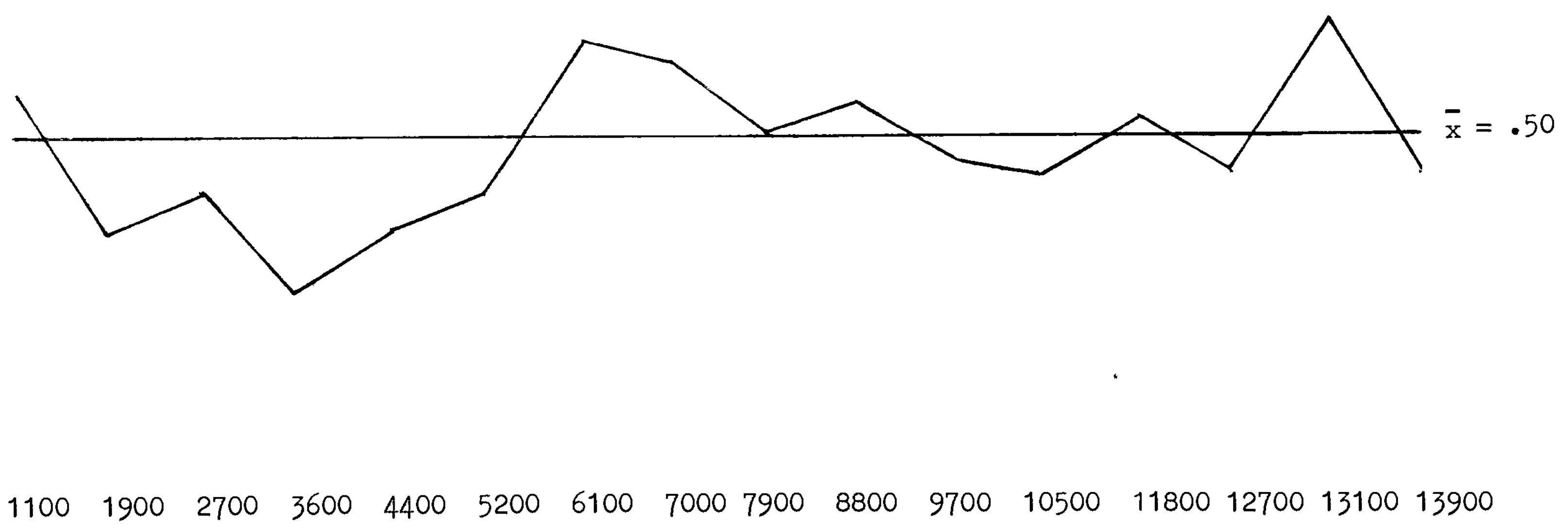


FIGURE 5

CONTROL CHART

HUE OF A CRITICAL HALFTONE OVERPRINT

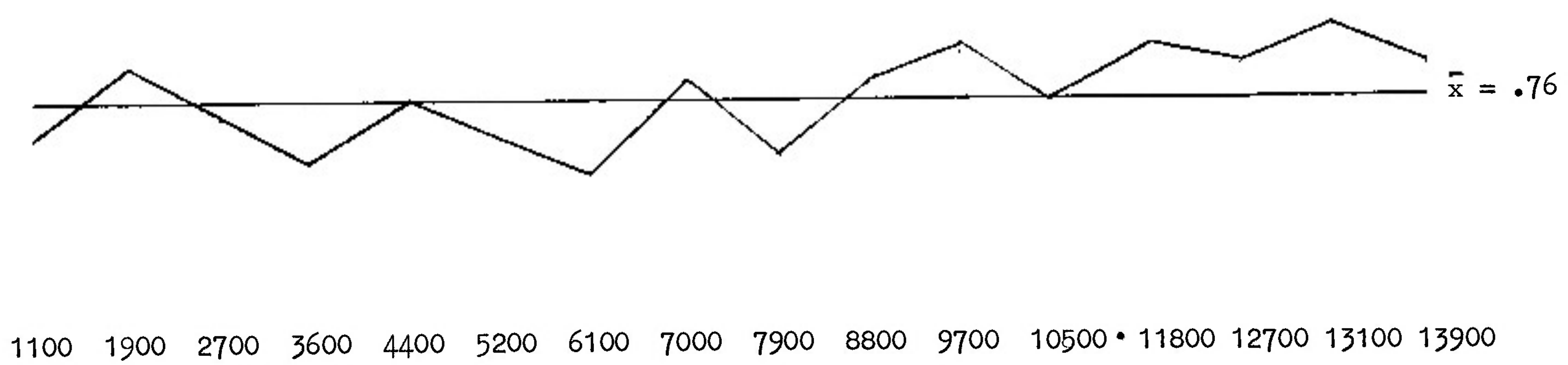


FIGURE 6

CONTROL CHART

HUE OF RED HALFTONE OVERPRINT

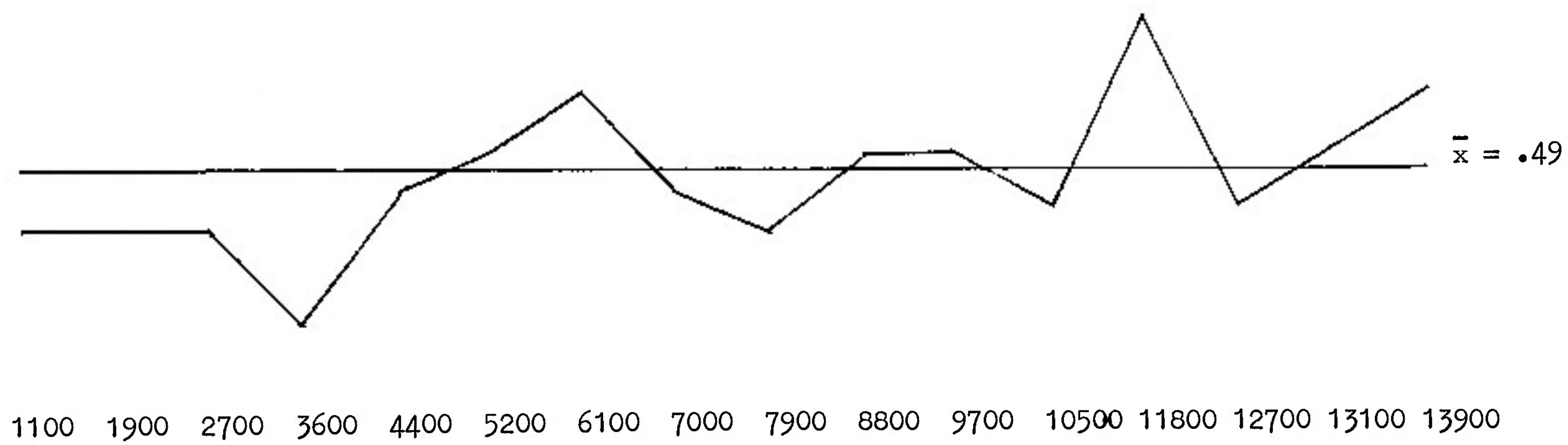
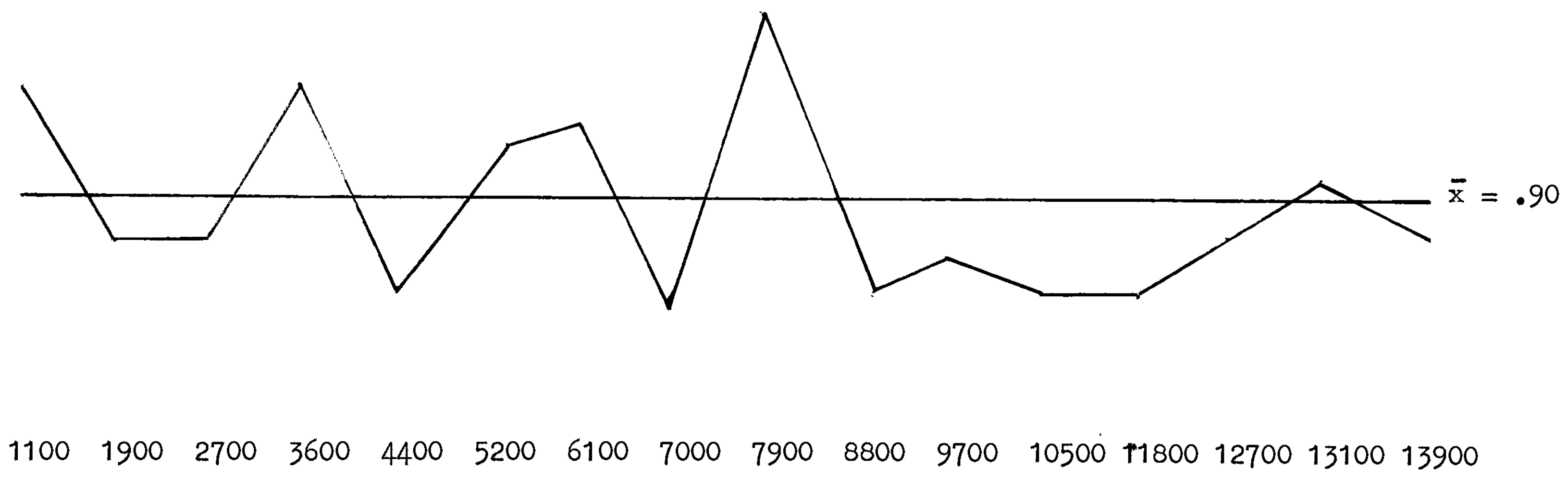


FIGURE 7

CONTROL CHART
HUE OF BROWN HALFTONE OVERPRINT



APPENDIX D

Tables and Scatter Diagrams

Densities of Solid Process Colors

vs.

Complimentary Filter Densities of Screened Overprint Colors

TABLE 4

TOTAL RED FILTER DENSITY OF SOLIDS

vs.

RED FILTER DENSITY OF BLUE OVERPRINTS

Count	Solids	Blue Overprint
13900	1.57	1.34
13100	1.52	1.30
12200	1.53	1.34
11300	1.50	1.26
10500	1.45	1.29
9700	1.51	1.27
8800	1.50	1.26
7900	1.48	1.29
7000	1.52	1.34
6100	1.46	1.27
5200	1.49	1.30
4400	1.40	1.28
3600	1.50	1.30
2700	1.39	1.27
1900	1.40	1.30
1100	1.45	1.27

$r = .51$ $r^2 = 26\%$

FIGURE 7

TOTAL RED FILTER DENSITY OF SOLIDS

vs.

RED FILTER DENSITY OF BLUE OVERPRINT

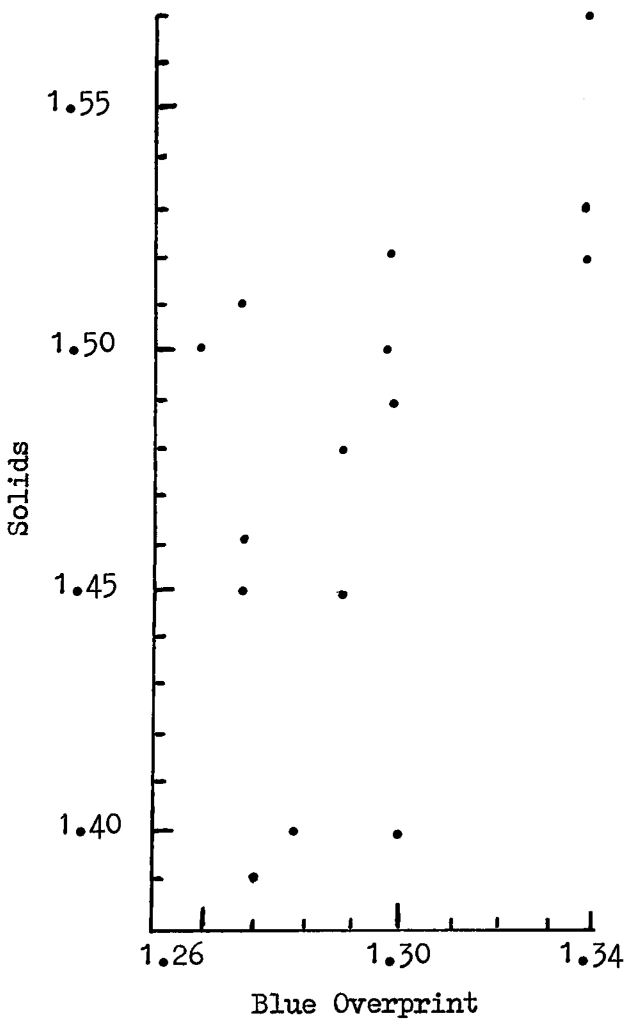


TABLE 5

TOTAL BLUE FILTER DENSITY OF SOLIDS

vs.

BLUE FILTER DENSITY OF GRAY OVERPRINT

Count	Solids	Gray Overprint
13900	1.42	.80
13100	1.41	.86
12200	1.38	.84
11300	1.43	.82
10500	1.40	.85
9700	1.43	.82
8800	1.44	.84
7900	1.36	.79
7000	1.41	.82
6100	1.39	.85
5200	1.45	.85
4400	1.31	.81
3600	1.37	.85
2700	1.36	.81
1900	1.31	.79
1100	1.31	.82

$r = .46$ $r^2 = 21\%$

FIGURE 8

TOTAL BLUE FILTER DENSITY OF SOLIDS

vs.

BLUE FILTER DENSITY OF GRAY OVERPRINT

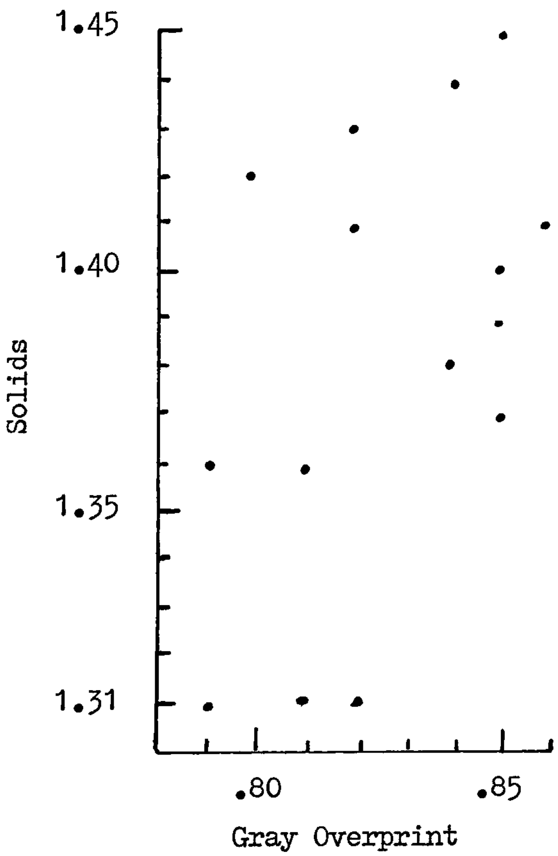


TABLE 6

TOTAL BLUE FILTER DENSITY OF SOLIDS

vs.

BLUE FILTER DENSITY OF CRITICAL HALFTONE

Count	Solids	Critical Color
13900	1.42	.87
13100	1.41	.88
12200	1.38	.90
11300	1.43	.85
10500	1.40	.90
9700	1.43	.87
8800	1.44	.83
7900	1.36	.81
7000	1.41	.90
6100	1.39	.90
5200	1.45	.90
4400	1.31	.87
3600	1.37	.85
2700	1.36	.84
1900	1.31	.87
1100	1.31	.84

$r = .26$ $r^2 = 7\%$

FIGURE 9

TOTAL BLUE FILTER DENSITY OF SOLIDS

vs.

BLUE FILTER DENSITY OF CRITICAL HALFTONE

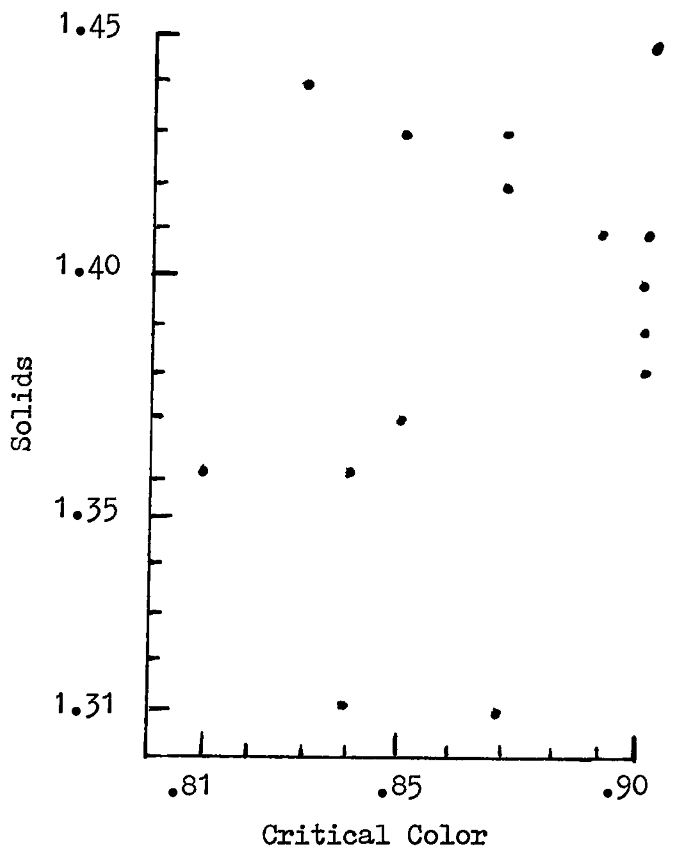


TABLE 7

TOTAL GREEN FILTER DENSITY OF SOLIDS

vs.

GREEN FILTER DENSITY OF BROWN OVERPRINT

Count	Solids	Brown Overprint
13900	1.66	1.13
13100	1.64	1.14
12200	1.61	1.15
11300	1.66	1.20
10500	1.60	1.21
9700	1.63	1.19
8800	1.63	1.17
7900	1.58	1.10
7000	1.60	1.19
6100	1.60	1.21
5200	1.60	1.18
4400	1.51	1.19
3600	1.54	1.13
2700	1.47	1.16
1900	1.45	1.17
1100	1.53	1.09

$r = .15$ $r^2 = 2\%$

FIGURE 10

TOTAL GREEN FILTER DENSITY OF SOLIDS

vs.

GREEN FILTER DENSITY OF BROWN HALFTONE

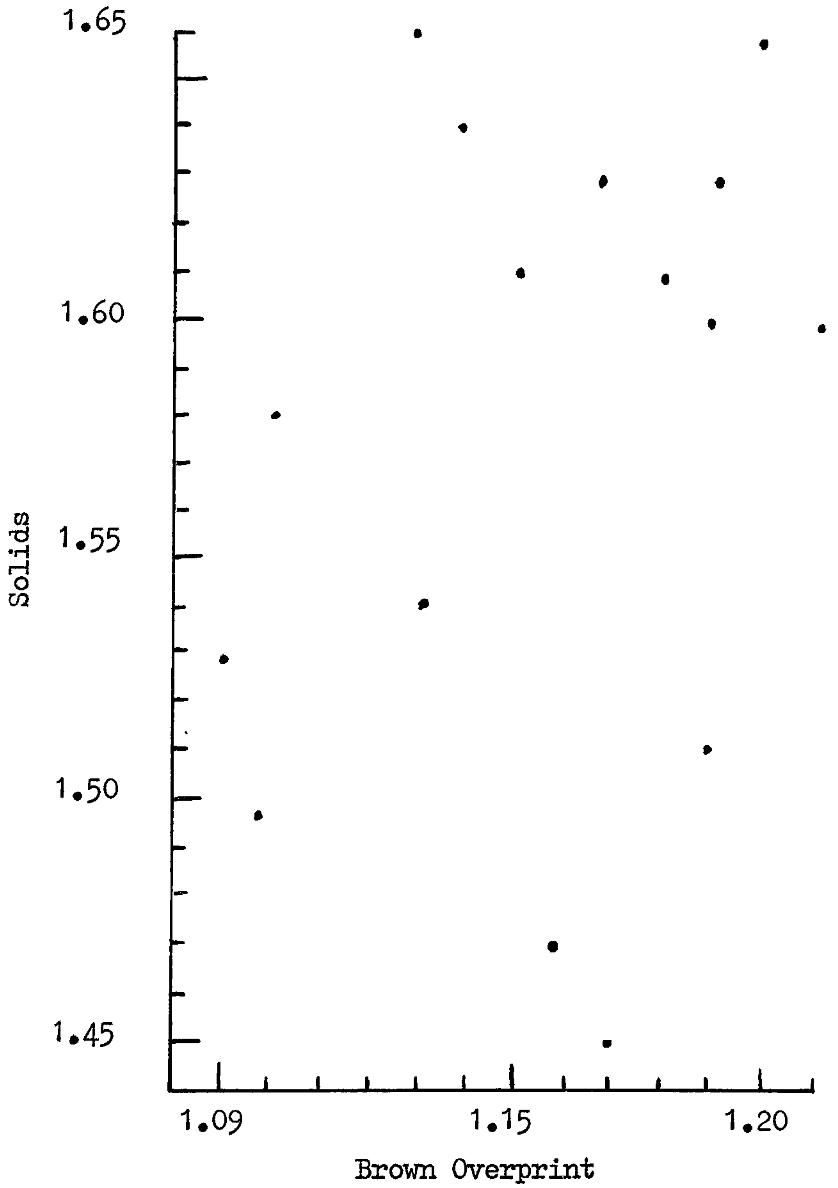


FIGURE 11

TOTAL GREEN FILTER DENSITY OF SOLIDS

vs.

GREEN FILTER DENSITY OF RED HALFTONE

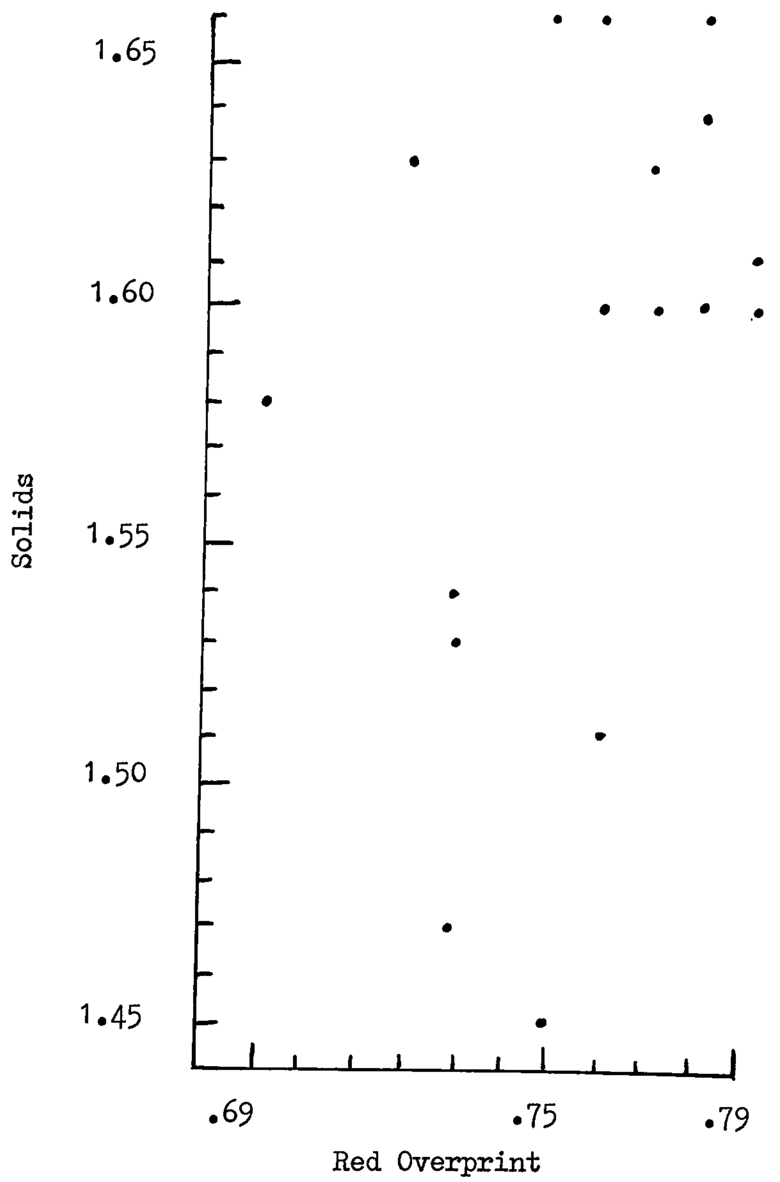
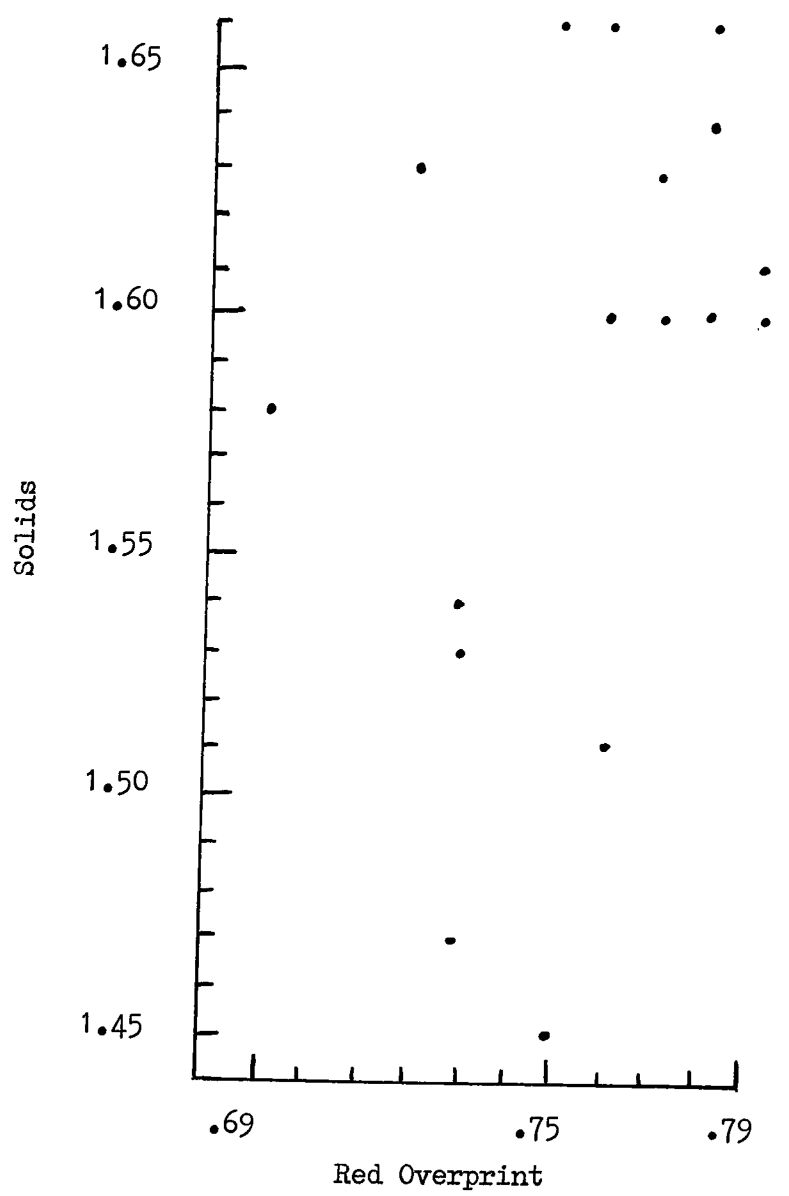


FIGURE 11

TOTAL GREEN FILTER DENSITY OF SOLIDS

vs.

GREEN FILTER DENSITY OF RED HALFTONE



APPENDIX E

Tables and Scatter Diagrams

Density of Screened Process Colors

vs.

Hue Error of Screened Overprint Colors

TABLE 9

TINTS vs. HUES OF BROWN OVERPRINT

Count	Difference	Hue Error
13900	.32	.88
13100	.32	.91
12200	.33	.88
11300	.27	.85
10500	.33	.85
9700	.31	.87
8800	.26	.85
7900	.24	1.00
7000	.32	.84
6100	.33	.94
5200	.30	.93
4400	.27	.85
3600	.24	.96
2700	.26	.88
1900	.26	.88
1100	.24	.96

$r = -.39$ $r^2 = 15\%$

FIGURE 12

TINTS vs. HUES OF BROWN OVERPRINT

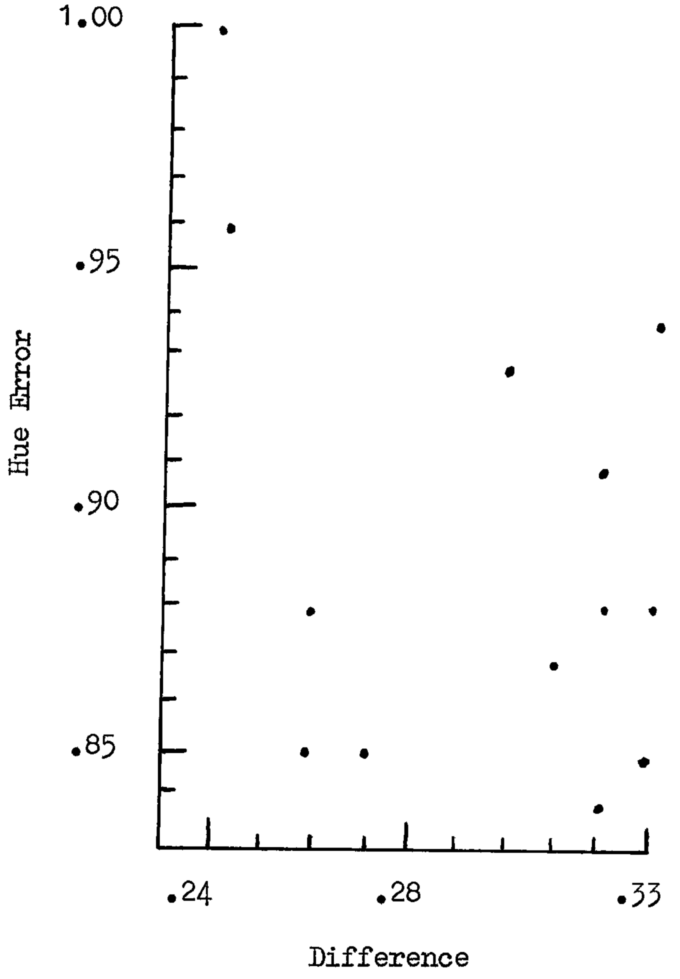


TABLE 10

TINTS vs. HUES OF BLUE OVERPRINT

Count	Difference	Hue Error
13900	.66	.56
13100	.62	.60
12200	.66	.61
11300	.60	.57
10500	.61	.62
9700	.60	.62
8800	.61	.61
7900	.65	.54
7000	.65	.57
6100	.58	.65
5200	.62	.60
4400	.63	.60
3600	.63	.59
2700	.61	.57
1900	.65	.54
1100	.62	.65

$r = -.59$ $r^2 = 34\%$

FIGURE 13

TINTS vs. HUES OF BLUE OVERPRINT

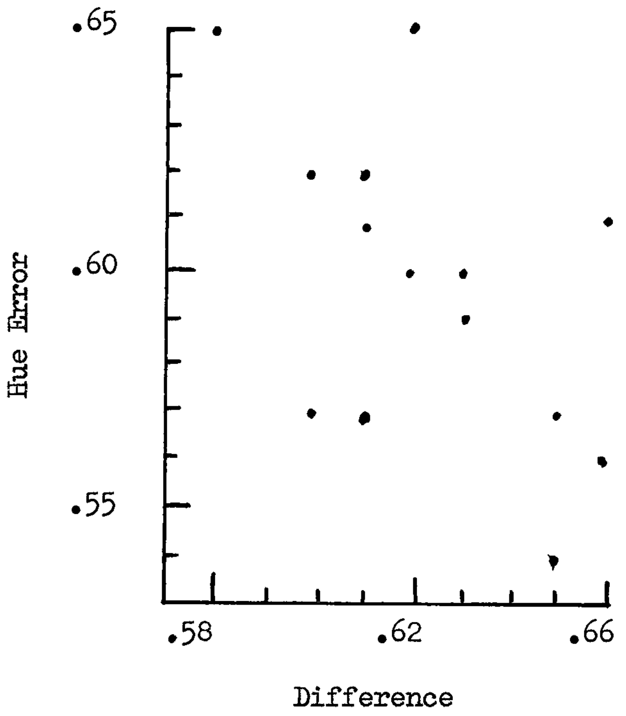


TABLE 11

TINTS vs. HUES OF GRAY OVERPRINT

Count	Difference	Hue Error
13900	.33	.48
13100	.34	.56
12200	.33	.48
11300	.35	.51
10500	.33	.48
9700	.35	.49
8800	.33	.52
7900	.34	.50
7000	.35	.54
6100	.36	.55
5200	.38	.47
4400	.31	.45
3600	.33	.42
2700	.32	.47
1900	.31	.45
1100	.31	.52

$r = .35$ $r^2 = 12\%$

FIGURE 14

TINTS vs. HUES OF GRAY OVERPRINT

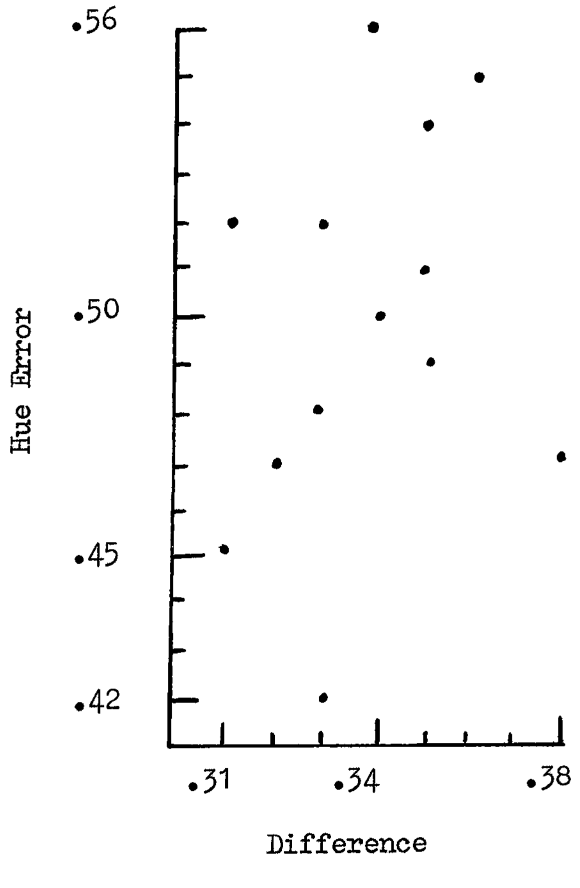


TABLE 12

TINTS vs. HUES OF CRITICAL COLOR

Count	Difference	Hue Error
13900	.49	.78
13100	.49	.80
12200	.50	.78
11300	.48	.79
10500	.50	.76
9700	.47	.79
8800	.47	.77
7900	.44	.73
7000	.48	.77
6100	.50	.72
5200	.50	.74
4400	.46	.76
3600	.45	.73
2700	.44	.75
1900	.46	.78
1100	.42	.74

$r = .32$ $r^2 = 10\%$

FIGURE 15

TINTS vs. HUES OF CRITICAL COLOR

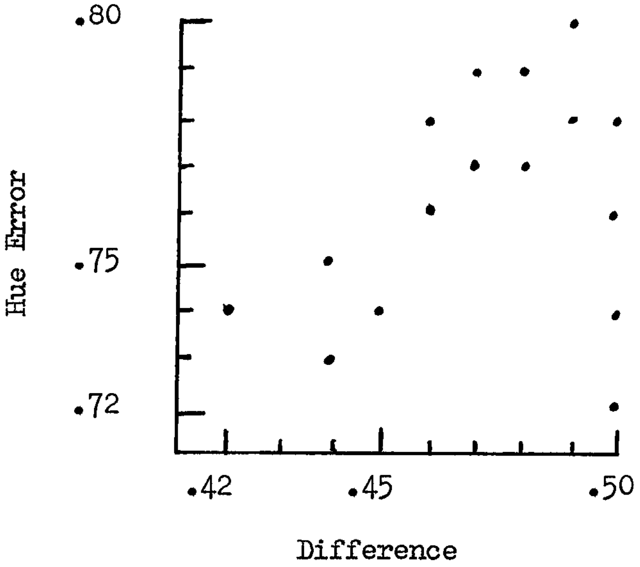


TABLE 13

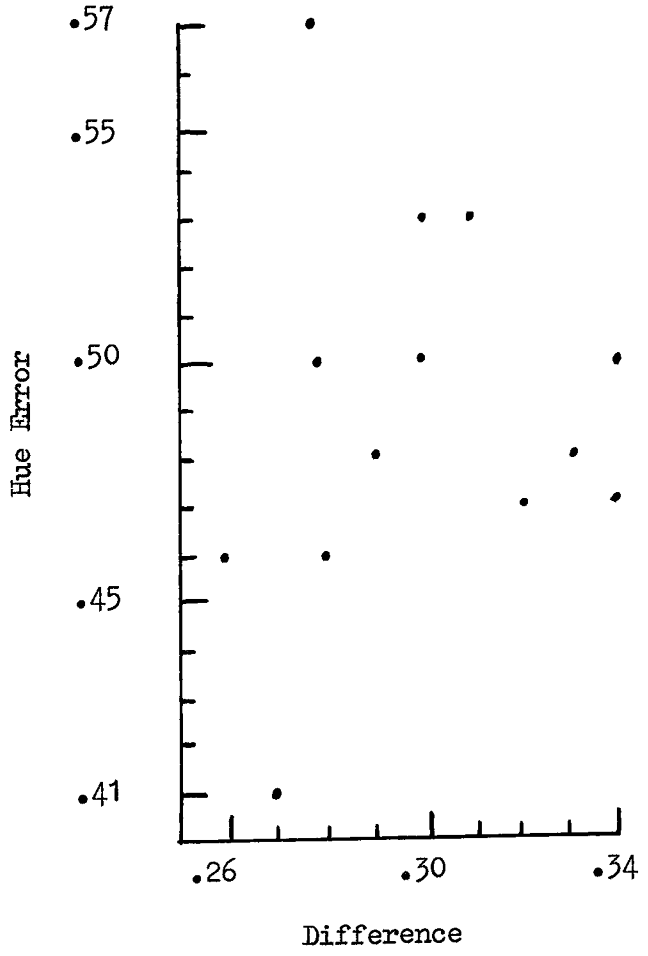
TINTS vs. HUES OF RED OVERPRINT

Count	Difference	Hue Error
13900	.32	.53
13100	.34	.50
12200	.34	.47
11300	.28	.57
10500	.32	.47
9700	.28	.50
8800	.30	.50
7900	.26	.46
7000	.33	.48
6100	.30	.53
5200	.30	.50
4400	.29	.48
3600	.27	.41
2700	.26	.46
1900	.28	.46
1100	.28	.46

$r = .26$ $r^2 = 7\%$

FIGURE 16

TINTS vs. HUES OF RED OVERPRINT



APPENDIX F

Red, Green, and Blue Filter Density of Screened Overprints

vs.

Gray Value of Screened Overprint Colors

TABLE 14

TINTS vs. GRAY VALUE OF GRAY OVERPRINT

Count	Difference	Gray Value
13900	.33	.59
13100	.34	.60
12200	.33	.61
11300	.35	.57
10500	.33	.61
9700	.35	.57
8800	.33	.61
7900	.34	.57
7000	.35	.57
6100	.36	.58
5200	.38	.55
4400	.31	.62
3600	.33	.61
2700	.32	.60
1900	.31	.61
1100	.31	.62

$r = -.88$ $r^2 = 77\%$

FIGURE 17

TINTS

vs.

GRAY VALUE OF GRAY OVERPRINT

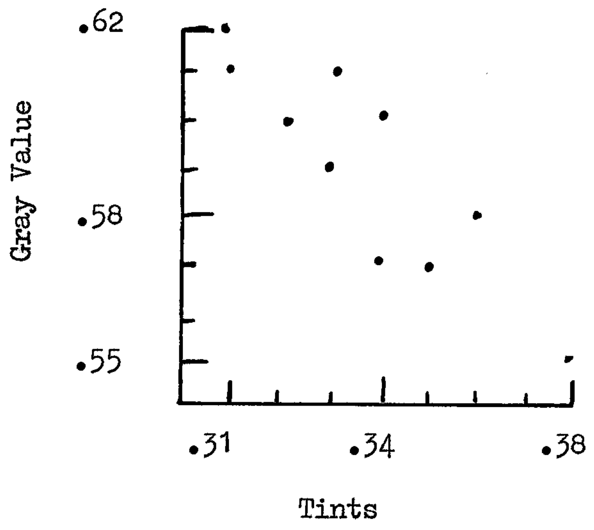


TABLE 15

TINTS vs. GRAY VALUE OF CRITICAL COLOR

Count	Difference	Gray Value
13900	.49	.44
13100	.49	.44
12200	.50	.44
11300	.48	.44
10500	.50	.44
9700	.47	.46
8800	.47	.43
7900	.44	.46
7000	.48	.47
6100	.50	.44
5200	.50	.44
4400	.46	.47
3600	.45	.47
2700	.44	.48
1900	.46	.47
1100	.42	.50

$r = -.83$ $r^2 = 69\%$

FIGURE 18

TINTS vs. GRAY VALUE OF CRITICAL HT

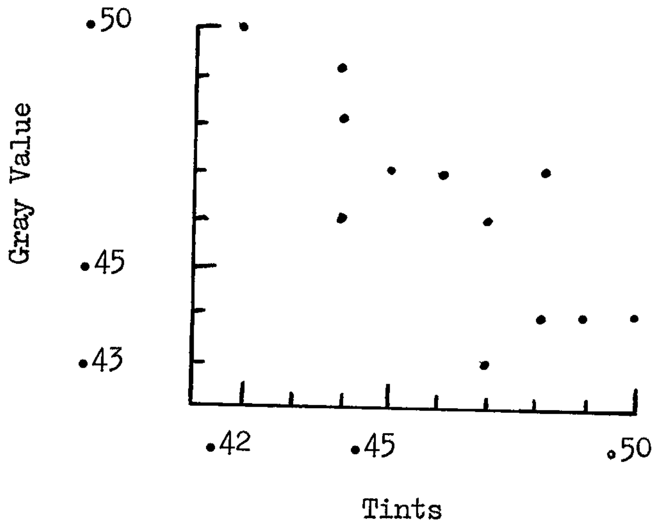


FIGURE 19

TINTS vs. GRAY VALUE OF RED HT

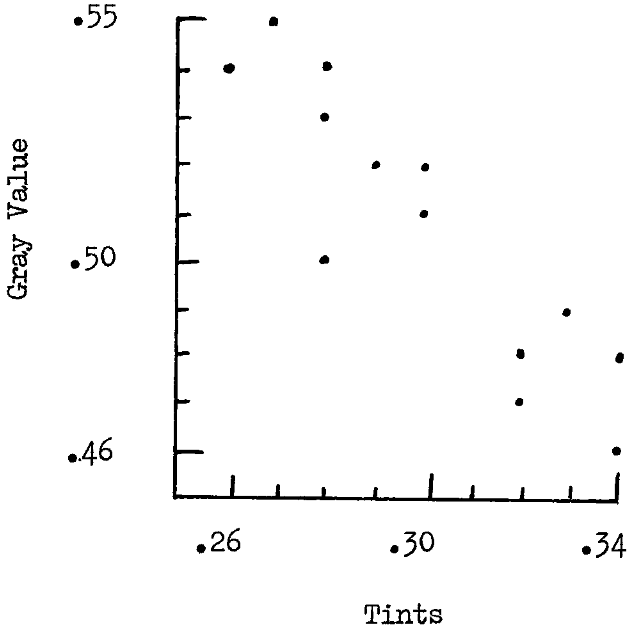


TABLE 16

TINTS vs. GRAY VALUE OF RED HT

Count	Difference	Gray Value
13900	.32	.47
13100	.34	.46
12200	.34	.48
11300	.28	.50
10500	.32	.48
9700	.28	.53
8800	.30	.51
7900	.26	.54
7000	.33	.49
6100	.30	.52
5200	.30	.52
4400	.29	.52
3600	.27	.55
2700	.26	.54
1900	.28	.53
1100	.28	.54

$r = -.90$ $r^2 = 81\%$

TABLE 17

TINTS vs. GRAY VALUE OF BLUE HT

Count	Difference	Gray Value
13900	.66	.51
13100	.62	.52
12200	.66	.51
11300	.60	.52
10500	.61	.53
9700	.60	.53
8800	.61	.52
7900	.65	.50
7000	.65	.51
6100	.58	.54
5200	.62	.52
4400	.63	.51
3600	.63	.52
2700	.61	.52
1900	.65	.50
1100	.62	.51

$r = -.85$ $r^2 = 72\%$

FIGURE 20

TINTS vs. GRAY VALUE OF BLUE HT

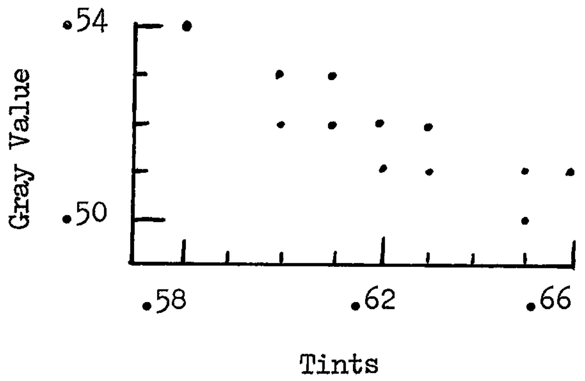


TABLE 18

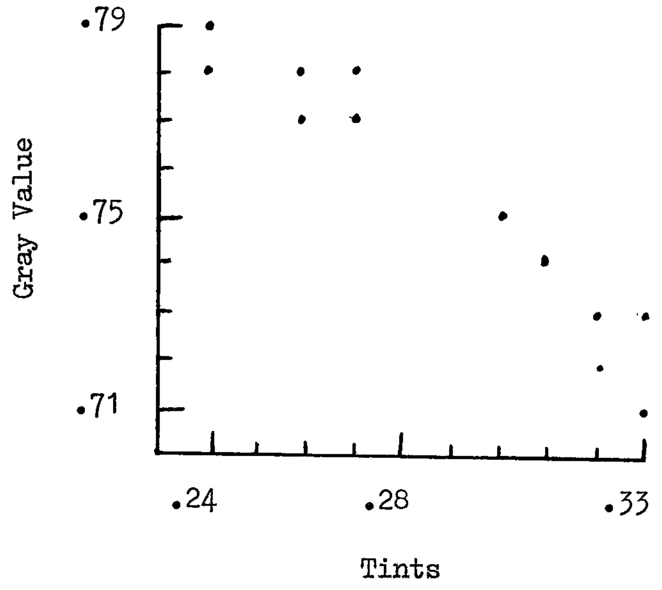
TINTS vs. GRAY VALUE OF BROWN HT

Count	Difference	Gray Value
13900	.32	.72
13100	.32	.72
12200	.33	.71
11300	.27	.78
10500	.33	.73
9700	.31	.74
8800	.26	.77
7900	.24	.78
7000	.32	.73
6100	.33	.73
5200	.30	.75
4400	.27	.77
3600	.24	.79
2700	.26	.78
1900	.26	.77
1100	.24	.78

$r = -.96$ $r^2 = 92\%$

FIGURE 21

TINTS vs. GRAY VALUE OF BROWN HT



APPENDIX G

Green Filter Density of Screened Overprints

vs.

Green Filter Density of a Near Neutral Gray

TABLE 19

GREEN FILTER DENSITIES OF BLUE HT

vs.

GREEN FILTER DENSITIES OF GRAY HT

Count	Blue Overprint	Gray Overprint
13900	1.05	.63
13100	1.05	.71
12200	1.08	.67
11300	1.01	.65
10500	1.06	.68
9700	1.04	.64
8800	1.02	.68
7900	.99	.62
7000	1.08	.66
6100	1.06	.69
5200	1.05	.65
4400	1.03	.64
3600	1.04	.66
2700	1.01	.64
1900	1.00	.62
1100	1.05	.67

$r = .57$ $r^2 = 32\%$

FIGURE 22

GREEN FILTER DENSITIES OF BLUE HALFTONE

vs.

GREEN FILTER DENSITIES OF GRAY HALFTONE

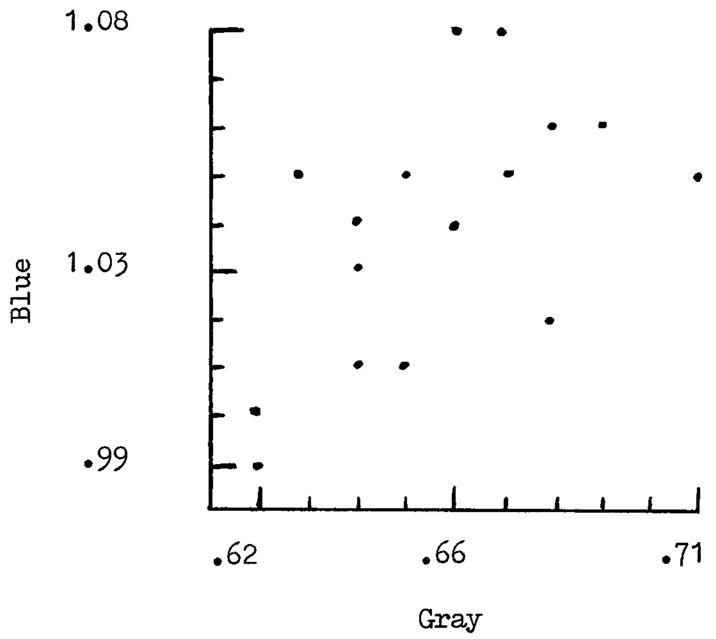


TABLE 20

GREEN FILTER DENSITIES OF RED OVERPRINT

vs.

GREEN FILTER DENSITIES OF GRAY OVERPRINT

Count	Red Overprint	Gray Overprint
13900	.60	.63
13100	.63	.71
12200	.65	.67
11300	.56	.65
10500	.62	.68
9700	.59	.64
8800	.61	.68
7900	.57	.62
7000	.65	.66
6100	.62	.69
5200	.62	.65
4400	.60	.64
3600	.60	.66
2700	.57	.64
1900	.60	.62
1100	.61	.67

$r = .58$ $r^2 = 34\%$

FIGURE 23

GREEN FILTER DENSITIES OF RED HALFTONE HT

vs.

GREEN FILTER DENSITIES OF GRAY HALFTONE HT

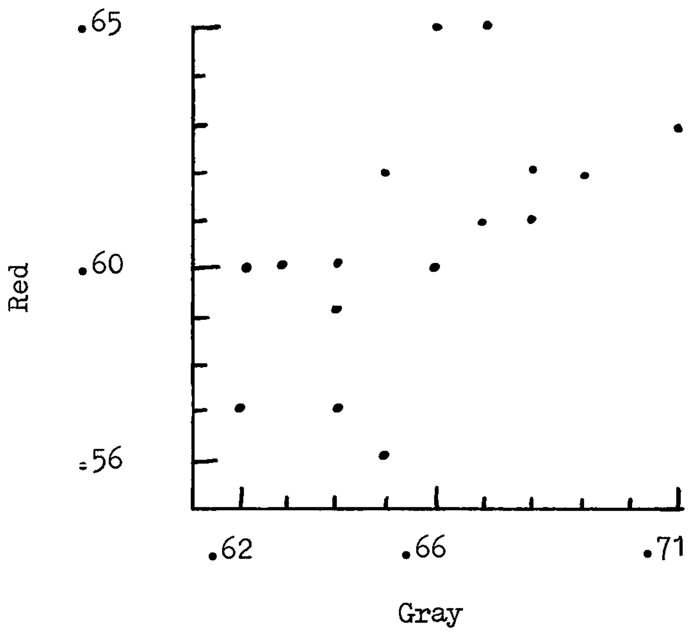


TABLE 21

GREEN FILTER DENSITIES OF CRITICAL HT

vs.

GREEN FILTER DENSITIES OF GRAY HT

Count	Critical Color	Gray Overprint
13900	.76	.63
13100	.78	.71
12200	.79	.67
11300	.75	.65
10500	.78	.68
9700	.77	.64
8800	.72	.68
7900	.69	.62
7000	.79	.66
6100	.76	.69
5200	.77	.65
4400	.76	.64
3600	.73	.66
2700	.73	.64
1900	.75	.62
1100	.73	.67

$r = .37$ $r^2 = 14\%$

FIGURE 24

GREEN FILTER DENSITIES OF CRITICAL HT

vs.

GREEN FILTER DENSITIES OF GRAY HT

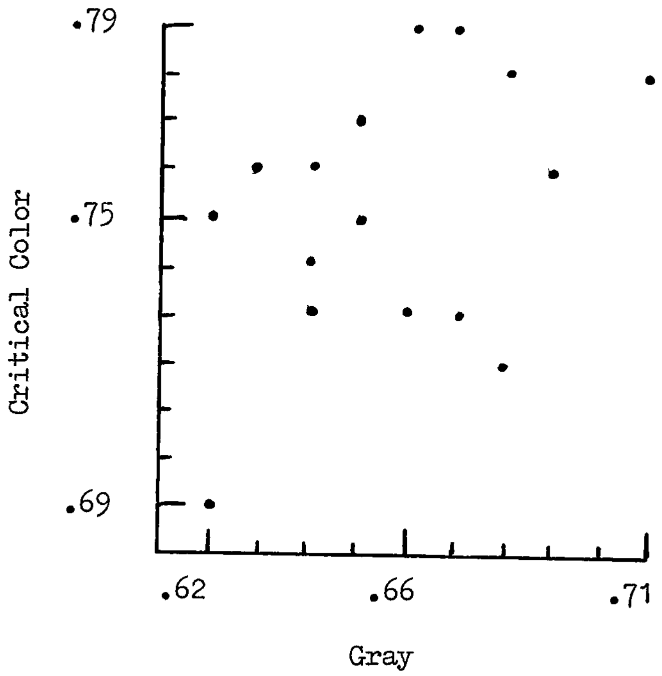


TABLE 22

GREEN FILTER DENSITIES OF BROWN HT

vs.

GREEN FILTER DENSITIES OF GRAY HT

Count	Brown Overprint	Gray Overprint
13900	1.13	.63
13100	1.14	.71
12200	1.15	.67
11300	1.20	.65
10500	1.21	.68
9700	1.19	.64
8800	1.17	.68
7900	1.10	.62
7000	1.19	.66
6100	1.21	.69
5200	1.18	.65
4400	1.19	.64
3600	1.13	.66
2700	1.16	.64
1900	1.17	.62
1100	1.09	.67

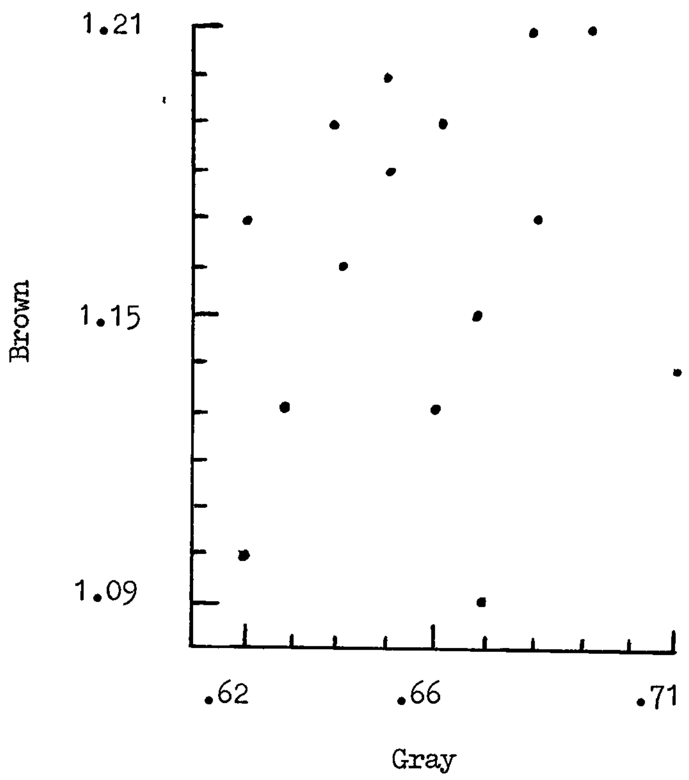
$r = .15$ $r^2 = 2\%$

FIGURE 25

GREEN FILTER DENSITIES OF BROWN HT

vs.

GREEN FILTER DENSITIES OF GRAY HT



APPENDIX H

Table and Scatter Diagrams

Density of Solid Process Colors

vs.

Density of Screened Process Colors

TABLE 23

RED FILTER DENSITY OF CYAN SOLID

vs.

RED FILTER DENSITY OF BLUE HT

Count	Solid	Blue Overprint
13900	1.23	1.34
13100	1.24	1.30
12200	1.26	1.34
11300	1.22	1.26
10500	1.21	1.29
9700	1.24	1.27
8800	1.23	1.26
7900	1.21	1.29
7000	1.26	1.34
6100	1.19	1.27
5200	1.22	1.30
4400	1.17	1.28
3600	1.24	1.30
2700	1.17	1.27
1900	1.17	1.30
1100	1.22	1.27

$r = .48$ $r^2 = 23\%$

FIGURE 26

RED FILTER DENSITY OF CYAN SOLID

vs.

RED FILTER DENSITY OF BLUE HT

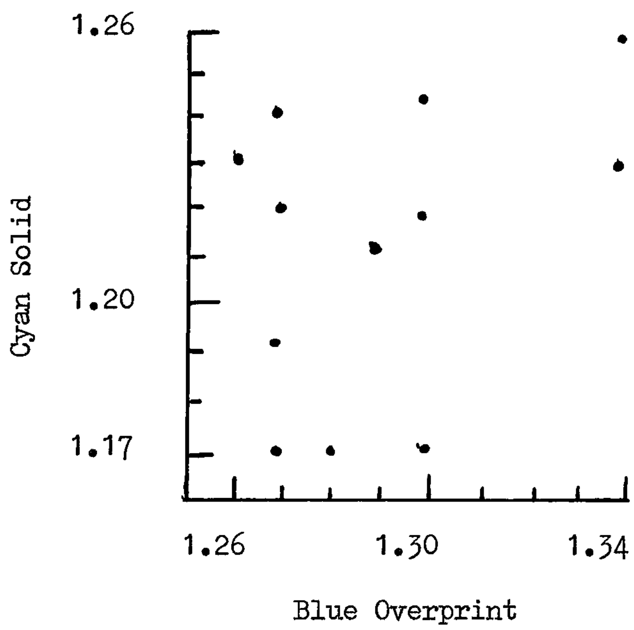


TABLE 24

GREEN FILTER DENSITY OF MAGENTA SOLID

vs.

GREEN FILTER DENSITY OF RED HT

Count	Solid	Red Overprint
13900	1.21	.60
13100	1.19	.63
12200	1.16	.65
11300	1.23	.56
10500	1.17	.62
9700	1.21	.59
8800	1.19	.61
7900	1.13	.57
7000	1.17	.65
6100	1.17	.62
5200	1.17	.62
4400	1.10	.60
3600	1.12	.60
2700	1.07	.57
1900	1.04	.60
1100	1.12	.61

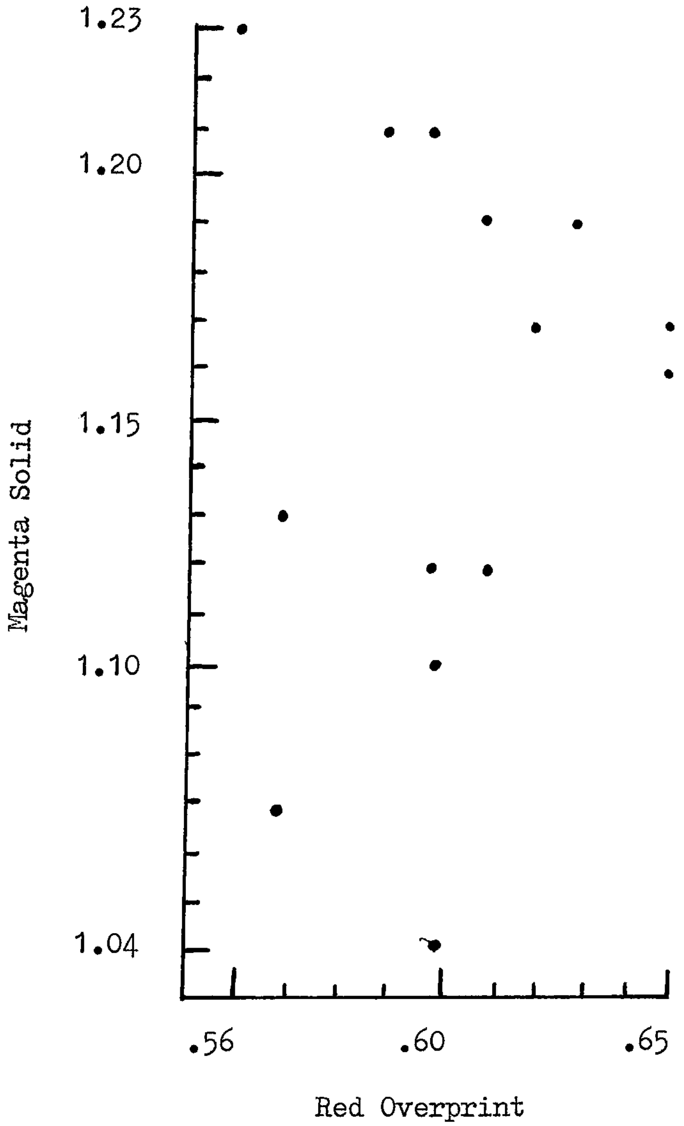
$r = .14$ $r^2 = 2\%$

FIGURE 27

GREEN FILTER DENSITY OF MAGENTA SOLID

vs.

GREEN FILTER DENSITY OF RED HT



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