Final Report

THE IMPROVEMENT OF REMOTE SENSING TECHNOLOGY AND ITS APPLICATION TO CORN YIELD ESTIMATES

to

Statistical Reporting Service

United States Department of Agriculture

Remote Sensing Institute
South Dakota State University
Brookings, South Dakota 57006

ABSTRACT

This project was a cooperative effort between the Remote Sensing Institute and the Statistical Reporting Service, United States Department of Agriculture. During a pilot program for predicting corn yields, investigators recognized the variability of remotely sensed data between aerial data collection missions. Therefore a control experiment, a field experiment, and a pattern recognition experiment were designed to study that variability.

The objective of the control experiment was to study the variability of photometric characteristics in relation to the variability of radiometric data. Results indicated that cameras, F stop setting and type of day were significant sources of variation in photographic densities. Using radiometric measuring devices, equations were generated to correct film density for the type of day on which the film was exposed.

The objectives of the field experiment were to study the influence of atmospheric attenuation and interference on photographic imagery and to establish correction procedures using concomitant radiation measuring instruments so that these correction procedures could be included in the procedure for estimating corn yields in a statistically designed experiment. Altitudes, dates of flight, fields and many interactions of these factors were significant sources of variation in film density in this experiment. Correlations between film density and corn plant characteristics indicated that the first week of August was the best time to estimate corn yield from film density.

Using the K-Class classifier, it was found that three levels of corn yield and four different corn fields could be differentiated from the original uncorrected film density with 50% to 90% correct classification. The adjustment of film density using the equations derived in the control experiment increased the capability of the K-class classifier to correctly identify the yield levels of the field plots.

The objective of the pattern recognition experiment was to investigate the application of certain pattern recognition procedures to crop identification. Using the K-class classifier, it was possible to identify up to 10 different crops with an accuracy between 60% and 80%. It was found that a priori information increased overall classification accuracy by increasing the classification accuracy of the larger classes. Color infrared film (2443) provided a more accurate classification of crops than did color film (2448). Imagery collected from the 1220-meter altitude produced better results than that from the 610-meter altitude.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

PROLOGUE

The Remote Sensing Institute, South Dakota State University, in cooperation with the Statistical Reporting Service, took part in a pilot program which investigated remote sensing procedures for estimating corn and wheat yields. This effort was started late in the growing season. Corn yields were estimated for three fields on two different farms. Data from remote sensors were gathered for eight plots within each of the three corn fields. The analysis of these data was, to a certain extent, encouraging; however, the differences among films, filters, and atmospheric radiation conditions for the various data collection missions made interpretation difficult.

At present, a major portion of remote sensing analysis is qualitative and based on visual photointerpretation techniques. This type of analysis is done best on slightly overexposed film. Automatic analysis, on the other hand, can utilize underexposed film and in fact derive more information from it. However, automatic machine analysis is influenced by extraneous variables as well as by real reflectance values. These extraneous factors tend to mask the relationships that must be detected before yield estimates can be relied upon.

From results of the pilot program, three experiments were designed to measure, control, or otherwise account for encountered variables. Specific objectives of these experiments were as follows:

(1) To study the variability of photometric characteristics in relation to the variability of radiometric data in a control experiment.

(2) To study the influence of atmospheric attenuation and interference on photographic imagery and to use concomitant radiation measurements in a derived correction procedure to improve statistical estimates of corn yields.

(3) To investigate the application of a pattern recognition procedure for crop identification and yield prediction.

The report which follows describes each of the three experiments in a separate section. Figures and tables referenced in the narrative are included sequentially in appendices A and B respectively. Appendix C contains data tabulations for parts I, II and III. Conclusions and recommendations are included at the end of the discussion of each experiment.

PART I

THE CONTROL EXPERIMENT

INTRODUCTION

Images of the same area at different times within a day or between days have different densities due to varying incoming radiation. The angle of the sun with respect to the object being photographed, and to the camera, influences density differences. Clouds also affect film densities. For example, solar radiation is higher when reflected from the leading or trailing edge of cumulus type clouds to an object on the ground. High thin cirrus overcast, however, reduces the total radiation reaching a ground object.

These variations in incoming radiation can cause density differences on photographs which are considerably greater than the reflectance contrasts that one would normally expect. This phenomenon becomes extremely serious in numerical, color optical density, computer, or other studies where optical and/or electronic signals must be evaluated assuming constant radiation.

The control experiment was designed to evaluate the foregoing factors as they relate to the sensor system to be used.

OBJECTIVE

The objective of this experiment was to study the variability of photometric characteristics in relation to the variability of radiometer data in a control experiment.

PROCEDURES

GENERAL APPROACH

The plan for the control experiment was to collect photographic and radiometric data in May and again in August. At each of these times, data were to be collected on a clear day and on a cloudy day for comparison of photographic and radiance differences. The same type and lot number of film was planned for use in each collection of photographic data. The film exposed on the two dates in May and in August was to be processed simultaneously in May and in August. These procedures were designed to eliminate film lot and processing differences for the two dates in each major data collection period.

Data were collected as planned on May 11 at 12:16 EST and at 14:31 EST. The exposed film was held for five days while waiting for a cloudy day on which to collect data for comparison. Since a cloudy day did not occur within a reasonable time, the film exposed on May 11 was processed in order to prevent deterioration.

The second data collection was conducted as planned on August 25, a clear day, at 13:30 EST and again at 13:30 EST on August 31 which was a cloudy day. Film from the two August data collection dates was processed simultaneously as indicated in the planned approach.

The data collected in May were analyzed for differences which occurred within a clear day and the August data were analyzed for differences between a clear and a cloudy day.

EQUIPMENT USE AND DESCRIPTION

Equipment utilized in the control experiment consisted of four 70-mm Hasselblad 500 EL cameras, one 35-mm Minolta camera with fisheye lens, one Eppley Model 2 pyranometer, two sets of four Sol-A-Meter (hereafter called solameter) brand radiometers manufactured by Matrix, Inc., and one Macbeth TD404 transmission densitometer.

The cameras and radiometers were used in the control experiment to measure photographic and radiometric data over a target consisting of four blocks of different colored cardboard (Figure 1). The center strip on the target board was a standard color spectrum chart of the visible light range. The cameras were mounted three and one half meters (11.5 feet) directly above the target. A calibration radiometer was positioned four meters (13.2 feet) away and two meters (6.6 feet) above the cameras (Figure 2). Location of the sensors on the south roof-edge of the building shown in Figure 2 eliminated structural shadows from the target.

Solameters were used for measuring both reflected and incident solar radiation in discrete wavelengths. A set was comprised of three MK1-RF solameters which were separately filtered with an 89B, (infrared), 25 (red), and a 58 (green) filter. Data from this solameter set were recorded on a Texas Instruments strip chart recorder. The set was alternately pointed upward and downward to measure both incoming and reflected radiation during the May experiment. During the August experiment, two additional sets of solameters were available. These sets, consisting of four model MK1-RF solameters, were seperately filtered as the previous set with 89B (infrared), 25 (red), and 58 (green) filters, and the fourth solameter in the set was unfiltered. Simultaneous incident and reflected radiation measurements were recorded on single channel recorders, i.e. eight separate strip charts. One set of solameters was positioned next to the cameras, looking downward, and the upward-looking set was located four meters (13.2 feet) away and two meters (6.6 feet) above the cameras.

In addition to the solameters described above, an Eppley Model 2 pyranometer was used to measure total incoming radiation for both the May and August experiments. The Eppley has a 180° upward-looking, unfiltered, field of view. It was located on a platform four meters (13.2 feet) away and two meters (6.6 feet) above the cameras (Figure 2).

Four Hasselblad 500 EL 70-mm format cameras were used for both the May and August experiments. Film used for the experiments was from the same lot for each type and was kept under refrigeration until use in order to minimize variability and deterioration. The following film-filter combinations were used: Black and white film (2402) with filter 25 recorded the red radiation; black and white infrared film (2424) with filter 89B recorded the infrared radiation; color infrared film (2443) with filters 15 and 30M recorded red, green and infrared radiation in false color; and color film (2448) without a filter recorded red, blue and green radiation in a standard color image. Spectral sensitivity curves are published by Kodak for each of the film types cited.

An optimum shutter opening or F stop, determined by prior experience, was selected for each film-filter combination (see Table 1). Furthermore, the exposures were bracketed one F stop either side of optimum. Where two F stops are listed for a particular film type in Table 1, the F stop used was the half-stop value between the values cited.

A 35-mm Minolta camera with a fisheye lens was pointed vertically skyward by level bubble indication. It was located 40 meters (1320 feet) south of the Hasselblad cameras at ground level. The shutter was tripped at three minute intervals during the period of data collection to record cloud position for further analysis (Figure 3). Since the sky condition continued to remain clear on August 25, only four photographs are included in Figure 3 for that date.

A Macbeth model TD404 transmission densitometer was used to digitize the film. Data from each target block on the color board (Figure 1) was considered to be an individual observation. The spot size for densitometry measurements on the film was one millimeter. Two one-millimeter spot readings were taken from each target block (one from each of two frames exposed) for each film/filter combination in the experiment.

The filters on the densitometer for color separation are Wratten 93 (green), 94 (blue), 92 (red), and 106 (neutral). The MacBeth densitometer with the red band pass filter was used to measure densities in the red layer of color film (2448). However, the green filter of the densitometer was used to read the red sensitive layer which is printed green on color infrared film (2443) because of the characteristics of color infrared film. The neutral density filter on the densitometer was used to provide red band densities on the black and white (2402) film with the red (25) filter. Thus, correlations between "red light" as recorded by film types 2402, 2448, and 2443 are affected by film sensitivity, filter cutoff, etc. When evaluating correlations and analyses of variance, this must be kept in mind. Table 2 provides a summary of the relationship of film/filter combinations to densitometer filters and to the wave lengths measured.

STATISTICAL ANALYSES

Statistical analyses pursued were designed to evaluate the effect of the following factors on photographic film densities: individual camera, F stop setting, target block, time of day and cloud condition. The design required a pair of days, one clear and one cloudy, during which the remaining factors could be varied. The first attempt in May accomplished acquisition of data for clear conditions but continued clear weather aborted the remainder of the experiment. An August re-run met the total requirements. Analyses were then pursued on camera, F stop, target block and time of day factors in the May data set; camera, F stop, target block and days in the August data set; and clear-day comparisons between May and August data sets.

Analyses of variance for May and August data sets were designed to evalute the effects of the factors. Also for each data set, the correlation of measured film density with solameter data was used to evaluate the potential effectiveness of solameter data in accounting for density variations. May and August data sets were compared via correlation of the clear day data by pairing within matching factor subclasses. Multiple linear regression of cloudy August film densities, incoming solameter and reflected solameter data was used to estimate clear August data. The estimated clear-day data and aetual clear day data were processed via analysis of variance to compare the effect of the regression-equation correction procedure on sources of variation.

MAY EXPERIMENT

HYPOTHESIS

The hypothesis of interest in this experiment was that individual cameras of the same type, selected F stops, different target blocks, and various times of day for photography caused differences in density of photographic film.

MODEL AND ANALYSIS OF VARIANCE

The model for this analysis is:

$$D_{ijklm} = \mu + C_i + S_j + CS_{ij} + T_k + CT_{ik} + ST_{jk} + CST_{ijk} + B_l + CB_{il} + SB_{jl} + CSB_{ijl} + TB_{kl} + CTB_{ikl} + STB_{jkl} + CSTB_{ijkl} + E_{ijkl} + SE_{ijklm}$$

where μ is the overall mean

D is the density of the photographic film,

C_i $i = 1,4$ is the differential effect of the i^{st} camera,

S_j $j = 1,3$ is the differential effect of the j^{st} F stop,

T_k $k = 1,2$ is the differential effect of the k^{st} time of day,

B_l $l = 1,4$ is the differential effect of the l^{st} target block,

E_{ijkl} is the experimental error, and

SE_{ijklm} $m = 1,2$ is the sampling error.

The analysis of variance for the August data was as follows:

Source	Degrees of Freedom (DF)	Expected Mean Square (EMS)
Camera (C)	3	$\sigma^2_e + jkl\sigma^2_c$
F stop (S)	2	$\sigma^2_e + ikl\sigma^2_s$
C x S	6	$\sigma^2_e + kl\sigma^2_{cs}$
Days(T)	1	$\sigma^2_e + ijl\sigma^2_t$
C x T	3	$\sigma^2_e + jl\sigma^2_{ct}$
S x T	2	$\sigma^2_e + il\sigma^2_{st}$
C x S x T	6	$\sigma^2_e + l\sigma^2_{cst}$
Target Block (B)	3	$\sigma^2_e + ijk\sigma^2_b$
C x B	9	$\sigma^2_e + jk\sigma^2_{cb}$
S x B	6	$\sigma^2_e + ik\sigma^2_{sb}$
C x S x B	18	$\sigma^2_e + k\sigma^2_{csb}$
T x B	3	$\sigma^2_e + ij\sigma^2_{tb}$
C x T x B	9	$\sigma^2_e + j\sigma^2_{ctb}$
S x T x B	6	$\sigma^2_e + i\sigma^2_{stb}$
C x S x T x B	18	$\sigma^2_e + \sigma^2_{cstb}$
Experimental Error	0	σ^2_e
Sampling Error	96	σ^2_{se}
Total	191	

All factors are fixed with no estimate available for experimental error. The fourth-order interaction was used to test all factors.

OBSERVATIONS

The observations used for this experiment were single one-millimeter densitometer readings from film exposed over each of the four color panels which were referred to as target blocks (see Figure 1). For every factor combination, two frames were exposed to determine sampling error with one one-millimeter spot reading taken from each frame.

EXPERIMENTAL ERROR

There was no source of experimental error as shown in the model on page 5. Therefore, the fourth-order interaction was assumed to be the best estimate of experimental error and was used to test all effects above it in the model. This method should provide a conservative test as can be seen from the expected mean squares on page 6.

The experimental error was consistent for all analyses except for color infrared film (2443) digitized with the blue density filter which was one or two magnitudes larger than the others.

DATA LIMITATIONS

The May experiment did not provide information relative to the objective concerning the variability of incoming radiation because a cloudy day did not occur before the film exposed on a clear day required development to preclude the possibility of latent images forming. Because of the constant incoming radiation during the clear day data collection, there was no variability in the solameter data measurements to analyze.

The May experiment did provide information as to variability of cameras, F stops, target blocks, and data collected at different times on the same day.

ANALYSES OF VARIANCE

Ten analyses are shown in Tables 3 through 12. There are ten analyses because black and white film (2402) and black and white infrared film (2424) were digitized with one densitometer filter (neutral) for one analysis each and color film (2448) and color infrared film (2443) were digitized with four filters (neutral, red, green, and blue) for four analyses each. Sources of variation analyzed were time, F stop, camera, target blocks and interactions of these factors.

INDEPENDENT EFFECTS

The effect of time was significant at the .01 level of probability for black and white infrared film (2424) digitized with a neutral filter, color film (2448) digitized with a green filter, color film (2448) digitized with a blue filter, color infrared film (2443) digitized with a red filter, and color infrared film (2443) digitized with a green filter. Therefore the effect of time was significant in five of the ten analyses conducted. It appears that the infrared band may be more sensitive to the time of day than the red, blue or green bands.

Cameras presented a significant source of variation for all analyses. This singular result is rather surprising as all cameras had been calibrated prior to this experiment. The result indicates that care should be used when comparing data exposed by different cameras.

F stop settings also caused a significant source of variation for all analyses. Although this variable is seldom reported or used when digital analyses of photography are reported, it is an important source of variation.

Target blocks or color panels showed another significant source of variation for all analyses. This result indicates all films and layers of film were able to differentiate among the various blocks.

INTERACTIONS

Although many interactions caused significant sources of variation, only the time and camera interaction was of interest. This interaction was significant for seven out of the ten analyses. This result indicates that photographic densities are affected by the camera used and the time of day at which data is collected.

RADIOMETER CORRELATIONS

Correlations were not computed between photographic densities as read by the MacBeth densitometer and the radiometer readings because the radiometer readings were invariant, i.e., the radiometer readings produced a straight line on the graph which did not vary beyond the instrument error of the Texas Instruments recorder.

There was a four percent drop in incoming radiation between the morning and afternoon data collection times. Thus, various times of day would show different incoming radiation readings, but radiation readings would not vary appreciably during short-time, mid-day data collection missions.

AUGUST EXPERIMENT

HYPOTHESIS TO BE TESTED

The hypothesis for this experiment was that individual cameras of the same type, selected F stops, different target blocks and a cloudy day versus a clear day caused differences in density of photographic film.

MODEL AND ANALYSIS OF VARIANCE

The model for this analysis is:

$$D_{ijklm} = \mu + C_i + S_j + CS_{ij} + T_k + CT_{ik} + ST_{jk} + CST_{ijk} + B_l + CB_{il} + SB_{jl} + CSB_{ijl} + TB_{kl} + CTB_{ikl} + STB_{jkl} + CSTB_{ijkl} + E_{ijkl} + SE_{ijklm}$$

where μ is the overall mean

D is the density of the photographic film,

C_i i = 1,4 is the differential effect of the i^{st} camera,

S_j j = 1,3 is the differential effect of the j^{st} F stop,

T_k k = 1,2 is the differential effect of the k^{st} day,

B_l l = 1,4 is the differential effect of the l^{st} target block,

E_{ijkl} is the experimental error, and

SE_{ijklm} m = 1,2 is the sampling error.

The analysis of variance for the May data was as follows:

Source	Degrees of Freedom (DF)	Expected Mean Square (EMS)
Camera (C)	3	$\sigma^2_e + jkl\sigma^2_c$
F Stop (S)	2	$\sigma^2_e + ikl\sigma^2_s$
C x S	6	$\sigma^2_e + kl\sigma^2_{cs}$
Time of Day (T)	1	$\sigma^2_e + ijl\sigma^2_t$
C x T	3	$\sigma^2_e + jl\sigma^2_{ct}$
S x T	2	$\sigma^2_e + il\sigma^2_{st}$
C x S x T	6	$\sigma^2_e + l\sigma^2_{cst}$
Target Block (B)	3	$\sigma^2_e + ijk\sigma^2_b$
C x B	9	$\sigma^2_e + jk\sigma^2_{cb}$
S x B	6	$\sigma^2_e + ik\sigma^2_{sb}$
C x S x B	18	$\sigma^2_e + k\sigma^2_{csb}$
T x B	3	$\sigma^2_e + ij\sigma^2_{tb}$
C x T x B	9	$\sigma^2_e + j\sigma^2_{ctb}$
S x T x B	6	$\sigma^2_e + i\sigma^2_{stb}$
C x S x T x B	18	$\sigma^2_e + \sigma^2_{cstb}$
Experimental Error	0	σ^2_e
Sampling Error	96	σ^2_{se}
Total	191	σ^2_{se}

All factors were fixed with no estimate available for experimental error. The fourth-order interaction was used to test all factors.

OBSERVATIONS

The observations for this experiment were obtained in the same manner as those in May, namely that single one-millimeter densitometer readings were taken from photographs of each color panel (Figure 1).

EXPERIMENTAL ERROR

There was no source of experimental error. The fourth-order interaction was assumed to be the best estimate of experimental error.

A problem exists in designing an experiment of this type with no source of experimental error. If data collected at successive times are used for repetition, a real variable due to time lag between data collections may inflate the estimate. Repetition by comparing duplicate frames provides an estimate of sampling error. However, this estimate is much smaller than one would expect an experimental error to be. Repetition by comparing imagery from duplicate experiment sites would provide the best estimate but would be costly to obtain in terms of additional equipment, personnel, time and processing required.

The magnitude of the experimental error (fourth-order interactions) varied according to the film types. The error for black and white film (2402) was .02 which corresponded to the error for the four filters used on color infrared film (2443) which was .02, .01, .03, and .05. The error for black and white infrared film (2424) was .0008 which was smaller than for the four filters used on color film (2448) which was .004, .006, .005, and .004. No reason can be determined for this phenomena.

ANALYSES OF VARIANCE

The analyses of variance are presented in Tables 13 through 22. The tables are arranged by film and densitometer filter. The black and white film (2402) and black and white infrared film (2424) were digitized using the neutral densitometer filter for one analysis each. Color film (2448) and color infrared film (2443), being multilayer films, were digitized with four filters (neutral, red, green and blue) for four analyses each.

ADEQUACY OF DATA

The August data did provide information relative to the objective of measuring the variability of density on film exposed under different radiation conditions. The independent effect of cloudy vs clear days was significant at the .01 level of probability for all analyses. Thus a difference is established between the clear day and the cloudy day data with respect to photographic densities. The correction of the cloudy day film density to a clear day basis is discussed later in this report.

INDEPENDENT EFFECT

Cameras induced a significant source of variation for all analyses. This result indicates that comparisons of photography which is simultaneously exposed by separate cameras of the same type would be invalid when using photographic density as an index.

The various F stop settings also induced a significant source of variation for analyses. This result indicates the importance of using the same F stop while exposing photography which may be used for comparing photographic densities.

Target blocks or color panels presented a significant source of variation for all analyses which indicates that all films and layers of film recorded data with which it was possible to differentiate among the various blocks.

INTERACTIONS

Although many interactions indicate significant sources of variation, the day-by-camera interaction is of special interest. A significant source of variation in all analyses, this interaction indicates that photographic density is affected by which camera is used on which day.

CLOUDY AND CLEAR DAY CORRELATIONS

The product-moment correlations were computed between densitometer densities from color films exposed on the clear day and color films exposed on the cloudy day. The data were matched by the subclasses of the design for the August analysis of variance. Correlation coefficients are presented in Table 23 for the August clear day vs cloudy day. The magnitude of the correlations between days as compared to the correlations between bands within a day is of interest. Apparently clouds contribute to the reduction of within-class correlation. This reduction for color infrared film (2443) is about 25 percent while for color film (2448) it is 10-15 percent.

RADIOMETER-DENSITY SUBSET CORRELATION

A common statistical method of removing a source of variation from an analysis is to compute the sum of squares within each class. The correlations between spot film densities as digitized on the MacBeth densitometer and solameter readings reported in Table 24 were computed on a within days, F stops, cameras and target block subclass. Thus the sum of squares and cross products for these correlations were computed in each subclass and added.

Spot photgraphic densities of the four films as measured on the MacBeth densitometer were correlated with concurrent solameter readings. Black and white film (2402) and black and white infrared film (2424) are negative films; thus photographic density of these films correlates positively with the solameter readings. Conversely, color film (2448) and color infrared film (2443) correlate negatively with the solameter readings.

The green reflectance solameter data did not significantly correlate with any film layer. This may have been due to a malfunction of that solameter although none was noted at time of operation.

The infrared layer of color infrared film (2443) correlated very poorly with infrared incoming and reflected radiation as measured by the solameters. The characteristic Density-Exposure (D-E) curve for color infrared film (2443) shows a limited straight line section, indicating that the latitude of this film spans only one F stop. With the design of this experiment such that F stops are changed one full stop either side of what is considered optimum, one and sometimes two of the exposures representing the F stop variable will fall in the toe or shoulder of the D-E curve, thus introducing a variable that reduces the variance. The above problem may occur with respect to regular color film, but to a lesser degree, because the straight line portion of the D-E curve permits a 2-stop latitude.

COMPARISON OF MAY AND AUGUST EXPERIMENTS

CLEAR DAY CORRELATIONS

Correlation coefficients between photographic densities of the two color films which were exposed in the May and August experiments are presented in Table 25. The factor combinations were paired from each experiment, using data collected at the same relative time of day in May and August.

The color infrared film (2443) generally correlated less than the regular color film (2448). This would indicate that the change of F stop did not maintain an optimum setting for the color infrared film (2443). There was a change of two F stops from May to August. The latitude of color infrared film (2443) is less than one stop either side of optimum which may have influenced the correlations.

Interesting comparisons may be made by comparing correlations within an experiment to those between experiments. For example, the correlation between May total light and May red light is .97 while the correlation between May total light and August red light is .45 for color infrared film (2443).

FISHEYE PHOTOGRAPHY

Photographs were taken with the Fisheye camera every three minutes during the May and August experiments. The fisheye photographs are shown in Figure 3 for August 25 and 30. There are no clouds in the August 25 photographs with the only image being the sun and its reflection. The May photographs are identical to the August 25 photographs and therefore are not shown. Clouds are visible in the August 30 photographs. The position of the clouds relative to the center of the photograph indicates their distance from the target blocks. The picture covers approximately five linear miles. However, the altitude of the clouds may influence the linear coverage. The clouds increased within the photographs for the August 30 data from frames 1 through 14. These data verified the clear and cloudy day designation.

CORRECTION OF AUGUST DATA

GENERATION OF CORRECTION COEFFICIENTS

Multiple linear regression techniques were used to generate correction coefficients. Four equations were computed for the color infrared (2443) film. Each equation consisted of the August clear day photographic densities as the dependent variable and three independent variables (August cloudy day densities, incident radiation, and reflected radiation). One equation each was computed for the total, infrared, red and green wavelengths.

The film densities for the August cloudy day were corrected to the August clear day film densities by the following procedure. First the color infrared film (2443) was selected because its layers were sensitive to the same bands of light as were measured by the solameters. The latitude of color infrared film (2443) is not as great as for color film (2448) and this was considered to be a drawback.

Four regression equations were computed, one for each layer. The dependent variable was film density on the August clear day. There were three independent variables for each equation. These were the corresponding cloudy day film density, the matching solameter band data collected with the solameter pointing up, and the matching solameter band data collected with the solameter pointing down. For example, the cloudy day red densitometer reading (infrared on 2443) and the readings from the 89B filter for incident and reflected solameters were regressed on the red densitometer reading for the clear day.

Four analyses of variance were then recomputed using the original data for the clear day, but using the estimated data for the cloudy day. These four analyses of variance correspond to the three layers of color infrared film (2443) and the neutral filter (Wrattern 106) of the densitometer.

CORRECTION EQUATIONS

The regression coefficients and other pertinent information are presented in Tables 26 through 29. Actual values of the dependent variable, predicted values of the dependent variable, and residuals are presented in the appendix (A.9 through A.12). The equations are:

clear day density total = .105 + .715 (cloudy day density total) + .246 (incoming solameter total) + (-2.005 (reflected solameter total))

clear day density red = .101 + .645 (cloudy day density red) + [-.211 (incoming solameter infrared)) + (-4.888 (reflected solameter infrared))

clear day density green = -1.076 + .993 (cloudy day density green) + .607 (incoming solameter red) + 2.959 (reflected solameter red)

clear day density blue = 1.245 + .720 (cloudy day density blue) + (-.066 (incoming solameter green)) + (-.161 (reflected solameter green)).

Remember, the red, green, and blue densities correspond to infrared, red and green bands of light on color infrared film (2443). The proportion of the clear day density variation explained by the independent variables was given by the R^2 values. These are .57 for the total band of light, .45 for the infrared band of light, .64 for the red band of light, and .57 for the green band of light. This is a relatively high portion to explain considering other significant sources of variation in this data as portrayed by the analyses of variance.

RECOMPUTED ANALYSIS OF VARIANCE

The four analyses of variance for color infrared film (2443) in the August experiment were recomputed using the original data for the clear day, but using the estimated data (for each data point from regression) for the cloudy day. These analyses are presented in Tables 30 through 33.

COMPARISON

The days source of variation was reduced to zero in all analyses.

This result could be expected as the cloudy day mean was made equal to the clear day mean via the regression. The sum of squares for other main effects - F stops, cameras, and target blocks were reduced for neutral, red, and green filter analyses but increased for the blue filter analysis. The opposite occurred for the interactions which were generally increased for the first three analyses but decreased for the blue filter analysis. The sampling error was reduced for all analyses except for the red filter.

USE OF CORRECTION PROCEDURES

The regression coefficients and intercept were utilized in the field experiment. By using incident and reflectance solameters on the flight line in the field similar to the control experiment set, each of the readings from the three layers and total filter were corrected. Although this procedure does little to correct other sources of variation, the clear day to cloudy day variation should be decreased.

CONCLUSIONS

The following conclusions have been reached from the results of the control experiment:

1. A two hour difference in data collection time in May on the same day will affect some film types and multi-layer films but not others. Infrared film (2424) is one type on which photographic density will change due to the time difference.

2. Cameras of the same make and type although previously calibrated can produce a significant source of photographic film density variation.

3. F stop setting induces a significant source of variation in photographic densities and should be reported in all studies.

4. Photographic film densities are affected by the presence of clouds as indicated by the clear versus cloudy day source of variation in this case. However, extrapolation can not be made to all cloudy days as this conclusion is based on the fixed effect of clear versus cloudy conditions with only one cloudy day considered.

5. Using reflectance and incident solameter data (with multiple linear regression techniques,) from 45 to 64 percent of photographic density variation of the analyzed film types may be accounted for in clear to cloudy day differences.

6. Recomputing analyses of variance indicates little effect on other sources of variation with a large effect on clear versus cloudy day photographic densities when using multiple linear regression generated parameters for correction of photographic densities.

PART II

THE FIELD EXPERIMENT

INTRODUCTION

Corn yields in the United States influence the price of corn in the United States and on world markets as well. Transportation and storage facilities, other feed grain prices and animal feeder markets are also affected. Therefore, the capability to accurately estimate corn yields prior to harvest could be of significant economic importance. One possible method of estimating corn yields involves the use of remote sensing photographic information. Before accurate yield estimates can be made from film, however, corrections must be made for incident radiation and other influencing factors.

OBJECTIVES

The objectives of this experiment were to study the influence of atmospheric attenuation and interference on photographic imagery; to establish correction procedures using concomitant radiation measuring instruments; and to use these correction procedures in estimating corn yields in a statistically designed experiment.

HYPOTHESES

One hypothesis was that density of photographic film, exposed for the purpose of determining corn yield, was influenced by variables such as the altitude from which the film was exposed and the various dates on which the missions were flown. A related hypothesis was that recognition of several levels of corn yield could be improved by using radiometer data to correct photographic densities with the equations developed in the control experiment.

GENERAL PROCEDURES

STUDY SITE SELECTION

An eight-kilometer flight line covering approximately 6.4 square kilometers was selected near Volga, South Dakota after studying the soil maps of Brookings County. The flight line was located on the second terrace of the Sioux River valley. This selection assured fairly uniform soils. The soil map of the flight line area is shown in Figure 4 (Appendix A).

It was determined that with the available resources, four corn fields could be observed during each weekly mission. It was further decided that the corn fields to be observed should be equally spaced as nearly as possible along the flight line. A study was made prior to field selection to determine the size and the location of corn fields available for observation. After locating all of the corn fields in the flight line, four were selected by using a numeric random sampling method. Thus, distribution along the flight line was assured.

Within the selected corn fields, twelve randomly located circular plots were laid out. These plots were 22.34 meters in diameter and about 391.77 square meters in area. From previous corn yield surveys in South Dakota, it was determined that the average row width was about 0.95 meters. This means a 22.34-meter diameter circle would include about 23 corn rows.

Within each circular plot, each row was divided into a subsampling unit 2.74 meters long. This length was a compromise between an adequately large unit and one short enough to provide a good fit of units within a 22.34-meter diameter plot. There were 146 possible 2.74-meter-by-one-row subsample units associated with each circular plot. Four subsample units were selected at random from the 146 units on which counts and measurements were made.

AIRCRAFT COVERAGE

A flight by the RSI aircraft was flown on May 11, 1971 to map the area for soil type verification and to determine the cropping pattern for the experiment. Additional aerial photography used for this experiment was flown on the following dates in 1971: July 8, July 16, July 22, July 30, August 5, August 20, August 27, and September 14.

One flight line provided sufficient areal coverage from 1220 meters altitude but two parallel flight lines were required from 610 meters altitude in order to provide the same areal coverage. The two flight lines produced duplicate coverage of some plots from 610 meters altitude. Photographic densities were measured on plots covered by both passes. It was decided that the density readings nearest the edge of the film on duplicate data should be discarded unless clouds or other problems were present.

ESTIMATES OF MEANS, TOTALS, AND VARIANCES

The sample design used to collect the field data was a three stage sample where the fields were the primary sampling unit, plot within field was the secondary sampling unit, and the 2.74-meter length of row subsample unit was the last stage of sampling. The relevant sample means for the sampling units are as follows:

$$\bar{y}_{ij} = \frac{\sum_{u=1}^{k} y_{iju}}{k}, \quad \bar{\bar{y}}_i = \frac{\sum_{j=1}^{m} \sum_{u=1}^{k} y_{iju}}{mk}, \quad \bar{\bar{\bar{y}}} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{u=1}^{k} y_{iju}}{nmk}$$

where y_{iju} is the value obtained for the u^{th} third stage unit in the j^{th} second stage unit drawn from the i^{th} primary unit and where there are n units in the first stage (four fields), m units in the second stage (12 plots), and k units in the third stage (four 2.74-meter-of-row-by-one-row units within plots).

If simple random sampling is used in all three stages, an unbiased estimate of the variance of $\bar{\bar{\bar{y}}}$ from the sample is:

$$v(\bar{\bar{\bar{y}}}) = \frac{(1-f_1)s_1^2}{n} + \frac{f_1 (1-f_2)s_2^2}{nm} + \frac{f_1 f_2 (1-f_3)s_3^2}{nmk}$$

where f_1, f_2, and f_3 are the respective sampling fractions for the three stages of sampling and s_1^2, s_2^2, and s_3^2 are the respective variances for each stage calculated as follows:

$$s_1^2 = \frac{\sum_{i=1}^{n} (\bar{\bar{y}}_i - \bar{\bar{\bar{y}}})^2}{n-1}$$

$$s_2^2 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} (\bar{y}_{ij} - \bar{\bar{y}}_i)^2}{n(m-1)}$$

$$s_3^2 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{u=1}^{k} (y_{iju} - \bar{y}_{ij})^2}{nm(k-1)}$$

MODEL AND ANALYSES OF VARIANCE

The model for this experiment was as follows:

$$D_{ijklm} = \mu + A_i + T_j + A_iT_j + F_k + A_iF_k + T_jF_k + A_iT_jF_k$$
$$+ P_l/F_k + P_l/F_kA_i + P_l/F_kT_j + P_l/F_kA_iT_j + E_{ijklm}$$

where D_{ijklm} is the photographic spot density for each plot,

A_i, i = 1,2 is the differential effect of the i^{th} altitude,
T_j, j = 1,9 is the differential effect of the j^{th} date,
F_k, k = 1,4 is the differential effect of the k^{th} field,
P_l/F_k, l = 1, 12 is the differential effect of the l^{th} plot in the k^{th} field, and
E_{ijklm} is the error variance associated with this experiment.

The Analysis of Variance was as follows:

Source of Variation	Degrees of Freedom (DF)	Expected Mean Square
1. Altitude (A)	1	$\sigma^2_e + T\sigma^2_{AP/F} + TFP\sigma^2_A$
2. Dates (T)	8	$\sigma^2_e + P\sigma^2_{TP/F} + AFP\sigma^2_T$
3. A x T	8	$\sigma^2_e + \sigma^2_{ATP/F} + FP\sigma^2_{AT}$
4. Fields (F)	3	$\sigma^2_e + PT\sigma^2_{P/F} + ATP\sigma^2_F$
5. A x F	3	$\sigma^2_e + T\sigma^2_{AP/F} + TP\sigma^2_{AF}$
6. T x F	24	$\sigma^2_e + P\sigma^2_{TP/F} + AP\sigma^2_{TF}$

(continued)

Source of Variation		Degrees of Freedom (DF)	Expected Mean Square
7.	A x T x F	24	$\sigma^2_e + \sigma^2_{ATP/F} + P\sigma^2_{ATP}$
8.	Plots/Fields (P/F)	44	$\sigma^2_e + PT\sigma^2_{P/F}$
9.	A x P/F	44	$\sigma^2_e + T\sigma^2_{AP/F}$
10.	T x P/F	352	$\sigma^2_e + P\sigma^2_{TP/F}$
11.	A x T x P/F	352	$\sigma^2_e + \sigma^2_{ATP/F}$
12.	Experimental Error	0	σ^2_e
	Total	863	

The expectations as stated above are determined under the assumption that altitudes, dates, and fields are fixed while plots is a random variable. As can be seen from the expectations, no true experimental error exists. Therefore line 11 was used to test lines 8, 9 and 10 as no appropriate error was available. All other tests were appropriate and were as follows:

Line 1 - Altitude (A) - tested by line 9
Line 2 - Date (T) - tested by line 10
Line 3 - A x T - tested by line 11
Line 4 - Fields (F) - tested by line 8
Line 5 - A x F - tested by line 9
Line 6 - T x F - tested by line 10
Line 7 - A x T x F - tested by line 11

DATA COLLECTION PROCEDURES

AERIAL CAMERAS AND FILM-FILTER COMBINATIONS

The cameras used were Hasselblad, model 500 EL. The same film type was used in the same camera for each flight because of the control experiment results indicating camera differences. The cameras were fitted with the following film/filter combinations:

Film	Filter
Ektachrome 2448	HF3, HF4
Ektachrome 2443	Wratten G15, 30M
Black and White Infrared 2424	Wratten 89B
Plus X Aerographic 2402	Wratten 25A, HF3

The HF3 haze filter was used at the 610-meter altitude while the HF4 haze filter was used at 1220-meters altitude to provide comparable reduction of haze effect. The 30 magenta filter is a color correction filter and was used to increase the relative response of the infrared layer.

FILM CONTROL STRIPS

Photographic control strips were processed with the film from each flight. The mean grey level on the control strips gave an indication of photographic differences due to film processing. These data are presented in Table B.26 (Appendix C).

DENSITOMETRY

Spot densities were measured with a Macbeth densitometer for each film type on each plot. The one-millimeter orifice was used on the 1220-meter altitude data and the two-millimeter orifice was used on the 610-meter altitude data. Thus the ground area was sampled equally at both altitudes.

SOLAMETERS

The energy measuring devices (solameters) used in the experiment were calibrated with the filters attached to the solar cell. The calibration curves for each are presented as Table B.25 (Appendix C). The program to compute cal cm^{-2} min^{-1} or the energy received by the cell is presented as Table B.24 (Appendix C). Dates on which good solameter data were taken are July 16, July 22, July 30, August 5 and September 14. Data taken during other flights were judged to be non-reliable mostly due to recording difficulties.

Four solameters were pointed upward for incident radiation and four were pointed downward for reflected radiation. Filters used on these sets were 25A (red), 89B (infrared) 58 (green) and no filter for total radiation.

GROUND COVER PHOTOGRAPHS

Vertical and oblique 35-mm photographs of the test plots were used to estimate ground cover and shadow length. Vertical photographs were exposed in the south unit of each test plot from the top of a ladder. Oblique photos were oriented toward the north at an angle which produced maximum ground cover and minimum sky cover. A blackboard containing pertinent data was placed so as to appear in the lower right hand corner of each oblique photograph. The photographs were taken during the aircraft overflight in order to record current shadow and ground cover data. Each photo was coded as to percent of ground cover. Ground shadows were measured in centimeters and were recorded along with height measurement of representative plants.

Data available from the 35-mm photographs proved to be of minimum value since shadow length did not represent a significant input and only limited coverage could be obtained from the vertical photographs for determination of ground cover. Therefore, no further analyses of these data were completed.

CAMERA WITH FISHEYE LENS

A fisheye camera loaded with 35-mm Panatomic film (ASA 32 Black & White) was used for the purpose of recording the amount and type of cloud cover at the time of each aircraft overflight. The camera was positioned pointing upward and was levelled using the bubble on the tripod. The arrow on the camera was oriented toward the north. The F stop and shutter speed were recorded along with the film roll number and the starting time of the aircraft overflight. Exposures were taken at 3-minute intervals during each overflight.

SOIL MOISTURE DATA

The soil moisture data were taken by two methods. The Troxler Neutron Probe, Model 1257 was used to measure moisture at 15, 30, 60, 90, and 120-cm depths. Gravimetric samples were taken of the homogeneous top layer of soil. The field procedures used were as follows:

GRAVIMETRIC SAMPLING

1. Samples were taken in each of the 48 circular plots.
2. Samples were taken of the homogeneous top layer of soil.
3. Filled soil cans were weighed and the weights were recorded as soon as possible.
4. The filled soil cans were then dried and weighed again.
5. Percent moisture was calculated as

$$\frac{\text{wet weight - dry weight}}{\text{dry weight}} \times 100.$$

SOIL MOISTURE TUBES

1. Two standard counts were taken prior to use.
2. Readings were taken at the following depths as marked on the probe: 15 cm, 30 cm, 60 cm, 90 cm, 120 cm.
3. Two standard counts were taken after use.
4. All information was recorded on neutron probe data sheets.

These data were correlated with film densities as determined by the Macbeth densitometer and other ground truth variables.

PATTERN RECOGNITION PROCEDURES

The spot densities from each of the four film types for the nine dates on which data were collected were classified using the K-class pattern recognition algorithm as implemented at the Remote Sensing Institute. This procedure was reported in SDSU-RSI-73-8 by Serreyn and Nelson. K-class develops the classifying vectors. Percentage of correct classification is then the maximum separation possible with the training set used.

Pattern recognition results for the black and white film densities (2424 and 2402) were not reported because of an error in the classifier for a one-feature, three-class problem. The results due to this error were not wrong per se, however they were not optimum.

Two methods were used in the classification procedure. Classification vectors were derived using equal probability of occurrence for each class and a priori probability of occurrence for each class.

CLASSIFICATION OF CORN FIELDS

For each film type and date of flying, twelve spot densities were measured in each of the four fields (one measurement/plot; 12 plots/field) for each altitude. The K-class program was used to classify these 48 spot densities in order to determine the accuracy with which the four corn fields could be differentiated. The chief interest was in finding whether or not soil and average yield differences were affecting the spot densities.

CLASSIFICATION OF YIELD LEVELS

The K-class program was used to classify the yields of the various plots, disregarding fields, into three levels for each film type, date, and altitude combination. The three ranges were 0-25 bushels/acre, 26-55 bushels/acre, and 56-80 bushels/acre.

RESULTS

ANALYSES OF VARIANCE

Ten analyses of variance are presented in Tables 34 through 43, -- one for each film/filter combination. The factors used in each analysis were altitudes, dates of flights, fields, and plots within fields. The measured variable was density of the photographic film as measured by the Macbeth densitometer.

ALTITUDES

Altitudes were a significant source of variation in all analyses except the neutral densitometer readings for color infrared film (2443). The variation approached zero for this combination. This phenomena may be due to chance. Differences due to altitude are caused by attentuation by aerosols and also due to blending of discrete objects on the ground into a larger resolution element from the higher altitude.

DATES

Dates were a significant source of variation for all analyses. This was an expected result as the crop canopy changed during the growing season. The important aspect was to determine which date best indicates the corn yield potential. That question will be discussed in conjunction with the pattern recognition analyses.

FIELDS

Fields were a significant source of variation in seven analyses. They were not significant for the readings from the neutral and green densitometer filters on the color infrared (2443) film or for the readings from the neutral densitometer filter on the black and white (2402) film. The neutral densitometer filter on black and white film (2402) and the green densitometer filter on color infrared film (2443) permitted reading the red band of light on both film types. These results indicate that the soils of the four fields had about the same red reflectivity. However, the differing amounts of reflectivity in the infrared and green bands indicate real differences in the quality and quantity of corn canopy.

INTERACTIONS

The altitude-by-fields interaction was not significant for the infrared band of light for black and white infrared film (2424) or color infrared film (2443). It also was not significant for the red band of light as measured by the green densitometer filter for color infrared film (2443).

The plots-within-fields-by-dates interaction was not significant for the neutral, red, or blue densitometer filter on color infrared film (2443). Thus the rank order of plots within fields was not changing over the various dates for color infrared film (2443) but was for the other three film types. This result in general indicates that color infrared film (2443) is superior to the other three film types for measuring plant growth and canopy over the growing season.

The altitude-by-dates, dates-by-fields, altitude-by-dates-by-fields, plots-within-fields, and plots-within-fields-by-altitude interactions were significant sources of variation for all analyses. The interpretation of main effects in these analyses must therefore consider the interrelation of these factors.

CORRELATIONS

DUPLICATE DENSITY READINGS

The necessity to fly two parallel flight lines at 610 meters in order to provide complete photo coverage from that altitude resulted in duplicate density readings for some plots. As stated in the procedures, it was decided that the density reading nearest the edge of the film on duplicate data should be discarded unless clouds or other problems were present. No assessment was made of the effect of discarding these data other than correlations between duplicate densities. These correlations were high (>.855) for the color film (2448) and approximately .5 for all other films. Therefore the choice made by the decision rule was more critical for film types other than for color film (2448).

CORN YIELD VS. DATE

The best time to conduct remote sensing flights for the most valid corn yield estimates is of interest. A partial answer may be determined by casual inspection of Table 44. The majority of correlations which were significantly different than zero are clustered around the first week of August. This clustering indicates that no matter which film type was used, the data collection date was critical for estimating corn yield with film density.

CORN YIELD VS. ALTITUDE

There were ten significant correlations among the data collected on July 30th from the 1220-meter altitude, but none among the data collected from the 610-meter altitude. On August 5th, there were nine significant correlations among the 1220-meter data and six among the 610-meter data. These results indicate that the 1220-meter altitude is superior for collecting data from which to make corn yield estimates.

CORN YIELD VS. FILM TYPE

The red band of light as measured by the neutral densitometer filter on red-filtered black and white film (2402) correlated significantly with corn yield on seven of the nine dates. The red band of light as measured on color film (2448) and color infrared film (2443) correlated significantly with corn yield on five and four dates respectively. The infrared band of light had six significant correlations when measured on color infrared film (2443) and four when measured on black and white infrared film (2424). These results indicate the red band of light when measured by black and white film (2402) through a 25A filter and the infrared band of light when measured on color infrared film (2443) produce the best results for estimating corn yield.

PATTERN RECOGNITION

CORN FIELDS

The four fields represented a significant source of variation in seven of the ten analyses of variance. It was therefore of interest to calculate the accuracy with which each photographic density measurement could be classified relative to fields. This was done with the K-class classifier. Four density readings (neutral, red, green, and blue) were measured on both color (2448) and color infrared film (2443). These four features were used in the four-class corn field classification problem. Each field with its twelve plots was identified as a class. Thus, the percentages presented in Table 45 represent the number of the 48 spot densities correctly mapped by the classifier divided by 48 for each date and each film type. The most accurate classification occurred with color infrared film (2443) on July 8, August 20 and 27, and September 14. However, the classification results were generally high for all dates, which indicates that spot densities from either type of film could be used to separate these four fields. This analysis was a between-field analysis using the multivariate approach.

CORN YIELDS

The correct recognition of corn yield levels was tested in this analysis. Data from the 48 plots were stratified into three yield levels. There were 14 plots in the range 0-25 bushels/acre, 20 plots in the range 26-55 bushels/acre, and 14 plots in the range 56-80 bushels/acre. The classifier then classified the photographic spot densities from each film type by date of flight and altitude. The number of correct classifications for each yield level are given in Tables 46 and 47.

Over all dates and altitudes, the total number of correct classifications differed only slightly for a priori and equal probabilities between color infrared film (2443) and color film (2448). Color film (2448) had the most correct classifications in both cases. These results agree with the number of significant correlations between yield and the various layers of these film types. In this analysis, the use of color infrared film (2443) or the addition of infrared light did not increase the accuracy of correct classification.

The average maximum accuracy of correct classification for each flight, altitude, and film type combination was between 60% and 80%. However, date of flight did not materially affect the classifier accuracy. It would be indicated from the correlations previously presented that data collected during the first weeks in August should be optimum for a high percentage of correct classification.

DATA CORRECTION

CORRECTION EQUATIONS

The correction of aerial photographic data to a clear day basis by concomitant radiometric measurements was tested on 1220-meter and 610-meter altitude data for July 22, 1971. The data were corrected via the following four equations generated in the control experiment:

$$\hat{y}_N = .01528 + .71513X_1 + .24630X_5 - 2.00507X_9$$

$$\hat{y}_{IR} = .10136 + .64450X_2 - .21116X_8 - 4.88840X_{12}$$

$$\hat{y}_R = -1.07604 + .99312X_3 + .60749X_7 + 2.95924X_{11}$$

$$\hat{y}_G = -1.24516 + 1.13211X_4 + 1.05821X_6 + 2.10773X_{10}$$

where

$\hat{y}_N$ is the neutral spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer corrected to a clear day,

$\hat{y}_{IR}$ is the infrared sensitive layer spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer corrected to a clear day,

$\hat{y}_R$ is the red sensitive layer spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer corrected to a clear day,

$\hat{y}_G$ is the green sensitive layer spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer corrected to a clear day,

X_1 is the neutral spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer,

X_2 is the infrared sensitive layer spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer,

X_3 is the red sensitive layer spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer,

X_4 is the green sensitive layer spot density of a plot on color infrared film (2443) measured by the Macbeth densitometer,

X_5 is the total incident solameter reading in calories/cm^2/min,

X_6 is the green incident solameter reading in calories/cm^2/min,

X_7 is the red incident solameter reading in calories/cm^2/min,

X_8 is the infrared incident solameter reading in calories/cm^2/min,

X_9 is the total reflectance solameter reading in calories/cm^2/min,

X_{10} is the green reflectance solameter reading in calories/cm^2/min,

X_{11} is the red reflectance solameter reading in calories/cm^2/min, and

X_{12} is the infrared reflectance solameter reading in calories/cm^2/min.

The spot density readings for each layer and the total density readings for color infrared film (2443) were corrected according to the above equations generated in the control experiment. The residuals of this procedure are given in Table 48.

SOLAMETER DATA

The solameter data are presented by mission mean in calories/centimeter^2/minute in Table 49. The solameter data may be visually compared mission by mission to the fisheye pictures (Figures 5-13). Comparing July 16 and

July 22, the clouds on July 22 produced a smaller mean and the mean for July 30 is even smaller. The mean, however, does not tell the entire story. The variation of data from the solar recording instrument is an indication that clouds are present. It does not indicate the presence of haze. The solameter readings are presented in Appendix C as tables B.19-B.23.

PATTERN RECOGNITION OF ADJUSTED DATA

The K-class classifier was used on the adjusted data for both altitudes combined and was compared to the original classification. Using a priori probabilities, the results for the uncorrected data were:

CLASSIFIED AS

	Yield	Low	Medium	High	Correct
ACTUAL	Low	15	9	4	15/28
	Medium	9	27	4	27/40
	High	4	13	11	11/28
					53/96

The results for the corrected data were:

CLASSIFIED AS

	Yield	Low	Medium	High	Correct
ACTUAL	Low	24	4	0	24/28
	Medium	0	27	13	27/40
	High	4	9	15	15/28
					65/96

As can be seen from the above, 53 of 96 densities were correctly classified for the uncorrected data and 65 of 96 densities were correctly classified for the corrected data. This is an increase of 14% accuracy in classification for the corrected data.

Using equal probabilities of class occurrence, the results for the uncorrected data were:

CLASSIFIED AS

	Yield	Low	Medium	High	Correct
ACTUAL	Low	18	4	6	18/28
	Medium	15	14	11	14/40
	High	4	4	20	20/28
					52/96

The results for the corrected data were:

CLASSIFIED AS

	Yield	Low	Medium	High	Correct
ACTUAL	Low	24	2	2	24/28
	Medium	3	20	17	20/40
	High	8	3	17	17/28
					61/96

There were 52 of 96 densities correctly classified for the uncorrected data and 61 of 96 correct classifications for the corrected data. This is an increase from 54% to 64% or 10% by using the corrected data.

The results indicate that concomitant radiation measurements are useful for increasing the accuracy of corn yield estimates.

CONTROL STRIPS

The control strips used in processing were standard Kodak supply. The black and white strips have ten wedge steps and the color strips have four wedge steps. The averages of the control strips are presented in Appendix C as Figure B.26.

New chemicals were precisely measured and mixed for each processing operation. It was therefore assumed by photographic personnel that the differences in image density due to processing would be minimal as indicated in the following paragraph.

All graphs were basically linear in the region of interest, i.e. the range of densities of the plots on the four film types was in the linear portion of the curve. However, the means were slightly affected by processing differences. For example, step 3 of the red filter reading on the color film (2448) control strip had a range of .25 density units about the average of all 2448 film for step three. Therefore numerical comparisons of these two extreme films would have a .25 density difference for the same plot due to processing. The standard deviation for all type 2448 film at step three using the red filter reading was .12. The results indicate that a sensitometric strip on each film would be useful for the correction of numerical data due to processing differences.

PICTURES FROM THE FISHEYE CAMERA

Pictures from the fisheye camera for each of the flights are presented in Figures 5 through 13. July 8 was a very cloudy day as can be seen from the print (Fig. 5). The clouds increase from moderate clouds in frame 5 to heavy clouds in frame 18. This increase was due to cumulus build up. July 16, August 5, August 11, and August 27 were cloud free days with differences only in haze. September 14 (Fig. 13) was a clear day up to the last three frames. The decrease in available sunlight may be noted here as the frames are darker. July 22 (Fig. 7) had high scattered cirrus with little overall decrease in solar light.

July 30 (Fig. 8) and August 20 (Fig. 11) are examples of days when taking quantitative radiometric data was very difficult. The clouds on these days increased in quantity as shown on the photographs from the beginning frames to the ending frames. The types of clouds for those two dates were different and the altitudes of occurrence were different. The July 30 (Fig. 8) clouds were reported to be at 1200 meters above ground level while the August 20 (Fig. 11) clouds were reported to be at 6100 meters. The July 30 clouds were fluffy cumulus and the August 20 clouds were strato cumulus. The July 30 clouds cast definite shadows with increased reflectance from the edges of the clouds.

FIELD AND PLANT DATA

The yield and plant characteristic data collected as ground truth is summarized in Appendix C as Tables B.27 through B.44. Given is the estimated yield for each plot in each field. These estimates are based on samples of harvested corn from the plot for all plots except some in field four. These plots were cut for silage and the information was lost. Estimates for these plots are based on the number of ears in August with evidence of kernel formation.

There were definite yield differences between fields. Field one was low (6.9 bu./acre) while field two (66.4 bu./acre) was the highest. Fields four (54.0 bu./acre) and three (36.6 bu./acre) had medium yields.

The rows were closer in fields one and three (3.18 ft) compared to field two and four (3.28 ft). Field one averaged about 2000 less plants per acre than the other three fields.

REGRESSION OF PLANT INDICATORS ON YIELD

Multiple regression equations were computed using yield indicators regressed on the actual yield. The yield indicators were:

1. Number of plants
2. Height
3. Width of leaves
4. Number of leaves
5. Plants x height x width x leaves x 10^{-6}
6. Plants x leaves x 10^{-6}
7. Leaves/plant
8. Plants x height x 10^{-3}
9. (Leaves x width/144)/23^2 x π
10. Plants x leaves x width x 10^{-6}

Equations were computed with no more than five independent variables at a time for all combinations of the above variables. The multiple correlation coefficient squared (R^2) was calculated for each equation. This value was about .56 for all equations containing five variables regardless of which they were. Thus one half of the variation in yield was accounted for by equations of a combination of five of the above variables. The R^2 value was less (.2 → .3) for equations with four or less variables regardless of which they were.

CORRELATIONS BETWEEN FILM DENSITIES AND GROUND TRUTH

Correlations between film density data for August 20 and the following variables were computed:

1. Soil moisture - gravimetric
2. Number of leaves
3. (Leaves x width/144)/23^2 x π
4. Plants x leaves x width x 10^{-6}

These correlations are presented in Tables 50 and 51. The soil moisture correlations were not significant for any of the film types. The other three variables were correlated (∿.6) at 1220 meters altitude for black and white film (2402) but not at 610 meters for black and white film (2402) or at either altitude for black and white infrared film (2424).

The three plant variables were correlated (about .4 → .7) at 1220 meters altitude for all layers of color film (2448) and color infrared film (2443). However, none were significant for color film (2448) at 610 meters yet all were significant for the infrared and red layers of color infrared film (2443) at 610 meters.

These results indicate that data collected from the higher altitude (1220 meters) would be preferable for deriving estimates of these plant characteristics. Likewise, color infrared film (2443) would be selected as the best indicator of plant parameters. The fact that moisture was not correlated with film density may be due to the general lack of moisture on this date.

CONCLUSIONS

The following conclusions may be drawn from the field experiment.

1. Altitude affected the density of the film in this experiment and comparisons of densities on film exposed at different altitudes would not be valid.

2. Data collected on various dates were significantly different with respect to film density as a result of different radiant conditions and changes in the ground scene.

3. The four corn fields had different plant and yield characteristics and affected film density accordingly.

4. There were many interaction sources which were significant, indicating that problems exist in correcting the data for main effects.

5. The correlations between film density and corn yield indicate that the first week of August is the best time to estimate corn yield with film density.

6. The K-class classifier may be used to differentiate between corn fields with an accuracy of about 80% correct classification.

7. By using the K-class classifier it was possible to classify field plots into three yield levels with an accuracy between 60 percent and 80 percent. The date of flight did not affect accuracy of the classifier to any large extent.

8. The adjustment of data via the equations derived in the control experiment increased the capability of the K-class classifer to correctly identify the yield levels of the field plots.

9. Fisheye pictures of the cloud cover are a cheap and efficient method of qualitatively accounting for film density changes due to incoming radiation and recording the type of day on which data were taken.

10. Soil moisture did not correlate with film density in this experiment. Plant canopy characteristics did correlate between .4 and .7 with the higher altitude film density data of both color films.

PART III

PATTERN RECOGNITION EXPERIMENT

INTRODUCTION

In the process of obtaining aerial photographic imagery of the corn fields in the field experiment (Part II), imagery of the other crops along the flight line was obtained as well. An interest was expressed in using this additional information to conduct a pattern recognition experiment in which the K-Class classifier was used for crop type discrimination. Since the imagery and ground truth were already available for this type of experiment, the only additional data collection necessary was the densitometry.

OBJECTIVE

The objective of this experiment was to investigate the application of certain pattern recognition procedures to crop identification.

HYPOTHESIS

The hypothesis of interest in this experiment was that matrices of film density values -- each from a light sensitive layer of multilayer film -- could be used to identify several crop types. This hypothesis was quantitatively tested by determining the percentage of correct identification for each crop type and for over all crops.

PROCEDURES

DATA COLLECTION

Spot densitometer readings from the imagery collected for the field experiment were taken with the Macbeth densitometer. Color infrared film (2443) and color film (2448) were chosen for this experiment because of their multilayer, multifeature nature. Photography for the following dates was selected for analysis: July 8 and 16, August 11 and 27, and September 14.

DATA SELECTION

Each quarter section (160 acres) was subdivided into four 40-acre areas. Each 40-acre area was called a Primary Sampling Unit (PSU) for convenience. All PSU's were sampled with each PSU having nine systematic sample points.

For each altitude, five random templates were selected out of a possible 25. These templates were furnished by the Bladical Reporting Service, U.S. Department of Agriculture. Each template had a 90 degree reference angle. This angle was matched up on the appropriate PSU corner of the transparencies.

The sample points on the template were in rows and columns. Relative to the reference angle, the rows were rotated by 22 degrees. This procedure gave grid coordinates for each sample point which were unique at that altitude. Four densitometer readings were taken at each grid point -- total, red, green, blue. These readings corresponded to the bands of light recorded by the color film (2448) and had total, infrared, red and green band of light correspondence for the color infrared film (2443).

K-CLASS

The K-class classifier, as reported in the Remote Sensing Institute's publication SDSU-RSI-73-08, was used to fulfill the objectives of the pattern recognition experiment. This supervised classifier requires training data as input. The output of the classifier is the maximum class separation (maximum percent correct classification) possible for the given data. The information from the training step may then be used to extend the classification to data other than that used for training. However, in this experiment, all of the data were used to train the classifier. Therefore, it was not possible to test the utility of the classifer on data not included in the training set.

MODEL

The model used in this experiment was:

[L, M, H] = [T, R, G, B] d;

where L is the low yield class,

M is the medium yield class,

H is the high yield class,

T is the total density reading,

R is the reading density reading,

G is the green density reading and

B is the blue density reading.

The actual decision variable is defined as d_i where:

$$d_i = p_i[\overline{X}^i - \overline{X}]^T \phi^{-1} [x-\overline{x}] + p_i$$

The classification process is to pick class i if

$$d_i > d_j, \text{ for all } j \neq i.$$

The symbols used for defining d_i are explained as follows:

p_i = a priori probability of class i

$\overline{X}^i$ = mean feature vector for class i

$\overline{x}$ = mean feature vector for all classes

ϕ = covariance matrix for all features and classes

$(\phi = \overline{XX^T} - \overline{X}\overline{X}^T)$

ϕ^{-1} = inverse of covariance matrix

$\{ \}^T$ = denotes transpose

X = attribute or feature vector of event being classified.

Numerical examples, further definitions, and calculation procedures are given in the SDSU-RSI-73-08 report.

RESULTS

A PRIORI VS. EQUAL PROBABILITY

The results of the K-class analyses are presented as tables 52 through 75. The organization of these tables is such that classification results using a priori information are on the top of the line while results using equal sample occurrence are on the bottom. The overall correct percentage for each analysis is given at the bottom of each table.

The use of a priori information for statistical and judgement decision is not new. Accuracy of decisions is generally increased using a priori information. Inspection of Tables 52 through 71 reveals that a priori information drastically increases the percent correct classification of the larger classes. For example, in the first row of Table 52, 77 percent of the 143 sample points were correctly identified with a priori information compared to 16 percent with equal probabilities. However, further inspection reveals that the two large classes, corn and oats, overrode the smaller classes where correct recognition was zero for the a priori case. The equal probability analysis had some correct recognition for six of the eight classes in Table 52. Inspection of all the tables reveals that the correct percentage using a priori information is about two times as large as the correct percentage for equal probability in every case. This result was due to the larger classes being classified correctly. Therefore, if the number of points per class varies greatly and the goal of the analysis is to correctly identify sample points in the large classes, then a priori information should be used.

EXAMPLE COMPARISON

Using the results of Tables 52 through 71 for the a priori corn classification, comparisons were made for dates, film types, and altitudes. The results for the data collected in July and early August appeared to be somewhat better than the results for the data collected in late August and September. However, there did not appear to be a significant difference for film type or altitude.

SUMMATION ACROSS DATES

The data from Tables 52-71 for five crops were averaged across the five dates. These data are presented in Tables 72 through 75. Corn and oats were classes with large numbers. Therefore, these classes were identified correctly a large percentage of the time when a priori probabilities were used. When equal probabilities were used, the misclassification of corn was spread across the other crops. It was mistaken for beans the largest number of times when it was misclassified.

Soybeans and alfalfa were classified as corn using a priori information but were more correctly identified using equal probabilities. Barley was misclassified as oats using a priori probabilities and was correctly identified using equal probabilities.

CONCLUSIONS

The following conclusions were drawn from this experiment:

1. The K-class classifier can be used to identify crops using multilayer film densities with an accuracy between 60 and 80%
2. A priori information increases overall classification accuracy of the larger classes.
3. Data collected in July and early August appears to be better than data collected in late August or September for correct classification of corn.

APPENDIX A

Figures

LIST OF FIGURES

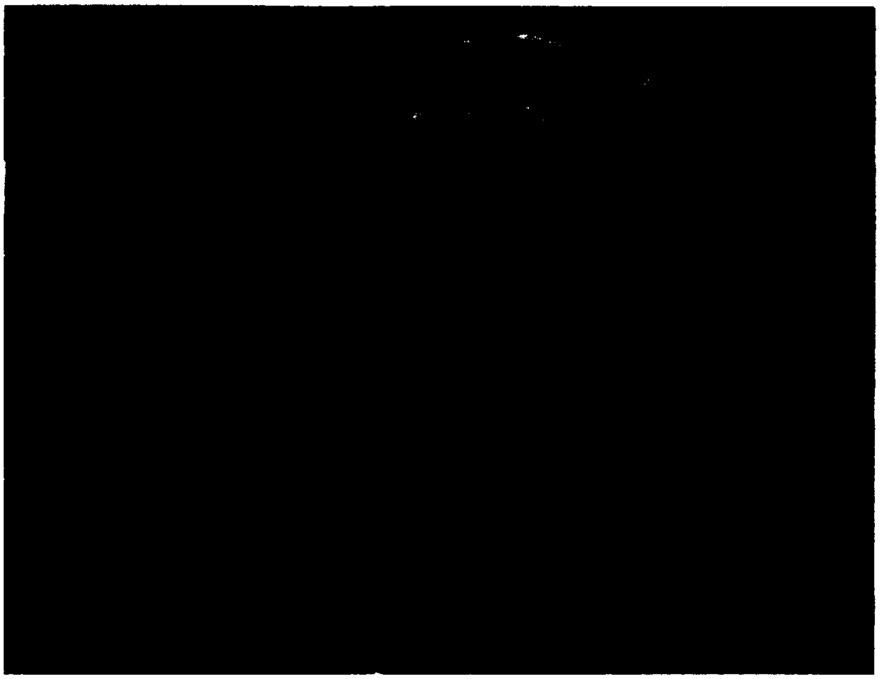


Figure 1. Target Board used for Control Experiment.

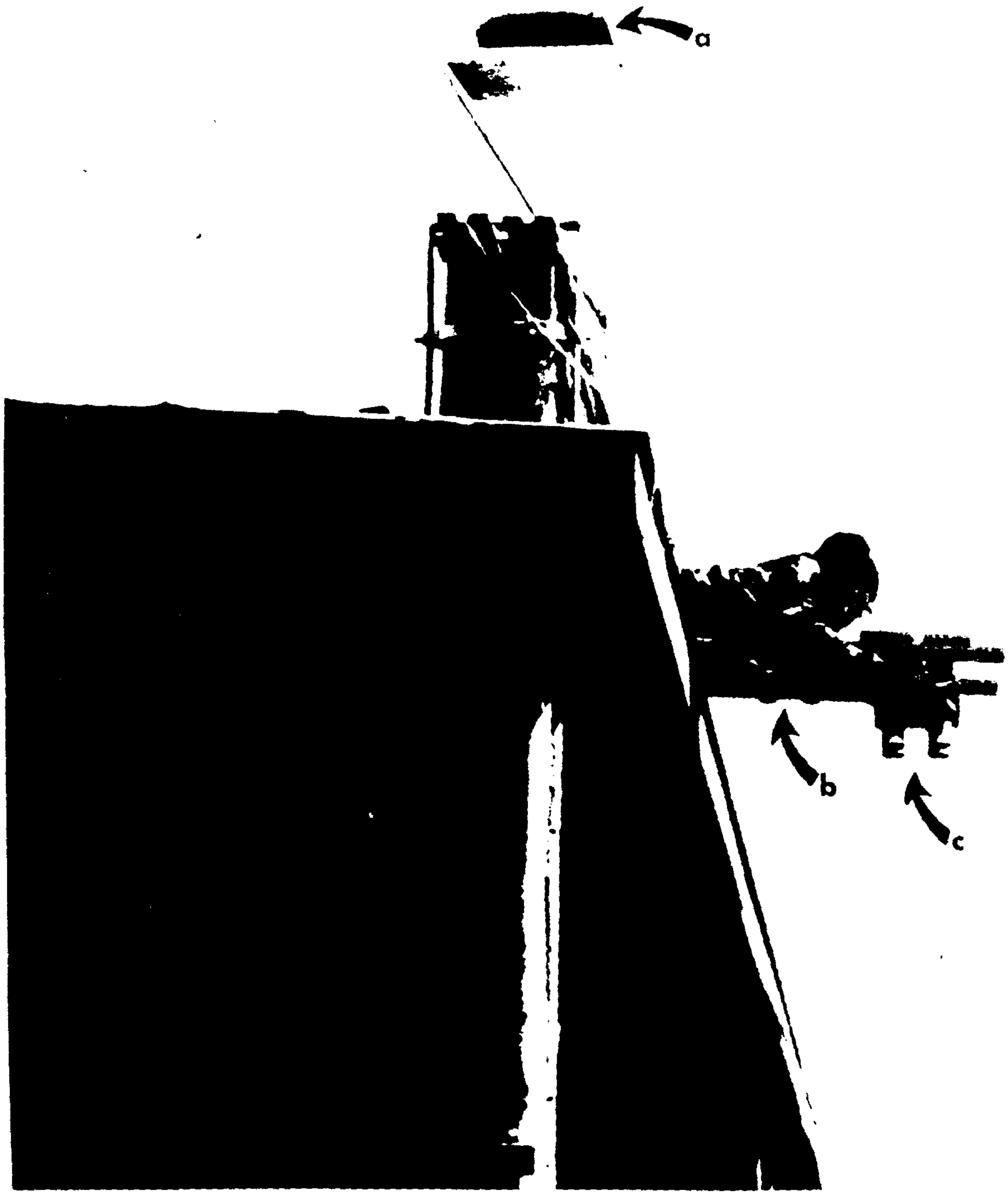


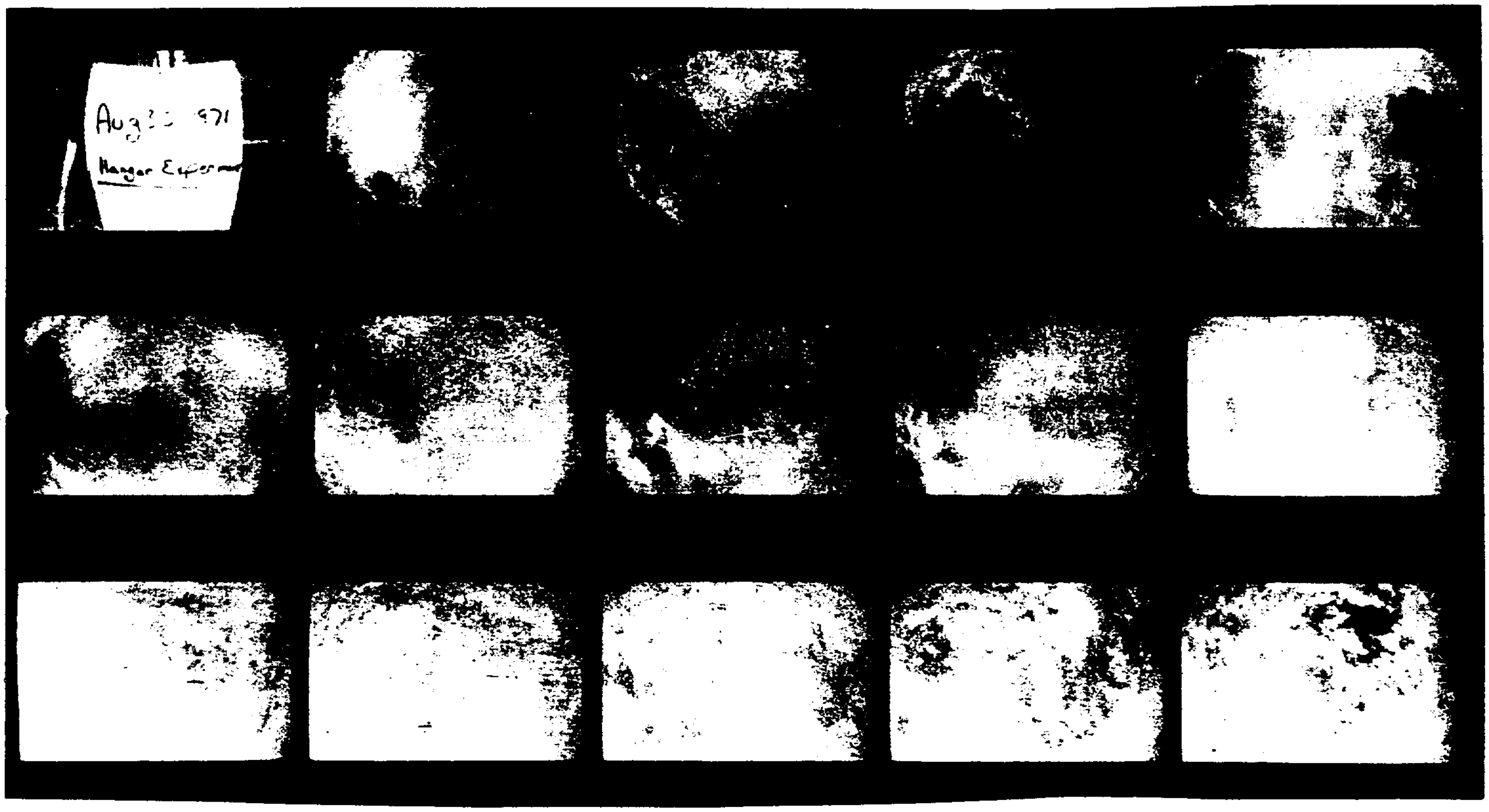
Figure 2. Equipment Arrangement for Control Experiment.

a. Eppley Model 2 Pyranometer

b. Solameters

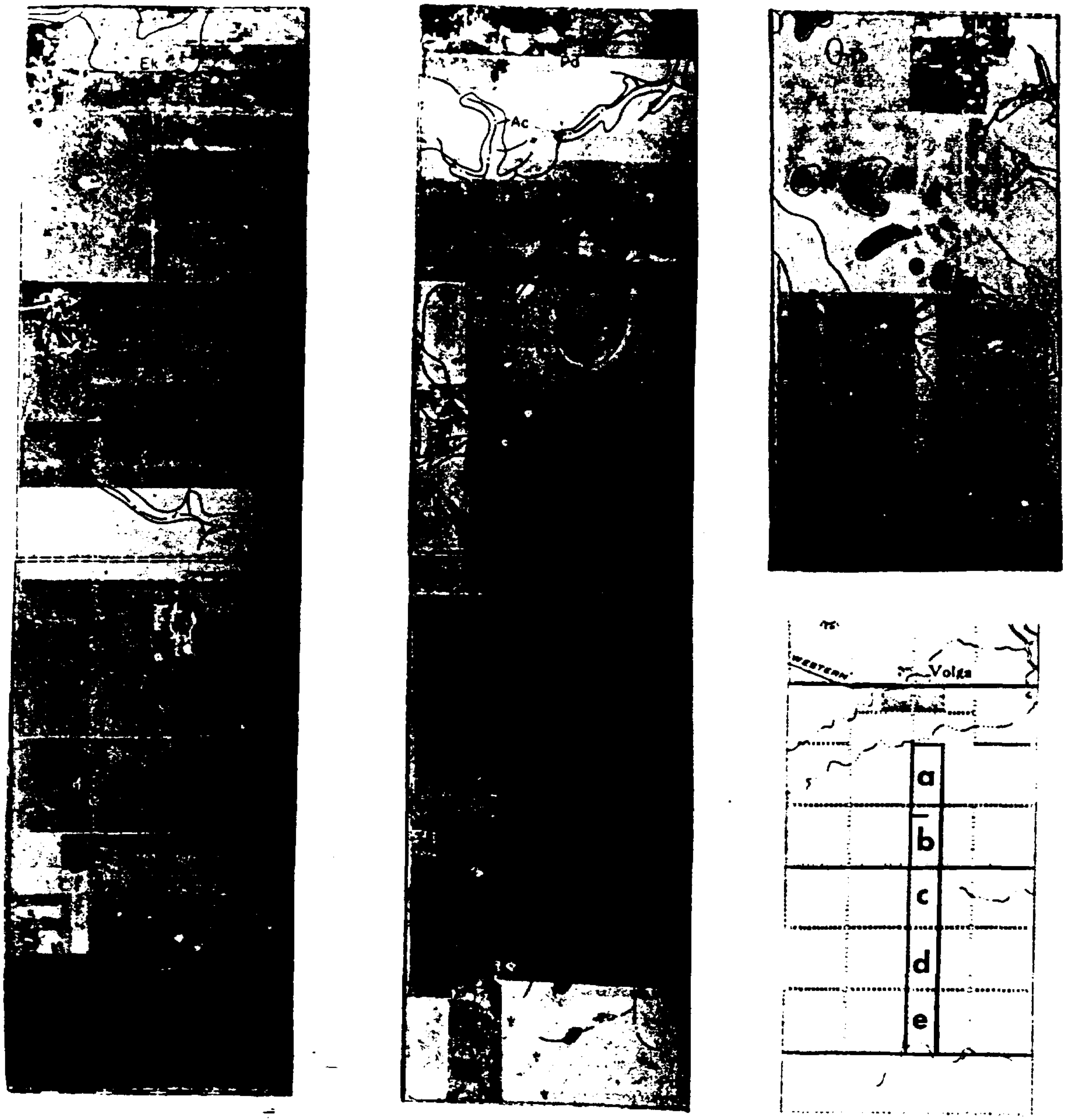
c. Hasselblad Cameras

AUGUST 25th



AUGUST 30th

Figure 3. Photographs of Cloud Conditions from Fisheye Camera.



Major Soils

Ee--Estelline silt loam, nearly level
Pd--Poinsett silt loam, gently undulating
Pc--Poinsett silt loam, nearly level
Pe--Poinsett silt loam, undulating

Drainageway Soils

Ac--Athelwood silty clay loam, nearly level
Wb--Waubay silty clay loam, drainageways

Figure 4 - Soil Map of the Volga Flight Line. Locations a through e are west halves of sections 26, 35, 2, 11 and 14, respectively. Scale: 1:20,000. (From Soil Survey, Brookings County, South Dakota, USDA-SCS, 1959)

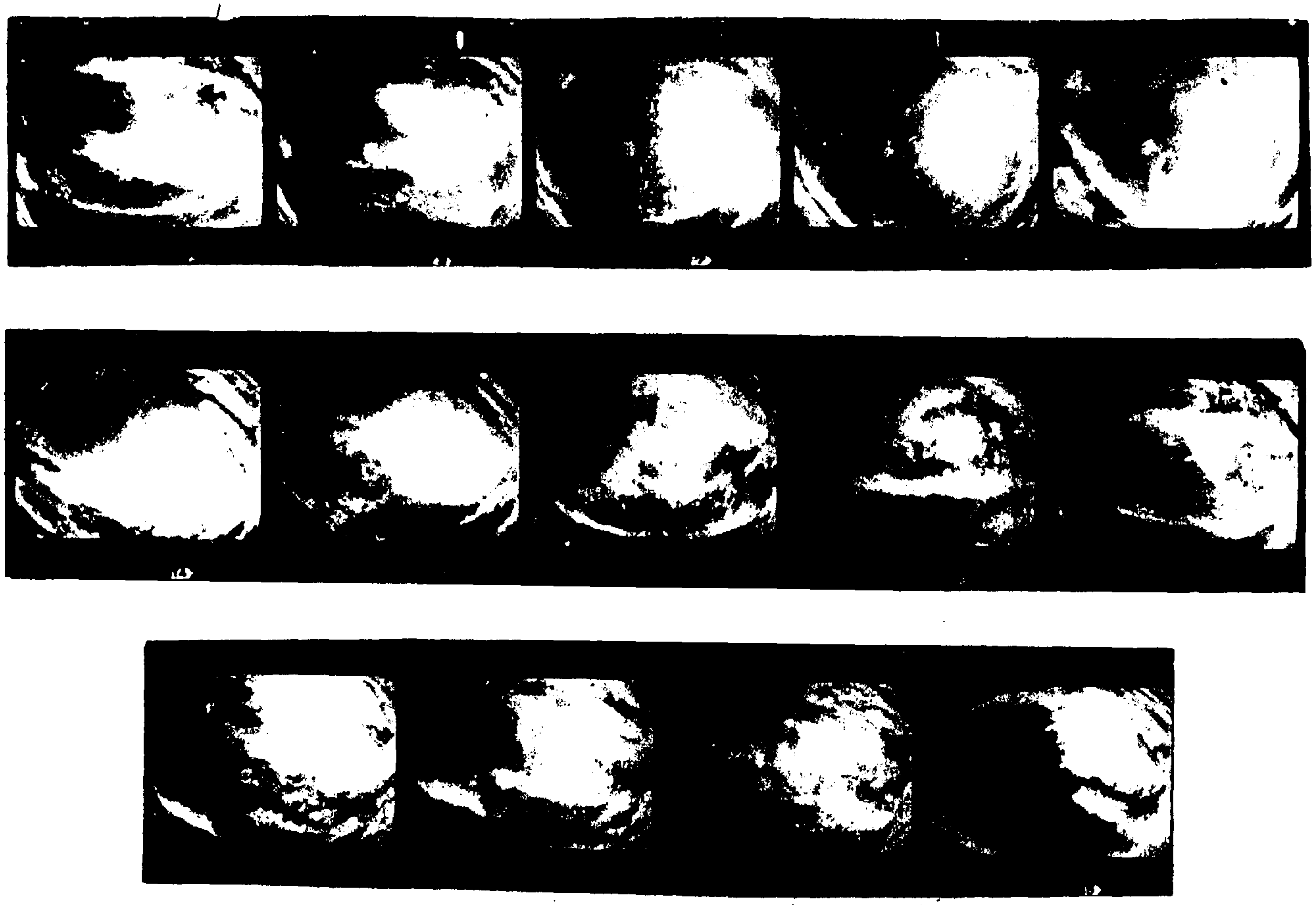


Figure 5 - Fisheye pictures of clouds for the July 8, 1971 flight.
Note: Frame (time) sequence is from right to left.

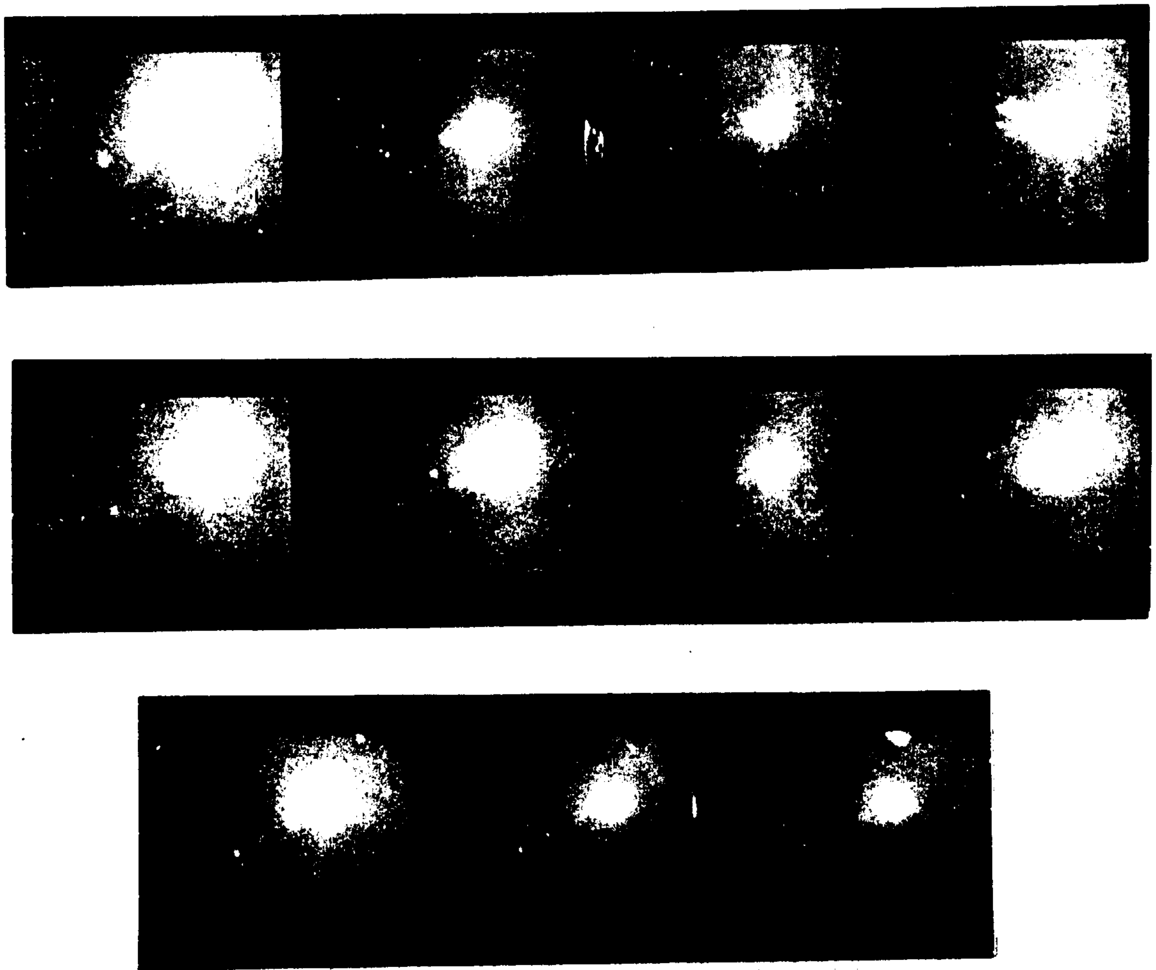


Figure 6 - Fisheye pictures of clouds for the July 16, 1971 flight.
Note: Frame (time) sequence is from right to left.

Figure 7 - Fisheye pictures of clouds for the July 22, 1971 flight.
Note: Frame (time) sequence is from right to left.

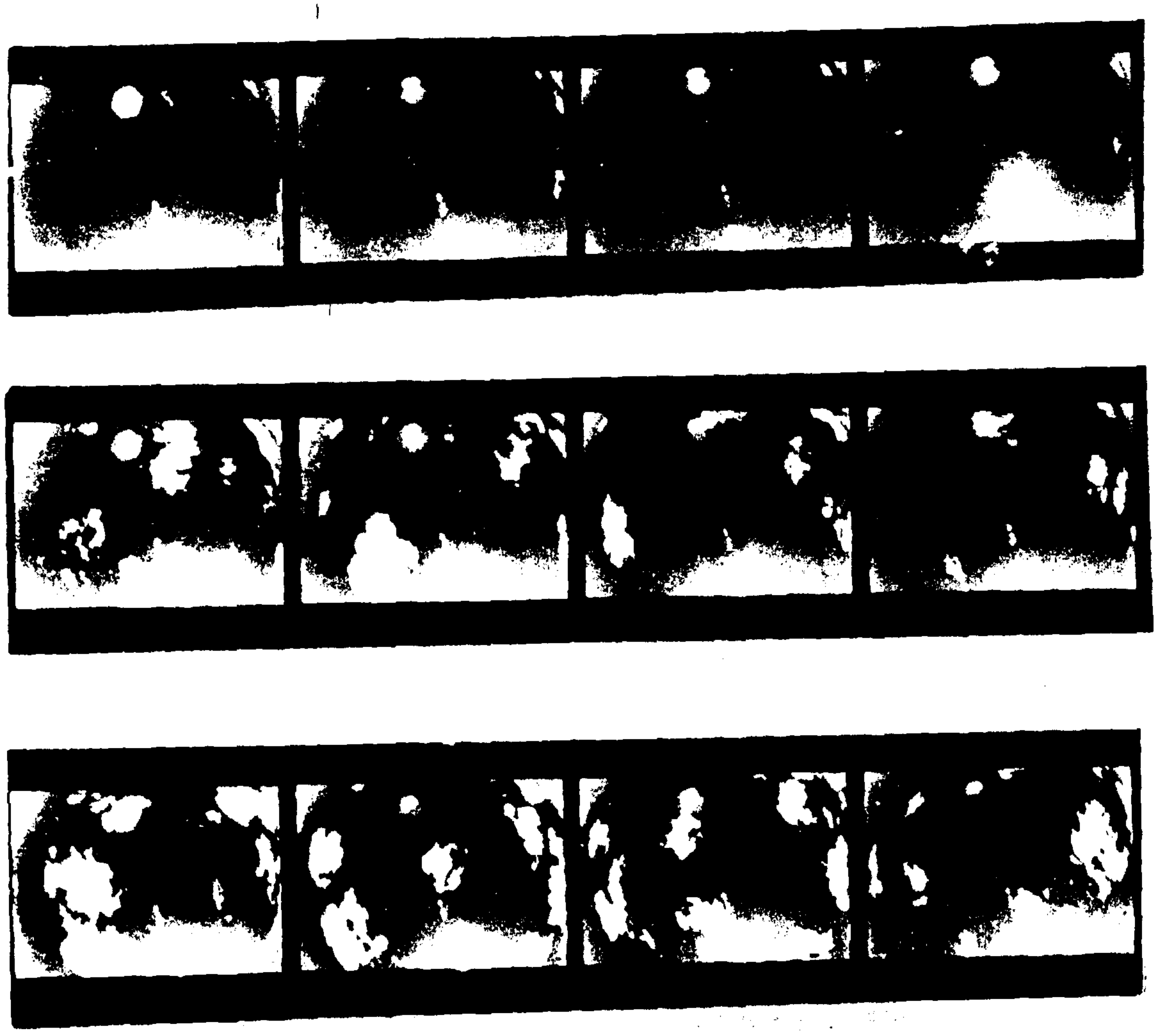


Figure 8 - Fisheye pictures of clouds for the July 30, 1971 flight.
Note: Frame (time) sequence is from right to left.

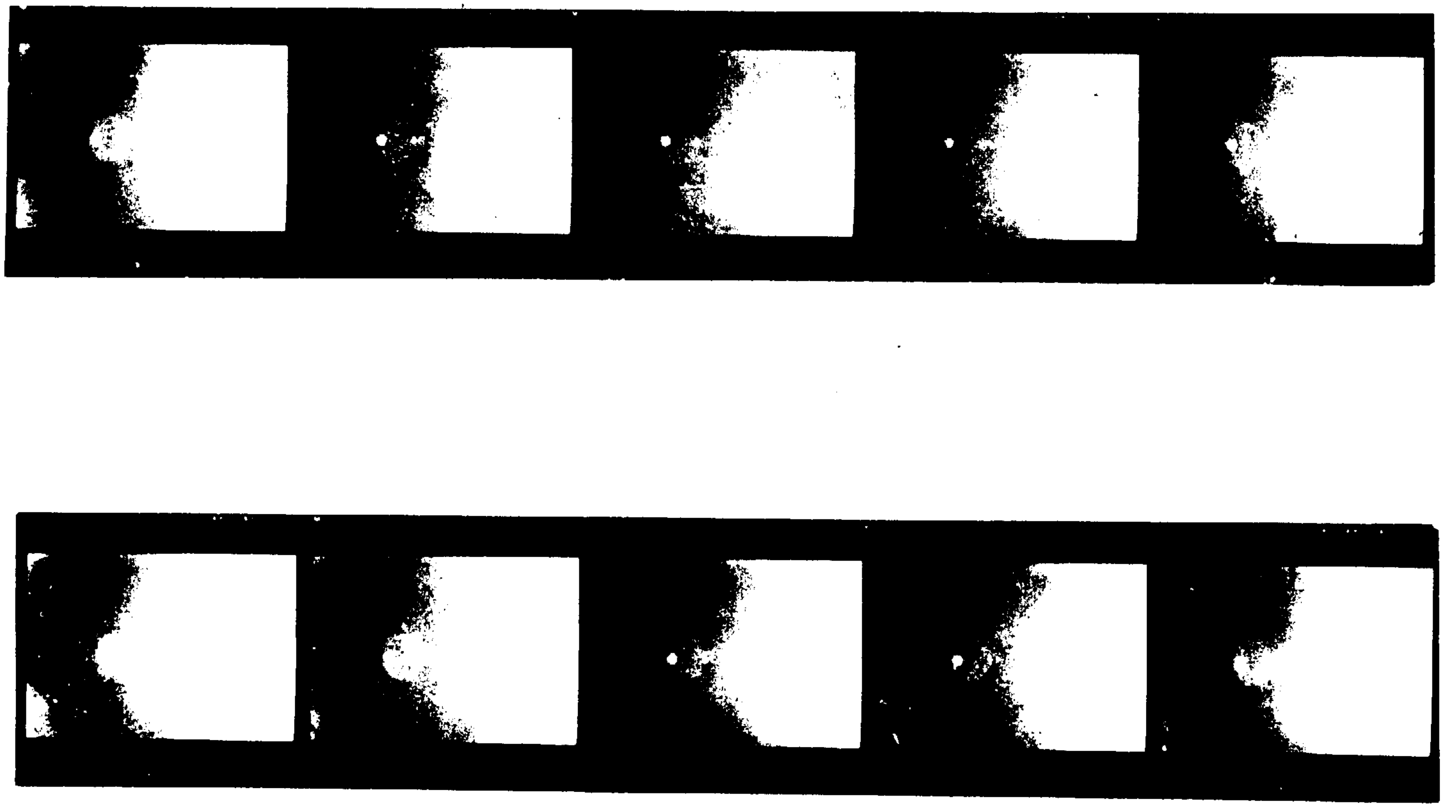


Figure 9 - Fisheye pictures of clouds for the August 5, 1971 flight.
Note: Frame (time) sequence is from right to left.

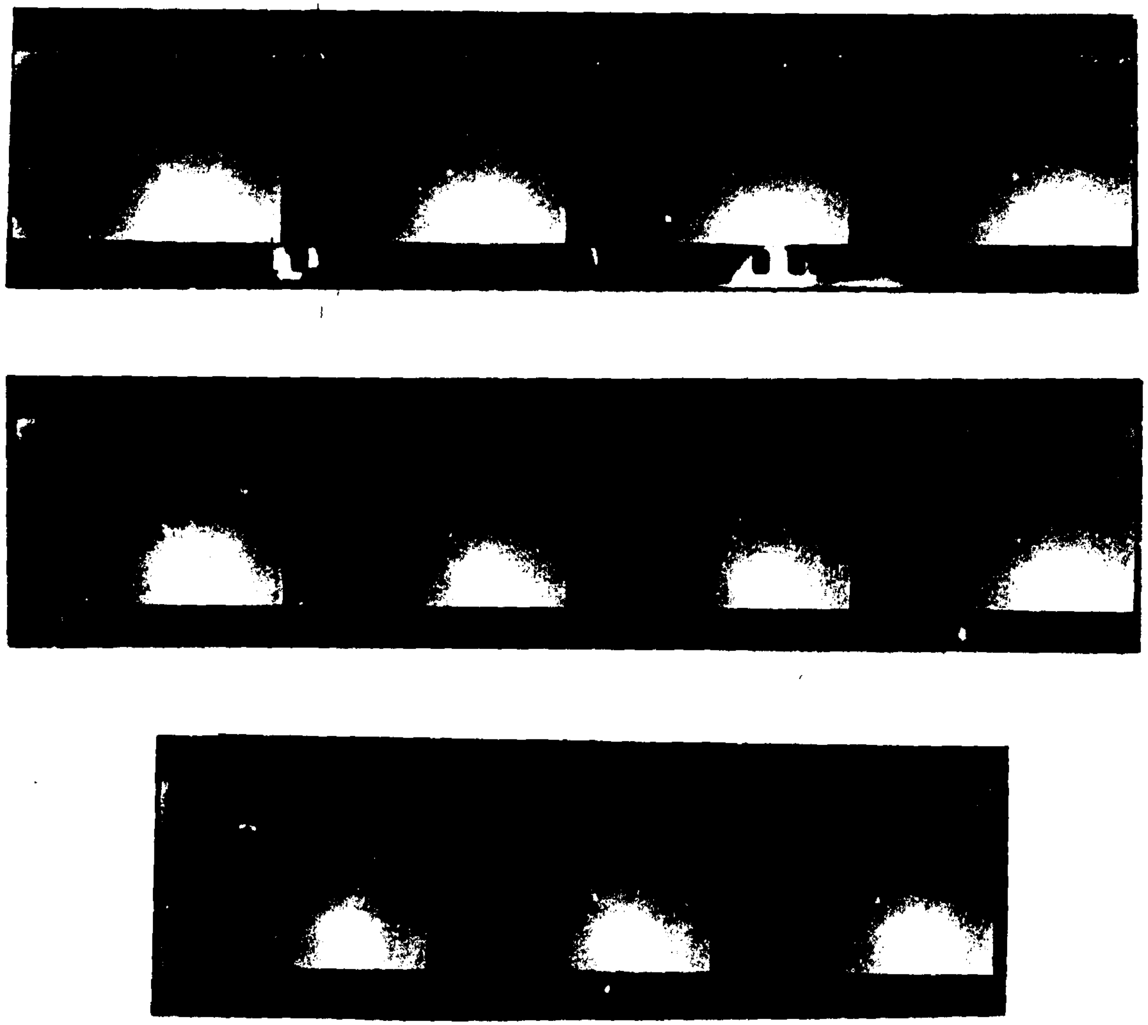


Figure 10 - Fisheye pictures of clouds for the August 11, 1971 flight.
Note: Frame (time) sequence is from right to left.

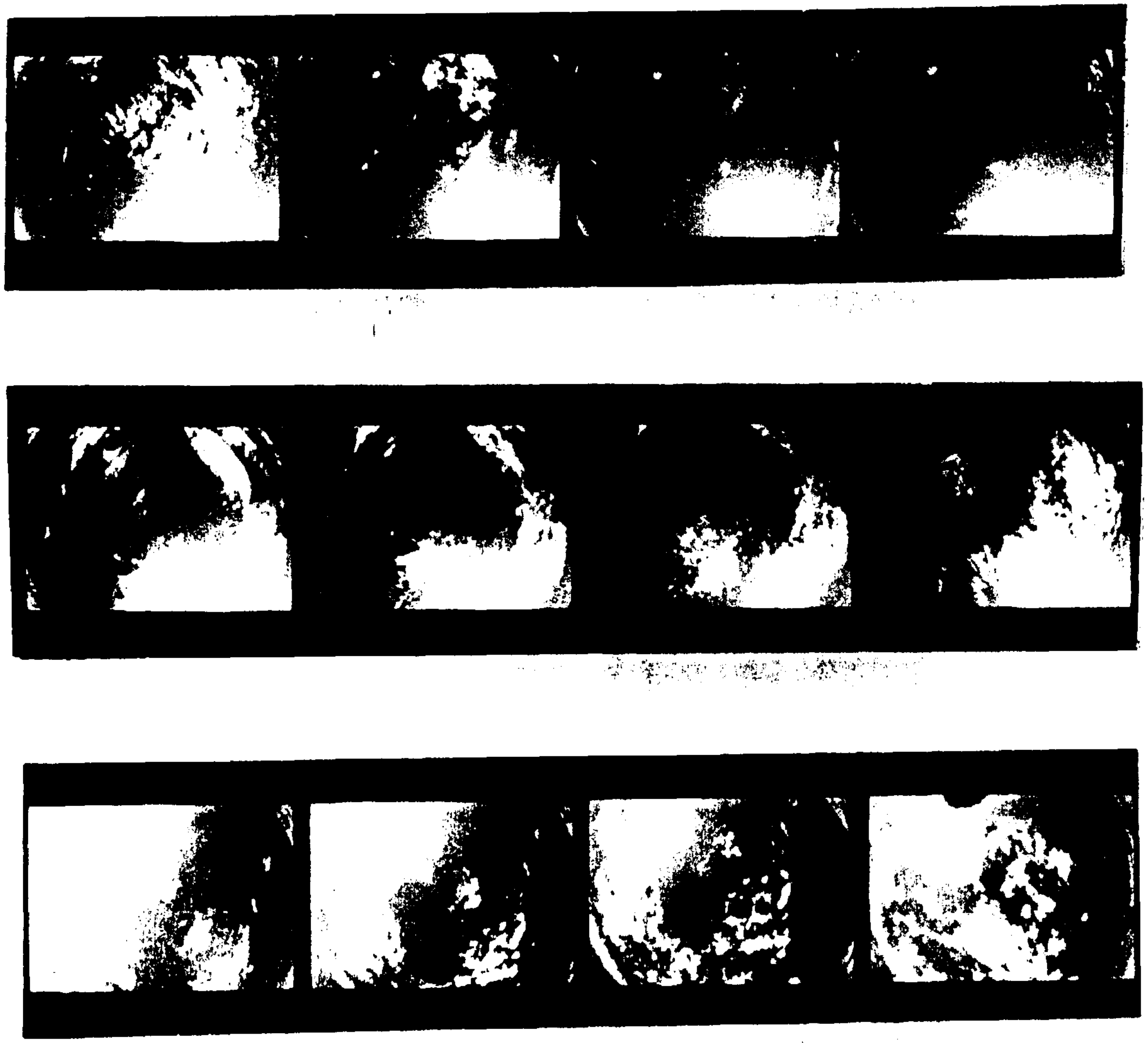


Figure 11 - Fisheye pictures of clouds for the August 20, 1971 flight.
Note: Frame (time) sequence is from right to left.

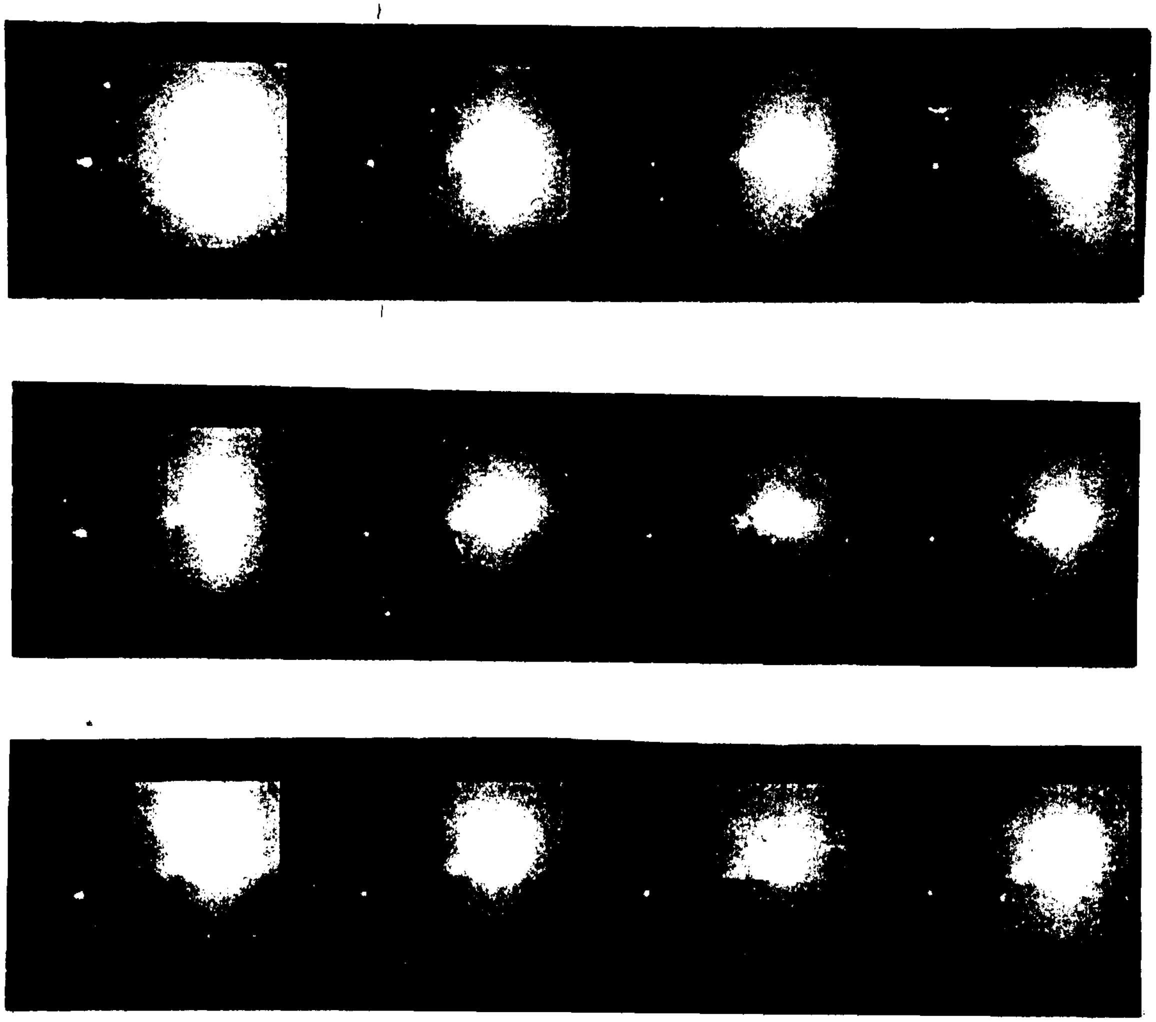


Figure 12 - Fisheye pictures of clouds for the August 27, 1971 flight.
Note: Frame (time) sequence is from right to left.

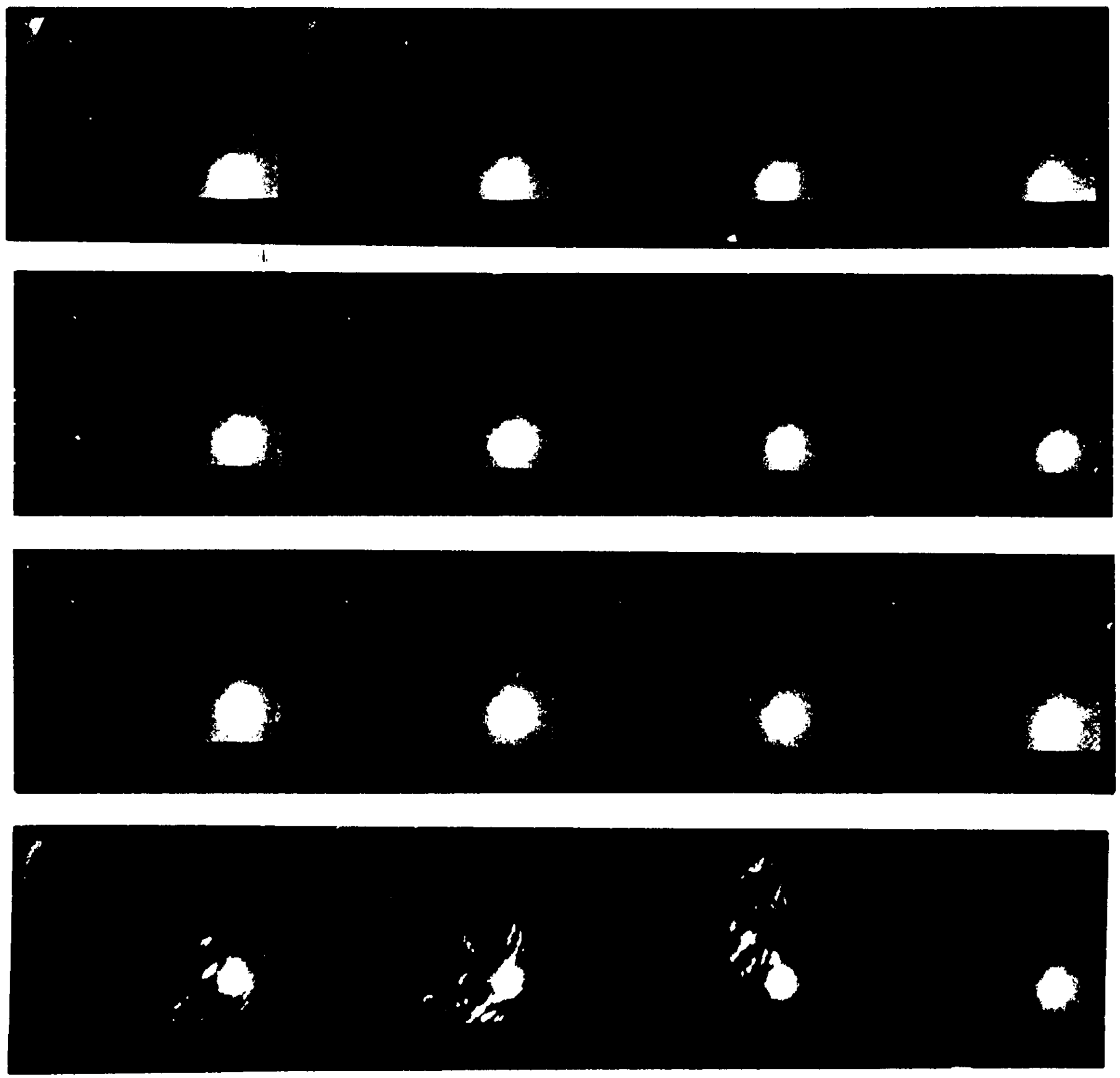


Figure 13 - Fisheye pictures of clouds for the September 14, 1971 flight.
Note: Frame (time) sequence is from right to left.

APPENDIX B

Tables

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

Table 1. F Stops Used in Control Experiment for Different Film Combinations in May and August

F Stop	Film	May F Stop	August F Stop
Overexposed	2448	4	5.6
	2443	4-5.6*	11
	2402	5.6-8*	8-11*
	2424	11	11
Selected**	2448	5.6	8
	2443	5.6-8*	16
	2402	8-11*	11-16*
Optimum	2424	16	16
Underexposed	2448	8	11
	2443	8-11*	22
	2402	11-16*	16-22*
	2424	22	22

* Camera set between values for half F stop.
** These values considered to be optimum setting by past experience.

Table 2. Relationship of Film/Filter Combination to Densitometer Filters and Light Measured*

Film/Filter	Densitometer Wratten Filter			
	Neutral (106)	Red (92)	Green (93)	Blue (94)
2402/25	Red	--	--	--
2424/89B	Infrared	--	--	--
2448/None	Blue → Red	Red	Green	Blue
2443/15 /30M	Green → Infrared	Infrared	Red	Green

* The names in the table represent approximate bands of light measured for each film filter combination with the particular densitometer filter.

Table 3. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2402 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.26	3	0.09	12.26*
F Stop (S)	11.14	2	5.57	796.55*
C x S	0.37	6	0.06	8.92*
Time of Day (T)	0.05	1	0.05	6.93
C x T	0.03	3	0.01	1.30
S x T	0.06	2	0.03	4.31
C x S x T	0.33	6	0.05	7.78*
Target Block (B)	39.51	3	13.17	1884.03*
C x B	0.12	9	0.01	1.97
S x B	3.49	6	0.58	83.30*
C x S x B	0.12	18	0.01	0.93
T x B	0.02	3	0.01	1.08
C x T x B	0.01	9	0.00	0.14
S x T x B	0.01	6	0.00	0.13
C x S x T x B	0.13	18	0.01	16.10*
Sampling Error	0.04	96	0.00	
Total	55.68	191		

* Significant at the .01 level of probability.

Table 4. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2424 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.22	3	0.07	319.74*
F Stop (S)	6.75	2	3.37	14669.04*
C x S	0.34	6	0.06	243.09*
Time of Day (T)	0.38	1	0.38	1667.04*
C x T	0.48	3	0.16	693.22*
S x T	0.28	2	0.14	612.09*
C x S x T	0.59	6	0.10	425.17*
Target Block (B)	0.11	3	0.04	155.52*
C x B	0.00	9	0.00	1.87
S x B	0.02	6	0.00	12.83*
C x S x B	0.01	18	0.00	1.74
T x B	0.00	3	0.00	4.26
C x T x B	0.00	9	0.00	2.09
S x T x B	0.00	6	0.00	1.48
C x S x T x B	0.00	18	0.00	0.54
Sampling Error	0.04	96	0.00	
Total	9.22	191		

* Significant at the .01 level of probability.

Table 5. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2448 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.53	3	0.18	103.88*
F Stop (S)	1.42	2	0.71	419.04*
C x S	0.18	6	0.03	17.41*
Time of Day (T)	0.01	1	0.01	6.89
C x T	0.23	3	0.08	45.30*
S x T	0.10	2	0.05	29.82*
C x S x T	0.12	6	0.02	11.23*
Target Block (B)	8.32	3	2.77	1630.59*
C x B	0.16	9	0.02	10.73*
S x B	0.31	6	0.05	30.04*
C x S x B	0.05	18	0.00	1.46
T x B	0.04	3	0.01	7.57*
C x T x B	0.05	9	0.01	3.26
S x T x B	0.02	6	0.00	2.24
C x S x T x B	0.03	18	0.00	2.24
Sampling Error	0.01	96	0.00	
Total	11.57	191		

* Significant at the .01 level of probability.

Table 6. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2448 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Red Filter in a Controlled Experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	1.13	3	0.38	183.29*
F Stop (S)	1.96	2	0.98	476.00*
C x S	0.15	6	0.03	12.18*
Time of Day (T)	0.00	1	0.00	1.46
C x T	0.75	3	0.25	120.92*
S x T	0.07	2	0.04	18.00*
C x S x T	0.09	6	0.02	7.50*
Target Block (B)	16.51	3	5.50	2671.46*
C x B	0.24	9	0.03	12.85*
S x B	0.39	6	0.07	31.51*
C x S x B	0.05	18	0.00	1.45
T x B	0.02	3	0.01	3.33
C x T x B	0.09	9	0.01	4.80*
S x T x B	0.03	6	0.00	2.33
C x S x T x B	0.04	18	0.00	14.34*
Sampling Error	0.01	96	0.00	
Total	21.54	191		

* Significant at the .01 level of probability.

Table 7. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2448 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Green filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	1.15	3	0.38	134.41*
F Stop (S)	2.29	2	1.15	400.98*
C x S	0.14	6	0.02	8.35*
Time of Day (T)	0.04	1	0.03	12.22*
C x T	0.70	3	0.23	82.07*
S x T	0.08	2	0.04	13.77*
C x S x T	0.09	6	0.01	5.17*
Target Block (B)	12.94	3	4.31	1508.28*
C x B	0.28	9	0.03	10.81*
S x B	0.66	6	0.11	38.68*
C x S x B	0.08	18	0.00	1.51
T x B	0.15	3	0.05	17.95*
C x T x B	0.11	9	0.01	4.20*
S x T x B	0.54	6	0.01	3.13
C x S x T x B	0.05	18	0.00	278.87*
Sampling Error	0.01	96	0.00	
Total	18.83	191		

* Significant at the .01 level of probability.

Table 8. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2448 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Blue Filter in a Controlled Experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	1.14	3	0.38	148.38*
F Stop (S)	3.20	2	1.60	627.30*
C x S	0.24	6	0.04	15.65*
Time of Day (T)	0.13	1	0.13	49.84*
C x T	0.60	3	0.20	78.60*
S x T	0.14	2	0.07	27.18*
C x S x T	0.14	6	0.02	9.00*
Target Block (B)	12.96	3	4.32	1693.98*
C x B	0.27	9	0.03	11.79*
S x B	0.83	6	0.14	54.00*
C x S x B	0.08	18	0.00	1.82
T x B	0.20	3	0.07	26.34*
C x T x B	0.11	9	0.01	4.65*
S x T x B	0.07	6	0.01	4.34*
C x S x T x B	0.05	18	0.00	18.26*
Sampling Error	0.01	96	0.00	
Total	20.15	191		

* Significant at the .01 level of probability.

Table 9. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2443 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.07	3	0.02	16.82*
F Stop (S)	0.40	2	0.20	148.24*
C x S	0.04	6	0.01	5.29*
Time of Day (T)	0.00	1	0.00	2.45
C x T	0.02	3	0.01	4.75
S x T	0.01	2	0.00	2.65
C x S x T	0.02	6	0.00	2.02
Target Block (B)	0.66	3	0.22	162.43*
C x B	0.08	9	0.01	6.68*
S x B	0.56	6	0.09	68.13*
S x T x B	0.06	18	0.00	2.53
T x B	0.01	3	0.00	1.33
C x T x B	0.02	9	0.00	1.47
S x T x B	0.01	6	0.00	0.91
C x S x T x B	0.03	18	0.00	34.00*
Sampling Error	0.00	96	0.00	
Total	1.98	191		

* Significant at the .01 level of probability.

Table 10. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2443 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Red Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.18	3	0.06	162.70*
F Stop (S)	0.32	2	0.16	428.97*
C x S	0.06	6	0.01	26.68*
Time of Day (T)	0.24	1	0.24	660.51*
C x T	0.13	3	0.04	114.32*
S x T	0.01	2	0.00	8.86*
C x S x T	0.04	6	0.01	15.81*
Target Block (B)	0.14	3	0.05	124.81*
C x B	0.01	9	0.00	3.46
S x B	0.10	6	0.02	43.62*
C x S x B	0.01	18	0.00	1.86
T x B	0.01	3	0.00	6.22*
C x T x B	0.00	9	0.00	1.11
S x T x B	0.00	6	0.00	1.30
C x S x T x B	0.01	18	0.00	9.73*
Sampling Error	1.25	96	0.00	
Total	1.25	191		

* Significant at the .01 level of probability.

Table 11. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2443 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Green Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.49	3	0.16	33.52*
F Stop (S)	1.07	2	0.53	109.38*
C x S	0.23	6	0.04	7.77*
Time of Day (T)	0.31	1	0.31	63.77*
C x T	0.20	3	0.07	13.92*
S x T	0.02	2	0.01	1.52
C x S x T	0.10	6	0.02	3.51
Target Block (B)	2.32	3	0.77	158.29*
C x B	0.35	9	0.04	7.89*
S x B	2.17	6	0.36	74.05*
C x S x B	0.28	18	0.02	31.68*
T x B	0.01	3	0.00	0.47
C x T x B	0.70	9	0.01	1.54
S x T x B	0.19	6	0.00	0.64
C x S x T x B	0.09	18	0.00	83.21*
Sampling Error	0.01	96	0.00	
Total	7.72	191		

* Significant at the .01 level of probability.

Table 12. Analysis of Variance of Cameras, F Stops, Time of Day, and Target Block for Film 2443 in the May Run Using Photographic Density as Measured by the MacBeth Densitometer Blue Filter in a Controlled Experiment

Source of Variance	Sum of squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	0.50	3	0.17	7.14*
F Stop (S)	2.98	2	1.49	63.30*
C x S	0.86	6	0.14	6.06*
Time of Day (T)	0.44	1	0.44	1.89
C x T	0.31	3	0.10	4.36
S x T	0.08	2	0.04	1.63
C x S x T	0.07	6	0.12	0.52
Target Block (B)	5.06	3	1.69	71.70*
C x B	0.80	9	0.09	3.79*
S x B	3.84	6	0.64	27.18*
C x S x B	0.55	18	0.03	1.29
T x B	0.08	3	0.02	1.00
C x T x B	0.12	9	0.01	0.58
S x T x B	0.22	6	0.04	1.56
C x S x T x B	0.42	18	0.02	1.96
Sampling Error	1.15	96	0.01	
Total	17.47	191		

* Significant at the .01 level of probability.

Table 13. Analysis of Variance of Cameras, F Stops, Day, and Target Block for Film 2402 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	4.54	3	1.51	67.89*
F Stop (S)	28.89	2	14.45	648.41*
C x S	0.43	6	0.07	3.25
Days (T)	18.63	1	18.63	836.24*
C x T	3.49	3	1.16	52.05*
S x T	0.11	2	0.06	2.52
C x S x T	0.55	6	0.09	4.11*
Target Block (B)	68.80	3	22.93	1029.35*
C x B	0.19	9	0.02	0.95
S x B	0.89	6	0.15	6.68*
C x S x B	0.43	18	0.02	1.07
T x B	0.43	3	0.14	6.14*
C x T x B	0.16	9	0.17	0.78
S x T x B	1.64	6	0.27	12.31*
C x S x T x B	0.40	18	0.02	130.82*
Sampling Error	0.02	96	0.00	
Total	129.60	191		

* Significant at the .01 level of probability.

Table 14. Analysis of Variance of Cameras, F Stops, Day, and Target Block for Film 2424 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	2.50	3	0.83	1043.74*
F Stop (S)	21.08	2	10.54	13174.51*
C x S	0.23	6	0.04	48.68*
Day (T)	20.21	1	20.21	25260.66*
C x T	3.98	3	1.32	1656.32*
S x T	1.63	2	0.81	1018.62*
C x S x T	0.38	6	0.06	79.69*
Target Block (B)	1.04	3	0.34	431.60*
C x B	0.03	9	0.00	3.86*
S x B	0.03	6	0.01	6.61*
C x S x B	0.15	18	0.00	1.08
T x B	0.07	3	0.02	29.04*
C x T x B	0.01	9	0.00	1.85
S x T x B	0.00	6	0.00	0.64
C x S x T x B	0.14	18	0.00	0.94
Sampling Error	0.08	96	0.00	
Total	51.31	191		

* Significant at the .01 level of probability.

Table 15. Analysis of Variance of Camera, F Stops, Day, and Target Block for Film 2448 in the August Run Using Photographic Density as Measured the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	2.51	3	0.84	183.56*
F Stop (S)	14.56	2	7.28	1600.21*
C x S	0.18	6	0.03	6.44*
Day (T)	13.05	1	13.05	2867.44*
C x T	2.16	3	0.72	158.60*
S x T	0.93	2	0.46	102.04*
C x S x T	0.14	6	0.02	5.13*
Target Block (B)	31.19	3	10.40	2285.18*
C x B	0.30	9	0.03	7.44*
S x B	1.46	6	0.24	53.45*
C x S x B	0.10	18	0.01	1.22
T x B	1.46	3	0.49	106.77*
C x T x B	0.26	9	0.03	6.31*
S x T x B	0.18	6	0.03	6.75*
C x S x T x B	0.02	18	0.00	15.91*
Sampling Error	0.03	96	0.00	
Total	68.59	191		

* Significant at the .01 level of probability.

Table 16. Analysis of Variance of Cameras, F Stops, Day, and Target Block for Film 2448 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Red Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	2.07	3	0.69	101.09*
F Stop (S)	13.37	2	6.69	977.57*
C x S	0.17	6	0.03	4.18*
Day (T)	10.40	1	10.40	1520.77*
C x T	1.73	3	0.58	84.30*
S x T	0.76	2	0.39	56.71*
C x S x T	0.12	6	0.02	2.95
Target Block (B)	48.77	3	16.26	2376.90*
C x B	0.30	9	0.33	4.89*
S x B	1.32	6	0.22	32.10*
C x S x B	0.14	18	0.01	1.13
T x B	1.31	3	0.44	63.73*
C x T x B	0.25	9	0.03	4.01*
S x T x B	0.19	6	0.03	4.62*
C x S x T x B	0.12	18	0.01	22.77*
Sampling Error	0.03	96	0.00	
Total	81.08	191		

* Significant at the .01 level of probability.

Table 17. Analysis of Variance of Camera, F Stops, Day, and Target Block for Film 2448 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Green Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	2.33	3	0.78	140.43*
F Stop (S)	18.21	2	9.11	1649.76*
C x S	0.24	6	0.04	7.12*
Day (T)	13.11	1	13.11	2375.86*
C x T	1.93	3	0.64	116.81*
S x T	0.83	2	0.42	75.38*
C x S x T	0.18	6	0.03	5.35*
Target Block (B)	30.35	3	10.12	1832.83*
C x B	0.27	9	0.03	5.45*
S x B	1.45	6	0.24	43.70*
C x S x B	0.12	18	0.01	1.18
T x B	1.34	3	0.45	81.16*
C x T x B	0.24	9	0.03	4.76*
S x T x B	0.26	6	0.04	7.84*
C x S x T x B	0.10	18	0.01	17.44*
Sampling Error	0.03	96	0.00	
Total	70.99	191		

* Significant at the .01 level of probability.

Table 18. Analysis of Variance of Cameras, F Stops, Day, and Target Block for Film 2448 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Blue Filter in a Controlled Experiment

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	1.76	3	0.59	154.70*
F Stop (S)	16.83	2	8.41	2219.96*
C x S	0.24	6	0.04	10.75*
Day (T)	11.36	1	11.36	2997.04*
C x T	1.61	3	0.54	141.46*
S x T	0.53	2	0.26	69.76*
C x S x T	0.15	6	0.02	6.55*
Target Block(B)	31.73	3	10.58	2790.79*
C x B	0.30	9	0.03	8.81*
S x B	2.14	6	0.36	93.97*
C x S x B	0.09	18	0.01	1.37
T x B	1.69	3	0.56	148.92*
C x T x B	0.31	9	0.03	9.09*
S x T x B	0.07	6	0.01	3.22
C x S x T x B	0.07	18	0.00	14.97*
Sampling Error	0.02	96	0.00	
Total	68.91	191		

* Significant at the .01 level of probability.

Table 19. Analysis of Variance of Cameras, F Stops, Day, and Target Block for Film 2443 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Neutral Filter in a Controlled Experiment

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	8.83	3	2.94	135.00*
F Stop (S)	46.37	2	23.19	1063.62*
C x S	2.31	6	0.39	17.66*
Days (T)	35.02	1	35.02	1606.46*
C x T	7.21	3	2.40	110.18*
S x T	0.18	2	0.09	4.17
C x S x T	2.77	6	0.46	21.18*
Target Block (B)	40.01	3	13.34	611.75*
C x B	0.29	9	0.03	1.45
S x B	1.10	6	0.18	8.43*
C x S x B	0.51	18	0.03	1.30
T x B	1.39	3	0.46	21.18*
C x T x B	0.18	9	0.02	0.94
S x T x B	2.12	6	0.35	16.22*
C x S x T x B	0.39	18	0.02	13.82*
Sampling Error	0.15	96	0.00	
Total	148.83	191		

* Significant at the .01 level of probability.

Table 20. Analysis of Variance of Cameras, F Stops, Day, and Target Block for Film 2443 in the August Run Using Photographic Density as Measured by the MacBeth Densitometer Red Filter in a Controlled Experiment

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Test
Camera (C)	8.27	3	2.76	216.98*
F Stop (S)	45.83	2	22.92	1802.93*
C x S	3.16	6	0.53	41.48*
Days (T)	32.36	1	32.36	2545.81*
C x T	7.16	3	2.39	187.90*
S x T	0.82	2	0.41	32.29*
C x S x T	3.92	6	0.65	51.40*
Target Block (B)	13.54	3	4.51	354.99*
C x B	0.14	9	0.02	1.25
S x B	0.42	6	0.07	5.47*
C x S x B	0.30	18	0.02	1.33
T x B	0.99	3	0.33	26.03*
C x T x B	0.09	9	0.01	0.75
S x T x B	1.20	6	0.20	15.77*
C x S x T x B	0.23	18	0.01	4.58*
Sampling Error	0.27	96	0.00	
Total	118.70	191		

* Significant at the .01 level of probability.