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LARS Technical Memorandum T17 030672

Calibration of Aircraft Scanner Data Using Ground Reflectance Panels

by

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&
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An experiment is described in which aircraft scanner data from calibrated reflectance panels in the scene was used to calibrate the scanner data for nearby targets. The method used permits reflectance calibration of scanner data for areas which are in environmental proximity to the reflectance panels. That is, the calibration is valid for areas receiving the same illumination, from the same sun angle and for the same aircraft altitude. Atmospheric condition changes, cloud cover changes, different sun angles, and other environmental factor changes will alter the calibration and render the panel reference parameters invalid. The method described here is experimental and is disclosed for the use of LARS researchers wishing to experiment with estimation of approximate reflectance data even though it includes the variances caused by the environmental factors.

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Reflectance Panels

A set of eight reflectance panels provided by the Data Corporation of Dayton, Ohio (now Mead Technology Inc.) were in use by LARS for obtaining reflectance reference data throughout 1971. On every flight for each mission of the 1971 Corn Blight Watch, the University of Michigan scanner carrying aircraft flew over the eight panel array at a nominal altitude of 1000 feet. Thus, panel data exists in the LARS data storage tape library for a sizeable number of aircraft scanner flights.

The eight panels consist of five gray panels having nominal reflectances of 4, 8, 16, 32, and 64%; and a red, green, and a blue panel. The reflectances of the panels were measured in the laboratory by the manufacturer and by LARS personnel on a DK-2 spectrometer. The laboratory measurements represent total reflected energy from a sample of the reflectance panels. The reflectance values are valid for diffusely reflecting surfaces but are diffuse reflectance equivalents of materials having bi-directional reflectance properties. The reflectance panels are essentially diffuse reflectance surfaces and is assumed that the values obtained from the DK-2 measurements can be used for aircraft scanner data calibration directly.

The laboratory reflectance values are plotted in Figures 1, 2, 3 for the eleven reflectance channels of the aircraft scanner. The values plotted are average reflectances over the bandpass of each channel. The reflectance curves for gray panels are relatively flat and little error is expected in these estimates. The color panel curves are extremely variable and larger average reflectance errors are expected in these cases.

Aircraft Scanner Data

Radiometric measurements made by the ERIM airborne spectrometer are converted to electrical signals by the detectors in 12 wavelength bands and recorded on analog magnetic tape. A variety of factors influence the levels of these signals. There are ten major factors causing variability in scanner data for the reflective portion of the spectrum. The thermal IR region is not studied in this report. Thus, the remainder of this discussion will refer only to the eleven reflective channels of the University of Michigan scanner (ERIM) (Ch.1-11). Variability Factors Affecting Reflectance Calibration:

1. Zero reference
2. System gain
3. System nonlinearity
4. Zero reference drift
5. Gain drift
6. Altitude
7. Haze, cloud cover, other atmospheric factors
8. Illumination Intensity as a function of wavelength

9. Angle of Illumination (Azimuth and Elevation)
10. Scanner Look Angle and Azimuth

Included with each scan line of data are three calibration samples giving a measure of the black or zero signal level, a sample from a precision calibration lamp, and a sample from a sun sensor located on top of the aircraft. These three sources have the potential to significantly improve the accuracy of classification over extended areas. Black level calibration compensates for type 1 (Zero level drift) effects, calibration lamp for type 2 and 5 (System gain and Gain drift) and the sun sensor for type 8 (Incident Illumination Variation).

The calibration lamp values included with the scanner data represent a given and precisely fixed luminous energy dependent only on the lamp current, lamp age, and lamp filter used. For a given panel solar illumination, the scanner data values can be related to their known reflectances using the calibration lamp values. The aircraft sensor system utilizes arbitrary gains to maximize the use of the system dynamic range. When analog scanner data is converted to digital form at LARS, the amplifier gains are arbitrarily set to utilize the maximum dynamic range of the data system. Thus, the numerical values obtained for the measurements in each channel are unrelated to those in other channels or to a radiometric standard. For any one set of conditions, however, the values in any one channel are directly related to scene reflectance.

The LARSYS data retrieval program GADLIN (LARSYS 005) includes the capability to utilize the calibration samples in one of several combinations. LARS Information Note 071069, "Calibration of Scanner Data for Operational Processing Programs", describes the capabilities of the calibration algorithms in detail and the program abstract for GADLIN contains a description of the algorithm. In general, the algorithm performs a first order transformation of the form:

$$D_o = A_c \cdot D_t + B_c$$

D_t = Data Stored on Tape

D_o = Data Delivered to the User.

A_c and B_c are calculated for each scan line of data and used throughout the whole scan line for which they have been calculated. The calculation of A_c and B_c can be based on any one of seven combinations of the values of the three calibration values available (i.e. black level-C_o, lamp-C_1, or sun sensor-C_2).

Correction of Arbitrary System Gain Using Reflectance Panels

The data values observed in uncalibrated aircraft scanner data of the calibration panels can be used to estimate gain correction factors which will produce diffuse equivalent spectral curves which will more closely approximate actual scene reflectance than present spectral curves obtained from the LARSYS or other processors using aircraft data.

Let: R_i (X) be the mean reflectance of green, red, etc., panel in channel (i) for the 5 gray panels, and the three color panels.

(X = G1, ...G5, R, G, B)

Let: $C_{1,i}$ - be the C_1 value for channel i for the uncorrected scanner data from the flight over the panels for code 4 calibration with $C_o = 0$, and $C_1 = C_1 - C_o$. (See the GADLIN writeup.)

Let: S_i (X) be the data value produced for channel i for panel X with (code 4) calibration with $C_o = 0$ and $C_1 = C_1 - C_o$.

Thus, when value S_i (X) is obtained for panel X, the value of reflectance represented is R_i (X). The value of reflectance represented by C_1 $(C_{1,i})$ is assumed to be linearly related to the observed panel values.

Thus:

$$R_i\ (C_1) = \frac{R_i\ (X) \cdot C_{1,i}}{S_i\ (X)}$$

The equivalent reflectance R_i $(C_{1,i})$ of $C_{1,i}$ depends on the panel illumination, atmospheric effects, lamp current, lamp calibration curve, and filter used. If the system gain or other sensor system multiplicative factor is changed, both the numerator and denominator are changed by the same factor and R_i $(C_{1,i})$ stays constant. Thus for a given filter, lamp, and lamp current the reflectance equivalent is constant for the illumination on the scene at the time and altitude of the flight.

Table 1 contains reflectance values obtained from manufacturers curves for the color and gray panels used in the flight by the University of Michigan on July 13, 1971. The values are average reflectances over the full passband for each channel of the University of Michigan scanner configuration. Table 2 contains the aircraft scanner data values for each of the panels from corn blight watch run 71034100 over the panels on the Purdue Agronomy Farm for the July 13 flight at 2:12 P.M. at an altitude of 1000 feet. Table 3 contains the calibration data for the run. The eight estimates of reflectance for each channel enables a least square slope to be computed for each channel as follows:

If the reflectance is expressed as:

$$R = KS + I$$

The least square estimate for K and I is:

$$\begin{pmatrix} \hat{K}_j \\ \hat{I}_j \end{pmatrix} = [A_j^T A_j]^{-1} A_j^T \overline{R}_j \qquad \overline{R}_j = \begin{pmatrix} r_1 \\ \vdots \\ r_8 \end{pmatrix}$$

= Vector of reflectances for the 8 panels for Channel j.

Where:

$$A_j = \begin{bmatrix} S_1 & 1 \\ S_2 & 1 \\ \vdots & \vdots \\ S_8 & 1 \end{bmatrix}$$

S_i = Data values for panel i with reflectances r_i, for channel j.

A_j = A 2 column 8 row matrix with 1's in column 2.

The least squares estimate of the equivalent reflectance of C_1 for channel j is then:

$$\hat{R}_j (C_1) = C_{1,j} \cdot \hat{K}_j + \hat{I}_j$$

Table 1 REFLECTANCE VALUES FOR LARS CALIBRATION PANELS (%)

June 28, 1971

	GRAY PANELS					COLOR PANELS		
CHANNEL	G1	G2	G3	G4	G5	RED	BLUE	GREEN
1	61.6	31.0	17.7	8.6	3.0	3.4	39.0	16.5
2	61.5	30.7	17.2	8.2	3.0	3.3	29.0	28.0
3	61.0	29.8	16.5	7.9	3.0	3.3	16.0	34.0
4	60.5	29.0	15.9	7.5	3.0	3.7	8.5	30.0
5	60.0	28.1	15.1	7.1	3.0	6.5	6.0	18.0
6	60.0	27.5	14.8	7.0	3.0	30.0	5.4	8.0
7	60.3	27.4	14.5	7.0	3.0	62.0	5.7	9.0
8	60.0	27.0	14.0	6.8	3.0	71.0	37.0	26.0
9	60.0	27.0	14.0	6.8	3.0	75.0	73.0	77.0
10	60.0	27.0	14.0	6.8	3.0	63.0	71.0	70.0
11	60.0	27.0	14.0	6.8	3.0	45.0	54.0	51.0

Table 2 CALIBRATION PANEL VALUES FROM SCANNER DATA

RUN 71034100, MISSION 41M, July 13, 1971

	GRAY PANELS					COLOR PANELS		
CHANNEL	G1	G2	G3	G4	G5	BLUE	GREEN	RED
1	40.6*	136.2	73.5	42.7	25.6	129.4	80.3	28.2
2	-16.8*	-16.1*	108.5	62.4	37.9	159.7	144.5	41.0
3	-2.7*	149.9	92.5	53.5	33.6	104.6	42.5*	35.5
4	139.3*	54.8*	100.3	56.7	38.6	71.9	166.4	40.4
5	160.1	101.5	55.7	30.9	21.8	29.7	64.4	28.8
6	11.4*	114.1	62.6	34.9	25.1	31.2	44.6	86.3
7	49.6*	109.8	59.4	33.0	24.3	31.9	34.8	152.3
8	148.8	85.1	49.3	31.5	28.9	62.9	50.5	179.9
9	149.2	88.9	57.8	38.4	37.9	176.8	178.2	178.7
10	179.5	99.6	61.8	39.9	38.6	208.5	202.9	190.5
11	158.4	103.8	63.6	43.8	44.6	187.2	178.9	165.3

* Data system failed for these points; data invalid.

The K_j and I_j are computed and listed in Table 4 for this run. The equivalent C_1 reflectances are also given in Table 4. This data can be used for runs having the same illumination conditions and altitude. For different altitudes and illumination conditions, the results will be in error. The error is due to three main factors: 1) Different level and direction of illumination and 2) different shape of the spectral distribution of energy, 3) altitude. Since most of the flights were flown near noon on clear days, the variation in illumination is not going to be excessively large for sites near the panel locations. The data points for the panels and their reflectances are plotted in Figure 1 for channel 8 or run 71034100.

To use the data in Table 4, set the C_0 calibration parameter to the intercept value and set the C_1 value to the one in the table by punching it on the channels card. Use Code 4 calibration. The data will be returned on a scale of 0-100 from LARSYS with 100 representing 100% reflectance.

The mean data values obtained from *STATISTICS LARSYS calculations for the three color panels were plotted in Figures 1, 2, and 3 along with the DK-2 laboratory reflectance curves. These curves indicate the accuracy being achieved using this approach. The errors observed are due to the fact that a linear estimate was used which approximates the actual point in a curve such as shown in Figure 4 on a least square basis. The scanner response is possibly nonlinear for small values of reflectance

Table 3--Scanner Data Calibration Values

Run 71034100 $C_o = 0$

CHANNEL	C_1	C_2
1	17.7	44.6
2	30.8	71.6
3	27.7	68.7
4	32.2	79.2
5	21.8	46.9
6	28.9	54.8
7	25.4	54.7
8	58.0	41.0
9	9.1	39.9
10	27.5	69.3
11	39.9	70.2

Table 4--Regression Results and C_1 Equivalent Reflectances for Run 71034100

CHANNEL	Slope $\hat{K}$	Intercept $\hat{I}$	C_1 Equivalent $R(C_1)\%$
1	.294	-4.67	0.53
2	.222	-5.73	1.11
3	.222	-4.60	1.55
4	.209	-5.13	1.63
5	.392	-6.15	2.38
6	.316	-4.33	4.80
7	.413	-7.94	2.56
8	.419	-2.77	21.53
9	.505	-15.2	10.61
10	.392	-10.7	0.16
11	.366	-10.2	4.41

since negative intercepts are observed for all channels. Also, differences in the reflectivity of the panels in the field and the sample used in the laboratory could cause this effect.

An additional experiment was conducted to observe the effect of the calibration procedure on agricultural field data. The calibration parameters in Table 6 were used to compute statistics for Corn Blight Watch field I-6 in Segment 208 for the last four CBW missions. The before and after calibration curves are presented in Figures 5a and b. The negative values obtained in the visible spectrum are partly due to illumination and atmospheric attenuation effects due to the 5000 ft. altitude of the field data flight vs the 1000 ft. altitude of the panel flight. It should be noted again here that this procedure is only a first step toward improving the calibration quality of scanner data and still includes many variables which will distort the spectral response observed.

Procedure for Obtaining Gain Calibration Coefficients

The steps for obtaining gain correction coefficients are as follows:

1. Obtain laboratory reflectance curves for the eight panels and estimate the average reflectance values over the bandwidth of each of the eleven reflective scanner channels. The values in Table 1 can be used as reasonable approximations.
2. Locate the color panels in the *PICTUREPRINT printout for the scanner data. Punch up a field card enclosing all the

panels and run an *CLUSTER job to locate the individual panels. Experimentation with different channel sets may be needed to isolate each panel. MAXCLAS should set greater than the number of panels, i.e. 8. THRESH should be set to zero.

3. Punch up eight field cards for the panels making sure that the borders are within the panel edges. Run the eight fields in a *STATISTICS job asking for correlation matrices and histograms and use Code 4 calibration with C_o = o and $C_1 = C_1 - C_o$. Check the histograms for unimodality. Extract the mean values for each panel for each channel and punch these along with the panel reflectances on data cards in the following format:

   Col. 1,2   Sequence number of point

   Col. 3-8   Reflectance value in F6.2 format

   Col. 9-14   Panel mean value in F6.2 format

   Note: The CHANNELS card for the panel mean *STATISTICS job should be:

   CHANNEL   4(1/0.0, $C_{1,1}$/, 2/0.0,$C_{1,2}$/, ... 11/0.0, $C_{1,11}$/)

   Where: $C_{1,i}$ is the C_1 value from the *IDPRINT output minus the C_o value from the *IDPRINT output. *IDPRINT is obtained from the LARSYS program.

4. Set up and run an // JOB POLRG run with card deck organized as follows: (44PS JOB CONTROL EXAMPLE IS SHOWN. Appropriate modifications are required for running under CMS.)

5. Data Cards as defined in step 3.

6. /*

Set up these // polynomial regression runs on one job and run it. Make a table of the results in the form of Table 4.

5. Compute the C_1 equivalent reflectance for each channel:

$R_j\ (C_1) = C_{1,j} \cdot \hat{K}_j + \hat{I}_j$ where $C_{1,j}$ is the value of C_1 for channel j based on $C_o = 0$. This is obtained by subtracting the value of C_o from the value of C_1 in the *IDPRINT for the run.

When the intercepts and equivalent reflectance values for C_1 have been obtained, punch the values in the channels cards as follows:

CHANNEL $4(1/\hat{I}_1, R_1(C_1)/, 2/\hat{I}_2, R_2(C_1)/, \ldots$
$11/\hat{I}_{11}, R_{11}(C_1)/)$

Use this card (it actually spreads out to 3 cards) for all *STATISTICS, *CLUSTER run.

These five steps produce the calibration parameters for a particular flight over the reflectance panels. The parameters are valid for data gathered near the panels and near to the time the panels were flown for clear days. What "near" is in time or distance is unknown however, and further analysis must be carried out to determine error characteristics.

Table 5 contains a list of reflectance panel runs for the Corn Blight Watch. The user is advised to use the run data and time closest to the date and time data he wishes to calibrate. Best results will of course be obtained for sites in the same run as the panels. Certain of the runs listed in Table 5 have been redigitized and contain larger amounts of data than the "00" series listed. These runs have a "01" designation when available, i.e. 71029401, and will be listed in the LARS RUNTABLE listing.

Solution of the negative intercept problem is not attempted here since insufficient reference data available for small reflectance values, and field spectrometer curves are not available for the panels. The negative intercept could be due to one or all of three factors: 1) The actual reflectance of the panels is higher than that indicated by the integrated laboratory measurements in the direction of the scanner line of sight, 2) The scanner sensor response curve is nonlinear for low radiance values and 3) Background radiation due to atmospheric scattering in the scanner field of view. Further work needs to be done to identify these factors and correct the approach outlined in this note.

It should be pointed out again that the reflectance values produced by this scheme are diffuse or lambertian equivalent reflectances based on assumed lambertian calibration panels. Also, the incident illumination, and atmospheric attenuation

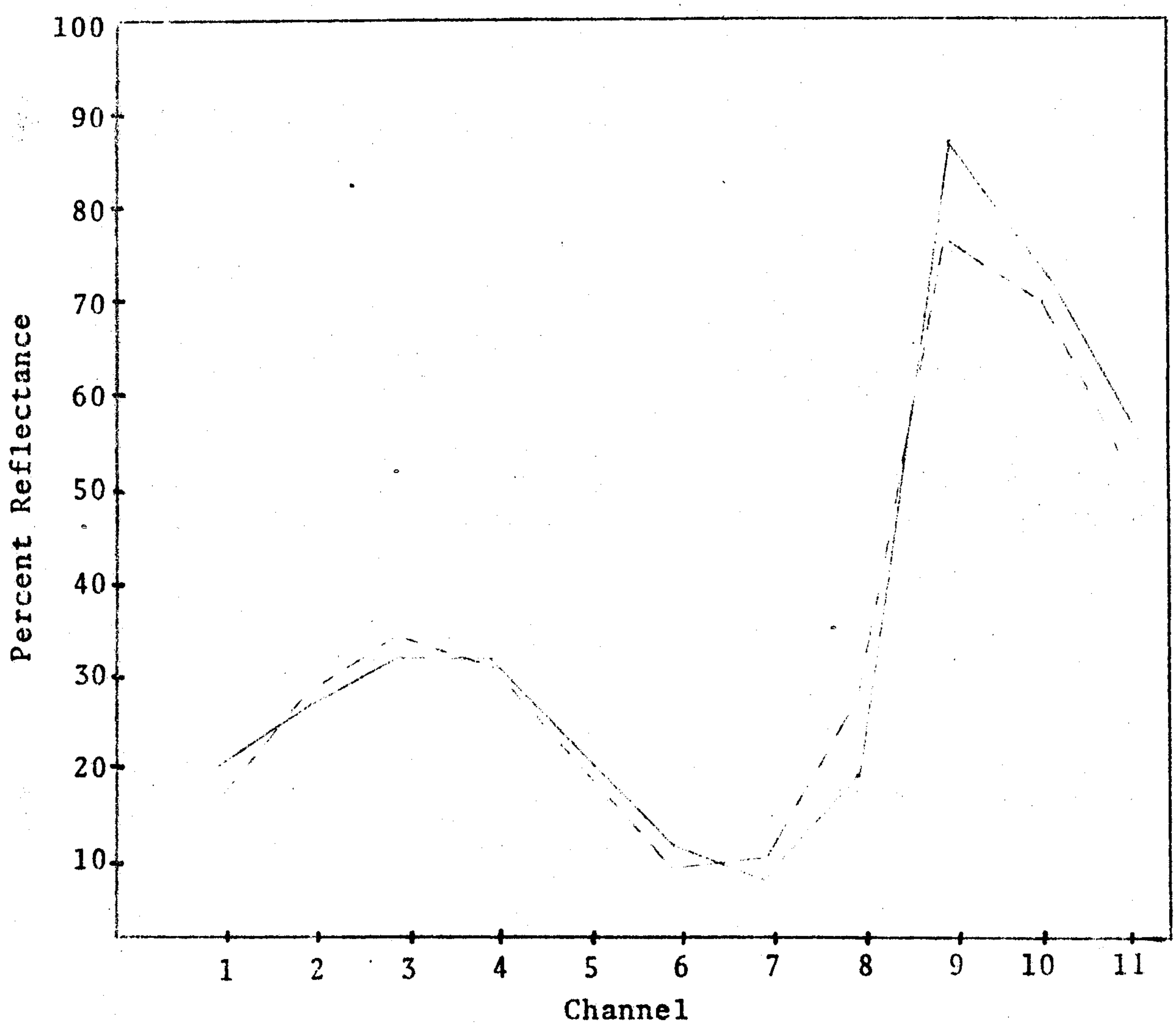
TABLE 5 CALIBRATION PANEL RUNS DURING 1971 CORN BLIGHT WATCH (6MILLIRADIAN SAMPLING)

RUN	TIME	DATE
71029400	1401	July 12
71034100	1412	July 13
71054700	1407	July 16
71054400	1305	July 21
71054500	1511	July 27
71054600	1229	July 29
71046800	1117	July 31
71050300	1233	Aug. 5
71052200	1221	Aug. 11
71060500	1249	Aug. 26
71069900	1308	Sept 14

are assumed to be the same as at the instant of observation of the panels. Scene materials exhibiting directional properties will give reflectance readings dependent on the illumination and look angle. Silvestro[1] implemented and evaluated a similar scheme for calibration of multiband aerial photography. He points out these problems and states an estimated error of 8% for reflectance calibration experiment. It is expected that this is a reasonable error magnitude for the scheme described here; however, an error analysis should be conducted to properly evaluate this method.

[1]Silvestro, Frank B., "Multispectral Photographic Determination of Reflectance," Photogrammetric Engineering, Vol. 35, No. 3, March 1969, pp. 258-262.

Figure 2--Comparison of Laboratory and Calibrated Aircraft Scanner Data for Green Reflectance Panel



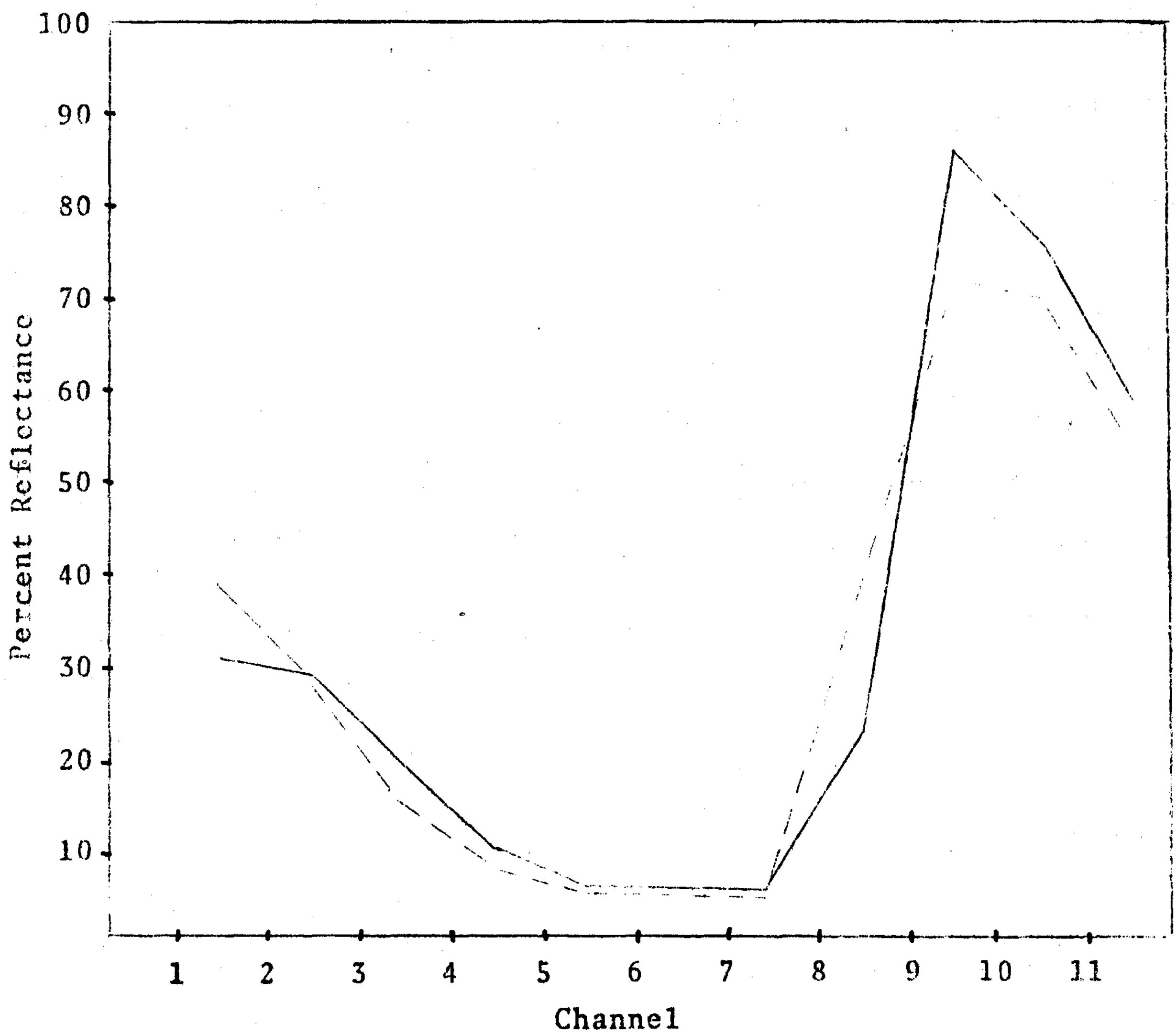
GREEN PANEL

- - - - - - - DK-2 Laboratory Reflectance Spectra

———————— Calibrated Scanner Data

Panel Run 71034100 July 13, 1971

Figure 1--Comparison of Laboratory Measurements
and Calibrated Aircraft Scanner Data
for Blue Reflectance Panel



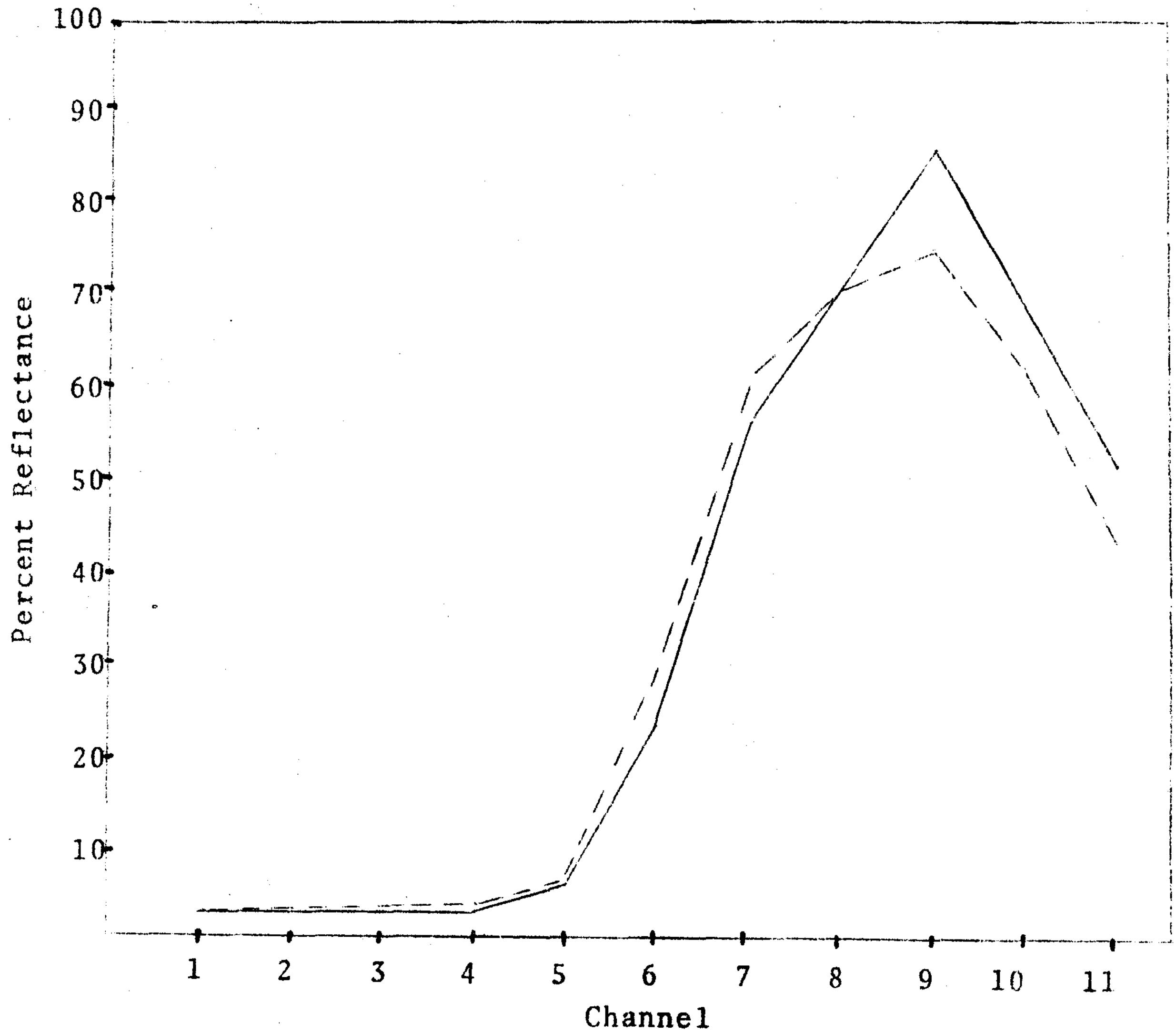
BLUE PANEL

——————— Calibrated Scanner Data

Panel Run 71034100 July 31, 1971

– – – – – – DK-2 Laboratory Reflectance Spectra

Figure 3--Comparison of Laboratory and Calibrated Aircraft Scanner Data for Red Reflectance Panel



RED PANEL

- - - - - DK-2 Laboratory Reflectance Spectra

———— Calibrated Scanner Data

Panel Run 71034100 July 13, 1971

Figure 4--Linear Regression Curve for Panel Data Values from Scanner Data and Laboratory Measured Reflectance Values

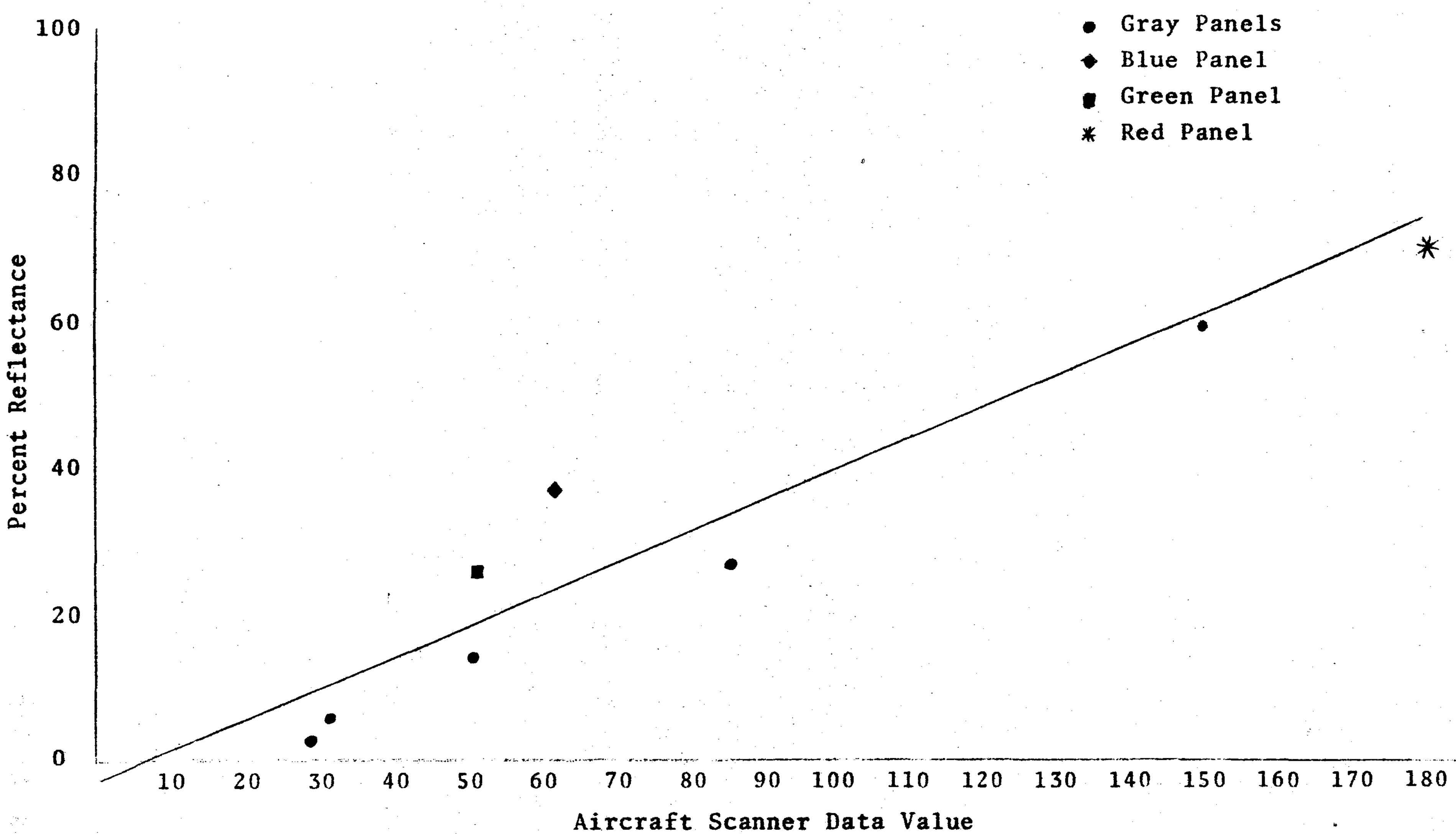


Figure 5a--Aircraft Scanner Data Values for Corn Field I-2 Before Reflectance Calibration

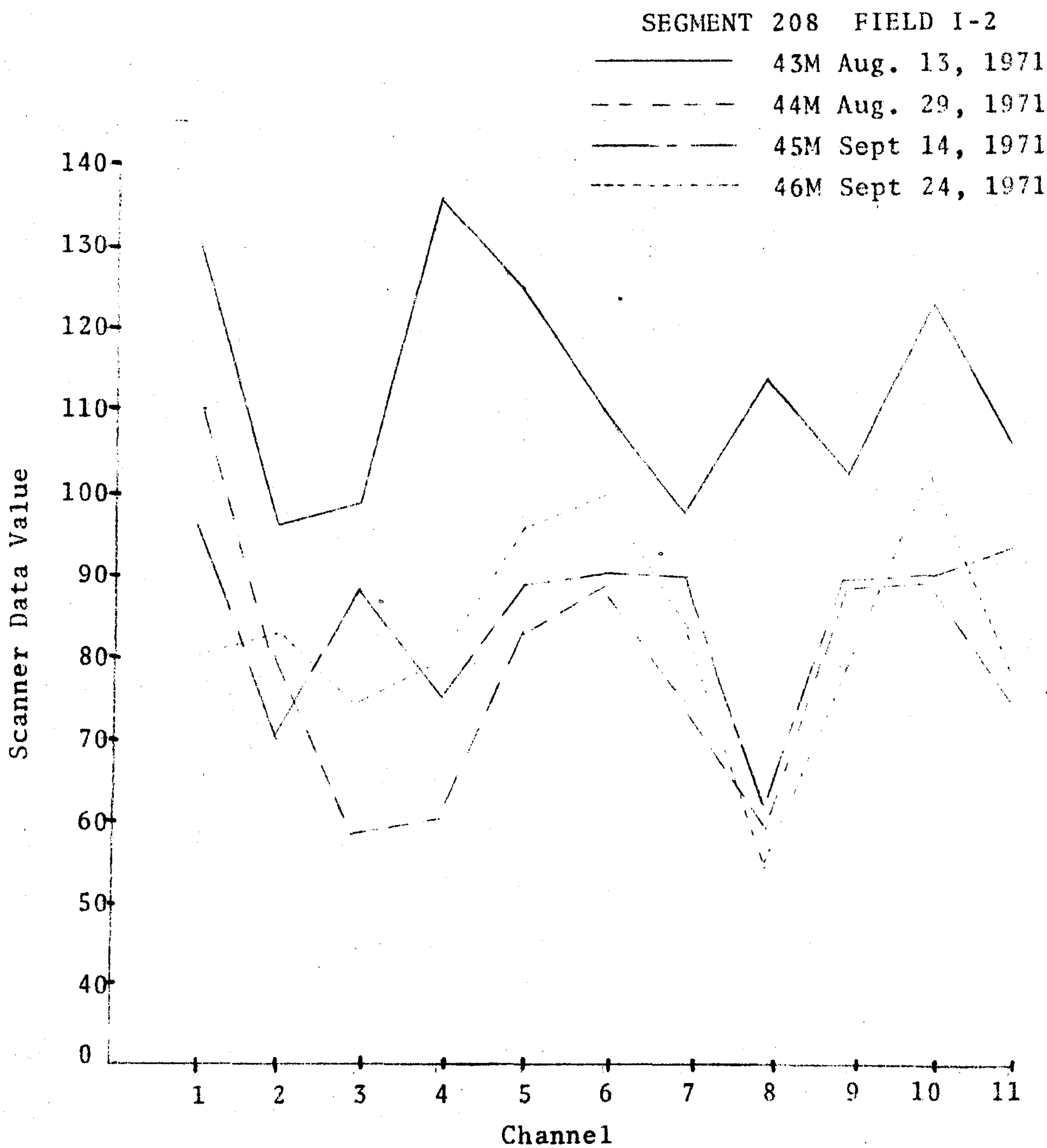


Figure 5b--Reflectance Calibrated Aircraft Scanner Data for Corn Field I-2