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PREFACE

The work described in this report was performed by the Space Sciences Division of the Jet Propulsion Laboratory, under the cognizance of the Mariner Mars 1971 Project.

ACKNOWLEDGMENT

This report provides information that enhances the usefulness of the reduced data from the Mariner 9 television cameras. The authors find themselves, somewhat by happenstance, in the position of providers of this information. By far the greater credit is due to the providers of the data itself: those who helped to develop the correction algorithms (John Kreznar, Tom Rindfleisch, Arnold Schwartz), those who helped to develop the techniques for large-scale automated picture data processing (Al Rammelkamp, Jim Soha), and those who performed the routine job of daily production data processing (Fred Akers, Jean Lorre, David McAdoo, Raim Quiros, Ruth Reese, Andrée Smith). Also acknowledged is the assistance of various members of the Mariner Mars 1971 Television Experiment Team. Numerous injustices would be done in attempting to list them; however, Jim Cutts and Andrew Young are specifically thanked for their careful reviews of this report.

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ABSTRACT

The Mariner 9 television experiment used two cameras to photograph Mars from an orbiting spacecraft. For quantitative analysis of the image data transmitted to Earth, the pictures were processed by digital computer to remove camera-induced distortions. The removal process was performed by the JPL Image Processing Laboratory (IPL) using calibration data measured during prelaunch testing of the cameras. The Reduced Data Record (RDR) is the set of data which results from the distortion-removal, or "decalibration," process. The principal elements of the RDR are numerical data on magnetic tape and photographic data. Numerical data are the result of correcting for geometric and photometric distortions and residual-image effects. Photographic data are reproduced on negative and positive transparency films, strip contact and enlargement prints, and microfiche positive transparency film. The photographic data consist of two versions of each TV frame created by applying two special enhancement processes to the numerical data. This report describes the RDR data, including picture identification, numerical data, picture data, picture label information, microfiche, and RDR data tapes; data processing algorithms; picture processing documentation, including the particulars of the IPL Enhancement Catalog; and limb profile plots.

I. INTRODUCTION

The Mariner 9 television experiment involved analysis of the image data transmitted to Earth by two cameras mounted on a spacecraft orbiting Mars. A large portion of the analysis was based on images processed by digital computer to remove camera-induced distortions. This processing, performed by JPL's Image Processing Laboratory (IPL), made use of calibration data recorded during prelaunch testing of the cameras. Almost all of the more than 7000 pictures underwent this "decalibration"; the resulting set of data is called the Television Reduced Data Record (TV RDR). It will henceforth be referred to as the RDR.

The principal products resulting from decalibration, and which constitute the RDR, are of two types: numerical data on magnetic tape and photographic data. The numerical data are the result of correcting the raw video data (the TV Experiment Data Record or EDR) as received from the spacecraft for geometric distortion, for residual image effects when possible, and for photometric distortion. At each sample point in the RDR format picture, the sample numerical value (DN) is proportional to the apparent luminance of the corresponding point in the camera field of view. The detailed meaning of the RDR numerical data is discussed in Section III. The format of the RDR data on magnetic tape is given in Section II-F.

The photographic data were originally recorded on 70-mm transparency film (negative); subsequent photographic reproduction resulted in 70-mm positive transparency film, 70-mm strip contact prints, 20 x 25-cm (8 x 10-in.) enlargement prints, and microfiche positive transparency film. If the numerical RDR data were recorded on film in a strictly proportional way, the resulting pictures would be very flat and lacking in contrast. To create more useful visual images, the numerical data were "enhanced" before recording on film. Two types of enhancement were applied, resulting in two photographic versions of each original picture. These enhancements are described in more detail in Section II-C.

Appearing beneath each photographic version of an RDR picture is a label block. The label block contains descriptive information about the conditions under which the picture was taken and its image processing history. Sections II-D and IV describe the label block in detail and define each element of the label.

A large part of the distribution of the RDR photographic data is in the form of microfiche cards. These are compact film transparencies having many picture frames in a small area. A special viewer is required to use microfiche cards. Section II-E gives information relevant to the use of the RDR data in this form.

Although not formally a part of the RDR, the IPL Enhancement Catalog provides information about the versions of each picture in the RDR. The tape volume (reel) serial number and file number are given for the numerical data version of each RDR picture. For each photographic version, a film roll number and process time are given to permit retrieval of these products. The Enhancement Catalog also lists "enhancement codes" for each version of the original picture. These codes can be used to distinguish among the RDR versions of an original picture and other special versions which are not part of the RDR, but which are also listed in the Enhancement Catalog. The IPL Enhancement Catalog is described in further detail in Section IV.

Section V of this document describes a set of data, the limb profile plots, produced by subsequent processing of the RDR data. It is included for convenience of distribution, and because use of the limb plot data requires an understanding of the RDR data from which they are derived.

II. RDR DATA DESCRIPTION

A. Picture Identification

Each Mariner 9 television image can be identified with a "DAS time," inserted into the spacecraft telemetry by the spacecraft Data Acquisition System (DAS). DAS time is a single integer number which is incremented by one count every 1.2 seconds throughout the mission. Mariner 9 data users will observe some variation in the DAS time identifiers referring to a given television image. The DAS time used to identify RDR products is that associated with readout of the first picture element of the first line of the image. This differs from other conventions, such as the one used on "real-time" pictures that labelled the image with the DAS time of the first line received (telemetry dropouts may have caused the first picture lines to be missing), or the one used for the Supplementary Experiment Data Record (SEDR) that used the DAS time at which the frame was shuttered (as opposed to the time the electron beam began its scan). Occasionally, a totally erroneous DAS time was assigned due to telemetry data errors. For a given frame, DAS time differences among the various conventions are usually of the order of 5 to 10.

To assist in deciphering the DAS time problem, note that the scan of 700 image lines consumed 42 seconds; the DAS count incremented every 1.2 seconds, resulting in a DAS time increment of 35 counts between images shuttered sequentially by different cameras, and of 70 counts between sequential frames from the same camera.

Retrieval of Mariner 9 data usually begins with the DAS picture identifier. If some other descriptor is known, it must first be converted to DAS time using one of the many catalogs of Mariner 9 data. RDR data are not organized in any straightforward way. The reason for this is that the frames were not processed in order of receipt as the real-time versions were. The TV Experiment Team established the order for processing of sequences of pictures. This order was established to meet the changing mission requirements, since the early processing took place concurrently with mission operations. To an outsider, the RDR processing order appears to be random. Each processed picture was assigned an "IPL roll number," and, except for the microfiche, all photographic versions are stored and retrieved by this roll number. The IPL Enhancement Catalog described in Section IV provides the IPL roll number for each photographic version. For microfiche users, Section II-E describes the use of the separate microfiche catalog.

B. Numerical Data

The Television Reduced Data Record consists of a set of data in various physical forms, all representing a certain set of digital image processing steps applied to the raw television data. These steps, comprising the decalibration procedure, are intended to remove known distortions from the raw picture data as received from the spacecraft. The distortions introduced by the television camera are its undesirable but unavoidable side effects. The types of distortions which the decalibration procedure corrects are: nonuniformity and nonlinearity of photometric response; geometric distortion; and the residual-image effect, the existence in a given picture of a "ghost" of the previous image. The goal of the decalibration procedure applied to a given raw picture is a picture which would have been produced by an ideal camera: no geometric distortion, no residual-image effect, and a brightness proportional to that of the original scene at each point in the image field. The computational algorithms used in each step of decalibration are described in Section III.

It should be recognized by those desiring to make quantitative use of the RDR data that the goal of decalibration has been approached but not achieved. The accuracy of RDR data is limited by the accuracy and completeness of calibration data, and by the accuracy of the assumptions on which the correction algorithms are based. At this time it would be premature to attempt a realistic estimate of the accuracy of the RDR. Work is still under way to make such estimates, and is expected to appear in the open literature.

The decalibrated picture is in the form of digital image data, much the same as the raw picture received in the form of telemetry from the spacecraft. The picture is broken up into video scan lines (800 for the RDR format versus 700 for the EDR); each scan line is divided into discrete samples called pixels (950 per line for the RDR versus 832 for the EDR). Each of the more than one-half million pixels represents the brightness in a small element of the picture by a numerical value ranging from 0 through 511. This range results from the use of a nine-bit binary representation for the "data number" (DN). The digital image processing that constitutes "decalibration" may be regarded as computing the proper value of the data number for each pixel from the data numbers for each pixel in the raw picture and the appropriate calibration files.

The decalibration processing steps were not identical for all pictures. First, there are variations dependent on the input data. The processing algorithms use different calibration data for each of the two cameras, and for each of the eight optical filters associated with camera A. In addition, residual-image correction could not be applied to a picture when the preceding raw picture from the same camera did not exist in complete form.

Second, as processing of RDR pictures proceeded, minor improvements were made to the processing algorithms and to the calibration data used in the correction processes. The variations in processing are identified by a decalibration code associated with each RDR picture. The decalibration enhancement code, or D-code, is available in the Enhancement Catalog, and its significance is fully described in Section V.

A further possible variation in RDR picture results is due to the existence of two sets of raw data: an EDR and a preliminary EDR that was available much earlier than the EDR. In general the EDR was of higher quality and more complete than the preliminary EDR. Since RDR processing was required to proceed on a rigid schedule, the preliminary EDR was used when the EDR was not yet available. The use of one or the other set of raw data for producing the RDR is also distinguishable from the D-code.

Occasionally, two or more reduced versions of a given raw frame were produced. This situation usually occurred when a picture was processed once early in the mission, and the processing algorithms, calibration data, or raw picture data used for it were later judged inadequate for a particular purpose. It was then reprocessed using the latest data and algorithms. Multiple RDR versions of a given raw picture are identified by multiple occurrences in the Enhancement Catalog with different D-codes.

Each digital RDR picture was recorded on magnetic tape. The use of the data on these tapes is facilitated by information given in Section II-F.

C. Picture Data

The pictures, which are the result of operations described above and in Section III and which are represented by the digital data recorded on the

RDR magnetic tapes, are in general very flat and lacking in contrast. If recorded on film, they would look very similar to the "raw" version of "real-time" pictures. Consequently, this version of the RDR pictures was never recorded on film. Instead, two special enhancement processes were applied to the RDR digital picture data. The two pictures resulting from these processes were recorded on film, and are the photographic versions of each unique TV frame comprising the RDR.

The two photographic versions are the contrast-stretched or albedo version, and the high-pass filtered version. These two processes were chosen to provide visually useful pictures of two different types. The first portrays the RDR with the relative brightnesses exaggerated in a linear fashion, but not distorted. This would be of primary interest to those interested in surface albedo. The second version suppresses the large scale variations in brightness and enhances the contrast of smaller features. This would be of primary interest to those interested in surface detail.

The contrast-stretched version is an attempt to match the range of RDR data numbers to the black-to-white dynamic range of the photographic medium. At each pixel, the data number from the RDR is subjected to a linear transformation of the form

$$d^c = 511 \frac{d^r - \ell}{h - \ell} \qquad (1)$$

where d^c is the contrast-stretched data number, d^r is the RDR data number,[1] and ℓ and h are low and high stretch limits. The constants ℓ and h represent the RDR data numbers displayed as black and white, respectively. They may be converted to scene luminance using the photometric scale factor as described previously and in Section III-C. The stretch limits are adapted to each RDR picture based on a histogram of the data numbers in

[1]RDR data numbers are in the range 0 to 511, and are proportional to absolute luminance through a photometric scale factor. See Section III-C.

that picture. They are chosen so that a selected percentage of pixels have data numbers below the lower limit, and a selected percentage have data numbers above the upper limit. The stretch limits appear in the label block of each contrast-stretched picture following the word STRETCH. The new picture consisting of the contrast-stretched data numbers is recorded on film, with data number 0 (or less) displayed as black, 511 (or more) displayed as white, and intermediate data numbers representing proportionate shades of gray.

The high-pass filtered version involves a somewhat more complicated algorithm employing a spatial filter. The data numbers in the filtered picture are computed from the formula

$$d^f_{jk} = \frac{511}{h - \ell}\left(d^r_{jk} - \frac{1}{(2M+1)(2N+1)} \sum_{m=-M}^{M} \sum_{n=-N}^{N} d^r_{j-m, k-n} + 256 - \ell\right) \quad (2)$$

where d^r_{jk} and d^f_{jk} are the data numbers for the pixels at line j, sample k, in the RDR and high-pass-filtered pictures, respectively, M and N are half the height and width, respectively, of the two-dimensional impulse response function, and ℓ and h are stretch limits as before. More details on the filter operation are given in Ref. 1.

Comparing Eqs. (1) and (2), it is seen that the filtering operation includes a linear contrast stretch as the final operation. As with the previous process, the stretch limit parameters h and ℓ are found in the picture label block. For almost all pictures, N = 0 and M = 75. The IPL Enhancement Catalog includes for each high-pass-filtered RDR picture an enhancement code of the form MDxx, where xx is a two-digit number specifying the parameters of this step in the process in more detail. These codes are defined in Table 1.

D. Picture Label Information

The label which accompanies RDR pictures (in fact, all pictures processed in the IPL) consists of two parts. The first six lines contain data that are independent of the data processing which has been applied, and includes raw TV frame identification and camera and spacecraft parameters. The remainder of the label contains information about data processing subsequent to receipt of the raw frame.

A typical RDR frame label is shown in Fig. 1. A list of the data quantities in the first six lines and the source for those data is shown in Table 2. Note that for some frames, data from the Supplementary Experiment Data Record (SEDR) were not inserted into the label, and asterisks appear in those fields. This was due to a variety of reasons, the two main ones being: (1) the SEDR was not available when the frame was decalibrated, and (2) only a preliminary version of the SEDR was available, and, in some circumstances, preliminary SEDR data were not inserted into the frame label. Data users should note that there is no guarantee that the TV SEDR data in an RDR frame label are from the final TV SEDR. Thus, any analysis that is sensitive to these data should be based on final TV SEDR data, not on data contained in the RDR frame label.

E. RDR Microfiche

The RDR picture data are being distributed in microfiche form. The data are being released in several parts to provide reduced data to the user as early as possible. Part I contains 116 cards in the COSATI format (60 images/card) as was used by the MTC/MTVS Microfiche Library. However, the pictures are not arranged in chronological order and only two enhancements are displayed for each of the 3500 frames (no replays). At the beginning two supplementary indices provide cross-reference information: DAS time versus card number and XY picture position per card; and microfiche card number and XY position versus DAS time, IPL roll number. The former index also supplies the Supplementary Experiment Data Record in the format illustrated in Fig. 2. Part II and subsequent releases may add up to 2000 additional frames. The complete set of microfiche will not, however, contain a reduced picture for every Mariner 9 picture.

F. RDR Data Tapes

The numerical data for each picture in the Mariner 9 RDR is recorded on standard 1/2-in. (1.27-cm) magnetic computer tape. Processing was performed on an IBM 360/75 computer, and the original tapes were written by standard IBM tape drives. This section gives sufficient information to allow the use of either the original RDR data tapes or copies of them. Since copies of tapes may not adhere to all aspects of the originals (for example, 7 track versus 9 track), the logical data format will be described first and then the physical format.

The RDR data tapes contain two files for each picture, arranged consecutively on the tape. The first file of the pair contains the video data for the RDR version of the picture. The second file, which always immediately follows the picture data, contains the location of each reseau mark in the raw (EDR) version of the picture. Each file is composed of a group of data records terminated by a tape mark (end-of-file). The logical record length is 1900 eight-bit bytes, corresponding to the fact that an RDR picture line has 950 samples, each of which is described by a 16-bit (2 byte) binary integer having a value between 0 and 511. The picture file has 800 records of video data, corresponding to the 800 video lines in an RDR picture. The reseau file has one record of reseau location data. Both types of file have header label records preceding the video or reseau data record(s).

Only the first 360 bytes of each label record are used. Each label record is broken down into 5 labels of 72 characters each. The first 68 characters of each label except the first appear graphically in the label block below the picture area of the photographic versions of the RDR. The last character of each label is a continuation character; an "L" appears in this position in the last label, while a "C" appears in all preceding labels. The record containing video line 1 or the reseau data follows the label record containing the last label. Figure 3 illustrates the data format.

Original RDR data tapes are in standard 7-track, IBM-compatible, 800-bpi (800-bit/2.54 cm), odd parity format. The data converter feature is used to pack the 8-bit bytes on the 7-track tape. The 1900-byte records are blocked three to a physical block. The block size is therefore 5700. (The OS JCL parameters are UNIT = 2400-2, DCB = (RECFM = FB, LRECL = 1900, BLKSIZE = 5700, DEN = 2, TRTCH = C)). There is a tape mark at the end of each file. Copies of these tapes may conform in all respects to the originals, or may differ in some details. Copies may be on 9-track tapes, and the blocking factor may be different. If the blocking factor is unity, the label blocks may be shortened to 360 bytes.

III. DATA PROCESSING ALGORITHMS

This section provides a detailed discussion of the data processing algorithms used in creating the RDR version of a picture from the EDR, or raw, version. The enhancement algorithms which were used to produce visual RDR images on film were already described in Section II-C.

"Decalibration" processing consists of three possible steps, corresponding to the three major types of distortion introduced by the camera and which are to be corrected. The first is geometric correction, the second is residual-image correction, and the third is photometric correction. Residual-image correction of a given frame requires the immediately preceding frame from the same camera. If this previous frame was not recorded, or is of poor quality, residual-image correction cannot be performed.

A. Geometric Distortion

Straightforward reconstruction of raw digital picture data from the Mariner 9 cameras produces pictures with severe geometric distortion. Figure 4 shows a calibration target consisting of a rectangular grid of uniformly ruled straight lines. Figure 5 is a picture of that target taken by a Mariner 9 camera, where the film was recorded using the raw, unprocessed digital video signal from the camera. The geometric distortion is evident in the curvature of the grid lines, especially near the edges of the picture. An effect not so readily seen in the distorted picture is a difference between the vertical and horizontal scales. This is due to the fact that the spacing between scan lines in the vidicon differs from the sample-to-sample spacing along a scan line by a ratio of about 0.9 to 1 (sometimes called the aspect ratio[2]). This effect can be compensated by recording the image on film using a display raster having the camera's non-unity aspect ratio, as was done for the Mission Test Computer (MTC) "real-time" picture products. The philosophy adopted in the RDR processing was that pixels would

[2]Not to be confused with the ratio of picture width to height which is also sometimes called "aspect ratio."

represent equal sampling intervals vertically and horizontally, corresponding to an aspect ratio of unity.

Correction for geometric distortion is the first step in the standard decalibration sequence of operations which produces the RDR version from a raw picture. This process can be thought of as the generation of a new digital video signal which, if recorded on film using a uniform raster of pixels, would produce an image with no geometric distortion. An image with no geometric distortion is defined as a perspective projection onto a plane of all points in the object scene. In other words, the point in the image plane corresponding to any object point is located on a straight line extended from the object point through a fixed point called the center of projection. The center of projection is located at a fixed distance, the effective focal length, from the image plane. Figure 6 illustrates the ideal perspective projection.

Correction of the digital image for camera system distortion is a specific instance of the general process of geometric transformation of digital images. The transformation algorithm used for geometric correction of Mariner 9 images is called GEOMA, and works as follows. The output picture size was chosen as 800 lines by 950 samples per line. This choice reflects a desire to avoid excessive loss of resolution due to the interpolation step of the algorithm, and yet not be so large as to cause excessive consumption of computer processing time in subsequent processing of RDR format images. An array of 111 control points is specified in terms of line and sample coordinates in the (800 × 950) output picture format. The reason for using 111 points is that there are 111 reseau marks appearing in each A camera picture. After a picture has been geometrically corrected, the reseau marks appear at the control point locations in the RDR picture; that is, the control point locations represent the "correct" reseau locations after correction. The B camera has reseau marks only at points numbered 1 through 63; control points numbered 64 through 111 for the B camera do not correspond to actual reseau marks and are called pseudo-reseau marks. Reseau marks are physically located on the sensitive surface of the vidicon and are used for determining the geometric distortion unique to each given frame. The exact coordinates for each control point in the RDR format were determined by a procedure described below.

Figure 7 shows the relative locations of the control points (and reseau marks), along with the numbering scheme adopted. The image field is divided into triangular regions by connecting neighboring control points as shown in Fig. 8. For each control point in the output picture, a corresponding location in the input (raw, distorted) picture is determined. For those control points which correspond to reseau marks, the raw frame locations are the actual locations of the reseau marks. These are determined by a separate program which finds each reseau mark in the raw frame by correlation with stored patterns representing each reseau mark in each camera. Reference 2 describes the automatic reseau location algorithm in detail. For the pseudoreseau control points, the raw frame locations are calculated as the average of nearby reseau locations. Within each triangular region, a linear two-dimensional transformation (Eq. 3)

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} \tag{3}$$

is uniquely defined by the requirement that the control point (reseau) locations in the raw picture transform to the predefined control point locations in the output picture. In Eq. (3), (x', y') represents a point in the input frame and (x, y) represents the corresponding point in the output picture. The coefficients $(a, \ldots, f)$ are computed for each triangular region. Notice that due to the linear transformations employed within the triangles, along the boundary between two triangles the transformation is the same regardless of which triangle's transformation coefficients are used. This fact implies that the total picture transformation is continuous across triangle boundaries.

For each pixel in the output picture, the sample value is computed as follows. First, the triangle containing the pixel is determined. Then the coordinates of the corresponding point in the input picture are computed, using Eq. (3) with the coefficients for that triangle. In general, this corresponding point will not have integral line and sample coordinates, and so will not correspond to an actual pixel in the raw picture, but will instead lie between actual pixels. The four nearest actual pixels are selected, and a bilinear interpolation is performed on the sample values of these four pixels. The resulting value is assigned as the sample value of the output picture pixel. This operation is repeated for each of the 800 by 950 pixels in the output picture. This completes the computer processing to generate a geometrically transformed picture.

During an extensive period of ground testing of the camera system, a series of geometric calibration data was recorded. This consisted of photographing the grid target shown in Fig. 4 and recording the raw picture data on a digital magnetic tape. Approximately four frames for each camera were used in the final data reduction. These frames were used to determine the locations of the control points ("correct" reseau locations) in the geometrically corrected pictures. In addition to the data taken by the cameras, the location of each target grid intersection in the camera's field of view was measured with a theodolite. This provided a set of "true" grid intersections.

In essence, the "correct" reseau locations were chosen such that, when the grid target frames are geometrically corrected, the grid intersections appear as close as possible, in a least-squares sense, to the "true" locations determined with the theodolite. The grid intersection locations in the raw calibration frames were determined automatically using a computer algorithm which looks for the intersections of vertical and horizontal lines. The determination of the "correct" reseau locations was carried out, not by actually performing a geometric correction of each frame, but instead by correcting only the automatically located grid intersections using Eq. (3). Starting with a trial set of "correct" reseau locations, the correction computations were carried out, and the computed corrected locations were compared with the "true" locations. The mean-square error was calculated, and a new set of "correct" locations was determined such that this mean-square error was reduced. When no further reduction in the mean-square error could be obtained by variation of the "correct" reseau locations, the process was terminated. The least-squares error minimization was carried out over all visible intersections in all four calibration grid frames.

Because the "true" grid locations can only be determined in relationship to each other, there are arbitrary translation and scale factors which cannot be determined by the above process. These were selected somewhat arbitrarily as follows. The translational position of the geometrically corrected picture is fixed by requiring that the center reseau mark (number 32) fall at the center of the RDR picture format: line 400, sample 475. The rotational position is fixed by requiring that video line 400 in the RDR picture format be the best straight-line fit, in the least-squares sense, to the center horizontal line of reseau marks (numbers 28 through 36). The scaling of RDR pictures is determined by selecting a scale factor relationship with the camera focal plane of 75 pixels/mm. That is, a distance of 1 mm in the actual camera focal plane is equivalent to a distance of 75 pixels in the RDR picture. The control point (reseau) coordinates in RDR pictures are given in Table 3. Figure 9 shows a grid target frame after correction for geometric distortion.

B. Residual-Image Reduction

The residual-image phenomenon, in which a picture from a vidicon camera is affected by preceding images, is quite complex. It is dependent on many factors in a way that is not totally understood. Even if an accurate physical model of the phenomenon were available, it is doubtful that it could be used due to the expected large amount of required calibration data. Experimental studies on residual image in the Mariner Mars 1971 camera system resulted in the development of a model based on two sequential frames. While it is recognized that the model is not totally accurate, it does not require an impossibly large amount of calibration data, it is suitable for automated data processing, and it significantly reduces the amount of residual in a given image.

The model used assumes that a given image is affected by only the immediately preceding image. Suppose I_1 and I_2 represent two sequential images which would have been recorded by a camera having no residual-image problem. Due to the residual-image effect, the second picture is distorted to $I_2' = I_2 + \zeta I_1$, where ζI_1 is a fraction of the first image present in the second. Figure 10 illustrates the problem with an actual pair of sequential images. The residue ζI_1 present in the second sequential image is expected to be a nonlinear function of several variables. These include:

(1) Wavelength of the incident light on the vidicon surface.

(2) Temperature of the camera system.

(3) Position on the vidicon surface.

(4) Intensity of the image being received.

(5) Intensity of the preceding sequential image.

The model used considers the residue in a given image to be a function of

(1) Location of a pixel in the image.

(2) Optical filter used.

(3) DN of a pixel in the given image, I_2'.

(4) DN of a pixel in the preceding image, I_1.

Measurement of residual image was obtained from the Flight 1 Bench 3 calibration. A complete set of calibration data is available for the B camera, while only filter positions 2 (orange) and 8 (violet) are available for the A camera. During the calibration, the temperature of the TVS approximated its expected nominal mission operating value. By combining this set of calibration data with less complete data on the other filter positions, calibration files have been generated for the B camera and for filter positions 2, 4, 6, 8 (orange, green, blue, and violet filters) of the A camera. The calibration file for the green filter is used for filter positions 1, 3, 5, 7 (the wide band and polarization filters).

After images I_1 and I_2' have been geometrically corrected, correct correlation of pixel locations in I_1 and I_2' is assured; correction for residual-image distortion is done at this point in the decalibration sequence.

Not every combination of possible DN values for both I_1 and I_2' and the corresponding residue ζI_1 for each pixel was measured. So the calibration files are organized to facilitate an interpolation algorithm. Figure 11 is a pictorial example of exactly one representative of the calibration file for the B camera. It is a 5 x 5 matrix: each element in the matrix is the residue ζI_1, corresponding to the DNs for I_1 (across the top) and I_2' (down the side). For example, given some location (i, j) in the RDR picture format, assume the DN for I_1 at that location is 117 and for I_2' is 77. Then the residue present at that location is 6.60 DN (using the matrix in Fig. 11):

$$I_2 = I_2' - \zeta I_1 = 77 - 6.60 \approx 70 \text{ at location } (i, j)$$

Keep in mind that for each pixel in the RDR format and in each calibration file, there is a 5 x 5 matrix. And the matrix in Fig. 11 can be thought of as the representative for location (i, j) relative to I_1 and I_2' in the B camera calibration file.

The algorithm to correct for residual-image distortion is implemented as follows. Given two sequential images I_1 and I_2 but read out as I_1 and $I_2' = I_2 + \zeta I_1$ and a picture element at location (i, j) to be corrected:

(1) Select the appropriate calibration file based on camera and filter position.

(2) Select the representative of the calibration file that corresponds to RDR location (i, j).

(3) Using the data numbers corresponding to I_1 and I_2' at (i, j), compute the residue ζI_1, using bilinear interpolation in the 5 × 5 (I_1, I_2') matrix.

(4) Subtract ζI_1 from I_2' at (i, j) to obtain the corrected pixel.

(5) Repeat this process for all (i, j) pixels in the image.

Figure 12 represents the image in Fig. 10 after the algorithm has been applied to it.

C. Photometric Distortion

The vidicon camera systems utilized for Mariner 9 introduce significant photometric distortion in the returned imagery. The distortion is caused by several complex physical processes occurring within the vidicon target material and while the image is being scanned with the electron beam. The net effect on returned imagery can be summarized as follows:

(1) The camera response to input light is nonlinear (i.e., linear increases in luminance result in nonlinear changes in the output digitized signal).

(2) The camera response varies nonlinearly with temperature.

(3) The camera response varies across the camera field of view.

(4) The camera response varies as different spectral filters are utilized.

(5) Imperfect erasure between successive exposures causes difficulties with residual image.

This section discusses the preflight camera calibration performed to characterize the first four of these phenomena. (The residual-image problem is discussed separately in Section III-B.) In addition, this section contains a detailed discussion of the calibration data processing performed to generate data files used in processing Mariner 9 flight images. The algorithm used to process flight images is also described, and the units of the Mariner 9 Television Reduced Data Record are explained.

1. Photometric Calibration. The basic calibration data set used to generate a photometric data file is the "light transfer sequence," which is a sequence of nine uniformly illuminated frames recorded at successively higher exposures starting with a dark current frame and ending with a frame for which some or all of the picture elements are saturated. For Mariner 9 these sequences were recorded a number of times for each camera system and for each filter on the A camera. Sequences exist for "bench calibrations" (calibrations taken on an optical bench, in air, with temperature regulated only by standard room air conditioning), "thermal vacuum calibrations" (calibrations at each of three temperatures taken with the camera system in a vacuum chamber with strict temperature control) and Spacecraft Assembly Facility (SAF) and Eastern Test Range (ETR) calibration verifications (camera system on the spacecraft with no strict temperature control and less precise photometry than is possible in either bench or thermal vacuum testing). The bench and thermal vacuum calibration data served as the basic data to be used in decalibrating flight data. The SAF and ETR tests were used only to evaluate the behavior of the TV subsystem on the spacecraft and to detect large deviations from past camera system performance.

The best existing summary of preflight camera photometric behavior is the Mariner 9 Television Subsystem Calibration Report (Ref. 3). Reduced photometric data for each light transfer sequence recorded on the flight cameras are contained in that report. For each light transfer sequence, luminance was incremented from zero to a level sufficient to exceed the system dynamic range in nine steps. At each step, a frame was recorded at a reference shutter speed, establishing the relation between input luminance and output digital DN (data number) at each pixel. For engineering evaluation of camera performance, this relationship was calculated for five areas of the camera field of view using DN averages over 100 x 100-pixel squares for each area. This relationship is called a light transfer curve. Light transfer sequences were recorded at least once for every filter position on the wide-angle A camera.

Average transfer data are sufficient to allow engineering evaluation of the camera systems, and the majority of the light transfer data contained in Ref. 3 is of this form. The five areas were selected to provide gross indication of the variation in response at different parts of the vidicon tube, and a comparison of this type of output for different temperatures can indicate the gross temperature variation in tube sensitivity. To support the stringent photometric requirements of the Mariner 9 mission, it was necessary for the Image Processing Laboratory to perform extensive analysis and reduction of the raw light transfer sequence data. The reduced light transfer data were combined into photometric calibration data files (PCDFs). To indicate the magnitude of this task, the light transfer data for the 100 x 100-pixel areas were generated by IPL within 24 hours of receipt of data, while the production of the actual PCDFs used in processing flight data took several months.

Although all calibration tests provided useful engineering data, hardware and procedural problems restricted the use of the majority of the photometric calibration data for generating final PCDFs. Table 4 tabulates the problems encountered and their effects. The selection of the appropriate data for use in the generation of PCDFs was dictated by what was left after all the invalid data was excluded. Table 5 designates the calibration data selected for the A and B cameras, and the PCDF resulting from their use. It is important to note that many of the problems described in Table 4 (e.g., negative residual image) were very subtle effects and were not discovered until long after the calibrations were performed.

Experience gained from TV calibrations performed for the Mariner Mars 1969 Project created an awareness of problems caused by the following distortions and defects: missing lines, bit errors, geometric distortions, residual image, random and periodic noises. Before an accurate relationship between digital DN and luminance can be established, these artifacts must be removed by digital computer processing. The next section describes the extensive processing effort required.

2. Computer Processing of Preflight Data. A detailed description of the reduction of calibration data is given in Ref. 5. The overall processing sequence is shown in Fig. 13. The specific steps in the processing are as follows:

a. The first step was a preliminary process of insuring the completeness of each image. A complete image is one that contains 700 lines and 832 elements of flat field data. To accomplish this goal, all missing lines were filled in by linear interpolation.

b. The filtering techniques applied to remove noise in subsequent steps produce serious artifacts associated with abrupt spatial discontinuities. Therefore, the reseau and mask portions of an image were replaced with the average DN value of surrounding or adjacent pixels. The reseau marks were removed by four-point bilinear interpolation over an eight-line by eleven-sample array centered about the midpoint of each mark. The mask, the black strip at the left and right sides, was removed by calculating the average DN of the pixels in the image adjacent to the mask, and then replacing mask pixels with this average.

c. Periodic and random noise must be removed from calibration data so that the decalibration process does not increase the noise present in flight data. The technique for removal involves the application of a two-dimensional "ramp" filter with horizontal and vertical sizes designed to provide maximum attenuation at the frequency of the primary periodic noise (2400 Hz). This frequency was measured from two-dimensional Fourier transforms. The effectiveness of this procedure was verified with difference pictures and measurements of noise variance.

d. Geometric distortions in the Mariner Mars 1971 camera system are a consequence of electronic and optical influences, with electronic effects dominating. The geometric distortion was observed to vary slightly from one frame to the next, and, in particular, to vary with the light level. Changes in geometric distortion are also associated with the change from Earth to space environments. Consequently, a pixel at given line-sample coordinates in raw frames does not represent a fixed location on the vidicon photosensitive surface. A fundamental assumption of the photometric calibration-decalibration process is that the responsivity of the vidicon can be completely characterized as a property of the photosensitive surface. To insure that the same pixel in every image for each camera represents the same vidicon location, light transfer calibration frames and all flight frames are first geometrically transformed to object space. Section III-A and Ref. 2 define the theory and procedure used to accomplish this transformation.

e. Residual image is that portion of a current image introduced by the charge left on the vidicon from some previous exposure on the same camera. This phenomenon persists even though each vidicon is erased 14 times between exposures. This effect must be removed as described in Section III-B before an accurate pixel DN-to-luminance relationship can be established.

f. All data files were generated for "reference" shutter speeds, 48 ms for the A camera and 12 ms for the B camera. Based on calibration data taken over the range of available shutter times, the cameras were observed to be reciprocal; if a frame was taken at a shutter speed t and exposure E, the exposure level stored in the data file, E_{ref}, was computed from

$$E_{ref} = \frac{Et}{t_{ref}} \tag{4}$$

where t_{ref} is the reference shutter speed. The shutter speeds utilized were the "nominal" shutter speeds: 3, 6, 12, 24, 48, 96, . . . , 6144 ms. This is discussed in more detail in Subsection 3, below.

g. The luminance level B_{max}, at which the entire vidicon saturates, was computed. If the entire vidicon is not saturated at the highest exposure level in the light transfer sequence, the light transfer behavior of the unsaturated portion of the vidicon was analyzed and a best estimate was input for each file, obtained by extrapolating the unsaturated data. The use of this value is discussed in Subsection 3, below.

The application of the processing steps described prepares the nine light transfer sequence frames for use as accurate photometric data. These nine frames relate geometrically and residual-image corrected pixel DNs to xenon lamp luminance. To use this spatial relationship more effectively, the nine individual frames are combined into a large data file known as a PCDF. This file can be thought of as a matrix of curves, one curve for each pixel in the RDR picture format, where each curve is represented by nine numbers, one number from each frame in the light transfer sequence.

PCDFs generated at calibration temperatures for a given camera and filter position are least-squares-fitted into an interpolated temperature PCDF. Interpolated files were generated whenever possible for each camera and filter position at temperatures bracketing the predicted Mars encounter temperature. For each pixel, the DN value for a given exposure level E at a temperature T is computed using a second-order fit:

$$DN(i, j, E, T) = A(i, j, E) + B(i, j, E)T + C(i, j, E)T^2 \tag{5}$$

where the constants A, B, and C are obtained from the three input calibration files at temperatures T_1, T_2, and T_3 using

$$\begin{bmatrix} A(i, j, E) \\ B(i, j, E) \\ C(i, j, E) \end{bmatrix} = \begin{bmatrix} 1 & T_1 & T_1^2 \\ 1 & T_2 & T_2^2 \\ 1 & T_3 & T_3^2 \end{bmatrix}^{-1} \begin{bmatrix} DN(i, j, E, T_1) \\ DN(i, j, E, T_2) \\ DN(i, j, E, T_3) \end{bmatrix} \tag{6}$$

for each pixel (i, j). This method is based on the assumption that the operating temperature is not far from the temperatures at which calibration data were taken.

3. Photometric Decalibration of Flight Data. This section describes the photometric correction of a Mariner 9 television frame using a photometric data file generated as described in Subsection 2, above. Before photometric correction is performed, the frame must be geometrically

transformed to the reference space in which the calibration data file is generated, and residual-image correction (if any) must be applied. Assuming these steps have been performed, the photometric correction consists of a pixel-by-pixel interpolation in the photometric data file to determine the luminance corresponding to an input DN at each pixel.

For each flight frame, with shutter speed t, the luminance levels from the PCDF are adjusted for shutter speed assuming reciprocity (Eq. 4). Also, for film recorder playback, the output is scaled by dividing the output luminance values by a constant that insures that the maximum luminance B_{max} will be equal to 511. The scaling constant is printed on the frame label and is on the RDR tape as part of the frame label, allowing conversion to units of foot-lamberts if required (1 ft-L = 3.42 cd/m^2).

The presence of saturated pixels in the input frame, and in the calibration data file, and the presence of the mask all make the photometric correction process somewhat more complicated. The flowchart in Fig. 14 presents each of the decisions made during photometric correction of an individual picture element.

Several important points should be noted when utilizing Mariner 9 RDR data for photometric analyses. These are:

a. All shutter speed adjustments are based on <u>nominal</u> camera shutter times. The actual shutter times differ from the nominal times, and the results from measurements made during component calibration (before final camera assembly) are presented in Ref. 3. However, post-calibration changes may have occurred, and there is no guarantee that shutter times measured during preflight calibration are valid for flight data. To the date of this writing, only preliminary work has been done to determine actual shutter speeds using in-flight data (Refs. 6 and 7). RDR users should be aware that large percentage errors are likely at the shorter shutter speeds.

b. All luminance units refer to calibrated xenon lamp units. The spectral reflectivity of Mars is different from the spectral characteristics of the light cannons used in calibration. It was not possible to assume a surface spectral model for each image, and thus all decalibrations were performed to xenon lamp units. All light transfer data in the calibration report (Ref. 3) are listed in these units, so users can utilize the calibration report as the standard reference. The calibration report also contains the spectral properties of the calibration light cannons, so that RDR users can compute the correct brightness conversion units once they have assumed a surface photometric model.

c. Photometrically corrected images exist in three versions as part of the Mariner 9 TV RDR. The numerical data for each image are on tape, and two enhanced versions of each image exist on film. Quantitative photometry should only be attempted through analysis of the numerical data. The enhancement processing and subsequent film processing used to create hard-copy film products totally destroy the brightness units of the RDR. Thus, densitometry of film products should never be utilized for precise photometric analysis. Also, note that the gray scales on each hard copy image are placed on the film only for quality control purposes. The gray scales are not photographed by the camera and bear no relationship to image brightness or detail within each image.

d. Based on several analyses (Refs. 6 and 7), significant changes in camera photometric performance have occurred after launch. During RDR processing, it was not possible to utilize the limited in-flight camera performance data to update camera photometric data files. Thus, all RDR data were processed using preflight photometric calibration data. Users of these data are advised to consult the existing analyses of in-flight camera performance (Refs. 6, 7, and 8) before undertaking precise photometric analysis based on RDR data.

e. The calibration of the polarization filters (3, 5, and 7) was minimal, due to resource constraints and the preflight plan that few frames would be taken through these filters. Consequently, only a single light transfer sequence (from Bench 3 calibration) was recorded for filter position 5. Unfortunately, a mechanical failure of the filter wheel occurred during orbit 118, causing all subsequent A camera pictures to be taken using filter position 5. The decalibration of all filter position 5 frames was based on a single light transfer sequence. No other light transfer data exist for this filter, and no adequate in-flight calibration was performed.

f. As has been mentioned, not all pictures in the RDR have been corrected for residual image, due to the occasional unavailability of the preceding sequential image from the same camera. Since the subsequent photometric correction is based on the assumption that residual-image correction has been performed, an error in photometry has thus been made. The error may be estimated from the residual calibration data, the raw frame data numbers, and a guess about the preceding frame data numbers. The error is usually of the order of 10%.

IV. PICTURE PROCESSING DOCUMENTATION

It is occasionally necessary to determine what data processing steps have been applied to a given picture. Documentation of data processing performed on each picture processed by IPL, including but not limited to the RDR, is contained in two places: the picture label and the IPL Enhancement Catalog. This section is intended to aid the user of Mariner 9 pictures in determining what processing steps have been applied to the picture data before it was recorded on film. Only picture products made by the Image Processing Laboratory are covered; so-called "real-time" products were produced by the Mission Test Computer (MTC) Facility and are excluded. A glossary will be presented as two tables listing processing descriptors and their definitions. First, some background information will be given to aid in interpreting the tables.

IPL received the Mariner 9 picture data in computer-readable form on magnetic tape. It remained in computer-readable form as long as digital processing was to be performed. The data were stored frame by frame. All processing was done by digital computer, using computer programs which operated on (usually) one version of one TV frame at a time to produce another version of that frame. The computer programs are general in nature, so it was usually necessary to execute a sequence of these programs to produce a specific desired effect; the version of a picture produced by one program is used as the input data for the next program in the sequence. After the final program in the chain has been executed, the resulting processed data are recorded on film transparency from which prints and other photo products can be made. Since it is no longer in computer-readable form, the film transparency cannot be subsequently processed by IPL.

In order to aid in determining what has been done to a picture, at any step in the processing sequence, the computer-readable data representing each version of each frame has a set of labels consisting of alphanumeric characters stored with it, also in computer-readable form. Whenever an individual program processes a set of data, a label is added to the set of input labels. Usually this new label is just the name of the processing program. Such names are always eight or less characters in length, and may be preceded by an asterisk (*). Sometimes variable parameters of the program are added; an extreme example is the mapping projection program which adds data sufficient to completely determine the map to which the picture has been projected. Thus, at any stage of processing, it is possible to get an indication of what has been done to a picture, up to that point, from the label. However, it is generally not possible to determine exactly what was done because the label will not indicate the parameters used with most programs. An extreme example is the program FILTER, which can produce a variety of different results, depending on the parameters used with the program. All of these different results would have the same label, "FILTER."

When the processed data are finally recorded on film, the label data are normally added in a block below the image area. When looking at a photo product, one may use the information in the label block, along with the descriptions in Table 6, to get an idea of what processing has been applied to obtain the particular picture version. RDR pictures may be identified by the occurrence in the frame label of the sequence:

GEOMA - FICOR71
TO CONVERT TO FT-L, MULTIPLY DN BY xxx
STRETCH xxx-xxx

The sequence "RESRED71, CORRECTED FOR RESIDUAL IMAGE" appears after "GEOMA" if such processing was performed, and "FASTFIL2" appears on the high-pass filtered version of the picture. An asterisk (*) normally precedes the program names, and indicates that the processing was performed on the production computer, an IBM 360/75.

An additional aid in determining what operations have been performed on a given picture is the IPL Enhancement Catalog. This catalog lists each frame by the DAS time identifier. For each original frame, the catalog lists each processed version which has been recorded on film or on magnetic tape. Film versions are indicated by entries under "Process Time" and "Roll No." Process time is a six-digit number appearing in the lower right corner of the label block of every picture, which distinguishes different pictures on a given film roll. Roll number usually appears in the label block, but was occasionally omitted. These two numbers can be used to reference uniquely a film version of a frame. Tape versions are indicated by entries under "Tape No." and "File." These numbers can be used to reference uniquely a version on tape.[3] In addition to the retrieval information, each version is described by a sequence of four-character "enhancement codes." The enhancement codes each stand for a process which has been applied to the picture data, and the sequence of enhancement codes indicates the order in which the processes were applied. The definitions of the enhancement codes are given in Table 1. An enhancement code may stand for a single program which has been executed, in which case the enhancement code would correspond to a single program name in the picture label. Examples are MAPG and RESR. In order to be economical with respect to the number of enhancement codes describing a given picture version, a single code may describe a sequence of programs. Examples are the codes for standard decalibration and standard rectification and scaling. Sometimes a program name or description appears in the picture label which is not covered by an enhancement code. This is the case when the program's functional emphasis is not on fundamental change to the picture data, but rather a superficial one not ordinarily of interest to the end user. For example, certain programs such as PIXH and HB71 are concerned primarily with data format, and would therefore not correspond to any enhancement code.

RDR versions of pictures may be identified in the Enhancement Catalog by the enhancement code Dxxx, where xxx is a number expressing details of the processing as described in Table 1. The tape version has only this code, and a tape number with the prefix "TVR." The photographic versions have this code, followed by CSL for the contrast stretched version, and by

[3]Because tapes may be recycled, the frame may not actually be available as indicated by the catalog. RDR tapes (prefix TVR) are not subject to recycling.

MDxx for the high-pass filtered version, where xx is a number expressing specific parameters of the processing.

V. LIMB PROFILE MICROFICHE

Approximately 850 Mariner 9 pictures of the Martian limb have been processed to produce plots of data number versus position along straight lines perpendicular to the limb. These plots, along with two enhanced versions of each picture, have been collected and photographed onto microfiche to comprise the Limb Profile Microfiche Library.

This library contains nearly 200 cards consisting of an index catalog, photographs, and limb plots arranged in the COSATI format (≤60 images/card). The data are approximately in DAS time sequence; however, reference to the index file will be necessary in many cases. Each catalog entry contains basic camera information, including latitude-longitude and Sun elevation and phase angles for points on the limb near the edge of a given frame; Fig. 15 shows the format of the catalog as anticipated at the time of this writing.

Each card contains up to five individual frames, together with enhancements and plots arranged according to row. For example, beginning at the left side: (1) RDR high-pass-filtered image to show surface detail, (2) special contrast-enhanced image to show atmospheric detail (on both photographs the positions of the corresponding limb plots are indicated together with supporting data), and (3) up to eight plots with relevant information. Figure 16 shows a typical plot format of data number versus relative sample (pixel) number. Users are cautioned that the data number plotted in the limb profiles is one-half the RDR data number. This fact is essential in making inferrences about absolute luminance values. Directly beneath the abscissa scale is the corresponding radial altitude (km) based on the spacecraft range to the limb. Also found in the data block are the DAS time, principal investigator identifier (revolution, camera, picture number/total number of pictures per revolution), latitude, longitude, Sun elevation, phase angle, and Sun azimuth at the point of limb crossing (line and sample), scale (km/pixel), and the starting and ending coordinates (line and sample) of the scan in the RDR picture.

Further information concerning Mariner 9 limb profile calculations may be found in Volume I of the Mariner Mars 1971 Television Picture Catalog (Ref. 10).

The Mariner 9 Limb Profile Microfiche Library will be available in June 1974 at the National Space Science Data Center, GSFC, Greenbelt, Maryland 20771.

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Table 1. Enhancement catalog code definitions

Code	Definition
AVG	Low-pass filter, subsample
BITR	Bit error removed
BLEM	Blemishes removed
BLOG	Logged from BCE tape
CNR	Coherent noise removal
CNTR	Contoured
COMP	Data complemented
CONC	Concatenated with one or more other pictures
CONX	Contrast stretch
CPRO	2-standard conic projection
CR	Has been used in color reconstruction
CSL	Contrast stretch, linear
CST	Contrast stretch, table
DG	Standard decalibration geometric correction
DIFF	Differenced with another frame
DPC	Standard decalibration photometric correction
DRI	Standard decalibration residual-image processing
Dxxx	Standard decalibration processing, including geometric correction, possible residual-image correction, and photometric correction. The "xxx" specifies details that were subject to variation. Odd numbers specify the absence of residual-image correction, and even numbers specify that this correction is included. Explanation of "xxx" codes for standard processing: 001, 002 — Special geometric correction using the correction generated for DAS 00603702 for all frames; preliminary EDR data tapes.

Table 1 (contd)

Code	Definition	
Dxxx (contd)	003, 004	Same as above, but with updated photometric calibration data file for B camera.
	005, 006	Same as above, but with normal geometric correction.
	007, 008	Same as above, but with updated photometric data file for A camera, filter position 2, and improved extrapolation algorithm in residual-image correction program.
	009, 010	Same as above, but with correction for random bit errors in raw video data.
	011, 012	Same as above, but with improved reseau location algorithm (RESEAU72).
	013, 014	Same as above, but with EDR data tapes (all previous codes imply use of preliminary EDR data).
	015, 016	Same as above, but with improved algorithm for correcting bit errors in label data.
	017, 018	Same as above, except preliminary EDR data tapes are used.
FA	Has been averaged with at least one other frame	
FRD	Has been registered and differenced with at least one other frame	
FREG	Registered with another frame	
GDyy	General-purpose automated production processing, where the "yy" defines the details of the processing as shown below.	
	Explanation of "yy" codes for general-purpose processing:	
	10	a. Use EDR as input.
		b. Locate reseau coordinates and save onto E-tape.
		c. Filter with two-dimensional filter.
		d. Contrast enhanced linear 10%.

Table 1 (contd)

Code			Definition
GDyy (contd)		e.	Map grid superimposed.
		f.	Masked onto V-tape.
	12	a.	Use EDR as input.
		b.	Contrast enhanced linear 12%.
		c.	Masked onto V-tape.
	13	a.	Use EDR as input.
		b.	Filter with one-dimensional filter.
		c.	Contrast enhanced linear 244-270.
		d.	Masked onto V-tape.
GRAD	Direction of gradient		
GRAM	Magnitude of gradient		
GRID	Latitude-longitude grid overlayed		
GTS	Special geometric transformation		
LADL	Limb scan lines overlayed		
LPRO	Lambert conformal projection		
MAPG	Pixel grid overlayed		
MDxx	"Maximum discriminability" processing: high-pass filter followed by linear contrast stretch. The "xx" code details the parameters for the programs used as follows:		
	01	FASTFIL2: NLW 151 NSW 1 THRESH 50 MM71 ASTRTCH2: HALF COMP HIST SPIKES 1	
	02	FASTFIL2: NLW 151 NSW 1 THRESH 50 MM71 MASK: HALF COMP HIST STRETCH 246 266	
	03	FASTFIL1: NLW 1 NSW 101 THRESH 25 MASK: COMP HIST STRETCH 123 133	
	04	FASTFIL1: NLW 1 NSW 101 THRESH 25 ASTRTCH2: COMP HIST	

Table 1 (contd)

Code		Definition
MDxx (contd)	05	FASTFIL1: NLW 1 NSW 151 THRESH 25 MASK: STRETCH 123 133
	06	FASTFIL2: MM71 ASTRTCH2: HALF COMP HIST
	07	FASTFIL2: NLW 151 NSW 11 MM71 STRETCH: HALF LINEAR 246 266
	08	FASTFIL2: MM71 NLW 151 NSW 1 STRETCH: LINEAR 246 266
	09	FASTFIL2: NLW 151 NSW 1 THRESH 50 MM71 MASK: HALF COMP HIST STRETCH 246 269
	10	FASTFIL2: NLW 151 NSW 1 THRESH 25 MM71 STRETCH: HALF LINEAR 246 269
	11	FASTFIL2: NLW 151 NSW 1 THRESH 50 MM71 STRETCH: HALF LINEAR 246 269
	12	FASTFIL2: NLW 151 NSW 1 THRESH 50 MM71 STRETCH: HALF LINEAR 246 269
	13	FASTFIL2: MM71 THRESH 25 ASTRTCH2: HALF
	14	FASTFIL2: NLW 151 NSW 1 THRESH 50 MM71 STRETCH: HALF LINEAR 240 277
	15	FASTFIL2: MM71 NSW 151 NLW 1 THRESH 25 STRETCH: HALF LINEAR 240 277
	16	FASTFIL2: NLW 151 NSW 1 THRESH 25 MM71 STRETCH: HALF LINEAR 246 269
	17	FASTFIL2: NLW 151 NSW 1 THRESH 25 MM71 STRETCH: HALF LINEAR 239 275

(The program parameters listed may not be completely intelligible without the corresponding program documentation available from the Image Processing Laboratory. The numbers following "NLW" and "NSW" are, respectively, 2M + 1 and 2N + 1, where M and N are defined in Section II-C. The two numbers following "STRETCH" or "LINEAR" are lower and upper stretch limits, ℓ and h, defined in Section II-C. The other parameters should be of minor concern.)

Table 1 (contd)

Code	Definition
MOS	Has been computer mosaiced with at least one other frame
MPRO	Mercator projection
OLAY	Latitude-longitude grid overlayed
OPRO	Orthographic projection
ORIG	Original raw picture
PCL	Linear photometric correction
PCS	Special photometric correction
PR	Has been ratioed to at least one other frame
PRCF	Linear photometric correction, bit error correction
PS2	Two-dimensional power spectrum
RESR	Reseaux removed by four-point bilinear interpolation
RIS	Special residual-image process
ROTT	Rotated
Rxyy	Standard rectification and scaling processing. The "x" code indicates the projection type, and the "yy" code specifies details of the associated processing as shown below.
RSyy	Orthographic projection. Explanation of "yy" codes for orthographic projection is as follows:
	01 Preliminary EDR data tapes used; fixed geometric correction transformation (rather than adapted to each frame, as in RDR processing).
	02-05 RDR data tapes used; reseau marks removed by interpolation.
	06 RDR data tapes used; reseau marks and three major A camera blemishes removed by interpolation.

Table 1 (contd)

Code	Definition		
RLyy	Lambert conformal conic projection		
RMyy	Mercator projection		
RPyy	Polar stereographic projection		
	Explanation of "yy" codes for Lambert, Mercator, and polar stereo projections:		
	01	a.	Reseau removed.
		b.	A camera blemishes removed.
		c.	MD17 applied.
		d.	Truncated to byte data.
		e.	Projected (background set to zero).
		f.	Masked onto E-tapes.
	02	a.	Reseau removed.
		b.	A camera blemishes removed.
		c.	MD17 applied.
		d.	Truncated to byte data.
		e.	Projected (background set to 121 DN).
		f.	Masked onto E-tapes.
	03	a.	Reseau removed.
		b.	A camera blemishes removed.
		c.	Truncated to byte data.
		d.	Projected (background set to zero).
		e.	Written on save tape.
	04	a.	Reseau removed.
		b.	A camera blemishes removed by percentage models.

Table 1 (contd)

Code			Definition
RLyy RMyy RPyy (contd)		c.	MD17 applied.
		d.	Truncated to byte data.
		e.	Projected (background set to 121 DN).
		f.	Masked onto E-tapes.
	05	a.	Reseau removed.
		b.	Blemishes removed.
		c.	Filtered 151 lines × 1 sample threshold 25.
		d.	Truncated to byte data.
		e.	Projected (background set to zero).
		f.	Written on save tape.
		g.	Histogram generated.
	06	a.	Contrast enhanced linear percent 10.
		b.	Truncated to byte data.
		c.	Projected (background set to 121 DN).
		d.	Masked onto E-tape.
	07	a.	Reseau removed.
		b.	First 40 and last 40 lines replaced with 41st and 760th, respectively.
		c.	A camera blemishes located at line 155, sample 190, and line 285, sample 866, removed by quantitative correction.
		d.	A camera blemish at line 5 and 7, sample 155, removed by four-point bilinear interpolation.
		e.	MD17 applied.
		f.	Truncated to byte data.

Table 1 (contd)

Code		Definition
RLyy RMyy RPyy (contd)		g. Projected (background set to 121 DN).
		h. Masked onto E-tape.
	08	a. Truncated to byte data.
		b. Projected (2000 × 2000 output image size)
		c. Masked onto E-tape.
	09	Same as "07" except projection output image size was 2000 lines × 2000 samples.
SCRB	Segment of picture scribed	
SFHP	Special filtering, high pass	
SFLP	Special filtering, low pass	
SFS	Special filtering	
SFTR	Special high emphasis filter, also known as "GP filter" or "Rindfleisch filter"	
SMAG	Segment of image magnified	
SMTF	Standard MTF filtering	
SPRO	Special projection	
STPR	Stereographic projection	
SUNN	Correction for solar illumination angle variation	
VARI	Variance plot	

Table 2. TV RDR frame label data description

Quantity	Description	Data source[a]
Picture ID	XXXCNN/TTD, where	
	XXX = orbit number	Hand input via TV SEDR
	C = camera ID (A or B)	TV EDR
	NN = picture number on this orbit	Hand input via TV SEDR
	TT = total number of images on this orbit	Hand input via TV SEDR
	D = discipline group indicator (e.g., this image is of interest to geodesy group)	Hand input via TV SEDR
Year, day, GMT	Year, day and GMT when data were received on the Earth	TV EDR
DAS time	DAS time of start of readout of line 1 of this image (DAS time is simply a numerical count maintained in the spacecraft and which is incremented every 1.2 seconds throughout mission) This is the primary identification used to index and catalog Mariner 9 pictures.	TV EDR
Picture number	Cumulative picture count since start of mission	Hand input via TV SEDR
Exp time	Shutter speed for this frame	TV EDR
Filter pos	A camera filter position or * for B camera	TV EDR

[a]Data obtained from the TV EDR originated in the spacecraft or in the ground telemetry processor. Data obtained from the TV SEDR was computed on the ground from raw telemetry data, except for the hand input quantities.

Table 2 (contd)

Quantity	Description	Data source[a]
View zenith angle	Angle between ray from spacecraft to surface and surface normal at center of field of view; deg	TV SEDR
Solar zenith angle	Angle between ray from Sun to surface and surface normal at center of field of view; deg	TV SEDR
Phase angle	Angle between ray from Sun to surface and ray from spacecraft to surface, at center of field of view; deg	TV SEDR
Longitude:		
Center	Longitude on surface at center reseau mark; deg	TV SEDR
Corners	Longitude on surface at corner reseau marks, given in following order: upper left, upper right, lower left, lower right; deg	TV SEDR
Latitude: Center/ corners	Corresponds to longitude data. When latitude-longitude data are missing for a particular reticle mark but other SEDR data are present, it indicates the line of sight through that reticle mark does not intersect the planet surface.	TV SEDR

[a]Data obtained from the TV EDR originated in the spacecraft or in the ground telemetry processor. Data obtained from the TV SEDR was computed on the ground from raw telemetry data, except for the hand input quantities.

Table 3. Coordinates of control points (reseau marks) in RDR format pictures

Control point No. [a]	Camera A		Camera B [b]		Control point No. [a]	Camera A		Camera B [b]	
	Line	Sample	Line	Sample		Line	Sample	Line	Sample
1	42.434	14.708	45.199	19.456	57	758.753	204.774	757.706	203.129
2	41.413	69.067	42.884	71.446	58	758.769	339.906	757.579	339.434
3	41.230	204.927	41.844	204.505	59	758.871	474.795	757.935	474.767
4	40.421	339.124	42.420	340.244	60	759.069	610.620	757.942	609.490
5	40.946	474.796	42.052	475.290	61	758.714	745.529	758.079	744.292
6	40.311	610.311	42.111	610.336	62	759.657	881.045	758.303	879.539
7	39.818	746.342	42.569	745.137	63	760.378	938.119	756.072	932.087
8	40.121	881.955	43.204	879.574	64	85.165	13.491	88.907	17.908
9	42.024	937.488	42.659	935.277	65	84.808	136.839	86.995	137.953
10	131.046	12.493	131.998	16.232	66	84.378	271.905	86.422	272.412
11	131.144	69.894	129.688	70.593	67	84.134	407.131	86.635	407.652
12	131.049	204.357	129.512	204.770	68	83.945	543.010	86.567	542.759
13	130.777	339.533	130.183	340.298	69	83.362	678.348	86.638	677.240
14	130.475	475.124	129.977	475.063	70	83.185	813.828	87.792	811.472
15	130.181	610.428	130.454	610.372	71	84.778	938.986	88.091	934.615
16	129.951	746.031	130.257	745.083	72	196.848	13.565	199.501	15.970
17	130.491	881.854	130.774	880.455	73	197.067	136.847	198.123	138.351
18	130.971	939.070	131.386	934.296	74	196.879	271.705	197.738	272.235
19	265.392	12.259	265.956	15.064	75	196.739	407.098	197.748	407.258
20	266.360	68.990	264.857	69.830	76	196.556	542.850	197.692	542.754
21	266.161	204.216	265.039	205.177	77	196.067	678.440	197.930	677.099
22	266.377	339.412	264.905	339.707	78	196.049	813.724	198.383	811.501
23	265.991	475.013	264.976	475.130	79	197.127	938.338	199.088	933.697
24	265.614	610.558	264.941	610.303	80	331.882	12.516	333.918	15.455
25	265.401	745.929	265.535	745.185	81	332.282	136.501	333.078	137.840
26	265.449	881.749	265.396	880.468	82	332.134	271.834	332.681	272.487
27	266.335	938.629	265.646	935.539	83	332.094	407.208	332.494	407.497
28	399.482	12.125	401.170	15.053	84	331.753	543.097	332.427	542.916
29	399.971	68.964	400.020	69.906	85	331.888	678.351	332.521	677.183
30	400.098	204.234	399.842	204.844	86	331.472	814.039	332.818	811.811
31	400.040	339.553	399.802	339.835	87	332.424	939.009	332.787	934.829
32	400.000	475.000	400.000	475.000	88	467.775	12.963	468.700	15.532
33	399.666	610.679	399.960	610.072	89	467.674	136.689	467.637	137.697
34	399.541	746.018	400.153	744.894	90	467.783	271.814	467.453	272.298
35	399.357	881.887	400.168	880.134	91	467.706	407.182	467.420	407.282
36	400.097	938.739	399.944	935.835	92	467.502	542.930	467.465	542.997
37	534.472	12.689	536.315	15.253	93	467.300	678.143	467.278	676.978
38	533.589	69.362	535.061	70.393	94	467.388	813.944	467.036	812.107
39	533.926	204.315	534.834	204.704	95	467.800	938.551	467.294	934.058
40	533.781	339.489	534.886	339.645	96	603.034	13.026	603.319	16.328
41	533.616	474.908	534.921	474.900	97	602.932	136.956	602.326	138.057
42	533.773	610.561	535.099	609.896	98	603.050	271.746	602.228	272.500
43	533.448	745.511	534.682	744.875	99	602.910	407.231	602.374	407.202
44	533.337	881.425	535.267	879.834	100	602.628	542.951	602.129	542.887
45	534.435	938.838	535.532	934.277	101	602.740	678.289	601.953	677.075
46	669.027	12.458	670.665	16.836	102	602.894	813.376	601.556	811.473
47	668.836	69.112	669.290	70.626	103	603.559	938.937	600.814	933.922
48	668.871	204.352	670.105	204.340	104	714.988	13.012	714.029	18.016
49	669.061	339.631	669.934	339.496	105	715.251	136.828	713.407	137.839
50	668.884	474.941	669.976	474.693	106	715.529	271.764	713.492	272.280
51	669.260	610.395	670.023	609.842	107	715.326	407.164	713.649	407.305
52	668.918	745.542	669.886	744.717	108	715.488	542.641	713.438	542.747
53	669.099	881.242	670.619	879.510	109	715.076	678.246	713.366	676.901
54	670.096	938.659	669.867	934.686	110	715.317	813.464	712.887	810.960
55	758.124	14.411	757.394	19.304	111	716.137	938.573	712.889	933.446
56	758.662	69.263	757.277	70.316					

[a] Numbering scheme is shown in Fig. 7.

[b] There are no reseau marks corresponding to points numbered 64 through 111 for camera B.

Table 4. Calibration test problems and effects

Calibration	Date	Comments
Bench 1	7/9/70	a. Temperature data not recorded.
		b. Because of new predicted encounter temperature, the TVS gain was subsequently reset and all photometric data from this test was rendered invalid.
		c. Imaging targets preceded photometric light transfer sequences resulting in residual image distortion of up to 20 DN to first sequence.
Environmental 1 Environmental 2 Environmental 3	7/24/70 7/28/70 7/29/70	a. Above reset of gain rendered these data invalid also.
		b. Imaging targets preceded photometric light transfer sequences resulting in residual image distortion of up to 20 DN to first sequence.
Environmental 4 Environmental 5 Environmental 6	8/19/70 8/20/70 8/21/70	a. B camera frames rendered invalid by replacement of B camera vidicon in September 1970.
		b. The A frames were illuminated with the 30.48-cm (12-in.) light cannon which had a different spectral response than the 12.70-cm (5-in.) light cannon utilized on all other calibrations. Analysis by the TVS engineering group resulted in a memorandum (Ref. 4) stating that the data was valid and could be used to photometrically correct flight frames.
		c. Imaging targets preceded photometric light transfer sequences resulting in residual image distortion of up to 20 DN to first sequence.

Table 4 (contd)

Calibration	Date	Comments
Bench 2	8/25/70	a. B camera vidicon replacement rendered this data invalid.
		b. Temperature data not recorded.
		c. Imaging targets preceded photometric light transfer sequences resulting in residual image distortion of up to 20 DN to first sequence.
Bench 2A	10/26/70	a. B camera frames exposed out of focus.
		b. Temperature data not recorded.
		c. Imaging targets preceded photometric light transfer sequences resulting in residual image distortion of up to 20 DN to first sequence.
Bench 2B Bench 2C	10/29/70 11/10/70	a. Temperature data not recorded.
		b. Imaging targets preceded photometric light transfer sequences resulting in residual image distortion of up to 20 DN to first sequence.
Environmental 7	11/3/70	a. Scene brightness target overexposed on B camera beyond decay point. This introduced negative residual image in subsequent B frames rendering them invalid.
		b. Imaging data preceded light transfer data.
Environmental 8	11/4/70	a. Negative residual image introduced during Environmental 7 rendered B frames invalid.

Table 4 (contd)

Calibration	Date	Comments
Environmental 9	11/5/70	a. Imaging targets preceded light transfer data.
Bench 3	2/3/71	a. Temperature data not recorded.
SAF cal verification	11/30/70	a. Temperature data not recorded.
ETR tests	3/24/71 to launch	a. Temperature data not recorded.

Table 5. Calibration data selected for use in generating temperature-interpolated PCDF

Camera	Filter	Calibration test name and temperature	Temperatures of interpolated PCDFs
B	-	ENV-9: -13.9°C	5.0°C
		BENCH-3: 25 ±3°C	10.0°C
			15.0°C
A	1	ENV-4: 18.4°C	2.22°C
		ENV-5: 2.8°C	7.22°C
		ENV-6: -12.2°C	12.22°C
A	2	ENV-4: 18.4°C	4.71°C
		ENV-8: 2.2°C	7.22°C
			12.81°C
A	3	BENCH-3: 25 ±3°C	
A	4	ENV-7: 18.3°C	2.22°C
		ENV-8: 2.2°C	7.22°C
		ENV-9: -12.2°C	12.22°C
A	5	BENCH-3: 25 ±3°C	
A	6	ENV-7: 18.3°C	2.22°C
		ENV-8: 2.2°C	7.22°C
		ENV-9: -12.2°C	12.22°C
A	7	BENCH-3: 25 ±3°C	
A	8	ENV-7: 18.3°C	2.22°C
		ENV-8: 2.2°C	7.22°C
		ENV-9: -12.2°C	12.22°C

Table 6. Picture label code definitions

Label	Inserted by program...	Function
GEOMA	GEOMA	Geometric transformation program; usually used to perform geometric decalibration, but may be used to perform any type of geometric transformation such as simple linear expansion of pixel format.
FICOR71	FICOR71	Photometric correction program for Mariner 9 pictures. The algorithm is described in Ref. 9.
TO CONVERT TO FT-L, MULTIPLY BY . . .	FICOR71	This message is added to the label by FICOR71 to provide the proper conversion factor from RDR data numbers to luminance in foot-lamberts.
STRETCH	STRETCH	Program for almost any pixel-by-pixel operation on a picture; usually used for contrast enhancement or contouring of the bit-clip type. The label may be followed by two numbers separated by a hyphen; this indicates a linear contrast stretch where the two numbers are the original DNs which have become black and white, respectively, on the enhanced picture.
...PROJECTION	MAP2	General-purpose mapping program for performing Mercator, Lambert Conformal, Polar Stereographic, and Orthographic map projections. Other data in the label block gives the particular parameters of the map such as scale, orientation, and location.
RESSAR	RESSAR	The reseau marks are eliminated by interpolation from the surrounding pixels.
SAR	SAR	General-purpose program for interpolating within a rectangular region; sometimes used to eliminate a blemish.

Table 6 (contd)

Label	Inserted by program...	Function
BLEM2	BLEM2	Special program for removing the two prominent dust speck shadows in the upper right corners of A camera frames. The data numbers within the blemishes are multiplied by a correction factor. Occasionally a ring-shaped artifact may remain.
NOISREM	NOISREM	Program for optimally subtracting a noise pattern from a picture, based on local correlation. This program is part of a sequence used for coherent noise removal.
QSAR	QSAR	Adds a constant (positive or negative) to each pixel in specified rectangular regions of a picture.
PSAR	PSAR	Adds a constant (positive or negative) to each pixel in specified polygonal regions of a picture.
ROTATE	ROTATE	Rotates a picture 90 deg clockwise or counterclockwise.
ROTATE2	ROTATE2	Rotates a picture by an arbitrary specified angle.
FLOT	FLOT	Rotates a picture 90 deg clockwise or counterclockwise, or "reflects" the picture across a vertical or horizontal centerline.
LGEOM	LGEOM	Performs same function as GEOM; only difference is in the computer algorithm.
CONCAT	CONCAT	Creates a picture consisting of several separate pictures juxtaposed. Only the label of the upper left segment is retained.

Table 6 (contd)

Label	Inserted by program...	Function
PICAVE	PICAVE	Averages several pictures, pixel by pixel. Only the label of the first one specified by the analyst is retained.
BLEM3	BLEM3	Program for removing the dust speck shadow in the lower left corner of A camera frames. The algorithm is a bilinear interpolation within a rectangular area circumscribing the blemish.
FILTER	FILTER	General-purpose convolution program used for MTF correction. May also be used for various special purpose filters too numerous to describe.
DIFFPIC	DIFFPIC	Add or subtract two pictures, pixel by pixel.
PIXH	PIXH	Program to add, subtract, multiply, or divide two pictures, pixel by pixel; may also be used to add, subtract, multiply, or divide one picture by a constant value.
GEOM	GEOM	Geometric transformation program; often used to linearly expand the pixel format, but may be used to perform a variety of geometric transformations.
GRID LAT INC = ...	OVERLAY	Overlays picture with a latitude-longitude grid. The label describes the grid spacing.
FFT2	FFT2	Two-dimensional Fourier transformation.
FFTPIC	FFTPIC	Program for converting the complex data in a Fourier transform into conventional 8-bit integer format, suitable for making a brightness display. The data numbers generated, and thus the brightness in a

Table 6 (contd)

Label	Inserted by program...	Function
FFTPIC (contd)	FFTPIC (contd)	resulting picture, may represent the AMPLITUDE (modulus), INTENSITY (modulus squared), or PHASE of the original complex samples. The label will describe which format was selected.
SPIKMASK	SPIKMASK	Program for multiplying a complex format Fourier transform by an integer format picture. This program is part of a sequence used for coherent noise removal.
MAPGRID	MAPGRID	A reference grid has been superimposed on the picture. This is usually done to aid in locating particular pixels by line and sample position. It is not related to mapping.
IPL ROLL NO. ...	(inserted by analyst)	This label indicates the IPL roll number according to which the negative is filed in the Science Data Library.
FASTFIL2	FASTFIL2	General-purpose high-pass filter program used for suppressing low spatial frequency content of a picture. The algorithm is described in Ref. 1.
NINE BIT DATA TRUNCATED TO EIGHT BITS	HB71	The original data range (0--511) has been compressed to 0--255 by eliminating the least-significant bit of the nine-bit representation. This is usually done when a subsequent program is used which cannot process the original data range.
RESRED71 CORRECTED FOR RESIDUAL IMAGE	RESRED71	Residual-image correction performed.
SUNANGLE MINNAERT ...	SUNANGLE	Compensation for varying solar illumination and phase angles within the picture field of view.

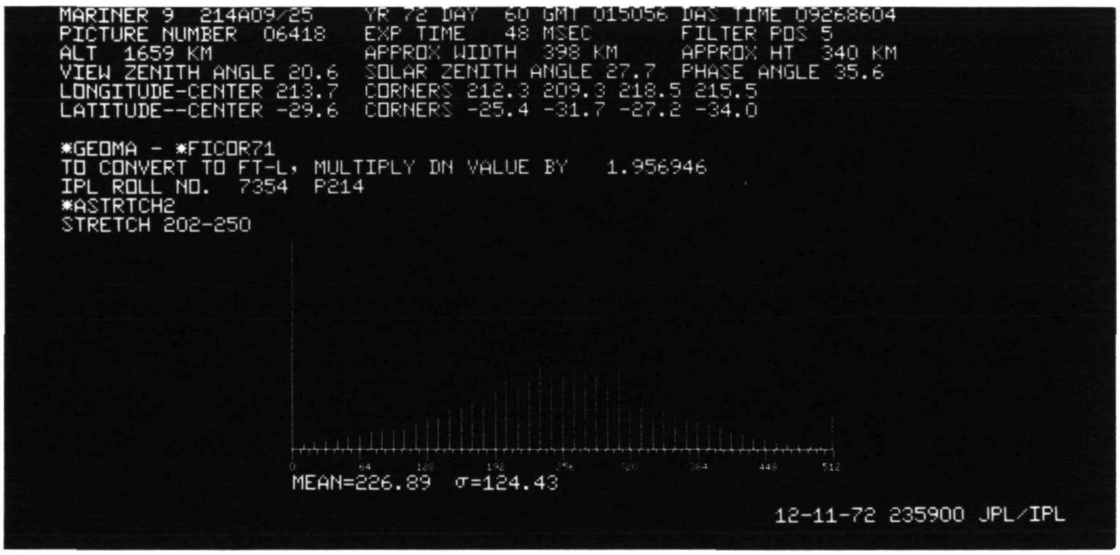

Fig. 1. Typical RDR frame label

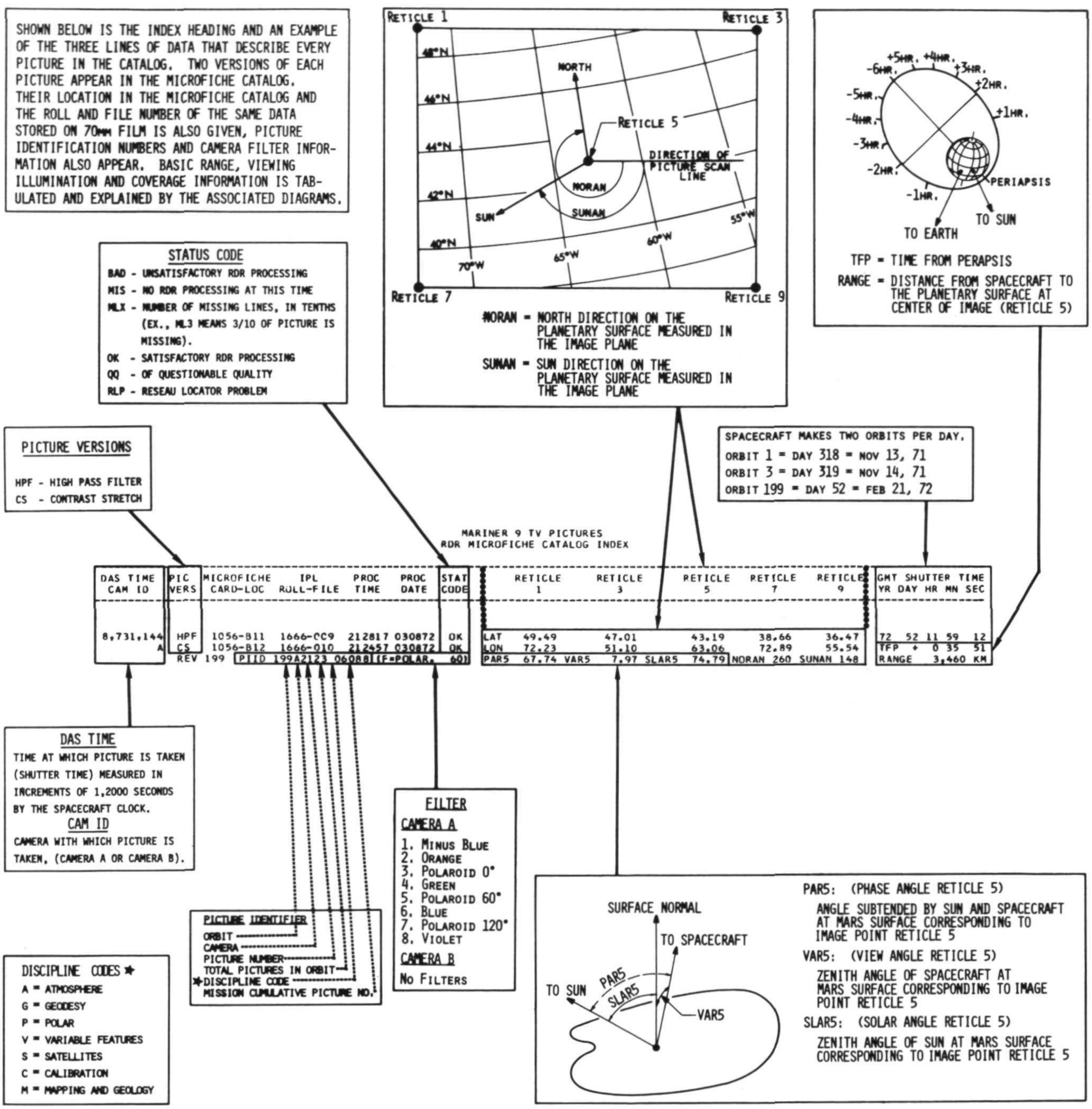

Fig. 2. Explanation of data on microfiche catalog index

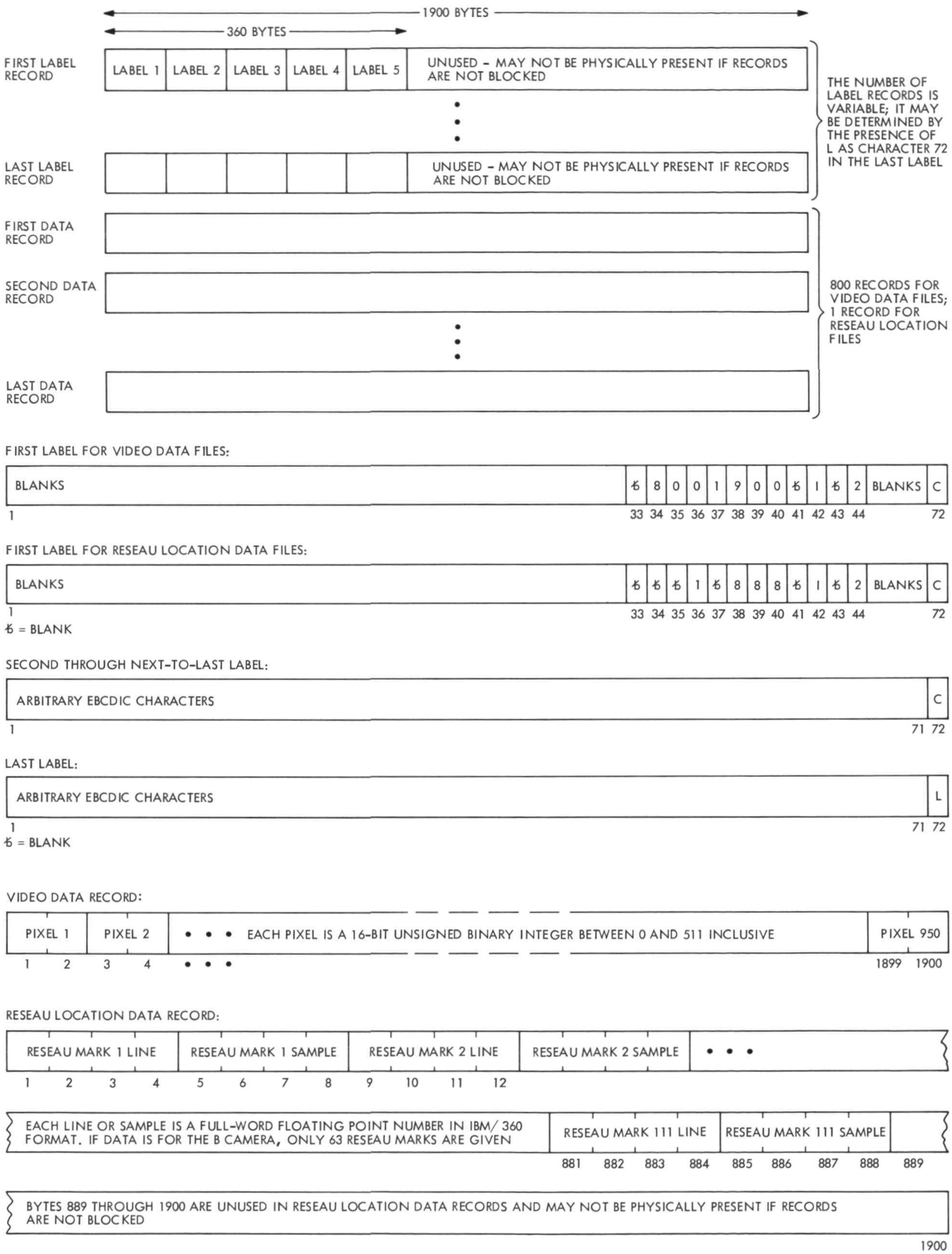

Fig. 3. RDR data tape logical record format

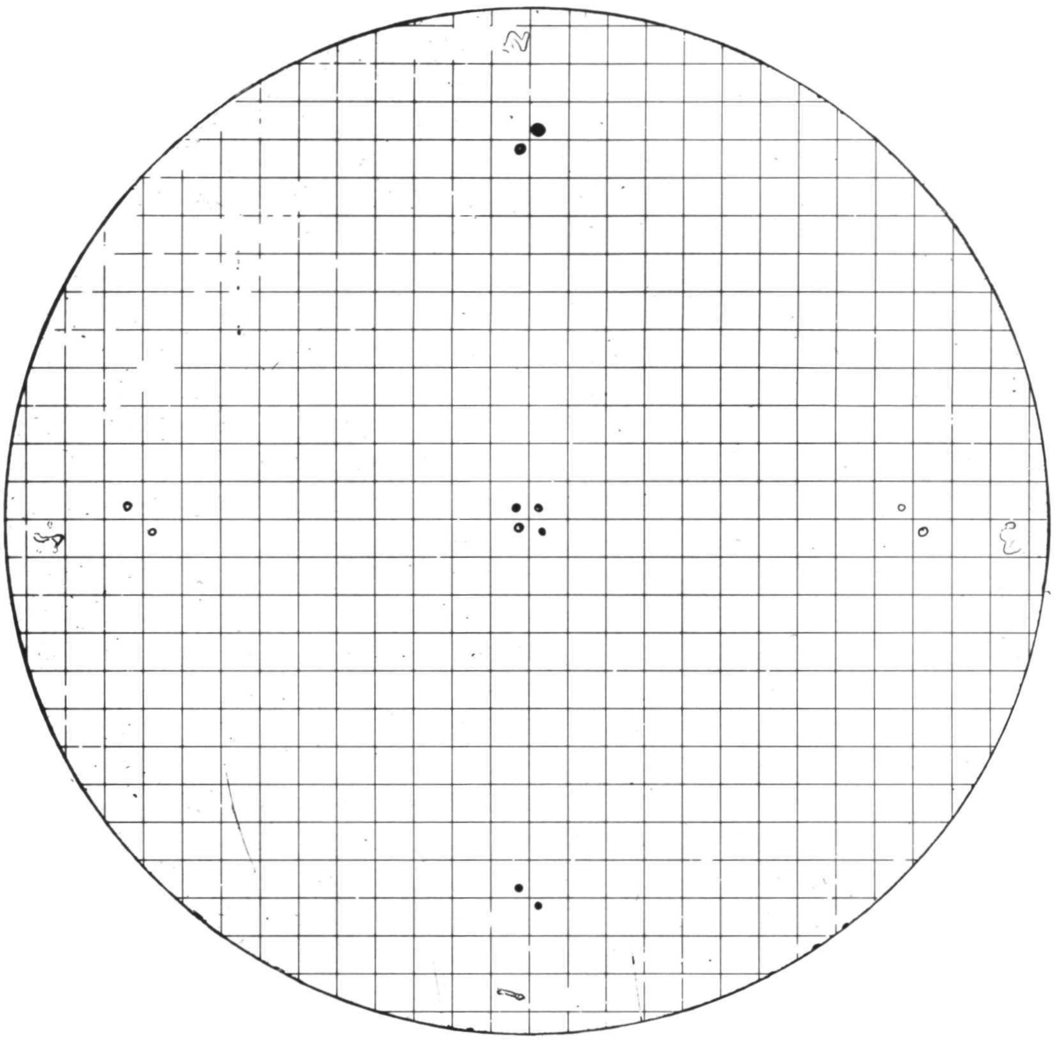

Fig. 4. Grid target for geometric calibration

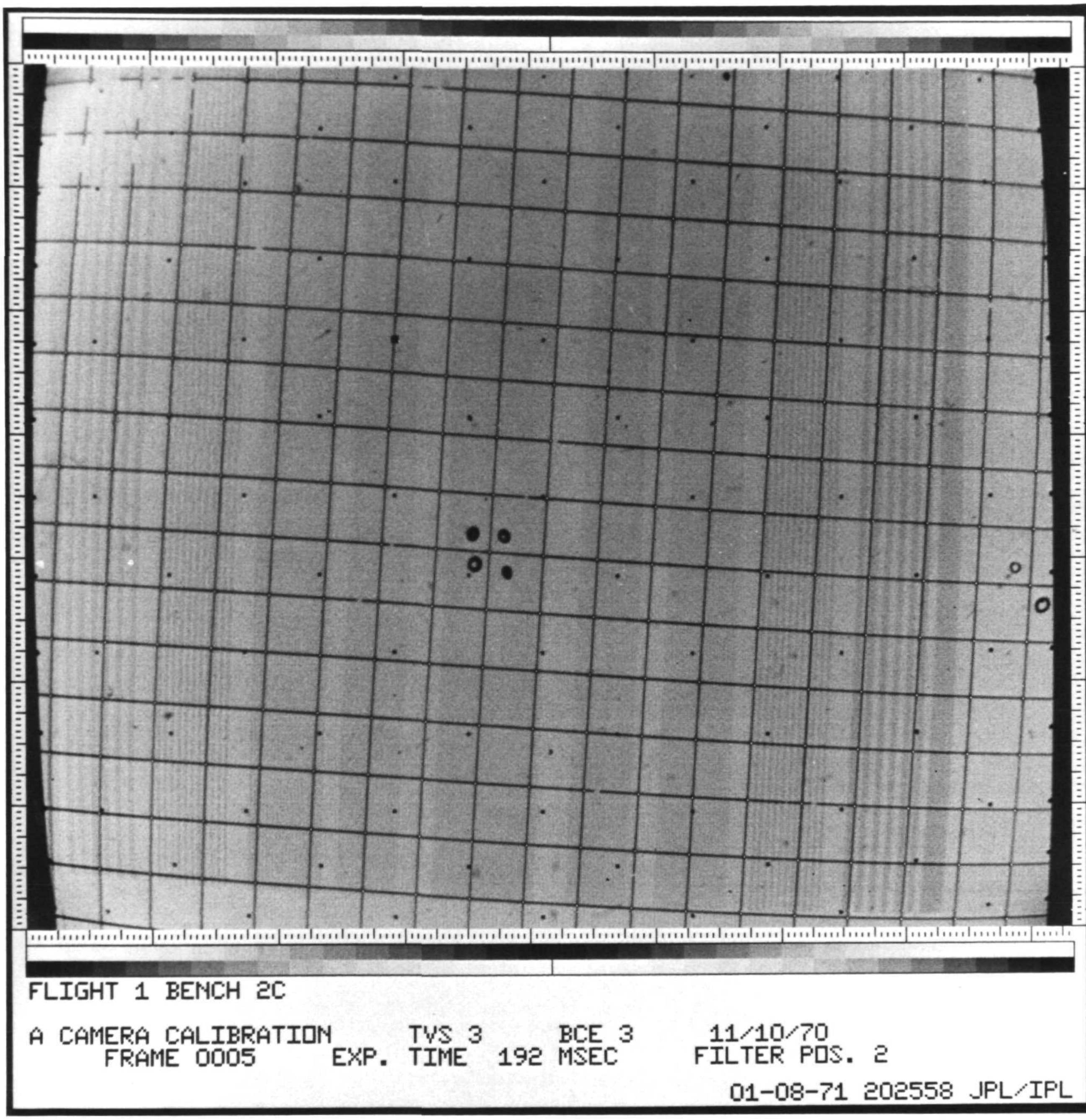

Fig. 5. Unprocessed TV image of grid target

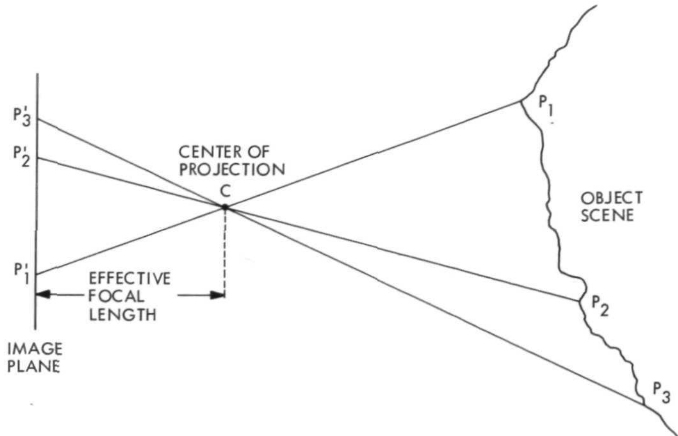

Fig. 6. Ideal perspective projection. In a geometrically perfect camera image, object scene points such as P_1, P_2, and P_3 "project" along straight lines through center of projection C onto the image plane at P'_1, P'_2, and P'_3. The effective focal length of the camera determines the scale relationship between the image plane and the object scene.

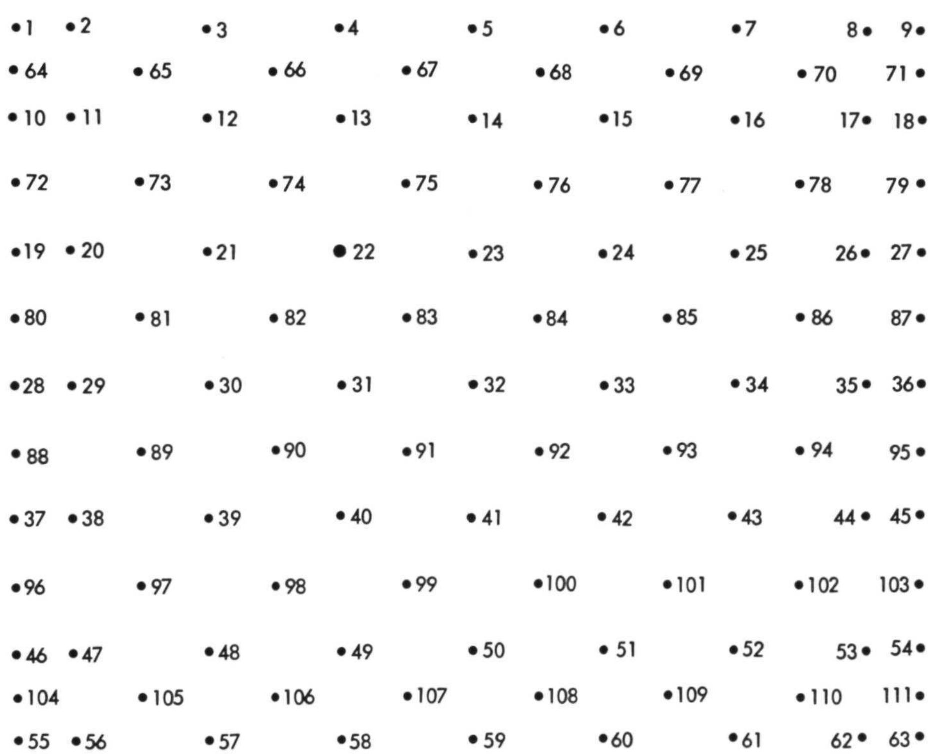

Fig. 7. Relative locations of control points (reseau marks) in image field

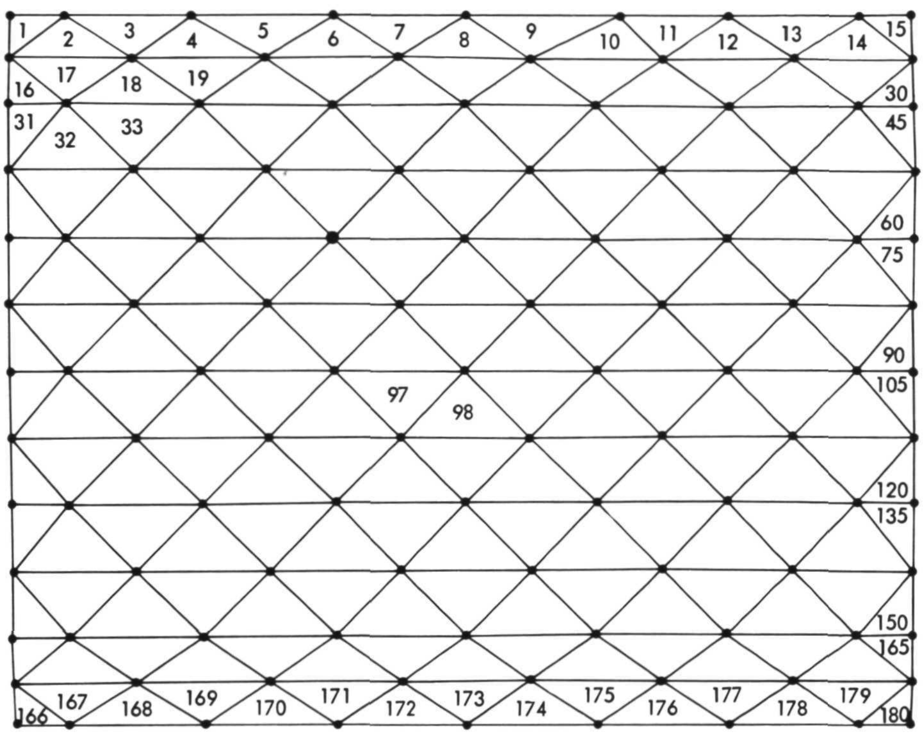

Fig. 8. Triangular tessellation of image field based on control points

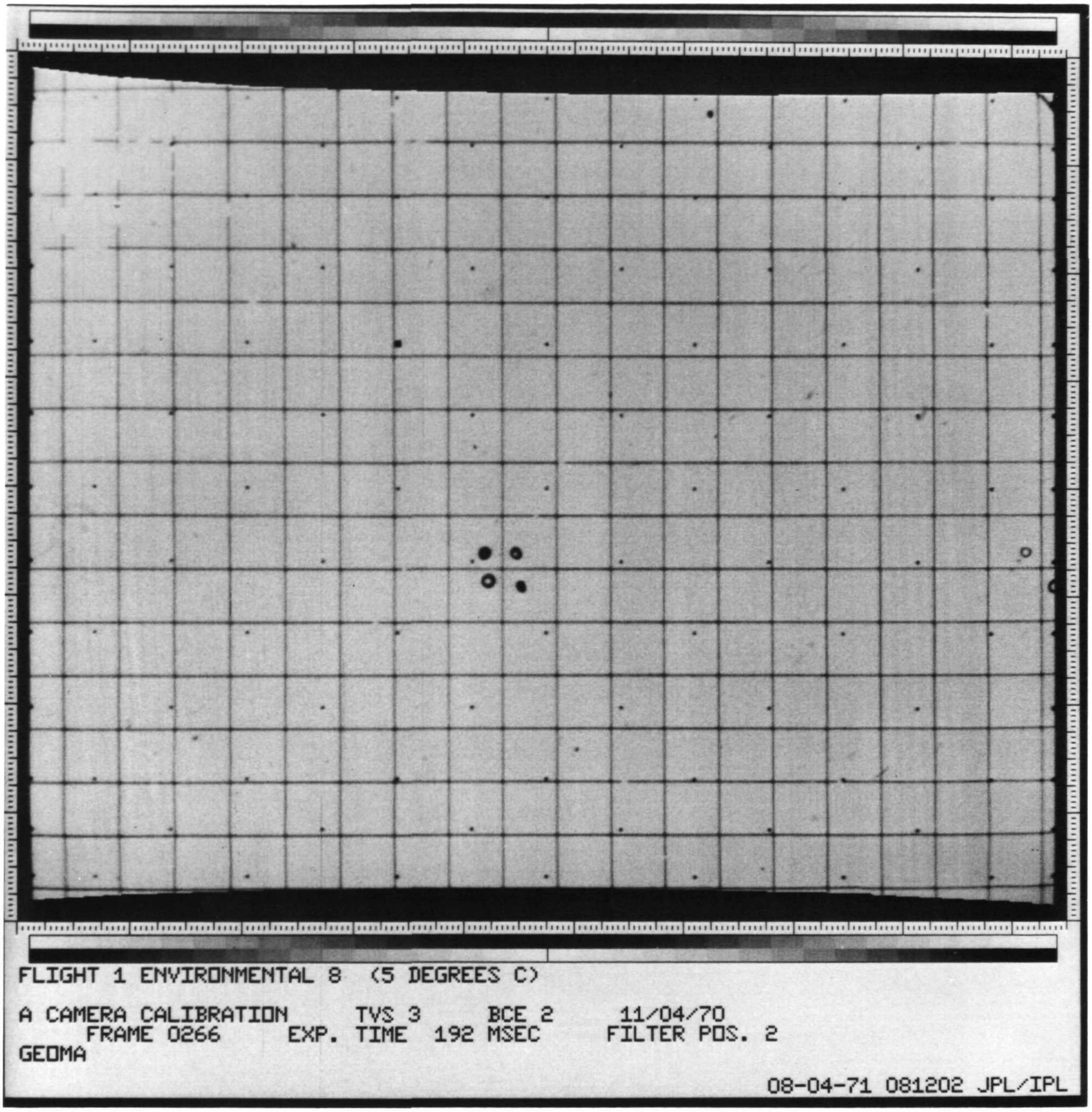

Fig. 9. TV grid target frame after correction for geometric distortion

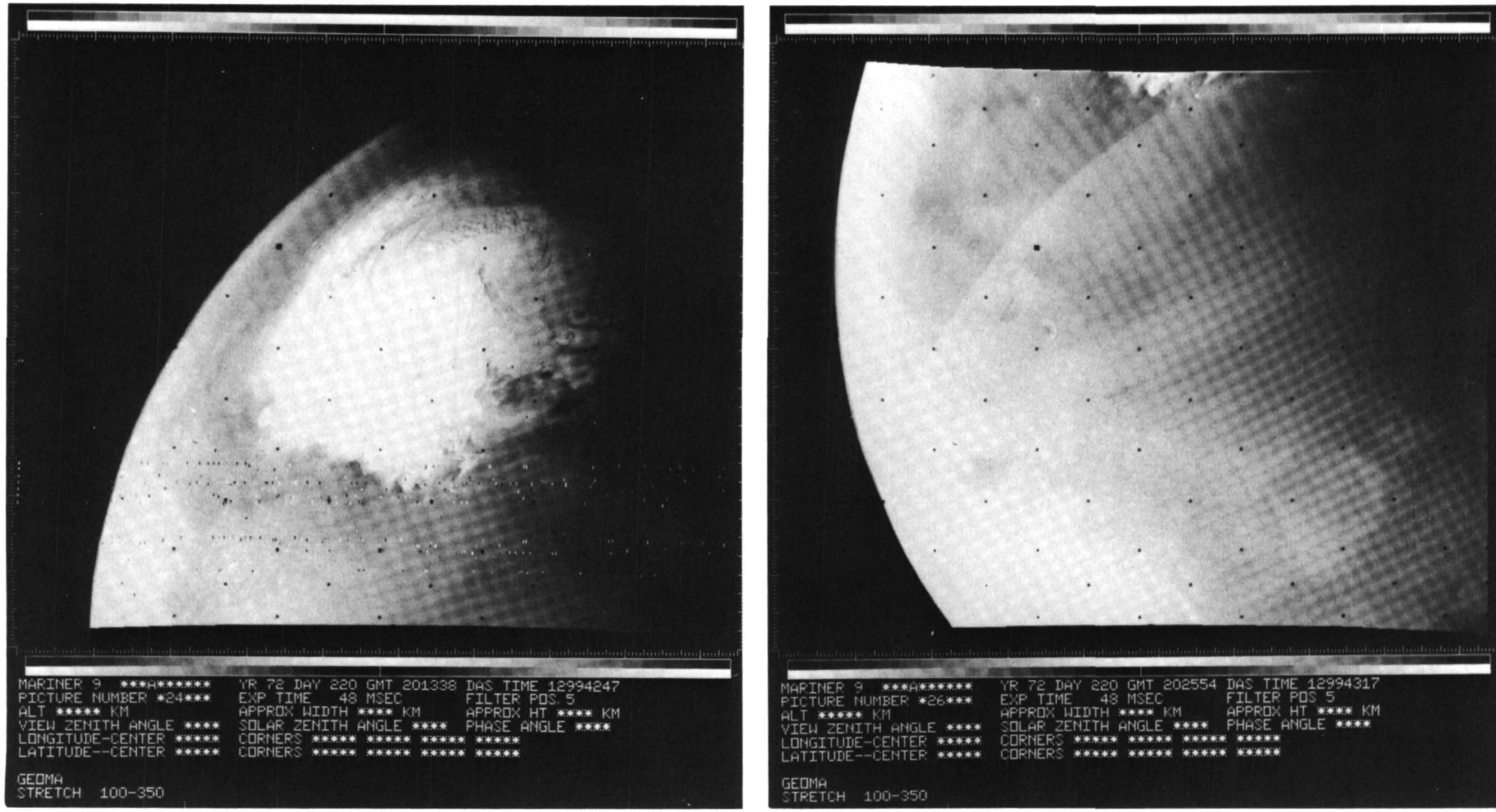

Fig. 10. Image sequence illustrating the residual image effect. These two frames were recorded sequentially by the wide-angle camera. The first frame (left) is denoted I_1 in the text. The second frame (right) is denoted I'_2. The planet limb in I_1 can be seen as a residual image in I'_2.

I_2' DN \ I_1 DN	44	77	147	199	267
65	3.83	5.25	7.45	9.24	10.9
117	4.65	6.60	9.40	11.4	13.6
215	5.58	6.70	9.95	12.3	14.9
290	4.18	6.15	9.20	11.4	14.2
372	3.36	4.87	7.08	8.74	10.8

Fig. 11. Residual image as a function of previous image I_1 DN and current image I_2' DN

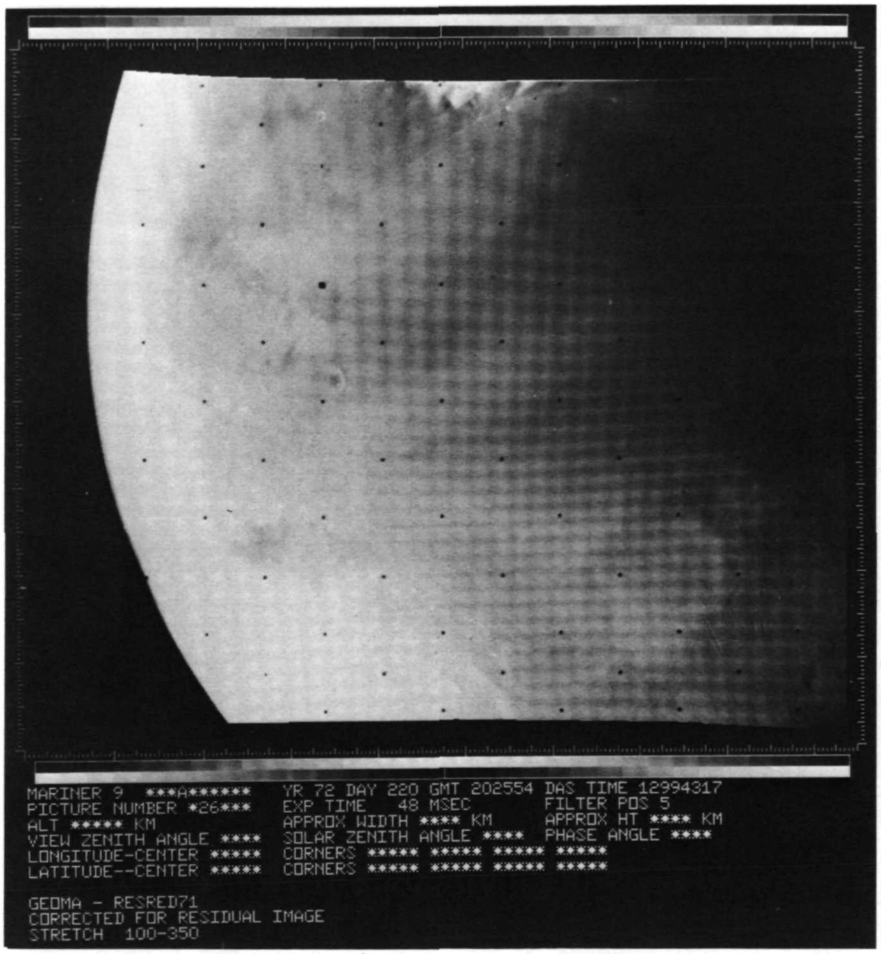

Fig. 12. Second frame from Fig. 10 after correction for residual image

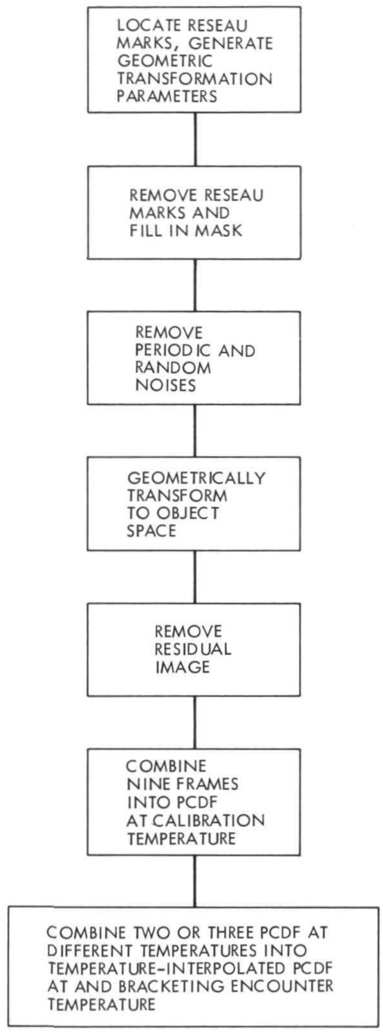

Fig. 13. Processing sequence of preflight data

INPUT: (1) INPUT FRAME AT SHUTTER SPEED t WITH A DN VALUE OF N AT PIXEL x, y.

(2) PHOTOMETRIC DATA FILE AT SHUTTER SPEED t_{ref} CONTAINING EXPOSURE LEVELS b_i $(i = 1, 2, \ldots, NE)$ AND A SET OF DN VALUES DN_i $(i = 1, 2, \ldots, NE)$ AT PIXEL x, y.

OUTPUT: THE LUMINANCE B_0 OF PIXEL x, y.

INITIAL COMPUTATIONS: (1) CONVERT ALL LUMINANCE VALUES TO MARS ft-L AT SHUTTER SPEED t:

$$B_i = b_i t_{ref}/t, \quad B_{max} = b_{max} t_{ref}/t$$

(2) COMPUTE LUMINANCE SCALE FACTOR $C = B_{max}/511$

CALCUATIONS FOR EACH PIXEL:

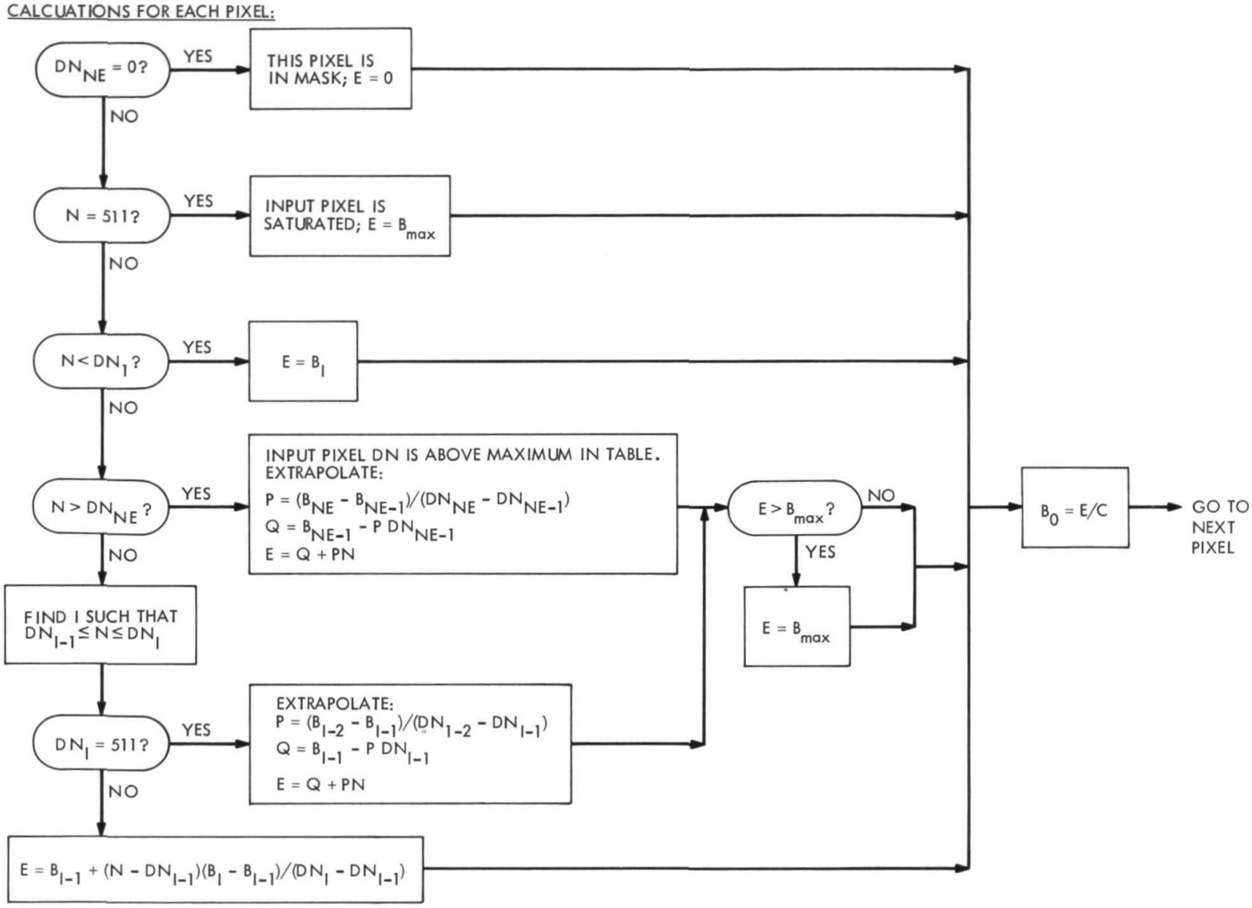

Fig. 14. Photometric decalibration flowchart

DAS	FICHE	CAM	REV	EXPOSURE	CAM A	LEFT LIMB EXTREME				RIGHT LIMB EXTREME				RANGE	RET 5
TIME	CARD-ROW	ID	NO.	(MS)	FILTER	LAT	LON	SLA	PHA	LAT	LON	SLA	PHA	TO LIMB	PHA
XXXXXXXX	XX-X	X	XXX	XXXX	XXXXXXXXX	±XX.XX	XXX.XX	XXX.XX	XXX.XX	±XX.XX	XXX.XX	XXX.XX	XXX.XX	XXXXXX	XXX.XX

REV NO.	SAME AS ORBIT NUMBER OR PERIAPSIS NUMBER
LIMB EXTREME	THE LIMB NORMALLY INTERCEPTS THE FRAME EDGES IN TWO PLACES, WHICH ARE REFERRED TO AS THE "LIMB EXTREMES." THE LEFT ONE IS THE ONE WITH THE SMALLER SAMPLE COORDINATE.
LAT	SOUTH LATITUDES ARE INDICATED BY A NEGATIVE SIGN
LON	LONGITUDE WEST OF THE PRIME MERIDIAN
SLA	SOLAR ZENITH ANGLE AT LIMB EXTREME; SEE TABLE 2
PHA	PHASE ANGLE AT LIMB EXTREME; SEE TABLE 2
RANGE TO LIMB	DISTANCE FROM SPACECRAFT TO LIMB, KILOMETERS
RET 5 PHA	SAME AS PHASE ANGLE IN PICTURE LABEL; SEE TABLE 2

Fig. 15. Limb profile microfiche catalog format

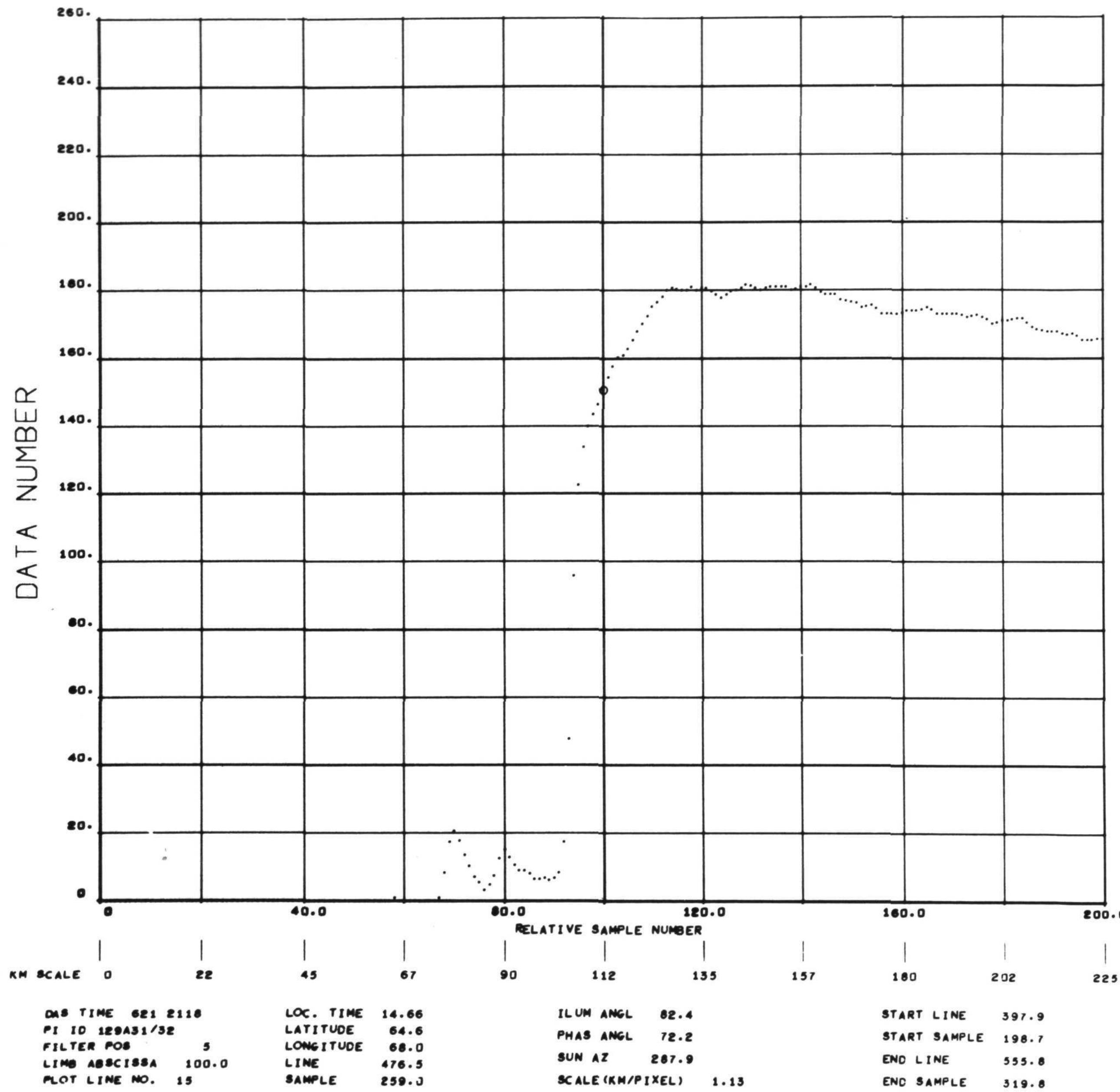

Fig. 16. Mariner 9 limb plot

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