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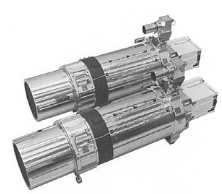
**Mariner Mars 1969 Far Encounter Analytic Geometric Camera Model:
the basis for a NAIF SPICE Instrument Kernel**



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1 Introduction

The Mariner Mars 1969 Mission had two spacecraft, Mariner 6 and Mariner 7, each carrying a narrow and a wide angle camera. The Wide Angle (WA) cameras had Zeiss refractor optics with shutters that incorporated four spectral filters in a rotary wheel in the order red, green, blue and green again. The Narrow Angle (NA) cameras had Schmidt-Cassegrain reflector optics without filters. The wide angle f/5.6 lenses had focal lengths of about 52.5 mm and the narrow angle f/2.4 lenses had focal lengths of about 504 mm. The optics focused images onto vidicons to obtain images of Mars. The vidicons were etched with 7 x 9 grids of reseaux to aid in computing the geometric distortions in the digital images. All four cameras produced 945 sample by 704 line, 8 bit/pixel digital images after ground processing to produce the Experiment Data Record image archive. The NAIF SPICE spacecraft and camera identification numbers are given in Table 1.

A generic analytic geometric camera model is presented for the Far Encounter images to map from object space, through the optics onto the vidicon focal plane and then to the digital image coordinates, that is applicable to all four cameras. The image coordinates of the reseau grid need to be measured in each Far Encounter image to determine geometric model parameter values that change from image to image. For a given image, the geometric model is accurate at the pixel level within 400 pixels of the image center but degrades beyond this distance because of electro-magnetic readout distortions within the vidicons. For the areas beyond 400 pixels from the Far Encounter image center, extra corrections need to be added to the geometric model, for example by a bi-linear interpolation process, to maintain pixel level model fidelity.

To validate the analytic model, the Mariner 6 and 7 Far Encounter images were processed to determine the camera model parameter values as part of the first year effort of a NASA Planetary Data Archive, Restoration and Technology (PDART) task. Only Narrow Angle images were obtained in these mission phases; therefore only geometric parameter values were determined for the Narrow Angle cameras in this report. The second year of this PDART task will include the Near Encounter Narrow and Wide Angle images that will be used to determine the Wide Angle camera parameter values and validate the Narrow Angle camera parameter values determined here.

2 Geometric Camera Model

The geometric model for the 1969 Mariner 6 and 7 NA and WA cameras include terms for the optics and additional terms for the vidicon that are needed to predict the image coordinates of celestial objects, such as Mars, its moons and stars that are outside of the camera optics, and also to predict the image coordinates of the grids of reseaux that are etched into the vidicon photo sensitive surfaces. The predicted image locations, using the geometric model parameter values, are the sample and line coordinates in the original, raw (level-1) images that were transmitted to earth.

To define the geometric camera model, a camera-fixed $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ coordinate system is defined in the vidicon focal plane with axis $\bar{\mathbf{x}}$ is in the direction of increasing sample number, axis $\bar{\mathbf{y}}$ is in the direction of increasing line number and axis $\bar{\mathbf{z}}$ completing the orthogonal right-handed system and is in the direction of the optical axis (Figure 1). For each Mariner Mars 1969 vidicon detector, the origin of $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ is placed at their central reseau. The geometric camera model will be developed

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in terms of an optical component and a vidicon component that are described in the next subsections.

2.1 Optics Model

A camera-fixed unit direction vector $\hat{\mathbf{p}}$ in $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ to an object can be mapped through the optics onto the camera-fixed, undistorted vidicon focal plane coordinates x, y using the following set of analytic equations based upon the co-linear equations of photogrammetry (Thompson, 1966, Figure 1)

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{f}{p_z} \begin{bmatrix} p_x \\ p_y \end{bmatrix} \qquad \text{(mm)} \tag{1}$$

where f is the camera focal length (mm) and $p_x,\ p_y,\ p_z$ are the unitless, direction cosines to the object in camera-fixed $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ coordinates. Optics produce distortions in the radial direction, especially for larger fields-of-view, that deflect the undistorted focal plane coordinates x, y in equation 1 into optically distorted focal plane coordinates that are modeled by

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \alpha_1 \begin{bmatrix} o_x \\ o_y \end{bmatrix} r_o^2 + \alpha_2 \begin{bmatrix} o_x \\ o_y \end{bmatrix} r_o^4 \quad \text{(mm)} \tag{2}$$

where x', y' are the actual focal plane, optically distorted, coordinates on the vidicon,

$$o_x = x - x_o; \quad o_y = y - y_o; \quad r_o^2 = o_x^2 + o_y^2 \tag{3}$$

and x_o, y_o are the focal plane coordinates of the optical principal point, the center of the optical distortion relative to the central reseau. The distance r' of the optically distorted vidicon location x', y' from the central reseau is

$$r' = \sqrt{x'^2 + y'2} \tag{4}$$

The terms $f, x_o, y_o, \alpha_1, \alpha_2$ make up the optics contribution to the geometric camera model. The camera-fixed direction vector that gives optically distorted focal plane coordinates of the principal point, x_o, y_o, is used to define camera pointing. No information was obtained to determine the optical distortion parameter values; therefore camera pointing for the Far Encounter images are relative to the central reseaux. The focal length values were constant over all Far Encounter images.

2.2 Vidicon Model

To readout an image captured on a vidicon, an electron beam was swept across the vidicon and image brightnesses are digitized 945 times in the sample direction and repeated 704 times in the line direction. The two electromagnetic deflection fields that sweep the electron beam over the vidicon were not orthogonal, had slightly different sweep rates and were slightly mis-aligned with the vidicon-fixed $\bar{\mathbf{x}}$ - $\bar{\mathbf{y}}$ axes. Both radial and tangential distortions were introduced into image coordinates during image readout relative to the vidicon distortion center located at x_v, y_v in the $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ coordinate system. The radial r_r and tangential r_t distortions introduced by the vidicon readout are modeled using similar equations that are given by

$$r_r = \beta_1 r_v + \beta_2 r_v^2 + \beta_3 r_v^3 + \beta_4 r_v^4 \qquad \text{(radial component, mm)} \tag{5}$$

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$$r_t \;=\; \gamma_1\, r_v \;+\; \gamma_2\, r_v^2 \;+\; \gamma_3\, r_v^3 + \;\gamma_4\, r_v^4 \quad \text{(tangential component, mm)} \tag{6}$$

where

$$v_x \;=\; x' - x_v; \quad v_y \;=\; y' - y_v; \quad r_v^2 \;=\; v_x^2 \;+\; v_y^2 \tag{7}$$

x', y' are the actual optically distorted coordinates in equation 2 and the β's and γ's are the distortion coefficients . It is noted that β_1 is a scale factor error along r_v and γ_1 gives a simple rotation about x_v, y_v. Therefore the radial and tangential vidicon distortions will position the electron beam at the location $x", y"$ (Figure 2) on the vidicon focal plane that is expressed as

$$\begin{bmatrix} x" \\ y" \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} r' + r_r \\ r_t \end{bmatrix} \quad \text{(mm)} \tag{8}$$

where $r'^2 = x'^2 + y'^2$. From Figure 2

$$\cos\theta \;=\; \frac{x'}{r'}; \quad \sin\theta \;=\frac{y'}{r'} \quad \text{for } r' \;>\; 0 \tag{9}$$

Therefore equation 7 becomes

$$\begin{bmatrix} x" \\ y" \end{bmatrix} \;=\; \frac{1}{r'} \begin{bmatrix} x'(r' + r_r) - y' r_t \\ y'(r' + r_r) + x' r_t \end{bmatrix} \quad (\text{mm} - \text{for } r' \;>\; 0) \tag{10}$$

or

$$\begin{bmatrix} x" \\ y" \end{bmatrix} = \begin{bmatrix} x' \\ y' \end{bmatrix} \quad (\text{mm} - \text{for } r' \;=\; 0) \tag{11}$$

Given the optical and vidicon distorted focal plane coordinates $x", y"$ in equation 9, the image coordinates of sample, s, and line, l, can be computed for the direction vector $\hat{\mathbf{p}}$ in $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ from

$$\begin{bmatrix} s \\ l \end{bmatrix} \;=\; \begin{bmatrix} K_{sx} & K_{sy} \\ K_{lx} & K_{ly} \end{bmatrix} \begin{bmatrix} x" \\ y" \end{bmatrix} \;+\; \begin{bmatrix} s_0 \\ l_0 \end{bmatrix} \quad \text{(pixels)} \tag{12}$$

where the K's are scale factors mapping between optical and vidicon distorted focal plane coordinates of mm to image coordinates of s, l and s_0, l_0 are the sample and line image coordinates of the central reseau, the origin of the camera-fixed coordinate system. For all four cameras

$$1 \;\le\; s \;\le\; 945 \quad \text{and} \;\; 1 \;\le\; l \;\le\; 704 \tag{13}$$

The K terms give four degrees of freedom: 1) a common scale factor along r for s, l; 2) a difference in scale for s and l; 3) a common rotation of the two vidicon electromagnetic deflection fields about the central reseau; and 4) a non-orthogonality between the two vidicon electromagnetic deflections fields. Therefore, effects similar to β_1 and γ_1 in equations 3 and 4 are also included in these four degrees of freedom given by the K terms and are dropped. The $K, x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4, s_0, l_0$ terms make up the vidicon contribution to the geometric camera model. In an ideal vidicon, K_{sx} would equal K_{ly} and $K_{sy}, K_{lx}, x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3$ and γ_4 would be equal to zero.

The Mariner 6 and 7 Narrow and Wide Angle camera geometric model (equations 1 - 12) is defined by the values of $f, x_o, y_o, \alpha_1, \alpha_2, K_{sx}, K_{sy}, K_{lx}, K_{ly}, x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4, s_0$ and l_0. The following sections describe how the values for these parameters were determine from the Far Encounter images for the Narrow Angle cameras. The values of s_0, l_0 are determined directly from the s, l image coordinates of the central reseau in each picture.

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3 Reseau Grid

As a direct aid in determining the K's, $x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4, s_0$ and l_0, a 7 x 9 grid of reseaux was etched onto each vidicon and the actual focal plane x', y' coordinates in equation 2 of each reseau were measured for each vidicon (Figure 3.). Note that the direction of $+\mathbf{y}$ in this figure is opposite to the convention used here and therefore the negative of the y coordinatess shown in Figure 3. need to be used in equation 7. Unfortunately, the focal plane coordinates for only the Mariner 6 WA vidicon reseaux were found (Table 1. - Danielson and Montgomery, 1971). Therefore for the remainder of this analyses, it is assumed that all four vidicons have the same reseau grid focal plane coordinates as shown in Figure 3. With K_{sx} and K_{sy} being about 74 pixels / mm, it is expected that any errors made by this assumption will be of less than 1 pixel across all vidicons.

From equation 4 - 12, it is seen that observing the image coordinates of the reseau grid would yield the vidicon geometric parameters $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0, x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4, s_0$, and l_0. As mentioned previously, the reseaux grid needs to be measured in each picture for model fidelity as the vidicon readout distortions change from picture to picture at the pixel level .

4 Linear Partial Derivative Equations

A weighted, least-squares, minimum variance, square-root parameters estimation technique (Beirman, 1977) was used to determine the vidicon geometric camera model parameter values. The s, l image coordinates of the reseaux will be measured in the raw (level-2) images and used as the observables in the estimation process. The vidicon geometric model parameter values will be adjusted in equation 4 - 10 by the estimation process to minimize the variance between the observed reseau image coordinates and the predicted images coordinates. The linear equations to be used in the estimation process together with the differences between the observed and predicted reseau image locations will be derived from the partial derivatives of s, l with respect to the estimated parameters, e. g., the vidicon geometric model parameters of $K_{sx}, K_{sy}, K_{lx}, K_{ly}, x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4, s_0$ and l_0. The following gives the derivation of these linear, partial derivative expressions used to form the linear equations for each observed reseau image location.

$$\frac{\partial(s,l)}{\partial(x", y")} = \begin{bmatrix} K_{sx} & K_{sy} \\ K_{lx} & K_{ly} \end{bmatrix} \tag{14}$$

$$\frac{\partial(x", y")}{\partial(r_r, r_t)} = \frac{1}{r'} \begin{bmatrix} x' & -y' \\ y' & x' \end{bmatrix} \qquad (\text{mm} - \text{for } r' > 0) \tag{15}$$

or

$$\frac{\partial(x", y")}{\partial(r_r, r_t)} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \qquad (\text{mm} - \text{for } r' = 0) \tag{16}$$

$$\frac{\partial(r_r, r_t)}{\partial(\beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4)} = \begin{bmatrix} r_v^2 & r_v^3 & r_v^4 & 0 & 0 & 0 \\ 0 & 0 & 0 & r_v^2 & r_v^3 & r_v^4 \end{bmatrix} \tag{17}$$

$$\frac{\partial(r_v)}{\partial(x', y', x_v, y_v)} = \frac{1}{r_v} \begin{bmatrix} v_x & v_y & -v_x & -v_y \end{bmatrix} \qquad \text{for } r_v > 0 \tag{18}$$

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or

$$\frac{\partial(r_v)}{\partial(x', y', x_v, y_v)} = \begin{bmatrix}0 & 0 & 0 & 0\end{bmatrix} \quad \text{for } r_v = 0 \tag{19}$$

$$\frac{\partial(r_r, r_t)}{\partial(x', y')} = \begin{bmatrix}2\beta_2 v_x + 3\beta_3 v_x r_v + 4\beta_4 v_x r_v^2 & 2\beta_2 v_y + 3\beta_3 v_y r_v + 4\beta_4 v_y r_v^2 \\ 2\gamma_2 v_x + 3\gamma_3 v_x r_v + 4\gamma_4 v_x r_v^2 & 2\gamma_2 v_y + 3\gamma_3 v_y r_v + 4\gamma_4 v_y r_v^2\end{bmatrix} \tag{20}$$

$$\frac{\partial(r_r, r_t)}{\partial(x_v, y_v)} = -\frac{\partial(r_r, r_t)}{\partial(x', y')} \tag{21}$$

$$\frac{\partial(x', y')}{\partial(\alpha_1, \alpha_2)} = \begin{bmatrix}o_x r_o^2 & o_x r_o^4 \\ o_y r_o^2 & o_y r_o^4\end{bmatrix} \tag{22}$$

$$\frac{\partial(r_o)}{\partial(x, y, x_o, y_o)} = \frac{1}{r_v}\begin{bmatrix}o_x & o_y & -o_x & -o_y\end{bmatrix} \tag{23}$$

$$\frac{\partial(x', y')}{\partial(x)} = \begin{bmatrix}1 + \alpha_1\ r_o^2 + 2\alpha_1\ o_x^2 + \alpha_2\ r_o^4 + 4\alpha_2\ o_x^2\ r_o^2 \\ 2\alpha_1\ o_x\ o_y + 4\alpha_2\ o_x\ o_y\ r_o^2\end{bmatrix} \tag{24}$$

$$\frac{\partial(x', y')}{\partial(y)} = \begin{bmatrix}2\alpha_1\ o_x\ o_y + 4\alpha_2\ o_x\ o_y\ r_o^2 \\ 1 + \alpha_1\ r_o^2 + 2\alpha_1\ o_y^2 + \alpha_2\ r_o^4 + 4\alpha_2\ o_y^2\ r_o^2\end{bmatrix} \tag{25}$$

$$\frac{\partial(x', y')}{\partial(x_0, y_0)} = -\frac{\partial(x', y')}{\partial(x, y)} \tag{26}$$

$$\frac{\partial(x, y)}{\partial(p_x, p_y, p_z, f)} = \frac{1}{p_z}\begin{bmatrix}f & 0 & -x & p_x \\ 0 & f & -y & p_y\end{bmatrix} \tag{27}$$

Equations 12 - 25 can be combined using the chain rule to form the $\partial(s, l)$ with respect to the $\partial(p_x, p_y, p_z, f, x_o, y_o, \alpha_1, \alpha_2, K_{sx}, K_{sy}, K_{lx}, K_{ly}, x_v, y_v, \beta_0, \beta_2, \gamma_0, \gamma_2, s_0, l_0)$ to be used as the linear equation in the estimation process.

$$\frac{\partial(s, l)}{\partial(p_x, p_y, p_z, f)} = \frac{\partial(s, l)}{\partial(x", y")}\frac{\partial(x", y")}{\partial(r_r, r_t)}\frac{\partial(r_r, r_t)}{\partial(x', y')}\frac{\partial(x', y')}{\partial(x, y)}\frac{\partial(x, y)}{\partial(p_x, p_y, p_z, f)} \tag{28}$$

$$\frac{\partial(s, l)}{\partial(x_0, y_0)} = \frac{\partial(s, l)}{\partial(x", y")}\frac{\partial(x", y")}{\partial(r_r, r_t)}\frac{\partial(r_r, r_t)}{\partial(x', y')}\frac{\partial(x', y')}{\partial(x_0, y_0)} \tag{29}$$

$$\frac{\partial(s, l)}{\partial(\alpha_1, \alpha_2)} = \frac{\partial(s, l)}{\partial(x", y")}\frac{\partial(x", y")}{\partial(r_r, r_t)}\frac{\partial(r_r, r_t)}{\partial(x', y')}\frac{\partial(x', y')}{\partial(\alpha_1, \alpha_2)} \tag{30}$$

$$\frac{\partial(s, l)}{\partial(K_{sx}, K_{sy}, K_{lx}, K_{ly})} = \begin{bmatrix}x" & y" & 0 & 0 \\ 0 & 0 & x" & y"\end{bmatrix} \tag{31}$$

$$\frac{\partial(s, l)}{\partial(x_v, y_v)} = \frac{\partial(s, l)}{\partial(x", y")}\frac{\partial(x", y")}{\partial(r_r, r_t)}\frac{\partial(r_r, r_t)}{\partial(x_v, y_v)} \tag{32}$$

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$$\frac{\partial(s,l)}{\partial(\beta_2,\beta_3,\gamma_2,\gamma 3)} = \frac{\partial(s,l)}{\partial(x",y")}\frac{\partial(x",y")}{\partial(r_r,r_t)}\frac{\partial(r_r,r_t)}{\partial(\beta_2,\beta_3,\gamma_2,\gamma_3} \tag{33}$$

$$\frac{\partial(s,l)}{\partial(s_0,l_0)} = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} \tag{34}$$

Table 2 lists the analytic partial derivatives and the differenced partial derivatives for reseaux in the upper left corner in an image. The center two columns are for the sample partial derivative comparisons and the right two columns are for the line partial derivation comparisons. The partial derivatives are only dependent on image location and not for any specific image. This comparison validates the analytic partial derivatives to better than 0.1%, sufficient for this data analysis.

It is noted that the p_x, p_y, p_z terms in equation 1 are used for objects outside of the cameras such as Mars, Phobos, Deimos and stars that are used to compute camera optical model parameters, planetary constants of the bodies being imaged (e. g., size, shape, orientation, ephemerides) and camera pointing.

5 Mariner 6 and 7 Far Encounter Narrow Angle Vidicon Models

One Mariner 6 image, 6F49, and one Mariner 7 image, 7F92, were used to study the behavior of the vidicon model in the Far Encounter images. These images were selected because the largest number of reseaux were observable in these images. The image coordinates, s and l, of all visible reseaux were measured in each of these images and used in a square-root, weighted-least squares parameter estimation (Bierman, 1977) process as observables and equations 26 - 32 were used to form the sets of linear equations for each observed s, l image location pair. Six cases of vidicon geometric models were studied:

Case 1: $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0$

Case 2: $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0, \beta_2, \beta_3, \gamma_2, \gamma_3$

Case 3: $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4$

Case 4: $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0, x_v, y_v, \beta_2, \gamma_2$

Case 5: $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0, x_v, y_v, \beta_2, \beta_3, \gamma_2, \gamma_3$

Case 6: $K_{sx}, K_{sy}, K_{lx}, K_{ly}, s_0, l_0, x_v, y_v, \beta_2, \beta_3, \beta_4, \gamma_2, \gamma_3, \gamma_4$

to determine the nature of the vidicon behaviors.

To measure the reseau locations, the images were high-pass filtered with filter weights selected to match the shapes of the reseaux. Figure 4 shows the original 6N49 image (top) and the resultant high-pass, matched filtered (Weiner, 1949) image (bottom) where the reseaux within the Mars images are now easily seen and measured. The reseau image location measurements were iterated 8 times in the least-squares estimation process to ensure parameter convergence. *A priori* parameter values of 73 pixels/mm were used for K_{sx}, K_{ly}, 0.0 pixels/mm were used for K_{sy}, K_{lx}, 0.0 mm was used for x_v, y_v and all of the β, γ terms had zero *a priori* values for the first iteration in all six cases. The values used for s_0, l_0 were the observed image locations of the central reseau in each picture

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and were then not estimated but held fixed for all iterations. Each iteration for all six cases were started with *a priori* 1-σ parameter uncertainties of 2.0 pixel/mm for $K_{sx}, K_{sy}, K_{lx}, K_{ly}$, 0.5 mm for x_v, y_v, 5 x 10^{-2} pixels/mm^3 for β_2, γ_2, 5 x 10^{-3} pixels/mm^4 for β_3, γ_3, and 5 x 10^{-4} pixels/mm^5 for β_4, γ_4.

As a figure of merit to determine the geometric model accuracy for each picture using the six model cases, the post-fit 1-σ residual statistics (the differences between observed reseau image locations and those predicted reseau locations using the post-fit analytic model parameters) were computed. Figures 5 - 10 show plots of the post-fit 1-σ reseau sample and line locations residual statistics (x 20) for all six geometric model cases applied to 7F92 where 49 reseaux were observed. As seen, the residual statistics for the simpler models are many pixels while Cases 5 and 6 approach the 1 pixel level of accuracy. Table 3 lists the vidicon model parameter values for all six cases. Figure 11 plots the post-fit 1-σ line and sample residuals for all six cases for 7F92. It is seen that it is important to include the origin of the vidicon distortion center location x_v, y_v in the model to increase fidelity but little model accuracy improvement is obtained by adding β_4, γ_4. However, even the Case 6 geometric model gives errors larger than 1 pixel when further than 400 pixels from the central reseau.

A similar analysis was performed on 6F49 and the post-fit residuals are shown in Figure 12 for the 35 reseaux observed. The results for all six cases were the same as for 7F92: it is important to include x_v, y_v in the model to increase fidelity; little model accuracy improvement is obtained by adding β_4, γ_4; and even the Case 6 geometric model gives errors larger than 1 pixel when further than 400 pixels from the central reseau.

6 Far Encounter Narrow Angle Vidicon Model Parameter Values

Based upon the study of the six cases for the Mariner 6 and 7 images, the vidicon model up to β_3, γ_3 (Case 5) was used to determine the vidicon models for all Mariner 6 and 7 Far Encounter images. The vidicon model parameter values for Cases 5 from 6F49 and from 7F92 were used as *a priori* values to start the parameter estimations for all Mariner 6 and 7 Far Encounter images, respectively. The *a priori* parameter uncertainties as previously listed were used to start each parameter estimation iteration. However, if less than 8 reseaux were observed in an image, that would yield a singular, rank deficient set of linear equations for parameter estimation, the vidicon model parameters were not estimated and the *a priori* parameters were used for those images. In all images, the observed location of the central reseau was used to provide the model values for parameters s_0, l_0. Because accurate *a priori* parameter values were used to start the parameter estimation, only 5 iterations were used here. Tables 3 - 13 list the vidicon model parameter values for all 49 Mariner 6 and all 92 Mariner 7 recovered Far Encounter images. It is noted 7F02 was not found and is not listed in the Collins, 1971 document. The Mariner 7 Tape Recorder could only hold 33 full frame images and images 7F34 and 7F68 were not recovered. The time tag and trajectory parameters for 7F00 were not included in Campbell, 1971. Collins, 1971 states that this image was taken about 5 hours earlier than 7F01. Therefore the time tag for 7F00 was set to 5 hours earlier than 7F01 and viewing / lighting / trajectory parameters were computed at this time. The average parameter values are listed at the ends of the Tables including the number of images used to determine the averages. Since different *a priori* parameter values were used here than in the previous section and the data were only iterated 5 times, the parameter values determined here

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as compared to the previous section for 6F49 and 7F92 are slightly different but model fidelity differs much less than a pixel over the entire image space.

7 Optical Model Parameter Values

For the optical parameters, only the focal lengths f were determined in this analysis using the size of Mars in the images. Limb and terminator overlays were produced by varying the value of f in equation 1 until good matches were made with the images. Mars was modeled as a spheroid with a polar radius of 3376 km and an equatorial radius of 3396 km. Then the shape of Mars and its terminator were mapped through the optics and vidicon geometric models, using the vidicon geometric parameter values given in Tables 3 - 10, onto the images. Figure 13 shows such an example. The pre-launch focal lengths, 505.41 mm and 502.66 mm for the Mariner 6 and 7 narrow angle camera, respectively, (Danielson and Montgomery, 1971), were verified to an accuracy of 0.2% (1 mm) 1-σ. No optical distortions could be determined from this approach. The optical principal point and distortion terms will be included in the second year of this PDART task where the geometric camera calibration study will include the Near Encounter images where Mars fills the pictures and known Mars surface features (landmarks) will be used as "pseudo" stars. Therefore, for the Far Encounter images, camera pointing is tied directly to the central reseaux location in each image.

These optical and vidicon geometric parameters and their values will be used to create NAIF SPICE Instrument Kernels (IK - Acton, 1996 and Acton, *et. al.*, 2017) for the Mariner 6 and 7 Narrow Angle cameras.

8 Far Encounter Narrow Angle Camera Average Parameters

The optical parameter values (Table 14) are fixed over all Far and Near Encounter images from each camera. The camera models and average parameter values for the Narrow Angle Cameras during the Far Encounter sequences are included in the SPICE instrument kernels, *mr6_na_tcd_v10.ti* and *mr7_na_tcd_v10.ti*. Since the vidicon distortions vary at the pixel level from image to image, the camera parameter values listed in Tables 6 - 13 for each Far Encounter image are included in table *mr69_camera_distortion_catalog.tab*.

Other useful camera geometric quantities included in the instrument kernels were computed using metrics extrapolated from the reseaux grid shown in Figure 3 for all cameras. Each vidicon image area is guessed to be 12.32 mm x 9.6 mm covered by 945 samples and 704 lines, giving a pixel size of 0.013037 mm x 0.013636 mm. The M6 NA IFOV is 0.00148614 x 0.00155717 deg^2 or 0.00002579 x 0.00002713 rad^2. The M7 NA IFOV is 0.00148614 x 0.00155717 deg ^{2} or 0.00002594 x 0.00002713 rad^2.

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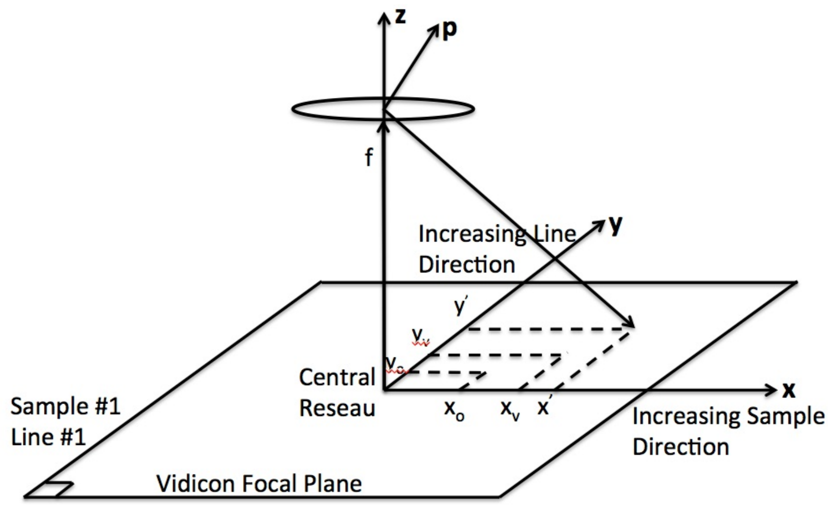

Figure 1: The vidicon-fixed focal plane $\bar{\mathbf{x}}\bar{\mathbf{y}}\bar{\mathbf{z}}$ coordinate system showing an optical system having a focal length f an optical principal point x_0, y_0, a vidicon distortion center at x_v, y_v and an undistorted image location for the camera fixed vector to an object $\mathbf{p}$ at x, y

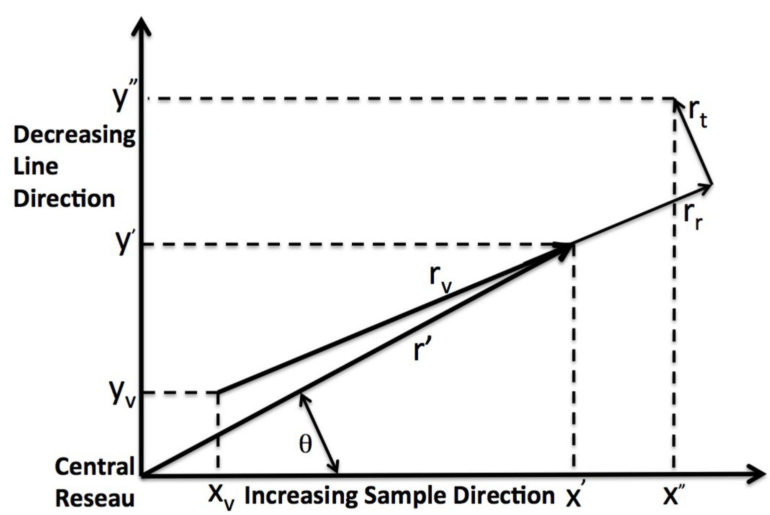

Figure 2: Vidicon radial r_r and tangential r_t distortions having a distortion center at x_v, y_v that adds additional distortion to the optically distorted coordinates x', y' to yield the actual image location at x'', y''

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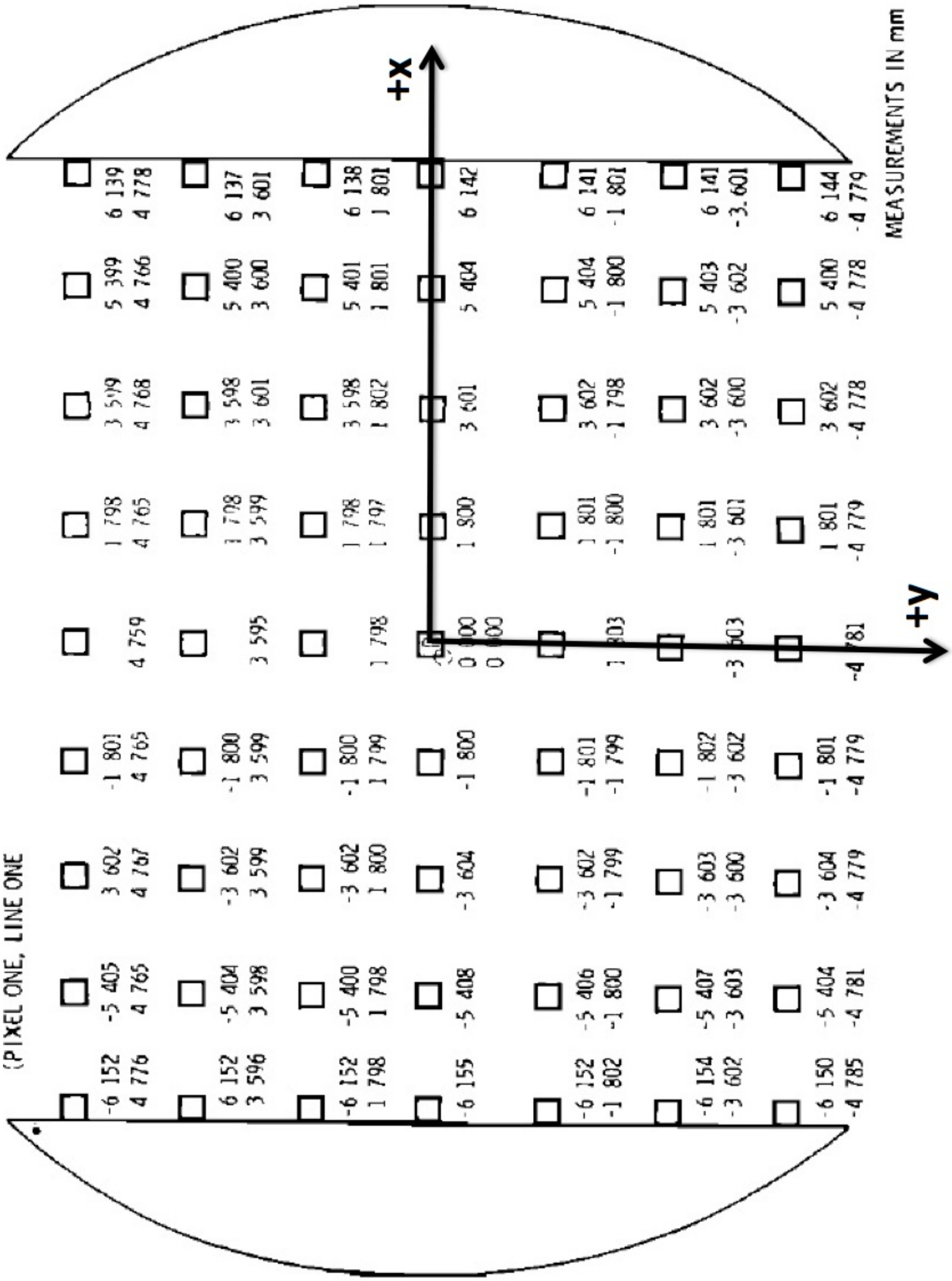

Figure 3: A reseau grid was etched onto each vidicon. NOTE: the y coordinates are reversed in sign

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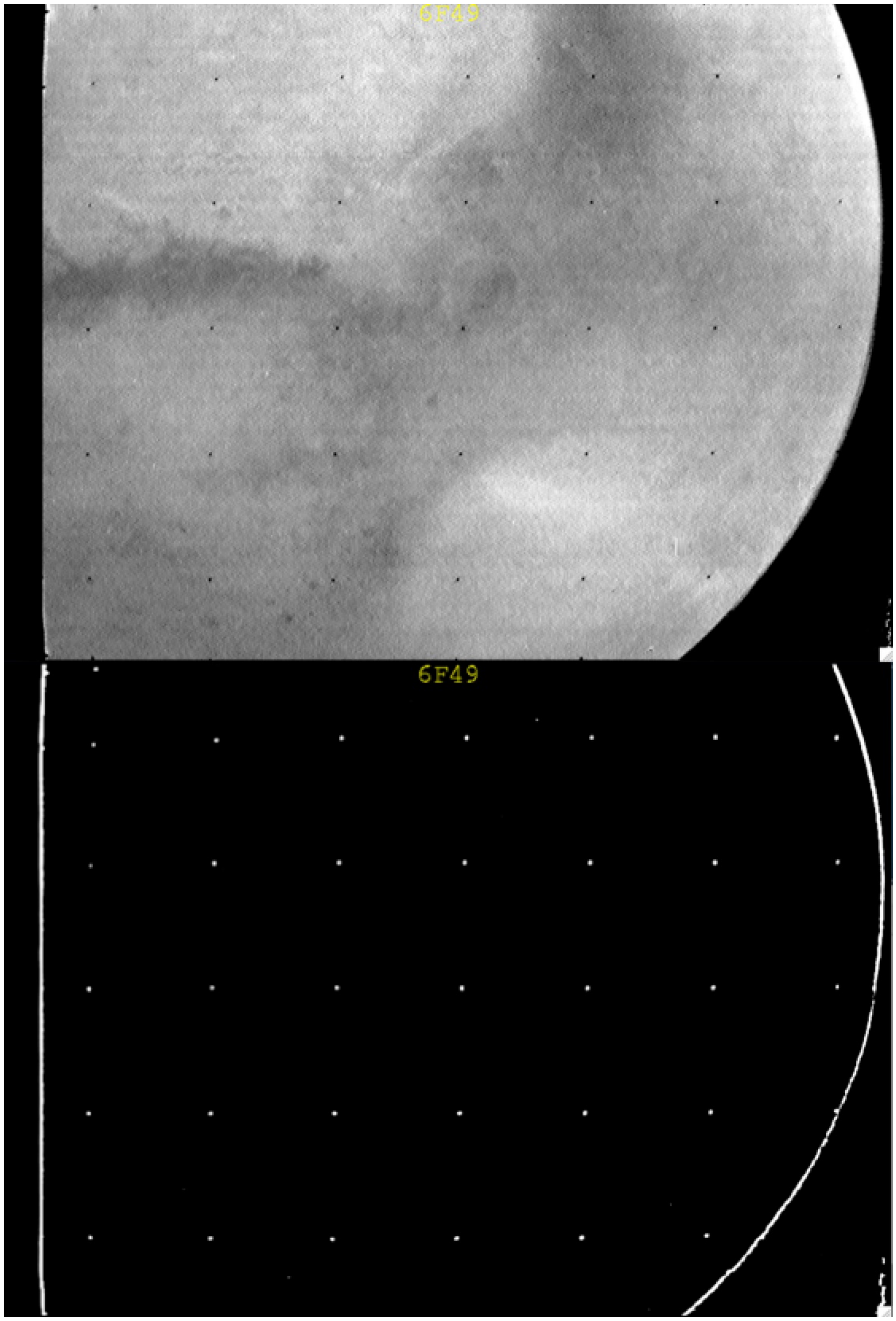

Figure 4: Mariner 6 Far Encounter image number 49 (6F49 - top) and its high pass filtered version (bottom) where the reseaux are enhanced to facilitate measuring their image locations.

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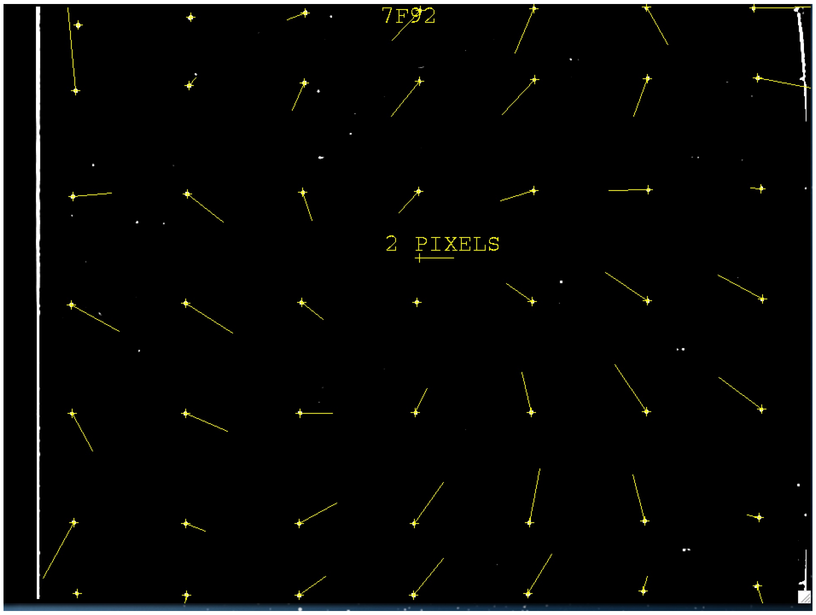

Figure 5: Geometric model errors (residuals) for 7F92 and Case 1.

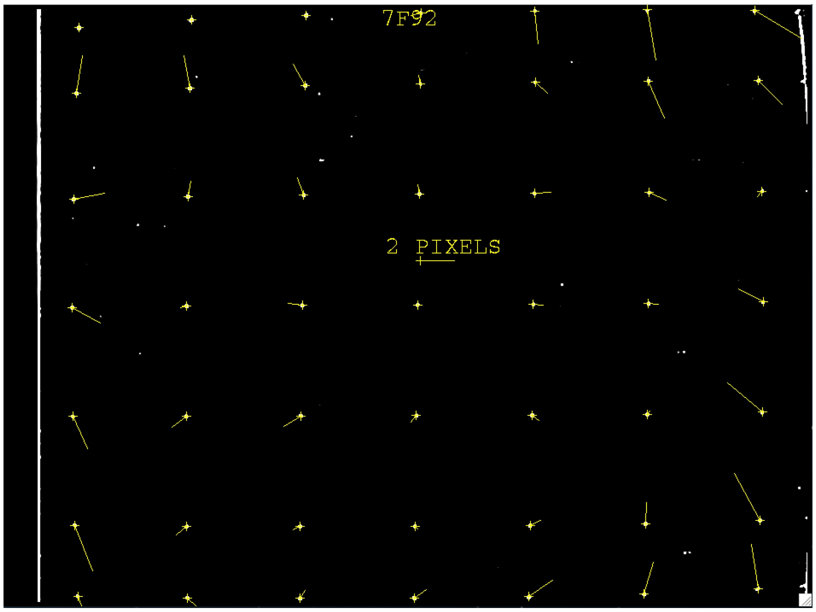

Figure 6: Geometric model errors (residuals) for 7F92 and Case 2.

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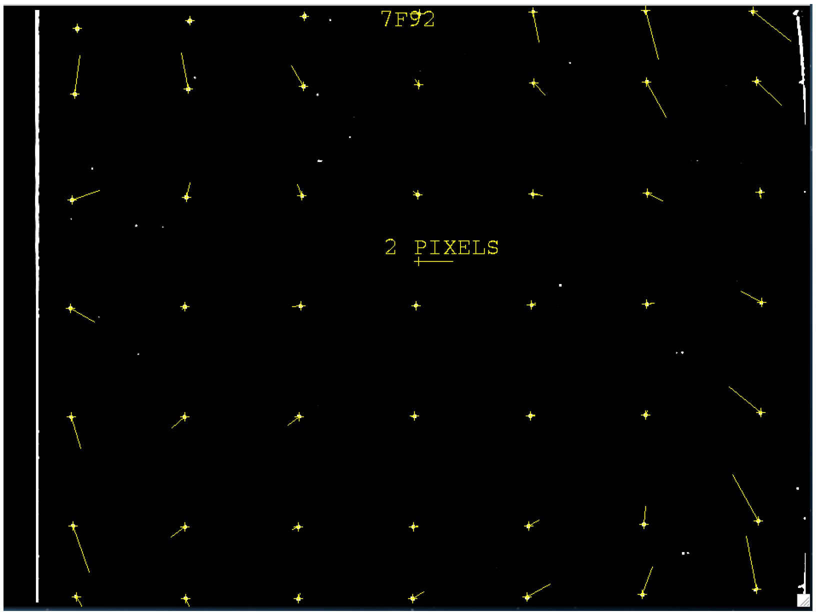

Figure 7: Geometric model errors (residuals) for 7F92 and Case 3.

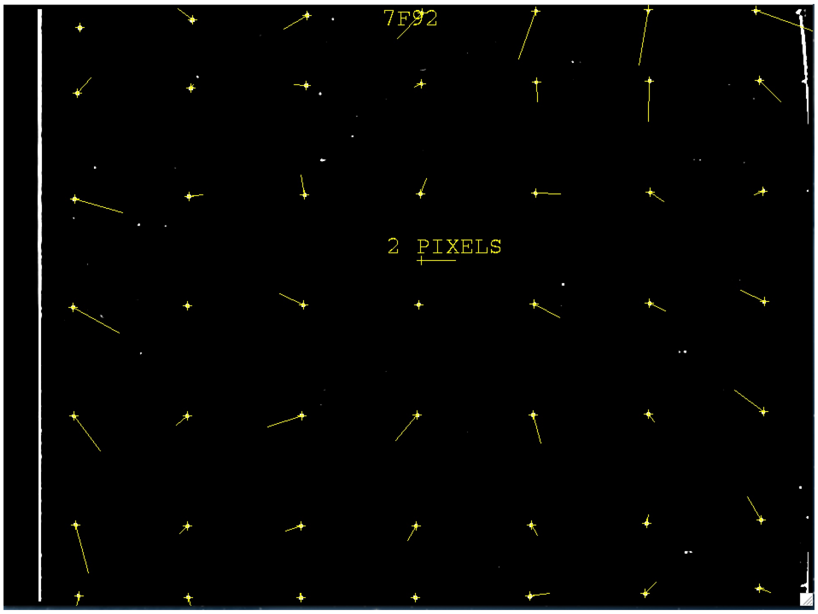

Figure 8: Geometric model errors (residuals) for 7F92 and Case 4.

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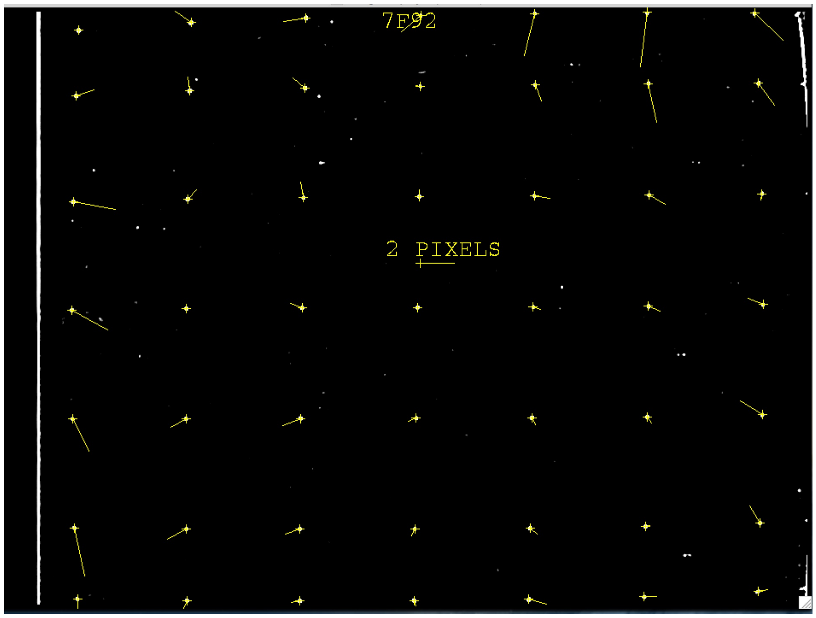

Figure 9: Geometric model errors (residuals) for 7F92 and Case 5.

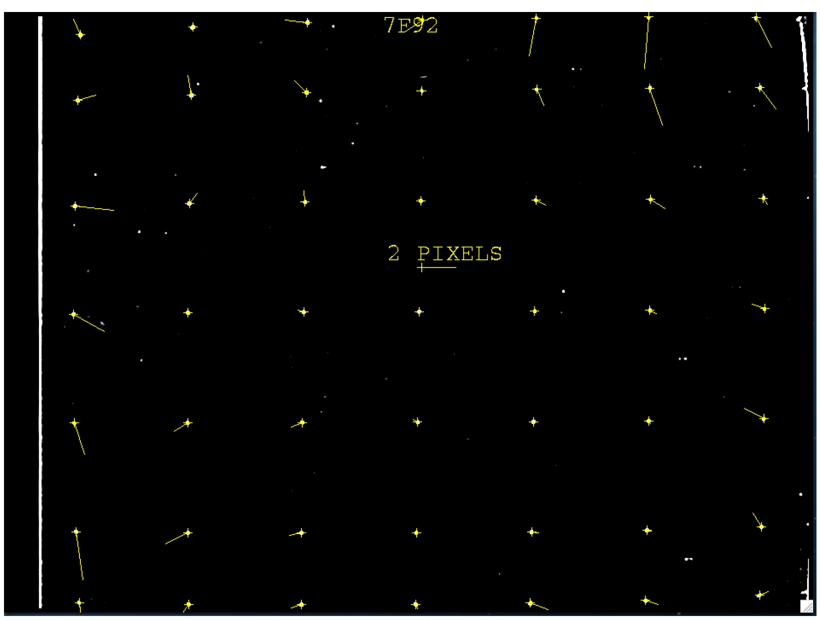

Figure 10: Geometric model errors (residuals) for 7F92 and Case 6.

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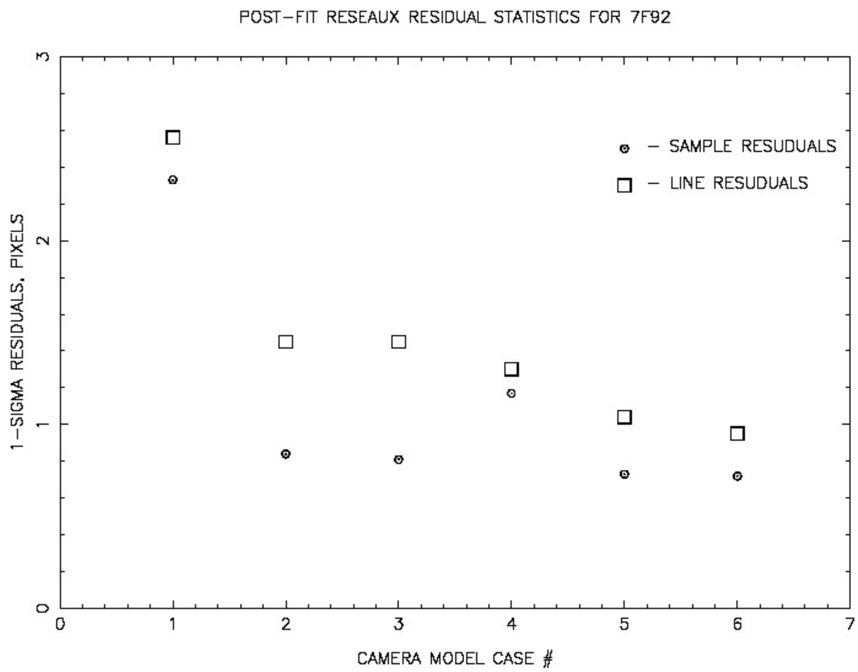

Figure 11: Geometric model errors (residuals) for Cases 1 - 6 applied to 7F92.

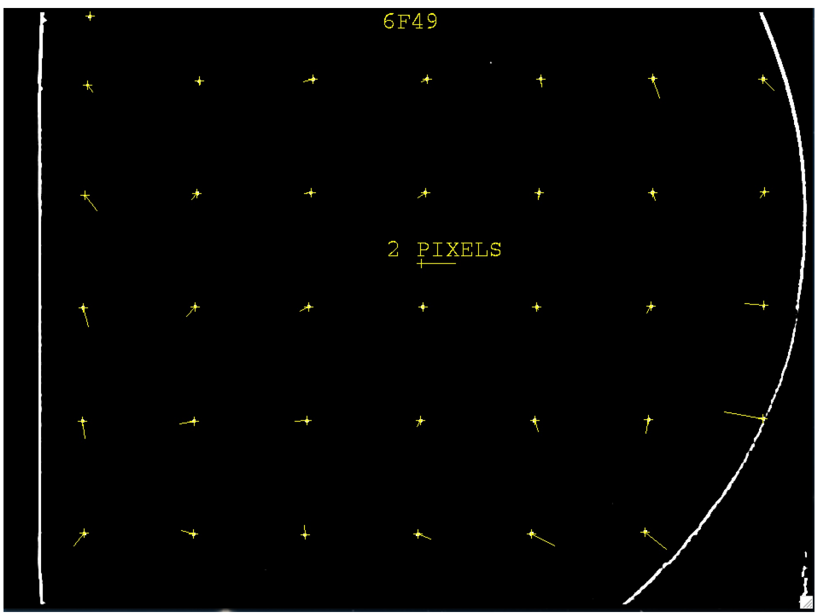

Figure 12: Geometric model errors (residuals) for 6F49 and Case 5.

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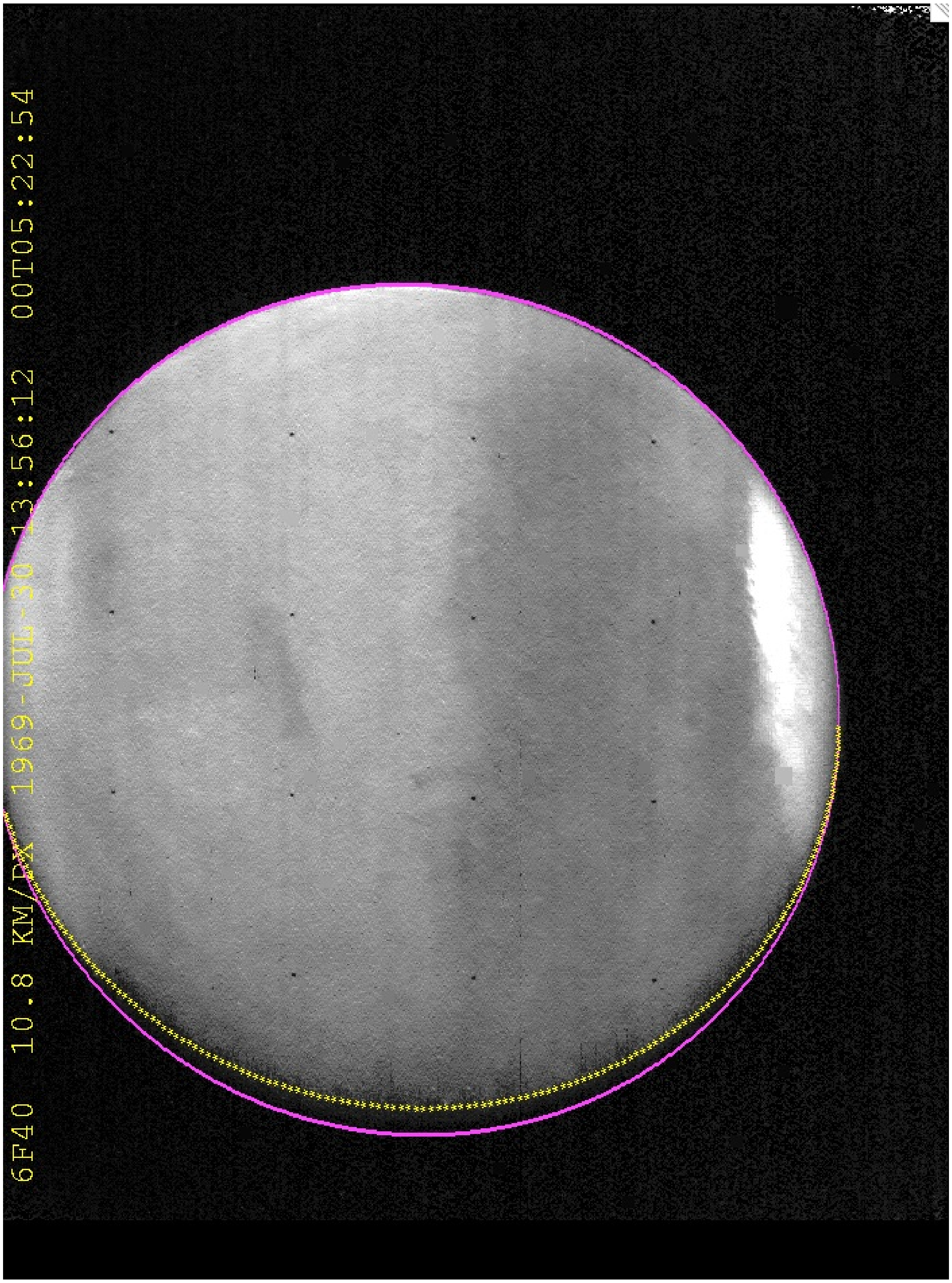

Figure 13: Figure 13. The Narrow Angle focal lengths were determined by varying the focal length values in the analytic model until the overlays matched the image. This process validated the pre-flight calibration values.

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Table 1: Mariner Mars 1969 SPICE Spacecraft and Camera Identification Numbers

S/C	S/C (S & SCLK) Kernels	S/C (C, F & I) Kernels	Narrow Angle Camera	Wide Angle Camera
Mariner 6	-530	-530000	-530101	-530102
Mariner 7	-531	-531000	-531101	-531102

Table 2: Comparing the partial derivatives computed using the analytic expressions vs numerically differenced values. The partial derivatives are only dependent on image location and not on any specific image.

Partial	Analytic	Differenced	Analytic	Differenced
$\partial(s,l)/\partial(K_{sx})$	-5.40	-5.40	0.00	0.00
$\partial(s,l)/\partial(K_{sy})$	-4.82	-4.82	0.00	0.00
$\partial(s,l)/\partial(K_{lx})$	0.00	0.00	-5.40	-5.40
$\partial(s,l)/\partial(K_{ly})$	0.00	0.00	-4.82	-4.82
$\partial(s,l)/\partial(v_x)$	-0.08	-0.09	-1.27	-1.45
$\partial(s,l)/\partial(v_y)$	-0.07	-0.08	-1.12	-1.29
$\partial(s,l)/\partial(\beta_2)$	-2991.73	-2991.73	-2639.93	-2639.93
$\partial(s,l)/\partial(\beta_3)$	-21968.01	-21968.01	-19384.74	-19384.74
$\partial(s,l)/\partial(\beta_4)$	-161308.97	-161308.97	-142340.23	-142340.23
$\partial(s,l)/\partial(\gamma_2)$	2639.93	2639.93	-2991.73	-2991.73
$\partial(s,l)/\partial(\gamma_3)$	19384.74	19384.74	-21968.01	-21968.01
$\partial(s,l)/\partial(\gamma_4)$	142340.23	142340.23	-161308.97	-161308.97

Table 3: Vidicon geometric model parameters for Cases 1 - 6 applied to 7F92

VALUE	CASE #1	CASE #2	CASE #3	CASE #4	CASE #5	CASE #6
K_{sx}	74.444702	74.083000	75.727097	76.746803	74.189598	74.746101
K_{sy}	-0.464800	-0.540500	-0.977000	-1.923100	-0.790600	-1.632000
K_{lx}	-0.852700	-0.702800	-0.314700	0.574900	-0.448400	0.336600
K_{sy}	71.331902	70.868698	72.458199	73.452499	70.994003	71.540398
v_x	0.000000	0.000000	0.000000	0.127000	0.165900	0.124600
v_y	0.000000	0.000000	0.000000	-0.252500	-0.491400	-0.399700
β_2	0.000000	0.009399	-0.006277	-0.005340	0.008652	0.001970
β_3	0.000000	-0.001438	0.001950	0.000000	-0.001349	0.000273
β_4	0.000000	0.000000	-0.000228	0.000000	0.000000	-0.000119
γ_2	0.000000	-0.003673	0.000342	0.003364	-0.002651	0.007049
γ_3	0.000000	0.000680	-0.000187	0.000000	0.000605	-0.001729
γ_4	0.000000	0.000000	0.000057	0.000000	0.000000	0.000167

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Table 4: Mariner 6 NA camera geometric model parameters: vidicon K terms

PICNO	# RES	K_{sx}	K_{sy}	K_{lx}	K_{ly}	s_0	l_0
6F01	1	73.8343	-1.0011	-0.4015	73.7763	492.21	349.02
6F02	2	73.8343	-1.0011	-0.4015	73.7763	491.69	350.97
6F03	2	73.8343	-1.0011	-0.4015	73.7763	491.94	350.94
6F04	2	73.8343	-1.0011	-0.4015	73.7763	491.78	351.28
6F05	2	73.8343	-1.0011	-0.4015	73.7763	491.63	351.14
6F06	2	73.8343	-1.0011	-0.4015	73.7763	491.95	351.41
6F07	2	73.8343	-1.0011	-0.4015	73.7763	491.80	351.31
6F08	2	73.8343	-1.0011	-0.4015	73.7763	491.76	351.20
6F09	2	73.8343	-1.0011	-0.4015	73.7763	491.60	351.31
6F10	2	73.8343	-1.0011	-0.4015	73.7763	491.97	351.29
6F11	2	73.8343	-1.0011	-0.4015	73.7763	491.70	351.29
6F12	3	73.8343	-1.0011	-0.4015	73.7763	491.51	351.00
6F13	2	73.8343	-1.0011	-0.4015	73.7763	491.66	350.96
6F14	3	73.8343	-1.0011	-0.4015	73.7763	491.71	351.14
6F15	3	73.8343	-1.0011	-0.4015	73.7763	491.66	350.81
6F16	3	73.8343	-1.0011	-0.4015	73.7763	491.62	351.02
6F17	2	73.8343	-1.0011	-0.4015	73.7763	491.94	351.75
6F18	3	73.8343	-1.0011	-0.4015	73.7763	491.47	350.92
6F19	3	73.8343	-1.0011	-0.4015	73.7763	491.92	351.27
6F20	3	73.8343	-1.0011	-0.4015	73.7763	491.92	351.05
6F21	3	73.8343	-1.0011	-0.4015	73.7763	491.89	351.15
6F22	3	73.8343	-1.0011	-0.4015	73.7763	491.73	351.20
6F23	2	73.8343	-1.0011	-0.4015	73.7763	491.75	351.23
6F24	3	73.8343	-1.0011	-0.4015	73.7763	491.56	350.90
6F25	3	73.8343	-1.0011	-0.4015	73.7763	491.52	350.97
6F26	4	73.8343	-1.0011	-0.4015	73.7763	491.64	350.90
6F27	4	73.8343	-1.0011	-0.4015	73.7763	491.77	351.07
6F28	4	73.8343	-1.0011	-0.4015	73.7763	491.63	351.08
6F29	4	73.8343	-1.0011	-0.4015	73.7763	491.54	350.96
6F30	4	73.8343	-1.0011	-0.4015	73.7763	491.39	350.71
6F31	5	73.8343	-1.0011	-0.4015	73.7763	491.59	351.11
6F32	5	73.8343	-1.0011	-0.4015	73.7763	491.63	348.97
6F33	4	73.8343	-1.0011	-0.4015	73.7763	491.60	350.95
6F34	9	74.1308	-1.4632	-0.2202	74.2984	491.57	350.51
6F35	9	74.5662	-1.0957	-0.4029	74.5637	491.86	346.50
6F36	10	73.8464	-1.1649	-0.2859	74.0700	491.49	350.86
6F37	12	73.6698	-1.2265	-0.4990	73.9465	491.50	350.93
6F38	13	73.9619	-1.1301	-0.4784	74.1671	491.58	350.57
6F39	14	73.7865	-0.9467	-0.7045	74.0256	491.33	350.96

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Table 5: Mariner 6 NA camera: vidicon K terms - Continued

PICNO	# RES	K_{sx}	K_{sy}	K_{lx}	K_{ly}	s_0	l_0
6F40	16	73.5763	-1.0270	-0.4608	73.9031	491.54	350.97
6F41	16	74.1520	-0.6699	-0.7786	74.4118	491.63	350.97
6F42	18	73.5300	-1.1691	-0.3917	73.9688	491.69	350.78
6F43	22	74.5964	-0.3772	-1.1048	74.6325	492.02	351.07
6F44	23	74.6060	-0.6459	-0.8680	74.7279	491.82	350.94
6F45	27	74.3613	-0.8530	-0.6763	74.4467	491.82	351.08
6F46	29	73.4403	-1.3484	-0.0891	73.4969	491.50	350.86
6F47	30	73.2222	-0.9664	-0.4691	73.2263	491.73	350.71
6F48	33	73.7931	-1.1514	-0.3226	73.7366	491.40	350.80
6F49	35	73.8358	-0.9998	-0.4029	73.7778	491.60	350.92
6AVE	7	73.9793	-0.9060	-0.5618	74.0064	491.70	350.91

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Table 6: Mariner 6 NA camera geometric model parameters: additional vidicon terms

PICNO	x_v	y_v	β_2	β_3	γ_2	γ_3
6F01	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F02	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F03	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F04	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F05	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F06	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F07	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F08	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F09	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F10	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F11	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F12	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F13	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F14	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F15	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F16	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F17	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F18	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F19	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F20	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F21	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F22	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F23	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F24	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F25	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F26	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F27	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F28	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F29	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F30	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F31	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F32	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F33	0.2562	-.1313	0.47770E-02	-0.94400E-03	0.34480E-02	-0.59900E-03
6F34	0.4741	-.2773	0.42971E-02	-0.94657E-03	-0.80845E-03	-0.34946E-03
6F35	-.1436	0.5299	0.36977E-02	-0.15807E-02	0.13653E-02	-0.41099E-03
6F36	-.3409	-.1002	0.49582E-02	-0.10487E-02	0.29675E-02	-0.66891E-03
6F37	-.2501	0.6405	0.55297E-02	-0.10355E-02	0.41284E-02	-0.88790E-03
6F38	-.0981	-.0453	0.56003E-02	-0.11850E-02	0.18056E-02	-0.64808E-03
6F39	-.3243	0.6994	0.49293E-02	-0.78756E-03	0.31879E-02	-0.66258E-03

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Table 7: Mariner 6 NA camera: additional vidicon terms - Continued

PICNO	x_v	y_v	β_2	β_3	γ_2	γ_3
6F40	0.1255	0.2332	0.55247E-02	-0.10224E-02	0.52587E-02	-0.10754E-02
6F41	0.4870	0.3443	0.30695E-02	-0.66895E-03	0.46176E-02	-0.87063E-03
6F42	-.0211	0.5370	0.63497E-02	-0.99955E-03	0.17538E-02	-0.57835E-03
6F43	0.5317	-.6166	0.21944E-03	-0.26970E-03	0.54998E-02	-0.82259E-03
6F44	0.4391	-.5273	-0.59959E-03	-0.14780E-03	0.37169E-02	-0.58443E-03
6F45	0.0544	-.6117	0.25648E-03	-0.33533E-03	0.43819E-02	-0.65930E-03
6F46	-.0516	-.0556	0.69975E-02	-0.12157E-02	0.20129E-02	-0.52531E-03
6F47	-.1649	-.2169	0.86713E-02	-0.14252E-02	0.42460E-02	-0.75570E-03
6F48	0.2103	-.2820	0.50063E-02	-0.98505E-03	0.30513E-02	-0.57949E-03
6F49	0.2564	-.1316	0.47682E-02	-0.94350E-03	0.34555E-02	-0.60004E-03
6AVE	0.1822	-.3488	0.3617E-02	-0.7600E-03	0.3766E-02	-0.64700E-03

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Table 8: Mariner 7 NA camera geometric model parameters: vidicon K terms

PICNO	# RES	K_{sx}	K_{sy}	K_{lx}	K_{ly}	s_0	l_0
7F00	1	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F01	1	74.1840	-0.8676	-0.3954	71.0212	486.49	351.33
7F03	1	74.1840	-0.8676	-0.3954	71.0212	487.09	351.99
7F04	1	74.1840	-0.8676	-0.3954	71.0212	487.01	351.20
7F05	1	74.1840	-0.8676	-0.3954	71.0212	487.11	351.65
7F06	1	74.1840	-0.8676	-0.3954	71.0212	486.85	351.14
7F07	1	74.1840	-0.8676	-0.3954	71.0212	486.90	351.75
7F08	1	74.1840	-0.8676	-0.3954	71.0212	486.52	351.56
7F09	1	74.1840	-0.8676	-0.3954	71.0212	487.16	351.27
7F10	1	74.1840	-0.8676	-0.3954	71.0212	486.94	351.83
7F11	1	74.1840	-0.8676	-0.3954	71.0212	486.79	351.31
7F12	1	74.1840	-0.8676	-0.3954	71.0212	486.91	351.97
7F13	1	74.1840	-0.8676	-0.3954	71.0212	486.62	351.49
7F14	1	74.1840	-0.8676	-0.3954	71.0212	487.01	351.69
7F15	1	74.1840	-0.8676	-0.3954	71.0212	487.14	351.61
7F16	1	74.1840	-0.8676	-0.3954	71.0212	487.09	351.27
7F17	1	74.1840	-0.8676	-0.3954	71.0212	487.22	350.50
7F18	1	74.1840	-0.8676	-0.3954	71.0212	486.51	351.49
7F19	1	74.1840	-0.8676	-0.3954	71.0212	487.36	351.55
7F20	1	74.1840	-0.8676	-0.3954	71.0212	486.88	351.26
7F21	1	74.1840	-0.8676	-0.3954	71.0212	486.77	351.68
7F22	1	74.1840	-0.8676	-0.3954	71.0212	487.10	351.88
7F23	1	74.1840	-0.8676	-0.3954	71.0212	486.80	351.39
7F24	1	74.1840	-0.8676	-0.3954	71.0212	487.03	351.84
7F25	1	74.1840	-0.8676	-0.3954	71.0212	487.00	351.49
7F26	1	74.1840	-0.8676	-0.3954	71.0212	486.81	351.44
7F27	1	74.1840	-0.8676	-0.3954	71.0212	487.05	351.86
7F28	1	74.1840	-0.8676	-0.3954	71.0212	487.00	352.55
7F29	1	74.1840	-0.8676	-0.3954	71.0212	487.02	351.87
7F30	1	74.1840	-0.8676	-0.3954	71.0212	486.74	351.53
7F31	1	74.1840	-0.8676	-0.3954	71.0212	487.22	352.70
7F32	2	74.1840	-0.8676	-0.3954	71.0212	486.80	352.09
7F33	1	74.1840	-0.8676	-0.3954	71.0212	486.87	351.27
7F35	2	74.1840	-0.8676	-0.3954	71.0212	486.78	351.30
7F36	2	74.1840	-0.8676	-0.3954	71.0212	487.18	351.62
7F37	2	74.1840	-0.8676	-0.3954	71.0212	487.16	351.91
7F38	2	74.1840	-0.8676	-0.3954	71.0212	486.63	351.39
7F39	3	74.1840	-0.8676	-0.3954	71.0212	486.60	351.49

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Table 9: Mariner 7 NA camera: vidicon K terms - Continued

PICNO	# RES	K_{sx}	K_{sy}	K_{lx}	K_{ly}	s_0	l_0
7F40	3	74.1840	-0.8676	-0.3954	71.0212	486.83	351.74
7F41	2	74.1840	-0.8676	-0.3954	71.0212	487.01	351.55
7F42	2	74.1840	-0.8676	-0.3954	71.0212	486.77	350.60
7F43	2	74.1840	-0.8676	-0.3954	71.0212	486.69	351.16
7F44	3	74.1840	-0.8676	-0.3954	71.0212	486.54	351.39
7F45	2	74.1840	-0.8676	-0.3954	71.0212	486.92	352.75
7F46	3	74.1840	-0.8676	-0.3954	71.0212	486.95	351.69
7F47	3	74.1840	-0.8676	-0.3954	71.0212	486.73	351.51
7F48	3	74.1840	-0.8676	-0.3954	71.0212	486.69	351.33
7F49	0	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F50	3	74.1840	-0.8676	-0.3954	71.0212	487.02	351.50
7F51	2	74.1840	-0.8676	-0.3954	71.0212	486.98	351.80
7F52	4	74.1840	-0.8676	-0.3954	71.0212	486.86	351.32
7F53	3	74.1840	-0.8676	-0.3954	71.0212	486.86	351.37
7F54	4	74.1840	-0.8676	-0.3954	71.0212	486.98	351.94
7F55	4	74.1840	-0.8676	-0.3954	71.0212	487.07	351.73
7F56	2	74.1840	-0.8676	-0.3954	71.0212	487.08	351.87
7F57	2	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F58	0	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F59	1	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F60	1	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F61	0	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F62	4	74.1840	-0.8676	-0.3954	71.0212	486.94	351.64
7F63	4	74.1840	-0.8676	-0.3954	71.0212	487.06	351.81
7F64	5	74.1840	-0.8676	-0.3954	71.0212	487.10	351.86
7F65	5	74.1840	-0.8676	-0.3954	71.0212	486.96	351.89
7F66	4	74.1840	-0.8676	-0.3954	71.0212	486.74	351.41
7F67	6	74.1840	-0.8676	-0.3954	71.0212	486.72	351.41
7F69	9	74.4949	-0.6322	-0.5490	71.5591	486.70	351.22
7F70	10	75.0087	-1.0013	-0.2554	72.1394	486.71	351.23
7F71	10	75.1314	-1.0032	-0.2810	72.0957	487.01	351.61
7F72	12	74.5203	-0.7362	-0.5561	71.5570	487.00	351.55
7F73	12	74.6539	-0.9413	-0.3754	71.6472	486.76	351.17
7F74	14	74.4853	-0.8628	-0.4322	71.4894	486.92	351.65
7F75	14	75.0514	-1.1013	-0.0930	71.9361	487.13	351.56
7F76	18	75.0944	-0.9543	-0.3819	71.9697	486.79	351.16
7F77	20	74.8815	-1.0005	-0.3206	71.7896	486.73	351.27
7F78	23	75.1875	-0.9379	-0.3896	72.0579	486.92	351.58
7F79	26	75.2294	-1.1686	-0.1242	72.0261	486.67	351.25

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Table 10: Mariner 7 NA camera: vidicon K terms - Continued

PICNO	# RES	K_{sx}	K_{sy}	K_{lx}	K_{ly}	s_0	l_0
7F80	27	74.9725	-1.2732	-0.0373	71.8385	486.78	351.45
7F81	34	74.8997	-1.2247	-0.0562	71.6836	487.08	351.60
7F82	38	75.2504	-0.9677	-0.3471	72.0822	486.58	351.41
7F83	43	74.9457	-0.9422	-0.3572	71.7898	486.53	351.30
7F84	45	74.0804	-1.1240	-0.1373	70.8680	487.19	351.79
7F85	45	74.3031	-0.8247	-0.4473	71.0512	486.81	351.92
7F86	49	74.0495	-0.9685	-0.2633	70.9171	486.84	351.48
7F87	49	73.9675	-0.8152	-0.4183	70.7862	486.95	352.00
7F88	49	74.0854	-1.0218	-0.2005	70.9234	487.22	351.76
7F89	49	74.1035	-0.7818	-0.4479	70.9319	487.01	351.84
7F90	49	74.2250	-0.6597	-0.5535	71.0350	486.55	351.43
7F91	49	73.9484	-0.9455	-0.2733	70.7932	486.88	351.56
7F92	49	74.1896	-0.7906	-0.4484	70.9940	486.99	351.69
7F93	35	74.5520	-1.0068	-0.4485	71.4501	487.00	351.58
7AVE	17	74.5218	-0.9679	-0.3100	71.3540	486.87	351.58

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Table 11: Mariner 7 NA camera geometric model parameters: additional vidicon terms

PICNO	x_v	y_v	β_2	β_3	γ_2	γ_3
7F00	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F01	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F03	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F04	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F05	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F06	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F07	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F08	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F09	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F10	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F11	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F12	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F13	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F14	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F15	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F16	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F17	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F18	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F19	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F20	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F21	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F22	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F23	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F24	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F25	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F26	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F27	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F28	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F29	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F30	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F31	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F32	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F33	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F35	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F36	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F37	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F38	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F39	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03

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Table 12: Mariner 7 NA camera: additional vidicon terms - Continued

PICNO	x_v	y_v	β_2	β_3	γ_2	γ_3
7F40	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F41	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F42	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F43	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F44	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F45	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F46	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F47	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F48	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F49	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F50	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F51	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F52	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F53	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F54	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F55	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F56	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F57	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F58	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F59	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F60	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F61	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F62	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F63	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F64	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F65	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F66	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F67	0.1412	0.5653	0.85620E-02	-0.13250E-02	0.23320E-02	-0.57600E-03
7F69	0.0788	-.0527	0.74756E-02	-0.13015E-02	0.24522E-02	-0.38577E-03
7F70	0.1437	0.5969	0.33042E-02	-0.10863E-02	0.20366E-02	-0.10448E-02
7F71	0.3173	0.7281	0.40164E-02	-0.13025E-02	0.10660E-02	-0.55247E-03
7F72	-.0811	-.2138	0.64556E-02	-0.10875E-02	0.18276E-02	-0.28678E-03
7F73	0.0876	0.0016	0.59433E-02	-0.11094E-02	0.61110E-03	-0.32078E-03
7F74	-.1657	0.0970	0.64356E-02	-0.10767E-02	0.93233E-03	-0.28890E-03
7F75	-.2091	0.8137	0.32420E-02	-0.81722E-03	0.60059E-03	-0.62867E-03
7F76	0.2795	0.4664	0.34315E-02	-0.88126E-03	0.12950E-02	-0.46423E-03
7F77	0.2443	0.3037	0.50165E-02	-0.10971E-02	0.20063E-03	-0.20595E-03
7F78	0.4943	0.3569	0.22686E-02	-0.65018E-03	0.11020E-02	-0.37003E-03
7F79	0.2731	0.3993	0.16584E-02	-0.52495E-03	-0.10956E-02	-0.58719E-04

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Table 13: Mariner 7 NA camera: additional vidicon terms - Continued

PICNO	x_v	y_v	β_2	β_3	γ_2	γ_3
7F80	0.1338	0.3293	0.34598E-02	-0.75483E-03	-0.21842E-02	0.12447E-03
7F81	0.1915	0.2758	0.44664E-02	-0.90471E-03	-0.12007E-02	-0.67981E-04
7F82	0.3477	0.1328	0.12240E-02	-0.44764E-03	0.19905E-03	-0.20111E-03
7F83	0.3708	0.3416	0.38630E-02	-0.81382E-03	0.72649E-03	-0.30950E-03
7F84	0.1798	0.4403	0.96467E-02	-0.14691E-02	0.46058E-03	-0.36772E-03
7F85	0.2538	0.3432	0.84875E-02	-0.13593E-02	0.17006E-02	-0.43898E-03
7F86	0.1589	0.5387	0.91925E-02	-0.13873E-02	0.15386E-02	-0.49685E-03
7F87	0.1337	0.4649	0.99184E-02	-0.14730E-02	0.23198E-02	-0.56636E-03
7F88	0.1259	0.5124	0.91033E-02	-0.13879E-02	0.13982E-02	-0.49773E-03
7F89	0.1478	0.4596	0.90868E-02	-0.13893E-02	0.26001E-02	-0.60111E-03
7F90	0.2005	0.4751	0.85554E-02	-0.13475E-02	0.31213E-02	-0.64024E-03
7F91	0.1196	0.4918	0.98351E-02	-0.14584E-02	0.18239E-02	-0.53983E-03
7F92	0.1659	0.4914	0.86516E-02	-0.13492E-02	0.26512E-02	-0.60541E-03
7F93	0.0873	0.9616	0.61398E-02	-0.10146E-02	0.23973E-02	-0.57000E-03
7AVE	0.2134	0.4305	0.6504E-02	-0.1108E-02	0.1045E-02	-0.3770E-03

Table 14: Mariner 6 and 7 NA camera optical model parameter values

SPACECRAFT	f, mm	x_o, mm	y_o, mm	α_1, mm^{-2}	α_2, mm^{-4}
M'6	505.41	0.0	0.0	0.0	0.0
M'7	502.66	0.0	0.0	0.0	0.0