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3 ARACON PHOTOGRAMMETRIC ATTITUDE SYSTEM DESCRIPTION 6

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FOREWORD

This document by ARACON Geophysics, a division of Allied Research Associates, Inc., Concord, Massachusetts presents a general system description of ARACON's photogrammetric attitude determination system. These studies were performed for the National Aeronautics and Space Administration under Contract No. NAS5-3953.

This report supplements two previously published volumes— an operator's manual (Ref. 1) and a hardware description (Ref. 2).

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1. SATELLITE ATTITUDE DETERMINATION: THE PROBLEM

At any moment the position of a satellite can be described by six numbers: three to tell where it is and three more to tell how it is oriented. Estimation of the former parameter is often referred to as "orbit determination;" estimation of the latter is "attitude determination."

There are several reasons why scientists seek precise estimates of spacecraft attitude. Some typical ones are:

1. To pinpoint attitude at the instant of picture-taking to allow proper geographic referencing of picture content – a vital need for TIROS, Nimbus, Ranger, Mariner, Samos, and other vehicles;

2. To aid in engineering evaluation of attitude control systems – e.g. on TIROS Wheel, QOMAC spin-vector steering, MASC spin-rate control, and TEAM nutation damping;

3. To confirm conditions pre-requisite to orbit modification, e.g. preparation for Mercury or Gemini re-entry or for Ranger or Mariner mid-course corrections.

There are also several independent sources of data for attitude estimation. A few of these are:

1. infrared radiation records
2. visible-light photographs
3. sun-angle sensor records
4. star-scan information

Each of the attitude determination systems available has both good points and bad. For a given satellite, some bases of choice are:

1. the type of satellite(The necessary sensors may already be on board for other purposes, e.g. to gather meteorological data, as on Nimbus and TIROS.)
2. sensor cost and reliability
3. accuracy
4. cost of data reduction
5. time of data reduction before estimates are made available.

This report describes in detail a system to determine attitude of the TIROS Wheel satellite from interpretation of its photographs of the earth.

2. THE ARACON/ITEK FILM READER

Under Contract No. NAS5-3953, ARACON has developed a flexible photogrammetric satellite attitude determination system. Any satellite camera system which yields 35 mm film can be accommodated. System hardware is a general-purpose film reader along with formatting and control electronics (Fig 2-1). Off-line operation of this equipment produces a paper tape containing raw attitude data. Computer programs have been provided to calculate TIROS attitude parameters with the aid of a Control Data 160-A (with 8K memory and two tape transports). The system was first made operational for the TIROS IX wheel configuration satellite. Since then minor software changes have been made to accommodate TIROS X with its "conventional" camera mount geometry.

The paper tape produced by film reader operation contains several varieties of data, some numerical and some not. The primary numerical data are X-Y coordinates of three different types of data "points": landmarks, horizon points, and matchpoints (common features in pictures with overlapping coverage). These data are obtained by reading the positions of cursors centered by an operator over selected image points of cloud pictures displayed on the film reader.

Figure 2-2 shows the data displayed on the film reader screen. Two consecutive frames of TIROS 35 mm film appear on the right-hand side of the screen. The upper frame can be rotated 360° by an operator to permit alignment of the two TIROS frames, thereby facilitating matchpoint measurements. The legend of the lower frame is displayed immediately below the frame itself. Landmark maps, on a series of 35 mm slides, are displayed on the left-hand side of the screen.

Two sets of perpendicular crosswires (cursors) ride immediately behind the reader display screen. The intersection of each set defines a point in the image plane of the reader. Either set can be positioned at any point on the display screen. The projection mechanism and crosswire assemblies (not including the electronic readout) are described in detail in the "ARACON/Itek Film Record Reader" instruction manual. The rest of the hardware is described in Reference 2.

Figure 2-3 shows a simplified block diagram of the electronics which convert crosswire position to digital codes punched on paper tape. A shaft position encoder is mechanically linked to the prism mechanism which rotates the upper TIROS image, providing an indication of image rotation. Additional data sources are a keyboard, and control switches mounted on the control panel of the film reader. Data from the shaft encoders and the control panel are punched onto paper tape through an electronic sequencer.

Fig. 2-1Photogrammetric Attitude System

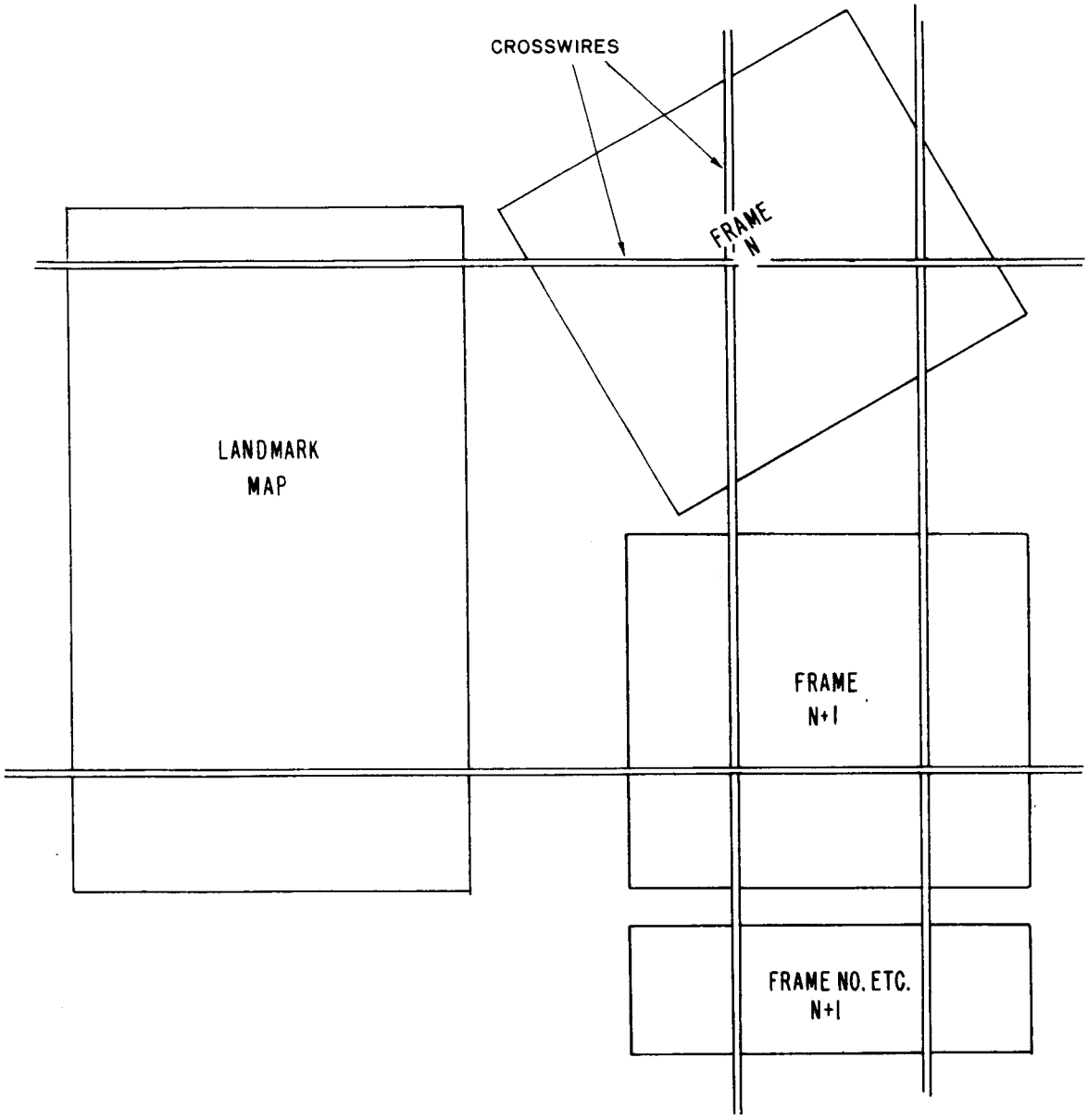

Figure 2-2 Film Reader Display

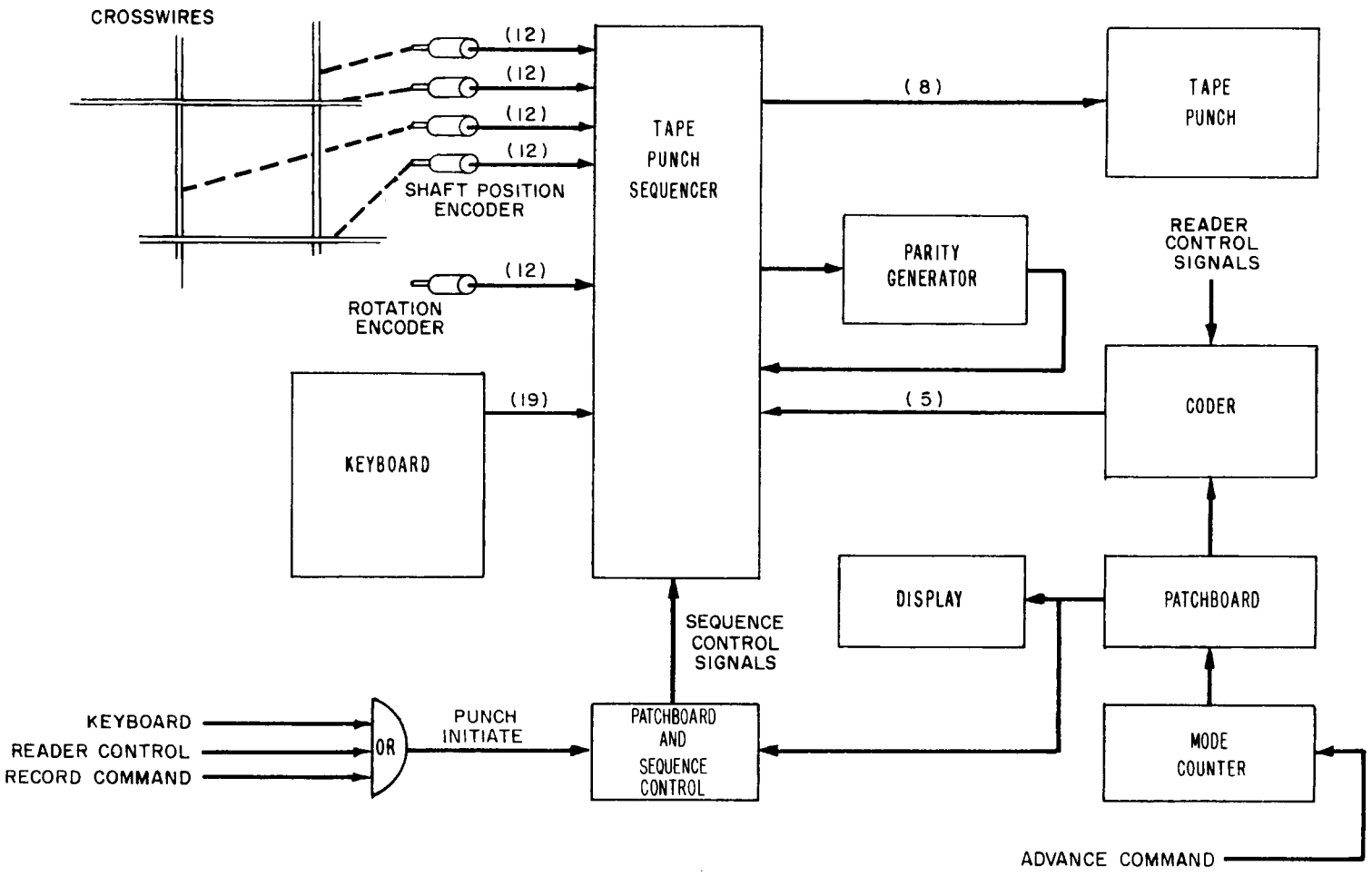

Figure 2-3 Simplified System Block Diagram

A feature of the system is programed control of the sequence of measurements to be made on each cloud picture. The type of point (picture fiducial, landmark, horizon point, etc.) defines the measurement "mode" of the reader. The mode is displayed to an operator from an illuminated display device mounted on the reader control panel. The order of measurement modes is determined by the pin setting of the mode sequence patchboard. After completing operations in a given mode, an operator depresses a mode advance pushbutton. The mode, or type of measurement, is also sequenced onto paper tape with the outputs of the shaft encoders.

A second patchboard allows selection of the various data sources for each type of measurement or mode. Each mode requires somewhat different data to be punched on tape. For instance, when measuring horizon points, data is taken from only the upper picture and the outputs of shaft encoders for only one crosswire set are needed, whereas matchpoint measurements require readout of both crosswire sets. The patchboard permits selection of the punched data for each of eight types of measurements or modes.

3. COMPUTATIONAL EQUIPMENT

It has been mentioned that the film reader is operated off line to produce an eight-level paper data tape. This tape and a short flexowriter tape containing orbital data are the two inputs to the photogrammetric attitude program.

At each TIROS readout station the ARACON support team utilizes the following computer configuration:

- 1 - 160-A (8K) Computer Console with Paper Tape Reader and Punch
- 1 - 168-2 Arithmetic Unit
- 1 - 161 Input/Output Typewriter
- 1 - 162-1 Magnetic Tape Synchronizer
- 2 - 603 Magnetic Tape Units
- 1 - 165-2 On-line Calcomp Plotter
- 1 - Off-line Flexowriter

4. FROM PICTURES TO PARAMETERS

Photogrammetric determination of TIROS attitude is not a new venture with the advent of the Wheel. Manual techniques such as those devised by Fujita have been used operationally in the past — on the conventional TIROS. There are several reasons, however, for turning to machines for assistance. Great gains in speed and accuracy are possible. More importantly, perhaps, specialized ad hoc solutions can be replaced by a general approach readily adaptable to any camera-carrying vehicle.

TIROS pictures and picture sequences offer many clues to spacecraft attitude. At a glance a human can often give a fair estimate of attitude from one or more gross indications, e.g. the general appearance of the earth horizon. Preliminary study on the present contract suggested three distinct types of picture data as independent sources for computer-aided attitude estimates.

4.1 The Horizon

Though not always available, the horizon is perhaps the most easily used feature of the earth-disc image (Fig. 4-1). For early TIROS satellites, a "quick look) technique matched picture horizons to curves on plastic overlays to give rough attitude values. Elliptical orbits and canted cameras (no longer looking down spin axes) can complicate such manual methods and make them lose their "quick and easy" appeal.

It should be noted that reduction of TIROS Wheel infrared V-scan data is also an attempt to detect the horizon. Infrared radiation is monitored rather than visible light. Sensor field of view is much narrower than that of the cameras. Average temperature (or its rate of change) in the scan element is continuously recorded; with the camera, a highly structured wide-angle field of view is recorded (typically) twenty times per orbit per camera.

4.2 Landmarks

The interior of the earth image provides many quasi-points of data. Some of these are "permanent" landmarks of known latitude and longitude (Fig. 4-1). Although the majority of these landmarks appear at land-water interfaces, they also occur within land masses. For example, the peaks of some high mountains are readily

TIROS 9, Orbit 108, Camera 2, Tape Frame 4, 052811 UT, 31 January 1965

TIROS 9, Orbit 108, Camera 2, Tape Frame 3, 052915 UT, 31 January 1965

+ Horizon Points

→ Matchpoints

-+- Landmarks

Figure 4-1 Satellite Pictures Showing Horizon, Landmark, and Matchpoint Data

detectable by their glacial cover. If landmarks can be recognized in a satellite picture, latitude-longitude coordinates can be assigned to various points in the image plane, and knowing the satellite location, its attitude can be mathematically determined. Due to the large ocean areas and often extensive cloud cover, this technique is usually applicable only on a few frames per pass.

4.3 Matchpoints

Even if earth-image "points" are not recognizable landmarks, they may still yield attitude information. If satellite height, picture interval, and camera field of view combine to give substantial (~30% or more) overlap between adjacent pictures, many matching points can often be found in a given picture pair (Fig. 4-1). We shall refer to such point pairs as "matchpoints" — or we may also refer to a point and its "matchpoint." Cloud "notches" are the usual matchpoints but landmarks or snow patterns are secondary sources. As any recognizable point feature which appears in two pictures can be used, matchpoints provide a far greater supply of usable data than do landmarks.

5. TERMINOLOGY AND BASIC CONCEPTS

To promote the understanding of the algorithms and the program listings certain basic terms will be defined.

5.1 Fiducials

On the on-board vidicon faceplate are five fiducial or reference marks as in Figure 5-1:

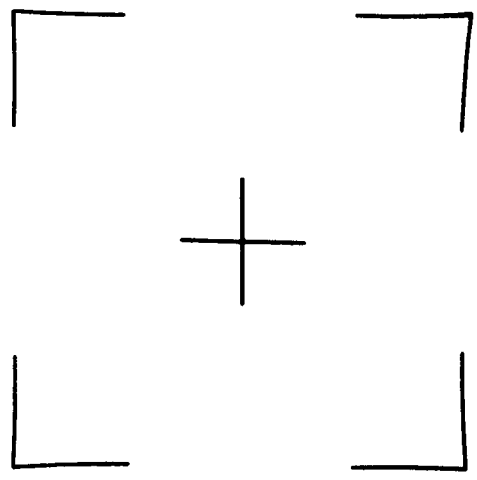

Figure 5-1 Camera Fiducial Array

In practice these marks are presumed to form an ideally square array.

If they were measurably non-square, two of them could arbitrarily be chosen for a reference or they could be treated in a least-squares sense.

5.2 Optical Axis and Principal Point

At camera calibration time a working definition is used for the optical axis. A front-surface mirror (on an optically flat blank and with a central reticle) is fastened to the front element of the camera lens assembly. (The front element has a planar surface.) That ray which passes through the reticle perpendicular to the mirror surface is the optical axis.

Whenever an image is formed by the camera system, that point which is imaged along the optical axis (centrally) is called the principal point.

5.3 Camera Calibration

For recent TIROS satellites, camera calibrations have been performed by the prime contractor, Radio Corporation of America (Ref. 3). Pictures are taken of a carefully surveyed bull's-eye target. Positive transparencies from the tests have been supplied to ARACON personnel. With the aid of the film reader, a two-dimensional (radial and azimuthal) radial distortion polynomial has been generated. Using this polynomial and the fiducial measurements from a given picture, the photogrammetry programs can map information into a virtually distortion-free standard image plane. The generation of the polynomial will be outlined briefly.

A calibration transparency is projected on the film reader. Target feature coordinates are measured (in shaft-encoder counts). The bull's eye has radial lines at every 15°. Separate polynomial coefficients are produced for each of the 24 "spokes." A least-squares curve fit is performed such that

$$R_u = C_1 R_d + C_2 R_d^3 + C_3 R_d^5$$

where

R_u = distortion-free radial distance in focal-length units (calculated from target survey and distance from target to front nodal point

R_d = distorted radial distance in shaft-encoder counts.

The radial distortion should vanish at the lens center. Therefore C_1 should give the proper ratio between focal lengths and shaft-encoder counts — for the picture as imaged at the projection scale of the film reader.

The coordinates of the calibration picture fiducials are stored in focal length units (with a translation to set the sums of the x's and of the y's equal to zero). All other pictures are imaged — by fitting of fiducial arrays — onto the calibration picture and from there to a distortion-free plane.

A part of the RCA camera calibration is the determination of the camera mounting angles. Let us define a set of three angles which will determine the "looking direction" of the camera:

1. Cant - The angle between the camera optical axis and the satellite baseplate;
2. Azimuth - Passing through the baseplate center is a directed line parallel to the camera optical axis projection on the baseplate; the azimuth of this line relative to some baseplate reference mark is the camera azimuth; the two TIROS Wheel camera azimuths are very nearly 180° apart;
3. Skewness - If the fiducials were a perfectly square array, an ideal camera mounting would leave two sides of the fiducial square parallel to the baseplate; for a mounted camera there is some smallest angle (of rotation about the optical axis) which will provide this parallelism; we call this the skewness angle ζ. (Note: A skewness angle has not been published for TIROS IX and X cameras. Since an ideal mount would leave $\zeta = 0^{\circ}$ and mountings are near-ideal, in practice ζ has been set to 0.)

5.4 Effective Image Plane

Throughout this documentation "effective image planes" are discussed. They are always presumed to be planes between the "origin of look" and the object space being viewed. Items in object space are ideally imaged at the point where the ray from the origin to the item passes through the effective (or equivalent) image plane.

Because of the great distances (>400 mi.) between the satellite and the earth, parallax can be ignored. The cameras can be considered to have their "origin of look" at the center of the satellite.

5.5 Vertical, Subpoint, Azimuth to North

Three more basic terms which need careful definition are:

1. Vertical - The directed line from the instantaneous satellite position to the "earth center" (the center of the oblate spheroid, first-order-corrected earth);
2. Subpoint - The nearer point on the earth intercepted by the vertical;

3. Azimuth to north - At any time there is an orbital plane perpendicular to the orbital angular velocity vector; there is also a rotation of the orbital plane (around the vertical) which would: 1) put the North Pole in the orbital plane; and 2) leave land to the west of the subpoint track in the same halfspace as the orbital angular velocity vector. Note: for a 97° (inclination angle) orbit the azimuth to north is 7° at ascending node (northward equator crossing) and 90° at peak northern latitude.

5.6 A Set of X, Y, Z Body Coordinates

We now define a set of right-handed Cartesian coordinates fixed in the TIROS spacecraft body. The negative X axis is the positive spin vector. The Y and Z axes lie in the plane of the satellite baseplate, with the Z axis at the azimuth of the (a given) camera. When the TIROS Wheel satellite is in its "ideal" orientation in orbit, the negative Z axis is the vertical and the negative X axis is parallel to the orbital angular velocity vector. The Y axis then points nominally ahead in the orbit.

5.7 Yaw, Roll, and Pitch

Yaw, roll and pitch will be used in the same sense as in ordinary discussions of vehicles. They are sequential rotations about body-fixed axes. When applied, these rotations twist the spacecraft from some ideal position to any unique space orientation. For the TIROS Wheel satellite we choose an ideal position with the spin axis parallel (not antiparallel) to the orbital angular velocity vector. Yaw, roll, and pitch are sequential rotations about the Z^-, Y^+, and X^+ axes, respectively.

5.8 Phimax and Lambda

The two spin-axis pointing parameters are:

1. ϕ_{max} (teletype symbol PHIMAX) - the complement of the angle between the spin axis and the orbital plane;

2. λ (teletype symbol LAMBDA) - the argument in orbit where maximum yaw occurs; this is 90° ahead of the occurrence of maximum roll.

5.9 The Operators Θ and K

Finally, for brevity in presenting coordinate transformations we define two operators. Θ (angle)$_X$ signifies that new axes are being adopted and that they can be found by rotating the old set through the given angle about the X (in this case) axis. K (distance)$_Y$ signifies that the new axes can be found by simply translating the old set through the given distance along the Y axis. With primes signifying new axes,

$\Theta\,(\xi)_X$ implies

$$Y' = Y\cos\xi + Z\sin\xi$$

$$Z' = Z\cos\xi - Y\sin\xi$$

and

$K(h)_Y$ implies

$$Y' = Y - h$$

6. ALGORITHMS

Whether horizons, landmarks or matchpoints are the primary data, the same basic algorithm is employed. The process can be described as follows:

1. film-reader data are processed to normalize all measurements into distortion-free image planes;

2. an error function (in the attitude parameters to be estimated) is minimized one variable at a time — each variable estimate usually being improved several times;

3. attitude results from individual pictures (or picture pairs) are integrated over the entire picture sequence to give best estimates of the two spin-axis pointing parameters; in this process, suspicious looking data are screened out on the premise that their large deviations from consensus stem from errors outside the "normal" mechanisms of measurement error.

The rest of this section will describe the data reduction process in detail.

6.1 From Film-Reader Image to Distortion-Free Image Plane

There are two distinct parts to the generation of distortion-free image planes: (1) mapping of a given projected image onto the image of a camera calibration picture; (2) transforming the calibration picture mapping into an essentially distortion-free image plane.

6.1.1 Mapping a Given Image Onto the Calibration Image

There are several reasons why the mapping of any (projected) TIROS picture is not quite like the mapping of the (projected) calibration image.

Changes in the on-board vidicon, the transmitting and receiving equipment, and the readout station kinescope can cause substantial modifications of the image. X and Y scale changes of several percent (probably caused by on-board power supply fluctuations) are noted within most filmstrips. Even the rotation angles of the images vary by as much as 2° within many of the filmstrips. Although these quality control problems would not disturb many TIROS picture users, they cannot be ignored in photogrammetry.

A general attack is made on this problem of the changeable picture mapping. By comparing fiducial mark positions in any picture with those in the calibration picture a set of five transformation parameters is found. The least-squares fitting parameters will allow a picture to be:

(1) translated along the X-axis
(2) translated along the Y-axis
(3) rescaled in the X dimension
(4) rescaled in the Y dimension
(5) rotated

6.1.2 From Calibration Picture to a Distortion-Free Image Plane

The primary tool for removing distortion from the calibration picture (or any equivalent image plane) is the two-dimensional radial distortion polynomial. The effectiveness of this technique for our photogrammetry purposes has been studied and found acceptable. Note, however, that several independent sources of distortion are being accommodated at one time. Most severe is the barrel distortion of the on-board lens system. Second, there is the pincushion distortion of the CDA station kinescopes. (The kinescopes have been found to be very similar in distortion in daily operations. Small-order non-linearities are detectable but picture-specific and therefore unremovable in practice.) Third, there is the contribution of the on-board vidicon. Fourth, there is the on-board tape recorder. Finally, there is the transmitting and receiving equipment and a ground tape recorder and camera. Erratic operation of any link in the chain could introduce serious errors in final attitude parameters. Experience suggests that we have been protected by two safeguards: 1) generally good quality control in maintenance of CDA station electronics; 2) the ability of a human operator to detect even small-order troubles (e.g. sync difficulties) and avoid problem pictures.

6.2 The Error Functions: Do the Attitude Parameter Estimates Fit the Data?

To infer camera orientation from picture content one needs to answer the question: "Do the (a set of assumed) attitude parameter estimates fit the data?" Further, would the data and parameter estimates agree more closely if the parameters were re-estimated? Finally, what is the best set of estimates in the light of a given picture (pair)?

6.2.1 The Horizon Error Function

Were the earth truly spherical, the image of the earth horizon would be independent of satellite yaw. Fortunately, ignoring earth non-sphericity does not occasion troublesome attitude errors. The rest of this section will deal with a mean spherical earth.

Imagine that (as happens in practice) we know approximate ($\sim \pm 1^{\circ}$) values for satellite roll and pitch at the time of a given picture. To these estimates there corresponds a hypothetical horizon locus. Do the measured horizon points lie near this locus?

Barring TV and optical distortions, the image of the earth is elliptical. If the camera axis had pointed down the vertical, the horizon would have appeared circular. In the computer programs the proper transformations are used to map from a tilted-plane elliptical horizon to a normal-plane circular one. And since satellite height is well known, the radius of the theoretical image is also well known.

Figure 6-1 pictures the goodness-of-fit situation. Points P_1', P_2', P_3', and P_4' have been mapped from a distortion-free (for the sake of discussion) tilted plane onto a normal plane. This mapping involves four rotation values: (1) the rotation of the camera about its optical axis (skew angle) which would leave two sides of the fiducial frame parallel to the baseplate; (2) the cant angle; (3) an estimate of satellite pitch; (4) an estimate of satellite roll. Since the estimated attitude differs from actual attitude, the point-set [P] will not in general be mapped into a circle. As estimates are improved, however, [P] converges on circularity. The measure of goodness of fit between the hypothetical horizon and set of mapped measured points is simply

$$F_{(\text{roll, pitch})} = \sum^{n} (r_i' - r)^2$$

where

r_i' is the radial distance of P_i

r is the expected horizon radius, a function of height alone

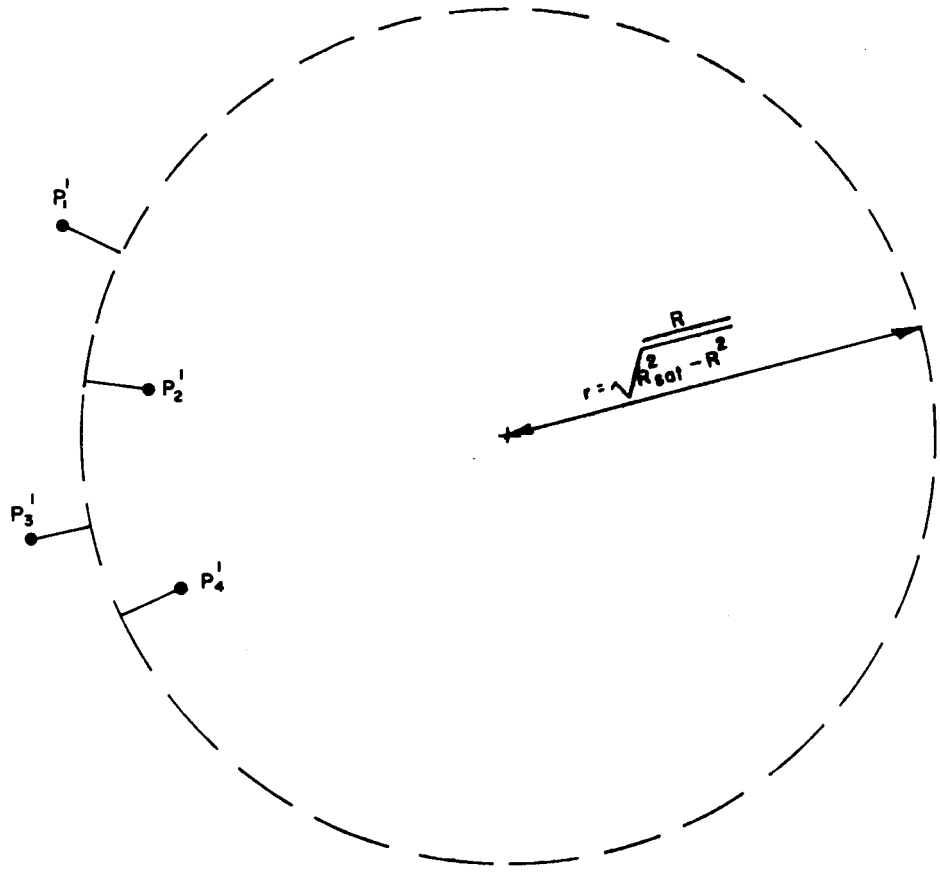

Figure 6-1 Measured Horizon Points on Distortion-Free Normal Plane

6.2.2 The Landmark Error Function

When landmark measurements have been made, the data reduction is not unlike that for horizon points. Measurements of landmarks are converted from shaft-encoder counts to focal-length units in a distortion-free plane. The film-reader operator has correlated these landmarks in the pictures with the corresponding items from map-slide images by simultaneously encoding both the observed landmark, and the map coordinates. The measurements made from the map slides are converted from shaft-encoder counts to geodetic latitude/longitude values using the projection equations of the slide maps (Lambert Conformal or Polar Stereographic). The corresponding geocentric latitude is computed, and then the radial distance (from earth center) to the landmarks is computed for a first-order corrected earth. A chain of transformations is used to map these known object-space points (landmarks of known latitude/longitude) into the distortion-free plane mentioned above for an assumed attitude (yaw, roll, and pitch). Let us sketch the mathematics involved.

For a given landmark, the map-slide measurements yield a set of three spherical coordinates:

$\phi = 90^{\circ}$ - (north latitude of the landmark)

ρ = the oblate-earth radial distance as a function of latitude

θ = (east longitude of the landmark) - 90° - (the longitude of the subpoint)

In a Cartesian coordinate system the landmark is at

$$X = \rho \sin \phi \cos \theta$$
$$Y = \rho \sin \phi \sin \theta$$
$$Z = \rho \cos \phi$$

where

Z^{+} passes through the North Pole

Y^{-} passes through the subpoint longitude at the equator

Then the following transformations are applied:

(1) rotating about X^{+} so that Z^{+} passes through the satellite
$\Theta(90^{\circ}$ - north latitude of the subpoint$)_X$

(2) ascending to a satellite-centered system
$K\,(RSAT)_Z$

(3) rotating so that the Y axis points north
$\Theta(-\,AZTONO)_Z$

(4) yawing the satellite
$\Theta(-\ YAW)_Z$

(5) rolling the satellite
$\Theta(ROLL)_Y$

(6) pitching the satellite
$\Theta(PITCH)_X$

(7) canting the camera
$\Theta(CANT)_Y$

At this time the coordinates of the map slide landmark are known in a camera-referenced coordinate system. To find the coordinates of the actual landmark's ideal (distortion-free) image, the ray to the landmark is intersected with an effective image plane. That is, the X and Y values are scaled down by the Z distance (down the optical axis):

$$X_{IDEAL} = -\ X/Z$$

$$Y_{IDEAL} = -\ Y/Z$$

The error function is like that used for matchpoints. For any given mapping of landmarks into an image plane (i.e., for any combination of yaw, roll, and pitch guesses) a "sum of deviations squared" is computed. Loosely speaking, the deviations are between where a point would be expected to appear and where it "actually" appeared in the image plane.

6.2.3 The Matchpoint Error Function

Using matchpoint data is not too unlike using landmarks. In this case, however, a fit is attempted between two sets of image-plane measurements. Loosely speaking, the points from picture n are projected into the image plane of picture n + 1, where near coincidence of matchpoints is expected.

First of all, the measurements from both pictures are mapped into distortion-free image planes. After this has been done, a string of 15 coordinate transformations and two projections connects these two standardized image planes.

The transformations are (with all rotations about the positive X, Y, Z axes):

(1) uncanting the camera

$\Theta(-CANT)_Y$

(2) unpitching the satellite from the nth picture position

$\Theta(-PITCH_n)_X$

(3) unrolling the satellite

$\Theta(-ROLL_n)_Z$

(4) unyawing the satellite

$\Theta(YAW_n)_Z$

(5) projecting the image points onto the earth surface

$X = AX$

$Y = AY$

$Z = AZ$

where

$$A = \frac{-B - \sqrt{B^2 - C(R_{SAT}^2 - R_{OBJ}^2)}}{C}$$

$B = Z\,R_{SAT}$

$C = X^2 + Y^2 + Z^2$

R_{OBJ} = the radial distance of the object-space item, e.g., a cloud, from the earth center.

(6) descending to an earth-centered coordinate system

$K\,(-\,RSAT_n)_Z$

(7) turning the Y axis out of the orbital plane so it becomes coplanar with a longitude circle (i.e., "points north")

$\Theta(AZTONO_n)_Z$

(8) turning about X so that the Z axis passes through the North Pole

$\Theta(SPLAT_n - 90^\circ)_X$

(9) turning about Z so that Y passes through the longitude of the subpoint for picture n + 1

$\Theta(SPLONG_{n+1} - SPLONG_n + 90^o)_Z$

(10) turning about X so that the Z passes through the latitude of the subpoint for picture n + 1

$\Theta(90^o - SPLAT_{n+1})_X$

(11) turning the Y axis back into the orbital plane

$\Theta(- AZTONO_{n+1})_Z$

(12) ascending to a satellite-centered coordinate system

$K\ (RSAT_{n+1})_Z$

(13) yawing the satellite

$\Theta(- YAW_{n+1})_Z$

(14) rolling the satellite

$\Theta(ROLL_{n+1})_X$

(15) pitching the satellite

$\Theta(PITCH_{n+1})_X$

(16) canting the camera

$\Theta(CANT_{n+1})_Y$

(17) projecting the object-space point back into the effective image plane

$X = X/Z$

$Y = Y/Z$

In practice, measurements from picture n are mapped into a standardized distortion-free plane. Then they are mapped through transformations 1 and 2. Similarly, picture n + 1 data are made distortion-free and mapped through transformations 17, 16 and 15. A matrix is developed to provide transformations 5-12 inclusive.

An error function, $F(\phi_{max}, \lambda)$, is investigated and minimized sequentially in its two variables. This involves testing many combinations of ϕ_{max} and λ — or YAW_n, $ROLL_n$, YAW_{n+1}, $ROLL_{n+1}$ — to complete the chain of transformations from 3-14.

The matchpoint error function is

$$F(\phi_{max}, \lambda) = \sum^{n} (X_i' - X_i'')^2 + (Y_i' - Y_i'')^2$$

where

X_i', Y_i' are the coordinates of the "i" th point from picture n mapped through transformations 1-14

X_i'', Y_i'' are the coordinates of the "i" th point from picture n+1 mapped through transformations 17, 16, 15.

This error function is simply the sum of the deviations squared — i.e., the deviations of points from their matchpoints after both have been mapped into a common image plane.

6.3 Sequential Minimization of the Error Functions

In the preceding sections, error functions have been described for horizon, landmark, and matchpoint data. Unlike in many respects, these functions are nevertheless all: (1) functions of at least two attitude parameters; (2) transcendental in these parameters in such a way that the normal equations form a system of transcendental equations soluble only by successive approximations. What is desired when investigating the function for any data group is a set of values V_1, V_2, V_3 such that $\frac{\partial F}{\partial V_1} = \frac{\partial F}{\partial V_2} = \frac{\partial F}{\partial V_3} = 0$. Fortunately, these error functions are in practice "rolly, polynomial-like" three and four-dimensional sheets. Computational minimizing of these functions can be accomplished by an "orthogonal descent into a valley" with very little risk of finding only a relative minimum. In general, attitude parameter initial estimates are accurate to within a few degrees. Within this neighborhood of the minima the error functions are especially well behaved.

If we sample an error function for several values of V_1, (V_2 and V_3 being held at some reasonable estimates), we develop a one-dimensional tabular function. What we seek is the value of V_1 for which this tabular function is minimal. To do this we rely on Stirling's interpolation formula:

$$y = y_o + u \frac{\Delta y_{-1} + \Delta y_o}{2} + \frac{u^2}{2} \Delta^2 y_{-1} + \frac{u(u^2-1)}{3!} \frac{\Delta^3 y_{-2} + \Delta^3 y_{-1}}{2} + \cdots$$

where

$$\Delta y_{-1} = y_o - y_{-1}$$

$$\Delta^2 y_{-1} = \Delta y_o - \Delta y_{-1}$$

$$u = \frac{x_{min\ F} - x_o}{h}$$

h = the constant sampling interval

Differentiating, we get

$$\frac{dy}{dx} = \frac{1}{h} \frac{\Delta y_1 + \Delta y_o}{2} + u\Delta^2 y_1 + \frac{3u^2 - 1}{3!} \frac{\Delta^3 y_2 + \Delta^3 y_1}{2} +$$

for

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} = \frac{1}{h} \frac{dy}{du}$$

Since the error functions are so well behaved, we use the first two terms of the expansion for $\frac{dy}{dx}$. Setting $\frac{dy}{dx} = 0$ and solving for u, we get

$$u = \frac{\Delta y_{-1} + \Delta y_o}{2\Delta^2 y_{-1}}$$

and then $x_{min} = x_o + hu$

The formulae just presented imply the use of just three sampling points in estimating the location of the minimum. Of necessity, the minimum must occur somewhere between end samples. In the program the error function is sampled at the best estimate of the parameter being improved, V_o. (See Fig. 6-2). Then a sample is made at $V_o + h$ (where h is often $\sim 1^o$). If $F(V_o + h) \leq F(V_o)$ the search is continued (in this same direction) until $F(V_i + h) > F(V_i)$ — at which time the minimum is embraced by the last three samples. If initially $F(V_o + h) > F(V_o)$, the search is made in the other direction until $F(V_i - h) > F(V_i)$. In practice, after the first improvement of the attitude parameters, there is almost never a need for more than three samplings per minimization. The estimation of

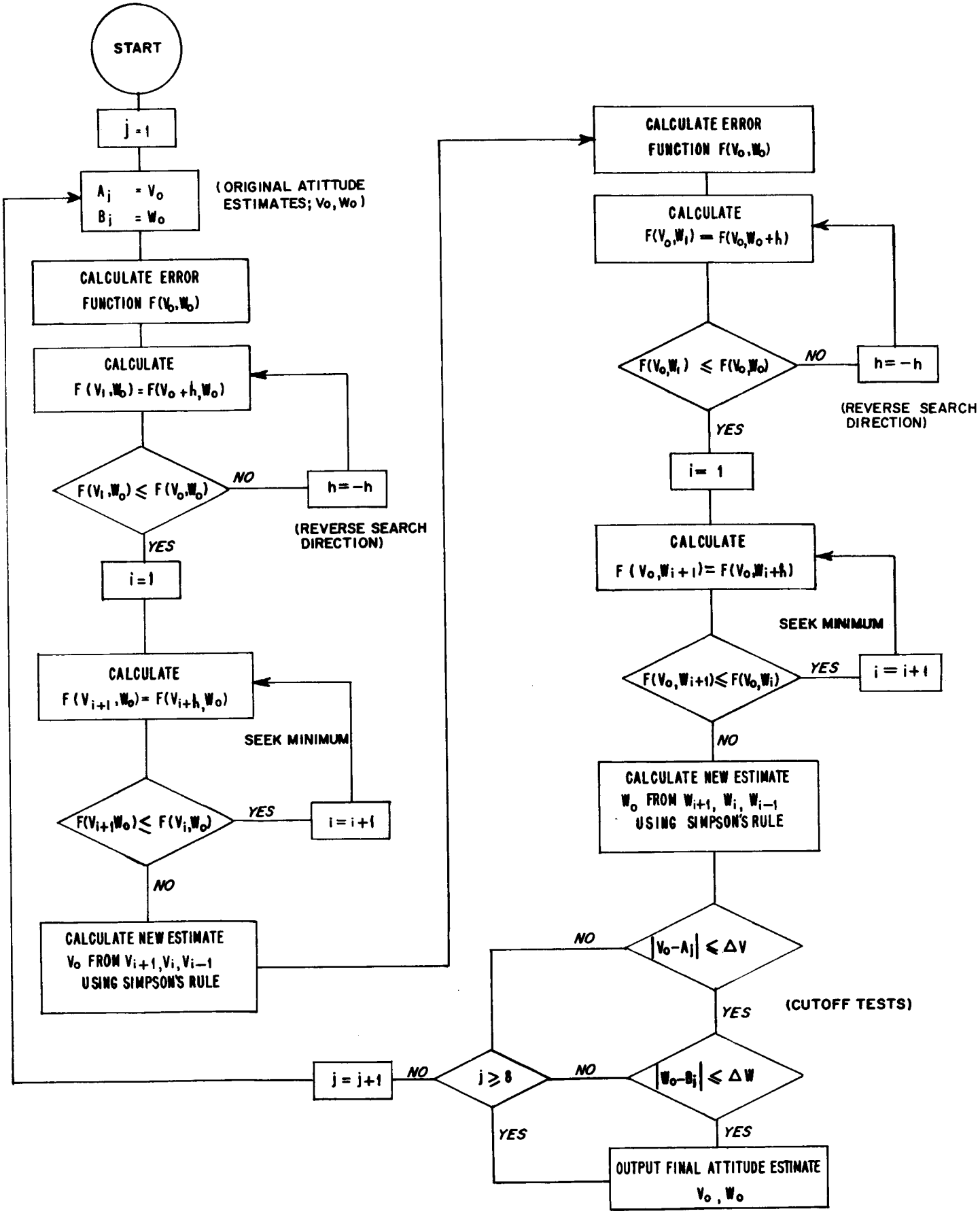

Figure 6-2 Error Function Minimization

the set of parameters is done no more than eight times for a given data group. In the programs, an arbitrary cutoff test is used. For example, in the horizon program if the estimate of roll is altered by less than $.1^{\circ}$ after the first improvement of roll and pitch, the process is stopped and the values are recorded. Experimentation has shown this practice to be quite reasonable. Figure 6-2 is a general flow chart outlining the error function minimization process for two attitude parameters. The extension to three or more parameters is straightforward.

6.4 Smoothing Data Over an Entire Picture Sequence

There are several levels of data integration available in operational TIROS photogrammetry.

First, data from horizon, landmark, and matchpoint techniques could be combined for any given picture (pair). This has not been done because of the experimental nature of the programs and the consequent decision to keep them independent.

Second, spin-axis parameters – ϕ_{max} and λ – for several days of orbits could be smoothed, with the help of magnetic steering information. This job is presently being done for all TIROS attitude data by the NASA Theory and Analysis Office at Greenbelt, Maryland. ARACON has made no attempt to duplicate this NASA effort.

Third, information can be integrated over a single picture-taking sequence. This work has been done to estimate ϕ_{max} and λ from a given filmstrip.

6.4.1 Sine-Curve Fitting

It is a well-known relationship that

$$\sin R = \sin \phi_{max} \sin (\ell - \lambda)$$

and that

$$\sin Y = \sin \phi_{max} \cos (\ell - \lambda).$$

Therefore, the sines of the roll estimates from individual pictures should lie on a sinusoid of amplitude $\sin \phi_{max}$. To integrate the roll information from a string of pictures is simply a job of least-squares sine curve fitting.

Take the function $y = A \sin (x + \delta) + K$. To least-squares fit this form to a data set, one demands that $\frac{\partial F}{\partial A} = \frac{\partial F}{\partial K} = \frac{\partial F}{\partial \delta} = 0$, where $F = \sum^{n} [y_i - A \sin (x_i - \delta) + K]^2$

The reader may wonder why a three-parameter sine fit (including translation constant) has been described. After all, the sines of the yaw and roll data should be sinusoidal without translation. Remember, however, that the yaw and roll values are produced by a long chain of computations. One of the danger signs to look for is precisely this possible asymmetry about the zero level (i.e., translation). Doing both two and three parameter sine fits has proved to be a valuable exploratory tool.

6.4.2 Data Rejection

It often happens, for one reason or another, that "wild" values show up among the yaw and roll estimates. Film-reader operator error is generally the source, although there can be other causes. What should be done with these bad values? Moreover, how can one decide just how deviant a point should be before it is rejected?

Empirically the yaw and roll values have been found to be rather normally distributed. A handy rejection test has been the following. All data are fit with a sinusoid. The most deviant point is found. Its rarity is computed as though the distribution were normal.

$$p = \frac{1}{(.019527W^4 + .000344W^3 + .115194W^2 + .196854W + 1)^4}$$

where

$$W = \sqrt{\frac{(\max \Delta)^2}{\frac{\Sigma \Delta^2}{n-1}}}$$

If $p < \frac{1}{2n}$, the point is rejected. Thus, for example, a point of less than 2-1/2% probability is rejected if n = 20. This rejection test is re-applied until the (then) most deviant point satisfies the conditions.

The solutions to the normal equations are:

$$\delta = \arctan \frac{S_1 P_1 - S_5 P_2 + S_7 P_3}{-[S_5 P_1 - S_2 P_2 + S_8 P_3]}$$

$$A = \frac{sP_1 + cP_2}{n(c^2 S_1 + s^2 S_2 + scS_5) - P_4^2}$$

$$= \frac{sP_2 - cP_1}{n[sc(S_1 - S_2) + (s^2 - c^2) S_5] - P_4 (sS_7 - cS_8)}$$

$$K = \frac{S_6 - AP_4}{n}$$

where

$$P_1 = nS_4 - S_8 S_8$$

$$P_2 = nS_3 - S_6 S_7$$

$$P_3 = S_3 S_3 - S\ S_7$$

$$P_4 = cS_7 + sS_8$$

$$s = \sin \delta$$

$$c = \cos \delta$$

and

$$S_1 = \Sigma \sin^2 x_i$$

$$S_2 = \Sigma \cos^2 x_i$$

$$S_3 = \Sigma y_i \sin x_i$$

$$S_4 = \Sigma y_i \cos x_i$$

$$S_5 = \Sigma \sin x_i \cos x_i$$

$$S_6 = \Sigma y_i$$

$$S_7 = \Sigma \sin x_i$$

$$S_8 = \Sigma \cos x_i$$

(NOTE: There are two expressions given for A. In computational work, that expression should be used whose denominator has the larger absolute value. This will avoid the inaccuracies found in near-zero differences of large numbers.)

7. COMPUTER PROGRAMS

The photogrammetric attitude program has been written in eight relatively independent sections. Each has been separately compiled in FORTRAN – except Section 1, an assembly language (OSAS) input routine. The programs form an automatic chain which will run to completion once it is called by an operator.

To accomplish chaining of programs, a function –DROPF the "drop function"– was added to the FORTRAN compiler. It is called with a dummy argument in an operational statement:

Q = DROPF (Q)

To insure a standard starting location for the FORTRAN sections, each was written with a PAUSE statement at or near the beginning. The section was then compiled and run – through the PAUSE instruction – before being dumped on to paper tape.

The eight program sections are:

1. Input Routine
2. Fiducial Fitter and Secondary Ephemerides Generator
3. Mode Record Processor
4. Horizon Section
5. Landmark Section
6. Matchpoint Section
7. Line-Curve Fitter
8. Output Section

The program listings for these sections are given in Appendix B. Appendix A contains an index of the important mnemonics used in these programs. We shall now briefly describe the role of each subprogram.

7.1 Input Routine

The Input Routine reads two paper tapes (See Ref. 1). The first is a short flexowriter tape with specific information about the filmstrip which was processed. The second is the eight-level tape turned out by the film reader. This section combines the two inputs and writes two blocks on the magnetic scratch tape: 1) primary ephemerides for the orbit involved; 2) mode records. Tables 7-1 and 7-2 show the primary ephemerides and mode record formats.

Table 7-1

PRIMARY EPHEMERIDES

Primary ephemeris data are in one logical record on the scratch tape – to be referred to as PRIEPH.

It is produced by machine-language Program No. 1 from a combination of direct inputs from flex tape and orbital elements written into the program by ARACON service routines. The array is written in FORTRAN floating point format and comprises the first two physical records on the data tape.

1	HRE	secs $\times 2^{-27}$	Epoch time, GMT (orbital elements)
2	ANP (2 items)	secs $\times 2^{-27}$	Anomalistic period & secular change
4	INC	circles	Inclination of orbit to equator
5	RAN (2 items)	circles	Right ascension of ascending node & change
7	PER (2 items)	circles	Argument of perigee & change
9	NAN	circles	Mean anomaly
10	ECC	fraction as is	Eccentricity
11	SMA	earth radii $\times 2^{-3}$	Semi-major axis (converted to meters)
12	(2 items)		Moments of inertia (not used)
14	LDA	integer $\times 2^{-27}$	Last day of epoch month
15	MOE	integer $\times 2^{-27}$	Epoch month
16	DAE	integer $\times 2^{-27}$	Epoch day
17	OPTION	Special	Logical copy of plotter switch settings
18	ORB	integer $\times 2^{-27}$	Picture orbit number
19	MON	integer $\times 2^{-27}$	Month of reference orbit ascending node
20	DAY	integer $\times 2^{-27}$	Day of reference orbit ascending node
21	ANT	secs $\times 2^{-27}$	Time of reference ascending node, GMT
22	LAN	circles	Longitude of reference ascending node (East is +)
23	ROL	circles	Satellite maximum roll angle
24	TOT	mins $\times 2^{-8}$	Time of ϕ_{max} occurrence, after ascending node
25	ERP	circles	Estimated pitch bias
26	PDA	integer $\times 2^{-27}$	Day of first picture
27	CAM	integer $\times 2^{-27}$	Camera number
28	QTY	integer $\times 2^{-27}$	Quantity of pictures to be referenced
29	INT	secs $\times 2^{-27}$	Normal interval between pictures
30	GMT (48 items)	secs $\times 2^{-27}$	Individual picture times
31	SWA		Swath number for landmark slides

Additional comments:

1. The scalings indicated are carried over from the standard ARACON input service routines. The values are reconverted as efficiently as possible in the first FORTRAN Program (No. 2) for use in orbit generation and for transfer to SECEPH. For example, SMA is immediately converted to meters by Program No. 2 before computations are performed.

Table 7-2

MODE RECORDS

Program No. 1 converts the eight-level film-reader paper tape data into a long list of mode records (MODREC's) on the data tape. Each MODREC is a distinct logical record consisting of a nine-integer array in FORTRAN integer format. The organization of data within the various types of MODREC's is as follows:

Modes 0, 1, 3 (Calibration, Picture Fiducial, and Matchpoint)

1 Frame No. (Picture No.)
2 Mode Type
3 Rotation Angle
4 UC-x (upper crosswire x)
5 UC-y
6 LC-x
7 LC-y
8 Dummy
9 Parity

Mode 2 (Horizons)

1 Frame No.
2 Mode Type
3 Rotation Angle
4 UC-x
5 UC-y
6 Dummy
7 Dummy
8 Dummy
9 Parity

Mode 4 (Cataloged Landmarks)

1 Frame No.
2 Mode Type
3 Map Slide No.
4 Rotation Angle
5 UC-x
6 UC-y
7 Dummy
8 Dummy
9 Parity

Mode 5 (Map Slide Fiducials)

1 Frame No.
2 Mode Type
3 LC-x
4 LC-y
5 Dummy
6 Dummy
7 Dummy
8 Dummy
9 Parity

Mode 6 (Uncataloged Landmarks)

1 Frame No.
2 Mode Type
3 Slide No.
4 Rotation Angle
5 UC-x
6 UC-y
7 LC-x
8 LC-y
9 Parity

7.2 Fiducial Fitter and Secondary Ephemerides Generator

This section performs two distinct tasks. First, it searches through the scratch tape for all fiducial mode records. Picture by picture it does a least-squares fiducial fit and writes a set of five parameters on the scratch tape for each fit performed. Secondly, this section computes certain ephemerides for the time of each picture. These results are also written on the scratch tape (See Table 7-3).

7.3 Mode Record Processor

This section takes the raw shaft-encoder counts from the mode records and produces X-Y coordinates in distortion-free image planes.

7.4 Horizon Section

This program finds (on the scratch tape) the horizon data for each picture and from them computes roll and pitch estimates. For each picture the horizon error function is minimized sequentially in these two variables. The results are written on the scratch tape. A flow diagram outlining the sequence of events in the attitude program using horizon data is shown in Figure 7-1.

7.5 Landmark Section

This program finds the landmark data for each picture and from them computes yaw and roll estimates. For each picture the landmark error function is minimized sequentially in these two variables. The results are written on the scratch tape. A flow diagram outlining the sequence of events in the attitude programs using landmark data is shown in Figure 7-2.

7.6 Matchpoints Section

This program finds the matchpoint data for each picture pair and from them computes ϕ_{max} and λ estimates. For each picture pair the matchpoint error function is minimized sequentially in these two variables. The results are written on the scratch tape. A flow diagram outlining the sequence of events in the attitude program using matchpoint data is shown in Figure 7-3.

Table 7-3

SECONDARY EPHEMERIDES

Secondary ephemeris data are in two distinct logical records on the scratch tape – to be referred to as SECEPH and $SECEPH_B$.

They are produced by subprogram No. 2 (from PRIEPH, the primary ephemerides record) and are written on the data tape immediately following PRIEPH.

$SECEPH_A$

1	ARG (48 items)	The argument of the satellite past ascending node; for all 48 pictures
49	INC	The inclination angle of the orbit
50	ANT	Time of ascending node
51	ROL	The best predicted value of $ROLL_{max}$
52	TOT	The best predicted value of $TIME_{ROLL_{max}}$
53	CAM	The camera number

$SECEPH_B$

1	OTY	Number of pictures on the film strip
2	OPTION	An option code work generated by the initial setting of the plotter switches
3	ERP	The best predicted value of a pitch bias
4	LAN	Longitude of ascending node
5	CMEAS (10 items)	The coordinates of the five fiducials as read on the starting picture; x(fid. 1), y(fid. 1), etc.; all coordinates altered by translation to make the sum of the x's and the sum of the y's equal 0.
15	TRANSX	Note on 15-19: These are the five parameters
16	TRANSY	from the fiducial fit in Program No. 2.
17	RESCX	Rescale X
18	RESCY	Rescale Y
19	THETA	
20	RSAT (48 items)	Note on 20-212: These are the radial
68	ESTYAW (48 items)	distances from earth center to satellite,
116	SPLONG (48 items)	estimated yaw, subpoint longitude, subpoint
164	SPLAT (48 items)	latitude, and azimuth to north for each of the
212	AZTONO (48 items)	48 pictures.

Additional Comments:

1. Both arrays above are in floating-point format.
2. OPTION is only superficially a floating-point number. Its middle twelve-bits are a copy of the plotter switch settings and it will be tested by a Boolean operation.
3. All angles will exist in SECEPH in radian measure. All distances are in meters. All times are GMT.

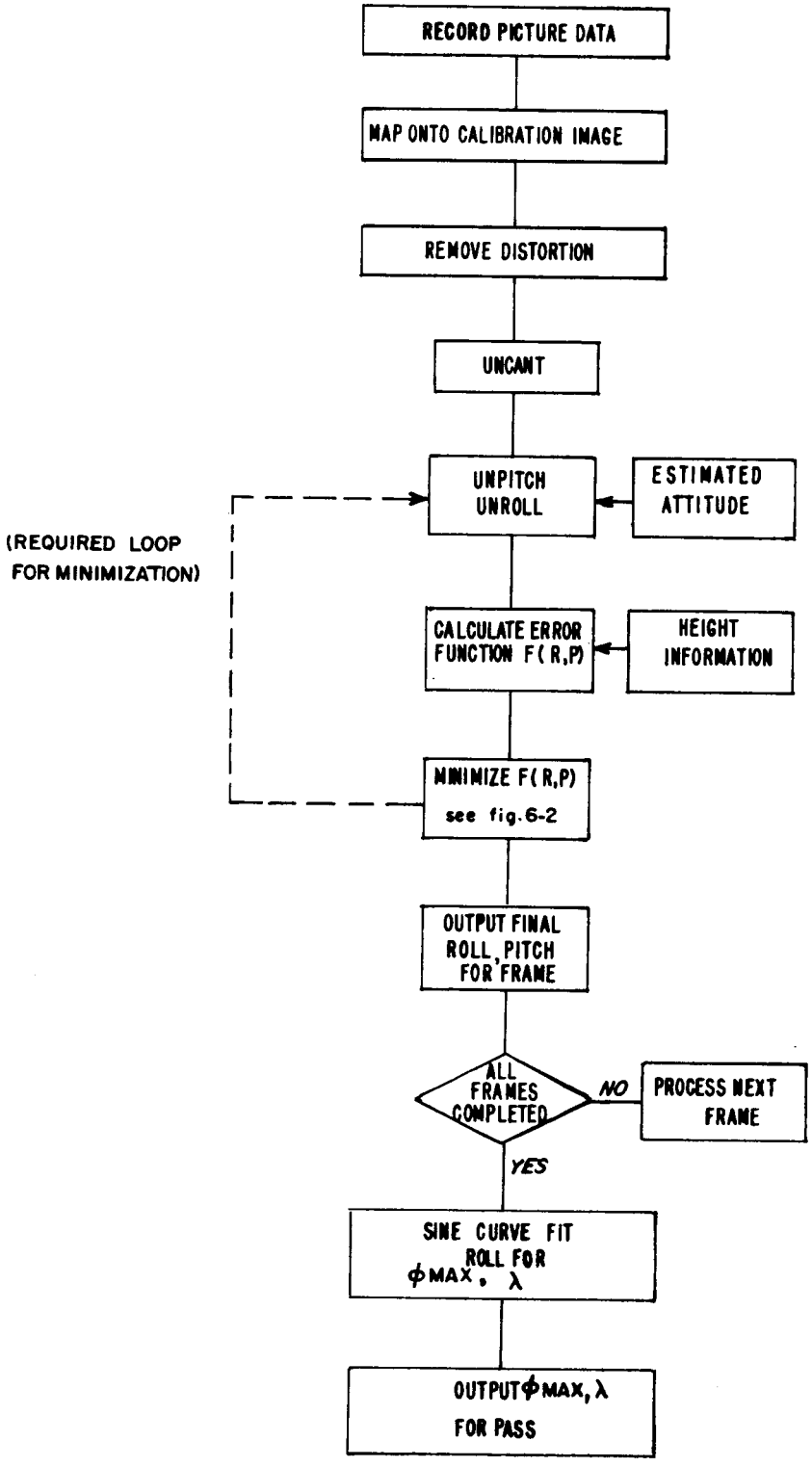

Figure 7-1 Flow Chart Outlining Use of Horizon Data

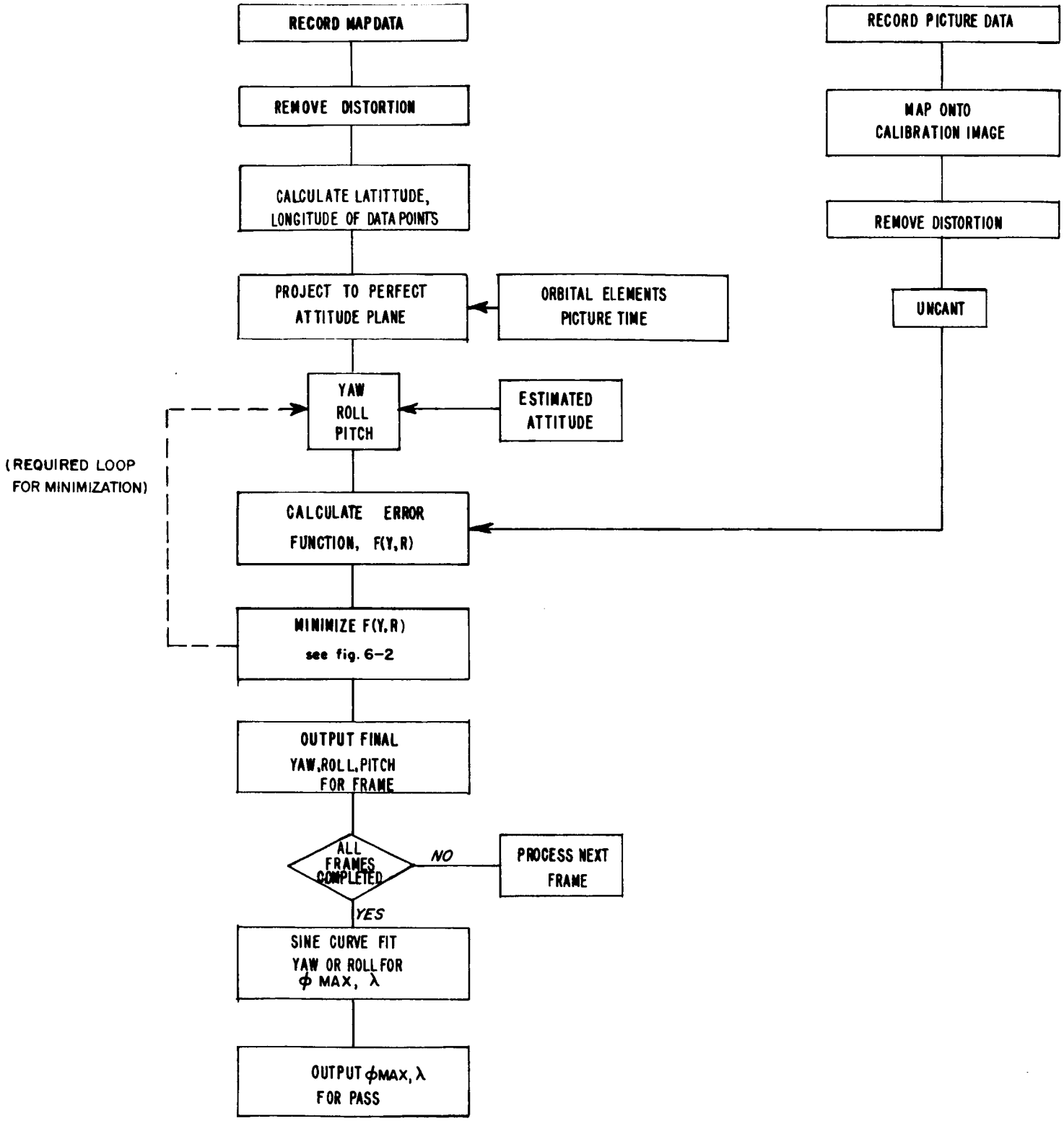

Figure 7-2 Flow Chart Outlining Use of Landmark Data

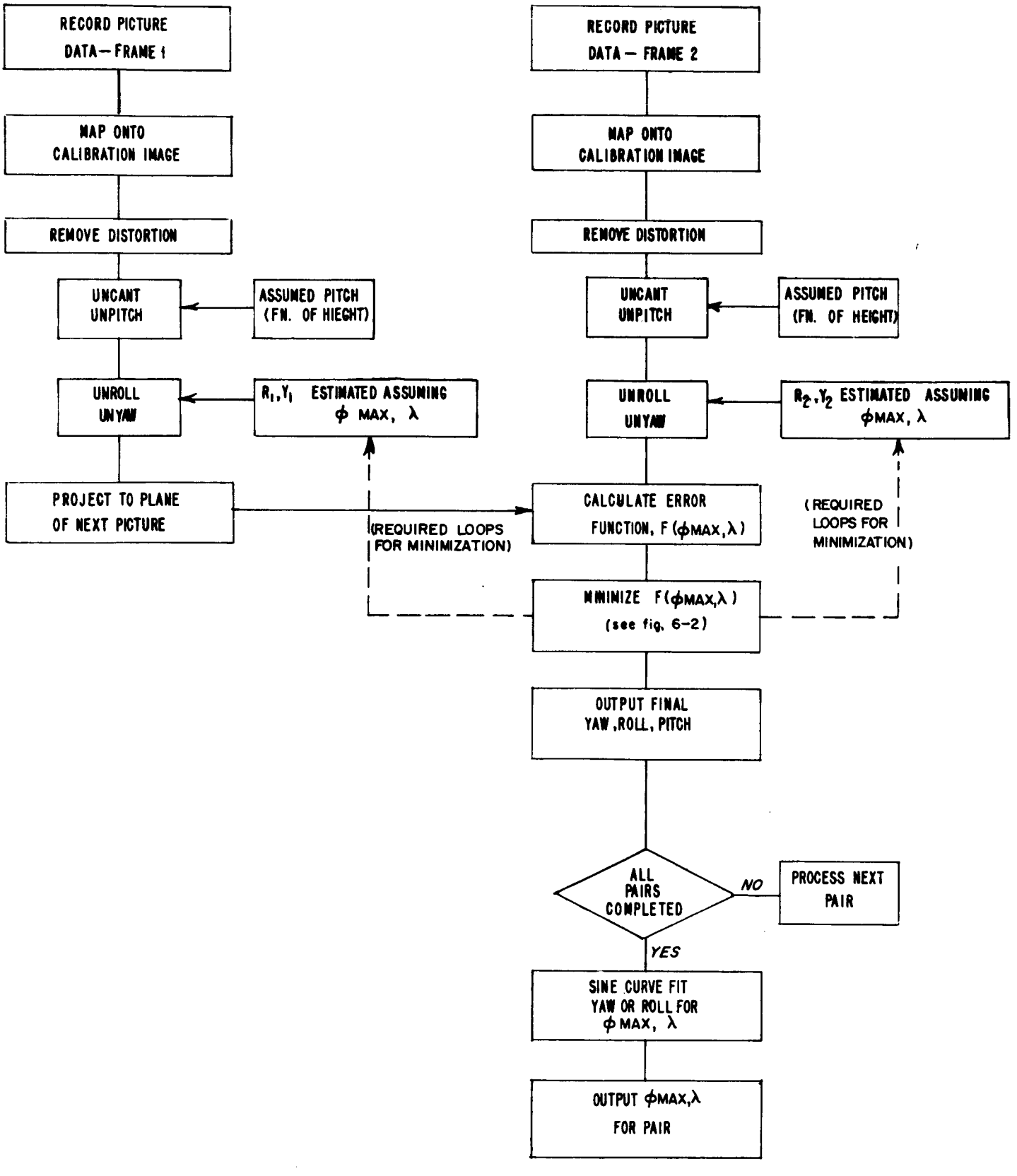

Figure 7-3 Flow Chart Outlining Use of Matchpoint Data

7.7 Sine-Curve Fitter

Three distinct least-squares sine curve fits are performed by this program: first, roll values from horizons are used; then roll values from landmarks; and finally yaw values from matchpoints. The most deviant point in each set must pass a liklihood test. If the test fails, the point is rejected and the test re-applied. Phase and amplitude, ϕ_{max} and λ, are written on the scratch tape.

7.8 Program Output

Figure 7-4 shows a typical output from the program. On this run the operator could not find useful landmarks or chose not to use them. One frame of horizon data (Frame No. 17) gave obviously faulty roll and pitch estimates, and these were rejected.

* * * ARACON GEOPHYSICS CO. * * *
TIROS WHEEL PHOTOGRAMMETRIC ATTITUDE PROGRAM

6 / 6 / 65 ORB 1639 CAM 2

HORIZONS

FRAME	GMT	YAW	ROLL	PITCH	PTS	ITERS
1	015509	.1E 20	-3.52	-18.33	4	2
2	015304	.1E 20	-2.91	-18.22	4	2
3	015053	.1E 20	-2.99	-18.22	4	2
4	014845	.1E 20	-3.13	-14.93	4	4
5	014640	.1E 20	-1.88	-18.03	4	3
6	014429	.1E 20	-1.90	-17.30	4	3
7	014221	.1E 20	-2.09	-16.78	4	3
8	014013	.1E 20	-.83	-15.46	4	2
9	013805	.1E 20	-.08	-15.62	4	3
10	013557	.1E 20	.33	-14.41	4	2
11	013349	.1E 20	.66	-14.10	4	3
12	013141	.1E 20	.93	-13.46	4	3
13	012933	.1E 20	.99	-12.72	4	3
14	012725	.1E 20	1.60	-11.24	4	2
15	012517	.1E 20	2.32	-10.65	4	3
16	012309	.1E 20	2.88	-9.50	4	3
17	012101	.1E 20	6.65R	-20.35	4	3
18	011853	.1E 20	3.58	-7.32	4	3
19	011648	.1E 20	3.48	-6.73	4	3
20	011437	.1E 20	3.53	-5.15	4	2

PHI MAX 4.4 DEGREES

LAMBDA 191.8 DEGREES

1 PT (S) REJECTED

Figure 7-4a Horizon Output

* * * ARACON GEOPHYSICS CO. * * *
TIROS WHEEL PHOTOGRAMMETRIC ATTITUDE PROGRAM

6 / 6 / 65 ORB 1639 CAM 2

MATCHPOINTS

FRAME	GMT	YAW*	ROLL	PITCH	PTS	ITERS
1	015509	184.12	-2.68	-18.28	3	3
2	015304	182.06	-1.04	-18.10	3	3
3	015053	184.35	-2.12	-17.84	3	2
4	014845	184.06	-1.65	-17.54	3	3
5	014640	182.23	-3.19	-17.17	3	4
6	014429	184.35	-.88	-16.73	3	2
7	014221	185.90	.12	-16.23	3	3
8	014013	184.29	-1.56	-15.67	3	3
9	013805	184.29	.58	-15.04	3	3
10	013557	185.33	2.08	-14.34	3	3
11	013349	184.41	1.91	-13.58	3	3
12	013141	182.52	1.85	-12.76	3	3
13	012933	183.95	3.11	-11.87	3	3
14	012725	183.72	2.64	-10.91	3	2
15	012517	184.52	3.57	-9.90	3	2
16	012309	183.66	5.70	-8.84	3	4
17	012101	180.86	3.72	-7.63	3	3
18	011853	182.92	5.93	-6.59	3	3
19	011648	182.35	6.80	-5.47	3	3
20	NO DATA					

PHI MAX 4.4 DEGREES
LAMBDA 198.8 DEGREES
O PT (S) REJECTED

Figure 7-4b Matchpoint Output

* After turn-around, indicated yaw values oscillate about 180°

REFERENCES

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2. Bartlett, R.P., 1965: ARACON Photogrammetric Attitude System Hardware Description and Maintenance Manual, Technical Report No. 3, Contract No. NAS 5-3953, ARACON Geophysics Company.

3. Astro-Electronics Division, RCA, 1964: Alignment and Calibration Data for the TIROS IX Meteorological Satellite, Contract No. NAS 5-3173.

APPENDIX A

LISTING OF IMPORTANT MNEMONICS

A.1 Fiducial Fitter and Secondary Ephemerides Generator

A.1.1 Arrays

STFIDS	Set of standard fiducials
SEA	Secondary ephemerides - sec A
SEB	Secondary ephemerides - sec B
MODREC	Mode records
CSTND	Standard fiducial fit coordinates
CMEAS	Measured fiducial fit coordinates
FIDFIT	Fiducial fit array

A.1.2 Variables

RPD	Radiance per degree
IFLIP	Image inverter option (for direct frames)
IQTY	Quantity of pictures on film strip
ARGPER	Argument of perigee
ECANOM	Eccentric anomaly
FMAV	Mean angular velocity
TPA	Time of picture after ascending node
SINROL	Sine of roll
SININC	Sine of inclination
COSINC	Cosine of inclination
TPICA	Time of picture after perigee
ARG	Argument of satellite past perigee
ASHCAN	Storage for items read but not needed
NPIC	Picture number
DFID	Distance between fiducials
THETA	Rotation angle of fiducial array
RESCX	X rescaling factor
RESCY	Y rescaling factor

A.2 Mode Records Processor

A.2.1 Arrays

SWATH	Map slide swath number
PEAK	Peaks of distortion removal curves
COEF	Coefficients of distortion removal polynomial
XPRPT	X coordinate, principal point
YPRPT	Y coordinate, principal point
MODPIC	Processed information from MODREC's
FLATC	Central latitude of map slide
DLATG	Distance from central to generating latitudes
XMFID	X coordinates of map fiducials
YMFID	Y coordinates of map fiducials
R3C	Pole-central latitude distance
RCG	Central-generating latitude distance

A.2.2 Variables

NUMCAM	Camera number
KFID	Fiducial number
XMAP	X of map landmark
YMAP	Y of map landmark
NXLIDE	Slide number
HEMIS	North or south hemisphere
SIN213	Sine of longitude difference between map fiducials
COS213	Cosine of longitude difference between map fiducials
NOPEAK	Number of distortion removal peak
NUMPTS	Number of landmark points
XROTCT	X coordinate of center of frame rotation
YROTCT	Y coordinate of center of frame rotation
ROTANG	Angle of rotation of upper picture

A.3 Horizon Subprogram

A.3.1 Arrays

ESTVAR	Estimates of attitude parameters
RHOR	Radial distance of horizon points
REST	Roll estimates from horizons
PESTH	Pitch estimate from horizons
RSAT	Earth center-satellite distance
RTHEOR	Theoretical radial distance of horizon points
VS	Sine of given attitude variables
CS	Cosine of given attitude variables
ISW	Chooses variable to be improved

A.3.2 Variables

COUNTR	Subscript for error function samples
DELTA	Constant sampling interval
VALNEW	Latest sampling of error function
VALMID	Next to latest sampling of error function
VALOLD	Oldest of three most recent error function samplings
DIFNEW	VALNEW-VALMID
DIFOLD	VALMID-VALOLD

A.4 Landmark Subprogram

A.4.1 Arrays

YRESTL	Yaw estimates from landmarks
PESTL	Pitch estimates from landmarks
ESTYAW	Estimate of yaw
SPLONG	Subpoint longitude
SPLAT	Subpoint latitude
AZTONO	Azimuth to north
FLMLAT	Landmark latitude
FLMLON	Landmark longitude
SCANT	Sine cant angle
CCANT	Cosine cant angle

A.4.2 Variables

RLM	Radial distance of landmarks

A.5 Matchpoints Subprogram

A.5.1 Arrays

SINARG	Sine satellite argument
COSARG	Cosine satellite argument
ROTRIX	Rotation matrix

A.5.2 Variables

ROBJSQ	Square of object-space point radial distance

A.6 Sine Curve Fit

A.6.1 Arrays

TOP	Numerator of fractions used to compute amplitude of sine curve
DENOM	Denominator of fractions used to compute amplitude of sine curve

A.6.2 Variables

NOVALS	Present number of values being sine fitted
NVORIG	Original number of values being sine fitted
AMPL	Amplitude of sine curve
K	Translation constant of sine curve
DSQMAX	Maximum of deviations squared
SDEVSQ	Sum of deviations squared
DEV	A given deviation
DEVSQ	Square of deviation
RARITY	Probability of occurrence of given datum
ROLMAX	Maximum roll
ARGYMX	Argument at maximum yaw
NORJPT	Number of rejected points

A.7 Output Subprogram

A.7.1 Arrays

E	Eccentricity
MON	Month
NDAY	Day
NORB	Orbit number
NCAM	Camera number

A.7.2 Variables

REFARG	Reference satellite argument
LREF	Reference angle in radians

APPENDIX B

PROGRAM LISTINGS

```
                        REM                 PG9-1  MACHINE LANGUAGE INPUT SUBPROGRAM

                        REM                 ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM

                        REM                 TIROS WHEEL VERSION
                        REM                 REVISED -
        0000            BNKO
        0010            CON    10
0010    0000    CONVK                       XIN CONVERSION CTR
                        REM                 WA FILM READER INPUT
                        REM                 WORKING INFO STORAGE
0011    0000    PTY                         PARITY ACCUMULATOR
0012    0000    FRAME                       CURRENT FILM FRAME NUMBER
                        REM                 COUNTERS
0013    0000    MRK                         MODE RECORD STRG CTRS
0014    0000    MRK2
0015    0000    MRK3
0016    0000    SFK                         SFR STRG CTRS

0017    0000    SFK2

                        REM                 TEMPORARY STORAGE

0020    0000    SFSTO                       SFR-FRIN TEMP STRG
0021    0000    PETSTO                      PET TEMP STRG
0022    0000    PCSTO                       PCTR TEMP STRG
0023    0000    GWD                         GRAY-CODED 12 BIT WORD
0024    0000    BIT                         GRACON TEMP STRG
0025    0000    BWD                         GRACON CONVERTED WORD
0026    0000    XCAM                        CAMERA NR FROM FLEX
0027    0000    OPT                         PLOTTER SW SETTINGS
        0050            CON    50
0050    7777    KK             7777
0051    0020            SICO
0052    2150            LDI    KK
0053    0011            SRJI
```

```
0054  0000  KSGN
0055  0000  KQ            0
0056  0000  NOT           0
      0100          PRG   100
0100  0060          SIDO
0101  7500          EXC   2102          HI DENSITY MT 2
0102  2102

0103  7500          EXC   1162          REWIND 2

0104  1162

0105  0420          LDN   20

0106  4051          STD   51
0107  2200          LDC   2150
0110  2150

0112  0411          LDN   11
0113  4053          STD   53
0114  0400          LDN   0
0115  4056          STD   NOT
0116  0140  INPUT   SBUO
0117  7720          SLJ2  IN7
0120  0124
0121  2200          LDC   4102
0122  4102
0123  6103          NZF   3
0124  2200  IN7     LDC   4220
0125  4220
0126  4225          STF   INLOC   I
0127  7524          EXF   INLOC   I
0130  0020          SICO
0131  0041          SDCI
0132  0400          LDN   0
0133  4076          STD   76
0134  4300          STS
0135  7600          INA
```

```
0136  6401          ZJB   1

0137  0777          SBN   77

0140  6403          ZJB   3

0141  0626          ADN   26
0142  6106          NZF   NOTAB
0143  7600          INA
0144  0745          SBN   45
0145  6502          NZB   2
0146  7600          INA
0147  6213          PJF   IN8      1
0150  0651   NOTAB  ADN   51
0151  6211          PJF   IN8      1
0152  7500   INLOC  EXC   7777
0153  7777
0154  0041          SDCI
0155  0020          SICO
0156  0400          LDN   0

0157  4076          STD   76

0160  4300          STS

0161  7600   IN8    INA
0162  0752          SBN   52
0163  6104          NZF   4
0164  0403          LDN   3
0165  4076          STD   76
0166  6605          PJB   IN8
0167  0604          ADN   4
0170  6404          ZJB   4
0171  0646          ADN   46
0172  7665          HWI   65
0173  2077   IN6    LDD   77
0174  6413          ZJB   IN8
0175  6723          NJB   INLOC
```

```
0176  4040          STD   40
0177  7040          JPI   40
0200  7101          JFI   1
0201  7777  INDATA        7777
0202  0430          LDN   30
0203  4071          STD   71
0204  0501          LCN   1

0205  4067          STD   67

0206  7600          INA
0207  0745          SBN   45
0210  6436          ZJB   INLOC
0211  0704          SBN   4
0212  6504          NZB   4
0213  7600  IN4     INA
0214  7673          HWI   73
0215  2077  IN2     LDD   77
0216  6403          ZJB   IN4

0217  6307          NJF   IN5

0220  4171  IN3     STI   71
0221  5471          AOD   71
0222  2067          LDD   67
0223  6302          NJF   2
0224  5467          AOD   67
0225  6512          NZB   IN4
0226  1456  IN5     SCD   56
0227  6407          ZJB   IN3
0230  7675          HWI   75
0231  6177  IN1     NZF   77
0232  5467  INDPT   AOD   67
0233  6420          ZJB   IN4
0234  0401  INMIN   LDN   1
0235  4300          STS
0236  6623          PJB   IN4
0237  6637  INCR    PJB   INDATA -1
```

```
0240  0400   INCON1 LDN   0

0241  6210          PJF   INCON4

0242  2200   INCON2 LDC   211

0243  0211
0244  6205          PJF   INCON4
0245  0433   INCON5 LDN   33
0246  6203          PJF   INCON4
0247  2200   INCON6 LDC   113
0250  0113
0251  7663   INCON4 HWI   63
0252  7655          HWI   55
0253  0111          LS6
0254  7641          HWI   41
0255  2067          LDD   67
0256  6314          NJF   INCOA5
0257  0710   INCOA1 SBN   10
0260  6304          NJF   4

0261  0410          LDN   10

0262  4067          STD   67

0263  6210          PJF   INCOA5  1
0264  0400          LDN   0
0265  4171          STI   71
0266  5471          AOD   71
0267  5467          AOD   67
0270  6511          NZB   INCOA1

0271  0000   INCOSW
0272  5467   INCOA5 AOD   67
0273  0021          SICI
0274  2071          LDD   71
0275  3467          SBD   67
0276  0040          SDCO
```

```
0277  4047            STD   47
0300  4070            STD   70
0301  3100            ADM   67
0302  0067
0303  4071            STD   71
0304  7100            JPR   DAF
0305  0572
0306  7100   INCOA3   JPR   KK
0307  0050

0310  0641                  SHIFTR
0311  0000                  0
0312  0077                  77

0313  0470                  INSTO
0314  1164                  MACH
0315  2047            LDD   47
0316  4071            STD   71
0317  0430            LDN   30
0320  4070            STD   70

0321  7100            JPR   DBI
0322  0601
0323  0433            LDN   33
0324  0777   INCOA4   SBN   77
0325  4205            STF   HAND
0326  7100            JPR   KK
0327  0050
0330  0610                  SHIFTL
0331  0000                  0
0332  0000   HAND           0
0333  0000                  0
0334  0747                  ADD
0335  0000                  0
0336  0470                  INSTO
0337  0470                  INSTO
0340  1164                  MACH
0341  2350            LDB   INCOSW
```

```
0342  6022            ZJF    INCOAE

0343  0701            SBN    1

0344  6011            ZJF    INCOA2

0345  7100            JPR    KK
0346  0050
0347  0730                   DIVF
0350  0473                   INCRC1
0351  0470                   INSTO
0352  0000                   0
0353  1164                   MACH
0354  6110            NZF    INCOAE
0355  7100   INCOA2   JPR    KK
0356  0050
0357  0645                   MULT
0360  0000                   0
0361  0501                   INSXT2
0362  0000                   0

0363  1164                   MACH

0364  0061   INCOAE   SID1

0365  2061            LDD    61
0366  6010            ZJF    INEND1
0367  0400            LDN    0
0370  4061            STD    61
0371  0040            SDC0
0372  2075            LDD    75
0373  0041            SDC1
0374  4176            ST1    76
0375  7053            JP1    53
0376  2076   INEND1   LDD    76
0377  4205            STF    APE
0400  0040            SDC0
0401  7100            JPR    KK
```

```
0402  0050
0403  1073                  STOREX
0404  0000   APE            0
0405  1164                  MACH
0406  0041          SDCI
0407  7053          JPI     53
0410  2071   INCON7 LDD     71

0411  0040          SDCO

0412  0021          SICI

0413  4047          STD     47

0414  0400          LDN     0
0415  4100          STM     INSTO
0416  0470
0417  4100          STM     INSTO   1
0420  0471
0421  4100          STM     INSTO   2

0422  0472

0423  0433          LDN     33
0424  4046   INCOB3 STD     46
0425  2047          LDD     47
0426  3446          SBD     46
0427  6303          NJF     3
0430  0702   INCOB1 SBN     2
0431  6601          PJB     1
0432  3046          ADD     46
0433  4071          STD     71
0434  4045          STD     45
0435  2046          LDD     46
0436  0703          SBN     3
0437  4070          STD     70
0440  7100          JPR     OB1
0441  0601
```

```
0442  7100          JPR   KK

0443  0050

0444  0747                ADD

0445  0000                0
0446  0470                INSTO
0447  0470                INSTO
0450  1164                MACH
0451  2045          LDD   45
0452  3447          SBD   47
0453  6467          ZJB   INCOAE
0454  7100          JPR   KK
0455  0050
0456  0645                MULT
0457  0476                INSXTI
0460  0000                0
0461  0000                0

0462  1075                STOREY

0463  0470                INSTO

0464  1164                MACH
0465  2045          LDD   45
0466  0603          ADN   3
0467  6643          PJB   INCOB3
0470  2200    INL   LDC   LAN
0471  0201
0472  6111          NZF   INTO2
0473  2200    INB   LDC   BDA
0474  0207
0475  6106          NZF   INTO2
0476  2200    INE   LDC   ERP
0477  0212
0500  6103          NZF   INTO2
0501  2200    INF   LDC   FAX
```

```
0502  0204
0503  5076   INT02  RAD   76
0504  7100          JPR   INDATA
0505  0201
0506  7101          JFI   1
0507  0242                INCON2
0510  2200   INK    LDC   KPT

1     0511  0465

0512  6114          NZF   INI     2
0513  2200   INTT   LDC   TAL
0514  0457

0515  6111          NZF   INI     2
0516  2200   INA    LDC   ANT
0517  0176
0520  6106          NZF   INI     2
0521  2200   ING    LDC   GMT
0522  0231

0523  6103          NZF   INI     2

0524  2200   INI    LDC   INT
0525  0226
0526  5076          RAD   76
0527  7100          JPR   INDATA
0530  0201
0531  7101          JFI   1
0532  0410                INCON7
0533  2200   INR    LDC   ROT
0534  0462
0535  6130          NZF   INQ     2
0536  2200   INN    LDC   NTR
0537  0454
0540  6125          NZF   INQ     2
0541  2200   INS    LDC   SWA
0542  0451
```

```
0543  6122          NZF   INQ     2

0544  2200   INP    LDC   PDA

0545  0215

0546  6117          NZF   INQ     2
0547  2200   INCC   LDC   CAM
0550  0220
0551  6114          NZF   INQ     2
0552  2200   INO    LDC   ORB
0553  0165
0554  6111          NZF   INQ     2

0555  2200   IND    LDC   DAY
0556  0173
0557  6106          NZF   INQ     2
0560  2200   INM    LDC   MON
0561  0170
0562  6103          NZF   INQ     2

0563  2200   INQ    LDC   QTY
0564  0223
0565  5076          RAD   76
0566  7100          JPR   INDATA
0567  0201
0570  7101          JFI   1
0571  0245                INCON5
0572  7777   DBF           7777

0573  0407          LDN   DB6     -DB3
0574  5232          RAF   DB5
0575  2303          LDB   DBF
0576  4203          STF   DBI
0577  6103          NZF   3
0600  7301          JFI   1
0601  7777   DBI           7777
0602  0600          LDN   0
```

```
0603  4075          STD   75
0604  4076          STD   76
0605  4077          STD   77
0606  2070          LDD   70
0607  3471          SBD   71
0610  6053          ZJF   DB4
0611  7500   DB1    EXC   3321
0612  3321
0613  0020   DB2    SICO

0614  2170          LDI   70

0615  7677          OTA

0616  7400          OTN   0
0617  7400          OTN   0
0620  7350          OUT   DB8
0621  0100                100
0622  7246          INP   DB8
0623  0100                100
0624  5470          ADD   70
0625  3471          SBD   71
0626  6013   DB5    ZJF   DB3
0627  7500          EXC   3301
0630  3301
0631  7337          OUT   DB8
0632  0100                100
0633  7412          OTN   12
0634  7400          OTN   0
0635  7400          OTN   0
0636  7232          INP   DB8
0637  0100                100
0640  6527          NZB   DB1
0641  0021   DB3    SICI
0642  2300          LDS
0643  6443          ZJB   DB1     -1
0644  2200          LDC   4000
0645  4000
```

```
0646  5077          RAD   77

0647  6747          NJB   DB1     -1

0650  7500   DB6    EXC   3300

0651  3300
0652  7400          OTN   0
0653  7400          OTN   0
0654  7400          OTN   0
0655  7313          OUT   DB8
0656  0100                100
0657  7312          OUT   DB7
0660  0675                DB7     4
0661  7207          INP   DB8
0662  0100                100
0663  0413   DB4    LDN   DB3     -DB5
0664  3200          ADC   6000
0665  6000
0666  4340          STB   DB5

0667  6526          NZB   DB3

0670  0075   DB8          75

0671  0672   DB7          DB7     1
0672  0400                400
0673  7536                7536
0674  0005                5
0675  0020   XIN    SICO
0676  0041          SDCI
0677  2200          LDC   GMT
0700  0231
0701  4076          STD   76
0702  2200          LDC   XINRET
0703  0734
0704  4053          STD   53
0705  2200          LDC   INCON7
```

```
0706  0410
0707  4100          STM    INDATA
0710  0201
0711  2100          LDM    INLOC    I
0712  0153
0713  4211          STF    XINEXC   I
0714  0020   XIN3   SICO

0715  0400          LDN    0

0716  4300          STS
0717  0430          LDN    30
0720  4071          STD    71

0721  0501          LCN    1
0722  4067          STD    67
0723  7500   XINEXC EXC
0724  0000
0725  7600   XIN2   INA

0726  0744          SBN    44              SLASH - EXIT

0727  6010          ZJF    CONV
0730  0705          SBN    5
0731  6504          NZB    XIN2            READ TO TAB
0732  7101          JFI    1
0733  0213                 IN4
0734  0403   XINRET LDN   3
0735  5076          RAD    76
0736  6522          NZB    XIN3
0737  2200   CONV   LDC    INLOC
0740  0152
0741  4053          STD    53
0742  0040          SDCO
0743  0021          SICI
0744  2200          LDC    HRE
0745  0102
0746  4010          STD    CONVK
```

```
0747  2100          LDM   MOE

0750  0100

0751  4100          STM   MOE2

0752  0154
0753  2100          LDM   DAE
0754  0101
0755  4100          STM   DAE2
0756  0157
0757  7500          EXC   4440          READ PLOTTER SWITCHES
0760  4440
0761  7600          INA
0762  4027          STD   OPT
0763  4100          STM   OPTION  1
0764  0163
0765  0404          LDN   4
0766  4100          STM   OPTION  2
0767  0164

0770  2100          LDM   CAM

0771  0220

0772  4026          STD   XCAM
0773  2010   CONV2  LDD   CONVK
0774  4250          STF   XFWA
0775  0603          ADN   3
0776  4206          STF   XLWAI
0777  0701          SBN   1
1000  4217          STF   XSGN    1

1001  7500          EXC   3342          NORMALIZE AND COUNT

1002  3342
1003  7341          OUT   XFWA
1004  0000   XLWAI
```

```
1005  0020          SICO
1006  7237          INP   175
1007  0100                100
1010  0021          SICI
1011  2077          LDD   77
1012  0111          LS6
1013  0237          LPN   37

1014  0110          LS3
1015  4074          STD   74
1016  2100   XSGN   LDM
1017  0000
1020  1200          LPC   4000

1021  4000
1022  3077          ADD   77
1023  1200          LPC   4007
1024  4007
1025  3200          ADC   2000
1026  2000

1027  3474          SBD   74

1030  4110          STI   CONVK
1031  5410          AOD   CONVK
1032  2076          LDD   76
1033  4110          STI   CONVK
1034  5410          AOD   CONVK
1035  2075          LDD   75
1036  4110          STI   CONVK
1037  5410          AOD   CONVK
1040  3600          SBC   TAL     3
1041  0462
1042  6747          NJB   CONV2
1043  6203          PJF   PRIEPH
1044  0000   XFWA
1045  0075   175          75
1046  0400   PRIEPH LDN   0              WRITE PRIMARY EPHEMERIS
```

```
1047  4100          STM   DAE              FORTRAN MT FORMAT

1050  0101

1051  7527          EXF   PRWMTF   1

1052  7350          OUT   IDAE
1053  0272                HRE      120D
1054  7100          JPR   PET
1055  1515
1056  0457          LDN   57
1057  4100          STM   HRE      119D
1060  0271
1061  7517          EXF   PRWMTF   1
1062  7337          OUT   PRFWA
1063  0462                HRE      240D
1064  7100          JPR   PET
1065  1515
1066  0510          LCN   10
1067  4013          STD   MRK

1070  7510   DUM    EXF   PRWMTF   1

1071  7331          OUT   IDAE              WRITE DUMMY RECORDS

1072  0272                HRE      120D
1073  7100          JPR   PET
1074  1515
1075  5413          AOD   MRK
1076  6706          NJB   DUM
1077  7500   PRWMTF EXC   2112              WRITE EOF
1100  2112
1101  7777          HLT   77
                    REM                     WA FILM READER INPUT
1102  0020          SICO                    IND BK • 0 THIS ROUTINE
1103  7551          EXF   FRRPTF   1
1104  7600   FRIN2  INA
1105  3600          SBC   360
```

```
1106  0360
1107  6503          NZB   FRIN2          READ TO START CODE
1110  2240          LDF   IDATA
1111  4015          STD   MRK3
1112  0601          ADN   1
1113  4013          STD   MRK
1114  4014          STD   MRK2

1115  0400          LDN   0

1116  4011          STD   PTY

1117  7101          JFI   1

1120  1237                SFR
1121  0271  PRFWA         HRE      1190
1122  0101  IDAE          DAE
                    REM
                    REM                    ...
                    REM
1123  7517  WMT     EXF   FRWMTF   1      WRITE MREC ON MT
1124  7323          OUT   ICODE
1125  1614                MREC     270
1126  7100          JPR   PET
1127  1515
1130  2220          LDF   IDATA
1131  4015          STD   MRK3
1132  0601          ADN   1
1133  4013          STD   MRK
1134  4014          STD   MRK2
                    REM
                    REM                    ...
                    REM
1135  2020  ENDTST  LDD   SFSTO
1136  3600          SBC   362
1137  0362
1140  6111          NZF   RMR            JUMP UNLESS END CODE READ
1141  7500  FRWMTF  EXC   2112           WRITE EOF
```

```
1142  2112

1143  7500   FRREWF EXC   2162          REWIND

1144  2162

1145  7101          JFI   1
1146  1614                BTRAN
1147  1560   ICODE        CODE
1150  1567   IDATA        DATA
                    REM
                    REM                 ***
                    REM
1151  0400   RMR    LDN   0             READ MODE RECORD
1152  4011          STD   PTY
1153  7500   FRRPTF EXC   4102          READ PAPER TAPE
1154  4102
1155  2020          LDD   SFSTO
1156  7100          JPR   PCTR
1157  1503

1160  0277          LPN   77

1161  4100          STM   MODE

1162  1565
1163  0704          SBN   4
1164  6221          PJF   SDB
1165  7600   RP     INA                 READ AND PACK
1166  7100          JPR   PCTR
1167  1503
1170  1200          LPC   300
1171  0300
1172  6142          NZF   FRWD          PARITY FRAME READ
1173  2022          LDD   PCSTO
1174  0111          LS6
1175  4113          STI   MRK
1176  7600          INA
```

```
1177  7100          JPR   PCTR
1200  1503
1201  7613          HWI   MRK
1202  0403          LDN   3
1203  5013          RAD   MRK
1204  6517          NZB   RP
1205  7600   SDB    INA                 SHORT DECIMAL TO BINARY

1206  7100          JPR   PCTR

1207  1503
1210  4213          STF   SDB2    1
1211  7600          INA
1212  7100          JPR   PCTR

1213  1503
1214  0112          MUT
1215  5206          RAF   SDB2    1

1216  7600          INA

1217  7100          JPR   PCTR

1220  1503
1221  0113          MUH
1222  5200   SDB2   RAC
1223  0000
1224  4113          STI   MRK
1225  2100          LDM   MODE
1226  1565
1227  0705          SBN   5
1230  6443          ZJB   RP
1231  0403          LDN   3
1232  5013          RAD   MRK
1233  6546          NZB   RP
1234  2012   FRWD   LDD   FRAME
1235  4100          STM   FRAMWD
1236  1562
```

```
                        REM

                        REM                    ...

                        REM

1237  2800   SFR     LDC   SFBLOK          SINGLE FRAME RECORDS
1240  1670
1241  4016           STD   SFK
1242  7600   SFR2    INA
1243  6401           ZJB   1               IGNORE LEADER BETWEEN MRECS
1244  4020           STD   SFSTO
1245  1200           LPC   300
1246  0300

1247  3600           SBC   200
1250  0200
1251  6025           ZJF   SFINT           HEAD OF NEXT RECORD READ
1252  2020           LDD   SFSTO
1253  1600           SCC   300

1254  0300

1255  0762           SBN   62

1256  6020           ZJF   SFINT           END CODE SPOTTED
1257  0601           ADN   1
1260  6112           NZF   SFR4
1261  2016           LDD   SFK             ERASE CODE DETECTED

1262  3722           SBB   SFR      1

1263  6104           NZF   SFR3
1264  2014           LDD   MRK2            ERASE MREC
1265  4013           STD   MRK
1266  6524           NZB   SFR2
1267  0501   SFR3    LCN   1               ERASE LAST SFR
1270  5016           RAD   SFK
```

```
1271  6527          NZB   SFR2
1272  0661   SFR4   ADN   61
1273  4116          STI   SFK
1274  5416          AOD   SFK
1275  6533          NZB   SFR2
1276  2200   SFINT  LDC   SFBLOK -1        SFR INTERPRETER
1277  1667
1300  4017          STD   SFK2
1301  5417   SFINT2 AOD   SFK2

1302  3416   SFINT3 SBD   SFK

1303  6071          ZJF   PCHECK           NO MORE SFR

1304  2117          LDI   SFK2
1305  1200          LPC   360
1306  0360
1307  6043          ZJF   SFDB
1310  2117   SFFA   LDI   SFK2             FILM ADVANCE
1311  0740          SBN   40
1312  6103          NZF   SFFA2
1313  5412          AOD   FRAME            FORWARD
1314  7106          JFI   SFFA3
1315  0701   SFFA2  SBN   1
1316  6105          NZF   SFAB
1317  0501          LCN   1                REVERSE
1320  5012          RAD   FRAME
1321  7101          JFI   SFFA3
1322  1301   SFFA3         SFINT2
1323  0722   SFAB   SBN   22               63 = A
1324  6104          NZF   SFAB2
1325  2200          LDC   2014
1326  2014
1327  6105          NZF   ABGMT
1330  0701   SFAB2  SBN   1                64 = B
1331  6530          NZB   SFINT2           IGNORE 32X CODES
                    REM                    IGNORE ALSO CODES NOT OF FORM 3XX
1332  2200          LDC   2024
```

```
1333  2024
1334  4211   ABGMT   STF    ABGMT2  1
1335  2012           LDD    FRAME
1336  0102           LSI
1337  3012           ADD    FRAME
1340  3200           ADC    GMT     -3
1341  0226
1342  4205           STF    ABGMT3  1
1343  0021           SICI
1344  2200   ABGMT2  LDC
1345  0000
1346  4100   ABGMT3  STM
1347  0000
1350  0020           SICO
1351  6550           NZB    SFINT2
1352  2117   SFDB    LDI    SFK2            CAM CHECK
1353  3426           SBD    XCAM
1354  6007           ZJF    SFDB2
1355  7525           EXF    TYPOF   1       ERROR TYPEOUT
1356  7445           OTN    45
1357  7416           OTN    16              C
1360  7430           OTN    30              A
1361  7407           OTN    7               M
1362  0000           ERR                    CAM DISCREPANCY
1363  5417   SFDB2   AOD    SFK2
1364  2117           LDI    SFK2
1365  0112           MUT
1366  4012           STD    FRAME
1367  5417           AOD    SFK2
1370  2117           LDI    SFK2
1371  0701           SBN    1
1372  5012           RAD    FRAME
```

```
1373  6672          PJR   SFINT2
1374  2011  PCHECK  LDD   PTY
1375  0277          LPN   77
1376  4100          STM   PTYFLG
1377  1612
1400  6012          ZJF   ERATST
1401  7500  TYPOF   EXC   4210          ERROR TYPEOUT

1402  4210

1403  7445          OTN   45

1404  7415          OTN   15            P

1405  7401          OTN   1             T
1406  7425          OTN   25            Y
1407  2027          LDD   OPT
1410  6202          PJF   2
1411  0000          ERR
                    REM

                    REM                 ***

                    REM
1412  2013  ERATST  LDD   MRK           TEST IF MREC HAS BEEN ERASED
1413  3414          SBD   MRK2
1414  6103          NZF   SKPTST
1415  7101          JFI   1
1416  1135                ENDTST
1417  2100  SKPTST  LDM   MODE
1420  1565
1421  0704          SBN   4
1422  6003          ZJF   SKIPB
1423  0702          SBN   2
1424  6107          NZF   GRACON
1425  0403  SKIPB   LDN   3
1426  5014          RAD   MRK2
1427  0400          LDN   0
```

```
1    1430  4115          STI   MRK3

     1431  0403          LDN   3

     1432  5015          RAD   MRK3

                         REM
                         REM                    ***
                         REM
     1433  2114   GRACON LDI   MRK2              GRAY CODE CONVERSION
     1434  4023          STD   GWD
     1435  0400          LDN   0
     1436  4025          STD   BWD              INITIALIZE CONVERTED WORD
     1437  4425   GR4    SRD   BWD
     1440  2023          LDD   GWD
     1441  1200          LPC   4000
     1442  4000
     1443  0102          LSI
     1444  4024          STD   BIT

     1445  5025   GR2    RAD   BWD

     1446  4423          SRD   GWD

     1447  4600          SRC   4000             COUNTER
     1450  4000
     1451  6311          NJF   GR5
     1452  4425          SRD   BWD
     1453  2023          LDD   GWD
     1454  6204          PJF   GR3
     1455  2024          LDD   BIT              COMPLEMENT BIT
     1456  0301          SCN   1
     1457  4024          STD   BIT
     1460  2024   GR3    LDD   BIT
     1461  6614          PJB   GR2
     1462  2025   GR5    LDD   BWD
     1463  1200          LPC   3777
     1464  3777
```

```
1465  4114          STI   MRK2
1466  2025          LDD   HWD
1467  3514          SBI   MRK2
1470  0102          LSI
1471  4115          STI   MRK3
1472  0403          LDN   3
1473  5015          RAD   MRK3

1474  0403          LDN   3

1475  5014          RAD   MRK2
1476  3413          SBD   MRK
1477  6544          NZB   GRACON          NEXT WORD

1500  7101          JFI   1
1501  1123                WMT
                    REM
                    REM                   ***
                    REM
1502  7101          JFI   1               PARITY COUNTER SR

1503  7777   PCTR         7777

1504  4022          STD   PCSTO
1505  2011          LDD   PTY
1506  1422          SCD   PCSTO
1507  4011          STD   PTY
1510  2022          LDD   PCSTO
1511  6607          PJB   PCTR    -1      END PCTR SR
                    REM                   18 CYCLES FOR JPR PCTR
1512  2200   AREG   LDC                   PARITY ERROR TEST SR
1513  0000
1514  7101          JFI   1
1515  7777   PET          7777
1516  4303          STB   AREG    1
1517  7500          EXC   1142            STATUS REQUEST UNIT 2
1520  1142
1521  7600          INA
```

```
1522  0204          LPN   4

1523  6105          NZF   PK              JUMP IF PARITY ERROR

1524  2200          LDC   4040

1525  4040
1526  4203          STF   PK       I       RESET 6 COUNTER
1527  6715          NJB   AREG             RETURN
1530  4600   PK     SRC   4040
1531  4040
1532  6202          PJF   2
1533  0000          ERR                    TRIED 6 TIMES

1534  0505          LCN   5
1535  5320          RAB   PET
1536  4021          STD   PETSTO
1537  0130          CTA
1540  0210          LPN   10
1541  6002          ZJF   2

1542  0401          LDN   1

1543  0620          ADN   20

1544  4203          STF   RESET
1545  0020          SICO
1546  2121          LDI   PETSTO
1547  0000   RESET                          RESTORE INDIR BK SETTING

1550  6303          NJF   BKSP
1551  0501          LCN   1
1552  5335          RAB   PET
1553  7500   BKSP   EXC   1122             BACKSPACE RECORD
1554  1122
1555  7600          INA
1556  6644          PJB   AREG
1557  6745          NJB   AREG             END PET SR
```

```
1560  0037   CODE          37
1561  0000   MREC          0
1562  0000   FRAMWD
1563  0000                 0
1564  0000                 0
1565  0000   MODE
1566  0000                 0

1567  0000   DATA   BSS   18D

1611  0000                 0

1612  0000   PTYFLG

1613  0000                 0
1614  0021   BTRAN  SICI                    REWRITE PRIEPH
1615  2100          LDM   INT               UNLESS INT =0
1616  0226
1617  0207          LPN   7
1620  6033          ZJF   INTRAN
1621  7524          EXF   BTF      1
1622  7344          OUT   IDAE2
1623  0272                HRE      120D
1624  7100          JPR   PET
1625  1515
1626  7517          EXF   BTF      1
1627  7340          OUT   BTFWA
1630  0462                HRE      240D
1631  7100          JPR   PET
1632  1515
1633  0510          LCN   10
1634  4013          STD   MRK
1635  7510   DUM2   EXF   BTF      1       REWRITE DUMMY RECORDS
1636  7330          OUT   IDAE2
1637  0272                HRE      120D
1640  7100          JPR   PET
1641  1515
1642  5413          AOD   MRK
```

```
1643  6706          NJB    DUM2

1644  7500   BTF    EXC    2112

1645  2112

1646  7400          OTN    0
1647  7100          JPR    PET
1650  1515
1651  7500          EXC    1162            REWIND 2
1652  1162
1653  0020   INTRAN SICO
1654  7504          EXF    4               SEARCH EOF
1655  7503          EXF    3               SKIP MT-ST
1656  7600          INA
1657  7500          EXC    2133            READ FORTRAN ST
1660  2133
1661  7203          INP    FSTFWA   1
1662  0536                 536
1663  2200   FSTFWA LDC    525

1664  0525

1665  0010   LENGTH SRJO

1666  0101   IDAE2        DAE
1667  0271   BTFWA        HRE      119D
1670  0000   SFBLOK BSS   100
      0001          BNKI
      0000          CON    0
0000  0000                 0
0001  0513                 INTT
0002  0000                 0
0003  0552                 INO
0004  0000                 0
0005  0000                 0
0006  0536                 INN
0007  0560                 INM
```

```
0010  0161          IN8
0011  0470          INL
0012  0533          INR
0013  0521          ING
0014  0524          INI
0015  0544          INP
0016  0547          INCC

0017  0000          0

0020  0476          INE

0021  0000          0

0022  0555          IND
0023  0473          INB
0024  0541          INS
0025  0000          0
0026  0801          INF

0027  0000          0

0030  0516          INA
0031  0000          0
0032  0000          0
0033  0010          10
0034  0000          0
0035  0563          INQ
0036  0510          INK
0037  0011          11
0040  0000          0
0041  0271          INCOSW
0042  7776          INI     -INDPT
0043  0000          0
0044  0675          XIN
0045  7771          INI     -INCR
0046  0000          0
0047  0000          0
```

```
0050  0000                 0

0051  0000                 0

0052  7774                 INI     -INMIN

0053  0152                 INLOC
0054  0000                 0
0055  0324                 INCOA4
0056  7777                 7777
0057  0000                 0
0060  0007                 7
0061  0000                 0
0062  0004                 4
0063  0312                 INCOA3  4
0064  0003                 3
0065  0173                 IN6
0066  0005                 5
0067  0000                 0
0070  0002                 2

0071  0000                 0

0072  0006                 6

0073  0215                 IN2
0074  0001                 1
0075  0231                 INI
0076  0000                 0
0077  0000                 0
      0100          PRG    100

0100  0000   MOE                          STANDARD ORB EL BLOCK
0101  0000   DAE           0              EPOCH DAY
0102  0000   HRE     BSS   3              EPOCH TIME IN HHMMSS
0105  0000   ANP     BSS   6              ANOM.PER.IN MIN.-MOTION OF THE ANOM.PER.
0113  0000   INC     BSS   3              INCLININATION IN DEGREES
0116  0000   RAN     BSS   6              RT.ASC.+MOTION OF RT.ASC. ASC.NODE/DAY
```

0124	0000	PER	BSS	6	ARG.OF PER. + MOTION OF ARG. OF PER.
0132	0000	NAN	BSS	3	MEAN ANOM. IN DEGREES
0135	0000	ECC	BSS	3	ECCENTRICITY
0140	0000	SMA	BSS	3	SEMI MAJOR AXIS
0143	0000	FMI	BSS	3	1ST MOMENT OF INER.
0146	0000	TMI	BSS	3	3RD MOMENT OF INER.
0151	0000	LDA		0	LAST DAY OF EPOCH MONTH
0152	0000			0	
0153	0000			0	
0154	0000	MQE2			
0155	0000			0	
0156	0000			0	
0157	0000	DAE2			
0160	0000			0	
0161	0000			0	
0162	0000	OPTION			PLOTTER SWITCHES
0163	0000			0	
0164	0000			0	
0165	0000	ORB	BSS	3	GRID TYPE INPUTS
0170	0000	MON	BSS	3	
0173	0000	DAY	BSS	3	
0176	0000	ANT	BSS	3	TIME OF ASC. NODE
0201	0000	LAN	BSS	3	E.LONG. OF ASC. NODE
0204	0000	FAX	BSS	3	MAX ROLL (PHI MAX)
0207	0000	BDA	BSS	3	ARG OF MAX YAW (LAMBDA)
0212	0000	ERP	BSS	3	SYSTEMATIC PITCH ERROR
0215	0000	PDA	BSS	3	
0220	0000	CAM	BSS	3	
0223	0000	QTY	BSS	3	
0226	0000	INT		0	PROGRAMMED PIC INTERVAL
0227	0000			0	
0230	0000			0	
0231	0000	GMT	BSS	144D	
0451	0000	SWA		0	MAP SLIDE SWATH NR

```
0452  0000                  0

0453  0000                  0

0454  0000   NTR     BSS    3              TRIGGER NUMBER

0457  0000   TAL     BSS    3              ALARM TIME
0462  0000   ROT            0              SATELLITE ROTATION PERIOD
0463  0000                  0
0464  6014                  6014
0465  0000   KPT            0
0466  0000                  0
0467  6014                  6014
                     REM                   CONSTS AND TEMP STRG
0470  0000   INSTO   BSS    3
0473  0000   INCRCI         0
0474  5000                  5000
0475  0005                  5
0476  0074   INSXTI         74
0477  0000                  0

0500  0000                  0

0501  0000   INSXT2         0

0502  0036                  36
0503  0000                  0
                     REM                   THIS IS THE LOAD X ROUTINE
0504  7101           JFI    1
0505  7777   KLOADX        7777
0506  2056           LDD    NOT
0507  6002           ZJF    FRI
0510  0021           SICI
0511  5450   FRI     AOD    KK
0512  2150           LDI    KK
0513  6013           ZJF    KLOADY -4
0514  4055           STD    KQ
0515  0021           SICI
```

```
0516  2155          LDI   KQ
0517  4075          STD   75
0520  5455          AOD   KQ
0521  2155          LDI   KQ
0522  4076          STD   76
0523  5455          AOD   KQ
0524  2155          LDI   KQ

0525  4077          STD   77

0526  0020          SICO
0527  6523          NZB   KLOADX -1
0530  6424          ZJB   KLOADX -1

0531  7101          JFI   1
0532  7777   KLOADY       7777
0533  2056          LDD   NOT
0534  6002          ZJF   FR
0535  0021          SICI
0536  5450   FR     AOD   KK
0537  2150          LDI   KK
0540  6016          ZJF   KLY
0541  4055          STD   KQ
0542  0021          SICI
0543  2155          LDI   KQ
0544  4072          STD   72
0545  5455          AOD   KQ
0546  2155          LDI   KQ
0547  4073          STD   73
0550  5455          AOD   KQ
0551  2155          LDI   KQ
0552  4074          STD   74
0553  0020          SICO
0554  6523          NZB   KLOADY -1
0555  6424          ZJB   KLOADY -1
0556  2075   KLY    LDD   75
0557  4072          STD   72
0560  2076          LDD   76
```

```
0561  4073          STD   73

0562  2077          LDD   77

0563  4074          STD   74

0564  6533          NZB   KLOADY -1
0565  6434          ZJB   KLOADY -1
                    REM                 THIS IS THE SHIFT LEFT AND SHIFT RIGHT ROU INE
0566  7101          JFI   1
0567  7777   KSHSN        7777
0570  2056          LDD   NOT
0571  6002          ZJF   2
0572  0021          SICI
0573  2077          LDD   77
0574  1264          LPF   KMPG    1
0575  4054          STD   KSGN
0576  2077          LDD   77
0577  0207          LPN   7
0600  4077          STD   77

0601  5450          AOD   KK

0602  2150          LDI   KK

0603  0110          LS3
0604  5077          RAD   77
0605  0020          SICO
0606  6520          NZB   KSHSN  -1
0607  6421          ZJB   KSHSN  -1
0610  7500   SHIFTL EXC   3302
0611  3302
0612  7100          JPR   KLOADX
0613  0505
0614  7100          JPR   KSHSN
0615  0567
0616  7326          OUT   KSHO
0617  0100                100
```

```
0620  7224          INP   KSHO
0621  0100                100
0622  2054          LDD   KSGN
0623  5077          RAD   77
0624  2056   ZHEADG LDD   NOT
0625  6010          ZJF   10
0626  2200          LDC   KRETRN
0627  1147
0630  0021          SICI

0631  4100          STM   KTORX
0632  1046
0633  7101          JFI   1
0634  1050                KTORX   2

0635  7100          JPR   KTORX
0636  1046
0637  7101          JFI   1
0640  1147                KRETRN

0641  7500   SHIFTR EXC   3303

0642  3303
0643  6531          NZB   SHIFTL  2
0644  0075   KSHO         75
                    REM                THIS IS THE MULTIPLICATION ROUTINE
0645  7100   MULT   JPR   KLOADY
0646  0532
0647  7100          JPR   KLOADX
0650  0505
0651  7500          EXC   3301
0652  3301
0653  7321          OUT   KMPY
0654  0100                100
0655  2077          LDD   77
0656  1474          SCD   74
0657  1200   KMPG   LPC   4000
0660  4000
```

```
0661  4054          STD   KSGN

0662  7212          INP   KMPY

0663  0100                100

0664  2077          LDD   77
0665  0207          LPN   7
0666  5054          RAD   KSGN
0667  4077          STD   77
0670  1310          LPB   KMPG     1
0671  5074          RAD   74
0672  7101          JFI   1
0673  0624                ZHEADG

0674  0072    KMPY        72
                    REM                THIS IS THE FRACTION AND INTEGER DIVISION  OUTINE
0675  7100    DIVI  JPR   KLOADY
0676  0532
0677  7500          EXC   3300

0700  3300

0701  7344          OUT   KDIVL1

0702  0075                75
0703  7400          OTN   0
0704  7400          OTN   0
0705  7400          OTN   0

0706  7100          JPR   KLOADX
0707  0505

0710  7336          OUT   KDIVL2

0711  0100                100
0712  2074    KDV   LDD   74
0713  1477          SCD   77
```

```
0714  1334          LPB   KMPG     1
0715  4054          STD   KSGN
0716  7230          INP   KDIVL2
0717  0100                100
0720  7225          INP   KDIVL1
0721  0075                75
0722  2077          LDD   77
0723  0207          LPN   7
0724  5054          RAD   KSGN

0725  4077          STD   77

0726  7101          JFI   1

0727  0624                ZHEADG
0730  7500   DIVF   EXC   3300
0731  3300
0732  7400          OTN   0
0733  7400          OTN   0
0734  7400          OTN   0
0735  7100          JPR   KLOADX
0736  0505
0737  7100          JPR   KLOADY
0740  0532
0741  7304          OUT   KDIVL1
0742  0100                100
0743  6531          NZB   KDV
0744  6432          ZJB   KDV
0745  0072   KDIVL1       72
0746  0075   KDIVL2       75
                    REM                THIS IS THE ADDITION/SUBTRACTION ROUTINE
0747  7100   ADD    JPR   KLOADY
0750  0532
0751  7100          JPR   KLOADX
0752  0505
0753  0020          SICO
0754  2077          LDD   77
0755  1474          SCD   74
```

```
0756  1243          LPF   ADDL    1

0757  6234          PJF   ADD1

0760  7500   SUB1   EXC   3361

0761  3361
0762  7362          OUT   ADD3
0763  0100                100
0764  7357          OUT   ADD2
0765  0075                75
0766  2077          LDD   77
0767  1232          LPF   ADDL    1
0770  4070          STD   70
0771  7253          INP   ADD3
0772  0100                100
0773  2070          LDD   70
0774  5077          RAD   77
0775  0210          LPN   10
0776  6031          ZJF   ADD4

0777  2077          LDD   77

1000  1600          SCC   4017

1001  4017
1002  4077          STD   77
1003  2476          LCD   76
1004  4076          STD   76
1005  2475          LCD   75
1006  4075          STD   75
1007  7500          EXC   3321
1010  3321
1011  6316          NJF   ADD4
1012  6215          PJF   ADD4
1013  7500   ADD1   EXC   3321
1014  3321
1015  7326          OUT   ADD2
```

```
1016  0100                  100
1017  2077          LDD     77
1020  1200   ADDL   LPC     4000
1021  4000
1022  4070          STD     70
1023  7221          INP     ADD3
1024  0100                  100

1025  2070          LDD     70

1026  5077          RAD     77

1027  7101   ADD4   JFI     1

1030  0624                  ZHEADG
1031  7100   SUB    JPR     KLOADX
1032  0505
1033  7100          JPR     KLOADY
1034  0532
1035  0020          SICO
1036  2077          LDD     77
1037  1474          SCD     74
1040  1317          LPB     ADDL     1
1041  6726          NJB     ADD1
1042  6662          PJB     SUB1
1043  0072   ADD2           72
1046  0075   ADD3           75
                    REM                      THIS IS THE STORE X AND STORE Y ROUTINE
1045  7101          JFI     1
1046  7777   KTORX         7777
1047  0020          SICO
1050  5450          AOD     KK
1051  2150          LDI     KK
1052  6405          ZJB     KTORX   -1
1053  4055          STD     KQ
1054  0021          SIC1
1055  2075          LDD     75
1056  4155          STI     KQ
```

```
1057  5455          AOD   KQ

1060  2076          LDD   76

1061  4155          STI   KQ

1062  5455          AOD   KQ
1063  2077          LDD   77
1064  1200          LPC   4007
1065  4007
1066  4155          STI   KQ
1067  4077          STD   77
1070  0020          SICO
1071  6524          NZB   KTORX   -1
1072  6425          ZJB   KTORX   -1
1073  7101   STOREX JFI   1
1074  0624                ZHEADG
1075  5450   STOREY AOD   KK
1076  2150          LDI   KK

1077  4055          STD   KQ

1100  0021          SICI

1101  2072          LDD   72
1102  4155          STI   KQ
1103  5455          AOD   KQ
1104  2073          LDD   73
1105  4155          STI   KQ
1106  5455          AOD   KQ
1107  2074          LDD   74

1110  1200          LPC   4007
1111  4007
1112  4155          STI   KQ
1113  7101          JFI   1
1114  1147                KRETRN
1115  5602          AOF   KTORY
```

```
1116  7101          JFI   1
1117  7777  KTORY         7777
1120  0021          SICI
1121  2302          LDB   KTORY
1122  4050          STD   KK
1123  2150          LDI   KK
1124  6017          ZJF   FRONT

1125  4055          STD   KQ

1126  2072          LDD   72
1127  4155          STI   KQ
1130  5455          AOD   KQ

1131  2073          LDD   73
1132  4155          STI   KQ
1133  5455          AOD   KQ
1134  2074          LDD   74
1135  1200          LPC   4007
1136  4007

1137  4155          STI   KQ

1140  0020          SICO
1141  6524          NZB   KTORY  -2
1142  6425          ZJB   KTORY  -2
1143  0475  FRONT   LDN   75
1144  4055          STD   KQ
1145  0020          SICO
1146  6520          NZB   KTORY   7
                    REM                THIS IS THE RETURN ROUTINE
1147  0021  KRETRN  SICI
1150  2056          LDD   NOT
1151  6007          ZJF   KRE2
1152  5450          AOD   KK
1153  4100          STM   KKI
1154  1175
1155  2200          LDC   KKI     1
```

```
1156  1176

1157  0031          IRJI

1160  5450   KRE2   AOD   KK

1161  2200          LDC   KK       I
1162  0051
1163  0030          IRJO
                    REM                    THIS IS THE MACHINE LANGUAGE ROUTINE
1164  0021   MACH   SICI
1165  2056          LDD   NOT
1166  6005          ZJF   MACH2

1167  0400          LDN   0
1170  4056          STD   NOT
1171  5450          AOD   KK
1172  0011          SRJI
1173  5450   MACH2  AOD   KK
1174  0010          SRJO

1175  0000   KKI

1176  0021          SICI
1177  0040          SDCO
1200  0401          LDN   1
1201  4056          STD   NOT
1202  2305          LDB   KKI
1203  4050          STD   KK

1204  2150          LDI   KK

1205  0011          SRJI

                    SUPR
      0000          END
```

```
C     PG9-2  FIDUCIAL FITS, PIC TIMES, EPHEMERIS
C     ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM
C     TIROS WHEEL VERSION
C     REVISED -
C
      COMMON E,STFIDS
      DIMENSION E(80),STFIDS(20),SEA(59),MODREC(8),AB(2,2)

      DIMENSION CSTND(2,5,2),CMEAS(2,5,2),S(6),SUM(2),SUM2(2),SEB(259),

     1FIDFIT (337)

      EQUIVALENCE (FIDFIT,SEB)

      RPD = .017453293
      TWO27 = 67108864.*2.
      TWOPI = 6.2831853
      AB(1,1) = 3.6  /TWO27
      AB(2,1) = 6.6  /TWO27
      AB(1,2) = 17.  /TWO27
      AB(2,2) = 14.  /TWO27
      IFLIP = 2
      KEOF = 1
77    PAUSE 77
C     EPHEMERIS PROCESSOR
      READ TAPE 2,E
      REWIND 2
C
C     PREPARE SECEPH
C     TRANSFERS FROM PRIEPH
      SEA(49) = E(4)*TWOPI
      SEA(50) = E(21)*TWO27
      SEA(51) = E(23)*TWOPI
      SEA(52) = E(24)*TWOPI
      SEA(53) = E(27)*TWO27
      SEA(56) = E(10)
      SEA(59) = E(78)*TWO27
      SEB(1) = E(28)*TWO27
```

```
      IQTY = SEB(1)

      SEB(2) = E(17)

      SEB(3) = E(25)*TWOPI

      SEB(4) = E(22)*TWOPI
C
C     PICTURE POSTDICTION
C     USING MEAN DELAY TIMES
      IF (E(29)*1.) 210,100,210
210   K = E(79)*TW027
      DO 299 I=1,IQTY
      J = E(I+29)
      IF(J) 201,201,202
201   E(I+29) = -1.
      GO TO 299
 202   E(I+29)=E(80)+(IQTY-I+1)*E(29)+AB(J,K)
299   CONTINUE
C

C     UPDATE PER AND RAN

100   Q = E(20)-E(16)+(E(21)-E(1))/86400.+(E(19)-E(15))*TW027*E(14)

102   Q = Q*TW027
      ARGPER = (Q*E(8)+E(7))*TWOPI
C
C     TIME OF PERIGEE
      CCONST = SQRTF((1.-E(10))/(1.+E(10)))
      CALL ARCTAN(CCONST*SINF(ARGPER/2.),COSF(ARGPER/2.),TEMP)
      ECANOM = 2.*TEMP
      TEMP = E(2)*TW027
      FMAV = TWOPI*(1.+TEMP*E(8)/86400.)/TEMP
      TPA = (ECANOM-E(10)*SINF(ECANOM))/FMAV
C
C     CONSTANTS FOR REPEATED USE
      E(11) = E(11)*51027104.
```

```
      BCONST = -E(11)*E(10)
      SINROL = SINF(SEA(51))
      SININC = SINF(SEA(49))
      COSINC = COSF(SEA(49))
C     INDIVIDUAL PICTURE DATA
      DO 199 I=1,IQTY
C

C     ARGUMENT OF SATELLITE AT PICTURE TIME

      IF (E(I+29)) 121,120,120
121   SEA(I) = 1000.
      GO TO 199

120   TEMP=E(26)-E(20)
      IF (TEMP) 1201,1202,1202
1201  TEMP=TEMP+E(14)
1202  TPICA=(E(I+29)-E(21)+TEMP*86400.)*TW027
      TEMP = FMAV*(TPICA-TPA)

110   ECANOM = TEMP

112   ECANOM = TEMP+E(10)*SINF(ECANOM)
      TEMP2 = ECANOM-E(10)*SINF(ECANOM)-TEMP
      IF (ABSF(TEMP2)-.1E-6) 115,115,112
115   CALL ARCTAN(SINF(ECANOM/2.),CCONST*COSF(ECANOM/2.),TEMP)
      ARG = 2.*TEMP+ARGPER
123   SINARG = SINF(ARG)
      COSARG = COSF(ARG)
      SEA(I) = ARG
C
C     SATELLITE DISTANCE
      SEB(I+19)= E(11)+BCONST*COSF(ECANOM)
C
C     SUBPOINT LATITUDE
      TEMP = SININC*SINARG
      SEB(I+163) = ATANF(TEMP/SQRTF(1.-TEMP*TEMP))
C
```

```
C       SUBPOINT LONGITUDE

        CALL ARCTAN(SINARG*COSINC,COSARG,TEMP)

        SEB(I+115)= TEMP+(E(22)+(E(6)/86400.-.11605775E-4)*TPICA)*TWOPI

C
C       ESTIMATED YAW
        TEMP = SINROL*COSF(ARG-SEA(52))
        SEB(I+67) = ATANF(TEMP/SQRTF(1.-TEMP*TEMP))
C       RESOLVE YAW AMBIGUITY BY PLOTTER SW
B       IF (40*E(17)) 131,132,131
131     SEB(I+67) = 3.1415927-SEB(I+67)
C
C       AZIMUTH TO NORTH
132     CALL ARCTAN (COSINC,SININC*COSARG,SEB(I+211))
199     CONTINUE
        WRITE TAPE 2,E
        WRITE TAPE 2,SEA
        WRITE TAPE 2,SEB

C

C       FIDUCIAL FIT SECTION

C       OPTION TO INVERT IMAGE
B       IF (400*E(17)) 901,902,901
901     DO 903 I=1,20
903     STFIDS(I) = -STFIDS(I)
        IFLIP = 1
902     K = (SEA(53)-1.)*10.

C       COLLECT OBSERVED FIDUCIALS

        READ TAPE 2,ASHCAN
3       READ TAPE 2,MODREC
        IF (IQTY-MODREC(1)) 3,4,4
4       IF (XEOF(Q)) 61,5,61
```

```
5       ITEMP = MODREC(1)
        IF (SEA(ITEMP)-1000.) 6,3,6
6       IF (MODREC(2)-1) 3,7,3
7       IF (MODREC(1)-NPIC) 62,8,62
8       J = 5.-SIGNF(1.,CMEAS(5)-MODREC(4))+SIGNF(3.,CMEAS(6)-MODREC(5))
C       REVERSE ORDER FOR INVERTED-IMAGE OPTION
        GO TO (9,904) IFLIP

9       J = 10-J

904     CMEAS(J) = MODREC(4)
        CMEAS(J+1) = MODREC(5)
        CMEAS(J+10) = MODREC(6)

        CMEAS(J+11) = MODREC(7)
        KFID = KFID+1
        GO TO 3
C       INITIALIZE FOR FID COLLECTION
65      DO 651 I=1,20
651     CMEAS(I) = .1E20

        KFID = 0

        J = 5
        NPIC = MODREC(1)
        GO TO (904,661) KEOF
C       COME HERE IF EOF READ
61      KEOF = 2
C       COME HERE IF PIC NUMBER CHANGES
C       OMIT FIT IF LESS THAN 3 FIDS ENTERED
62      IF (KFID-3) 65,621,621
C       OMIT FIT IF FIDFIT ARRAY IS FULL
621     IF (KFF-336) 622,65,65
622     DO 29 L=0,10,10
C       BEGIN FIDUCIAL FIT
C
C       INSERT STANDARD FIDUCIALS IN Z-PATTERN ORDER --
C       FOCAL LENGTH UNITS, WITH ORIGIN AT MEAN X,Y.
```

```
      DO 6221 I=1,20
6221  CSTND(I) = STFIDS(I)
      DO 623 I=1,2
      SUM(I) = 0.
623   SUM2(I) = 0.
      DO 624 I=1,6
624   S(I) = 0.
C FIND AVERAGES OF MEASURED X,S + Y,S   I.E., S(1) + S(2) RESP.
      DO 11 J=1,2
      DO 16 I=0,8,2
      IJL = I+J+L
      IJK = I+J+K
      IF (CMEAS(IJL)-.1E20) 15,16,16
15    SUM2(J) = SUM2(J)+CMEAS(IJL)
      SUM(J) = SUM(J)+CSTND(IJK)
16    CONTINUE
C ADJUST X,S + Y,S (MEASURED) SO THEY SUM TO ZERO
      SUM2(J) = SUM2(J)/KFID
      SUM(J) = SUM(J)/KFID
      DO 11 I=0,8,2
      IJK = I+J+K
      IJL = I+J+L
      IF (CMEAS(IJL)-.1E20) 10,11,11
10    CMEAS(IJL) = CMEAS(IJL)-SUM2(J)
      CSTND(IJK) = CSTND(IJK)-SUM(J)
11    CONTINUE
C CALCULATE THE 6 SUMMATIONS USED IN THE LEAST-SQUARES FIT
      DO 21 I=0,8,2
      DO 20 J=1,2
      IL = I+L
      IF (CMEAS(IL+1)-.1E20) 22,21,21
22    IJL = IL+J
```

```
      IJK = I+J+K
      S(J) = CSTND(IJK)*CMEAS(IL+1)+S(J)
      S(J+2) = CSTND(IJK)*CMEAS(IL+2)+S(J+2)
20    S(J+4) = CMEAS(IJL)*CMEAS(IJL)+S(J+4)
21    CONTINUE
C SOLVE FOR THETA AND THE RESCALING FACTORS FOR X + Y
      P1 = S(3)*S(4)*S(5)-S(1)*S(2)*S(6)

      P2 = S(6)*(S(1)*S(1) - S(2)*S(2)) + S(5)*(S(4)*S(4) - S(3)*S(3))

      THETA = ATANF(2.*P1/(P2+SQRTF(P2*P2+4.*P1*P1)))
      STH = SINF(THETA)
      CTH = COSF(THETA)

      RESCX = (S(1)*CTH - S(2)*STH)/S(5)
      RESCY = (S(3)*STH + S(4)*CTH)/S(6)
C     OPTION TO INVERT IMAGE
      GO TO (910,911) IFLIP
910   THETA = THETA+3.1415927
      SUM(1) = -SUM(1)
      SUM(2) = -SUM(2)
C

C     PUT PARAMETERS IN FIDFIT ARRAY
911   FIDFIT(KFF+1) = CMEAS(L+5)
      FIDFIT(KFF+2) = CMEAS(L+6)
      FIDFIT(KFF+3) = RESCX
      FIDFIT(KFF+4) = RESCY
      FIDFIT(KFF+5) = THETA
      FIDFIT(KFF+6) = SUM(1)
      FIDFIT(KFF+7) = SUM(2)
29    KFF = KFF+7
      GO TO (65,661) KEOF
C     FINALIZE FIDFIT ARRAY AND WRITE ON TAPE
661   MOVE = 337-KFF
      INCR = -1
      DO 662 I=KFF,1,INCR
      J = I+MOVE
```

```
662   FIDFIT(J) = FIDFIT(I)

      FIDFIT(I) = MOVE

      WRITE TAPE 2,FIDFIT

      REWIND 2
      Q = DROPF(Q)
      END
      SUBROUTINE ARCTAN(TOP,BOT,ANGLE)
      ANGLE = ATANF(TOP/(BOT+.1E-19))+1.5707963-SIGNF(1.5707963,BOT)
      END
```

```
C       PG9-3  MODREC PROCESSOR
C       ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM
C       TIROS WHEEL VERSION
C       REVISED -
C
        COMMON MODREC,SWATH,PEAK
        DIMENSION MODREC(8),SWATH(5,9),PEAK(2,2,25)
        DIMENSION ARRAY(2),COEF(2),XPRPT(2),YPRPT(2),P(2,2),MODPIC(700),
       1FIDFIT(337),ARG(48),R3C(2),RCG(2),FLATC(2),DLATG(2),XMFID(2),

       2YMFID(2),FFPAR(7,2),STH(2),CTH(2)
        EQUIVALENCE (MODPIC(195),FIDFIT)
C       COORDS OF PRINC PT W/RESP TO STD FIDS
        XPRPT(1) = 0.

        XPRPT(2) = 0.
        YPRPT(1) = 0.
        YPRPT(2) = 0.
        R3C(1) = 2.2442542

        R3C(2) = .77740587

        RCG(1) = .26112360
        RCG(2) = .23922423
        FLATC(1) = .40142574
        FLATC(2) = .89011794
        DLATG(1) = .26761716
        DLATG(2) = .24434610
        PAUSE 77
C       READ OVER PRIEPH TO SECEPHA
        READ TAPE 2,ASHCAN
        READ TAPE 2,ARG,(ASHCAN,J=1,4),TEMP,(ASHCAN,J=1,5),TEMP2
        NUMCAM = TEMP
C       READ MAP SLIDE DATA
        IF (TEMP2) 550,910,901
901     J = TEMP2
1       J = J-1
        IF (J) 903,904,902
```

```
902   READ TAPE 3,ASHCAN

      GO TO 1

903   STOP 63

904   READ TAPE 3,SWATH
C     READ SECEPHB
910   READ TAPE 2,ARRAY
C     SKIP OVER MODRECS TO FIDFIT ARRAY
      DO 912 I=1,2
911   READ TAPE 2,ASHCAN
      IF (XEOF(Q)) 912,911,912
912   CONTINUE
      READ TAPE 2,FIDFIT
      KFF = FIDFIT(1)
      REWIND 2
      DO 913 I=1,3
913   READ TAPE 2,ASHCAN
C

C ••• READ EOF,MODRECS,EOF ON DATA TAPE

3     READ TAPE 2,MODREC
      IF (ARRAY(1)-MODREC(1)) 3,4,4
4     IF (XEOF(Q)) 201,5,201
5     ITEMP = MODREC(1)
      IF (ARG(ITEMP)-1000.) 6,3,6
6     IF (MODREC(1)-NUMPIC) 202,7,202
7     IF (MODREC(2)-MODE) 202,8,202
8     ITEMP = MODREC(2)+1

      GO TO (3,101,102,103,3,105,106) ITEMP
101   GO TO (1011,1012,1013,3) KFID
1011  CALL UNROT (XFIDU,YFIDU)
      XFIDL = MODREC(6)
      YFIDL = MODREC(7)
1012  KFID = KFID+1
```

```
      GO TO 3
1013  IF (2*MK-3*KFF-388) 121,121,1016
121   IF (KFF-336) 1014,1012,1012
1014  DO 1015 I=1,14
      J = I+KFF
1015  FFPAR(I) = FIDFIT(J)
      DO 122 I=1,2
      STH(I) = SINF(FFPAR(5,I))
122   CTH(I) = COSF(FFPAR(5,I))

      GO TO 1017

1016  PAUSE 64

1017  KFF = KFF+14
      GO TO 1012
105   GO TO (1051,1051,3) MFIDSW
1051  XMFID(MFIDSW) = MODREC(3)
      YMFID(MFIDSW) = MODREC(4)
      MFIDSW = MFIDSW+1
      GO TO 3
B102  IF (1*ARRAY(2)) 550,1021,3
1021  IF (NUMPTS-12) 130,3,550
B103  IF (4*ARRAY(2)) 550,1031,3
1031  IF (NUMPTS-8) 120,3,550
B106  IF (2*ARRAY(2)) 550,1061,3
1061  IF (NUMPTS-8) 110,3,550
110   MKINCR = 4
C
C     MAP SLIDE INTERPOLATION  (LANDMARKS)
      XMAP = MODREC(7)
      YMAP = MODREC(8)
      DO 701 NSLIDE=1,9
      IF(ABSF(SWATH(1,NSLIDE))-MODREC(3)) 701,702,701
701   CONTINUE
7011  PAUSE 62
      GO TO 3
702   TEMP = NSLIDE/6
```

```
      HEMIS = (.5-TEMP)/.5

      IF (SWATH(1,NSLIDE)) 751,7011,703

C

C     POLAR MAP SLIDE INTERP
751   DX = XMFID(2)-XMFID(1)
      DY = YMFID(2)-YMFID(1)
      DXS = SWATH(4,NSLIDE)
      DYS = SWATH(5,NSLIDE)
      Q = DXS*DXS+DYS*DYS
      TEMP3 = SQRTF(Q/(DX*DX+DY*DY))
      TEMP =(DX*DYS-DXS*DY)*TEMP3/Q
      TEMP2 = (DX*DXS+DY*DYS)*TEMP3/Q
      XFI = TEMP3*XMFID(1)
      YFI = TEMP3*YMFID(1)
      CALL ROTATE (XFI,YFI,-TEMP,TEMP2)
      DX = XFI-SWATH(2,NSLIDE)
      DY = YFI-SWATH(3,NSLIDE)

      CALL ROTATE (XMAP,YMAP,-TEMP,TEMP2)

      XMAP = TEMP3*XMAP-DX

      YMAP = TEMP3*YMAP-DY
      TEMP = 2.*EXPF(XMAP)
      TEMP2 = EXPF(2.*XMAP)
      TEMP3 = COSF(YMAP)*TEMP/(TEMP2+1.)
      P(3) = ATANF(TEMP3/SQRTF(1.-TEMP3*TEMP3))*HEMIS
      CALL ARCTAN (TEMP*SINF(YMAP)*HEMIS,TEMP2-1.,P(4))
      GO TO 131
703   J = (NSLIDE+4)/2-2*((NSLIDE+2)/4)
C
C     NON-POLAR MAP SLIDE INTERP
      SIN213 = SWATH(5,NSLIDE)
      COS213 = SQRTF(1.-SIN213*SIN213)
      DX = (XMFID(2)-XMFID(1))*HEMIS
```

```
      DY = (YMFID(2)-YMFID(1))*HEMIS
      TEMP3 = SWATH(3,NSLIDE)/SQRTF(DX*DX+DY*DY)
      IF (HEMIS) 704,550,705
704   XFI = TEMP3*XMFID(2)
      YFI = TEMP3*YMFID(2)
      GO TO 706
705   XFI = TEMP3*XMFID(1)

      YFI = TEMP3*YMFID(1)

706   XMAP = TEMP3*XMAP-XFI

      YMAP = TEMP3*YMAP-YFI

      TEMP = TEMP3*DX*SWATH(4,NSLIDE)/SWATH(3,NSLIDE)
      TEMP2 = TEMP3*DY*SWATH(4,NSLIDE)/SWATH(3,NSLIDE)
      CALL ROTATE (TEMP,TEMP2,-SIN213,COS213)
      DX = TEMP-XMAP
      DY = TEMP2-YMAP
      TEMP3 = SQRTF(DX*DX+DY*DY)

      TEMP3 = R3C(J)-TEMP3

      P(3) = (FLATC(J)+ATANF((TEMP3/RCG(J))*SINF(DLATG(J))/COSF(DLATG(J)
     1))))*HEMIS
      TEMP3 = TEMP/TEMP2
      TEMP2 = (XMAP-TEMP)/(TEMP2-YMAP)
      TEMP = ATANF((TEMP3+TEMP2)/(1.-TEMP3*TEMP2))
      P(4) = SWATH(2,NSLIDE)+TEMP*HEMIS
      GO TO 131
C     BEGIN DIST REM FOR LOWER PIC (MATCHPOINTS)
120   MKINCR = 4
      P(3) = (MODREC(6)+FFPAR(8)-XFIDL)*FFPAR(10)
      P(4) = (MODREC(7)+FFPAR(9)-YFIDL)*FFPAR(11)
      J = 2
      ASSIGN 131 TO JUMP
      GO TO 132
C     TRANSFORM SHAFT-ENCODER COUNTS TO DISTORTION-FREE CAMERA COORDS
```

```
130   MKINCR $ 2

131   ASSIGN 140 TO JUMP

      IF (FFPAR(3)) 1311,1311,1312

1311  ARG(NUMPIC) = 1000.
      PAUSE 61
      GO TO 3
1312  J = 1
      CALL UNROT (P(1),P(2))
      P(1) = (P(1)+FFPAR(1)-XFIDU)*FFPAR(3)
      P(2) = (P(2)+FFPAR(2)-YFIDU)*FFPAR(4)
132   CALL ROTATE (P(1,J),P(2,J),STH(J),CTH(J))
      P(1,J) = P(1,J)+FFPAR(6,J)-XPRPT(NUMCAM)
      P(2,J) = P(2,J)+FFPAR(7,J)-YPRPT(NUMCAM)
C     GENERATE 3-TERM RADIAL DISTORTION POLY
      RSQ = P(1,J)*P(1,J)+P(2,J)*P(2,J)
      CALL ARCTAN (P(2,J),P(1,J),TEMP)

      TEMP = 25.-(TEMP+3.1415927-SIGNF(3.1415927,TEMP))/.2617995

      NOPEAK = TEMP

      DO 133 NODEG=1,2
133   COEF(NODEG) = PEAK(NUMCAM,NODEG,NOPEAK)+(TEMP-NOPEAK)*(PEAK(NUMCAM
     1,NODEG,NOPEAK+1)-PEAK(NUMCAM,NODEG,NOPEAK))
      TEMP = (COEF(2)*RSQ+COEF(1))*RSQ+1.
      P(1,J) = TEMP*P(1,J)
      P(2,J) = TEMP*P(2,J)
      GO TO JUMP
C     TRANSFER POINT TO MODPIC ARRAY
140   DO 141 I=1,MKINCR
      MODPIC(MK) = P(I)*.1E5
141   MK = MK+1
      NUMPTS = NUMPTS+1
C     DOES MODPIC ARRAY HAVE ROOM FOR ANOTHER DATA POINT
      IF (MK-696) 3,200,200
```

```
200   READ TAPE 2,Q
      IF (XEOF(Q)) 201,200,201
C     COME HERE IF EOF READ
201   IEOFSW = IEOFSW+1
      GO TO (2011,202) IEOFSW
2011  MK = 2
      IDLOC = 1

      GO TO 205
C     COME HERE IF MODE OR PIC NUMBER CHANGES
202   CONTINUE
      IF (NUMPTS-2) 2041,204,204
204   MODPIC(IDLOC) = MODE*10000+NUMPTS*MKINCR*100+NUMPIC

      IDLOC = MK
      MODPIC(IDLOC) = -1
2041  MK = IDLOC+1
205   CONTINUE
      NUMPTS = 0
      KFID = 1

      MFIDSW $ 1

      MODE = MODREC(2)
      NUMPIC = MODREC(1)
      GO TO (8,301) IEOFSW
301   IDLOC = 1
302   LWA = IDLOC+(MODPIC(IDLOC)-MODPIC(IDLOC)/10000*10000)/100
      WRITE TAPE 2, (MODPIC(I),I=IDLOC,LWA)
      IDLOC = LWA+1
      IF (MODPIC(IDLOC)) 30,550,302
30    DO 303 I=1,4
303   END FILE 2
      REWIND 2
      Q = DROPF(Q)
C     ERROR STOP FOR DEBUGGING
550   STOP 13
      END
```

```
C
C ••• SUBROUTINES
C
      SUBROUTINE ARCTAN (TOP,BOT,ANGLE)
      ANGLE = ATANF(TOP/(BOT+.1E-19))+1.5707963-SIGNF(1.5707963,BOT)
      END
C
      SUBROUTINE ROTATE (COMP1,COMP2,SIN,COS)
C     TURNS AXES COUNTERCLOCKWISE (+), OR ROTATES A VECTOR CLOCKWISE,
C     IN A FIXED PLANE
      TEMP = -COMP1*SIN+COMP2*COS
      COMP1 = COMP1*COS+COMP2*SIN
      COMP2 = TEMP
      END
C
      SUBROUTINE UNROT (X,Y)
C     TAKES SHAFT-ENCODER COUNTS FOR UC-X AND UC-Y AND GIVES BACK COORDS
C     (IN SHAFT-ENCODER COUNTS) OF PT AS IF MEASURED WITH NO PRISM ROT.,
C     AND WITH CENTER OF ROTATION AS ORIGIN
      COMMON MODREC
      DIMENSION MODREC(8)
      I = MODREC(2)/4
C     WALLOPS PRISM CALIBRATION NUMBERS
      PER360 = 3584.
      NOROT = 221
      XROTCT = 2770.
      YROTCT = 2468.
      ROTANG = (MODREC(I+3)-NOROT)/PER360*6.2831853
      X = MODREC(I+4)-XROTCT
      Y = MODREC(I+5)-YROTCT
      CALL ROTATE (X,Y,SINF(ROTANG),COSF(ROTANG))
```

```
      END

C     GILMORE PRISM CALIBRATION NUMBERS
      PER360 = 3584.
      NOROT = 164
      XROTCT = 2922.
      YROTCT = 2769.5
```

```
C       PG9-4  HORIZON SUBPROGRAM

C       ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM

C       TIROS WHEEL VERSION

C       REVISED -
C
        COMMON ISW,VS,VC,ESTVAR,NUMCAM,NUMPTS,PHS,PHC,RHOR,GEESQ
        DIMENSION VS(2),VC(2),ESTVAR(2),PHS(12),PHC(12),RHOR(12)
        DIMENSION RESTH(48),PESTH(48),ARG(48),ARRAY(19),RSAT(48),MODPIC(2,
       112)
        EQUIVALENCE (PESTH,ARG)
        PAUSE 77
C       READ OVER PIEPH TO SECEPHA
        READ TAPE 2, ASHCAN
        READ TAPE 2, ARG,(ASHCAN, J=1,4), TEMP
        NUMCAM = TEMP
C       READ SECEPHB
        READ TAPE 2, ARRAY, RSAT

B       IF (1*ARRAY(2)) 550,1,206

C       FILL RESTH WITH FLAGS

1       DO 2 I=1,48
2       RESTH(I) = .1E20
        DO 4 I = 1,2
3       READ TAPE 2,Q
        IF (XEOF(Q)) 4,3,4
4       CONTINUE
5       READ TABE 2,ID,MODPIC
        IF (XEOF(Q)) 202,6,202
6       IF (ID/10000-2) 5,7,5
7       NUMPTS = (ID-20000)/200
        NUMPIC = ID-20000-200*NUMPTS
        DO 8 I = 1, NUMPTS
        X = MODPIC (1,I)/.1E5
```

```
      Y = MODBIC(2,I)/.1E5
      RHOR(I) = SQRTF(X*X+Y*Y)
902   PHS(I) = Y/RHOR(I)
8     PHC(I) = X/RHOR(I)
C     FIT THEORETICAL HORIZONS TO PIC PTS
      TEMP = RSAT(NUMPIC)*RSAT(NUMPIC)
      GEESQ = (TEMP - .40683833E14)/TEMP
      R = 6378388.
      ESTVAR(2)=ATANF(R/SQRTF(TEMP-.40683833E14))+ARRAY(3)-1.0949

111   ESTVAR(1) = 0.
      DO 150 JJ=1,5
      ESTROL = ESTVAR(1)

      DO 150 ISW=1,2
      J = 3 - ISW
      CALL SINCOS(VS(J), VC(J), ESTVAR(J))
      CALL MINMIZ
      IF (JJ-1) 550,150,149

149   IF (ABSR(ESTROL-ESTVAR(1))-.17453293E-02) 151,151,150

150   CONTINUE
151   RESTH(NUMPIC) = (ESTVAR(1)+6.2831853)/10.
      PESTH(NUMPIC) = 10.*NUMPTS+JJ+(ESTVAR(2)+6.2831853)/10.
      GO TO 5
C
202   DO 204 I = 1,48
      IF (RESTH(I) -.1E20) 204,203,550
203   PESTH(I) = .1E20
204   CONTINUE
      WRITE TAPE 2, RESTH
      WRITE TAPE 2, PESTH
      DO 205 I = 1,3
205   END FILE 2
206   REWIND 2
      Q = DROPF(Q)
C     ERROR STOP FOR DEBUGGING
```

```
550   STOP 13

      END

C

      SUBROUTINE MINMIZ
      COMMON ISW,VS,VC,ESTVAR
      DIMENSION VS(2), VC(2), ESTVAR(2)
      DELTA = .17453293E-01
      COUNTR = -2.
      GO TO 2
1     TEMP = VALMID
      VALMID = VALNEW
      VALNEW = TEMP
      DIFNEW = -DIFNEW
      DELTA = -DELTA
2     COUNTR = COUNTR + 1.
      VALOLD = VALMID
      VALMID = VALNEW

      DIFOLD = DIFNEW

      ANGLE = ESTVAR(ISW) + (2.*COUNTR + 1.)*DELTA

      CALL SINCOS (VS(ISW), VC(ISW), ANGLE)
5     CALL ERRORH(VALNEW)
      DIFNEW = VALNEW - VALMID
      IF (DIFNEW) 2,3,3
3     IF (COUNTR) 2,1,4
4     ESTVAR(ISW) = ANGLE - DELTA*(3.*DIFNEW-DIFOLD)/(DIFNEW - DIFOLD)
      RETURN

      END

C
      SUBROUTINE ERRORH(ERROR)
      COMMON ISW,VS,VC,ESTVAR,NUMCAM,NUMPTS,PHS,PHC,RHOR,GEESQ
```

```
      DIMENSION VS(2),VC(2),ESTVAR(2),PHS(12),PHC(12),RHOR(12)
      DIMENSION STH(2),CTH(2),RTHEOR(12)
      STH(1) = -.44619782
      STH(2) = .44411401
      CTH(1) = .89493436
      CTH(2) = .89597029
      DO 1 I=1,NUMPTS
      T11 = CTH(NUMCAM)*PHC(I)*VS(1)+STH(NUMCAM)*PHC(I)*VC(2)*VC(1)-PHS(
     11)*VS(2)*VC(1)
      T12 = -STH(NUMCAM)*VS(1) + CTH(NUMCAM)*VC(2)*VC(1)
      T13 = T11*T11 - GEESQ
1     RTHEOR(I)=(-T11*T12-SQRTF(GEESQ*(T13+T12*T12)))/T13
      ERROR = 0.

      DO 2 I = 1,NUMPTS
      T11 = RHOR(I) -RTHEOR(I)
2     ERROR = ERROR + T11*T11
      RETURN
      END
C
      SUBROUTINE ARCTAN (TOP,BOT,ANGLE)
      ANGLE = ATANF(TOP/(BOT+.1E-19))+1.5707963-SIGNF(1.5707963,BOT)
      END
C
      SUBROUTINE ROTATE (COMP1,COMP2,SIN,COS)
C     TURNS  AXES COUNTERCLOCKWISE (+), OR ROTATES A VECTOR CLOCKWISE,
C     IN A FIXED PLANE
      TEMP = -COMP1*SIN+COMP2*COS
      COMP1 = COMP1*COS+COMP2*SIN
      COMP2 = TEMP
      END
C
      SUBROUTINE SINCOS (SINARG,COSARG,X)
      XSQ = X*X
      IF (XSQ - .0289) 2,1,1
1     SINARG = SINF(X)
      COSARG = COSF(X)
      RETURN
```

```
2     SINARG = X*(XSQ*(XSQ*.83333333E-02 -.16666667) + 1.)
      COSARG = XSQ*(XSQ*.41666667E-01 - .5) + 1.
      RETURN
      END
```

```
C     PG9-5  LANDMARKS SUBPROGRAM
C     ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM
C     TIROS WHEEL VERSION
C     REVISED -
C
      COMMON ISW,VS,VC,ESTVAR,NUMCAM,NUMPTS,XX,YY,ZZ,X,Y
      DIMENSION VS(3),VC(3),ESTVAR(3),XX(8),YY(8),ZZ(8),X(8),Y(8)

      DIMENSION YRESTL(48),PESTL(48),ARG(48),ARRAY(19),RSAT(48),

     1ESTYAW(48),SPLONG(48),SPLAT(48),AZTONO(48),MODPIC(4,8),FLMLAT(8),

     2FLMLON(8)

      EQUIVALENCE (PESTL,ARG)
      PAUSE 77
C     READ OVER PRIEPH TO SECEPHA
      READ TAPE 2,ASHCAN
      READ TAPE 2,ARG,(ASHCAN,J=1,4),TEMP
      NUMCAM = TEMP
C     READ SECEPHB
      READ TAPE 2,ARRAY,RSAT,ESTYAW,SPLONG,SPLAT,AZTONO

B     IF (2*ARRAY(2)) 550,1,206
C     FILL YRESTL WITH FLAGS
1     DO 2 I=1,48
2     YRESTL(I) = .1E20
      DO 4 I=1,2
3     READ TAPE 2,Q
      IF (XEOF(Q)) 4,3,4
4     CONTINUE
5     READ TAPE 2,ID,MODPIC
      IF (XEOF(Q)) 202,6,202
6     IF (ID/10000-6) 5,7,5
7     NUMPTS = (ID-60000)/400
      NUMPIC = ID-60000-400*NUMPTS
      DO 108 I=1,NUMPTS
      X(I) = MODPIC(1,I)/.1E5
```

```
      Y(I) = MODPIC(2,I)/.1E5

      FLMLAT(I) = MODPIC(3,I)/.1E5

8     FLMLON(I) = MODPIC(4,I)/.1E5

      IF (SENSE SWITCH 4) 101,102
101   TEMP = FLMLON(I)/.017453293
      TEMP2 = FLMLAT(I)/.017453293
      PRINT 70,NUMPIC,TEMP,TEMP2
70    FORMAT (1X,I2,2F8.2)
C     FIND GEOCENTRIC XYZ COORDS OF MAP PTS
102   THETA = FLMLON(I)-SPLONG(NUMPIC)
C     COR FOR EARTHS OBLATENESS
      RLM = 6371229.
      FLMLAT(I) = FLMLAT(I)-.003372655*SINF(2.*FLMLAT(I))
      CALL SINCOS (TEMP,TEMP2,FLMLAT(I))
      TEMP2 = RLM*TEMP2
      ZZ(I) = RLM*TEMP
      CALL SINCOS (TEMP,TEMP3,THETA)

      XX(I) = TEMP2*TEMP

      YY(I) = -TEMP2*TEMP3

      CALL SINCOS (TEMP,TEMP3,1.5707963-SPLAT(NUMPIC))
C     ROTATE AROUND X-AXIS SO Z+ GOES THRU SUBPT
      CALL ROTATE (YY(I),ZZ(I),TEMP,TEMP3)
C     LIFT COORD SYSTEM INTO THE SATELLITE
      ZZ(I) = ZZ(I)-RSAT(NUMPIC)
C     ROTATE AROUND Z-AXIS SO Y-AXIS LIES IN ORBITAL PLANE
      CALL SINCOS (TEMP,TEMP3,-AZTONO(NUMPIC))
      CALL ROTATE (XX(I),YY(I),TEMP,TEMP3)
108   CONTINUE
C
C     FIT TRANSFORMED MAP PTS TO PIC PTS
      ESTVAR(1) = ESTYAW(NUMPIC)
      ESTVAR(2) = 0.
```

```
      ESTVAR(3) = ATANF(6378388./SQRTF(RSAT(NUMPIC)*RSAT(NUMPIC)-.406838
     133E14))+ARRAY(3)-1.0949
111   CALL SINCOS (VS(3),VC(3),ESTVAR(3))
      DO 150 JJ=1,5
      ESTROL = ESTVAR(2)
      DO 150 I=1,3
      CALL SINCOS (VS(I),VC(I),ESTVAR(I))

      ISW = I+1-I/3*3

      CALL MINMIZ
      IF (JJ-1) 550,150,149
149   IF (ABSF(ESTROL-ESTVAR(2))-.17453293E-02) 151,151,150
150   CONTINUE
151   ITEMP = ABSF(1000.*ESTVAR(1))
      YRESTL(NUMPIC) = SIGNF(ITEMP+(ESTVAR(2)+6.2831853)/10.,ESTVAR(1))
      PESTL(NUMPIC) = 10.*NUMPTS+JJ+(ESTVAR(3)+6.2831853)/10.
      GO TO 5
C

202   DO 204 I=1,48

      IF (YRESTL(I)-.1E20) 204,203,550
203   PESTL(I) = .1E20
204   CONTINUE
2041  READ TAPE 2,Q
      IF (XEOF(Q)) 2042,2041,2042
2042  WRITE TAPE 2,YRESTL
      WRITE TAPE 2,PESTL
      DO 205 I=1,2
205   END FILE 2
206   REWIND 2
      Q = DROPF(Q)
C     ERROR STOP FOR DEBUGGING
550   STOP 13
      END
C
C *** SUBROUTINES
```

```
C
      SUBROUTINE MINMIZ

      COMMON ISW,VS,VC,ESTVAR

      DIMENSION VS(3),VC(3),ESTVAR(3)
      DELTA = .17453293E-01
      COUNTR = -2.
      GO TO 2
1     TEMP = VALMID
      VALMID = VALNEW
      VALNEW = TEMP
      DIFNEW = -DIFNEW

      DELTA = -DELTA
2     COUNTR = COUNTR+1.
      VALOLD = VALMID
      VALMID = VALNEW
      DIFOLD = DIFNEW

      ANGLE = ESTVAR(ISW)+(2.*COUNTR+1.)*DELTA

      CALL SINCOS (VS(ISW),VC(ISW),ANGLE)

5     CALL ERRORL (VALNEW)
      DIFNEW = VALNEW-VALMID
      IF (DIFNEW) 2,3,3
3     IF (COUNTR) 2,1,4

4     ESTVAR(ISW) = ANGLE-DELTA*(3.*DIFNEW-DIFOLD)/(DIFNEW-DIFOLD)

      END
C
      SUBROUTINE ERRORL (VALNEW)
      COMMON ISW,VS,VC,ESTVAR,NUMCAM,NUMPTS,XX,YY,ZZ,X,Y
      DIMENSION VS(3),VC(3),ESTVAR(3),XX(8),YY(8),ZZ(8),X(8),Y(8)
      DIMENSION SCANT(2),CCANT(2)
```

```
      SCANT(1) = -.44619782
      SCANT(2) = .44411401
      CCANT(1) = .89493436
      CCANT(2) = .89597029
      VALNEW = 0.
      DO 1 I=1,NUMPTS
      XT = XX(I)
      YT = YY(I)
      ZT = ZZ(I)

C     YAW COORD SYSTEM

      CALL ROTATE (YT,XT,VS(1),VC(1))

C     ROLL COORD SYSTEM
      CALL ROTATE (ZT,XT,VS(2),VC(2))
C     PITCH COORD SYSTEM
      CALL ROTATE (YT,ZT,VS(3),VC(3))
C     CANT COORD SYSTEM
      CALL ROTATE (ZT,XT,SCANT(NUMCAM),CCANT(NUMCAM))
      XT = -XT/ZT
      YT = -YT/ZT
1     VALNEW = VALNEW+(X(I)-XT)*(X(I)-XT)+(Y(I)-YT)*(Y(I)-YT)
      END
C
      SUBROUTINE ROTATE (COMP1,COMP2,SIN,COS)
C     TURNS AXES COUNTERCLOCKWISE (+), OR ROTATES A VECTOR CLOCKWISE,
C     IN A FIXED PLANE
      TEMP = -COMP1*SIN+COMP2*COS
      COMP1 = COMP1*COS+COMP2*SIN
      COMP2 = TEMP
      END
C
      SUBROUTINE SINCOS (SINARG,COSARG,X)
      XSQ = X*X
      IF (XSQ-.0289) 2,1,1
1     SINARG = SINF(X)
      COSARG = COSF(X)
```

```
      RETURN
2     SINARG = X*(XSQ*(XSQ*.83333333E-02-.16666667)+1.)
      COSARG = XSQ*(XSQ*.41666667E-01-.5)+1.
      RETURN
      END
```

```
C     PG9-6  MATCHPOINTS SUBPROGRAM
C     ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM
C     TIROS WHEEL VERSION
C     REVISED -
C
      COMMON ISW,VS,VC,ESTVAR,NUMCAM,NUMPTS,ARRAY,RSAT,SINARG,COSARG,TRI
     1X,X,Y,Z,NUMPIC

      DIMENSION VS(8),VC(8),ESTVAR(8),ARRAY(19),RSAT(48),SINARG(2),COSAR

     1G(2),TRIX(3,3),X(2,8),Y(2,8),Z(2,8)
      DIMENSION YRESTM(48),PESTM(48),ARG(48),SPLONG(48),SPLAT(48),AZTONO
     1(48),MODPIC(4,8),SCANT(2),CCANT(2)

      EQUIVALENCE (PESTM,ARG)
      HAPI = 1.5707963
      SCANT(1) = -.44619782
      SCANT(2) = .44411401
      CCANT(1) = .89493436
      CCANT(2) = .89597029

      PAUSE 77

C     READ OVER PRIEPH TO SECEPHA
      READ TAPE 2, ASHCAN
      READ TAPE 2, ARG,ASHCAN,ASHCAN,FMX,BDA,TEMP
      NUMCAM = TEMP
C     READ SECEPHB - SKIP ESTYAW
      READ TAPE 2, ARRAY,RSAT,SPLONG,SPLONG,SPLAT,AZTONO
B     IF (4*ARRAY(2)) 550,1,206
C     FILL YRESTM WITH FLAGS
1     DO 2 I = 1,48
2     YRESTM(I) = .1E20
      DO 4 I = 1,2
3     READ TAPE 2,Q
      IF (XEOF(Q)) 4,3,4
4     CONTINUE
5     READ TAPE 2, ID, MODPIC
```

```
      IF (XEOF(Q)) 202,6,202

6     IF (ID/10000-3) 5,7,5

7     NUMPTS = (ID-30000)/400

      NUMPIC = ID-30000-400*NUMPTS
      IF (ARG(NUMPIC+1)-1000.) 901,5,550
901   DO 8 I = 1,NUMPTS
      X(1,I) = MODPIC(1,I)/.1E5
      Y(1,I) = MODPIC(2,I)/.1E5
      X(2,I) = MODPIC(3,I)/.1E5
8     Y(2,I) = MODPIC(4,I)/.1E5
C     CLEAR TRIX
      DO 101 I = 1,9
101   TRIX(I) = 0.
C     GENERATE UNIT MATRIX
      DO 102 I = 1,3
102   TRIX(I,I) = 1.
C

C     PERFORM ROTATIONS

      CALL ROTRIX(3,AZTONO(NUMPIC))

      CALL ROTRIX(1,SPLAT(NUMPIC)-HAPI)
      CALL ROTRIX (3,SPLONG(NUMPIC+1)-SPLONG(NUMPIC))
      CALL ROTRIX(1,HAPI-SPLAT(NUMPIC+1))
      CALL ROTRIX(3,-AZTONO(NUMPIC+1))
C     RESULTANT MATRIX TRANSFORMS GEOCENTRIC, ORBITAL, SATELLITE-
C     ORIENTED COORDS OF A POINT ON ROTATING EARTH FROM PIC TO PIC.
C
      CALL SINCOS(SINARG(1),COSARG(1),ARG(NUMPIC))
      CALL SINCOS(SINARG(2),COSARG(2),ARG(NUMPIC+1))
      ESTVAR(1) = FMX
      ESTVAR(2) = BDA
      DO 111 I=1,2
111   CALL SINCOS (VS(I),VC(I),ESTVAR(I))
```

```
C       GENERATE PITCH ESTIMATES
        ISW = 0
        CALL ERRORM(ASHCAN)
        DO 112 N=0,1
        NA = NUMPIC+N
        NB = N+5
        NC = N+7

        TEMP = SQRTF(.40683833E14/RSAT(NA)/RSAT(NA)-VS(NB)*VS(NB))/VC(NB)
        ESTVAR(NC) = ATANF(TEMP/SQRTF(1.-TEMP*TEMP))+ARRAY(3)-1.0949
112     CALL SINCOS (VS(NC),VC(NC),ESTVAR(NC))
        DO 114 I=1,NUMPTS
        DO 113 N=1,2

        Z(N,I) = -1.
C       UNCANT
        CALL ROTATE (Z(N,I),X(N,I),-SCANT(NUMCAM),CCANT(NUMCAM))
C       UNPITCH
113     CALL ROTATE (Y(N,I),Z(N,I),-VS(N+6),VC(N+6))
        X(2,I) = X(2,I)/Z(2,I)
114     Y(2,I) = Y(2,I)/Z(2,I)
C       FIT IDEAL IMAGE POINTS TO EACH OTHER
        DO 150 JJ=1,7
        TEMP = ESTVAR(1)
        DO 150 ISW = 1,2
        J = 3-ISW
        CALL SINCOS(VS(J),VC(J),ESTVAR(J))
        CALL MINMIZ
        IF (JJ - 1) 550,150,149
149     IF (ABSF(TEMP-ESTVAR(1))-.17453293E-02) 151,151,150
150     CONTINUE
        JJ = 8
151     CALL SINCOS (VS(ISW),VC(ISW),ESTVAR(ISW))
        ISW = 0
        CALL ERRORM(ASHCAN)
        TEMP = ATANF(VS(3)/VC(3))+1.5707963-SIGNF(1.5707963,VC(3))
        ITEMP = ABSF(1000.*TEMP)
        YRESTM(NUMPIC) = SIGNF(ITEMP+(ATANF(VS(5)/VC(5))+6.2831853)/10.,
```

```
     (TEMP)

      PESTM(NUMPIC) = 10.*NUMPTS+JJ+(ESTVAR(7)+6.2831853)/10.

      GO TO 5

C
202   DO 204 I = 1,48
      IF (YRESTM(I)-.1E20) 204,203,550
203   PESTM(I) = .1E20
204   CONTINUE
      DO 2042 I=1,2
2041  READ TAPE 2,Q

      IF (XEOF(Q)) 2042,2041,2042
2042  CONTINUE
      WRITE TAPE 2,YRESTM
      WRITE TAPE 2, PESTM
205   END FILE 2
206   REWIND 2

      Q = DROPF(Q)

C     ERROR STOP FOR DEBUGGING
550   STOP 13
      END
C *** SUBROUTINES
C
      SUBROUTINE MINMIZ

      COMMON ISW,VS,VC,ESTVAR
      DIMENSION VS(8),VC(8),ESTVAR(8)
      DELTA = .1745329E-01
      COUNTR = -2.
      GO TO 2
1     TEMP = VALMID
      VALMID = VALNEW
      VALNEW = TEMP
```

```
      DIFNEW = -DIFNEW
      DELTA = -DELTA
2     COUNTR = COUNTR+1.
      VALOLD = VALMID
      VALMID = VALNEW
      DIFOLD = DIFNEW
      ANGLE = ESTVAR(ISW)+(2.*COUNTR+1.)*DELTA
      CALL SINCOS (VS(ISW),VC(ISW),ANGLE)
5     CALL ERRORM (VALNEW)

      DIFNEW = VALNEW-VALMID

      IF (DIFNEW) 2,3,3

3     IF (COUNTR) 2,1,4
4     ESTVAR(ISW) = ANGLE-DELTA*(3.*DIFNEW-DIFOLD)/(DIFNEW-DIFOLD)
      END
C
      SUBROUTINE ERRORM(VALNEW)
      COMMON ISW,VS,VC,ESTVAR,NUMCAM,NUMPTS,ARRAY,RSAT,SINARG,COSARG,TRI
     1X,X,Y,Z,NUMPIC
      DIMENSION VS(8),VC(8),ESTVAR(8),ARRAY(19),RSAT(48),SINARG(2),COSAR
     1G(2),TRIX(3,3),X(2,8),Y(2,8),Z(2,8)
      DIMENSION VECTOR(3)
      VALNEW = 0.
      DO 11 N=1,2
      VS(N+2) = VS(1)*(COSARG(N)*VC(2)+SINARG(N)*VS(2))
      VC(N+2) = SQRTF(1.-VS(N+2)*VS(N+2))
C     RESOLVE YAW AMBIGUITY BY PLOTTER SW
B     IF (40*ARRAY(2)) 12,13,12
12    VC(N+2) = -VC(N+2)
13    VS(N+4) = VS(1)*(SINARG(N)*VC(2)-COSARG(N)*VS(2))
11    VC(N+4) = SQRTF(1.-VS(N+4)*VS(N+4))
      IF (ISW) 18,19,18
18    CONTINUE
      DO 1 I = 1,NUMPTS
      XT = X(1,I)
      YT = Y(1,I)
```

```
      ZT = Z(1,1)
C     UNROLL
      CALL ROTATE (ZT,XT,-VS(5),VC(5))
C     UNYAW
      CALL ROTATE (XT,YT,VS(3),VC(3))
C     PROJECT POINT ONTO EARTH SFC
      TEMP = XT*XT+YT*YT+ZT*ZT
      TEMP2 = RSAT(NUMPIC)*ZT
      ROBJSQ = .40592559E14
      TEMP = (-TEMP2-SQRTF(TEMP2*TEMP2-TEMP*(RSAT(NUMPIC)*RSAT(NUMPIC)-R
     1OBJSQ)))/TEMP
      ZT = RSAT(NUMPIC)+TEMP*ZT
      XT = TEMP*XT
      YT = TEMP*YT
C     APPLY MATRIX TRANSFORMATION
      DO 2 J = 1,3
2     VECTOR(J) = TRIX(J,1)*XT+TRIX(J,2)*YT+TRIX(J,3)*ZT
      XT = VECTOR(1)
      YT = VECTOR(2)
      ZT = VECTOR(3)-RSAT(NUMPIC+1)
C     YAW
      CALL ROTATE (XT,YT,-VS(4),VC(4))
C     ROLL
      CALL ROTATE (ZT,XT,VS(6),VC(6))
      XT = X(2,1)-XT/ZT
      YT = Y(2,1)-YT/ZT
1     VALNEW = VALNEW+XT*XT+YT*YT
19    RETURN
      END
C
      SUBROUTINE ROTATE (COMP1,COMP2,SIN,COS)
C     TURNS AXES COUNTERCLOCKWISE (+), OR ROTATES A VECTOR CLOCKWISE,
```

```
C       IN A FIXED PLANE
        TEMP = -COMP1*SIN+COMP2*COS
        COMP1 = COMP1*COS+COMP2*SIN
        COMP2 = TEMP
        END
C
        SUBROUTINE SINCOS (SINARG,COSARG,X)
        XSQ = X*X
        IF (XSQ-.0289) 2,1,1

1       SINARG = SINF(X)
        COSARG = COSF(X)
        RETURN

2       SINARG = X*(XSQ*(XSQ*.83333333E-02-.16666667)+1.)
        COSARG = XSQ*(XSQ*.41666667E-01-.5)+1.
        RETURN
        END
C

        SUBROUTINE ROTRIX(I,A)

C       ROTATES MATRIX THRU ANGLE A ABOUT AXIS I
        COMMON DUM,TRIX
        DIMENSION DUM(97),TRIX(3,3)
        I = I +1-I/3*3
        J = I + 1-I/3*3
        DO 1 K = 1,3
1       CALL ROTATE (TRIX(I,K),TRIX(J,K),SINF(A),COSF(A))
        END
```

```
C       PG9-7  SINE CURVE FIT

C       ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM

C       TIROS WHEEL VERSION

C       REVISED -
C
        COMMON YAWROL
        DIMENSION ARG(48),SIN(48),COS(48),YAWROL(48,2),S(8),DENOM(2),TOP(2
       1)
        EQUIVALENCE (ARG, COS)
        RPD = .017453293
77      PAUSE 77
C SKIP PRIEPH. GET PERTINENT DATA FROM SECEPH-A AND SECEPH-B.
        ISWEOF = 0
      2 READ TAPE 2, ASHCAN
        READ TAPE 2,ARG
    501 READ TAPE 2, QTY, OPTION
        IQTY = QTY

C

C SEE IF OPERATOR WANTS THIS PROGRAM SUPPRESSED. . .
8601    IF (100*OPTION) 550,102,619
C
C ONCE ANF FOR ALL, COMPUTE SINES AND COSINES FOR POSITIONS IN ORBIT WHERE
C PICTURES WERE TAKEN.
    102 DO 202 N=1,IQTY
        SIN(N) = SINF(ARG(N))
    202 COS(N) = COSF(ARG(N))
C

C READ THRU MODE RECORDS -- BOTH RAW AND PROCESSED ONES -- TO ATTITUDE DATA.

    402 READ TAPE 2, ASHCAN
        IF (XEOF(ASHCAN)) 502,402,502
    502 ISWEOF = ISWEOF + 1
```

```
602   GO TO (402,402,4,4,4,619) ISWEOF
C READ COMPACTED YAW/ROLL DATA FROM DATA TAPE. WHEREVER DATA COMES IN, BREAK IT
C INTO YAW AND ROLL VALUES, GENERATE POINTS ON THE SINUSOID, AND RECORD HOW
C MANY VALUES WILL BE SENT TO THE CURVE-FIT SECTION.
4     READ TAPE 2,YAWROL
      IF (XEOF(Q)) 502,201,502
201   NOVALS = 0

      DO 10 N=1,IQTY
      IF (YAWROL(N) - .1E20) 8,10,550
8     ITEMP = ABSF(YAWROL(N))
      YAWROL(N,2) = SINF((ABSF(YAWROL(N))-ITEMP)*10.-6.2831853)
      YAWROL(N) = SINF(YAWROL(N)/1000.)

      NOVALS = NOVALS+1
   10 CONTINUE
      IF (NOVALS) 550,402,221
221   NVORIG = NOVALS
C
      NEX = 0

C SET ALL SUMS TO ZERO. THEN CALCULATE THEM.
   11 DO 511 I=1,8
  511 S(I) = 0.
      J = 2-ISWEOF/5
      ADDSUB = 1.
      DO 13 N=1,IQTY
      IF (YAWROL(N)-.1E20) 12,13,550
   12 S(1) = S(1) + SIN(N)*SIN(N)*ADDSUB
      S(2) = S(2) + COS(N)*COS(N)*ADDSUB
      S(3) = S(3) + YAWROL(N,J)*SIN(N)*ADDSUB
      S(4) = S(4) + YAWROL(N,J)*COS(N)*ADDSUB
      S(5) = S(5) + SIN(N)*COS(N)*ADDSUB
      S(6) = S(6) + YAWROL(N,J)*ADDSUB
      S(7) = S(7) + SIN(N)*ADDSUB
      S(8) = S(8) + COS(N)*ADDSUB
      NEX = NEX+1
   13 CONTINUE
```

```
      IF (ADDSUB) 313,550,413

313   NOVALS = NOVALS-1

      YAWROL(N) = .1E20

222   PRINT 98,N
98    FORMAT (8H REJECT ,I2)
C
C GET PHASE AND AMPLITUDE AND (IF DESIRED) TRANSLATION OF FITTED CURVE.
413   ADDSUB = -1
B     IF (200*OPTION) 550,513,613
  513 S(6) = 0.
      S(7) = 0.
      S(8) = 0.
  613 P1 = NOVALS*S(4) - S(6)*S(8)
      P2 = NOVALS*S(3) - S(6)*S(7)
      P3 = S(3)*S(8) - S(4)*S(7)
      CALL ARCTAN (S(1)*P1-S(5)*P2+S(7)*P3, -S(5)*P1+S(2)*P2-S(8)*P3,
     1PHASE)

      SPH = SINF(PHASE)

      CPH = COSF(PHASE)

      TEMP = CPH*S(7) + SPH*S(8)
      DENOM(1) = NOVALS*(CPH*CPH*S(1) + SPH*SPH*S(2) + 2.*SPH*CPH*S(5))
     1 - TEMP*TEMP
      DENOM(2) = SPH*CPH*(NOVALS*(S(1)-S(2))-S(7)*S(7)+S(8)*S(8))
     1+ (SPH*SPH - CPH*CPH)*(NOWALS*S(5) - S(7)*S(8))
C USE THE FRACTION WHOSE DENOMINATOR HAS THE LARGER ABSOLUTE VALUE.

      K = 1.5 + SIGNF(.5, ABSF(DENOM(2))- ABSF(DENOM(1)))
      TOP(1) = SPH*P1 + CPH*P2
      TOP(2) = SPH*P2 - CPH*P1
      AMPL = TOP(K)/DENOM(K)
      TRANS = (S(6)-AMPL*TEMP)/NOVALS
C
```

```
C FIND THE MOST DEVIANT POINT, ITS RARITY, AND WHETHER IT IS ACCEPTABLE.
      DSQMAX = 0.
      SDEVSQ = 0.
   14 DO 16 NN=1,48
      IF (YAWROL(NN)-.1E20) 514,16,550
514   DEV = YAWROL(NN,J)-AMPL*(SIN(NN)*CPH+COS(NN)*SPH)-TRANS
      DEVSQ = DEV*DEV

      SDEVSQ = SDEVSQ + DEVSQ

      IF (DSQMAX - DEVSQ) 15,16,16

   15 N = NN

      DSQMAX = DEVSQ
   16 CONTINUE
      W = SQRTF (DSQMAX/(SDEVSQ/(NOVALS-1)))
      IF (W - 2.5) 17,17,12
   17 TEMP=((1.019527*W+.000344)*W+.115194)*W+.196854)*W+1.
      RARITY = 1./TEMP/TEMP/TEMP/TEMP
      IF (SENSE SWITCH 4) 231,232
231   PRINT 99,RARITY,DSQMAX,W,N,NEX

99    FORMAT (3E15.8,2I3)
232   IF (RARITY-.5/NOVALS) 12,18,18
C
18    ROLMAX = ATANF(AMPL/SQRTF(1.-AMPL*AMPL))/RPD
      ARGYMX = -PHASE/RPD+(2-J)*90.
322   ARGYMX = ARGYMX-SIGNF(180.,ARGYMX)+SIGNF(180.,360.-ARGYMX)
      TRANS = TRANS/RPD
      NORJPT = NVORIG - NOVALS
      READ TAPE 2,ASHCAN
      WRITE TAPE 2, ROLMAX,ARGYMX,SDEVSQ,NOVALS,NORJPT
      IF (SENSE SWITCH 4) 323,402
323   PRINT 99,ROLMAX,ARGYMX,SDEVSQ,NOVALS,NORJPT
      PRINT 99,TRANS
C
      GO TO 402
```

```
  619 REWIND 2
      Q = DROPF(Q)
C
C A DEBUGGING AID TO CATCH UNDESIRED BRANCHING.
  550 PAUSE 13
      END
      SUBROUTINE ARCTAN(TOP,BOT,ANGLE)
      ANGLE = ATANF(TOP/(BOT+.1E-19))+1.5707963-SIGNF(1.5707963,BOT)
      END
```

```
C       PG9-8  OUTPUT SUBPROGRAM
C       ARACON PHOTOGRAMMETRIC ATTITUDE PROGRAM
C       TIROS WHEEL VERSION
C       REVISED -
C
        COMMON Q,E,MON,NDAY,NORB,NCAM
        DIMENSION E(80),SEA(59),SEB(259),MODREC(9),YREST(48),PEST(48)

        DIMENSION NN(6)
        TW027 = 67108864.*2.
        RPD = .017453293
77      PAUSE 77
        REWIND 2
100     READ TAPE 2,E

        READ TAPE 2,SEA
        IF(XEOF(Q)) 300,102,300
102     READ TAPE 2,SEB
        NORB = E(18)*TW027

        MON = E(19)*TW027

        NDAY = E(20)*TW027
        NCAM = SEA(53)
        IQTY = SEB(1)
200     DO 201 I=1,IQTY
        E(I+29) = (E(I+29)*TW027+.5)/3600.
201     SEA(I) = SEA(I)/RPD
        DO 202 I=68,259
202     SEB(I) = SEB(I)/RPD
        SEA(49) = SEA(49)/RPD
        SEA(50) = SEA(50)/3600.
        SEA(51) = SEA(51)/RPD
        SEA(52) = SEA(52)/RPD
        SEA(54) = SEA(54)/RPD
        SEA(55) = SEA(55)/60.
B       I = 7777*SEB(2)
204     SEB(2) = I
```

```
      SEB(3) = SEB(3)/RPD

      SEB(4) = SEB(4)/RPD

      SEB(19) = SEB(39)/RPD

      IF (SENSE SWITCH 4) 210,103
210   CALL ARACON
      PRINT 71,(E(I+29),SEA(I),SEB(I+19),SEB(I+163),SEB(I+115),I=1,IQTY)
      PRINT 72,(SEB(I+211),SEB(I+67),I=1,IQTY)
      PRINT 73,(SEA(I),I=49,59)
      PRINT 73,(SEB(I),I=1,19)
      DO 211 I=79,80

      E(I) = E(I)*TW027
211   PRINT 73,E(I)
103   DO 300 I=1,3
1031  READ TAPE 2,Q
      IF (XEOF(Q)) 300,1031,300
300   CONTINUE

      DO 499 K=1,3

4001  IF (SENSE SWITCH 1) 4002,4003

4002  SCALE = 4.
      GO TO 401
4003  SCALE = 2.
401   READ TAPE 2,YREST

      IF (XEOF(Q)) 499,4013,499

4013  READ TAPE 2,PEST
      CALL ARACON
      GO TO (4014,4015,4016) K
4014  PRINT 706
      GO TO 4017
4015  PRINT 707
```

```
      GO TO 4017
4016  PRINT 708
4017  PRINT 704
      Q = PLOTF(1.,1.,1)
      Q=PLOTF(0.,0.,2)
      CALL PLUS (0.,0.)
B     IFLAG = 10*Q
      IF (IFLAG) 4019,4018,4019
4018  Q = PLOTF(1.,0.,3)

      Q = PLOTF(-1.,0.,4)

      Q = PLOTF(0.,8.,3)

      Q = PLOTF(0.,-1.,4)
      CALL PLUS(0.,0.)
B4019 IF (20*Q) 4011,4012,4011
4011  SCALE = 10.
4012  ASSIGN 404 TO KK
      DO 410 I=1,IQTY
      IF (PEST(I)-.1E20) 402,403,403
402   GO TO (4021,4022,4022) K
4021  YAW = .1E20
      GO TO 4023
4022  YAW = YREST(I)/1000./RPD
4023  ITEMP = ABSF(YREST(I))
      ROLL = ((ABSF(YREST(I))-ITEMP)*10.-6.2831853)/RPD
      NUMPTS = PEST(I)/10.
      JJ = PEST(I)-10.*NUMPTS
      PITCH = ((PEST(I)-10.*NUMPTS-JJ)*10.-6.2831853)/RPD
      TEMP = E(I+29)
      DO 420 J=1,5,2
      NN(J) = TEMP/10.
      NN(J+1) = TEMP-10.*NN(J)
420   TEMP = (TEMP-10.*NN(J)-NN(J+1))*60.
      PRINT 701,I,NN,YAW,ROLL,PITCH,NUMPTS,JJ
      GO TO KK
404   LREF = SEA(I)/10.
```

```
      REFARG = 10*LREF

      ASSIGN 407 TO KK

407   ROLL = ROLL/SCALE

      IF (IFLAG) 410,406,410
406   IF (ABSF(ROLL)-5.) 405,405,410
405   CALL PLUS (ROLL,(REFARG-SEA(I))/10.)
      GO TO 410
403   PRINT 702,I
410   CONTINUE
      IF (IFLAG) 4102,4101,4102
4101  Q = PLOTF(0.,16.,3)
4102  READ TAPE 2,ROLMAX,ARGYMX,SDEVSQ,NOVALS,NORJPT
      ROLMAX = ROLMAX+.05
      ARGYMX = ARGYMX+.05
      IF (XEOF(Q)) 498,4103,498
4103  PRINT 709,ROLMAX,ARGYMX,NORJPT
411   READ TAPE 2,Q
      IF (XEOF(Q)) 498,411,498
498   IF (IFLAG) 499,4981,499
4981  PRINT 703,REFARG

      PRINT 705,SCALE
499   CONTINUE
      GO TO 77
C
71    FORMAT      (7X,3HGMT,12X,3HARG,12X,4HRSAT,10X,5HSPLAT,10X,6HSPLONG
     1/(5E15.8))
72    FORMAT (1H0,5X,6HAZTONO,9X,6HESTYAW/(2E15.8))
73    FORMAT (1H0,(2X,E15.8))
701   FORMAT (3X,I2,2X,6I1,3F7.2,3X,I2,4X,I2)
702   FORMAT (3X,I2,9H  NO DATA)
703   FORMAT (9HOREF ARG ,F7.1,5H DEGS)
704   FORMAT (47H FRAME   GMT    YAW    ROLL  PITCH   PTS  ITERS)
705   FORMAT (11H ROLL SCALE ,F7.1,10H DEGS/INCH)
706   FORMAT (9H HORIZONS)
```

```
707   FORMAT (10H LANDMARKS)
708   FORMAT (12H MATCHPOINTS)
709   FORMAT (8HOPHI MAX,F7.1,8H DEGREES/8H LAMBDA ,F7.1,8H DEGREES//I4,
     115H PT(S) REJECTED)
      END
C
      SUBROUTINE PLUS(X,Y)

      COMMON Q

      Q = PLOTF(X,Y-.05,3)

      Q = PLOTF(X,Y+.05,4)

      Q=PLOTF(X,Y,4)
      Q = PLOTF(X-.05,Y,4)
      Q = PLOTF(X+.05,Y,4)
      END
C
      SUBROUTINE ARACON
      COMMON Q,E,MON,NDAY,NORB,NCAM
      DIMENSION E(80)
      PRINT 700,MON,NDAY,NORB,NCAM
700   FORMAT (30H1*** ARACON GEOPHYSICS CO. ***/45H TIROS WHEEL PHOTOGRA
     1MMETRIC ATTITUDE PROGRAM//I3,1H/,I2,3H/65,6X,4HORB ,I4,6X,4HCAM ,
     2I1/)
      END
```