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ANALYTIC AEROTRIANGULATION UTILIZING SKYLAB EARTH TERRAIN CAMERA (S-190B) PHOTOGRAPHY

NOAA/National Ocean Survey
M. Keller

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CONTRACT NO. T-4110B

Principal Investigations Management Office
Lyndon B. Johnson Space Center
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FINAL REPORT

submitted by

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SURVEY
Rockville, Maryland 20852

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ANALYTIC AEROTRIANGULATION UTILIZING SKYLAB EARTH TERRAIN CAMERA (S-190B) PHOTOGRAPHY

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July 1975

PREFACE

This report on the feasibility of utilizing SKYLAB spacecraft photography to provide control for small scale mapping operations was prepared so as to enhance the comprehension of those readers not familiar with the principles of analytic aerotriangulation procedures and the SKYLAB Earth Resources Experiments mission.

All of the work involved in this study was performed in the offices of, and on equipment operated by, the National Oceanic and Atmospheric Administration, National Ocean Survey/Coastal Mapping Division, which is located in the Washington Science Center, Rockville, Maryland. Computer processing was performed on a CDC 6600 computer operated by NOAA and located at Suitland, Maryland.

The author wishes to express his sincere appreciation to Mr. D. Norman and Mr. I. Raborn of the Aerotriangulation Section who performed the photocoordinate measurements, assembled the data, and processed the material through the analytic aerotriangulation system of computer programs. Thanks are due to Commander W. V. Hull, Chief of the Coastal Mapping Division, and to Mr. C. Slama, Chief of the Photogrammetric Research Branch, for allowing the author to provide the time and effort needed to bring this study to a successful conclusion. A final vote of thanks is due Mrs. M. Taglieri, secretary for the Photogrammetric Research Branch, for her patience and diligence in preparing this report for delivery to the National Aeronautics and Space Administration.

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ABSTRACT

The objective of this study was to investigate the feasibility of utilizing SKYLAB spacecraft Earth Terrain Camera (S-190B) 1:946,000 scale photography in analytic aerotriangulation procedures to provide low-order, high-density control suitable for small-scale mapping operations.

The long range application is the employment of this technique for coastal zone mapping at medium and small scales, surveys in remote areas, forest and range management, various planning activities, and route location for highways, pipelines, transmission lines, and canals.

The National Oceanic and Atmospheric Administration, National Ocean Survey, (NOAA/NOS), office-identified the locations of 29 photo control points of known position and elevation on a strip of 12 photographs ranging along a 350-mile track from Charlotte, North Carolina, to the Rappahannock River in Virginia. The coordinates of pertinent images on each photograph were then processed through an established analytic aerotriangulation system of computer programs.

The inherent errors in using nonmetric SKYLAB photography and office-identified photo control made it necessary to perform numerous block adjustment solutions involving different combinations of control and weights. The final block adjustment was executed holding to 14 of the office-identified photo control points. The accuracy of the solution was evaluated by comparing the analytically computed ground positions of the 15 withheld photo control points with their known ground positions and also by determining the standard errors of these points from the variance values. A horizontal position RMS error of 15 meters was attained. The maximum observed error in position at a control point was 25 meters.

BACKGROUND

A basic framework of horizontal and vertical geodetic control is essential for coordinating surveys and the mapping of large areas. In the United States, the first- and second-order horizontal and vertical control surveys conducted by the National Ocean Survey of the National Oceanic and Atmospheric Administration provide this basic framework of geodetic control. Additional control surveys of third-order accuracy by various federal and state agencies then subdivide or extend the basic network by triangulation, traverse, and leveling methods in order to bring the control into the areas to be mapped. The control stations established by these surveys are usually monumented for future use.

Photogrammetry is a system of measuring and interpreting data recorded on photographs and is applicable to all sciences that depend on reliable geometric measurements of physical quantities occurring in a fixed or transitory state. The widest application of the photogrammetric art has been in the topographic mapping of the earth's surface, where it provides an alternative and/or supplement to conventional ground methods for establishing geodetic control and mapping geographical features.

Photogrammetric mapping procedures offer certain worthwhile advantages over ground methods, such as: 1. Detailed mapping can be performed more accurately, completely, efficiently, and economically than by ground methods. This advantage increases with the complexity of the details, as, for example, in city and harbor areas and along irregular coasts; 2. otherwise inaccessible areas can be more easily mapped; 3. maps can generally be produced from photographs with less ground control than is necessary for ground methods; and 4. the workload is transferred to the office, where operations are independent of weather and daylight.

Photogrammetry can provide the following primary services:

Provide three-dimensional stereoscopic models of the terrain that can be set in stereoscopic plotting instruments, so that planimetric and topographic details can be compiled from these models.

2. Extend the basic control network directly into the area of photography by using aerotriangulation methods to bridge between the high-order arcs of existing control. This procedure yields primarily fourth-order nonmonumented control and minimizes the need for field work to establish the photo control required to properly orient the stereoscopic models on the plotting instruments.

Aerotriangulation is a photogrammetric technique for deriving the ground coordinates of objects from a set of overlapping aerial photographs that show images of these objects and also of a relatively sparse distribution of other objects whose coordinates are known from classical measurements on the ground. The two principal methods employed to determine the desired three-dimensional ground coordinates for the objects are stereotriangulation and analytic aerotriangulation. Stereotriangulation depends on measurements made on a sequential series of overlapping stereoscopic models formed on a high-precision photogrammetric plotting instrument. Analytic aerotriangulation is a digital solution based on observed coordinates of the images created by pertinent objects appearing on each of the photographs covering the area. The analytic solution possesses a remarkably high accuracy potential as compared to stereotriangulation, because of the advantages accruing from automation, digital accuracy, least-squares adjustment, and freedom from the mechanical discrepancies contributed by the stereoscopic plotting instruments In addition, the systematic errors such as camera-lens distortion, film shrinkage, atmospheric refraction distortion, etc., can be more effectively eliminated by analytic methods than in stereotriangulation procedures. A disadvantage of the analytical solution is that the computations are complicated and require a large-size electronic computer to contain and process the large volume of data with economy and speed.

THE MATHEMATICAL BASIS OF ANALYTIC AEROTRIANGULATION

Several different variations in analytical aerotriangulation techniques have evolved. However, all of the methods basically consist of writing equations which relate the unknown elements of exterior orientation of each photograph to camera constants and refined $\underline{x}$ and $\underline{y}$ image coordinates observed on a comparator. The equations are solved for the unknown camera orientation parameters and the ground coordinates for each object creating observed images on the photographs. Since more observational information is normally available than is required for a unique solution, the method of least squares is used to obtain the most probable values of the unknown parameters in such a fashion that the sum of the squares of the residual observational discrepancies is a minimum.

The observation equations must be linear with respect to the unknown independent parameters; otherwise, a direct solution of the equations becomes difficult. If the mathematical model is nonlinear, as most photogrammetric problems are, a Taylor's expansion series is usually employed to linearize the equations. The computation requires initial approximations of the unknown parameters and is iterative because the second and higher degree terms of the Taylor's series are neglected to simplify the mathematics. The least squares solution provides corrections to the approximate values of the parameters. If the initial approximations are coarse, the corrections are added to them, giving fresh and improved approximations for a new solution. Least squares is used again to provide another set of corrections, and the procedure is repeated until some criterion of convergence is satisfied.

The most commonly used analytic methods are designed to enforce one of two conditions: coplanarity or collinearity. Coplanarity is the condition that the two perspective centers of an overlapping pair of photographs, any object point, and its corresponding image points on the two pictures all lie in a common plane; i.e., the rays passing through the two camera stations should intersect at a single object point. The purpose of the computation is to minimize the distance between the two rays at the object location. The observation equation utilized in each object space angle thus contains the four residual errors, v_x, v_y on first photo and v_x, v_y on second photo, involved in measuring the x and y image coördinates on each picture. This causes the solution to become cumbersome and difficult to solve properly when the object occurs on several or more photographs.

Collinearity is the condition that every object, its photographic image, and the camera exposure station must lie on a common straight line, as defined by the method of least squares in which the sum of the squares of the residual errors of image coordinate measurement is minimized. Two observation equations are written for every image and, except for the few control station images, contain only one residual error, v_x or v_y, in each equation. This simplifies the application of least squares so that any number of photographs can be routinely accommodated.

The principle of collinearity provides the basis for the NOS method of analytic aerotriangulation. The condition is utilized in an iterative manner to determine incremental corrections to initial approximations for the unknowns, which are reasonably close to the correct values.

COLLINEARITY CONDITION FORMULATION

The well known equations of collineation comprising the projective transformation are:

$$\frac{x}{z} = \frac{(X-X_0)\,a_{11} + (Y-Y_0)\,a_{12} + (Z-Z_0)\,a_{13}}{(X-X_0)\,a_{31} + (Y-Y_0)\,a_{32} + (Z-Z_0)\,a_{33}}$$

$$\frac{y}{z} = \frac{(X-X_0)\,a_{21} + (Y-Y_0)\,a_{22} + (Z-Z_0)\,a_{23}}{(X-X_0)\,a_{31} + (Y-Y_0)\,a_{32} + (Z-Z_0)\,a_{33}}$$

where the a- terms are the nine elements of the rotation matrix relating the x, y, z image coordinate system to the X, Y, Z ground coordinate system of the objects, and Xo, Yo, Zo are the coordinates of the camera station expressed in the ground coordinate system.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} \cos\varphi\cos\kappa & \cos\omega\sin\kappa + \sin\omega\sin\varphi\cos\kappa & \sin\omega\sin\kappa - \cos\omega\sin\varphi\cos\kappa \\ -\cos\varphi\sin\kappa & \cos\omega\cos\kappa - \sin\omega\sin\varphi\sin\kappa & \sin\omega\cos\kappa + \cos\omega\sin\varphi\sin\kappa \\ \sin\varphi & -\sin\omega\cos\varphi & \cos\omega\cos\varphi \end{bmatrix}$$

A Taylor's expansion series is applied to the transcendental collinearity equations to obtain linearized observation equations which can then be solved for the linear independent unknowns by the application of least squares. The complete form of the linearized observation equations is:

$$v_x = (P_{11}+P_{12}dw+P_{13}d\phi+P_{14}dk-P_{15}dXo-P_{16}dYo-P_{17}dZo+P_{15}dX+P_{16}dY+P_{17}dZ)/A_3B$$

$$v_y = (P_{21}+P_{22}dw+P_{23}d\phi+P_{24}dk-P_{25}dXo-P_{26}dYo-P_{27}dZo+P_{25}dX+P_{26}dY+P_{27}dZ)/A_3B$$

where the nine terms dw through dZ are incremental corrections to be applied to initial approximations of the unknowns. These two equations occur for each image on each photograph. Block adjustment requires the presence of all nine terms, whereas the space resection computations use only the first six terms dw through dZo. Sufficient photographs and images are needed to provide at least as many equations as there are unknowns to be computed. The solution is iterative and terminates when the incremental corrections to the angular parameters are smaller than the observed precision.

THE NATIONAL OCEAN SURVEY ANALYTIC AEROTRIANGULATION SYSTEM

Aerial Photography

The Coastal Mapping Division of NOS utilizes well calibrated precision aerial cameras to secure the near vertical aerial photography required for its photogrammetric operations. These cameras include the Wild RC-8, 6-inch focal length camera and the Wild RC-10 camera equipped with interchangeable 6-inch and 3.5-inch focal length cones.

The cameras are mounted in two aircraft operated by the Division; one being a DeHavilland Buffalo, while the other is an Aero Commander 690A. The Buffalo is a twin-engined turboprop craft, having a cruising speed between 120 and 180 knots at altitudes up to 32,000 feet. Its cruising range is 10 hours. The cabin is unpressurized, thereby requiring the crew to use oxygen above 10,000 feet. The Buffalo has been modified to simultaneously accommodate three aerial cameras mounted in three hatches. The plane is used on nearly all photographic missions conducted by the Division.

The Aero Commander 690A is a leased aircraft, employed to obtain photography for airport surveys. It is a twin-engined turboprop craft, having a cruising speed between 100 and 270 knots at altitudes up to 32,000 feet. Its cruising range is five hours. The pressurized cabin permits the crew to operate without relying on oxygen. However, this requires the photography to be taken through an optically flat glass window which covers the single hatch. A backup oxygen supply is available that permits aerial photography to be taken without the window in place over the hatch.

Photo Control Points

In order to implement analytic aerotriangulation methods, it is necessary to establish sufficient photo control to properly orient the aerial photography. Photo control refers to the establishment of horizontal positions and/or elevations with respect to the basic framework of geodetic control monuments of carefully chosen ground objects, which create sharp, distinct, and easily identifiable point images on the photographs. The positions and/or elevations are determined from the monumented control network by third- and fourth-order triangulation, traverse, and leveling methods. The photo control points selected in the field are usually prominent natural or cultural features providing sharp imagery on the overlapping photographs. Such examples are road intersections, fence-line intersections, lone trees, corners of buildings and wharves, and smaller stacks or towers.

For the more precise photogrammetric surveys, the placement of specially prepared targets on the control points, prior to photography, is desirable for facilitating accurate office identification of the photo control points. The targets are symmetrical in design, centered on the photo control points, and are of sufficient size to show on the photography. The targets are usually in the shape of a Y or a cross.

Pass Points

In analytical control extension, pass points are established in the nine standard relative orientation locations on each photograph. The pass points may be easily identifiable point images similar to those selected as photo control points. Usually, however, the pass points are simply holes drilled into the photographic emulsion, with the Wild PUG-2 stereoscopic point transfer device in areas providing an optimum stereoscopic perception. On 60 percent overlap photography, one ground object can appear as a pass point image on three successive photographs of a strip.

NOS programs permit two pass points to be used in each relative orientation location, even though only one pass point is sufficient to provide all of the data needed for the analytic computations. Then, if one of the pass points in a relative orientation location should exhibit an excessively large residual discrepancy during the solution, it can be discarded and its companion pass point substituted in its place.

Marking and Photocoordinate Measurement

A stereoscopic point transfer device, such as the Wild PUG-2, is first used to select, mark, and transfer suitable photo control and pass point images to adjacent photographs. The coordinates of each image on the photograph transparency are then measured to micron accuracy by either a digitized Mann monocomparator or by a stereocomparator, such as the Wild STK or the Zeiss PSK.

The use of a monocomparator means that the images on only one plate can be measured at a time. It, thus, is necessary to use a stereoscopic point transfer device to mark and transfer all images to every photograph. Stereocomparators, however, can simultaneously measure the photocoordinates of corresponding images on a stereoscopic pair of photographs. As a consequence, it is necessary to mark (drill) all of the images on only one photograph in each strip in order to specifically identify the image for measurement purposes. The drilled image can then be stereoscopically transferred to the second photograph and measured with the stereocomparator without actually ever drilling the image on the second photo. Since the images are drilled on only one plate, it is not necessary to use a stereoscopic point transfer device to mark the images. In practice, the PUG device is needed only as a means for transferring the images to any adjoining strips.

In essence, a stereocomparator consists of two mechanically united monocomparators. A monocomparator is, therefore, more accurate than a stereocomparator. In practice, however, the need for additional PUG operations with a monocomparator results in the accuracy of the monocomparator-PUG combination, being about equal to that of the stereocomparator.

After the photocoordinates have been measured, the data is submitted for processing through the series of computer programs comprising the analytic aerotriangulation system.

Computer Processing

The analytic aerotriangulation system developed at NOS consists of five programs: (1) Image coordinate refinement and three-photo orientation, (2) strip adjustment to ground control, (3) secant plane coordinate transformation, (4) block adjustment, and (5) accuracy analysis.

(1) Image Coordinate Refinement and Three-Photo Orientation: To obtain the highest possible degree of accuracy in analytical solutions, measured photocoordinates must be corrected for systematic errors which cause distortions in the image positions. The first program, therefore, begins with a refinement of the raw x and y image coordinates measured on each photograph on the comparator. The popularity of making positive prints of the photographs on glass plates (diapositives) has declined in recent years. Today polyester plastic bases are used because they provide a dimensionally stable base film that is much less sensitive to humidity, temperature, and laboratory processing. The photocoordinates observed on the photograph transparency are corrected for the systematic distortions introduced by the comparator, film shrinkage, camera lens, and atmospheric refraction. The problem of earth curvature is recognized in the third program, in which the ground coordinates of all objects are expressed in a geocentric, three-dimensional secant plane system that takes earth curvature into account.

The refined image coordinates are punched out to serve as input to the block adjustment program (4). The refined image coordinates theoretically should be nearly all free of systematic error and contain only residual observational discrepancies in them.

The program then proceeds to the three-photo camera orientation phase, which comprises an interrelated geometric fitting of the photographs based only on the refined image coordinates and is entirely independent from any ground control data. The computation is iterative and derives the orientation of each photograph relative to the previous two in the strip. It also determines the positions of all pertinent objects in a three-dimensional coordinate system at the scale of the photography. The collineation principle is imposed in a least squares solution that minimizes the discrepancies in the observed image coordinates. The residual errors are analyzed by the computer, which discards those images exhibiting excessively large discrepancies. The removal of these blunders provides "clean" image coordinate data for all subsequent computations.

(2) Strip Adjustment to Ground Control: The analysis of three photographs at a time automates the joining of the separate triplets into a continuous strip and develops a set of model

coordinates, which are analogous to the product obtained from conventional stereotriangulation on stereoscopic plotting instruments. The horizontal and vertical strip adjustment program transforms the model coordinate data into the prevailing ground control coordinate system by fitting to control stations through the application of polynomial equations and least squares. Any large residual discrepancies appearing in the resulting adjustment are corrected in order to obtain provisional ground position data that are free of blunders prior to entering the block adjustment computation.

The analytic computations may be terminated after strip adjustment or may continue through block adjustment, depending on the desired accuracy. While block adjustment can be performed without actually using the three-photo orientation and strip adjustment programs, these preliminary programs are employed in practice to furnish improved and complete data for the block adjustment in an effort to reduce the time and cost of "debugging" and computer operations.

(3) Secant Plane Coordinate Transformation: If maximum accuracy is desired, the provisional ground coordinates are first transformed into a geocentric and then into a special secant plane system that takes earth curvature into account. The block adjustment solution is performed using these secant plane coordinates for the objects, together with the previously obtained refined image coordinates. The secant plane transformation program is designed to operate in its inverse mode so that given secant plane coordinates can be transformed back into the prevailing ground coordinate system.

(4) Block Adjustment: This program permits the simultaneous solution of the absolute orientation (three linear elements of position and three angular elements of orientation) of all photographs in a block of overlapping strips of photography. Only the pass points and control station objects contribute equations and thus influence the least square orientation solution. Their finalized ground coordinates are computed simultaneously, along with the absolute orientation of all the photographs in the block. Those objects that are not pass points or control stations do not contribute equations and thus do not influence the orientation solution. The finalized camera parameters from the orientation solution and the refined image coordinates are used to compute the final ground X, Y, Z coordinates for these other objects by intersection. After the block adjustment is completed, the adjusted secant plane coordinates are transformed back into the original ground coordinate system by applying the secant plane transformation in its inverse mode.

The major task of the block adjustment program is the solution of the large number of simultaneous equations in a least square manner that efficiently utilizes the memory capacity of the computer. The largest program written at NOS can accommodate as many as 600 photographs in a single simultaneous least square adjustment. Some 36,000 observation equations containing about 10,000 unknowns may be generated in developing the normal equations. The number of objects whose final ground positions can be computed in the block adjustment solution is unlimited.

All of the analytic programs have been written to operate on the CDC 6600 computer. To date, the largest block adjustment problem processed through the computer contained 180 photograhs. The solution involved over 15,000 observation equations and about 4,500 unknowns. The CDC computer running time for the least square block adjustment was less than five minutes.

(5) Accuracy Analysis: In order to appreciate fully the accuracy potential of the system, and the error values at test points, a final computer program is used to develop the inverse of the matrix of normal equations, the variances, and the standard errors in centimeters in X, Y, and Z at all the points used throughout the area. The error E = Qe at any point is composed of two components where Q is the variance at the point as derived from the inverse, and e is the standard error of unit weight for the problem based on program (4). The quantity Q is affected by the geometry of the system, including the amount and distribution of control points, and e is related to the precision of the steps of the system including image resolution.

Accuracy of the NOS Analytic Aerotriangulation System

A significant increase in accuracy results when analytic aerotriangulation computations are continued through block adjustment. Studies conducted at NOS have yielded the following accuracy results:

> The horizontal position root-mean-square error in meters when using film cameras is $S10^{-5}$ where S is the denominator of the photography scale fraction. If a glass plate camera is used, and the pass points are premarked, then the expected RMS error in meters is about 1/5 of $S10^{-5}$.
>
> The vertical and horizontal errors are equal for a 3.5-inch focal length camera (base-height ratio = 1), whereas the vertical errors may be about 1.5 times larger than the horizontal errors for a 6-inch focal length camera (base-height ratio = 0.6).

This accuracy is achieved when: (a) 60 percent forward and side overlap exists between the photographs in the block; (b) a strong network of horizontal and vertical photo control exists around the perimeter of the area, along with a few interior vertical photo control stations; (c) all of these stations are premarked prior to photography; (d) the block consists of at least three strips of photography.

Note: The rms errors are considered to be essentially equal to the standard error of unit weight. The rms value therefore has a 68 percent reliability. The 90 percent reliability is about 1.6 times larger, and the 99 percent value is about 2.6 times larger.

SKYLAB

The SKYLAB mission was planned and implemented to determine the capability of man and spacecraft to conduct medical, solar physics stellar and solar astronomy, and Earth observational programs. On May 14, 1973, the National Aeronautics and Space Administration successfully launched the SKYLAB manned orbital facility into a nearly circular 234-nautical mile (435 km) orbit above the earth (SL-1). The first three-man team of astronauts manned the laboratory for 28 days, beginning on May 25, 1973, (SL-2); the second team occupied the facility for 60 days, starting on July 28, 1973 (SL-3); and the third team followed on November 16, 1973, for an 85-day mission (SL-4). The 50-degree inclination of the orbit permitted the astronauts to view 75 percent of the earth's surface--the area between 50 degrees North and 50 degrees South--and to pass over a given point once every five days.

The 100-ton SKYLAB spacecraft is actually a hollowed-out third stage of a Saturn rocket, originally assigned to the U.S. moon program, which has been converted to provide living and working space for the astronauts. Within the SKYLAB space station are complex scientific and technical instruments that will enable them to conduct investigations directed toward the accomplishment of medical experiments, solar astronomy experiments, technical experiments, and earth resources experiments as follows:

a. To study man: Medical experiments will determine physiology conditioning and performance capability in real time, in zero-gravity environment, for long-duration space flight.

b. To study the sun: Solar astronomy experiments will provide a synoptic survey and study of special phenomena on the solar disk in X-ray, ultraviolet (uv), and visible spectral wavelengths.

c. To study space technology: Technical experiments will evaluate coating degradation, spacecraft contamination, manufacturing and repair techniques, and manned-maneuvering units.

d. To study the Earth: Earth resources experiments will provide a synoptic survey of selected areas on the earth in visible, infrared (IR), and microwave spectral wavelengths.

EARTH RESOURCES EXPERIMENTS

Among the various SKYLAB investigations, the Earth Resources Experiments are unique in that they are concerned directly and exclusively with earth rather than space applications. The energy reflected and radiated from various plants, ground scenes, and bodies of water has specific spectral distributions, not only in the visible but in the infrared and microwave portions of the electromagnetic spectrum. These spectral "signatures" can be detected by utilizing instruments ranging from a multiband camera to infrared spectrometers and microwave radiometers. Six such electronic and photographic remote sensing systems for observing the earth have been combined into the Earth Resources Experiment Package (EREP) and mounted on board the manned SKYLAB orbital facility. Since SKYLAB is a solar-pointing, inertially stabilized spacecraft, it must be maneuvered into an earth-oriented mode in order to use the EREP sensors.

The EREP is designed as a facility with the vantage point of space for use by a variety of users, in a wide range of applications to earth resources management. The EREP sensors can be operated singly or in various combinations, depending on the scientific requirements or other factors, such as weather and/or vehicle capability limits. Data are recorded on tape and film so that each team of astronauts can bring back to earth the data recorded during its stay on the spacecraft. After initial processing at the Johnson Space Center in Houston, Texas, the data are distributed to more than 200 SKYLAB principal investigators.

The data acquired with the EREP sensors is expected to be useful for studies and analysis related to most Earth Resources disciplines. For example, these observations can be applied to research in agriculture, forestry, ecology, geology, geography, meteorology, geomorphology, hydrology, hydrography, oceanography, cartography, and similar fields for the purpose of identifying agricultural species; measuring growth rates; assessing crop vigor and stress; classifying land use; determining land surface composition and structure; mapping snow cover and assessing water runoff characteristics; mapping pollution, shorelines, and estuaries; evaluating sea roughness conditions; and similar projects.

The SKYLAB earth resources program has been structured into ten major disciplines as outlined in Table 1 below.

TABLE 1.

EREP PROGRAM STRUCTURE

100 AGRICULTURE/RANGE/FORESTRY

- Crop inventory
- Insect infestation
- Soil type
- Soil moisture
- Range inventory
- Forest inventory
- Forest insect damage

200 GEOLOGICAL APPLICATIONS

- Mapping
- Metals exploration
- Hydrocarbon exploration
- Rock types
- Volcanoes
- Earth movements

300 CONTINENTAL WATER RESOURCES

- Ground water
- Snow mapping
- Drainage basins
- Water quality

400 OCEAN INVESTIGATIONS

- Sea state
- Sea/Lake ice
- Currents
- Temperature
- Geodesy
- Living marine resources

500 ATMOSPHERIC INVESTIGATIONS

- Storms, fronts, and clouds
- Radiant energy balance
- Air quality
- Atmospheric effects

600 COASTAL ZONES, SHOALS, AND BAYS

- Circulation and pollution in bays
- Underwater topography and sedimentation
- Bathymetry
- Coastal circulation
- Wetlands ecology

700 REMOTE SENSING TECHNIQUES DEVELOPMEN

- Pattern recognition
- Microwave signatures
- Data processing
- Sensor performance evaluation

800 REGIONAL PLANNING AND DEVELOPMENT

- Land use classification techniques
- Environmental impacts - special topics
- State and foreign resources
- Urban applications
- Coastal/plains applications
- Mountain/desert applications

900 CARTOGRAPHY

- Photomapping
- Map revision
- Map accuracy
- Thematic mapping

000 USER AGENCY TASKS

- Department of the Army
- Department of the Interior

Each SKYLAB investigation has been given a three-digit task number, according to the subdisciplines in which work is done. In addition, every EREP study site has been given a three-digit designation that defines its geographic location.

DESCRIPTION OF EARTH RESOURCES EXPERIMENT PACKAGE (EREP) SENSORS

An extensive description of the photographic remote sensing system is given below, along with a brief description of the other EREP sensors.

Multispectral Photographic Facility (S-190A and S-190B)

The experiment objective is to photograph the earth's surface in a spectral range that includes visible light and extends into the near-infrared, with sufficient resolution and spectral definition to allow detailed analysis and interpretation by specialists in a variety of earth resources disciplines.

The facility is arranged in two parts. S-190A consists of an array of six 70-mm film cameras, precisely matched and boresighted, so that photographs from all six cameras will be accurately in register. Thus, all of the features seen in one photograph can be simultaneously aligned with the same features in the photographs from the other cameras. A combination of black-and-white and color films is used in conjunction with selective filters for spectral analysis, allowing comparison with imagery obtained with the IR spectrometer (S-191) and multispectral scanner (S-192) and with the Earth Resources Technology Satellite (ERTS). The camera array is mounted behind an optical glass window, just forward of the radial docking hatch in the Multiple Docking Adapter (MDA).

The second part, S-190B Earth Terrain Camera, consists of a single camera that is located behind an optical glass window in the Scientific Airlock (SAL) on the antisolar side of the Orbital Workshop (OWS). This camera is an adaptation of the Lunar Topographic Camera carried on the Apollo 14 mission.

Controls for the six-camera array are integrated with the controls for the other EREP sensors located in the MDA. However, the Earth Terrain Camera controls are mounted on the side of the camera housing and are independent of other EREP sensors.

For earth resources operations, SKYLAB departs from its normal solar orientation to an orbital mode that provides for continuous pointing of the cameras and other sensors at the ground directly below. The crewmen load film, install filters, set up the camera controls, remove the covers from the camera ports, uncover the window, install the Earth Terrain Camera in the Scientific Airlock, and make other preparations for camera operations.

The exposed film is the primary data returned at the end of each SKYLAB mission, for processing and analysis on the ground.

S-190A

The EREP multispectral photographic camera consists of six high-precision 70-mm film cameras with matched distortion and focal length. The f/2.8 lenses have a focal length of six inches. The camera has a field-of-view of 21.2 degrees across the flats based on the photographic format size of 2.25 inches square and provides ground coverage of 163 km square per frame at a scale of 1:2,850,000. The system is designed for the following wavelength/film combinations:

0.5 to 0.6	um	PAN X B&W
0.6 to 0.7	um	PAN X B&W
0.7 to 0.8	um	IR B&W
0.8 to 0.9	um	IR B&W
0.5 to 0.88	um	IR COLOR
0.4 to 0.7	um	HI-RES COLOR

S-190B

The body of the Earth Terrain Camera (ETC) is an extensively modified Hycon KA-74 reconnaissance camera body with a bidirectional focal-plane shutter and vacuum film flattening. The ETC is equipped with an f/4 lens having a focal length of 460 mm (18 inches), color correction, and a maximum radial distortion of 10 um. Forward image-motion compensation is provided by rocking the entire camera in its mount during the exposure. The ETC has a limited field-of-view of 14 degrees across the flats, based on the photographic format size of 4.5 inches square and provides ground coverage of 109 km square per frame at a scale of 1:946,000. The system is designed to utilize the following film types:

TYPE	DESCRIPTION	WAVELENGTH, um	ESTIMATED GROUND RESOLUTION (at low contrast)
SO-242	Aerial color, high resolution	0.4 to 0.7	70 ft. on ground
EK 3414	High-definition aerial B&W	0.5 to 0.7	55 ft. on ground
EK 3443	Aerochrome IR, color	0.5 to 0.88	100 ft. on ground

The ETC is not a metric camera in the photogrammetric sense. Because the image frame is a part of the removable film magazine and because of the use of a focal-plane shutter, the geometric quality of the photographs is limited. The shutter motion is in the flight direction for one exposure, and opposite the flight direction for the next exposure. This causes a slight scale compression or stretching in the flight direction, depending upon errors in the FMC. The principal point cannot be precisely located, and therefore analytical applications are limited. When the camera is operated for 60 percent overlap, the base-height ratio is only 0.10; thus, any stereoscopic height measurements from the photographs have especially limited accuracy.

In spite of these limitations, the ETC represents a significant advance in camera systems for earth resources observations from space. The ETC provides photography having a ground resolution from 3 to 20 times better than that of any other space photographic system previously used. As a consequence, the primary objective of the ETC is to obtain high-resolution stereoscopic photography to support the other EREP sensors by aiding in the interpretation of data gathered by them.

Note: A more complete discussion of the ETC is given in a paper by J. D. McLaurin, U.S. Geological Survey, entitled THE SKYLAB S-190B EARTH TERRAIN CAMERA--see Appendix A.

Infrared Spectrometer (S-191)

The primary objective of this experiment is to make a fundamental evaluation of the applicability and usefulness of sensing earth resources from orbital altitudes in the visible through near-infrared and in the far-infrared spectral regions. Correlation of SKYLAB spectrometer data, with data gathered by ground-based and aircraft sensors, will ensure that the radiance from the target and its characteristics will be accurately established. The extent to which the effects of the atmosphere can be removed from the data is a study of particular importance to all remote sensors, and this accuracy will be quantitatively tested. In addition, the parameters describing the atmosphere at the time of acquisition will be collected.

The filter wheel spectrometer has a 1-milliradian field-of-view, and its spectral range coverage is from 0.4 to 2.4 and 6.2 to 15.5 micrometers. The spectrometer has a pointing and tracking capability of 45 degrees forward, 10 degrees aft, and 20 degrees to the side of the ground track. The astronaut uses the view-finder/tracker to acquire and track target sites during data acquisition, which are in his field of view for less than a minute. The primary data are recorded on magnetic tape and are returned with each crew rotation.

Multispectral Scanner (S-192)

The primary objective of this experiment is to assess the feasibility of multispectral techniques for remote sensing of earth resources from space. Specifically, attempts will be made at spectral signature identification and mapping of ground test sites in agriculture, forestry, geology, hydrology, and oceanography.

The basic instrument design is that of an optical mechanical scanner using an image plane scanning mirror, with a folded reflecting telescope used as a radiation collector. The scanner operates in 13 spectral intervals of the visible, near-infrared, and thermal-infrared regions of the spectrum ranging from 0.41 to 12.5 um. The primary data are recorded on magnetic tape and are returned with each crew rotation.

The spectral range covered by the scanner overlaps the range of the multispectral cameras (S-190) and the IR spectrometer (S-191), permitting a cross-check of results deduced from these three systems. In addition, the IR spectrometer may provide atmospheric density profiles useful for correcting the primary causes of atmospheric attenuation of the scanner data.

Microwave Radiometer/Scatterometer and Altimeter (S-193)

The objectives of this experiment are simultaneous measurement of the radar differential backscattering cross section and passive microwave thermal emission of the land and ocean on a global scale, and engineering data for use in designing radar altimeters.

The microwave radiometer/scatterometer experiment is a combination of an active radar scatterometer and passive radiometer. The radar backscattering cross section measurement gives a measure of the combined effect of the dielectric properties, roughness, and brightness temperature of the terrestrial surface. Information over test sites is obtained by the NASA earth resources aircraft for validation and extrapolation of spaceborne measurements. All data are recorded on magnetic tape.

L-Band Radiometer (S-194)

The experiment objective is to obtain measurements of the brightness temperature of the earth's surface along the spacecraft track. The L-band radiometer has basically the same operating principle as the radiometer part of the microwave radiometer/scatterometer experiment, except that the operating frequency is changed from 13.9 GHz to 1.42 GHz. A function of the experiment is to supplement the measurement results of Experiment S-193 by taking into consideration the effect of clouds on radiometric measurements. By using two frequencies (S-193 at 13.9 GHz and S-194 at 1.42 GHz) simultaneously in measurements, corrections can be made on radiometric data to include the cloud effects. All data are recorded on magnetic tape.

A summary of the SKYLAB EREP sensor characteristics is given in Table 2.

Table 2.

SKYLAB
EREP SENSOR CHARACTERISTICS

SENSOR	DESCRIPTION	SPECTRAL COVERAGE	SPECTRAL RESOLUTION	GROUND COVERAGE	SPATIAL RESOLUTION
S-190(A) MULTISPECTRAL PHOTOGRAPHIC CAMERA	SIX 70mm CAMERA MATCHED DISTORTION AND FOCAL LENGTH (15.2cm) 12 METERS REGISTRATION 18 FILTERS 21° FOV	MICROMETERS .5 - .6 PANX B&W .6 - .7 PANX B&W .7 - .8 IR B&W .8 - .9 IR B&W .5 - .88 IR COLOR .4 - .7 HR COLOR	0.1 MICROMETERS	163 x 163 Km	APPROX. 24m TO 68m *
S-190(B) EARTH TERRAIN CAMERA	460 mm FOCAL LENGTH 114mm FILM FORMAT 3 FILTERS	0.4 TO 0.7 H. R. AERIAL COLOR 0.5 TO 0.88 IR COLOR 0.5 TO 0.7 HIGH DEFINITION AERIAL B & W	0.1 MICROMETERS	109 X 109 Km	APPROX. 10m TO 38m *
S-191 INFRARED SPECTROMETER	POINTED BY CREW FILTER WHEEL ONE SEC. SCAN RATE ONE mRAD FOV CRYOGENIC COOLER 16mm CAMERA	0.4 TO 2.4 AND 6.2 TO 15.5 MICROMETER	1% TO 4%	0-45° FWD 0-20° SIDE 0-10° REAR	0.44 Km SPOT
S-192 MULTISPECTRAL SCANNER	IMAGE PLANE SCANNER 6000RPM SCAN MIRROR CRYOGENIC COOLER HgCdTe DETECTORS (13 USED) 0.186 mRAD FOV	0.4 TO 2.35 AND 10.2 TO 12.5 MICROMETERS	13 BANDS: 0.04 TO 0.1 MICROMETERS	68 Km SWATH	80 x 80 m SPOT
S-193 MICROWAVE RADIOMETER/SCATTEROMETER AND ALTIMETER	1.1m PARABOLIC ANTENNA TWO AXIS GIMBAL (0-48° IN FIVE STEPS) 1.5° FOV DUAL POLARIZATION ALTIMETER NADIR SEEKER	13.8 TO 14.0 GHz (13.9 GHz CENTER FREQUENCY)	SCAT RECEIVER: FIRST IF. 500 MHz SECOND IF: 50 MHz RAD RECEIVER: SINGLE FREQUENCY	0-48 FWD 0-48 SIDE	11 x 11 Km SPOT
S-194 L-BAND RADIOMETER	1 m PHASED ARRAY (8 x 8 ELEMENTS) COLD AND HOT REF.	1.400 TO 1.427 GHz	18 MHz FROM CENTER FREQUENCY	111 Km CIRCLE	111 Km SPOT

NOTES: FOV = FIELD OF VIEW
* - DOES NOT INCLUDE LOSS DUE TO ATMOSPHERE EFFECTS OR FILM PROCESSING.

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Table 2.

IDENTIFICATION OF THE NOAA/NOS INVESTIGATION

The NOAA/NOS proposal to perform analytic aerotriangulation utilizing SKYLAB photography has been designated as SKYLAB EREP INVESTIGATION NO. 459 and was performed under NASA PURCHASE ORDER T-4110B. The task-site identification number for the study is 931651 in which 931 classifies the task as being in the CARTOGRAPHY MAP ACCURACY discipline, and 651 identifies the test site as the CARETS AREA, which runs from Charlotte, North Carolina, northeast to Delaware Bay.

The official NASA description of this investigation is as follows:

931 Investigate the feasibility of utilizing spacecraft (S-190B) imagery for analytic aerotriangulation methods to provide low-order, high-density control network suitable for small-scale mapping applications.

Employ this technique for coastal zone mapping at medium and small scales, surveys in remote areas, forest and range management, various planning activities and route location for highways, pipelines, transmission lines, and canals.

SKYLAB S-190B EARTH TERRAIN CAMERA (ETC) PHOTOGRAPHY

SKYLAB S-190B photography was secured over the test site, during orbit 36, on September 12, 1973 (SL-3). The film used in the ETC was Aerial-Color, High-Resolution SO-242. Second generation transparencies, positive in tone and direction when viewed on the emulsion side, were made from the original film by printing emulsion-to-emulsion in contact. These 1:946,000 scale, 4.5 x 4.5-inch transparencies and 9 x 9-inch contact paper prints were provided to the Coastal Mapping Division of the National Ocean Survey for processing through the analytic aerotriangulation system.

The photography consisted of a strip of 19 photographs ranging along a 500-mile track from Charlotte, North Carolina, (frame 86-288) to Atlantic City, New Jersey, (frame 86-306). A break in the required 60 percent overlap reduced the usable strip of photography to 12 photographs along a 350-mile track from Charlotte, North Carolina, (frame 86-288) to the Rappahannock River in Virginia (frame 86-299).

Although the photography provided sharp high-resolution imagery, the selection of pertinent images for measurement on the Wild STK stereocomparator was hampered by the extensive cloud cover occurring on most of the 11 stereoscopic models comprising the analytic strip.

PHOTO CONTROL

Despite the cloud cover, 29 photo control points of known position and elevation were office-identified on the SKYLAB photography. Road intersections were located by stereoscopically examining the photographs and comparing them with 1:24,000 scale USGS quadrangles covering the area. The Geographic Positions were scaled from the quadrangles by linear interpolation between the 2' 30" intervals shown on each quadrangle. The scaling was performed five times and a mean Geographic Position computed. In addition, aeronautical aids to navigation and airport runway ends were identified on the pictures, and their positions and elevations determined from data secured by the Coastal Mapping Division under its Airport Obstruction Chart Survey program. The office-identified road intersections and aeronautical aids provided images slightly superior in quality to that of the office-identified airport runway ends. The locations of these photo control points or stations on the ETC photographs is shown in Figure 1. Table 3 describes the stations and their approximate accuracy.

All of the photo control stations were at least 1/4-inch in from the sides of the 1:946,000, 4.5 x 4.5-inch transparencies. Twenty-five of the stations appeared on only two consecutive overlapping photographs in the strip, while four stations appeared on three consecutive photographs. The location of the camera clock within the photographic format prevented two control stations from creating imagery on three consecutive overlapping pictures.

PASS POINTS

Two pass points were established in the nine conventional relative orientation locations on each photograph. The pass points were drilled into the transparency emulsion with the Wild PUG-2 stereoscopic point transfer device in areas providing an optimum stereoscopic perception. As a consequence of the intrusion of the camera clock into the photographic format, it was necessary to set the pass points along the bottom easterly edge of the strip at least 1/2-inch in from the sides of the transparencies.

The two pass points were used in the preliminary analytic aerotriangulation programs consisting of the Image Coordinate Refinement and Three-Photo Orientation program, the Secant Plane Coordinate Transformation program, and the Strip Adjustment to Ground Control. However, only one of the two pass points in each relative orientation location was used in the block adjustment of the strip.

MARKING AND PHOTOCOORDINATE MEASUREMENT

The Wild PUG-2 stereoscopic point transfer device was used to select and mark only the pass points by drilling holes into the photographic emulsion at these images using a 60-micron diameter diamond-tipped

TABLE 3.

ACCURACY OF OFFICE IDENTIFIED CONTROL
USED IN
BLOCK ADJUSTMENT

CONTROL STATION NUMBER	APPROXIMATE HORIZONTAL ACCURACY (METERS)	APPROXIMATE VERTICAL ACCURACY (METERS)	DESCRIPTION
288100 288101 293100 294102 295100 299100	15	5.0	AERONAUTICAL AIDS Horizontal and vertical positions from Airport Surveys, NOS.
288110 288111 290110 296111	5	3.0	ROAD INTERSECTIONS Horizontal and vertical positions from 1:24,000 scale USGS quadrangles.
288201 288202 290201 290111 292110 292111 293110 296201 296110 298110 299110 299111	5	0.5	ROAD INTERSECTION SPOT ELEVATIONS Horizontal and vertical positions from 1:24,000 scale USGS quadrangles.
288120 291120 291121 293120 293121 297120 297121	1	0.3	CENTERLINE RUNWAY ENDS Horizontal and vertical positions from Airport Surveys, NOS.

drill. The photo control point images were not drilled in order to preserve the sharpness of the imagery.

The measurement of the $\underline{x}$ and $\underline{y}$ photocoordinates for the pass points and control stations was performed on a Wild STK stereocomparator. Use of the stereocomparator allowed the operator to drill the pass point images down the center of each photograph only and to then stereoscopically transfer the drilled image to the overlapping photograph for measurement, without actually ever drilling the image on the second photograph. The stereocomparator measuring mark consisted of a 165-micron diameter black circle having a 20-micron black dot at its center. The dot was centered in the 60-micron diameter drilled pass point image when observing the photocoordinates for the point.

FIDUCIAL MARKS

In the time interval occurring between the film exposure, its development, and the subsequent printing of the glass plate diapositive or transparency, the aerial film undergoes a random enlargement and shrinkage change. Since the accuracy of analytic photogrammetric computations depend on the use of a true central perspective, it is necessary to compensate for the film distortion and thereby mathematically return the film to the physical format present at the instant of exposure. This can be achieved by comparing the positions of the images created by the fiducial marks on each photograph with the true positions of these marks in the camera focal plane. The photograph is then mathematically stretched so as to place the fiducial marks back into their true positions.

In metric mapping cameras, the fiducial marks are located in the corners of the camera focal plane. Some cameras have additional fiducial marks at the midpoints of the sides of the focal plane. The marks are normally a part of the lens cone and thus remain in a fixed position relative to the camera lens. The intersection of the diagonals joining the corner fiducial marks should represent the principal point of the photograph, i.e., the foot of the perpendicular from the focal plane to the nodal point of the camera lens. The corner fiducial marks on the Wild aerial cameras owned by NOS consist of an interrupted cross having a 100-micron diameter dot at the center.

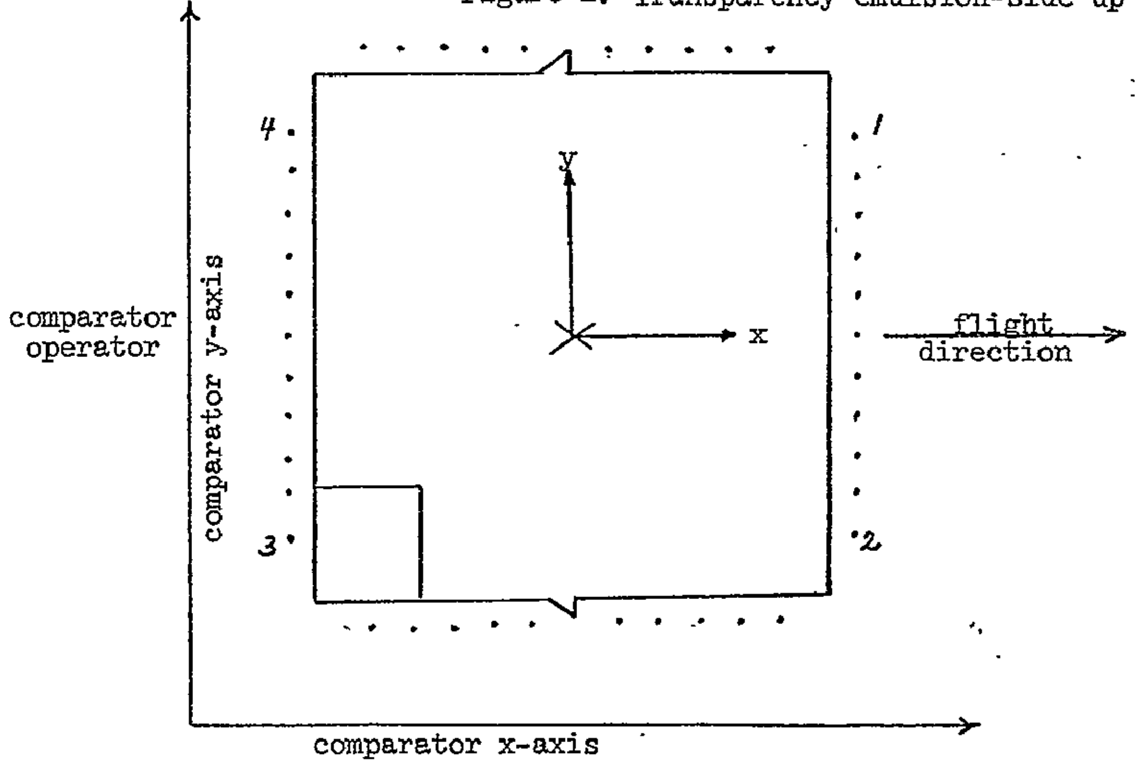
The ETC is not a metric camera in the photogrammetric sense because the fiducial marks and the image frame are a part of the removable film magazine and hence are not in a fixed position relative to the camera lens. Fortunately, the resulting lack of precision in locating the principal point on the photography is of minor consequence in narrow angle cameras, such as the ETC.

The ETC has a series of holes drilled around the perimeter of the image frame. These holes created photographic images having an approximate diameter of 330 microns. The images were of poor quality and rather ragged around the edges. For this reason, the stereocomparator operator centered the 165-micron circle of the measuring mark in the center of four holes selected to serve as fiducial marks.

NOS normally employs flash plates to provide a photographic record of the true relative positions of the camera fiducial marks. The flash plates are made in the laboratory by exposing a diapositive mounted in the camera so that its emulsion lies in the camera focal plane. Because the emulsion is secured on a stable glass base, the coordinates of the fiducial marks can be measured on a comparator later, with no concern for film shrinkage distortion.

Since no flash plate was available for the ETC, a nominal set of true fiducial coordinates was obtained by mounting each of the transparencies in turn on the comparator and then reading the photocoordinates for the four selected fiducial holes on each of the photos. The data were entered into a flash-plate-reduction program to accomplish the following tasks: 1. Correct the observed photocoordinates of the fiducial holes for comparator systematic errors, 2. determine by least square methods a meaned set of nominal true photocoordinates for the fiducial holes in a coordinate system, having its origin at the principal point (intersection of diagonals joining fiducials 1-3 and 2-4) and oriented so that $x_3 \cong y_3 = y_2$. See Figure 2 below. As a consequence of this computation, the direction of flight becomes the x-axis of the photocoordinate system.

Figure 2. Transparency emulsion-side up



The meaned set of nominal true photocoordinates for the fiducial holes provided by the flash-plate-reduction program are:

FIDUCIAL HOLE	x (microns)	y
1	59227.74	50154.18
2	59112.61	-50132.70
3	-59202.38	-50132.70
4	-59112.77	50132.84

The data were then prepared for processing through the NOAA/NOS analytic aerotriangulation system of computer programs. All of the computations were performed on the CDC 6600 computer.

COMPUTER PROCESSING

The 12-photo strip extended over the three states of South Carolina, North Carolina, and Virginia. The computational processing requires all of the ground positional data to be expressed in a common three-dimensional coordinate system. In order to attain this condition, and also to compensate for the presence of earth curvature in the data, the initial computation was to develop secant plane coordinates for each of the 29 office-identified control stations. Accordingly, the Geographic Positions and elevations of these points were processed through the Secant Plane Coordinate Transformation program.

Secant Plane Coordinate Transformation: The elevations of the control points obtained from the 1:24,000 scale USGS quadrangles and airport surveys are based on sea level and thus do not recognize the existence of earth curvature. The program computations begin with a conversion of the Geographic Positions and elevations to an orthogonal geocentric coordinate system having its origin at the center of the earth as defined by the Clarke 1866 Spheroid. The geocentric coordinates are then transformed into a secant plane coordinate system in which the secant plane intercepts the earth's surface near the edges of the area to be mapped so that most of the terrain objects will possess a positive Z (elevation) coordinate. The origin of the secant plane system is placed near the center of the project area. The secant plane origin selected for the SKYLAB study was Latitude 36° 20' 00", Longitude -78° 45' 00 The Z-axis is the extension of the normal to the ellipsoid which, because of the earth's ellipsoidal nature, does not pass through the center of the earth. The X-axis points towards the East and the Y-axis points towards the North.

Table 4 shows the Geographic Position and elevation input to the program and the resulting secant plane coordinate output from this program.

CONVERSION OF CONTROL STATION GEOGRAPHIC POSITIONS TO SECANT PLANE COORDINATES

```
SECANT PLANE ORIGIN
LATITUDE  36 20 00    LONGITUDE -078 45 00

GEOGRAPHIC POSITION INPUT
                                                           Elevation (feet)
288100    34 59 20.200         -080 57 18.000            650.0
288110    35 15 25.015         -081 01 37.254            710.0
288201    35 15 05.424         -081 01 43.630            633.0
288111    34 44 15.094         -080 40 58.811            565.000
288202    34 43 34.559         -080 42 15.428            598.0
288120    35 12 31.865         -080 57 00.375            707.0
288101    35 13 13.390         -080 56 18.073            740.00
290110    35 44 30.052         -080 21 43.729            760.00
290201    35 44 34.185         -080 21 48.169            753.0
290111    35 03 03.258         -079 50 57.400            456.0
291120    36 05 57.511         -079 57 09.510            926.0
291121    36 05 13.059         -079 56 15.037            900.0
292110    36 08 32.741         -079 47 26.181            843.0
292111    35 36 54.282         -079 02 53.990            185.0
293100    35 52 20.520         -078 47 01.000            430.00
293120    35 51 52.243         -078 47 51.245            398.0
293121    35 51 57.031         -078 46 49.346            401.0
293110    36 05 18.889         -079 03 46.083            516.00
294102    36 40 29.600         -079 00 53.200            530.00
295100    36 49 04.400         -077 54 11.700            350.00
296111    37 13 22.840         -077 59 24.112            322.00
296201    37 13 10.548         -077 59 37.971            339.0
296110    36 39 51.186         -077 34 17.309            156.0
297120    37 29 44.350         -077 18 25.908            161.0
297121    37 30 14.556         -077 18 38.599            160.0
298110    37 12 17.161         -076 59 13.914            112.0
299100    37 26 54.700         -076 42 42.100             10.00
299110    37 54 13.346         -076 51 44.738            031.0
299111    37 26 06.654         -076 20 11.559            013.0


SECANT PLANE OUTPUT IN METERS
                    X              Y              Z
   288100   -201278.692   -146855.736     -3874.837
   288110   -207169.956   -116985.134     -3424.735
   288201   -207344.107   -117584.396     -3464.941
   288111   -176997.192   -175263.639     -3901.313
   288202   -178969.743   -176473.122     -3979.759
   288120   -200294.019   -122480.950     -3309.711
   288101   -199196.924   -121226.254     -3241.238
   290110   -145819.163    -64433.577      -962.699
   290201   -145928.545    -64304.337      -966.024
   290111   -100287.221   -141707.209     -1430.977
   291120   -108297.906    -25295.089       110.910
   291121   -106952.115    -26681.925       119.998
   292110    -93656.711    -20679.874       333.841
   292111    -27029.441    -79651.423       297.541
   293100     -3035.511    -51147.971       721.944
   293120     -4296.418    -52018.862       704.400
   293121     -2743.370    -51871.929       707.371
   293110    -28172.927    -27112.861       834.668
   294102    -23669.361     37934.083       801.864
   295100     75550.344     54100.713       226.922
   296111     67448.740     98990.886      -231.394
   296201     67110.169     98609.407      -216.716
   296110    105357.883     37358.925      -134.052
   297120    127578.566    129930.492     -1756.009
   297121    127252.667    130856.770     -1768.812
   298110    156468.136     98126.586     -1843.117
   299100    180328.210    125649.347     -2988.252
   299110    165981.068    175874.338     -3784.177
   299111    213537.475    124932.816     -3997.981
```

Image Coordinate Refinement and Three-Photo Orientation: The x and y photocoordinates observed on the stereocomparator for the fiducial and nonfiducial images on each transparency were then processed through the image coordinate refinement and three-photo orientation program. All of the photocoordinates were first corrected for comparator calibration errors. The program then performed a least squares fit of the fiducial hole photocoordinates to the nominal true photocoordinates for these fiducial holes, as previously obtained from the flash-plate-reduction program. This operation of placing the fiducial holes back into their true positions serves to correct all of the data for film shrinkage distortion and to express the photocoordinates in a two-dimensional photocoordinate system having its origin at the principal point and oriented so that the x-axis is the direction of flight.

The systematic errors still remaining in the photocoordinate data are those due to the distortions introduced by the aerial camera lens and atmospheric refraction. The Addendum to LEC/ASD Technical Memo No. TM 73-002 - April 1973 issued on July 11, 1974, indicated the camera lens symmetrical distortion and the asymmetrical distortion caused by lens decentration to be probably insignificant from zero. In addition, distortion due to atmospheric refraction at camera altitudes above 40 miles is relatively negligible. For this reason, no attempt was made during the image coordinate refinement phase to compensate for camera lens and atmospheric refraction distortion.

The refined image coordinates provided by the program theoretically should be nearly all free of systematic error and contain only residual observational discrepancies in them. These refined coordinates were then punched out to serve as input to the block adjustment program.

The program then proceeded to the three-photo camera orientation phase, which comprises an interrelated geometric fitting of the photographs, based only on the refined photocoordinates and is entirely independent from any ground control data. The computation is iterative and derives the orientation of each photograph relative to the previous two in the strip. It also determines the positions of all pertinent objects in a three-dimensional coordinate system at the scale of the photography. The collineation principle is imposed in a least squares solution that minimizes the residual observational discrepancies in the image coordinates. The residual discrepancies are analyzed by the computer, which discards those images exhibiting excessively large discrepancies. The removal of these blunders provides "clean" photocoordinate data for all subsequent computations.

Strip Adjustment to Ground Control: The analysis of three photographs at a time automates the joining of the separate triplets into a continuous strip and develops a set of model coordinates that are analogous to the product obtained from conventional stereotriangulation on stereoscopic plotting instruments. The horizontal and vertical strip adjustment transforms the model coordinate data into the prevailing ground control coordinate system, which is a secant plane coordinate system for this study, by fitting to the control stations through the application of polynomial equations and least squares. Any large residual discrepancies appearing in the resulting adjustment are corrected in order to obtain blunder-free provisional ground position data prior to entering the block adjustment computation.

The strip adjustment of the SKYLAB photography was performed holding to the 14 photo control stations identified on Figure 1 by a ▲. Note: These same 14 stations were employed later to control the block adjustment solution. The strip adjustment was performed twice--going from frame 86-288 to frame 86-299 and then going from frame 86-299 to frame 86-288. In both adjustments, the resulting discrepancies at the 14 held photo control stations and 15 withheld stations increased in magnitude from about 25 meters at the beginning of the strip to approximately 100 meters at the tail end of the bridge. Results of this nature do not occur on normal photogrammetric mapping operations conducted by NOS. The appearance of these apparently systematic strip adjustment discrepancies on the SKYLAB bridge is assumed to be attributable to the failure to completely compensate for the systematic errors introduced into the data by the nonmetric characteristics of the Earth Terrain Camera.

Block Adjustment: In order to maximize the accuracy of the analytic aerotriangulation, the block adjustment program was applied, using the previously obtained refined photocoordinates and the provisional object coordinates. The program permits a simultaneous solution of the absolute orientation of all the photographs, together with a determination of the finalized coordinates for each object. This office has developed three simultaneous analytical aerotriangulation block adjustment programs for operation on the CDC 6600 computer.

1. 25-Photo Block Adjustment: This program was designed to service smaller organizations not having access to large-size computers and will accommodate blocks up to 25 photos in size. All input/output is on cards, and the program requires less than 50,000 words of computer core storage. The logic of the solution is similar to that of the 185-photo block adjustment program.

2. 185-Photo Block Adjustment: The block can contain as many as 185 photographs in a single simultaneous least squares solution. All input/output is on tape. Approximately one million words of storage are required, and therefore auxiliary disk storage and extended core storage is used to augment the CDC 6600 core memory.

   The area to be block adjusted may be of any shape. The strips of photography can be of variable length and may have any overlap with other strips in the block. Thus, diagonal cross-flights may be included, if desired. The photographs can be entered into the solution in any order. Photographs taken by aerial cameras having different focal lengths may be used simultaneously in the solution.

   All of the pass points and control stations contribute equations to the normal equation matrix and thus influence the least squares orientation solution. Corrections to the provisional coordinates for these objects are computed simultaneously with the determination of the absolute orientation of all the photographs in the block. The unweighted control stations perform as if they are pass points. The weighted control stations can be computed as if they are pass points by using their refined photocoordinates and the finalized camera parameters from the orientation solution to determine their ground coordinates by intersection.

3. 600-Photo Block Adjustment: Blocks up to 600 photographs in size can be accommodated in this version. All input/output is on tape. Auxiliary disk storage is necessary because the program requires nearly one million words of memory.

   This version is not as flexible as the 185-photo program in terms of data input organization, but the arithmetic approach employed results in a more efficient computation and a much shorter computer running time. The area should be square or rectangular in order to simplify the arrangement of input data. Photographs must be entered into the solution in the exact order in which they were taken and may not overlap each other by more than 60 percent. No strip can have more than 20 pictures in it. The program permits the mixing of photographs taken by aerial cameras of different focal lengths.

   All of the pass points and control stations contribute equations to the normal equation matrix and thus influence the least squares orientation solution. The finalized camera parameters from the orientation solution and the refined photocoordinates of the pass points and control stations are used to compute the final ground coordinates for these objects by intersection.

The 600-photo block adjustment program was used for the SKYLAB analytic aerotriangulation study. A Fortran listing of this program is given in Appendix B.

Thirty-six pass points (one in each relative orientation location) and all of the 29 office-identified photo control stations were permitted to contribute observation equations to the normal equation matrix and thereby influence the least squares orientation solution of the 12 photographs comprising the block. The provisional coordinates for these objects should be reasonably close to their true values in order to minimize the number of iterations required of the block adjustment solution. For this reason, the initial ground (secant plane) coordinates of the pass points consisted of the data furnished by the first half of the strip adjustment going from frame 86-288 to frame 86-299--and by the first half of the strip adjustment going from frame 86-299 to frame 86-288. The known true ground (secant plane) coordinates were used as the initial coordinates for the 29 photo control points.

Table 5 is a listing of the initial provisional ground (secant plane) coordinates for the pass points and the photo control stations. A listing of the refined photocoordinates for these pass points and photo control stations, as previously punched out by the Image Coordinate Refinement and Three-Photo Orientation program, is given in Table 6.

```
      292
292291310  -4.8126509E-02  -3.0527771E-02
292291320  -5.2868542E-02   4.7874533E-02
292291330  -5.1129797E-02   3.5506342E-03
292292310   1.8499420E-03  -3.0333683E-02
292292320   4.0858396E-03   4.8972518E-02
292292330  -9.3830666E-04   7.8532402E-03
292293310   5.1925419E-02  -2.8029944E-02
292293320   5.0031725E-02   5.0058976E-02
292293330   4.7535343E-02   4.5751374E-03
292292110  -1.9237138E-02   4.3086281E-02
292291120  -3.4734189E-02   4.8658235E-02
292291121  -3.4488084E-02   4.6586076E-02
292293100   3.8201346E-02  -4.1701161E-02
292293110   3.2417993E-02  -4.9433929E-03
292293120   3.6554509E-02  -4.1634943E-02
292293121   3.7984083E-02  -4.2517091E-02
292292111  -7.2191183E-04  -5.0470942E-02
      293
293292310  -4.6876203E-02  -3.1929435E-02
293292320  -4.4675254E-02   4.7409829E-02
293292330  -4.9701058E-02   6.2704290E-03
293293310   3.2954850E-03  -2.9647102E-02
293293320   1.3644901E-03   4.8547056E-02
293293330  -1.1609361E-03   3.0063077E-03
293294310   4.9291420E-02  -2.6523827E-02
293294320   5.0331744E-02   3.7760516E-02
293294330   5.0443036E-02   4.6554986E-03
293293100  -1.0472546E-02  -4.3320930E-02
293293110  -1.6304848E-02  -6.5265715E-03
293293120  -1.2119203E-02  -4.3255058E-02
293293121  -1.0684280E-02  -4.4135354E-02
293294102   2.9769123E-02   4.6062768E-02
      294
294293310  -4.5408740E-02  -3.1276435E-02
294293320  -4.7413524E-02   4.6910495E-02
294293330  -4.9922832E-02   1.3757361E-03
294294310   6.4136652E-04  -2.8164236E-02
294294320   1.6050855E-03   3.6179394E-02
294294330   1.7489357E-03   3.0448055E-03
294295310   4.8336748E-02  -2.7948864E-02
294295320   4.5921897E-02   3.1223507E-02
294294102  -1.9005334E-02   4.4462580E-02
294295330   5.0752810E-02   7.0171463E-03
      295
295294310  -4.8065487E-02  -2.9755754E-02
295294320  -4.7116111E-02   3.4612072E-02
295294330  -4.6971411E-02   1.4643224E-03
295295310  -2.8582516E-04  -2.9563473E-02
295295320  -2.7288240E-03   2.9684546E-02
295295330   2.1121530E-03   5.4490202E-03
295296310   4.8350200E-02  -3.0367873E-02
295296320   4.8859741E-02   4.8204153E-02
295296330   4.3942351E-02   9.7309548E-03
295296110   4.1888299E-02  -4.1150655E-02
295296111   4.9557802E-02   3.5889388E-02
295295100   2.7383244E-02  -7.6541133E-03
295296201   4.9025404E-02   3.5791637E-02
      296
296295310  -4.8912550E-02  -3.1175464E-02
296295320  -5.1417141E-02   2.8070525E-02
296295330  -4.6558160E-02   3.8367575E-03
296296310  -2.1747625E-04  -3.2005718E-02
296296320   2.4754045E-04   4.6660238E-02
296296330  -4.6724768E-03   8.1401176E-03
296297310   5.1814312E-02  -2.1334985E-02
296297320   5.1438535E-02   4.2232885E-02
296297330   4.9087131E-02   5.1457554E-03
296296110  -6.6781630E-03  -4.2801992E-02
296296111   9.5107825E-04   3.4330292E-02
296295100  -2.1251919E-02  -9.2674902E-03
296296201   4.1528880E-04   3.4232754E-02
```

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      297
297296310   -4.8884683E-02  -3.3540838E-02
297296320   -4.8471439E-02   4.5150300E-02
297296330   -5.3387673E-02   6.6214000E-03
297297310    3.2292043E-03  -2.2914424E-02
297297320    2.8155666E-03   4.0743480E-02
297297330    4.7887551E-04   3.6049954E-03
297298310    4.9384170E-02  -3.1794614E-02
297298320    4.8950281E-02   4.5322814E-02
297298330    5.3156090E-02   1.1645544E-02
297296111   -4.7770507E-02   3.2823481E-02
297297120    2.3627514E-02   2.0265087E-02
297297121    2.3945413E-02   2.1263032E-02
297298110    2.7641953E-02  -2.5576312E-02
297296201   -4.8307759E-02   3.2723607E-02
      298
298297310   -4.5428380E-02  -2.4470411E-02
298297320   -4.5919888E-02   3.9161207E-02
298297330   -4.8222649E-02   2.0387070E-03
298298310    8.0468845E-04  -3.3377516E-02
298298320    2.9431491E-04   4.3796670E-02
298298330    4.5390987E-03   1.0100176E-02
298299310    4.7350772E-02  -5.1665726E-02
298299320    4.4515357E-02   4.8243494E-02
298299330    5.1835518E-02   1.2330690E-02
298299110    3.7430048E-02   3.3063014E-02
298297120   -2.5071781E-02   1.8706945E-02
298297121   -2.4755306E-02   1.9706280E-02
298298110   -2.0994424E-02  -2.7139170E-02
298299100    1.7160147E-02  -1.9058386E-02
298299111    4.4993911E-02  -4.1062900E-02
      299       1   1
299298310   -4.7827856E-02  -3.4851692E-02
299298320   -4.8340167E-02   4.2357455E-02
299298330   -4.4103047E-02   8.6372888E-03
299299310   -1.1510283E-03  -5.3232239E-02
299299320   -4.0500174E-03   4.6813308E-02
299299330    3.2847107E-03   1.0854518E-02
299000301   -1.9679956E-10  -3.8623708E-09
299000302   -1.9679956E-10  -3.8623708E-09
299000303   -1.9679956E-10  -3.8623708E-09
299299110   -1.1156657E-02   3.1610337E-02
299299100   -3.1453155E-02  -2.0549835E-02
299299111   -3.5411964E-03  -4.2610240E-02
```

End of Table 6.

Weighting the Block Adjustment Solution: The weighting of the block adjustment solution is performed by applying image quality and control station weights to the data during the computations. These weights can be defined as follows:

Image Quality Weights: It is logical to weight a block adjustment in favor of those observation equations provided by the better quality images because their equations are more reliable. Image quality is primarily influenced by lens resolution and the type of ground object creating the image. The weighting is accomplished by multiplying each observation equation by a number expressing its relative reliability.

Control Station Weights: The observation equations are written for each image on every photograph in the block created by the pass points, control stations, and other objects which are used to influence the least square orientation solution. When written for image created by the control stations, it is necessary to recognize that their initial provisional X, Y, Z ground coordinates were obtained by classical ground surveying methods and should be favored during the block adjustment. This is accomplished by increasing the size of the main diagonal elements of the normal equation matrix, which are the coefficients of the unknown dX, dY, and/or dZ correction terms. This serves to reduce the size of the unknown dX, dY, and/or dZ correction terms when the normal equations are solved. By reducing the magnitude of the corrections to the initial approximations, the least square adjustment is constrained in favor of these initial values. Control stations that are not subjected to this type of weighting perform as pass points. These unweighted or withheld control stations provide a means for evaluating the accuracy of the block adjustment solution.

Presently, empirical values are used for these weights at NOS instead of being based on the standard error of the observations as required by rigorous statistical methods. Also, the present NOS block adjustment program multiplies the pertinent normal equation main diagonal terms by the control station weights instead of adding on a number to increase their size.

The resulting accuracy of the block adjustment can be expressed as a photogrammetric RMS error and a geodetic RMS error. The photogrammetric RMS error is computed using the residual v_x and v_y plate observational discrepancies of all images contributing observation equations to the orientation solution. The geodetic RMS error reflects a comparison of the X, Y, Z results of the block adjustment computation with the known X, Y, Z coordinates for the control stations that were obtained by classical ground surveying methods. In most NOS operations, weights are selected that cause the photogrammetric RMS error and the geodetic RMS error to be about equal. This has the effect of providing for an equal distribution of the block adjustment errors between the photogrammetric observations and the geodetic field observations.

The inherent errors in using nonmetric S-190B photography and office-identified photo control made it necessary to perform numerous block adjustment solutions involving different combinations of control and weights. The best results were achieved by using 14 weighted control stations distributed uniformly along the perimeter of the strip as shown in Figure 1. In NOS mapping operations using metric photography and field-identified photo control, eight weighted photo control stations would normally have been sufficient for a block adjustment of the 12 photos.

As previously noted, the pass points were drill holes in the emulsion and not images of specific terrain objects. The stereocomparator operator cannot remove parallax exactly on the drilled pass point holes when observing their photocoordinates. This reduces the reliability of the pass point images during the photocoordinate measurement process. The office-identified photo control stations, on the other hand, were prominent ground features providing sharp images on the overlapping photographs. Since drilling was not necessary for these stations, the comparator operator was able to remove parallax directly at the images before observing their photocoordinates. As a consequence of their higher reliability, a larger image quality weight was assigned to the control station images.

Many combinations of image quality and control station weights were applied to the 14 held photo control stations in an effort to optimize the accuracy of the block adjustment solution. In general all of these weight combinations yielded a horizontal position geodetic RMS error of approximately 15 meters for the 15 withheld (unweighted) photo control points. The maximum horizontal position error on any withheld control station was less than 26 meters.

Results of the Block Adjustment Solution: The weights used for each of the 14 held photo control stations in the final block adjustment of the SKYLAB data were: image quality weight = 6; control station weight for X and Y = 6; control station weight for Z = 3. A smaller weight was used for Z because of the limited accuracy in the stereo height determination resulting from the low base-height of 0.10, even though the known elevations of the control stations were of a higher accuracy than the known horizontal positions for these stations (see Table 3). In fact, a higher Z weight was found to degrade the block adjustment accuracy.

The pertinent output from the 600-photo block adjustment program for the SKYLAB study is shown in Table 7. A summary of the residual errors remaining at each of the 29 control stations is given in Table 8. All of the ground coordinate data and the residual errors are in meters and expressed in the secant plane coordinate system. The results presented here are from a block adjustment solution in which the standard error of the ground control was assumed to be 4.1 meters. The residual errors given in Table 8 are also shown on Figure 1 in red.

Table 7. Output from 600-photo block adjustment program

```
 SKYLAB  COL.WTS.-6   POS.WTS. XY-6 Z-3

ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001

POSITION WEIGHT VARIES

FL CONSTANT =  .4574110E+00   MAXIMUM ITERATIONS = 9   RESIDUAL LIMIT (MICRONS) =  .2500000E+02
RESOLUTION WEIGHTS WT712 =   .1000000E+01   WT12P =   .1000000E+01

CONTROL      EQUATION     XY      Z   (0=NO CONSTRAINT)
 288110          6         6      3
 288111          6         6      3
 290110          6         6      3
 290111          6         6      3
 292110          6         6      3
 292111          6         6      3
 293120          6         6      3
 294102          6         6      3
 296110          6         6      3
 296111          6         6      3
 297120          6         6      3
 298110          6         6      3
 299110          6         6      3
 299111          6         6      3

BLOCK CONTAINS  12 PHOTOGRAPHS AND   65 OBJECTS

PROGRAM PASS 1 LAST PLATE DZO IS  -.3014291E-04 DIVIDED BY  .5938125E-01
PROGRAM PASS 1 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF   .1001832E-01 FOR PLATE 293

PROGRAM PASS 2 LAST PLATE DZO IS   .9836336E-06 DIVIDED BY   .5717103E-01
PROGRAM PASS 2 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF  -.9886146E-03 FOR PLATE 289

PROGRAM PASS 3 LAST PLATE DZO IS  -.1579917E-07 DIVIDED BY  .5788628E-01
PROGRAM PASS 3 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF  -.1332512E-03 FOR PLATE 296

PROGRAM PASS 4 LAST PLATE DZO IS   .4289872E-08 DIVIDED BY   .5787685E-01
PROGRAM PASS 4 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF  -.3600510E-04 FOR PLATE 296

PROGRAM PASS 5 LAST PLATE DZO IS  -.3798135E-09 DIVIDED BY  .5787877E-01
PROGRAM PASS 5 PRODUCES A MAXIMUM ORIENTATION CORRECTION OF  -.7313948E-05 FOR PLATE 296

    PLATE       XO.            YO             ZO

       288  -212568.644  -167262.112   421918.350
       289  -175067.090  -136730.880   423734.409
       290  -136214.582  -107054.703   425036.943
       291   -99618.272   -73428.440   426552.677
       292   -62503.728   -47235.169   427155.800
       293   -22395.898   -13119.062   427359.469
       294    13053.297    13951.462   427610.488
       295    48517.492    49291.909   427063.759
       296    86692.365    76459.316   426677.202
       297   126788.565   111151.412   425606.606
       298   161820.156   130697.706   424551.076
       299   198498.585   168641.092   422904.608

    PLATE       OMEGA             PHI              KAPPA

       286     .2462385E-01    -.3925313E-01     .6067400E+00
       288     .9956953E+00     .9932293E+00     .7949004E+00
```

```
          289     .2056309E-01    -.3374767E-01     .6064451E+00
          289     .9997865E+00     .9994304E+00     .7951254E+00
          290     .1830683E-01    -.2309980E-01     .6062359E+00
          290     .9998324E+00     .9996850E+00     .7952649E+00
          291     .6856848E-02    -.2193608E-01     .6059955E+00
          291     .9999765E+00     .9997594E+00     .7954561E+00
          292     .1281470E-01    -.1641826E-01     .6059890E+00
          292     .9999179E+00     .9998304E+00     .7954730E+00
          293     .1431633E-03    -.6218802E-02     .6056331E+00
          293     .1000000E+01     .9999807E+00     .7957440E+00
          294     .3912340E-02    -.5802441E-02     .6046630E+00
          294     .9999923E+00     .9999632E+00     .7964814E+00
          295    -.1163633E-01    -.5493705E-02     .6047595E+00
          295     .9999323E+00     .9999849E+00     .7964005E+00
          296    -.1287806E-01     .1798298E-02     .6051827E+00
          296     .9999171E+00     .9999984E+00     .7960867E+00
          297    -.2250270E-01     .1243014E-01     .6048853E+00
          297     .9997468E+00     .9999221E+00     .7963126E+00
          298    -.2001792E-01     .1181435E-01     .6041539E+00
          298     .9997996E+00     .9999302E+00     .7968577E+00
          299    -.2335977E-01     .1497957E-01     .6046433E+00
          299     .9997271E+00     .9998878E+00     .7964964E+00
```

```
                    ***   INTERSECTION OF OBJECTS USED IN SOLUTION   ***
                           (SECANT PLANE COORDINATES - MICRONS)

OBJECT    X GROUND       Y GROUND      Z GROUND          IMAGE       VX PLATE RESID    VY PLATE RESID

288310   -175159.941   -178654.007    -3783.068       288288310          -.149              4.569
                                                      289288310           .147             -4.568
                                                           RMS OBJECT=   .3232136E+01 MICRONS

288320   -224533.782   -118960.309    -4350.547       288288320          -.035              1.137
                                                      289288320           .036             -1.137
                                                           RMS OBJECT=   .8042039E+00 MICRONS

288330   -196938.725   -154397.051    -3873.622       288288330          -.124              3.903
                                                      289288330           .125             -3.902
                                                           RMS OBJECT=   .2760765E+01 MICRONS

289310   -140968.327   -150574.857    -2564.325       288289310          7.206             31.507
                                                      289289310        -13.376            -14.702
                                                      290289310          8.169            -16.760
                                                           RMS OBJECT=   .1753481E+02 MICRONS

289320   -186866.970    -95485.277    -2601.182       288289320         -6.882             27.815
                                                      289289320         12.799              4.276
                                                      290289320         -5.876            -32.067
                                                           RMS OBJECT=   .1855604E+02 MICRONS

289330   -163941.845   -124266.507    -2443.416       288289330          -.528             30.417
                                                      289289330           .045               .612
                                                      290289330           .501            -30.986
                                                           RMS OBJECT=   .1773059E+02 MICRONS

△ 288110T -207169.956  -116985.134    -3424.735
△ 288110  -207159.931  -116964.805    -3657.839       288288110          -.133              4.255
              10.025        20.329     - 233.104      289288110           .136             -4.254
                                                           RMS OBJECT=   .3009886E+01 MICRONS

△ 288111T -176997.192  -175263.639    -3901.313
△ 288111  -177004.709  -175269.251    -3729.028       288288111          -.178              5.465
              -7.517        -5.612      172.285       289288111           .176             -5.464
                                                           RMS OBJECT=   .3865916E+01 MICRONS

           -207344.107  -117584.396    -3464.941
△-288201  -207333.116  -117576.669    -3661.657       288288201          -.097              3.101
              10.991         7.727     -196.716       289288201           .099             -3.100
                                                           RMS OBJECT=   .2193668E+01 MICRONS
```

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                -201278.692  -146855.736   -3874.837
△ 288100   -201266.954  -146866.219   -3905.180     288288100           -.098          3.089
                 11.738      -12.483      -30.343     289288100            .059         -3.088
                                                          RMS OBJECT=   .2165071E+01 MICRONS

                -199196.924  -121226.254   -3241.238
△ 288101   -199181.963  -121207.223   -3451.964     288288101           -.210          6.668
                 14.961       19.031     -210.726     289288101            .214         -6.664
                                                          RMS OBJECT=   .4716035E+01 MICRONS

                -200294.019  -122480.950   -3309.711
△ 288120   -200279.641  -122471.264   -3515.693     288288120           -.193          6.145
                 14.378        9.686     -205.982     289288120            .197         -6.142
                                                          RMS OBJECT=   .4346124E+01 MICRONS

                -178969.743  -176473.122   -3979.759
△ 288202   -178980.461  -176476.017   -3845.203     288288202           -.111          3.422
                -10.718       -2.895      134.556     289288202            .110         -3.421
                                                          RMS OBJECT=   .2420584E+01 MICRONS

  290310   -106548.364  -122833.069   -1039.850     289290310          -8.448         29.712
                                                    290290310          12.090         19.283
                                                    291290310          -3.719        -49.040
                                                          RMS OBJECT=   .2546531E+02 MICRONS

  290320   -152383.610   -63563.072   -1164.540     289290320            .067         12.399
                                                    290290320           -.787         -5.157
                                                    291290320            .741         -7.230
                                                          RMS OBJECT=   .6241998E+01 MICRONS

  290330   -131665.875   -96569.496    -899.691     289290330          -2.367         17.608
                                                    290290330           3.381         -3.560
                                                    291290330          -1.015        -14.040
                                                          RMS OBJECT=   .9468433E+01 MICRONS

  290110T  -145819.163   -64433.577    -962.699
△ 290110   -145821.193   -64426.763    -950.963     289290110           -.716         11.743
                 -2.030        6.814       11.736     290290110            .899         -5.985
                                                    291290110           -.169         -5.746
                                                          RMS OBJECT=   .5889054E+01 MICRONS

△ 290111T  -100287.221  -141707.209   -1430.977
  290111   -100286.078  -141713.583   -1517.218     289290111           -.006          2.551
                  1.143       -6.379      -86.241     290290111            .005         -2.545
                                                          RMS OBJECT=   .1801733E+01 MICRONS

                -145928.545   -64304.337    -966.024
△ 290201   -145925.244   -64306.415    -925.436     289290201           -.185         14.294
                  3.301       -2.078       40.588     290290201           -.377         -6.522
                                                    291290201            .543         -7.757
                                                          RMS OBJECT=   .7156405E+01 MICRONS
```

```
 291310     -73506.450   -91626.878      -629.069        290291310          -9.747              49.531
                                                         291291310          15.778             -34.368
                                                         292291310          -6.050             -15.182
                                                                RMS OBJECT=   .2860057E+02 MICRONS

 291320    -121335.359   -36081.667      -444.274        290291320          -2.976              34.124
                                                         291291320           4.270              13.212
                                                         292291320          -1.259              -7.310
                                                                RMS OBJECT=   .2451515E+02 MICRONS

 291330     -94988.940   -67968.199      -315.295        290291330          -5.054              33.280
                                                         291291330           9.535               1.613
                                                         292291330          -3.871             -34.861
                                                                RMS OBJECT=   .2026214E+02 MICRONS

 292310     -36515.376   -63241.457       449.438        291292310            .066              20.003
                                                         292292310           -.647                .606
                                                         293292310            .566             -20.573
                                                                RMS OBJECT=   .1172226E+02 MICRONS

 292320     -79693.386    -3100.307       295.041        291292320          -1.101             -15.172
                                                         292292320           1.278              22.173
                                                         293292320           -.163              -6.983
                                                                RMS OBJECT=   .1135391E+02 MICRONS

 292330     -60177.549   -36467.791       522.021        291292330           1.456              14.859
                                                         292292330          -2.995               -.601
                                                         293292330           1.552             -14.244
                                                                RMS OBJECT=   .8539582E+01 MICRONS

△ 292110T   -93656.711   -20679.874       333.841
  292110    -93657.861   -20673.281       295.369        291292110            .016                .505
                -1.150        6.593       -38.472        292292110           -.016               -.505
                                                                RMS OBJECT=   .3972315E+00 MICRONS

           -108297.906   -25295.089       110.910
△ 291120   -108298.113   -25288.198        32.891        291291120            .373              11.762
                -0.207        6.891       -78.019        292291120           -.373             -11.768
                                                                RMS OBJECT=   .8323276E+01 MICRONS

           -106952.115   -26681.925       119.998
△ 291121   -106939.471   -26688.740        94.786        291291121            .376              11.855
                12.644       -6.815       -25.212        292291121           -.375             -11.860
                                                                RMS OBJECT=   .8380516E+01 MICRONS
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△ 292111T    -27029.441   -79651.423      297.541
△ 292111     -27028.950   -79654.702      292.163        291292111              .029                .958
                 0.491       -3.279        -5.378        292292111             -.029               -.956
                                                                 RMS OBJECT=   .6772417E+00 MICRONS

  293310        -557.116   -33201.994      680.547        292293310            -2.875               2.025
                                                          293293310             6.135              -1.587
                                                          294293310            -3.271               -.437
                                                                 RMS OBJECT=   .3258629E+01 MICRONS

  293320      -46155.211    23748.689      755.439        292293320             -.172               54.404
                                                          293293320            -2.677              -25.514
                                                          294293320             2.998              -28.753
                                                                 RMS OBJECT=   .2724478E+02 MICRONS

  293330      -22306.105   -11480.969     1059.436        292293330             -.748               15.156
                                                          293293330              .735               -5.187
                                                          294293330              .030               -9.936
                                                                 RMS OBJECT=   .7707338E+01 MICRONS

              -3035.511    -51147.971      721.944
△ 293100      -3040.499    -51135.036      747.140        292293100              .021               -.421
                 -4.988        12.935       25.196        293293100             -.021                .421
                                                                 RMS OBJECT=   .2980114E+00 MICRONS

              -28172.927   -27112.861      834.668
△ 293110      -28159.653   -27103.189      821.656        292293110             -.352               7.091
                  13.274        9.672      -13.012        293293110              .352              -7.080
                                                                 RMS OBJECT=   .5016334E+01 MICRONS

△ 293120T     -4296.418    -52018.862      704.400
△ 293120      -4299.309    -52018.958      701.227        292293120             -.049                .965
                 -2.891        -0.096       -3.173        293293120              .048               -.963
                                                                 RMS OBJECT=   .6824631E+00 MICRONS

              -2743.370    -51871.929      707.371
△ 293121      -2734.791    -51864.219      701.808        292293121              .070              -1.385
                  8.579         7.711       -5.563        293293121             -.068               1.383
                                                                 RMS OBJECT=   .9797626E+00 MICRONS

  294310       31898.162    -4934.554      690.063        293294310             2.128               53.277
                                                          294294310            -8.526              -20.876
                                                          295294310             6.451              -32.427
                                                                 RMS OBJECT=   .2721705E+02 MICRONS

  294320       -3694.629   -43458.533      304.189        293294320             8.336               8.996
                                                          294294320           -17.449               2.727
                                                          295294320             9.112              -11.708
                                                                 RMS OBJECT=   .1066998E+02 MICRONS
```

```
 294330    15111.681   18897.434     550.016      293294330       6.616          27.264
                                                  294294330     -13.415         -21.197
                                                  295294330       6.834          -6.072
                                                       RMS OBJECT=   .1581093E+02 MICRONS

 294102T  -23669.361   37934.083     801.864
 294102   -23668.327   37935.490     804.347      293294102        .002           -.991
              1.034       1.407        2.332      294294102       -.003            .992
                                                       RMS OBJECT=   .7012278E+00 MICRONS

 295310    67366.805   22135.331      82.479      294295310      -4.769          11.168
                                                  295295310       8.057           4.448
                                                  296295310      -3.318         -15.607
                                                       RMS OBJECT=   .9006387E+01 MICRONS

 295320    32090.883   64818.444     330.914      294295320      -5.995          16.715
                                                  295295320       9.789          28.451
                                                  296295320      -3.809         -37.119
                                                       RMS OBJECT=   .1924273E+02 MICRONS

 295330    49365.290   49544.761     285.874      294295330      -3.558           -.723
                                                  295295330       7.263          23.595
                                                  296295330      -3.726         -22.823
                                                       RMS OBJECT=   .1387773E+02 MICRONS

 296310   104040.087   49038.235      87.815      295296310      -8.669          16.530
                                                  296296310      15.334          18.665
                                                  297296310      -6.736         -35.192
                                                       RMS OBJECT=   .1921706E+02 MICRONS

 296320    59972.357  107751.460    -348.662      295296320       1.360          -3.643
                                                  296296320      -2.538           1.108
                                                  297296320       1.177           2.534
                                                       RMS OBJECT=   .2258041E+01 MICRONS

 296330    78054.828   76365.232      94.902      295296330      -5.947          11.749
                                                  296296330      10.993           1.040
                                                  297296330      -5.066         -12.787
                                                       RMS OBJECT=   .8966062E+01 MICRONS

 296110T  105357.883   37358.925    -134.052
 296110   105353.664   37357.931    -104.927      295296110        .001           -.525
             -4.219      -0.994       29.125      296296110       -.000            .524
                                                       RMS OBJECT=   .3708215E+00 MICRONS

 296111T   67448.740   98930.886    -231.394
 296111    67450.678   98931.786    -238.805      295296111      -1.157           1.018
              1.938       0.900       -7.411      296296111       2.237          -1.125
                                                  297296111      -1.084            .108
                                                       RMS OBJECT=   .1260002E+01 MICRONS
```

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           75550.344    54100.713     226.922
△ 295100   75565.486    54087.760     156.211       295295100          -.014          11.393
              15.142      -12.953     -70.711       296295100           .006         -11.380
                                                         RMS OBJECT=   .6051476E+01 MICRONS

           67110.169    98609.407    -216.716
△ 296201   67109.161    98615.587    -213.343       295296201         -1.162           1.325
              -1.008        6.180       3.373       296296201          2.214           -.540
                                                    297296201         -1.055           -.785
                                                         RMS OBJECT=   .1292936E+01 MICRONS

  297310   136781.254    86353.340   -1159.746      296297310          -.447          45.128
                                                    297297310         -1.213         -35.761
                                                    298297310          1.657          -9.311
                                                         RMS OBJECT=   .2382777E+02 MICRONS

  297320   100539.722   133424.766   -1563.397      296297320         -3.332          52.275
                                                    297297320          4.436         -17.994
                                                    298297320          -.996         -34.204
                                                         RMS OBJECT=   .2664000E+02 MICRONS

  297330   119761.767   104510.673   -1230.994      296297330         -3.241          44.673
                                                    297297330          4.742         -26.463
                                                    298297330         -1.460         -18.152
                                                         RMS OBJECT=   .2256530E+02 MICRONS

  298310   176204.799   105752.504   -2617.263      297298310          1.402          21.888
                                                    298298310         -3.035         -22.784
                                                    299298310          1.656            .901
                                                         RMS OBJECT=   .1299309E+02 MICRONS

  298320   132263.976   162905.948   -3090.611      297298320         -5.011            .412
                                                    298298320         11.380           7.328
                                                    299298320         -5.366          -7.722
                                                         RMS OBJECT=   .7163833E+01 MICRONS

  298330   154437.310   140272.139   -2944.173      297298330         -5.729          12.990
                                                    298298330         10.638          -5.391
                                                    299298330         -4.858          -7.582
                                                         RMS OBJECT=   .8418980E+01 MICRONS

△ 297120T  127578.566   129930.492   -1756.009
  297120   127581.797   129937.544   -1893.776      297297120          -.055           3.226
               3.231        7.052    -137.767       298297120           .058          -3.226
                                                         RMS OBJECT=   .2281602E+01 MICRONS
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          127252.667   130856.770   -1768.812
△ 297121   127254.334   130858.812   -1904.261     297297121           -.046            2.700
            1.667        2.042      -135.449       298297121            .048           -2.700
                                                           RMS OBJECT=  .1909497E+01 MICRONS

▲ 298110T  156468.136    98126.586   -1843.117
  298110   156462.108    98122.969   -1757.118     297298110           -.033            1.924
           -6.028        -3.617       85.999       298298110            .035           -1.923
                                                           RMS OBJECT=  .1360382E+01 MICRONS

  299310   221333.928   118339.172   -4290.205     298299310           -.124            3.263
                                                   299299310            .120           -3.259
                                                           RMS OBJECT=  .2307715E+01 MICRONS

  299320   162683.562   191183.725   -4075.060     298299320           -.113            3.209
                                                   299299320            .112           -3.204
                                                           RMS OBJECT=  .2208768E+01 MICRONS

  299330   188418.605   168589.801   -4134.662     298299330            .059           -1.637
                                                   299299330           -.058            1.634
                                                           RMS OBJECT=  .1157261E+01 MICRONS

▲ 299110T  165981.068   175874.338   -3784.177
  299110   165977.778   175878.308   -3777.908     298299110           -.135            3.812
           -3.290         3.970        6.269       299299110            .134           -3.807
                                                           RMS OBJECT=  .2695222E+01 MICRONS

          180328.210   125649.347   -2988.252
△ 299100   180311.924   125630.652   -3126.692     298299100            .120           -3.276
          -16.286       -18.695     -138.440       299299100           -.118            3.272
                                                           RMS OBJECT=  .2316688E+01 MICRONS

▲ 299111T  213537.475   124932.816   -3997.981
  299111   213537.179   124931.293   -4024.813     298299111           -.031             .639
           -0.296        -1.523      -26.832       299299111            .031            -.638
                                                           RMS OBJECT=  .5935784E+00 MICRONS

 RMS RESIDUAL FOR ENTIRE BLOCK =   .1299558E+02 MICRONS
```

On all control: $RMS_x = \sqrt{\frac{2000.481761}{29}} = 8.306\,m$ $RMS_y = \sqrt{\frac{2328.910553}{29}} = 8.961\,m$ $RMS_{xy} = 12.218$ meters on ground

On withheld control: $RMS_x = \sqrt{\frac{1747.814214}{15}} = 10.794\,m$ $RMS_y = \sqrt{\frac{1658.125318}{15}} = 10.514\,m$ $RMS_{xy} = 15.068$ meters on ground

Note: 12.218 meters on ground = 12.915 microns @ plate scale

```
PLATE  RMS (MICRONS)

  288   .1072343E+02
  289   .8281893E+01
  290   .1812815E+02
  291   .1368011E+02
  292   .1512409E+02
  293   .1367805E+02
  294   .1198391E+02
  295   .1122428E+02
  296   .1943699E+02
  297   .1277646E+02
  298   .9159346E+01
  299   .3319604E+01
```

End of Table 7.

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PHOTO CONTROL STATION	X	Y	Z
△ 288100	11.738	-12.483	-30.343
▲ 288110	10.025	20.329	-233.104
△ 288201	10.991	7.727	-196.716
▲ 288111	-7.517	-5.612	172.285
△ 288202	-10.718	-2.895	134.556
△ 288120	14.378	9.686	-205.982
△ 288101	14.961	19.031	-210.726
▲ 290110	-2.030	6.814	11.736
△ 290201	3.301	-2.078	40.588
▲ 290111	1.143	-6.379	-86.241
△ 291120	-0.207	6.891	-78.019
△ 291121	12.644	-6.815	-25.212
▲ 292110	-1.150	6.593	-38.472
▲ 292111	0.491	-3.279	-5.378
△ 293100	-4.988	12.935	25.196
▲ 293120	-2.891	-0.096	-3.173
△ 293121	8.579	7.711	-5.563
△ 293110	13.274	9.672	-13.012
▲ 294102	1.034	1.407	2.332
△ 295100	15.142	-12.953	-70.711
▲ 296111	1.938	0.900	-7.411
△ 296201	-1.008	6.180	3.373
▲ 296110	-4.219	-0.994	29.125
▲ 297120	3.231	7.052	-137.767
△ 297121	1.667	2.042	-135.449
▲ 298110	-6.028	-3.617	85.999
△ 299100	-16.286	-18.695	-138.440
▲ 299110	-3.290	3.970	6.269
▲ 299111	0.296	-1.523	-26.832

Note: ▲ = weighted photo control station
△ = unweighted photo control station

Table 8. Residual errors in meters remaining at each of the computed positions for the 29 office-identified photo control stations after block adjustment solution, as expressed in the secant plane coordinate system.

The block adjustment program is designed to terminate the iterative computation when the computed corrections to all of the angular camera parameters are each less than 0.00001 radians (two arc-seconds). Table 7 shows that five iterations of the block adjustment orientation solution were required to achieve this condition for the SKYLAB study. Usually, only one such pass through the solution is necessary in conventional NOS mapping projects employing metric photography and field-identified photo control.

The residual errors at the control stations appear to be uniformly distributed throughout the test area, and there is no evidence that the least square solution was not able to absorb uncompensated systematic error, i.e., no large isolated discrepancies exist in the solution. The horizontal position geodetic RMS error for the 29 photo control stations was 12.218 meters and is equivalent to 12.915 microns at the SKYLAB photography scale of 1:946,000. The geodetic RMS error computed for only the 15 withheld photo control stations was 15.068 meters. The maximum horizontal position error was 24.794 meters and occurred at withheld station No. 299100. No serious attempt was made to hold closely to the elevations of the control stations because of the inherent limited accuracy in the stereo height determination. Consequently, several of the residual errors in $\underline{Z}$ exceeded -200 meters.

The photogrammetric RMS error was 12.996 microns at plate scale and was computed using the residual v_x and v_y plate discrepancies of all the images created on the photography by the 36 pass points and the 29 photo control stations. It should be noted that the photogrammetric RMS error is usually about eight microns on conventional NOS photogrammetric mapping projects.

<u>Inverse of the Secant Plane Coordinate Transformation</u>: After completion of the block adjustment solution, the adjusted computed secant plane coordinates were transformed back into the original ground coordinate system (Geographic Positions and elevations based on sea level) by applying the secant plane transformation in its inverse mode. The results of this inverse computation are displayed in Table 9.

Table 9.

SECANT PLANE COORDINATES - OUTPUT OF BLOCK ADJUSTMENT IN METERS

PASS POINTS

	X	Y	Z
288310	-175159.941	-178654.007	-3783.068
288320	-224533.782	-118960.309	-4350.547
288330	-196938.725	-154397.051	-3873.622
289310	-140968.327	-150574.857	-2564.325
289320	-186866.970	-95485.277	-2601.182
289330	-163941.845	-124266.567	-2443.416
290310	-106548.364	-122833.069	-1039.850
290320	-152383.610	-63563.072	-1164.540
290330	-131685.875	-96569.496	-899.891
291310	-73506.450	-91626.878	-629.069
291320	-121335.359	-36081.667	-444.274
291330	-94988.940	-67988.199	-315.295
292310	-36515.376	-63241.457	449.438
292320	-79693.386	-3100.307	295.041
292330	-60177.549	-36467.791	522.021
293310	-557.116	-33201.994	880.547
293320	-46155.211	23748.689	755.439
293330	-22306.105	-11480.969	1059.436
294310	31898.162	-4934.554	690.663
294320	-3694.629	43458.533	304.189
294330	15111.681	18897.434	550.016
295310	67366.805	22135.331	82.479
295320	32090.883	64818.444	330.914
295330	49365.290	49544.761	285.874
296310	104040.087	49038.235	87.815
296320	59972.357	107751.460	-348.662
296330	78054.828	76365.232	94.902
297310	136781.254	86353.340	-1159.746
297320	100539.722	133424.766	-1563.397
297330	119761.767	104510.673	-1230.994
298310	176204.799	105752.504	-2617.263
298320	132263.976	162905.948	-3090.611
298330	154437.310	140222.139	-2944.173
299310	221333.928	118339.172	-4290.205
299320	162683.562	191183.725	-4075.060
299330	188418.605	168589.801	-4134.662

14 HELD CONTROL STATIONS

288110	-207159.931	-116964.805	-3657.839
288111	-177004.709	-175269.251	-3729.028
290110	-145821.193	-64426.763	-950.963
290111	-100286.078	-141713.588	-1517.218
292110	-93657.861	-20673.281	295.369
292111	-27028.950	-79654.702	292.163
293120	-4299.309	-52018.958	701.227
294102	-23668.327	37935.490	804.347
296110	105353.664	37357.931	-104.927
296111	67450.678	98991.786	-238.805
297120	127581.797	129937.544	-1893.776
298110	156462.108	98122.969	-1757.118
299110	165977.778	175878.308	-3777.908
299111	213537.179	124931.293	-4024.813

15 WITHHELD CONTROL STATIONS

288100	-201266.954	-146868.219	-3905.180
288101	-199181.963	-121207.223	-3451.964
288120	-200279.641	-122471.264	-3515.693
288201	-207333.116	-117576.669	-3661.657
288202	-178980.461	-176476.017	-3845.203
290201	-145925.244	-64306.415	-925.436
291120	-108298.113	-25288.198	32.891
291121	-106939.471	-26688.740	94.786
293100	-3040.499	-51135.036	747.140
293110	-28159.653	-27103.189	821.656
293121	-2734.791	-51864.218	701.808
295100	75565.486	54087.760	156.211
296201	67109.161	98615.587	-213.343
297121	127254.334	130858.812	-1904.261
299100	180311.924	125630.652	-3126.692

GEOGRAPHIC POSITIONS - OUTPUT OF BLOCK ADJUSTMENT

PASS POINTS

	LATITUDE	LONGITUDE	Elevation (feet)
288310	34 42 26.38609	- 80 39 43.87202	1096.07686
288320	35 14 6.91221	- 81 13 2.76273	-279.18950
288330	34 55 18.68739	- 80 54 20.37638	796.27163
289310	34 57 57.28077	- 80 17 37.42388	-70.44538
289320	35 27 17.25727	- 80 48 31.79789	176.23997
289330	35 11 58.24487	- 80 33 1.74416	259.67279
290310	35 13 13.48098	- 79 55 13.16051	783.04996
290320	35 44 54.64260	- 80 26 5.64609	572.11904
290330	35 27 14.74808	- 80 12 2.23300	1293.58307
291310	35 30 16.84703	- 79 33 36.97538	-1124.96987
291320	36 0 1.95660	- 80 5 44.95660	44.75680
291330	35 42 57.32927	- 79 47 59.30026	-139.43936
292310	35 45 45.64825	- 79 9 13.58220	233.10629
292320	36 18 7.55350	- 79 38 14.22851	-13.95916
292330	36 0 10.10432	- 79 25 2.77197	370.14007
293310	36 2 2.81021	- 78 45 22.25265	557.46828
293320	36 32 46.46501	- 79 15 55.66983	555.24755
293330	36 13 46.60473	- 78 59 53.15875	1021.67941
294310	36 17 18.00507	- 78 23 41.73789	-82.35886
294320	36 43 29.95754	- 78 47 28.89599	-1127.14234
294330	36 30 12.68101	- 78 34 52.74101	-660.65358
295310	36 31 49.66979	- 77 59 51.81921	-1053.04192
295320	36 55 .94303	- 78 23 23.53281	-181.68449
295330	36 46 42.80926	- 78 11 49.19933	-418.66557
296310	36 46 10.50551	- 77 35 4.84073	1073.23836
296320	37 18 8.87137	- 78 4 24.81194	159.90532
296330	37 1 5.88875	- 77 52 22.45203	765.15397
297310	37 6 6.14785	- 77 12 40.16500	309.91260
297320	37 31 49.55763	- 77 36 44.86165	-554.28613
297330	37 16 3.46029	- 77 23 58.88423	-151.24184
298310	37 16 12.17141	- 76 45 46.80372	-338.95441
298320	37 47 32.17061	- 77 14 53.24438	-1411.50456
298330	37 35 4.08519	- 77 0 4.26612	-1072.32185
299310	37 22 26.46691	- 76 15 1.24412	-487.89597
299320	38 2 32.00796	- 76 53 47.32371	248.66309
299330	37 50 1.81199	- 76 36 33.11741	277.17958

14 HELD CONTROL STATIONS

288110	35 15 25.53695.	- 81 1 37.17181	-56.53923
288111	34 44 15.06445	- 80 40 58.91790	1130.99762
290110	35 44 30.27598	- 80 21 43.80370	798.41836
290111	35 3 2.98861	- 79 50 57.40463	173.57077
292110	36 8 32.95024	- 79 47 26.25236	716.77843
292111	35 36 54.17346	- 79 2 53.97097	167.48599
293120	35 51 52.23900	- 78 47 51.36030	387.59883
294102	36 40 29.64527	- 79 0 53.15813	538.16070
296110	36 39 51.15007	- 77 34 17.49878	251.29327
296111	37 13 22.87241	- 77 59 24.02989	297.80444
297120	37 29 44.66704	- 77 18 25.65847	-290.11984
298110	37 12 17.00557	- 76 59 14.24742	393.36137
299110	37 54 13.47135	- 76 51 44.87622	51.63104
299111	37 26 6.62123	- 76 20 11.53555	-75.09492

15 WITHHELD CONTROL STATIONS

288100	34 59 19.78010	- 80 57 17.56339	550.25723
288101	35 13 13.88282	- 80 56 17.75518	46.38242
288120	35 12 32.05602	- 80 57 .06754	29.57440
288201	35 15 5.55994	- 81 1 43.45203	-13.58050
288202	34 43 34.58196	- 80 42 15.70143	1040.36233
290201	35 44 34.13316	- 80 21 47.99968	885.94229
291120	36 5 57.72387	- 79 57 9.57444	669.99247
291121	36 5 12.83931	- 79 56 14.54521	816.69433
293100	35 52 20.94618	- 78 47 1.19852	512.32645
293110	36 5 19.20237	- 79 3 45.55598	472.98178
293121	35 51 57.27979	- 78 46 49.00424	382.53015
295100	36 49 3.99475	- 77 54 11.05976	118.26105
296201	37 13 10.74701	- 77 59 38.01136	350.34280
297121	37 30 14.71046	- 77 18 38.41834	-283.95531
299100	37 26 54.19126	- 76 42 42.61679	-446.64844

End of Table 9.

Accuracy Analysis: In order to evaluate fully the accuracy potential of the analytic system, a final computer program is used to develop the inverse of the matrix of normal equations, the variances, and the standard errors in X, Y, and Z at all of the points throughout the project area.

It can be assumed that the camera parameters and the ground positions of the pass points provided by the final pass through the block adjustment solution would not change significantly should an additional pass be made. Thus the same refined image coordinates, together with the final camera parameters and ground positions for the pass points, will yield essentially the same normal equations that occurred in the final block adjustment pass. This is the basis for the accuracy-analysis program.

The standard error E of the coordinates determined at a point in the block can be expressed as $E = Qe$ where Q is the variance of the point as derived from the inverse, and e is the standard error of unit weight for the problem and is considered to be essentially equal to the photogrammetric RMS error determined in the block adjustment solution. Both Q and e are relatively independent and provide a means for the comparison of tests conducted under varying conditions.

The variance Q is affected by the geometry of the block, such as the number of photographs and the number and distribution of horizontal and vertical control. Its value can be computed from simulated photographs before the pictures are actually taken and is unaffected by poor techniques. The standard error of unit weight e is a measure of the precision of the system and is affected by the camera, comparator, effectiveness of the corrections for systematic errors, overlap, premarking, operational techniques, etc. Its value is relatively constant for a given set of techniques and allows one to upgrade the system by improving the techniques. Thus, for example, the nonmetric characteristics of the Earth Terrain Camera and the use of office-identified photo control resulted in a standard error of unit weight of nearly 13 microns for the SKYLAB study. This is significantly larger than the eight microns or less that is found in NOS operations employing metric aerial cameras and field-identified photo control.

Table 10 shows the horizontal standard errors in meters in the secant plane coordinate system for each of the 15 withheld (unweighted) photo control stations. The horizontal position RMS error computed from these values is 16.414 meters and substantiates the validity of the geodetic RMS errors found in the previous block adjustment solution.

PHOTO CONTROL STATION	X meters	Y meters
288100	9.201	9.529
288201	9.961	15.053
288202	10.164	12.360
288120	9.003	13.679
288101	8.916	14.029
290201	7.271	10.185
291120	13.554	16.164
291121	13.158	15.701
293100	15.650	11.110
293121	15.736	11.260
293110	9.967	9.494
295100	9.377	10.147
296201	7.949	7.844
297121	10.949	8.993
299100	9.084	13.678

$\mathrm{RMS}_X = 10.963 \quad \mathrm{RMS}_Y = 12.216$

$\mathrm{RMS}_{XY} = 16.414$ meters

Table 10. The standard errors in meters in the secant plane coordinate system for each of the 15 withheld (unweighted) photo control stations.

FURTHER DISCUSSION OF SKYLAB ANALYTIC AEROTRIANGULATION RESULTS

In evaluating the results of the SKYLAB aerotriangulation study, it must be remembered that these results were achieved using a strip of photography instead of a block of overlapping strips of pictures. For the case of a strip, analytic computations are usually terminated after strip adjustment because there is no evidence of a significant improvement in accuracy by continuing on through block adjustment. However, the strip adjustment of the SKYLAB photography appeared to show apparently systematic adjustment discrepancies that were assumed to be attributable to a failure to compensate completely for the systematic errors introduced by the nonmetric characteristics of the camera and/or the office-identification of photo control. For this reason, the block adjustment program was applied in an effort to optimize the accuracy of the aerotriangulation solution.

The results obtained from the block adjustment were reasonably close to the values to be expected from the SKYLAB photography. Our experience indicates that the block adjustment of a strip of metric 1:946,000 scale photography using field-identified photo control would yield a geodetic RMS error of approximately 14 meters. This figure must be modified to allow for the additional errors introduced by the nonmetric characteristics of the Earth Terrain Camera (focal plane shutter, camera lens distortion assumed to be negligible, imprecise location of the photograph principal point, etc.) and the office-identification of photo control. Assuming a maximum error of 20 meters introduced by the ETC and a maximum error of 15 meters for the office-identified photo control, the overall expected geodetic RMS error for the block adjustment of the SKYLAB strip of pictures increases to nearly 16 meters. As noted in this report, the actual geodetic RMS error was 12.218 meters for all 29 office-identified photo control stations and 15.068 meters for the 15 withheld or unweighted photo control stations.

The National Standards of Map Accuracy require 90 percent of all map points to be correct to within 1/50 inch or 0.51 mm. for maps published at scales of 1:20,000 or smaller. Statistically, the SKYLAB results indicate that 90 percent of all 29 office-identified photo control stations were held to within 20 meters, and 90 percent of the 15 withheld or unweighted stations were held to within 24.7 meters. It is evident, therefore, that if the positions of all the planimetric detail required to construct a map of the project area were developed digitally by analytic block adjustment methods, 90 percent of these planimetric points would also be correct to within less than 25 meters. Thus, the analytic aerotriangulation method can be used in this manner with the 1:946,000 scale SKYLAB strip photography to construct a 1:50,000 scale map that will meet the National Standards of Map Accuracy.

The usual practice in mapping operations is to compile the planimetric details from stereoscopic models oriented to horizontal photo control established principally by analytic aerotriangulation procedures. Experience has shown that 90 percent of the horizontal photo control should be known to within 0.15 mm., as measured on the manuscript. This is equivalent to 24.75 meters at a map scale of 1:165,000. Thus, stereocompilation techniques can be combined with the analytic aerotriangulation methods to construct a map at 1:150,000 to 1:200,000 scale from the 1:964,000 SKYLAB strip photography.

Appendix A

THE SKYLAB S-190B EARTH TERRAIN CAMERA

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Ottawa, Canada
July 23-August 5, 1972

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THE SKYLAB S-190B EARTH TERRAIN CAMERA

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McLean, Va. 22101

One of the major objectives of the Skylab manned space station to be launched in 1973 is to collect earth resources data. The Earth Resources Experiment Package (EREP) of Skylab includes instruments for collecting data in several regions of the electromagnetic spectrum, ranging from the visible to the microwave. The sensors include the S-190A multispectral camera, the S-191 infrared spectrometer, S-192 multispectral scanner, the S-193 microwave system, and the S-194 L-band radiometer. These systems have all been described elsewhere (NASA-MSC, 1971). However, a new sensor, the S-190B Earth Terrain Camera (ETC), has recently been added to EREP. Because the ETC is not as well known as the other sensors, I will describe its characteristics and indicate some potential applications of ETC photographs.

The ETC was included in the EREP of the Skylab mission as an addendum to the S-190 experiment. It is designed to supply high-resolution photographs of areas within the field of view of the other EREP sensors to aid in the interpretation of data gathered by them. In some cases information from the ETC photographs will substitute for ground truth and for photographs obtained from aircraft underflights Furthermore, the resolution of the camera will permit certain investigations that would be impossible for any of the other EREP sensors alone.

The EROS (Earth Resources Observation Systems) Program of the Department of the Interior is interested in the ETC primarily because it has approximately the same photograph scale and ground resolution as the film-return satellite camera system which was recommend in 1967 by the National Academy of Sciences for cartographic and photogrammetric applications. That proposed satellite would be in a near-polar orbit at an altitude of 200 km and would include a metric camera of 300 mm focal length. In 1970 the Department of Interior proposed to NASA that a satellite of that type be flown, and we have a continued interest in it.

The ETC is a modified version of the Lunar Topographic Camera carried on the Apollo 13 and 14 missions. It is being built by Actron Industries, Inc. (formerly Hycon) under contract to NASA. The body is an extensively modified KA-74 reconnaissance camera body with a focal-plane shutter and vacuum film flattening. The lens has a focal length of 460 mm, a fixed aperture of f/4, color correction, and maximum radial distortion of 10 μm. Forward image-motion compensation is provided by rocking the entire camera in its mount during the exposure.

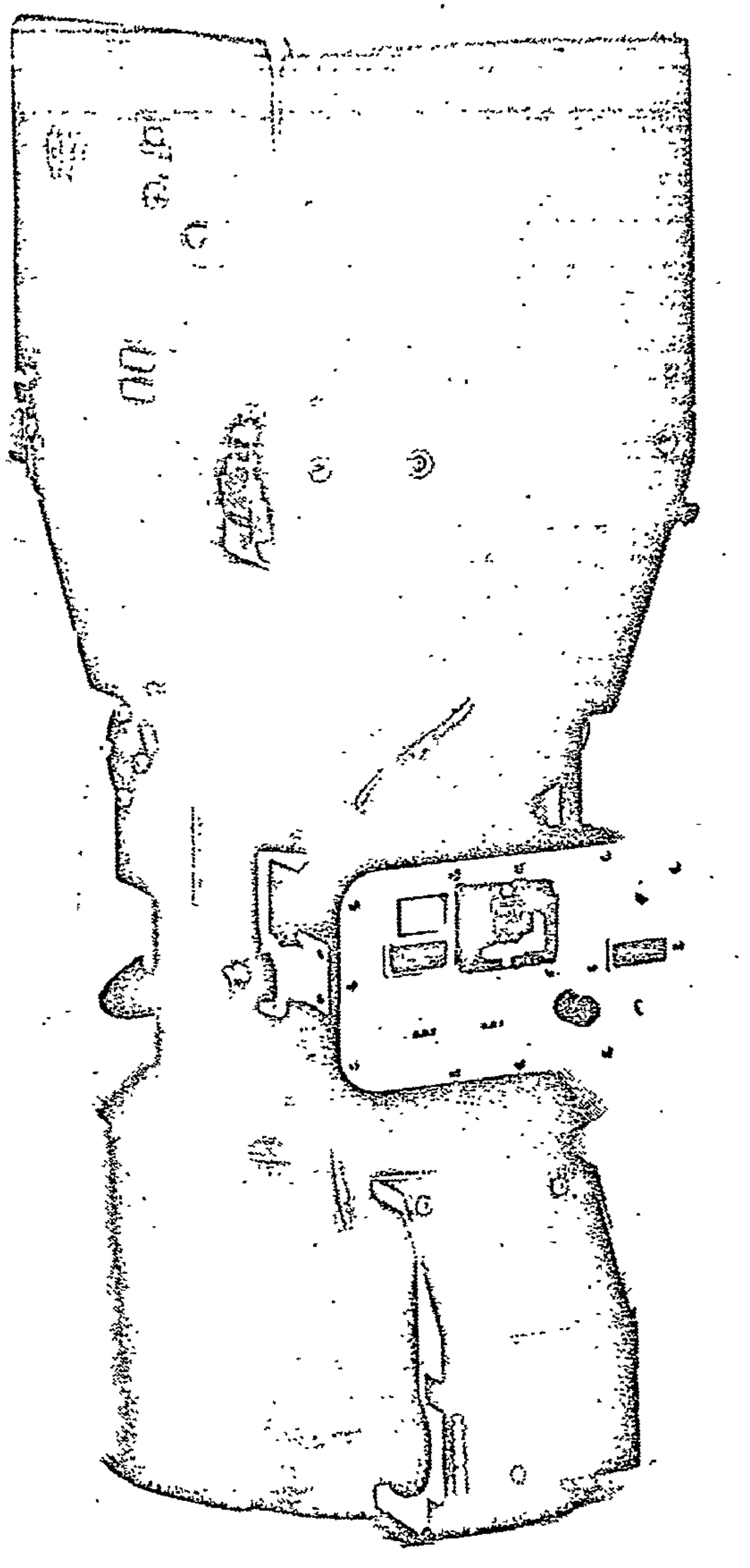

Figure 1.--The Skylab S-190B Earth Terrain Camera.

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The frame format is 115 mm by 115 mm so that at the Skylab altitude the format covers an area of 109 km by 109 km. Characteristics of the camera can be summarized as follows:

Lens--460 mm focal length, f/4 fixed aperture, color corrected

Lens distortion--Radial, ± 10 μm; tangential, ± 5 μm

Shutter--Focal plane, bidirectional; 1/100, 1/140, 1/200 sec.

Forward-motion compensation--By rocking camera, 0 to 25 mrad/sec.

Film--125 mm (5 in.), 2-mil base; 450 frames/roll

Format--115 x 115 mm

Framing rate--0 to 25 frames/min.

Overlap--15% Standard; 0 to 80% availabl

Ground coverage at nadir--109 x 109 km.

The camera has a control box with a switch for selection of manual or automatic operation. The forward-motion compensation system can be set to operate within the range of 0 to 25 mrad/sec, and the framing rate from 0 to 25 frames/min. Three shutter speeds are available, 1/100, 1/140, and 1/200 sec. Figure 1 is a photograph of the camera.

The ground resolution of the camera depends on the film used. The three films being considered are SO-242 high-resolution color, 3443 color infrared, and 3414 high-resolution black-and-white. To obtain estimated ground resolution for the different films, Actron has run computer simulations that model the forward-motion compensation system, the attitude-error rates of the spacecraft, the shutter speed, the lens characteristics, and the film and filter characteristics. Table 1 summarizes the simulations (the shutter speeds were subsequently changed). As can be seen, the expected ground resolution varies from 10 to 39 meters per optical line pair. In addition to the films listed, it is possible that a color infrared film of higher resolution will be available for at least one of the Skylab missions.

The ETC will be mounted in the Scientific Airlock of the orbital workshop of Skylab. The other EREP sensors will be located in the Multiple Docking Adapter. Figure 2 presents a view of the Skylab space station with the major components indicated. The ETC will be boresighted to record the same ground areas that the other EREP sensors are viewing.

Skylab will be operated as four missions (fig. 3). The first mission, Skylab 1, will launch the unmanned space station. The next day the first three-man crew will be launched in an Apollo spacecraft as mission Skylab 2, which will require the crew to occupy the space

TABLE 1. Predicted ETC resolution, in meters on the ground per optical line pair.

Case	Film	Shutter speed (sec)	High-contrast resolution (1000:1)	Low contrast resolution (2:1)
1	3443	1/100	21	39
2	3443	1/200	21	38
3	3443	1/500	21	38
4	3414	1/100	8	15
5	3414	1/200	6	11
6	3414	1/500	5	10
7	SO-242	1/100	12	22
8	SO-242	1/200	11	20
9	SO-242	1/500	11	20

Based on computer simulations by Actron Industries, Inc., July 1971.

station for about 28 days. The crew will conduct several experiments, including the EREP series. About 2 months after the return of the Skylab 2 crew, the Skylab 3 crew will be launched to occupy the space station for as long as 56 days, again conducting a variety of experiments. The final mission, Skylab 4, will start about 1 month after the return of the Skylab 3 crew and will also have a duration of up to 56 days.

Skylab will follow a 435 km circular orbit with an inclination of 50° which will carry the station over any portion of the earth between 50°N and 50°S latitude. The normal attitude of the space station is referred to as the solar-inertial mode, required by the solar panels and the heating constraints. For the EREP experiments the space station must be maneuvered into the z-local-vertical mode. Because of thermal and other constraints, the mode can only be used for a limited number of orbits. Current plans call for approximately 60 z-local-vertical passes.

The orbital and mission constraints will thus limit the number and location of EREP data-collection passes; it will not be possible to collect data for large contiguous areas, and repetitive coverage of an area will be limited. Nevertheless, considerable data of value to various earth resources investigations should be collected during the

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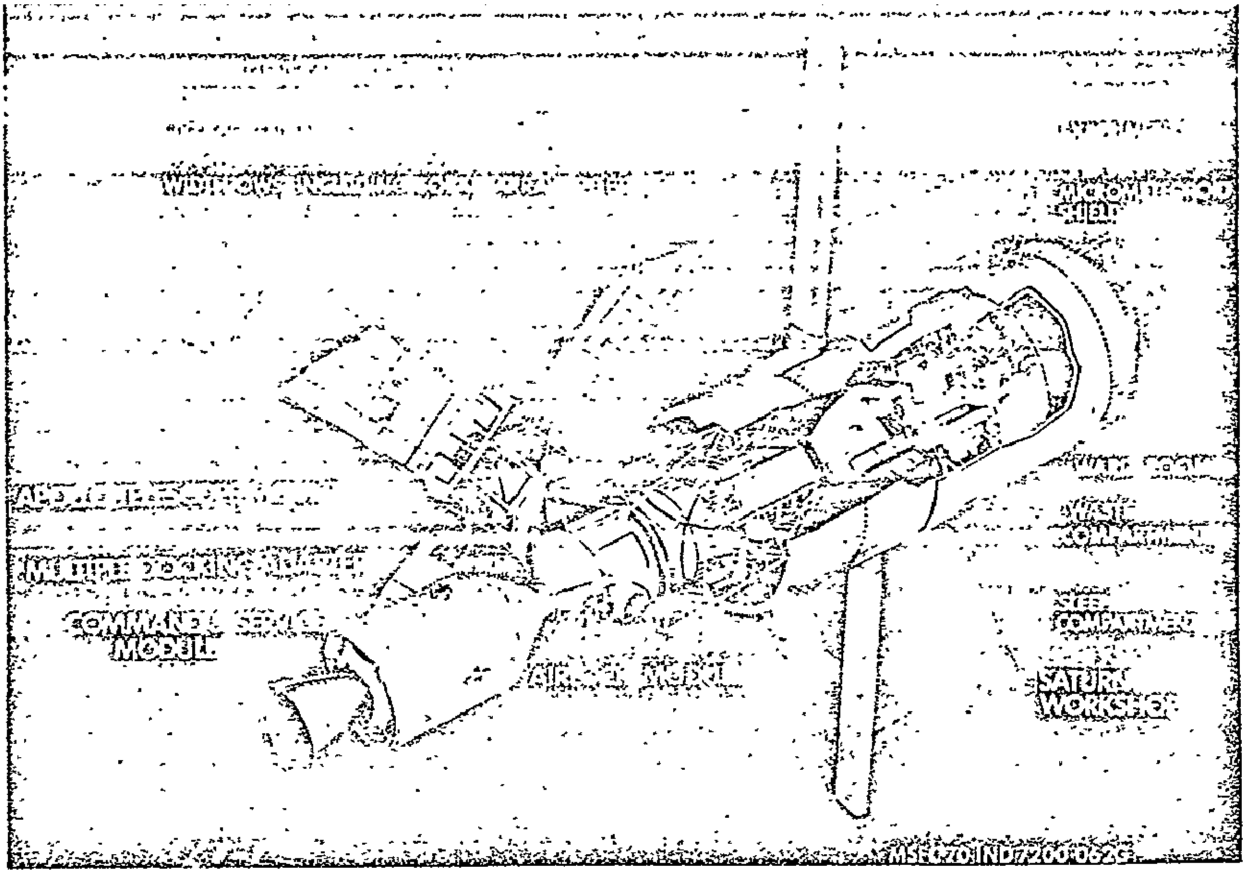

Figure 2.--The Skylab spacecraft.

Skylab program. For the Skylab 2 mission, 4 rolls of film containing 450 frames each will be available, and 6 rolls will be available for each of the other 2 missions. As many as 7200 ETC photographs may be obtained.

The exact areas of the United States where ETC photographs will be acquired have not yet been selected. Generally, the final areas for photographic coverage will be determined during the mission. Investigators whose EREP proposals were accepted by NASA have been notified of the addition of the ETC to Skylab, and many of them have requested ETC photographs of their test areas. In addition, many Federal and State agencies have requested ETC photographs of specific areas. The requests are being coordinated with the Skylab mission planners in an effort to take photographs of as many areas of interest as orbits, weather, and other constraints will permit. ETC photographs will be available to the public at nominal cost through the EROS Data Center of the U.S. Geological Survey, at Sioux Falls, S. Dak.

The design of the ETC will limit its applications. First, the ETC is not a metric camera in the photogrammetric sense. Because the image frame is a part of the removable film magazine and because of the use of a focal-plane shutter, the geometric quality of the photographs is limited. The principal point cannot be precisely located, and

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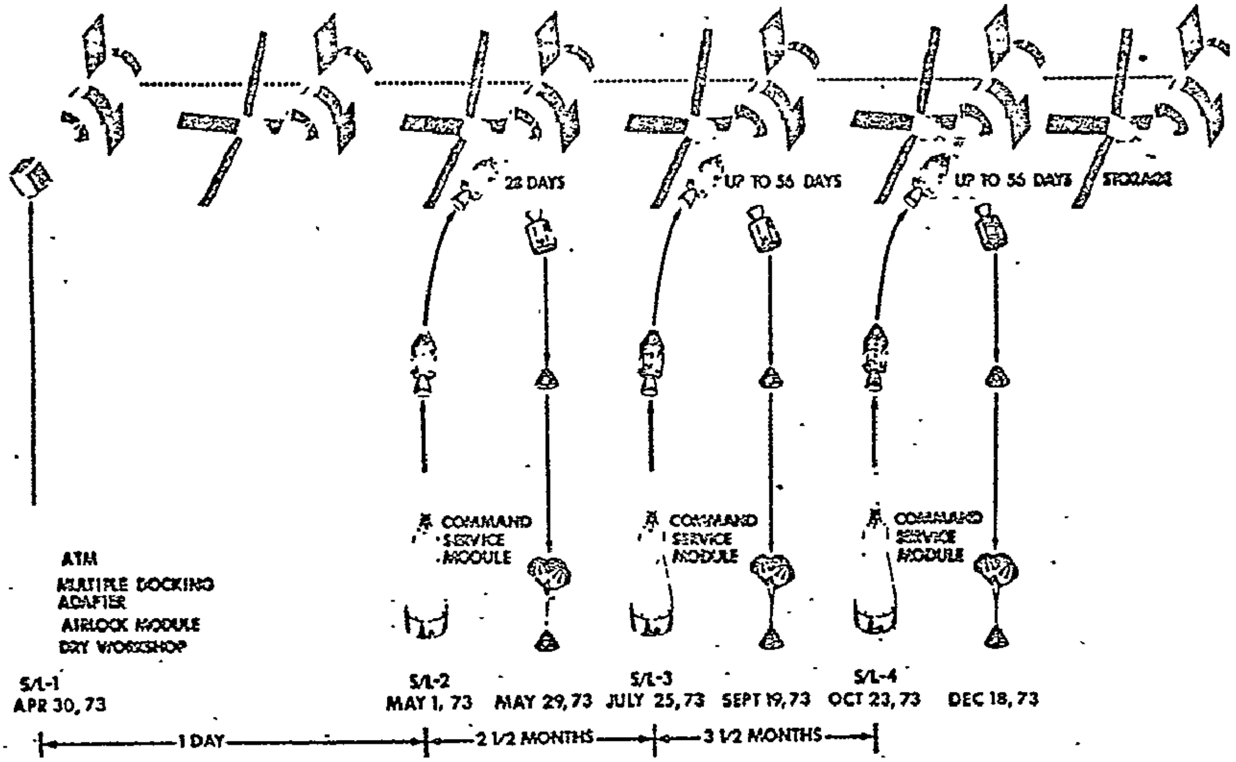

Figure 3.--Sequence of Skylab missions.

therefore analytical applications will be limited. The ETC has a limited field of view, 14°. When the camera is operated for 60% overlap, the base-height ratio is only 0.15; thus, the use of the ETC for stereoscopic height determination will be especially limited.

In spite of the limitations, the ETC represents a significant advance in camera systems for earth resources observations from space. The ground resolution is considerably better than that of any camera previously used. A recent paper by Colvocoresses (1972) compares the image resolution of ERTS, Skylab, and Gemini/Apollo space photographs. Table 2, compiled from data in that paper, summarizes the ground resolution of the various systems. From the tabulated data, it is obvious that the ETC has ground resolution from 3 to 20 times better than the other space photographic systems. Moreover, the ETC fills the gap between the other space systems and high-altitude aircraft cameras, which normally have ground resolution of 1 m or better.

The ETC will also permit a comparison of multispectral and multispatial data collection. The S-190A multispectral camera will provide narrow-spectral-band photographs useful for multispectral interpretation. The ETC, on the other hand, will provide photographs of a different

TABLE 2. Comparison of Ground Resolution for Space Imaging Systems. Ground resolution given in terms of the photographic criterion of optical line pairs, in meters on the ground per line pair.

System	High-contrast (100:1 or 1000:1)	Low-contrast (2:1 or 1.6:1)
ERTS-A		
RBV, green band	126	180
RBV, red band	126	180
RBV, infrared band	156	275
MSS	244	316
Skylab		
S-190A		
High-resolution film	22	38
Low-resolution film	49	99
S-190B (ETC)		
High-resolution film	10	15
Low-resolution film	20	38
Gemini/Apollo		
High-resolution film	50	70
Low-resolution film	80	125

scale and resolution, which can be compared with the S-190A photographs and thus provide an evaluation of multispatial data.

The S-190A and ETC photographs may also be used with aircraft photographs for multistage sampling, a technique that starts with the interpretation and classification of small-scale photographs of a large region. Interpretations are made on progressively larger scale photographs of smaller and smaller areas within the large region. The application of the technique in forestry has been described by Langley (1969).

Therefore, the principal applications of ETC photographs will be in experiments where high resolution is required. Each individual photograph will be a nearly orthographic view of the ground, with

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rather low distortion within the frame. The high resolution will greatly benefit experiments in which photointerpretation is important.

An example of the kind of experiment planned for the ETC photographs is photomapping at 1:250,000 and 1:100,000 scale. The image scale of the ETC photographs will be about 1:945,000. Doyle (1971) has proposed criteria for the resolution required for photomapping and the useful enlargement of the photographs:

$$R_g = 10^{-4} S_m$$

where R_g = required ground resolution (m/lp)

S_m = map scale number.

The suggested criterion for photographic enlargement is expressed as

$$M_a = \frac{rp}{10}$$

where rp = original photo resolution (lp/mm)

M_a = allowable enlargement from photograph scale.

According to criteria, the required ground resolution for 1:250,000 and 1:100,000 scale photomaps is 25 m and 10 m. Assuming the use of 3414 film, the approximate photograph resolution is 80 lp/mm and the allowable enlargement is 8X. Enlargement to 1:250,000 scale would require 3.8X and to 1:100,000 would require 9.5X. At 1:100,000 scale the image would still have a theoretical resolution of 8 lp/mm, which may be satisfactory in the practical sense.

The U.S. National Map Accuracy Standards (NMAS) require that 90% of the well defined points tested be no more than 0.5 mm from their correct position at map scale. For a 1:250,000-scale map the tolerance converts to 125 m while for a 1:100,000-scale map it is 50 m. A computer program prepared by DBA Systems, Inc., for the Geological Survey has been used to determine how much relief can be tolerated before planimetric image displacement exceeds NMAS. The program includes the effects of earth curvature, atmospheric refraction, terrain relief, location of the image in the photograph format, and map-projection scale factor. The computer analysis indicates that about 500 m of relief can be tolerated at the extremes of the usable photo format for the photograph to meet the standards for 1:250,000-scale mapping. For mapping at 1:100,000 scale, only about 300 m of relief can be tolerated. The UTM was used as the map projection in the analysis.

Conditions which could significantly affect the positional accuracy of the images, however, are the effects of the focal-plane shutter and of errors in the forward motion compensation (FMC) system.

A NASA study (McDermit, 1971) considered the effects of spacecraft residual rates, FMC errors, earth rotation, shutter type, and spacecraft rigidity. The study concluded that, in the worst case, errors due to the sources considered would amount to about 35 μm displacement between the leading and trailing edge of an image. That is, the dimension of a discrete image will be changed 35 μm in the direction of motion. Much of the error could be reduced by proper operation of the camera, but a random component of about 22 μm would probably remain, equivalent to 21 m on the ground. Thus, there is some question whether the 1:100,000 positional accuracy requirement can be met. Maps at the scale of 1:250,000, however, appear to be well within the capability of the camera. The USGS plans to conduct photomapping experiments at both scales in order to determine the usefulness of space photographs of ETC resolution.

Other mapping experiments planned for the ETC photographs include map revision and thematic mapping. Experiments will be conducted to determine the types of map revision information that can be derived from the photographs and applied to maps at scales of 1:24,000 and smaller.

Thematic mapping consists of the preparation of maps depicting such data as vegetation distribution, surface-water distribution, snow cover, and the massed works of man. Thematic mapping experiments at scales of 1:250,000 and 1:100,000 are planned, using color infrared photographs as the most suitable input for this kind of mapping.

ETC photographs will also be used for land-use mapping; urban development studies; sediment loads and dynamics of San Francisco Bay; geological synthesis of the Colorado Plateau; study of hazards and tectonics in the Cascades volcanoes; marine geology of the Pacific Northwest; and geologic studies of areas in California, Oregon, Oklahoma, and a portion of the Great Plains. The experiments will depend largely on photointerpretation of the ETC photographs. Some will require normal color photographs while others will require color infrared photographs. One of the primary objectives of the experiments will be comparison of ETC photographs with aircraft photos, S-190A photos, and ERTS-A images. Thus, a better assessment can be made of the scale and the resolution that are optimum for each particular investigation. The results of the experiments will be of great value in defining future data-collection systems for earth resources.

In conclusion, the Earth Terrain Camera provides an opportunity to acquire high-resolution space photographs for the study of mapping and for investigations of earth resources. The camera fills the gap between high-altitude aircraft photographs and other hitherto random space photographs. Although the camera has several limitations from the photogrammetric standpoint, it will supply high-resolution photographs of value to several disciplines.

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Appendix B

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B-2

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      PROGRAM B600 (INPUT,OUTPJT,TAPE1,TAPE2,TAPE3,TAPE11,TAPE12)      B600S     1
C     BLOCK ADJUSTMENT   ESSA-COAST AND GEODETIC SURVEY 1969 (KELLER)  B600      3
C     MAXIMUM NUMBER OF PHOTOS IN BLOCK = 600                          B600      4
C     MAXIMUM NUMBER OF PHOTOS IN A STRIP = 20                         B600      5
      DIMENSION A(259,259),G(12)36),CAM(600,12),B(3,180),C(3,860),     A600      1
     1P(13,10),E(3,58),TITLE(8),D(6,9)                                 B600      8
      DIMENSION INDEX1(600),INDEX2(600)                                B600S     2
      COMMON/CDBUF/LEN,NEXT,IFIRST,IXBUF,BUFF(1024),IQ,JST             B600      9
      COMMON/ODBUF/LENG,NEX,IFIR,IBUF,BUF(1024),IP,ENDFLQ              B600     10
      CALL LTRIO(5LTAPE1,1160,Q,Q,KS)                                  B600     11
      CALL LTRIO(5LTAPE2,1160,Q,Q,KS)                                  B600     12
      CALL LTRIO(5LTAPE3,1160,Q,Q,KS)                                  B600     13
      CALL OPENMS(11,INDEX1,600,0)                                     B600S     3
      CALL OPENMS(12,INDEX2,600,0)                                     B600S     4
      DATA(IEF=10000000000000B),(ENDFLQ=0.),                           B600     17
     1  (IP=24012005360000000000B)                                     B600     18
      DATA(XSTOP=1H )                                                  B6002     1
      IZYXW = 0                                                        B600     19
      CALL PATCH                                                       B600     20
      IF(IZYXW.EQ.0) GO TO 999                                         B600     21
      PRINT 98                                                         B600     22
   98 FORMAT(*1 JOB STEP ABORTED - INPUT AREA */)                      B600     23
      PRINT 99, (BUFF(I),I=1,1024)                                     B600     24
   99 FORMAT(1X, 8A10)                                                 B600     25
      IF((JST.AND.IEF) .NE.0) GO TO 1000                               B600     26
      CALL LTRIO (IQ,48, XX, XX, JST)                                  B600     27
  999 IZYXW = 1                                                        B600     28
 1000 IF (ENDFLQ.EQ.0.) CALL LTRIO (IP,1158,XX,XX,KST)                 B600     29
      ENDFLQ = 1.                                                      B600     30
      ITERAT=1                                                         B600     31
      LENG=0 $ NEX=IFIR=1                                              B600     32
      CALL OBUF (1)                                                    B600     33
      ENCODE (80,571,BUF(IBUF))  XSTOP                                 B600     34
  571 FORMAT(19HB        JOB STEP 1,A1)                                B600     35
C                                                                      B600     36
C     INPUT PHASE                                                      B600     37
C                                                                      B600     38
      KB = KC = LINE = ME = IOTHER = LOS = 0                           B600     39
      IGO = IRE = KOISK = 1                                            B600     40
      READ 531,TITLE                                                   B600     41
      IF(TITLE(1).EQ.XSTOP)CALL OBUF(0)                                B600     42
      PRINT 569,TITLE                                                  B600     43
      PRINT 532                                                        B600     44
      IPHO=JOYCE=MORT=0                                                B600     45
      LLL=259                                                          B600     46
C       READ BLOCK CONSTANTS AND CONTROL HEIGHTS                        B600     47
      READ 524,LARRY,FL,WT712,WT12P,WTCON,MAX,RESID,JERRY,INVER        A600      4
      IF(JERRY)1,1,2                                                   B600     49
    1 PRINT 567                                                        B600     50
      GO TO 3                                                          B600     51
    2 PRINT 568                                                        B600     52
    3 K=1                                                              B600     53
      PRINT 576,FL,MAX,RESID                                           B600     54
      PRINT 577,WT712,WT12P                                            B600     55
      PRINT 573                                                        B600     56
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B-3

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    4 READ 558,A(1,K),A(2,K),A(3,K),ITEST                            B600      57
      IS=A(1,K)                                                      B600      58
      IF(JERRY.NE.0) GO TO 321                                       B600      59
      NEIL=WTCON                                                     B600      60
      JOYCE=A(2,K)                                                   B600      61
      MORT=A(3,K)                                                    B600      62
      GO TO 322                                                      B600      63
  321 NEIL=A(2,K)                                                    B600      64
      IF(NEIL.EQ.0) NEIL=A(3,K)                                      B600      65
      IF(A(2,K).NE.0.0) JOYCE=WTCON                                  B600      66
      IF(A(3,K).NE.0.0) MORT=WTCON                                   B600      67
  322 PRINT 574,IS,NEIL,JOYCE,MORT                                   B600      68
      JOYCE=MORT=0                                                   A600       5
      IF(ITEST)5,5,6                                                 B600      69
    5 K=K+1                                                          B600      70
      IF(K-250)4,4,27                                                B600      71
   27 PRINT 570                                                      B600      72
      STOP                                                           B600      73
    6 J=1                                                            B600      74
      DO 7 I=2,K                                                     B600      75
      IF(A(1,I).GE.A(1,I-1))GO TO 7                                  B600      76
      J=-1                                                           B600      77
      DO 8 L=1,3                                                     B600      78
      SAVE=A(L,I)                                                    B600      79
      A(L,I)=A(L,I-1)                                                B600      80
      A(L,I-1)=SAVE                                                  B600      81
    8 CONTINUE                                                       B600      82
    7 CONTINUE                                                       B600      83
      IF(J.LT.0)GO TO 6                                              B600      84
C       READ IN ALL GROUND COORDINATES FOR BLOCK                     B600      85
      LEN=0 $ NEXT=IFIRST=1                                          B600      86
      IQ=24012005340000000000B                                       B600      87
      CALL DBUF(0)                                                   B600      88
      CALL DBUF(1)                                                   B600      89
      J=1                                                            B600      90
    9 NCON = J+5                                                     B600      91
      NCOM = NCON-2                                                  B600      92
      CALL DBUF(1)                                                   B600      93
      DECODE(80,527,BUFF(IXBUF))(G(I),I=J,NCOM),ITEST                B600      94
      DO 10 L=1,K                                                    B600      95
      IF(G(J)-A(1,L))11,12,10                                        B600      96
   10 CONTINUE                                                       B600      97
      GO TO 11                                                       B600      98
   12 G(J+4)=A(2,L)                                                  B600      99
      G(J+5)=A(3,L)                                                  B600     100
      GO TO 13                                                       B600     101
   11 G(J+4)=G(J+5)=0.                                               B600     102
   13 IF(ITEST)14,14,15                                              B600     103
   14 J=J+6                                                          B600     104
      GO TO 9                                                        B600     105
   15 NCON=NCON/6                                                    B600     106
      DO 22 J=1,256,3                                                B600     107
      DO 22 I=1,207                                                  B600     108
      A(I,J)=0.                                                      B600     109
   22 CONTINUE                                                       B600     110
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      LEN=0 $ NEXT=IFIRST=1                                                    B600      111
      IQ=24012005350000000008                                                  B600      112
      CALL DBUF(0)                                                             B600      113
      CALL DBUF(1)                                                             B600      114
      IF(NCON-2000)16,16,17                                                    B600      115
   17 PRINT 529,NCON                                                           B600      116
      STOP                                                                     B600      117
   16 IPHO=IPHO+1                                                              B600      118
      IF(IPHO-44)47,93,93                                                      B600      119
   93 NROW=ME=IPHO-43                                                          B600      120
C       GROUP ALL NEW OBJECTS AND THEIR IMAGES FOR PLATE AND PUT IN DISK      B600      121
   48 DO 83 I=ME,NROW                                                          B600      122
      JOYCE=215+I-43*((I-1)/43)                                                B600      123
      NEIL=A(JOYCE,31)                                                         B600      124
      L=1                                                                      B600      125
      DO 100 K=1,NEIL                                                          B600      126
      DO 101 NU=1,LINE                                                         B600      127
      IF(A(JOYCE,K)-G(6*NU-5))101,102,101                                      B600      128
  101 CONTINUE                                                                 B600      129
  102 MORT=NU-86*((NU-1)/86)                                                   B600      130
      M=(1+(NU-1)/86)*9 - 8                                                    B600      131
      J=M                                                                      B600      132
  106 IF(A(J,3*MORT-2))108,108,296                                             B600S       5
  296 C(1,L)=A(J,3*MORT-2)                                                     B600      138
      C(2,L)=A(J,3*MORT-1)                                                     B600      139
      C(3,L)=A(J,3*MORT)                                                       B600      140
      J=J+1                                                                    B600      141
      L=L+1                                                                    B600      142
      IF(J-M-8)106,106,108                                                     B600      143
  108 A(M,3*MORT-2)=-1.                                                        B600      144
  100 CONTINUE                                                                 B600      145
      NA=3*(L-1)                                                               B600      146
      CAM(I,12)=NA                                                             B600      147
      IF(NA.EQ.0) GO TO 83                                                     B600      148
      CALL WRITMS(11,C,NA,KDISK)                                               B600S       6
      KDISK=KDISK+(NA+407)/408                                                 B600      150
   83 CONTINUE                                                                 B600      151
      GO TO (47,95),IGO                                                        B600      152
C       READ IN REFINED IMAGE COORDINATES FOR PLATE BEING RESECTED            B600      153
   47 JOYCE=215+IPHO-43*((IPHO-1)/43)                                          B600      154
      NEIL=0                                                                   B600      155
      CALL DBUF(1)                                                             B600      156
      DECODE(80,525,BUFF(IXBUF))B(1,50),B(2,50),B(3,50),B(1,51),B(2,51)        B600      157
      IF(B(2,50).EQ.1.0) NCOM=IPHO                                             B600      158
      IF(B(3,50)-1.)318,317,318                                                B600      159
  317 I=IPHO-NCOM+1                                                            B600      160
      IF(I-20)352,352,351                                                      B600      161
  351 PRINT 572                                                                B600      162
      STOP                                                                     B600      163
  352 IF(I.GT.LOS) LOS=I                                                       B600      164
  318 IF(LARRY)91,91,90                                                        B600      165
   90 FL=B(2,51)                                                               B600      166
      CAM(IPHO,2)=FL                                                           B600      167
   91 IMAGE=1                                                                  B600      168
   36 CALL DBUF(1)                                                             B600      169
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      DECODE(80,526,BUFF(IXBUF))(B(J,IMAGE),J=1,3),ITEST               B600      170
      IF(ITEST)18,18,21                                                 C600        1
   18 IMAGE =IMAGE+1                                                    C600        2
      IF(IMAGE-30)36,36,20                                              C600        3
   20 IS=B(1,50)                                                        C600        4
      PRINT 545,IS                                                      C600        5
      STOP                                                              C600        6
C       SET UP ORDER LIST - STORE IMAGES BY OBJECT - SET UP OBJECT FILE B600      178
C       LIST FOR PHOTO - SAVE COORDINATES OF POTENTIAL RESECTION OBJECTS B600     179
   21 LAST=0                                                            B600      180
      IF(B(2,50))39,39,38                                               B600      181
   38 NROW=4                                                            B600      182
      GO TO 42                                                          B600      183
   39 IF(B(3,50))40,40,41                                               B600      184
   41 NROW=1                                                            B600      185
      NMI=6                                                             B600      186
      LAST=1                                                            B600      187
      GO TO 43                                                          B600      188
   40 NROW=1                                                            B600      189
   42 NMI=IMAGE                                                         B600      190
   43 DO 23 K=NROW,NMI                                                  B600      191
      J=B(1,K)*.000001                                                  B600      192
      FK=J*1000000                                                      B600      193
      FK=B(1,K)-FK                                                      B600      194
      NU=1                                                              B600      195
   32 MORT=NU-86*((NU-1)/86)                                            B600      196
      M=(1+(NU-1)/86)*9 - 8                                             B600      197
      IF(A(M,3*MORT-2))25,24,25                                         B600      198
   24 A(M,3*MORT-2)=B(1,K)                                              B600      199
      A(M,3*MORT-1)=B(2,K)                                              B600      200
      A(M,3*MORT)  =B(3,K)                                              B600      201
      LINE=LINE+1                                                       B600      202
      I=6*NU-5                                                          B600      203
      IF(G(I)-FK)26,49,26                                               B600      204
   26 G(12001)=G(I)                                                     B600      205
      G(12002)=G(I+1)                                                   B600      206
      G(12003)=G(I+2)                                                   B600      207
      G(12004)=G(I+3)                                                   B600      208
      G(12005)=G(I+4)                                                   B600      209
      G(12006)=G(I+5)                                                   B600      210
      NU=NU+1                                                           B600      211
      DO 28 L=NU,NCON                                                   B600      212
      IF(G(6*L-5)-FK)28,29,28                                           B600      213
   28 CONTINUE                                                          B600      214
      IS=FK                                                             B600      215
      PRINT 528,IS                                                      B600      216
      STOP                                                              B600      217
   29 G(I)   =G(6*L-5)                                                  B600      218
      G(I+1)=G(6*L-4)                                                   B600      219
      G(I+2)=G(6*L-3)                                                   B600      220
      G(I+3)=G(6*L-2)                                                   B600      221
      G(I+4)=G(6*L-1)                                                   B600      222
      G(I+5)=G(6*L)                                                     B600      223
      G(6*L-5)=G(12001)                                                 B600      224
      G(6*L-4)=G(12002)                                                 B600      225
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      G(6*L-3)=G(12003)                                         B600   226
      G(6*L-2)=G(12004)                                         B600   227
      G(6*L-1)=G(12005)                                         B600   228
      G(6*L)  =G(12006)                                         B600   229
   49 NEIL=NEIL+1                                               B600   230
      A(JOYCE,NEIL)=G(I)                                        B600   231
      IF(K-9)50,50,23                                           B600   232
   50 B(1,K+60)=G(I+1)                                          B600   233
      B(2,K+60)=G(I+2)                                          B600   234
      B(3,K+60)=G(I+3)                                          B600   235
      GO TO 23                                                  B600   236
   25 IF(FK-G(6*NU-5))30,31,30                                  B600   237
   30 NU=NU+1                                                   B600   238
      GO TO 32                                                  B600   239
   31 L=M+1                                                     B600   240
   35 IF(A(L,3*MORT-2))33,34,33                                 B600   241
   33 L=L+1                                                     B600   242
      IF(L-M-8)35,35,37                                         B600   243
   37 IS=G(6*NU-5)                                              B600   244
      PRINT 537,IS                                              B600   245
      STOP                                                      B600   246
   34 A(L,3*MORT-2)=B(1,K)                                      B600   247
      A(L,3*MORT-1)=B(2,K)                                      B600   248
      A(L,3*MORT)  =B(3,K)                                      B600   249
      I=6*NU-5                                                  B600   250
      GO TO 49                                                  B600   251
   23 CONTINUE                                                  B600   252
      IF(LAST)46,46,44                                          B600   253
   44 IF(IMAGE-9)46,46,45                                       B600   254
   45 NROW=10                                                   B600   255
      LAST=0                                                    B600   256
      GO TO 42                                                  B600   257
   46 A(JOYCE,31)=NEIL                                          B600   258
C                                                               B600   259
C     PHOTO RESECTION PHASE                                     B600   260
C                                                               B600   261
C       INITIAL APPROXIMATIONS OF CAMERA PARAMETERS             B600   262
  310 N=0                                                       B600   267
      DO 51 J=1,2                                               B600   268
      C(J,1)=B(J,66)                                            B600   269
      C(J,2)=0.                                                 B600   270
      C(J,3)=1.                                                 B600   271
   51 CONTINUE                                                  B600   272
C       ADJUST APPROXIMATE AZIMUTH PARAMETERS FOR SWING AND Z0  B600   273
      D(1,1)=B(2,4)-B(2,5)                                      B600   274
      D(1,2)=B(3,4)-B(3,5)                                      B600   275
      D(2,1)=B(1,64)-B(1,65)                                    B600   276
      D(2,2)=B(2,64)-B(2,65)                                    B600   277
      D(2,4)=D(2,1)*D(2,1)+D(2,2)*D(2,2)                        B600   278
      D(1,3)=(D(2,1)*D(1,1)+D(2,2)*D(1,2))/D(2,4)               B600   279
      D(2,3)=(D(2,2)*D(1,1)-D(2,1)*D(1,2))/D(2,4)               B600   280
      SCALE=SQRT(D(1,3)*D(1,3)+D(2,3)*D(2,3))                   B600   281
      C(3,2)=D(2,3)/SCALE                                       B600   282
      C(3,1)=FL/SCALE                                           B600   283
      C(3,3)=D(1,3)/SCALE                                       B600   284
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C      ORIENTATION FACTORS IN C ARRAY                              B600     285
   52 N=N+1                                                        B600     286
      IF(N-5)54,54,53                                              B600     287
   53 IS=B(1,50)                                                   B600     288
      PRINT 535,IS                                                 B600     289
      PRINT 557,(IS,(C(J,I),J=1,3),I=1,2)                          B600     290
      IRE=2                                                        B600     291
      GO TO 70                                                     B600     292
   54 K=0                                                          B600     293
   92 C(1,K+4)=C(2,K+3)*C(3,K+3)                                   B600     294
      C(1,K+5)=-C(2,K+3)*C(3,K+2)                                  B600     295
      C(1,K+6)=C(2,K+2)                                            B600     296
      C(1,K+10)=-C(2,K+2)*C(3,K+3)                                 B600     297
      C(1,K+11)=C(2,K+2)*C(3,K+2)                                  B600     298
      C(1,K+12)=C(2,K+3)                                           B600     299
      C(2,K+10)=C(1,K+4)*C(1,K+2)                                  B600     300
      C(2,K+11)=C(1,K+5)*C(1,K+2)                                  B600     301
      C(2,K+12)=C(1,K+2)*C(2,K+2)                                  B600     302
      C(3,K+10)=-C(1,K+4)*C(1,K+3)                                 B600     303
      C(3,K+11)=-C(1,K+5)*C(1,K+3)                                 B600     304
      C(3,K+12)=-C(1,K+3)*C(2,K+2)                                 B600     305
      C(2,K+4)=C(1,K+3)*C(3,K+2)  + C(2,K+12)*C(3,K+3)             B600     306
      C(2,K+5)=C(1,K+3)*C(3,K+3)  - C(2,K+12)*C(3,K+2)             B600     307
      C(2,K+6)=-C(1,K+2)*C(2,K+3)                                  B600     308
      C(3,K+4)=C(1,K+2)*C(3,K+2)  + C(1,K+10)*C(1,K+3)             B600     309
      C(3,K+5)=C(1,K+2)*C(3,K+3)  + C(1,K+11)*C(1,K+3)             B600     310
      C(3,K+6)=C(1,K+3)*C(2,K+3)                                   B600     311
      DO 55 I=7,9                                                  B600     312
      M=K+I                                                        B600     313
      C(1,M)=0.                                                    B600     314
      C(2,M)=-C(3,M-3)                                             B600     315
      C(3,M)=C(2,M-3)                                              B600     316
      C(I-6,K+13)=C(I-6,K+5)                                       B600     317
      C(I-6,K+14)=-C(I-6,K+4)                                      B600     318
      C(I-6,K+15)=0.                                               B600     319
   55 CONTINUE                                                     B600     320
      GO TO(56,71),IGO                                             B600     321
C       CLEAR NORMAL EQUATION D ARRAY TO ZERO                      B600     322
   56 DO 57 I=1,6                                                  B600     323
      DO 57 J=I,7                                                  B600     324
      D(I,J) = 0.                                                  B600     325
   57 CONTINUE                                                     B600     326
C       COMPUTE P TERMS FOR PASS POINTS USED FOR RESECTION         B600     327
      IF(B(2,50))59,59,58                                          B600     328
   58 M=4                                                          B600     329
      NROW=8                                                       B600     330
      GO TO 62                                                     B600     331
   59 IF(B(3,50))61,61,60                                          B600     332
   60 M=1                                                          B600     333
      NROW=5                                                       B600     334
      GO TO 62                                                     B600     335
   61 M=1                                                          B600     336
      NROW=9                                                       B600     337
   62 DO 63 NU=M,NROW                                              B600     338
      DO 64 K=1,3                                                  B600     339
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      C(K,16)=B(K,NU+60)-C(K,1)
   64 CONTINUE
      K=4
      DO 65 L=17,20
      DO 65 I=1,3
      C(I,L)=C(1,K)*C(1,16) + C(2,K)*C(2,16) + C(3,K)*C(3,16)
      K=K+1
   65 CONTINUE
      DO 66 I=1,2
      DO 67 L=1,4
      P(I,L)=(B(I+1,NU)*C(3,L+15)   +FL  *C(I,L+15))/C(3,17)
   67 CONTINUE
      DO 68 L=5,7
      P(I,L)=(-B(I+1,NU)*C(L-4,5)   -FL  *C(L-4,I+3))*C(3,1)/C(3,17)
   68 CONTINUE
      P(I,8)=-P(I,1)
   66 CONTINUE
C       CONTRIBUTION TO NORMAL EQUATIONS
      DO 63 I=1,6
      DO 63 J=I,7
      DO 63 K=1,2
      D(I,J)=D(I,J)+P(K,I+1)*P(K,J+1)
   63 CONTINUE
C       FORWARD SOLUTION
      DO 69 I=1,6
      SQR = 1./SQRT(D(I,I))
      DO 72 J=I,7
      D(I,J)=D(I,J)*SQR
   72 CONTINUE
      IF(I-6)73,74,74
   73 IP1=I+1
      DO 69 L=IP1,6
      DO 69 J=L,7
      D(L,J)=D(L,J)-D(I,L)*D(I,J)
   69 CONTINUE
C       BACK SOLUTION
   74 D(6,7)=D(6,7)/D(6,6)
      DO 75 I=1,5
      NMI=6-I
      NMIP1=NMI+1
      DO 76 J=NMIP1,6
      D(NMI,7)=D(NMI,7)-D(J,7)*D(NMI,J)
   76 CONTINUE
      D(NMI,7)=D(NMI,7)/D(NMI,NMI)
   75 CONTINUE
      DO 77 I=4,6
      D(I,7)=D(I,7)*C(3,1)
   77 CONTINUE
C       ADD LEAST SQUARES RESULTS TO CAMERA PARAMETERS IN C ARRAY
      DO 78 J=1,3
      C(J,1)=C(J,1)+D(J+3,7)
      C(J,4)=D(J,7)
      C(J,5)=SQRT(1.-C(J,4)*C(J,4))
      C(J,6)=C(J,2)*C(J,5)+C(J,3)*C(J,4)
      C(J,7)=C(J,3)*C(J,5)-C(J,2)*C(J,4)
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      C(J,2)=C(J,6)                                                      B600   395
      C(J,3)=C(J,7)                                                      B600   396
   78 CONTINUE                                                           B600   397
C       TEST MAGNITUDE OF CORRECTIONS FOR ORIENTATION PARAMETERS         B600   398
      DO 79 I=1,3                                                        B600   399
      IF(ABS(D(I,7))-.00001)79,79,52                                     B600   400
   79 CONTINUE                                                           B600   401
C       STORE CAMERA PARAMETERS AS COMPUTED FROM PHOTO RESECTION         B600   402
   70 CAM(IPHO,1)=B(1,50)                                                B600   403
      DO 80 J=1,3                                                        B600   404
      CAM(IPHO,J+8)=C(J,3)                                               B600   405
      CAM(IPHO,J+5)=C(J,2)                                               B600   406
      CAM(IPHO,J+2)=C(J,1)                                               B600   407
   80 CONTINUE                                                           B600   408
      IF(B(1,51))16,16,81                                                B600   409
   81 NROW=IPHO                                                          B600   410
      ME=ME+1                                                            B600   411
      IGO = 2                                                            B600   412
      LOS=2*LOS+3                                                        B600   413
      IF(IRE-2)48,82,82                                                  B600   414
   82 STOP                                                               B600   415
C       BLOCK SIZE                                                       B600   416
   95 IF(LINE-1978)84,84,85                                              B600   417
   85 PRINT 544,LINE                                                     B600   418
      STOP                                                               B600   419
   84 PRINT 543,IPHO,LINE                                                B600   420
C                                                                        B600   421
C     BLOCK ADJUSTMENT PHASE                                             B600   422
C                                                                        B600   423
  271 DO 86 I=1,258                                                      B600   424
      DO 86 J=I,259                                                      B600   425
      A(I,J)=0.                                                          B600   426
   86 CONTINUE                                                           B600   427
C     RESET PLATE WITH NEW OBJECTS AND FORM C ARRAY ROWS 1-15 FOR ALL    B600   432
C     PLATES ON WHICH THE NEW OBJECTS APPEAR                             B600   433
  301 INSECT=0                                                           B600   434
  234 KDISK=1                                                            B600   435
      ME=1                                                               B600   436
  105 NA=CAM(ME,12)                                                      B600   437
      IF(NA.EQ.0) GO TO 297                                              B600   438
      CALL READMS(11,B,NA,KDISK)                                         B600S    7
      KDISK=KDISK+(NA+407)/408                                           B600   440
  297 IF(ME-1)87,87,96                                                   B600   441
   87 IF(IPHO-43)88,88,89                                                B600   442
   88 LAST=IPHO                                                          B600   443
      GO TO 94                                                           B600   444
   89 LAST=43                                                            B600   445
      GO TO 94                                                           B600   446
   96 NMI=LAST=ME+42                                                     B600   447
      IF(NMI-IPHO)104,104,123                                            B600   448
   94 NMI=1                                                              B600   449
  104 DO 71 L=NMI,LAST                                                   B600   450
      K=20*(L-1) - 860*((L-1)/43)                                        B600   451
      DO 97 J=1,3                                                        B600   452
      C(J,K+1)=CAM(L,J+2)                                                B600   453
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            C(J,K+2)=CAM(L,J+5)                                               B600      454
            C(J,K+3)=CAM(L,J+8)                                               B600      455
         97 CONTINUE                                                          B600      456
            IF(INSECT.EQ.0) GO TO 92                                          B600      457
            C(1,K+4)=C(2,K+3)*C(3,K+3)                                        B600      458
            C(1,K+5)=-C(2,K+3)*C(3,K+2)                                       B600      459
            C(1,K+6)=C(2,K+2)                                                 B600      460
            C(2,K+4)=C(1,K+3)*C(3,K+2)  + C(1,K+2)*C(2,K+2)*C(3,K+3)          B600      461
            C(2,K+5)=C(1,K+3)*C(3,K+3)  - C(1,K+2)*C(2,K+2)*C(3,K+2)          B600      462
            C(2,K+6)=-C(1,K+2)*C(2,K+3)                                       B600      463
            C(3,K+4)=C(1,K+2)*C(3,K+2)  - C(2,K+2)*C(3,K+3)*C(1,K+3)          B600      464
            C(3,K+5)=C(1,K+2)*C(3,K+3)  + C(2,K+2)*C(3,K+2)*C(1,K+3)          B600      465
            C(3,K+6)=C(1,K+3)*C(2,K+3)                                        B600      466
         71 CONTINUE                                                          B600      467
   C        NEW OBJECTS BEING PROCESSED ON PLATE                              B600      468
        123 CONTINUE                                                          B600S       8
        303 N=1                                                               B600      473
            IF(INSECT.EQ.0.AND.NA.EQ.1) GO TO 169                             B600      474
            IF(INSECT.EQ.1) GO TO 360                                         B600      475
        110 J=B(1,N)*.000001                                                  B600      476
            FK=J                                                              B600      477
            DO 111 L=1,IPHO                                                   B600      478
            IF(FK-CAM(L,1))111,115,111                                        B600      479
        111 CONTINUE                                                          B600      480
        115 K=20*(L-1) - 860*((L-1)/43)                                       B600      481
            IF(LARRY)109,109,107                                              B600      482
        107 FL=CAM(L,2)                                                       B600      483
        109 FK=J*1000000                                                      B600      484
            FK=B(1,N)-FK                                                      B600      485
            IF(N-1)125,125,126                                                B600      486
        125 SQR=FK                                                            B600      487
            DO 146 I=1,3                                                      B600      488
            E(I,58)=0.                                                        B600      489
            DO 146 J=I,3                                                      B600      490
            E(I,J)=0.                                                         B600      491
        146 CONTINUE                                                          B600      492
            MORT=0                                                            B600      493
            DO 114 NU=1,LINE                                                  B600      494
            IF(SQR-G(6*NU-5))114,126,114                                      B600      495
        114 CONTINUE                                                          B600      496
        126 IF(FK-SQR)113,112,113                                             B600      497
   C          COMPUTE C ARRAY COLS 16 THROUGH 20 FOR IMAGE                    B600      498
        112 MORT=MORT+1                                                       B600      499
            D(1,MORT)=NCON=L                                                  B600      500
            DO 116 I=1,3                                                      B600      501
            M=6*NU-5+I                                                        B600      502
            C(I,K+16)=G(M)-C(I,K+1)                                           B600      503
        116 CONTINUE                                                          B600      504
            J=K+4                                                             B600      505
            DO 117 L=17,20                                                    B600      506
            M=K+L                                                             B600      507
            DO 117 I=1,3                                                      B600      508
            C(I,M)=C(1,J)*C(1,K+16) + C(2,J)*C(2,K+16) + C(3,J)*C(3,K+16)     B600      509
            J=J+1                                                             B600      510
        117 CONTINUE                                                          B600      511
```

```
C        COMPUTE P COEFFICIENTS OF OBSERVATION EQUATIONS FOR IMAGE       B600      512
         DO 118 I=1,2                                                    B600      513
         DO 119 L=1,4                                                    B600      514
         M=K+L                                                           B600      515
         P(I,L)=(B(I+1,N)*C(3,M+15)+FL*C(I,M+16))/C(3,K+17)              B600      516
     119 CONTINUE                                                        B600      517
         M=K+I                                                           B600      518
         DO 118 L=5,7                                                    B600      519
         P(I,L)=(-B(I+1,N)*C(L-4,K+5)-FL*C(L-4,M+3))*CAM(1,5)/C(3,K+17)  B600      520
     118 CONTINUE                                                        B600      521
C        ARRANGE AUGMENTED COEFFICIENT MATRIX                            B600      522
         DO 120 I=3,4                                                    B600      523
         DO 121 L=1,3                                                    B600      524
         P(I,L)=-P(I-2,L+4)                                              B600      525
     121 CONTINUE                                                        B600      526
         DO 122 L=4,9                                                    B600      527
         P(I,L)=P(I-2,L-2)                                               B600      528
     122 CONTINUE                                                        B600      529
         P(I,10)=-P(I-2,1)                                               B600      530
     120 CONTINUE                                                        B600      531
C        WEIGHTING CONTROL STATION OBSERV. EQUATIONS FOR TARGET QUALITY  C600        7
         M=6*NU-1                                                        B600      533
         IF(G(M))130,129,130                                             B600      534
     129 IF(G(M+1))135,136,135                                           B600      535
     135 IF(JERRY)131,131,137                                            B600      536
     137 WEIGHT=G(M+1)                                                   B600      537
         GO TO 133                                                       B600      538
     130 IF(JERRY)131,131,132                                            B600      539
     131 WEIGHT=WTCON                                                    B600      540
         GO TO 133                                                       B600      541
     132 WEIGHT=G(M)                                                     B600      542
     133 DO 134 I=3,4                                                    B600      543
         DO 134 J=1,10                                                   B600      544
         P(I,J)=P(I,J)*WEIGHT                                            B600      545
     134 CONTINUE                                                        B600      546
C        WEIGHTING EQUATIONS FOR LOCATION OF IMAGE ON PLATE (RESOLUTION) B600      547
     136 RADIUS=SQRT(B(2,N)**2 + B(3,N)**2)                              B600      548
         IF(RADIUS-.07)143,143,138                                       B600      549
     138 IF(RADIUS-.12)139,139,140                                       B600      550
     139 WEIGHT=WT712                                                    B600      551
         GO TO 141                                                       B600      552
     140 WEIGHT=WT12P                                                    B600      553
     141 DO 142 I=3,4                                                    B600      554
         DO 142 J=1,10                                                   B600      555
         P(I,J)=P(I,J)*WEIGHT                                            B600      556
     142 CONTINUE                                                        B600      557
C        COMPUTE NORMAL EQUATIONS FOR IMAGE AND STORE IN E AND A ARRAYS  B600      558
     143 DO 144 I=5,13                                                   B600      559
         DO 144 J=1,10                                                   B600      560
         P(I,J)=0.                                                       B600      561
     144 CONTINUE                                                        B600      562
         DO 145 I=1,9                                                    B600      563
         DO 145 IP1=3,4                                                  B600      564
         DO 145 M=I,10                                                   B600      565
         P(I+4,M)=P(I+4,M)+P(IP1,I)*P(IP1,M)                             B600      566
```

```
  145 CONTINUE
      DO 147 I=1,3
      DO 147 J=I,3
      E(I,J)=E(I,J)+P(I+4,J)
  147 CONTINUE
      E(1,58)=E(1,58)+P(5,10)
      E(2,58)=E(2,58)+P(6,10)
      E(3,58)=E(3,58)+P(7,10)
      DO 148 I=1,3
      NEIL=6*MORT-3
      DO 148 J=4,9
      NEIL=NEIL+1
      E(I,NEIL)=P(I+4,J)
  148 CONTINUE
      IF(IPHO-43)200,200,201
  201 IF(ME+42-IPHO)202,203,203
  202 I=6*NCON-6-6*(ME-1)
      GO TO 204
  203 I=6*NCON-6-6*(IPHO-43)
      GO TO 204
  200 I=6*NCON-6
  204 DO 149 K=8,13
      M=K-4
      J=I
      I=I+1
      A(I,LLL)=A(I,LLL)+P(K,10)
      DO 149 L=M,9
      J=J+1
      A(I,J)=A(I,J)+P(K,L)
  149 CONTINUE
      N=N+1
      IF(N-NA/3)110,110,151
  151 KC=1
C       APPLY POSITION WEIGHTS OF CONTROL STATIONS
  113 IF(G(6*NU-1))152,152,153
  153 IF(JERRY)154,154,155
  154 E(1,1)=E(1,1)*G(6*NU-1)
      E(2,2)=E(2,2)*G(6*NU-1)
      GO TO 152
  155 E(1,1)=E(1,1)*WTCON
      E(2,2)=E(2,2)*WTCON
  152 IF(G(6*NU))156,156,157
  157 IF(JERRY)159,159,158
  159 E(3,3)=E(3,3)*G(6*NU)
      GO TO 156
  158 E(3,3)=E(3,3)*WTCON
C       FORWARD SOLUTION OF NORMAL EQUATIONS FOR NEW OBJECT
C       FORWARD SOLUTION OF OBJECT ROWS IN E ARRAY
  156 NEIL=6*MORT+3
      DO 127 I=1,3
      SQR=1./SQRT(E(I,I))
      DO 128 J=I,NEIL
      E(I,J)=E(I,J)*SQR
  128 CONTINUE
      E(I,58)=E(I,58)*SQR
```

B13

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      IF(I-3)160,161,161
  160 IP1=I+1
      DO 127 M=IP1,3
      DO 162 J=M,NEIL
      E(M,J)=E(M,J)-E(I,M)*E(I,J)
  162 CONTINUE
      E(M,58)=E(M,58)-E(I,M)*E(I,58)
  127 CONTINUE
C       EFFECT OF OBJECT ROWS ON PERTINENT CAMERA ROWS
  161 DO 163 J=1,MORT
      IP1 =D(1,J)
      IF(IPHO-43)205,205,206
  206 IF(ME+42-IPHO)207,208,208
  207 LAST=6*IP1 -6*(ME-1)
      GO TO 209
  208 LAST=6*IP1 -6*(IPHO-43)
      GO TO 209
  205 LAST=6*IP1
  209 M=LAST-5
      DO 163 NROW=1,3
      NEIL=6*J-3
      DO 163 I=M,LAST
      NMI=J
      NCON=NEIL
      NEIL=NEIL+1
      A(I,LLL)=A(I,LLL)-E(NROW,NEIL)*E(NROW,58)
      DO 164 JOYCE=I,LAST
      NCON=NCON+1
      A(I,JOYCE)=A(I,JOYCE)-E(NROW,NEIL)*E(NROW,NCON)
  164 CONTINUE
      IF(J-MORT)165,163,163
  165 NMI=NMI+1
      IF(NMI-MORT)167,167,163
  167 IS=D(1,NMI)
      IF(IPHO-43)210,210,211
  211 IF(ME+42-IPHO)212,213,213
  212 NU=6*IS-6*(ME-1)
      GO TO 214
  213 NU=6*IS-6*(IPHO-43)
      GO TO 214
  210 NU=6*IS
  214 IMAGE=NU-5
      DO 168 JOYCE=IMAGE,NU
      NCON=NCON+1
      A(I,JOYCE)=A(I,JOYCE)-E(NROW,NEIL)*E(NROW,NCON)
  168 CONTINUE
      GO TO 165
  163 CONTINUE
      IF(KC)125,125,169
C       FORWARD SOLUTION OF CAMERA ROWS FOR THE RESET PLATE
  169 K=0
      IF(IPHO-43)170,170,171
  170 N=6*ME
      GO TO 174
  171 IF(ME+42-IPHO)172,173,173
```

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B14

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 172 N=6                                                      B600     677
     K=1                                                      B600     678
     GO TO 174                                                B600     679
 173 N=6*ME-6*(IPHO-43)                                       B600     680
 174 M=N-5                                                    B600     681
     NCON=M-1+6*LOS                                           B600     682
     IF(NCON.GT.258) NCON=258                                 B600     683
     DO 175 I=M,N                                             B600     684
     SQR=1./SQRT(A(I,I))                                      B600     685
     DO 176 J=I,NCON                                          B600     686
     A(I,J)=A(I,J)*SQR                                        B600     687
 176 CONTINUE                                                 B600     688
     A(I,LLL)=A(I,LLL)*SQR                                    B600     689
     A(I,I)=SQR                                               B600     690
     IF(I-N)177,180,180                                       B600     691
 177 IP1=I+1                                                  B600     692
     DO 175 L=IP1,N                                           B600     693
     DO 193 J=L,NCON                                          B600     694
     A(L,J)=A(L,J)-A(I,L)*A(I,J)                              B600     695
 193 CONTINUE                                                 B600     696
     A(L,LLL)=A(L,LLL)-A(I,L)*A(I,LLL)                        B600     697
 175 CONTINUE                                                 B600     698
 180 IF(K)178,178,181                                         B600     699
 181 DO 320 I=M,N                                             B600     700
     DO 186 J=I,NCON                                          B600     701
     A(J,I)=A(I,J)                                            B600     702
 186 CONTINUE                                                 B600     703
     A(LLL,I)=A(I,LLL)                                        B600     704
 320 CONTINUE                                                 B600     705
     CALL WRITMS(12,A,1554,ME)                                B600S      9
C    EFFECT OF RESET PLATE ON ROWS OF FOLLOWING CAMERAS       B600     707
 178 IF(ME-IPHO)182,179,179                                   B600     708
 182 NEIL=N+1                                                 B600     709
     DO 183 I=M,N                                             B600     710
     IF(I-N)184,185,185                                       B600     711
 185 IF (K) 184,184,305                                       B600S     10
 305 DO 196 L=NEIL,NCON                                       B600     717
     DO 197 J=L,NCON                                          B600     718
     A(L-6,J-6)=A(L,J)-A(L,I)*A(J,I)                          B600     719
 197 CONTINUE                                                 B600     720
     A(L-6,LLL)=A(L,LLL)-A(L,I)*A(LLL,I)                      B600     721
 196 CONTINUE                                                 B600     722
     JOYCE=NCON-5                                             B600     723
     DO 298 L=1,NCON                                          B600     724
     DO 298 J=JOYCE,NCON                                      B600     725
     A(L,J)=0.                                                B600     726
 298 CONTINUE                                                 B600     727
     DO 299 L=JOYCE,NCON                                      B600     728
     A(L,LLL)=0.                                              B600     729
 299 CONTINUE                                                 B600     730
     GO TO 183                                                B600     731
 184 DO 194 L=NEIL,NCON                                       B600     732
     DO 195 J=L,NCON                                          B600     733
     A(L,J)=A(L,J)-A(I,L)*A(I,J)                              B600     734
 195 CONTINUE                                                 B600     735
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      A(L,LLL)=A(L,LLL)-A(I,L)*A(I,LLL)                         B600     736
  194 CONTINUE                                                  B600     737
  183 CONTINUE                                                  B600     738
      ME=ME+1                                                   B600     739
      KC=0                                                      B600     740
      GO TO 105                                                 B600     741
C       BACK SOLUTION OF CAMERA ROWS AND ADD RESULTS TO CAM ARRAY B600     742
  179 SCALE=CAM(1,5)                                            B600     743
      IF(IPHO-43)198,199,199                                    B600     744
  198 K=JOYCE=6*IPHO                                            B600     745
      LAST=IPHO                                                 B600     746
      GO TO 215                                                 B600     747
  199 K=JOYCE=258                                               B600     748
      LAST=43                                                   B600     749
  215 SAVE=1./A(JOYCE,JOYCE)                                    B600     750
      PRINT 556,ITERAT,A(JOYCE,LLL),SAVE                        B600     751
      ME=1                                                      B600     752
  225 DO 216 NU=ME,LAST                                         B600     753
      NROW=IPHO+1-NU                                            B600     754
      IF(NU.GT.LOS)JOYCE=JOYCE-6                                B600     755
      IF(JOYCE-6*LOS)188,189,189                                B600     756
  188 JOYCE=6*LOS                                               B600     757
  189 DO 216 I=1,6                                              B600     758
      IF(NU.EQ.1.AND.I.EQ.1)GO TO 217                           B600     759
      M=K                                                       B600     760
      K=K-1                                                     B600     761
      DO 221 J=M,JOYCE                                          B600     762
      A(K,LLL)=A(K,LLL)-A(J,LLL)*A(K,J)                         B600     763
  221 CONTINUE                                                  B600     764
  217 A(K,LLL)=A(K,LLL)*A(K,K)                                  B600     765
      IF(I-3)218,218,219                                        B600     766
  218 J=6-I                                                     B600     767
      CAM(NROW,J)=CAM(NROW,J)+A(K,LLL)*SCALE                    B600     768
      GO TO 216                                                 B600     769
  219 J=12-I                                                    B600     770
      FK=SQRT(1.-A(K,LLL)*A(K,LLL))                             B600     771
      SAVE=CAM(NROW,J)*FK + CAM(NROW,J+3)*A(K,LLL)              B600     772
      CAM(NROW,J+3)=CAM(NROW,J+3)*FK - CAM(NROW,J)*A(K,LLL)     B600     773
      CAM(NROW,J)=SAVE                                          B600     774
      IF(NU.EQ.1.AND.I.EQ.4)GO TO 222                           B600     775
      IF(ABS(A(K,LLL))-ABS(G(12001)))216,216,222                B600     776
  222 NMI=NROW                                                  B600     777
      G(12001)=A(K,LLL)                                         B600     778
  216 CONTINUE                                                  B600     779
      ME=LAST=LAST+1                                            B600     780
      IF(ME-IPHO)220,220,227                                    B600     781
  220 NROW=IPHO+1-ME                                            B600     782
      CALL READMS(12,A,1554,NROW)                               B600S     11
      DO 223 J=7,258                                            B600     784
      I=265-J                                                   B600     785
      A(I,LLL)=A(I-6,LLL)                                       B600     786
  223 CONTINUE                                                  B600     787
  307 DO 224 I=1,6                                              B600     792
      DO 224 J=I,259                                            B600     793
      A(I,J)=A(J,I)                                             B600     794
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  224 CONTINUE                                                      B600     795
      K=7                                                           B600     796
      GO TO 225                                                     B600     797
  227 IS=CAM(NMI,1)                                                 B600     798
      PRINT 533,ITERAT,G(12001),IS                                  B600     799
      IF(ABS(G(12001))-.00001)230,230,228                           B600     800
  228 ITERAT=ITERAT+1                                               B600     801
      IF(ITERAT-MAX)229,229,230                                     B600     802
  229 IRE=1                                                         B600     803
      GO TO 231                                                     B600     804
  230 IRE=2                                                         B600     805
C                                                                   B600     806
C     BLOCK ORIENTATION SOLUTION COMPLETED                          B600     807
C                                                                   B600     808
      PRINT 541                                                     B600     809
      DO 232 I=1,IPHO                                               B600     810
      IS=CAM(I,1)                                                   B600     811
      PRINT 561,IS,(CAM(I,J),J=3,5)                                 A600       6
  232 CONTINUE                                                      B600     813
      PRINT 539                                                     B600     814
      DO 233 I=1,IPHO                                               B600     815
      IS=CAM(I,1)                                                   B600     816
      PRINT 557,IS,(CAM(I,J),J=5,8)                                 B600     817
      PRINT 557,IS,(CAM(I,J),J=9,11)                                B600     818
  233 CONTINUE                                                      B600     819
      PRINT 547                                                     B600     820
      PRINT 534                                                     B600     821
      PRINT 548                                                     B600     822
C                                                                   B600     823
C     INTERSECTION OF OBJECTS USED IN BLOCK ORIENTATION SOLUTION    B600     824
C                                                                   B600     825
  231 INSECT=1                                                      B600     826
      DO 329 I=220,225                                              B600     827
      DO 329 J=1,200                                                B600     828
      A(I,J)=0.                                                     B600     829
  329 CONTINUE                                                      B600     830
      KC=0                                                          B600     831
      ITEST=0                                                       B600     832
      GO TO 234                                                     B600     833
  360 IF(NA.EQ.0) GO TO 268                                         B600     834
C     SET UP IMAGES OF OBJECT TO BE COMPUTED BY INTERSECTION        B600     835
  355 IMAGE=1                                                       B600     836
  361 A(1,IMAGE)=B(1,N)                                             B600     837
      A(2,IMAGE)=B(2,N)                                             B600     838
      A(3,IMAGE)=B(3,N)                                             B600     839
  270 J=A(1,IMAGE)*.000001                                          B600     840
      FK=J                                                          B600     841
      DO 235 L=1,IPHO                                               B600     842
      IF(FK-CAM(L,1))235,236,235                                    B600     843
  235 CONTINUE                                                      B600     844
  236 A(4,IMAGE)=L                                                  B600     845
      A(5,IMAGE)=20*(L-1) - 860*((L-1)/43)                          B600     846
      IF(LARRY)358,358,357                                          B600     847
  357 A(6,IMAGE)=CAM(L,2)                                           B600     848
      GO TO 359                                                     B600     849
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  358 A(6,IMAGE)=FL                                                        B600      850
  359 FK=J*1000000                                                         B600      851
      A(7,IMAGE)=A(1,IMAGE)-FK                                             B600      852
      IF(IOTHER.EQ.1) GO TO 313                                            B600      853
      IF(A(7,1)-A(7,IMAGE))237,238,237                                     B600      854
  238 N=N+1                                                                B600      855
      IMAGE=IMAGE+1                                                        B600      856
      IF(N-NA/3)361,361,246                                                B600      857
  246 KC=1                                                                 B600      858
  237 IMAGE=IMAGE-1                                                        B600      859
      IS=A(7,1)                                                            B600      860
      P(11,1)=P(11,3)=0.                                                   B600      861
      DO 287 NU=1,LINE                                                     B600      862
      IF(A(7,1)-G(6*NU-5))287,238,287                                      B600      863
  287 CONTINUE                                                             B600      864
  288 GO TO (241,242),IRE                                                  B600      865
  241 IF(G(6*NU-1).NE.0.0.AND.G(6*NU).NE.0.0) GO TO 267                    B600      866
C     P COEFFICIENTS, CONSTANT TERMS, CONTRIBUTIONS TO NORMAL EQUATIONS    B600      867
  242 DO 124 I=1,3                                                         B600      868
      DO 124 J=I,4                                                         B600      869
      E(I,J)=0.                                                            B600      870
  124 CONTINUE                                                             B600      871
      DO 362 M=1,IMAGE                                                     B600      872
      K=A(5,M)                                                             B600      873
      IF(IOTHER.EQ.1) GO TO 323                                            B600      874
      DO 289 I=1,3                                                         B600      875
      J=6*NU-5+I                                                           B600      876
      C(I,K+16)=G(J)-C(I,K+1)                                              B600      877
  289 CONTINUE                                                             B600      878
      J=K+4                                                                B600      879
      DO 239 I=1,3                                                         B600      880
      C(I,K+17)=C(1,J)*C(1,K+15)+C(2,J)*C(2,K+15)+C(3,J)*C(3,K+16)         B600      881
      J=J+1                                                                B600      882
  239 CONTINUE                                                             B600      883
  323 IF(IOTHER.EQ.0)GO TO 363                                             B600S      12
      IF(A(10,M).EQ.0.0)GO TO 362                                          B600S      13
  363 DO 240 J=1,3                                                         B600S      14
      P(1,J)=(A(2,M)*C(J,K+6)+A(5,M)*C(J,K+4))/C(3,K+17)                   B600      886
      P(2,J)=(A(3,M)*C(J,K+6)+A(5,M)*C(J,K+5))/C(3,K+17)                   B600      887
  240 CONTINUE                                                             B600      888
      L=A(4,M)                                                             B600      889
      P(1,4)=P(1,1)*CAM(L,3)+P(1,2)*CAM(L,4)+P(1,3)*CAM(L,5)               B600      890
      P(2,4)=P(2,1)*CAM(L,3)+P(2,2)*CAM(L,4)+P(2,3)*CAM(L,5)               B600      891
      DO 245 I=1,3                                                         B600      892
      DO 245 J=I,4                                                         B600      893
      DO 245 L=1,2                                                         B600      894
      E(I,J)=E(I,J)+P(L,I)*P(L,J)                                          B600      895
  245 CONTINUE                                                             B600      896
  362 CONTINUE                                                             B600      897
C     SOLUTION OF NORMAL EQUATIONS FOR XYZ                                 B600      898
  311 DO 248 I=1,3                                                         B600      899
      SQR = 1./SQRT(E(I,I))                                                B600      900
      DO 249 J=I,4                                                         B600      901
      E(I,J)=E(I,J)*SQR                                                    B600      902
  249 CONTINUE                                                             B600      903
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          E(I,I)=SQR                                                        B600      904
          IF(I-3)250,251,251                                                B600      905
      250 IP1=I+1                                                           B600      906
          DO 248 M=IP1,3                                                    B600      907
          DO 248 J=M,4                                                      B600      908
          E(M,J)=E(M,J)-E(I,M)*E(I,J)                                       B600      909
      248 CONTINUE                                                          B600      910
      251 E(3,4)=E(3,4)*E(3,3)                                              B600      911
          DO 252 I=1,2                                                      B600      912
          NMI=3-I                                                           B600      913
          NMIP1=NMI+1                                                       B600      914
          DO 253 J=NMIP1,3                                                  B600      915
          E(NMI,4)=E(NMI,4)-E(J,4)*E(NMI,J)                                 B600      916
      253 CONTINUE                                                          B600      917
          E(NMI,4)=E(NMI,4)*E(NMI,NMI)                                      B600      918
      252 CONTINUE                                                          B600      919
          IF(IOTHER.EQ.1.AND.IGO.EQ.1) GO TO 274                            B600      920
          IF(IOTHER.EQ.1.AND.IGO.EQ.2) GO TO 276                            B600      921
C         TEST TO TERMINATE OBJECT INTERSECTION SOLUTION                    B600      922
          SAVE=ABS(E(1,4)-G(6*NU-4))*(-A(6,IMAGE)/C(3,K+17))                B600      923
          IF(SAVE-.000001)257,257,258                                       B600      924
      257 SAVE=ABS(E(2,4)-G(6*NU-3))*(-A(6,IMAGE)/C(3,K+17))                B600      925
          IF(SAVE-.000001)259,259,258                                       B600      926
      258 NEIL=2                                                            B600      927
          GO TO 273                                                         B600      928
      259 NEIL=1                                                            B600      929
      273 GO TO (243,264),IRE                                               B600      930
C         BLOCK ORIENTATION SOLUTION NOT COMPLETED - UPDATE ONLY NONCONTROL B600      931
C         XYZ FOR ITERATION OF THE BLOCK ORIENTATION SOLUTION               B600      932
      243 IF(G(6*NU-1))260,244,260                                          B600      933
      244 G(6*NU-4)=E(1,4)                                                  B600      934
          G(6*NU-3)=E(2,4)                                                  B600      935
      260 IF(G(6*NU))262,261,262                                            B600      936
      261 G(6*NU-2)=E(3,4)                                                  B600      937
      262 GO TO (267,242),NEIL                                              B600      938
C         BLOCK ORIENTATION SOLUTION COMPLETED                              B600      939
      264 IF(A(7,1).EQ.G(6*LINE-5)) ITEST=1                                 B600      940
          IF(KB)280,280,285                                                 B600      941
      280 IF(G(6*NU-1).NE.0.0.AND.G(6*NU).NE.0.0) GO TO 282                 B600      942
          IF(G(6*NU-1).NE.0.0) GO TO 281                                    B600      943
          IF(G(6*NU).EQ.0.0) GO TO 308                                      B600      944
          G(12003)=G(6*NU-2)                                                B600      945
          PRINT 560,IS,G(12003)                                             B600      946
          GO TO 284                                                         B600      947
      308 PRINT 562                                                         B600      948
          GO TO 284                                                         B600      949
      281 G(12001)=G(6*NU-4)                                                B600      950
          G(12002)=G(6*NU-3)                                                B600      951
          PRINT 554,IS,G(12001),G(12002)                                    B600      952
          GO TO 284                                                         B600      953
      282 PRINT 554,IS,G(6*NU-4),G(6*NU-3),G(6*NU-2)                        B600      954
          CALL OBUF(1)                                                      B600      955
          ENCODE(80,561,BUF(IBUF))IS,G(6*NU-4),G(6*NU-3),G(6*NU-2),ITEST    B600      956
      284 KB=1                                                              B600      957
      285 GO TO (346,265),NEIL                                              B600      958
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C.2

B19

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  265 G(6*NU-4)=E(1,4)
      G(6*NU-3)=E(2,4)
      G(6*NU-2)=E(3,4)
      GO TO 242
  266 DO 286 J=1,IMAGE
      K=A(5,J)
      P(13,1)=(A(2,J)+A(6,J)*C(1,K+17)/C(3,K+17))*1000000.
      P(13,2)=(A(3,J)+A(6,J)*C(2,K+17)/C(3,K+17))*1000000.
      IP1=A(1,J)
      IF(J-1)291,290,291
  290 PRINT 553,IS,E(1,4),E(2,4),E(3,4),IP1,P(13,1),P(13,2)
      IF(G(6*NU-1).NE.0.0.AND.G(6*NU).NE.0.0) GO TO 263
      CALL OBUF(1)
      IF(G(6*NU-1).NE.0.0) GO TO 292
      IF(G(6*NU).NE.0.0) GO TO 294
      ENCODE(80,561,BUF(IBUF)) IS,E(1,4),E(2,4),E(3,4),ITEST
      GO TO 263
  294 ENCODE(80,561,BUF(IBUF)) IS,E(1,4),E(2,4),G(12003),ITEST
      GO TO 263
  292 ENCODE(80,561,BUF(IBUF)) IS,G(12001),G(12002),E(3,4),ITEST
      GO TO 263
  291 PRINT 536,IP1,P(13,1),P(13,2)
  263 P(12,1)=P(12,1)+P(13,1)*P(13,1)+P(13,2)*P(13,2)
      P(12,3)=P(12,3)+2.
      P(11,1)=P(11,1)+P(13,1)*P(13,1)+P(13,2)*P(13,2)
      P(11,3)=P(11,3)+2.
      L=A(4,J)
      IF(L.LE.200) NROW=220
      IF(L.GT.200.AND.L.LE.400) NROW=222
      IF(L.GT.400) NROW=224
      K=L-200*((L-1)/200)
      A(NROW,K)=A(NROW,K)+P(13,1)*P(13,1)+P(13,2)*P(13,2)
      A(NROW+1,K)=A(NROW+1,K)+2.
  286 CONTINUE
      P(11,4)=SQRT(P(11,1)/P(11,3))
      PRINT 575,P(11,4)
      KB=0
C     RECYCLE FOR NEXT OBJECT OR NEXT PLATE
  267 IF(KC.EQ.0) GO TO 355
  268 ME=ME+1
      KC=0
      IF(ME-IPHO)105,105,269
  269 GO TO (271,272),IRE
  272 P(12,4)=SQRT(P(12,1)/P(12,3))
      PRINT 538,P(12,4)
      PRINT 578
      DO 348 L=1,IPHO
      IS=CAM(L,1)
      IF(L.LE.200) NROW=220
      IF(L.GT.200.AND.L.LE.400) NROW=222
      IF(L.GT.400) NROW=224
      K=L-200*((L-1)/200)
      A(NROW,K)=SQRT(A(NROW,K)/A(NROW+1,K))
      PRINT 557,IS,A(NROW,K)
  348 CONTINUE
```

B20

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C                                                                           B600    1014
C     INTERSECTION OF OBJECTS NOT USED IN THE BLOCK ORIENTATION SOLUTION   B600    1015
C                                                                           B600    1016
      PRINT 530                                                             B600    1017
      PRINT 534                                                             B600    1018
      PRINT 548                                                             B600    1019
      IOTHER=IMAGE=IGO=MORT=1                                               B600    1020
      JOYCE=LINE=0                                                          B600    1021
C     READ IN IMAGES OF THE OBJECT                                          B600    1022
  316 CALL DBUF(1)                                                          B600    1023
      DECODE(80,526,BUFF(IXBUF))(A(J,IMAGE),J=1,3)                          B600    1024
      IF(A(1,IMAGE).EQ.0.0) GO TO 315                                       B600    1025
      GO TO 270                                                             B600    1026
  313 IF(A(7,1)-A(7,IMAGE))315,314,315                                      B600    1027
  314 IMAGE=IMAGE+1                                                         B600    1028
      GO TO 316                                                             B600    1029
  315 IMAGE=IMAGE-1                                                         B600    1030
      IF(IMAGE.EQ.0) GO TO 350                                              B600    1031
      IS=A(7,1)                                                             B600    1032
      PRINT 562                                                             B600    1033
      DO 327 M=1,IMAGE                                                      B600    1034
      A(10,M)=1.                                                            B600    1035
      K=A(5,M)                                                              B600    1036
      L=A(4,M)                                                              B600    1037
      DO 328 J=1,3                                                          B600    1038
      C(J,K+1)=CAM(L,J+2)                                                   B600    1039
      C(J,K+2)=CAM(L,J+5)                                                   B600    1040
      C(J,K+3)=CAM(L,J+8)                                                   B600    1041
  328 CONTINUE                                                              B600    1042
      C(1,K+4)=C(2,K+3)*C(3,K+3)                                            B600    1043
      C(1,K+5)=-C(2,K+3)*C(3,K+2)                                           B600    1044
      C(1,K+6)=C(2,K+2)                                                     B600    1045
      C(2,K+4)=C(1,K+3)*C(3,K+2)  + C(1,K+2)*C(2,K+2)*C(3,K+3)              B600    1046
      C(2,K+5)=C(1,K+3)*C(3,K+3)  - C(1,K+2)*C(2,K+2)*C(3,K+2)              B600    1047
      C(2,K+6)=-C(1,K+2)*C(2,K+3)                                           B600    1048
      C(3,K+4)=C(1,K+2)*C(3,K+2)  - C(2,K+2)*C(3,K+3)*C(1,K+3)              B600    1049
      C(3,K+5)=C(1,K+2)*C(3,K+3)  + C(2,K+2)*C(3,K+2)*C(1,K+3)              B600    1050
      C(3,K+6)=C(1,K+3)*C(2,K+3)                                            B600    1051
      C(3,K+17)=1.                                                          B600    1052
  327 CONTINUE                                                              B600    1053
C     COMPUTE L.S. SOLUTION OF XYZ USING A3B EQUAL 1                        B600    1054
      GO TO 242                                                             B600    1055
  274 G(12001)=E(1,4)                                                       B600    1056
      G(12002)=E(2,4)                                                       B600    1057
      G(12003)=E(3,4)                                                       B600    1058
C     COMPUTE L.S. SOLUTION OF XYZ USING COMPUTED A3B                       B600    1059
      IGO=2                                                                 B600    1060
  346 DO 325 M=1,IMAGE                                                      B600    1061
      K=A(5,M)                                                              B600    1062
      DO 326 I=1,3                                                          B600    1063
      C(I,K+16)=E(I,4)-C(I,K+1)                                             B600    1064
  326 CONTINUE                                                              B600    1065
      J=K+4                                                                 B600    1066
      DO 325 I=1,3                                                          B600    1067
      C(I,K+17)=C(1,J)*C(1,K+15)+C(2,J)*C(2,K+15)+C(3,J)*C(3,K+15)          B600    1068
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      J=J+1
  325 CONTINUE
      IF(IOTHER.EQ.0) GO TO 266
      GO TO (242,347),MORT
C     TEST TO TERMINATE OBJECT INTERSECTION SOLUTION
  276 SAVE=ABS(E(1,4)-G(12001)) *(-A(6,IMAGE)/C(3,K+17))
      IF(SAVE-.000001)330,330,274
  330 SAVE=ABS(E(2,4)-G(12002)) *(-A(6,IMAGE)/C(3,K+17))
      IF(SAVE-.000001)331,331,274
C     TERMINATION TEST GOOD.  COMPUTE PLATE RESIDUALS
  331 MORT=2
      GO TO 346
  347 DO 332 M=1,IMAGE
      IF(A(10,M).EQ.0.0) GO TO 332
      K=A(5,M)
      A(8,M)=(A(2,M)+A(6,M)*C(1,K+17)/C(3,K+17))*1000000.
      A(9,M)=(A(3,M)+A(6,M)*C(2,K+17)/C(3,K+17))*1000000.
  332 CONTINUE
C     DETERMINE MAXIMUM PLATE RESIDUAL AND TEST AGAINST RESIDUAL LIMIT
      N=8
      M=J=1
      DO 275 I=8,9
  277 M=M+1
      IF(M-IMAGE)278,278,279
  278 IF(ABS(A(N,J))-ABS(A(I,M)))319,277,277
  319 N=I
      J=M
      GO TO 277
  279 M=0
  275 CONTINUE
      IF(ABS(A(N,J))-RESID)166,166,226
C     BAD IMAGE
  226 JOYCE=JOYCE+1
      IF(JOYCE-1)333,333,334
  333 IF(IMAGE-3)334,334,335
  335 A(8,J)=A(9,J)=A(10,J)=0.
      MORT=1
      GO TO 274
  334 A(10,J)=2.
C     OUTPUT XYZ AND PLATE RESIDUALS
  166 IP1=A(1,1)
      IF(A(10,1)-1.)336,337,338
  336 PRINT 549,IS,E(1,4),E(2,4),E(3,4),IP1
      GO TO 339
  337 PRINT 553,IS,E(1,4),E(2,4),E(3,4),IP1,A(8,1),A(9,1)
      GO TO 339
  338 PRINT 550,IS,E(1,4),E(2,4),E(3,4),IP1,A(8,1),A(9,1)
  339 CALL OBUF(1)
      ENCODE(80,561,BUF(IBUF)) IS,E(1,4),E(2,4),E(3,4)
      DO 340 M=2,IMAGE
      IP1=A(1,M)
      IF(A(10,M)-1.)341,342,343
  341 PRINT 551,IP1
      GO TO 340
  342 PRINT 536,IP1,A(8,M),A(9,M)
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          GO TO 340                                                  B600    1124
      343 PRINT 555,IP1,A(8,M),A(9,M)                                B600    1125
      340 CONTINUE                                                   B600    1126
      344 LINE=LINE+1                                                B600    1127
C         RECYCLE FOR NEXT OTHER OBJECT                              B600    1128
          IF(A(1,IMAGE+1).EQ.0.0) GO TO 350                          B600    1129
          DO 345 I=1,7                                               B600    1130
          A(I,1)=A(I,IMAGE+1)                                        B600    1131
      345 CONTINUE                                                   B600    1132
          JOYCE=0                                                    B600    1133
          IGO=IMAGE=MORT=1                                           B600    1134
          GO TO 314                                                  B600    1135
C                                                                    B600    1136
C         BLOCK ADJUSTMENT COMPLETED                                 B600    1137
C                                                                    B600    1138
      350 PRINT 552,LINE                                             B600    1139
          IF(INVER.EQ.0) GO TO 366                                   A600       7
          DO 365 I=1,IPHO                                            A600       8
          IS=CAM(I,1)                                                A600       9
          CALL OBUF(1)                                               A600      10
          ENCODE(80,561,BUF(IBUF)) IS,(CAM(I,J),J=3,5),INVER         A600      11
          CALL OBUF(1)                                               A600      12
          ENCODE(80,557,BUF(IBUF)) IS,(CAM(I,J),J=6,8)               A600      13
          CALL OBUF(1)                                               A600      14
          ENCODE(80,557,BUF(IBUF)) IS,(CAM(I,J),J=9,11)              A600      15
      365 CONTINUE                                                   A600      16
      366 PRINT 542                                                  A600      17
          CALL OBUF(0)                                               B600    1141
          GO TO 1000                                                 B600    1142
C                                                                    B600    1143
C         FORMAT STATEMENTS                                          B600    1144
C                                                                    B600    1145
      524 FORMAT(1X,I1,1X,E14.7,2(3X,F2.1),2X,F2.0,3X,I1,F6.0,8X,I1,9X,I1)  A600      18
      525 FORMAT(7X,F3.0,3(2X,F1.0),3X,E14.7)                        B600    1147
      526 FORMAT(1X,F9.0,2(2X,E14.7),37X,I1)                         B600    1148
      527 FORMAT(4X,F6.0,3(1X,F12.3),30X,I1)                         B600    1149
      528 FORMAT(/32H GROUND COORDINATES MISSING FOR I6, 5H-STOP/)   B600    1150
      529 FORMAT(44H PROVISIONAL GROUND COORDINATES ENTERED FOR I4, 35H OBJE B600    1151
         1CTS.  EXCEEDS 2000 LIMIT--STOP/)                           B600    1152
      530 FORMAT(1H1,28X,56H***   INTERSECTION OF OBJECTS NOT USED IN SOLUTI B600    1153
         1ON   ***)                                                  B600    1154
      531 FORMAT(8A10)                                               B600    1155
      532 FORMAT(/50H ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001/)  B600    1156
      533 FORMAT(14H PROGRAM PASS I1,46H PRODUCES A MAXIMUM ORIENTATION CORR B600    1157
         1ECTION OF E14.7, 11H FOR PLATE I3)                         B600    1158
      534 FORMAT(38X,37H (SECANT PLANE COORDINATES - MICRONS)//)     B600    1159
      535 FORMAT(/7H PLATE I3, 36H NEEDS OVER 5 RESECTION PASSES--STOP)  B600    1160
      536 FORMAT(48X,I16,F16.3,F19.3)                                B600    1161
      537 FORMAT(/8H OBJECT I6, 31H APPEARS ON OVER 9 PHOTOS--STOP)  B600    1162
      538 FORMAT(///33H RMS RESIDUAL FOR ENTIRE BLOCK = E14.7, 8H MICRONS)  B600    1163
      539 FORMAT(/52H      PLATE         OMEGA              PHI              KAPPA/)  B600    1164
      541 FORMAT(/44H      PLATE         XO             YO            ZO/)  B600    1166
      542 FORMAT(/54H B L O C K    A D J U S T M E N T    C O M P L E T E D)  B600    1167
      543 FORMAT(/16H BLOCK CONTAINS I3,17H PHOTOGRAPHS AND I4,8H OBJECTS/)  B600    1168
      544 FORMAT(/27H BLOCK ADJUSTMENT CONTAINS I4, 47H OBJECTS AND EXCEEDS  B600    1169
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       1LIMIT OF 1978--STOP)                                                 B600     1170
   545 FORMAT(/7H PLATE I3, 29H EXCEEDS 30-IMAGE LIMIT--STOP)                C600        8
   546 FORMAT(24H * DISK (PARITY) ERROR *)                                    B600     1173
   547 FORMAT(1H1,30X,52H***   INTERSECTION OF OBJECTS USED IN SOLUTION      B600     1174
      1 ***)                                                                 B600     1175
   548 FORMAT(*  OBJECT       X GROUND       Y GROUND       Z GROUND         B600     1176
      1 IMAGE        VX PLATE RESID       VY PLATE RESID *)                  B600     1177
   549 FORMAT(1X,I7,F14.3,2F13.3,I16,28H OVER LIMIT--IMAGE DISCARDED)        B600     1178
   550 FORMAT(1X,I7,F14.3,2F13.3,I16,2H *,F14.3,F19.3)                       B600     1179
   551 FORMAT(48X,I16,28H OVER LIMIT--IMAGE DISCARDED)                       B600     1180
   552 FORMAT(//40H TOTAL NUMBER OF INTERSECTED OBJECTS IS I4)               B600     1181
   553 FORMAT(1X,I7,F14.3,2F13.3,I16,F16.3,F19.3)                            B600     1182
   554 FORMAT(///1X,I7,1HT,3F13.3)                                           B600     1183
   555 FORMAT(48X,I16,2H *,F14.3,F19.3)                                      B600     1184
   556 FORMAT(/14H PROGRAM PASS I1, 19H LAST PLATE DZO IS E14.7, 12H DIVI B600     1185
      1DED BY E14.7)                                                         B600     1186
   557 FORMAT(1X,I9,2X,E14.7,2X,E14.7,2X,E14.7)                              B600     1187
   558 FORMAT(4X,F6.0,2X,F2.0,2X,F2.0,61X,I1)                                B600     1188
   560 FORMAT(///1X,I7,1HT,F39.3)                                            B600     1189
   561 FORMAT(1X,I9,1X,F12.3,1X,F12.3,1X,F12.3,30X,I1)                       A600       19
   562 FORMAT(1H //)                                                         B600     1191
   567 FORMAT(/23H POSITION WEIGHT VARIES/)                                  C600        9
   568 FORMAT(/25H POSITION WEIGHT CONSTANT/)                                C600       10
   569 FORMAT(1H1,8A10)                                                      B600     1194
   570 FORMAT(/40H OVER 250 WEIGHTED OBJECTS ENTERED--STOP)                  B600     1195
   572 FORMAT(51H NUMBER OF PHOTOS IN ORDERED STRIP EXCEEDS 20--STOP)        B600     1196
   573 FORMAT(54H CONTROL      EQUATION      XY       Z  (0=NO CONSTRAINT))  B600     1197
   574 FORMAT(2X,I6,8X,I2,8X,I2,5X,I2)                                       B600     1198
   575 FORMAT(60X,13H RMS OBJECT= E14.7,8H MICRONS)                          B600     1199
   576 FORMAT(15H FL CONSTANT = E14.7,24H   MAXIMUM ITERATIONS = I2,30H      B600     1200
      1 RESIDUAL LIMIT (MICRONS) = E14.7)                                    B600     1201
   577 FORMAT(28H RESOLUTION WEIGHTS WT712 = E14.7,10H  WT12P = E14.7)       B600     1202
   578 FORMAT(1H1,26H      PLATE  RMS (MICRONS) /)                           B600     1203
       END                                                                   B600     1204
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ORIGINAL PAGE IS
OF POOR QUALITY

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      SUBROUTINE DBUF (NORECS)                                          DBUF       2
C                                                                       DBUF       3
C  THIS PROGRAM IS SET UP FOR A DOUBLE BUFFER AREA ALTHOUGH IT IS USING DBUF       4
C  WAIT MODE INSTRUCTIONS. TO BE CHANGED IN THE FUTURE.                 DBUF       5
C                                                                       DBUF       6
      COMMON /CDBUF/ LENGT,NEXT,IFIRST,IXBUF,BUFF(1024),IQ,KS           DBUF       7
      DATA (ICOUNT=0)                                                   DBUF       8
      DATA (IT3=24012005360000000000B),(IEF=10000000000000000B),        DBUF       9
     1  (IPR=20000000000000000B)                                        DBUF      10
C                                                                       DBUF      11
      IF (NORECS) 70,10,70                                              DBUF      12
   10 CALL LTRIO (IQ,111B,BUFF(IFIRST),BUFF(IFIRST+511),KS)             DBUF      13
      IF (KS .LT. 0) GO TO 76                                           DBUF      14
      IF ((KS.AND.IPR) .NE. 0) PRINT 100,IQ                             DBUF      15
      IF ((KS.AND.IEF) .NE. 0) GO TO 60                                 DBUF      16
      IFIRST = MOD(IFIRST+512,1024)                                     DBUF1      1
      ICOUNT = 0                                                        DBUF      18
      RETURN                                                            DBUF      19
   60 ICOUNT = ICOUNT + 1                                               DBUF      20
      IF (ICOUNT .LT. 2) GO TO 10                                       DBUF      21
      PRINT 64                                                          DBUF      22
      CALL LTRIO (IT3,115B,A,B,JS)                                      DBUF      23
      STOP                                                              DBUF      24
   70 IF (MOD(LENGT,512)) 79,74,79                                      DBUF1      2
   74 CALL LTRIO (IQ,111B,BUFF(IFIRST),BUFF(IFIRST+511),KS)             DBUF      26
      IF (KS .LT. 0) GO TO 76                                           DBUF      27
      IF ((KS.AND.IPR) .NE. 0) PRINT 100,IQ                             DBUF      28
      IFIRST = MOD(IFIRST+512,1024)                                     DBUF1      3
   79 LENGT = MOD(LENGT+8*NORECS,1024)                                  DBUF1      4
      IXBUF = NEXT                                                      DBUF      31
      NEXT = LENGT + 1                                                  DBUF      32
      RETURN                                                            DBUF      33
   76 PRINT 77,KS                                                       DBUF      34
      STOP                                                              DBUF      35
  100 FORMAT (/* TROUBLE IN INPUT TAPE * O20 /)                         DBUF      36
   64 FORMAT(*1 JOB TERMINATED--  END OF DATA*)                         DBUF      37
   77 FORMAT(*1  JOB ABORTED-- STATUS WORD * O20)                       DBUF      38
      END                                                               DBUF      39
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      SUBROUTINE  OBUF                              CDC 6600 FTN V3.0-324  OPT=2  04/02/75  20.40.54.      PAGE    1

                    SUBROUTINE OBUF (NORECS)                                               OBUF        2
              C                                                                            OBUF        3
              C  THIS PROGRAM IS SET UP FOR A DOUBLE BUFFER AREA ALTHOUGH IT IS USING      OBUF        4
              C  WAIT MODE INSTRUCTIONS. TO BE CHANGED IN THE FUTURE.                       OBUF        5
              C                                                                            OBUF        6
                    COMMON /ODBUF /LENGT,NEXT,IFIRST,IXBUF,BUFF(1024),IP,ENDFLQ            OBUF        7
              C                                                                            OBUF        8
                    IF (NORECS) 10,40,10                                                   OBUF        9
                 10 LENGT = LENGT + NORECS                                                 OBUF       10
                    IF (LENGT.GT.64) GO TO 20                                              OBUF       11
                    IXBUF = NEXT                                                           OBUF       12
                    GO TO 30                                                               OBUF       13
                 20 CALL LTRIO (IP,112B,BUFF(IFIRST),BUFF(IFIRST+511),KS)                  OBUF       14
                    IF (KS .LT. 0) GO TO 80                                                OBUF       15
                    IXBUF = IFIRST = MOD(IFIRST+512,1024)                                  OBUF1       1
                    LENGT = NORECS                                                         OBUF       17
                 30 NEXT = IXBUF + NORECS*8                                                OBUF       18
                    RETURN                                                                 OBUF       19
                 40 INDEX = IFIRST + (LENGT-NORECS)*8 - 1                                  OBUF       20
                    CALL LTRIO (IP,112B,BUFF(IFIRST),BUFF(INDEX),KS)                       OBUF       21
                    IF (KS .LT. 0) GO TO 80                                                OBUF       22
                    ENDFLQ = 0.                                                            OBUF       23
                    RETURN                                                                 OBUF       24
                 80 PRINT 100,KS                                                           OBUF       25
                    STOP                                                                   OBUF       26
                100 FORMAT (*1  JOB ABORTED--  STATUS WORD *,O20)                          OBUF       27
                    END                                                                    OBUF       28
```