William P. Tayman
National Mapping Division
U.S. Geological Survey
Reston, VA 22092

User Guide for the USGS Aerial Camera Report of Calibration*

The various sections of the Report are discussed with reference to the current USGS aerial photography procurement specifications.

Abstract: *Calibration and testing of aerial mapping cameras includes the measurement of optical constants and the check for proper functioning of a number of complicated mechanical and electrical parts. For this purpose the U.S. Geological Survey performs an operational type photographic calibration. This paper is not strictly a scientific paper but rather a "user guide" to the USGS Report of Calibration of an aerial mapping camera for compliance with both Federal and State mapping specifications. The various sections of the Report are discussed with reference to the current USGS aerial photography procurement specifications.*

Introduction

The basic philosophy behind the calibration methods used at the U.S. Geological Survey (USGS) is to obtain camera calibration constants that will be applicable to a camera's normal use. The USGS photographic method of camera calibration approximates these as closely as possible. In order to avoid the random errors encountered in aerial use or in field calibration, the USGS calibrations are laboratory conducted. As far as is practical, the USGS calibration methods are in accordance with the International Society for Photogrammetry and Remote Sensing's "Recommended Procedures for Calibrating Photogrammetric Cameras and for Related Optical Tests," adopted at the Society Congress in 1960. Since adoption, these standard procedures have been modified or reaffirmed by each succeeding Congress, held every four years.

Due to the extreme environmental conditions of temperature and pressure changes, vibration, or shock to which an aerial camera is subjected, the precise alignment and spacing of the eight or more optical elements of a modern lens system can change and affect the lens performance. For this reason, the USGS requires a camera to have been calibrated within a three-year period prior to the scheduled opening date of a procurement solicitation.

For reference, a sample Report of Calibration on a typical aerial mapping camera is included as a part of this paper (Figure 1). Following the Report is a reprint of a section from a USGS Invitation For Bids solicitation for aerial photography (Section C, Part 7, Camera). Except for high altitude photography, the USGS no longer issues standard specifications for aerial photography in a separate booklet. The applicable focal length specifications are an included section in the solicitation. Section C lists the items to be included in a Report of Calibration and measurement requirements. The Report of Calibration enables the contracting officer to determine compliance of a contractors camera to the USGS procurement specifications. The numbered items in the Report of Calibration correspond to the same iem numbers listed in Section C, Part 7, of the USGS Invitation for Bids. The sample Report of Calibration will be discussed in this sequence.

Explanation of Camera Calibration Certifcate

The following section explains in some detail the various data reported in the USGS Report of Calibration. As previously noted, the paragraphs are keyed by Roman numerals to the section referenced in the Report of Calibration.

(*Text continued on page 582*)

* Presented at the ACSM-ASP Annual Convention, Washington, D.C., March 1983.

Photogrammetric Engineering and Remote Sensing,
Vol. 50, No. 5, May 1984, pp. 577-584.
0099-1112/84/5005-0577$02.25/0

USGS Report No. RSAS/999

SAMPLE

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

REPORT OF CALIBRATION of Aerial Mapping Camera — February 30, 1982

Camera type:	Camera serial no.: 12345
Lens type:	Lens serial no.: 67890
Nominal focal length: 153 mm	Maximum aperture: f/5.6
	Test aperture: f/5.6

Submitted by: All States Survey, Inc.
Ocean View, California 91919

Reference: Letter dated January 22, 1982, from Mr. C. L. Smith.

These measurements were made on Kodak micro flat glass plates, 0.25 inch thick, with spectroscopic emulsion type V-F Panchromatic, developed in D-19 at 68° F for three minutes with continuous agitation. These photographic plates were exposed on a multicollimator camera calibrator using a white light source rated at approximately 5200K.

I. Calibrated Focal Length: 153.206 mm

This measurement is considered accurate within 0.005 mm

II. Radial Distortion

Field angle	$\bar{D}_c$	D_c for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
degrees	um	um	um	um	um
7.5	-4	-3	-3	-5	-4
15	-7	-7	-7	-7	-6
22.5	-7	-6	-6	-7	-8
30	-1	-1	1	-1	-2
35	3	4	2	2	5
40	4	3	4	5	4

The radial distortion is measured for each of four radii of the focal plane separated by 90° in azimuth. To minimize plotting error due to distortion, a full least-squares solution is used to determine the calibrated focal length. $\bar{D}_c$ is the average distortion for a given field angle. Values of distortion D_c based on the calibrated focal length referred to the calibrated principal point (point of symmetry) are listed for azimuths 0°, 90°, 180° and 270°. The radial distortion is given in micrometers and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 um.

FIG. 1. Sample Report of Calibration of Aerial Mapping Camera.

USGS Report No. RSAS/999

SAMPLE

III. Resolving Power in cycles/mm

Area-weighted average resolution: 79.3

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	134	134	134	113	80	57	57
Tangential lines	134	134	113	95	67	48	48

The resolving power is obtained by photographing a series of test bars and examining the resultant image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from 5 to 268 cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the No. 123456, the No. 345678 and the No. 567890 filters accompanying this camera are within ten seconds of being parallel. The B filter was used for the calibration.

V. Shutter Calibration

Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.50 ms = 1/220 s	81%
1/400	2.12 ms = 1/470 s	81%
1/600	1.41 ms = 1/710 s	81%
1/800	1.06 ms = 1/940 s	81%
1/1000	0.80 ms = 1/1250 s	81%

The effective shutter speeds were determined with the lens at aperture f/5.6. The method is considered accurate within 3%. The technique used is Method I described in American National Standard PH3.48-1972(R1978).

VI. Magazine Platen

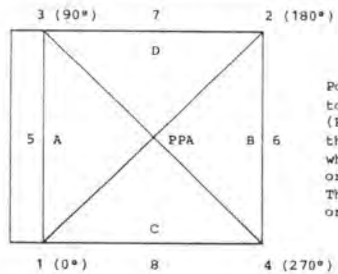
The platen mounted in film magazine No. 654321 does not depart from a true plane by more than 13 um (0.0005 in.).

The platen for this film magazine is equipped with an identification marker that will register in the data strip area for each exposure.

USGS Report No. RSAS/999

SAMPLE

VII. Principal Point and Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation (PPA) as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back, or a contact positive with the emulsion up. The direction-of-flight fiducial marker or data strip is to the left.

	X coordinate	Y coordinate
Indicated Principal point, corner fiducials	0.010 mm	0.000 mm
Indicated principal point, midside fiducials	0.009	0.026
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.008	-0.001

Fiducial Marks		
1	-103.941 mm	-103.946
2	103.956	103.939
3	-103.899	103.925
4	103.940	-103.946
5	-112.985	0.008
6	112.899	0.043
7	0.012	112.996
8	0.006	-112.991

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)
1-2: 294.002 mm 3-4: 293.951 mm
Lines joining these markers intersect at an angle of 89° 59' 50"

Midside fiducials
5-6: 225.885 mm 7-8: 225.987 mm
Lines joining these markers intersect at an angle of 89° 59' 24"

Corner fiducials (perimeter)
1-3: 207.870 mm 2-3: 207.855 mm
1-4: 207.881 mm 2-4: 207.885 mm

The method of measuring these distances is considered accurate within 0.005 mm.

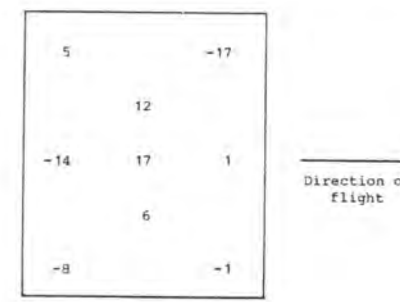
USGS Report No. RSAS/999

SAMPLE

IX. Stereomodel Flatness

Magazine No.: 654321 Base/Height ratio: 0.6

Platen ID: Maximum angle of field tested: 40°



Stereomodel
Test point array
(values in micrometers)

The values shown on the diagram are the average departures from flatness (at negative scale) for two computer-simulated stereomodels based on comparator measurements on contact glass (Kodak micro flat) diapositives made from Kodak 2405 film exposures. These measurements are considered accurate within 5 um.

X. Resolving Power in cycles/mm

Area-weighted average resolution: 44.3 Film: Type 2405

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	67	67	67	57	48	34	28
Tangential lines	67	57	57	57	40	34	28

This report supersedes the previous calibration of this camera contained in USGS Report of Calibration No. RT-R/555, dated April 30, 1979.

William P. Tayman
Chief, Optical Science Section
National Mapping Division

Fig. 1 (cont.)

REPRINT OF PORTION OF USGS INVITATION FOR BIDS FOR AERIAL PHOTOGRAPHY

SECTION C (Cont'd)

7. *Cameras*
   a. Calibrated precision aerial cameras that can take aerial photographs compatible with the precision stereoscopic mapping instruments used by the Geological Survey are required. In order to verify that each camera meets this requirement, a complete calibration of the camera system shall be performed to determine the following:
      (1) Calibrated focal length.
      (2) Radial distortion.
      (3) Resolving power from center to edge of field.
      (4) (a) Filter parallelism.
          (b) Filter antivignetting gradient density coating trace (for cameras calibrated since February 1980).
      (5) Shutter speed and efficiency.
      (6) Film—platen flatness and identification.
      (7) (a) Location of the corner and midside fiducials and point of symmetry with reference to the principal point of autocollimation.
          (b) x, y fiducial coordinates.
      (8) Distances between fiducial marks and 90° condition angle measurements.
      (9) Stereomodel flatness measurements for cameras of 153-mm and 88-mm (6-inch and 3.5-inch) focal length.
   b. The above measurements must have been performed within a three (3) year period prior to the scheduled opening date of the solicitation and the camera must meet the following requirements. (1) For 7a (1) through 7A (3).

      The characteristics of a nominal 6-inch camera shall be as follows:
      (a) Focal length, 153 ± 3.0 mm, Universal Aviogon, Pleogon A, or equivalent.
      (b) Usable angular field, at least 90°.
      (c) The following table lists the minimum acceptable radial and tangential resolution in cycles (line pairs) per millimetre (measured with type V-F spectroscopic emulsion on micro-flat glass plates exposed at maximum lens aperture):

0°	7.5°	15°	22.5°	30°	35°	40°
57	57	48	48	40	34	14

      (d) Radial distortion in the usable angular field based on the calibrated focal length referred to the calibrated principal point (point of symmetry) shall not exceed 0.010 mm.

   (2) For 7a (1) through 7a (3).
      The characteristics of a nominal 3½-inch focal length camera shall be as follows:
      (A) Focal length, 88 ± 4.0 mm, Super Aviogon II, S-Pleogon A, or equivalent.
      (b) Usable angular field, at least 120°.
      (c) The following table lists the minimum acceptable radial and tangential resolution in cycles (line pairs) per millimetre (measured with type V-F spectroscopic emulsion on micro-flat glass plates exposed at maximum lens aperture):

0°	7.5°	15°	22.5°	30°	35°	40°	45°	50°	54.5°
59	59	49	42	35	30	17	14	12	12

      (d) Radial distortion in the usable angular field based on the calibrated focal length referred to the calibrated principal point (point of symmetry) shall not exceed 0.015 mm.
   (3) For 7a (1) through 7a (3).
      The characteristics of a nominal 8¼-inch focal length camera shall be as follows:
      (a) Focal length, 210 ± 4.0 mm, Normal Aviogon II, Toparon A, or equivalent.
      (b) Usable angular field, at least 70°.
      (c) The following table lists the minimum acceptable radial and tangential resolution in cycles (line pairs) per millimetre (measured with type V-F spectroscopic emulsion on micro-flat glass plates exposed at maximum lens aperture):

0°	7.5°	15°	22.5°	30°
49	49	42	35	29

      (d) Radial distortion in the usable angular field based on the calibrated focal length referred to the calibrated principal point (point of symmetry) shall not exceed 0.020 mm.
   (4) For 7a (1) through 7a (3).
      The characteristics of a nominal 12-inch focal length camera shall be as follows:
      (a) Focal length, 302 ± 5.0 mm, Aviotar I and II, Topar A, or equivalent.
      (b) Usable angular field, at least 50°.
      (c) The following table lists the minimum acceptable radial and tangential resolution in cycles (line pairs) per millimetre (measured with type V-F spectroscopic emulsion on micro-flat glass plates exposed at maximum lens aperture):

0°	7.5°	15°	22.5°
48	48	28	24

(d) Radial distortion in the usable angular field based on the calibrated focal length referred to the calibrated principal point (point of symmetry) shall not exceed 0.020 mm.

(5) For 7a (4).

An appropriate glass filter with a metallic antivignetting coating shall be used. A microdensitometer trace shall be made and recorded of the antivignetting coating located on the lens side of the filter. A copy of this trace shall accompany the report of calibration to determine if any deterioration has occurred to the coating that would affect the uniformity of illumination in the image plane. The filter shall have surfaces parallel within 10 seconds of arc, and its optical quality shall be such that its addition to the camera shall not cause an undesirable reduction of image definition. A minus-blue glass filter shall be used with panchromatic emulsions.

(6) For 7a (5).

(a) The camera shall be equipped with a between-the-lens shutter of variable speed as approved by the Contracting Officer. The range of speed settings shall be such that, in conjunction with flight height and aircraft speed, the camera will produce high definition photographs. The shutter shall also have a speed of 1/200 second or slower for laboratory testing.

(b) The effective exposure time and the efficiency of the shutter as mounted in the camera will be measured at maximum aperture, and the shutter shall have a minimum efficiency of 70 percent at a speed of 1/200 second.

(c) This test shall be made in accordance with "Method I," American National Standard PH3-48-1972 (R1978).

(7) For 7a (6).

Cameras shall be equipped with an approved means of flattening the film at the instant of exposure. The platen against which the film is pressed shall not depart from a true plane by more than ±0.013 mm (0.0005 inch) when the camera/magazine vacuum is applied. The lens number, an alphanumeric mark (or symbol) which identifies the platen used, and the most recent calibrated focal length shall be recorded clearly on the film for each negative either on the inside of the focal plane frame or on a data strip between frames. Data markers which protrude inside the focal plane frame shall not exceed 6.35 mm (0.25 inch) in height and 25.4 mm (1.0 inch) in length and shall not obscure any part of the fiducial mark or reduce the usable image area.

(8) For 7a (7) through 7a (8).

(a) Each camera body shall be equipped with means of recording eight fiducial marks on each exposure, the marks to be located in each corner of the format and at the center of each side (see Exhibit 2). The corner fiducial marks shall form a quadrilateral whose sides are equal within 0.500 mm. The midside fiducial marks shall be equidistant within 0.500 mm from the adjacent corner fiducial marks. Lines joining opposite pairs of fiducial marks shall intersect at an angle of 90° ± 1 minute and indicate the position of the principal point of autocollimation within 0.030 mm. The fiducial centers and the point of symmetry shall fall within a 0.030 mm radius circle around the principal joint of autocollimation. For cameras with projection type fiducial marks, the projected images of all marks must be in focus on the emulsion surface. Any camera containing glass or plastic mounts of the fiducial marks will not be acceptable.

(b) All fiducial marks and other marks intended for precise measuring shall be clear and well defined on the negative and shall be of such a form that the standard deviation of repeated readings of the coordinates of each made on a comparator shall not exceed 0.002 mm. Drawings in Exhibit 2 show examples of fiducial marks.

(c) The size of the negative image shall be 23 × 23 cm (9 × 9 inches).

(9) For 7a (9).

Cameras will be tested for stereomodel flatness by exposing two film negatives in the camera while mounted on the UGSG multicollimator camera calibrator and analytically forming two stereomodels from them, using different halves of the exposures for each model. Each model thus formed will consist of a small fixed number of symmetrically arranged points. In either model, the deviation from flatness (elevation discrepancy at photography scale) at measured points may not exceed ±1/5000 of the focal length of nominal 6-inch (153 ± 3.0 mm) cameras. The deviation may not exceed ±1/5000 of the focal length of nominal 3½-inch (88 ± 4.0 mm) cameras. If elevation discrepancies exceed this value, the camera will not be acceptable.

c. Bidders are required to either have on file with the U.S. Geological Survey, National Mapping Division, Branch of Contract Management an acceptable report of calibration or submit such report with their bids. *The absence of a Report of Calibration will be cause for the rejection of bids.* The bidder's failure to provide the required Report of Calibration due to delays encountered by the testing facility shall not be considered reason for the Government to accept bids lacking such reports.

d. Prospective bidders and contractors requesting camera calibration shall ship their camera(s), including magazine(s), filters, controls, and complete operating instructions, to Mr. William Tayman, U.S. Geological Survey, National Center (Stop 526), Reston, VA 22092. A schedule for the test must be made by contacting Mr. Tayman ((703)860-6251). The combination of camera cone and magazine(s) submitted for testing, if acceptable, shall be the only combination used to take aerial photographs on U.S. Geological Survey contracts. Any other combination of cone and magazine(s) shall be considered an untested camera system and shall be reason for rejection of bids and/or rejection of any resulting photography.

e. The USGS reserves the right to retest a camera at anytime there is reason to believe that changes have occurred that would prevent the use of any resulting photography. In the event retesting of a camera is required by the U.S. Geological Survey, the bidder shall submit the camera, including magazines, filters, and controls, to the USGS for laboratory test within five (5) days after receipt of USGS notice for retesting. Notice issued by the U.S. Geological Survey that a camera requires retesting shall render previous reports of calibration invalid for future photography requirements of the USGS.

f. Laboratory tests (including retesting as described herein above) take approximately seven (7) days. The contractor shall bear the expense of testing and shipment to and from the USGS. Unless specified otherwise by the prospective bidder, cameras returned to the original shipper will be insured at the original shipper's expense for the same value as when received.

(Continued from page 577)

I. CALIBRATED FOCAL LENGTH

The focal length normally reported in a lens test is the equivalent focal length (EFL); however, in photogrammetry a calibrated focal length (CFL) is determined to minimize the plotting error due to distortion. The CFL is the scale factor used to convert transverse distances in the image plane of a photograph into corresponding distances in the object plane or in the scene photographed. For the image plane, it is determined by the radial distance of the image divided by the tangent of the half-field angle.

If the value varies across the image plane, it is an evidence of distortion which is normally expressed as the differential in radial distance required to keep the focal length constant. The CFL reported is the value that makes the positive and negative values of distortion equal when computed by the method of least squares. The EFL is the limiting value as the field angle goes to zero. If there is no distortion, the CFL and EFL are identical. The difference between the equivalent focal length and the calibrated focal length can be expressed as the value of Δf determined from the relation

$$\Delta f = (D_1 + D_2)/(\tan B_1 + \tan B_2)$$

where D_1 and D_2 are the values of distortion, referred to the equivalent focal length, at angles B_1 and B_2 for which equal but opposite values of distortion are desired. It should be emphasized that no physical shift of the focal plane takes place between the EFL and CFL. The only change is in the choice of a scale factor for use in interpreting measurements of distance separating various image points.

II. RADIAL DISTORTION

Distortion affects positions of image points in the image plane but not image quality. Distortion is a variation of scale of an image as a function of position in the image plane. The presence of distortion is of great importance in photogrammetry where the ultimate aim is to produce maps of uniform scale from measured images. The standard USGS procedure is to measure the radial distortion from a camera's format center to the corner along each diagonal. To minimize the maximum distortion displacement of the principal rays over the field, a least-squares solution is used to equalize the positive and negative values of distortion. The distortion is reported in micrometres at the collimator angle positions of the calibrator. Modern lenses today are nearly free of radial distortion, with measured values being under 10 micrometres based on the calibrated focal length referred to the calibrated principal point (point of best symmetry).

III. RESOLVING POWER

Resolving power is a numerical measure of lens performance, related to image definition. However, one should always consider the fact that resolution is as much a function of the receptor and the emulsion as of the optical system. Resolution of a particular lens and film together can never be more than that of the lens or the film, whichever is the lower. It is for this reason that the USGS measures resolving power on both fine-grain and medium-grain emulsions such as Kodak 2402 or 2405.

In Section III of the Report of Calibration, the resolving power obtained with the fine-grain or high-definition emulsion is given. The values given in Section X are for the fast panchromatic film emulsion used for standard USGS contract photography. Regardless of the grain size, both test emulsions have the same spectral sensitivity. The light source used in the test collimators is approximately 5,200K, considered to be noon sunlight. The test collimators have high-contrast resolution test charts as reticles. These charts have 24 three-line test patterns spaced at the fourth root of 2. For a 153-mm (6-inch) lens, the test patterns are 5 cycles (line pairs) per millimetre (chart 1) to 268 cycles per millimetre (chart 24).

The contract specifications list the minimum acceptable radial and tangential resolution in cycles per millimetre for the various field angles. These test values are given in Section III of the report. Also stated in the specifications are the type of test emulsion and the requirement that resolution test exposure be made at maximum lens aperture.

IV. FILTERS

The filters are measured to determine if the prismatic power is less than 10 seconds of arc, as required in the camera specifications. If the lack of parallelism is greater than 10 seconds of arc, the position of the principle point of autocollimation will shift, introducing unacceptable asymmetric distortion. The density of the antivignetting coating of a filter is designed to correct the light distribution of the photogrammetric lens with which it is used. A unique density gradient envelope is therefore specified. For each filter, this gradient is measured and compared with the specified envelope, while the coating is visually inspected for deterioration which would also affect the uniformity of illumination of the camera lens system.

Each filter that meets the specification requirement for parallelism is listed in Section IV of the Report of Calibration. Accompanying the report are microdensitometer curves showing the filter's measured antivignetting coating and a superimposed dashed line showing a normal curve when the measured coating curve is out of tolerance.

V. SHUTTER CALIBRATION

The USGS camera specifications specify the type of shutter, range of speed, minimum efficiency, and method of test. As stated in the specifications, the technique used in the camera calibration is Method I described in American National Standard PH 3.48-1972 (R 1978).

Normally, values are reported at the following indicated settings at maximum aperture, giving measurements for the effective shutter speed and efficiency:

1/200 second
1/400 second
1/600 second
1/800 second
1/1000 second

VI. MAGAZINE PLATEN

The platen is the flat surface against which the back surface of the film is pressed to ensure planeness of the emulsion surface during the time of exposure. Its outer edges overlap the camera focal-plane frame. It is essential that the platen surface be a true plane because small departures from planeness in this surface can produce shifts in image location similar to those produced by lens distortion. The specifications state the platen against which the film is pressed shall not depart from a true plane by more than 0.013 mm (0.0005 inch) when the camera/magazine vacuum is applied. Also included in this section of the report is the platen identification statement. The specifications require an alphanumeric mark (or symbol) which identifies the magazine platen. This mark or symbol will register on each exposure in the data strip area of the camera format.

VII. PRINCIPAL POINT AND FIDUCIAL COORDINATES

The *x-y* coordinates given in this section of the report are referenced to the principal point of autocollimation (PPA) as origin. If lines are drawn across the camera format connecting opposite fiducials 1-2, 3-4, and A-B, C-D, the intersections of these lines are the indicated principal points for either the corner or midside fiducials. The principal point of autocollimation (PPA) is the location at which the 0° collimator is recorded on the test negative when the focal plane is perpendicular to the axis of this collimator.

The calibrated principal point (point of best symmetry) is the shift that is necessary from the PPA to reduce the asymmetry of the distortion to a minimum. If there were no asymmetric distortion, this value would be zero. For specification compliance, the indicated principal points shall be within 0.030 mm of the PPA. The point of best symmetry shall be within a 0.030-mm radius circle around the PPA.

The *x-y* coordinates reported for the fiducials 1 through 8 are measurements made on the rigid emulsion of 7-mm thick microflat glass plates. The accuracy of these measurements depends on the quality of the imagery recorded. For clear, fine-lined, well-defined center dots, these measurements are accurate within a few micrometres. The geometry from these measurements is used for film deformation control for analytical aerotriangulation.

VIII. DISTANCES BETWEEN FIDUCIAL MARKS

The distances separating the members of opposite pairs of fiducial marks are constants that have specified requirements for length and angle intersect. The corner fiducial marks shall form a quadrilateral whose sides are equal within 0.500 mm. The midside fiducial marks shall be equidistant within 0.500 mm from the adjacent corner fiducial marks. Lines joining opposite pairs of fiducial marks shall intersect at an angle of 90° ± 1 minute of arc.

IX. STEREOMODEL FLATNESS

For specification compliance, the stereomodel distortion (Z-direction) shall not exceed 1/5000 of the flight height for cameras of 153-mm and 85- to 88-mm (6-inch and 3.5-inch) focal length. With the camera functioning in the normal mode of operation, a number of film exposures are made to simulate aerial photographs. Fifteen of the target collimators in the test instrument are so arranged that a pair of diapositives made from the exposed film form a stereomodel consisting of nine symmetrically arranged points (see Figure 2). That is, the right half of the diapositive serves as the left photograph of a stereopair and the left half of the diapositive serves as the right photograph of a stereopair. The left plate is held fixed and the right plate is oriented to it. The three-dimensional coordinates of the nine image points in the resulting stereomodel are computed by a least-squares solution. A regression plane for the best overall fit is made to the nine points, and the residual "lack of flatness" is determined.

For a camera to be acceptable, the deviation from flatness (elevation discrepancy at photography scale) at the nine test points cannot exceed the following values. The values given in the report are the average departures from flatness for two stereomodels as shown in Figure 2.

Camera Focal Length	Stereomodel Flatness
85–88 millimetres	17 micrometres
153 millimetres	30 micrometres

The base-height ratio is 0.6 for cameras having a 90° field and 1.0 for cameras having a 120° field.

Small defects in the camera, such as variation from planarity of the film platen, irregularity of the film flattening system (vacuum), distortions, centering of the camera lens elements, and nonparallelism of the filter surfaces, all contribute to the results of the stereomodel flatness measurements.

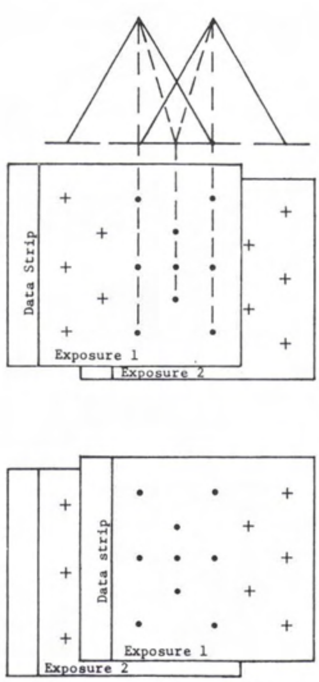


FIG. 2. Test point array showing the points used from two film exposures for the stereomodel flatness measurements. The diagram shows the geometric relation of rays for the nine corresponding point intersections.

SELECTED REFERENCES

American National Standards, "Shutter Tests For Still-Picture Cameras", PH 3.48-1972 (R1978).

MIL-STD-150A, "Photographic Lenses" (12 May 1959) with change 2 (28 January 1963).

Slama, C. C., ed., 1980. *Manual of Photogrammetry*, Fourth Edition: American Society of Photogrammetry, Ch. III, IV.

International Society of Photogrammetry, 1960. "Recommended Procedures for Calibrating Photogrammetric Cameras and for Related Optical Tests."

Tayman, W. P., 1974. Calibration of Lenses and Cameras of the USGS, *Photogrammetric Engineering*, Vol. 40, No. 11, pp. 1331-1334.

———, 1978. Analytic Multicollimator Camera Calibration, *Photogrammetria*, Vol. 34, pp. 179–197.

Tayman, W. P., and H. Ziemann, Photogrammetric Camera Calibration, *Photogrammetria*, (in press).

Washer, F. E., and W. P. Tayman, 1955. Variation of Resolving Power and Type of Test Pattern, *Journal of Research of the National Bureau of Standards*, Vol. 54, No. 3, pp. 135-142.

Washer, F. E., Tayman, W. P., and Darling, W. R., 1958. "Evaluation of Lens Distortion by Visual and Photographic Methods," *Journal of Research of the National Bureau of Standards*, Vol. 61, No. 6, pp. 509-518.

(Received 26 August 1983; accepted 28 November 1983; revised 2 January 1984)