*Relative Orientation of Segmented, Panoramic Grid Models on the AP-II**

CHARLENE GILL,
Supervisory Cartographer, U. S. Air Force, Aeronautical Chart and Information Center, St. Louis, Mo.

ABSTRACT: *The concepts of relative orientation of segmented, convergent, panoramic grid models are the result of tests on the Analytical Plotter-II, using working formulas developed at ACIC. The time-honored "swing-swing" and one-projector methods of removing Y parallax have given way to automation. Cited within this paper are the theory, formulas, and procedures that were established to do orientation of segmented panoramic models on a production basis.*

As NEW types of camera systems are used in USAF reconnaissance aircraft, it is necessary that military mapping agencies introduce more elaborate and futuristic plotting equipment into their photogrammetric operations in order to be able to use the outputs of these systems.

In the fall of 1961, the USAF Aeronautical Chart and Information Center in St. Louis inaugurated the prototype of analyical stereoplotters, the Analytical Stereoplotter, AP-I. This plotter, first suggested by Dr. U. V. Helava[1] of the Canadian National Research Council in Ottawa, was developed for the Air Force by Rome Air Development Center on contract to the Fairchild Camera and Instrument Corporation working jointly with Ottico Meccanica Italiana, Rome, Italy who built the optical-mechanical portion and The Bendix Corporation who constructed the computer.

CHARLENE GILL

Based upon tests and other experience with the AP-I, and to meet rapid mapping requirements using all types of inputs including panoramic photographic materials, the AP-I was modified into the AP-II. Upon receipt of this newly designed prototype, new tests were initiated. This paper is a report on a portion of those tests which deal with considerations of panoramic photography.

Several publications have been written to explain or define the concepts of an analytical stereoplotter, to explain its computer and computer programs and to indicate the expected and actual accuracies which are associated with this type of instrument.[2] The AP-II, with its computer programs, can automatically compensate for such effects as air refraction, earth curvature, differential film shrinkage and lens distortion. To apply such corrections, so as to have the flexibility to handle materials obtained from any USAF Reconnaissance system and to achieve normal production compilation accuracies of $\sigma_h = 15\mu - 25\mu$ at model scale, results in an instrument which is very costly.

* This paper has been cleared for open publication by the Department of Defense and Hq USAF.

The development of a truly universal analytical plotter has led ACIC from considering present day conventional vertical, or near vertical, mapping photography (as considered by the AP-I) to an analysis of futuristic convergent panoramic photography. The problems of viewing, rectification, transformation and correction for sweep and altitude distortions associated with panoramic photography make its use for high quality mapping seem less than desirable.

However, overcoming these difficulties is possible with the analytical plotter which can take contact diapositive plates of a convergent panoramic nature, enable them to be viewed, perform the rectifications, transformations, model deformation removal, etc., and produce a finished map compilation. The AP-II is designed to consider photography up to a 9×9 inch format. Since some panoramic materials being considered today have formats which exceed this limitation and in order not to sacrifice the resolution and geometry of these materials by using reduction processes, it was recognized that procedures would have to be developed to handle segments of these materials. In conventional instruments such an approach compromises perspective geometry by introducing undesirable distortions in the model which are difficult to compensate for in the compilation process. Because of the *analytical* nature of the analytical plotter this problem ceases to exist.

As long as the correct parameters are set into the AP-II computer, there is no limitation on the location of the segmented portion. However, for purposes of standardization both of production and of analytical formulation, the segmented "chunk" idea has been considered (as shown in Figure 1). This idea divides the photograph into parts or segments which are positioned on the 9″ diapositive in such a manner as to allow overlap with succeeding models of the other segments.

Relatively orienting these segmented models is not accomplished very easily using conventional relative orientation techniques associated with conventional full frame models. This is due to the higher degree of correlation between orientation elements as they affect Y-parallaxes. Tests at ACIC have demonstrated that numerical methods based upon observations of Y-parallaxes in the stereo model are more effective. The principle of the method is that Y-parallax observations are made in the model at preselected positions as shown in Figure 2. In the procedure Y-parallax at points 1, 2, 3, and 4 is used to determine relative κ and ϕ orientation of the model and points 5, 6, and 7 are used to determine relative bz, ω, and by (as shown in Figure 3). The mathematical theory of the method is based upon the classical linear approximation formula for Y-parallax in the stero model and, because the formulation is not exact, the procedure must be iterative until a satisfactory model solution is obtained.

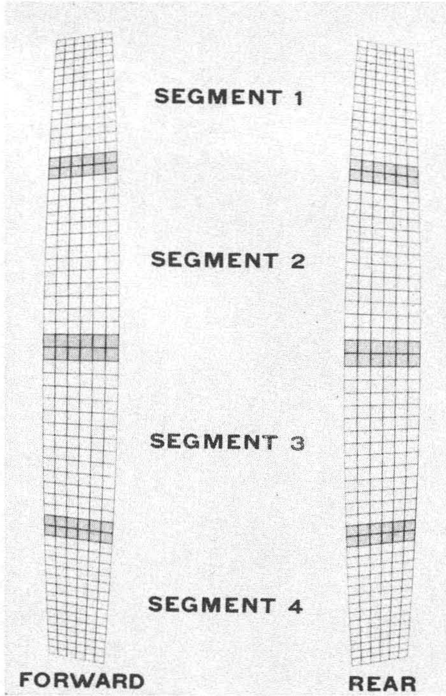


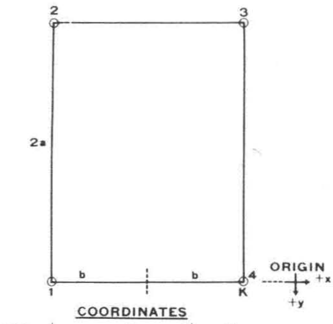
FIG. 1. Segmentation of panoramic grids.

To simplify the process on the AP-II, programs have been written into the AP-II computer to calculate and make model correction automatically after Y-parallax data has been read into the computer through the AP-II console.

Since the observations of Y-parallax are made in the stero model where panoramic and convergent distortions had been removed, the Y-parallax discrepancies at a point are related to elements of errors in relative orientation as shown in the following formula based upon dependent pairs:

$$Py = dby + \frac{Y}{h} dbz + \frac{(h^2 + Y^2)}{h} d\omega + \frac{XY}{h} d\phi + Xd\kappa$$

The following definitions are given to assist in understanding the development:



RIGHT TO LEFT
SEGMENTED–PANORAMIC GRID
IN-BOARD CHUNK
ORIGIN-NADIR OF #2

BASIC PARALLAX FORMULA

$$Py = dby + \frac{Y}{h} dbz + X d\kappa + \frac{(H^2 + Y^2)}{h} d\omega + \frac{XY}{h} d\varphi$$

COORDINATES

PT	X	Y
1	-(K + b)	0
2	-(K + b)	-2a
3	-(K − b)	-2a
4	-(K − b)	0

ERRORS

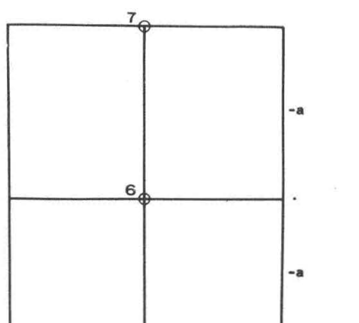
$$d\varphi = + \frac{h}{4ab} (P_1 - P_2 + P_3 - P_4)$$
$$d\kappa = - \frac{1}{2b} (P_1 - P_4)$$

FIG. 2. Dependent orientation of ϕ and κ.

$k = \frac{1}{2}$ air base distance
$a = \frac{1}{2}$ model length in y distance
$b = \frac{1}{2}$ model width in x direction
Pn = parallax-point, n
f = focal-length ($f \approx h$)
X, Y = Model coordinates whose origin is at the center of the nadir plane between photo centers. The coordinate system is right handed with a positive X in the direction of the line of flight.
dby dbz = Translation errors of photo number 2
$\Delta\phi$ $\Delta\omega$ $\Delta\kappa$ = Relative orientation errors of photo number 2
h = Projection distance to the stereo model ($h \approx$ focal-distance of camera)

The relative locations of the parallax points in the segmented model illustrated in Figures 2 and 3 are related to the nadir plane of the panoramic photograph. The coordinates of the four corner points are as shown. Combining the expressions for Y-parallax discrepancies observed at each point it is possible to determine a correction for ϕ and κ based only on these four points. At the center of the model a similar combination of parallax expressions result in formulas which will permit computation of the ω, bz, and by orientation errors. Figure 3 shows the development of this concept.

The formulation for the determination of the elements of orientation differ as one proceeds from segment to segment, but all exhibit a certain similarity which makes them



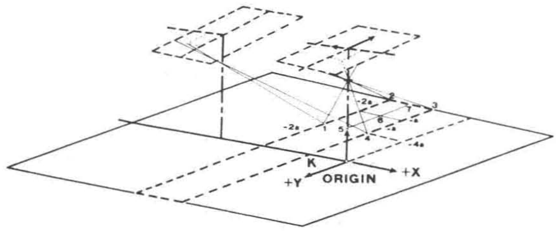
COORDINATES

PT	X	Y
5	-K	0
6	-K	-a
7	-K	-2a

ERRORS

(ω) $$d\omega = \frac{h}{2a^2} (P_5 - 2P_6 + P_7)$$
(bz) $$d\,bz = \frac{h}{2a} (3P_5 - 4P_6 + P_7)$$
(by) $$d\,by = P_5 - \frac{h^2}{2a^2} (P_5 - 2P_6 + P_7)$$

FIG. 3. Dependent orientation of W, BZ and BY.



COORDINATES

PT	X	Y
1	-(K + b)	-2a
2	-(K + b)	-4a
3	-(K − b)	-4a
4	-(K − b)	-2a
5	-K	-2a
6	-K	-3a
7	-K	-4a

(φ) $d\varphi = \frac{h}{4ab}(P_1 - P_2 + P_3 - P_4)$

(κ) $d\kappa = -\frac{1}{2b}(2P_1 - P_2 + P_3 - 2P_4)$

(ω) $d\omega = \frac{h}{2a^2}(P_5 - 2P_6 + P_7)$

(bz) $d\,bz = \frac{h}{2a}(7P_5 - 12P_6 + 5P_7)$ (by) $d\,by = 6P_5 - 8P_6 + 3P_7 - \frac{h^2}{2a^2}(P_5 - 2P_6 + P_7)$

FIG. 4. Relative position of rectified-transformed outboard segment.

easily adaptable to use by relatively unskilled operators. Note also that the signs in the formulation differ as the distance a is negative or positive with respect to the nadir plane of the model (as shown in Figure 4).

In the AP-II a set of program tapes are being programmed to:

a) automatically go from point to point for Y-parallax measurements
b) automatically compute and display these corrections
c) upon operator acceptance of these values, introduce the proper corrections.

When the theory portion had been completed, tests were begun on the AP-II to evaluate the procedure. For these tests, a test grid was analytically computed and precisely plotted to reflect the geometry of a photograph taken with a 15 degree convergent panoramic system assuming a 12 inch focal-length. The grid itself was approximately 30

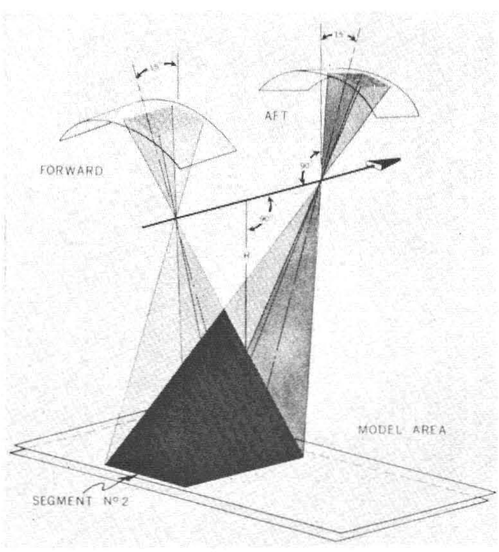


FIG. 5. Camera configuration.

TABLE I. IN-BOARD SEGMENT

$a = 80$ mm.; $b = 30$ mm.; $k = 81.67$ mm.; $f = 304.8$ mm.

Measured ΔPy Parallax Point No.	*1st Iteration*	*2nd Iteration*	*3rd Iteration*
1	−2.79	+0.31	0
2	+1.66	−0.33	0
3	+0.52	−0.33	0
4	−3.15	+0.31	0
Corrections	*1st Iteration*	*2nd Iteration*	
$d\phi$	−1°.4189	0	
$d\kappa$	−0°.3438	0	
Measured ΔPy Parallax Point No.	*1st Iteration*	*2nd Iteration*	*3rd Iteration*
5	−3.61	+0.31	0
6	−2.27	0	0
7	− .67	−0.33	0
Corrections	*1st Iteration*	*2nd Iteration*	
$d\omega$	− .191	− .027	
dbz	−6.134	−1.143	
dby	−27.454	+ .460	

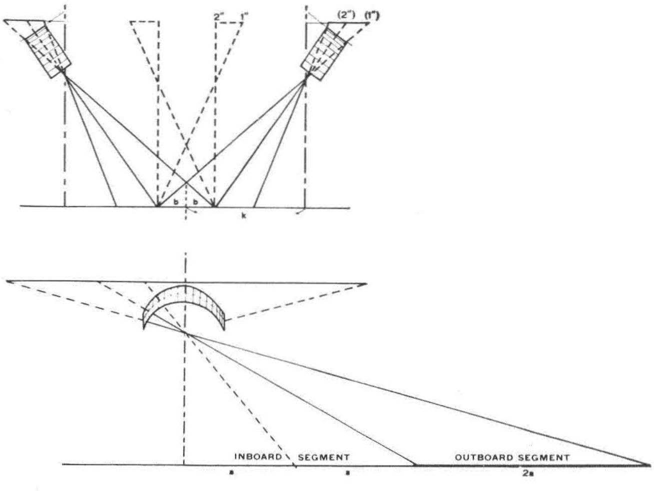


FIG. 6. Rectification and transformation—Convergent panoramic grid.

cm. long and projected as ½ centimeter squares in the model plane. The test grids used in the plotter were formatted as corresponding 9 inch segments taken by both forward and rearward looking cameras (as shown in Figure 5).

The photographic images of the test grid are not transformed to remove panoramic distortion to permit viewing by the operator. Instead the plotter is programmed to transform the original panoramic material through the viewing system of the plotter (as shown in Figure 6).

In the testing program conducted with the test grids, it was necessary to input certain initial values into the AP-II computer as constants. Since these grids were mathematically created, it was possible to either observe a perfect model by setting in the original grid values or to enter "disturbed" elements into the right projector and remove these to the original values by the process of parallax measurements and numerical relative orientation. Test results of a sample relative orientation are shown in Table 1.

Summing up, the following conclusions can be made:

a. Segmented convergent panoramic photography *can* be used successfully on the AP-II.
b. The formulas, as given, operate satisfactorily and at a fairly rapid rate of speed.
c. *Y*-parallax removal can be accomplished within the viewing accuracy of the in-

OUT-BOARD SEGMENT

$$d\varphi = \frac{h}{4ab}(P_1 - P_2 + P_3 - P_4)$$

$$d\kappa = -\frac{1}{2b}(2P_1 - P_2 + P_3 - 2P_4)$$

$$d\omega = \frac{h}{2a^2}(P_5 - 2P_6 + P_7)$$

$$d\,bz = \frac{h}{2a}(7P_5 - 12P_6 + 5P_7)$$

$$d\,by = 6P_5 - 8P_6 + 3P_7 - \frac{h^2}{2a^2}(P_5 - 2P_6 + P_7)$$

IN-BOARD SEGMENT

$$d\varphi = \frac{h}{4ab}(P_1 - P_2 + P_3 - P_4)$$

$$d\kappa = -\frac{1}{2b}(P_1 - P_4)$$

$$d\omega = \frac{h}{2a^2}(P_5 - 2P_6 + P_7)$$

$$d\,bz = \frac{h}{2a}(3P_5 - 4P_6 + P_7)$$

$$d\,by = P_5 - \frac{h^2}{2a^2}(P_5 - 2P_6 + P_7)$$

FIG. 7. Basic formulas.

strument and is limited only by the resolution of the original material.

d. The process, as described, can be used in production and should be learned quickly by the First Order Stereo-Instrument Operator.

e. Further investigation as to utilization of these basic formulas (as shown in Figure 7) should be considered by those interested in the use of panoramic convergent photography for mapping.

REFERENCES

1. Helava, U. V., "New Principle for Photogrammetric Plotters," *Photogrammetrica*, 2. 1957–1958, pp. 89–96.
Helava, U. V., "Analytical Plotter Using Incremental Computer," PHOTOGRAMMETRIC ENGINEERING, June 1960.
2. Friedman, S. J., "AP/1—A New Concept in Stereomapping," PHOTOGRAMMETRIC ENGINEERING, July 1962.
Mahoney, Dr. William C., "Operational Use of the AP-2 at ACIC," ACIC Technical Paper No. 11, USAF° Aeronautical Chart and Information Center, St. Louis, Missouri.

*Coordinate Measurement: The Elusive Micron**

ERWIN G. LOEWEN,
Head, Metrology Research & Development
Bausch & Lomb, Incorp.,
Rochester, N. Y.

ABSTRACT: *There exists a noticeable gap between the 1 micron least reading on coordinate measuring equipment and the attaining of true 1 micron accuracy. This is caused by inherent limitations of screws and scales which form the basic measuring reference. Often overlooked is the problem of transferring dimensions from the measuring reference to the working plane. For example, nearly all existing designs depend to a greater or lesser extent on both the straightness and orthogonality of two sets of ways, and their interaction. An error of only 0.9 seconds of arc in 9 inches corresponds to an error of 1 micron. Calibration of coordinate measuring tables is very difficult to perform reliably to less than a micron, since a precision ruled grid is the only good method available. Until now such grids have been difficult to obtain. A new facility is nearing completion that will fill this gap by ruling grids with errors small enough to be ignored in most practical situations of photogrammetry.*

INTRODUCTION

WHILE typical accuracy obtainable in current aerial photography is rarely better than 5 μ, there would be a distinct advantage in evaluating photographs with coordinate measuring equipment which is accurate to 1 μ. The reason for this is simply that instrumental errors would not have to be considered in data reduction. Even with modern computers it is desirable to avoid storing error information in a memory unit whose size and cost one should hold at a minimum. Coordinate measuring equipment for many years has been designed for 1 μ readout over 240 mm. square areas, but working accuracy has rarely been of the same order. Even calibrations to an accuracy of 1 μ have been very difficult to perform for lack of good reference standards. It is worth examining the difficulties involved both in instrument design and calibration in order to

* Presented at 30th Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., March 17–20, 1964.