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*The Wild A-7 Autograph as a Comparator**

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INTRODUCTION

PHOTOGRAMMETRY is commonly defined as, "The science or art of obtaining reliable measurements by means of photography."[1] To obtain the required "measurements" it is necessary to make certain other measurements on the photograph itself. These photo-measurements may be recorded as actual distances on the photograph, or may be converted by some instrument directly to the required results, recorded as a map or drawing. This is the system employed by the many projection type plotters in use today. Analytic photogrammetric methods require actual measurements on the photograph itself, as part of their basic data. It follows then, that the accuracy of the results depends in a large part on the accuracy of the photo-measurements.

In aerial photogrammetry these measurements are usually obtained as two-dimensional rectangular co-ordinates. The origin of the system is commonly the principal-point of the photograph as defined by the fiducial marks. The axes of the system are then the fiducial-axes with positive x being that axis which most nearly coincides with the line and direction of flight.

Many instruments have been adapted or developed for the specific purpose of measuring photoco-ordinates. These range from the simple engineers scale, with an accuracy of about 0.01″ to 0.005″, to the highly-refined monocular and binocular comparators, most of which have accuracies approaching 0.001 mm. or 1 micron.

This paper deals with the adaptation of yet another instrument—the Wild A-7 Autograph—to the function of measuring photo co-ordinates. The investigation was undertaken in order to determine if an organization—Cornell University in particular—which possesses an A-7, can make use of the instrument to perform the measurement task with accuracy sufficient for analytical methods of photogrammetric solution. A discussion of the instrument's construction and possible methods of use is included in this paper as well as the presentation of the test data which was gathered.

[1] American Society of Photogrammetry, MANUAL OF PHOTOGRAMMETRY, *2nd edition* p. 830.

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The Wild A-7 Autograph

"The Wild A-7 Autograph is a high-precision universal instrument for the stereoscopic plotting of pairs of aerial or terrestial photographs."[2] This statement plainly indicates the primary purpose for which this instrument has been constructed. In order to accomplish this primary task it is, of necessity, a highly refined piece of photogrammetric equipment, both mechanically and optically.

It is impossible to enter into a lengthy discussion of all the details of construction and functioning of this instrument in a paper of this type. However, certain principles of operation which are basic to the problem at hand will be considered.

The A-7 Autograph is constructed on the principle of mechanical projection. According to this principle every ray is reconstructed from the image point (p) on the photograph through the projection center by a mechanical rod known as a space-rod. Figure 1 illustrates the principle of mechanical projection as applied to two overlapping aerial photographs.

The two photographs (I and II) are placed in the same relative positions they occupied at the instant each was exposed. If the upper ends of the space-rods point to the image-points p_1 and p_2, the axes of the space-rods will intersect in the relative position of the ground point P. The surface defined by the location of many points such as P will produce a model of the area which is of the same scale as is b to B, the actual distance between exposure stations.

The A-7 Autograph utilizes positive or negative photographic prints on glass-plates or film, with up to 9″×9″ format. Usually positive prints on glass, known as diapositives, are used. These plates are held in plate carriers that are free to rotate about three independent and mutually perpendicular axes passing through two respective projection centers. This is mechanically accomplished by means of a Cardonic Joint which allows the plate to assume the same relative position as the sensitized medium in the camera occupied when the photograph was exposed.

Also passing through each projection-center and mounted so as to have free motion in any direction about the center, is a space-rod which corresponds to the ray of light in each "projection camera." These space-rods are comprised of two telescopic sections. This compensates for the fact that the distance from the projection center to random points

[2] Wild Heerbrugg, *Wild A-7 Autograph* p. 1.

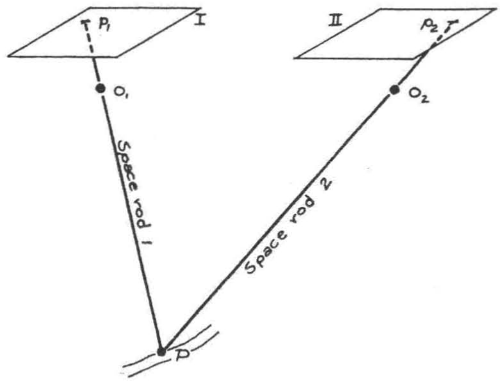

FIG. 1.

on the plate varies. The upper end of each space-rod carries a microscope which is attached to the rod by a universal joint and enables the operator to view the point at which the end of the space rod is pointing. This microscope remains always perpendicular to, and a constant distance from, the plane of the plate as it scans over it. It is in this microscope that the measuring mark is introduced into the optical system of the instrument.

The center of the universal-joint attaching the microscope to the space rod describes another plane which is parallel to the plane of the photograph as shown in Figure 2. If the perspective-center is now placed a distance equal to the focal-length of the camera away from the new plane and on the optical axis of the photo, the exact conditions of "interior orientation" will be recovered.

Since each perspective center in this instrument is in a fixed position, it was necessary that the space-rods should not actually intersect, so as not to interfere with each other, and in order to allow the base to be variable. Thus the entire plate carrier system is separated a distance (S) as shown in Figure 3. The base carriage which separates the effective intersection points, carries at each end three mutually perpendicular motions. This enables the base to be divided into its three components bx, by and bz, as shown in Figure 3.

In order to plot the position of any point within the model, the base carriage may be displaced in three mutually perpendicular directions. These three movements can be measured on co-ordinate counters mounted on the machine, or by means of a shaft digitizer take-off to an electro-magnetic co-ordinate printer. The counters can easily be read to 0.01 mm. which is also the finest

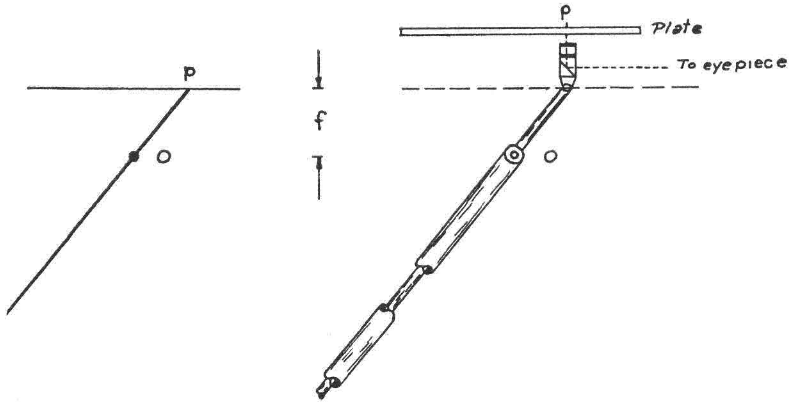

FIG. 2.

division the printer will register. However, it is possible to read the counter dials by estimation to one micron, although it is rather difficult to obtain consistent readings to this accuracy.

The x' and y' machine co-ordinates may be referred to any point as the origin of co-ordinates, but it is desirable to keep all the readings in the $+x$ and $+y$ quadrant, because the machine has no facility for distinguishing negative values. The z' measurement is referred to any given horizontal plane as set on the z counter dial. Figure 4 is a schematic diagram of the A-7 Autograph showing its basic construction along with the various motions mentioned above. Table 1 lists the ranges of these motions, and is abstracted from that shown on page 23 of Operation Manual provided with the A-7.

TABLE I

RANGES OF MOVEMENT

Focal length—f	98 to 215 mm.
Picture size	up to 230×230 mm. (9″×9″)
Base Components:	
bx	+280 to −280 mm.
by	+ 50 to − 50 mm.
bz	+ 27 to − 27 mm.
x′	+280 to −280 mm.
y′	+350 to −420 mm.
z′	−140 to −490 mm.

POSSIBLE METHODS OF PLATE CO-ORDINATE MEASUREMENT

With the A-7 Autograph we have a number of possibilities when we consider measuring

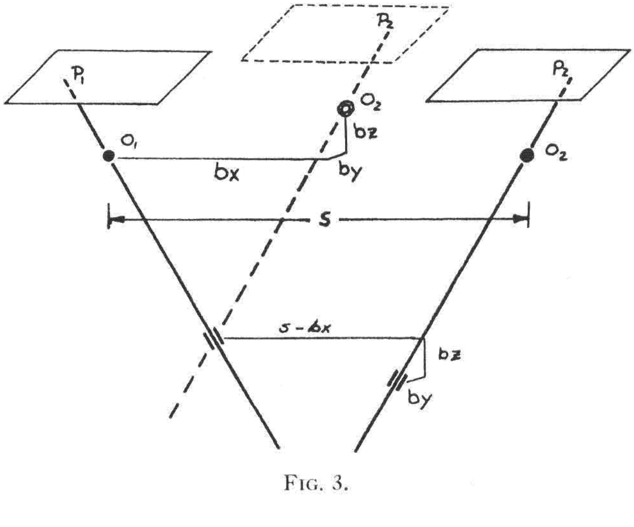

FIG. 3.

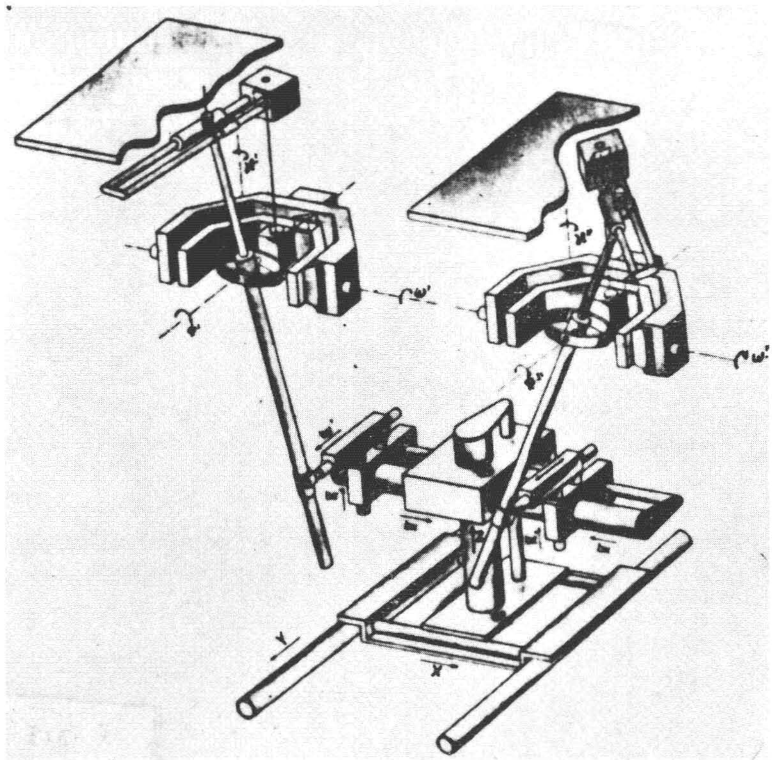

FIG. 4. Wild A-7 Autograph, Schematic Diagram.

plate co-ordinates. It is possible to view the plates either monocularly or stereoscopically, each of which have certain advantages. In both basic methods the mechanical projection principle in the A-7 is used to advantage as a mechanical magnifying device. For the purpose of this discussion, the presentation will be clearer if we assume the space-rods do intersect, thus eliminating the x' displacement of the intersection points.

METHOD I—MONOCULAR MEASUREMENT

When viewing monocularly only one photograph is seen and measured at a time. In this method the photo is placed in one of the plate-holders with all motions set at zero (ϕ, ω, κ). With the swing motion (κ) the x and y photo axes are then lined up with the x' and y' axes of the instrument. Since $\phi \epsilon \omega$ equal zero, the plate is perfectly parallel with the z' reference-plane of the instrument and the distance from the projection-center to the two dimensional "monocular model" in this plane is a constant.

By similar triangles (Figure 5),

$$x:f = x':z'$$

$$x = \frac{f}{z'} x'$$

It can be seen that a variable magnification factor, f/z, may be obtained since f, the nominal focal-length, does not have to be a specified value. With a small amount of planning an operator may select his magnification as he desires. Since the instrument has certain ranges, which have been specified, for each of the motions he must plan his operations only to the extent that he knows he will not exceed the limitations of the instrument coordinate system.

METHOD II—BINOCULAR MEASUREMENT

When making the measurements binocularly much more work is involved. The main advantage of this method over monocular viewing is the fact that points which are difficult to identify in a single photo may be more easily identified and measured with the aid of the stereoscopic model.

To achieve this advantage it is necessary to perform the task of relative-orientation of

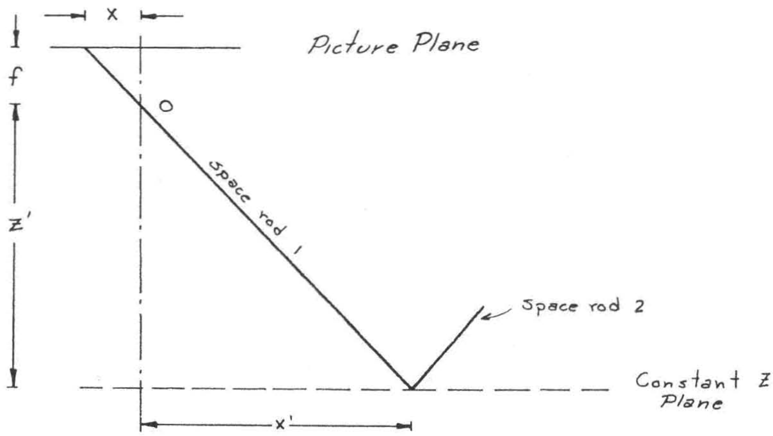

FIG. 5.

two photographs which in some cases would greatly increase the time needed for the measuring procedure. This orientation could be accomplished in either of two ways. One photo may be placed in its plate holder in the same manner as described under Method I and the other oriented to it. The alternate orientation method would be to simply make the orientation as would normally be done in this instrument, and then correct the measurements for the rotations of tilt, tip and swing. Utilizing an electronic computer and following either of these methods, would result in the advantage of being able to measure both plates at once. However, it is obvious that only the overlap area of the two photos could be measured stereoscopically, and that it would require two complete operations involving at least three photos of 60% overlap to view and completely measure all points in just one of the photos.

Let us first consider the ideal case for binocular viewing. (See Figure 6.) Given two perfectly vertical photographs with their x axes lying in the same vertical plane.

By similar triangles (Figure 6):

$$x_a : f = x_a' : z_a'$$

and

$$x_b : f = x_b' : z_b$$

therefore:

$$x_a = \frac{f}{z_a'} x_a'$$

$$x_b = \frac{f}{z_b'} x_b'$$

Two disadvantages of this system can easily be seen at this point. The first is due to the fact that if a true stereoscopic model is to be formed, the distance from the photo-plane to the projection-center must be equal to the

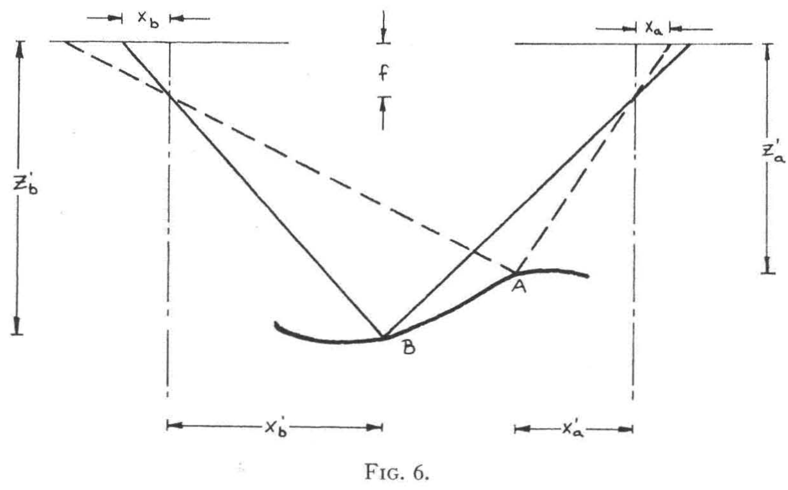

FIG. 6.

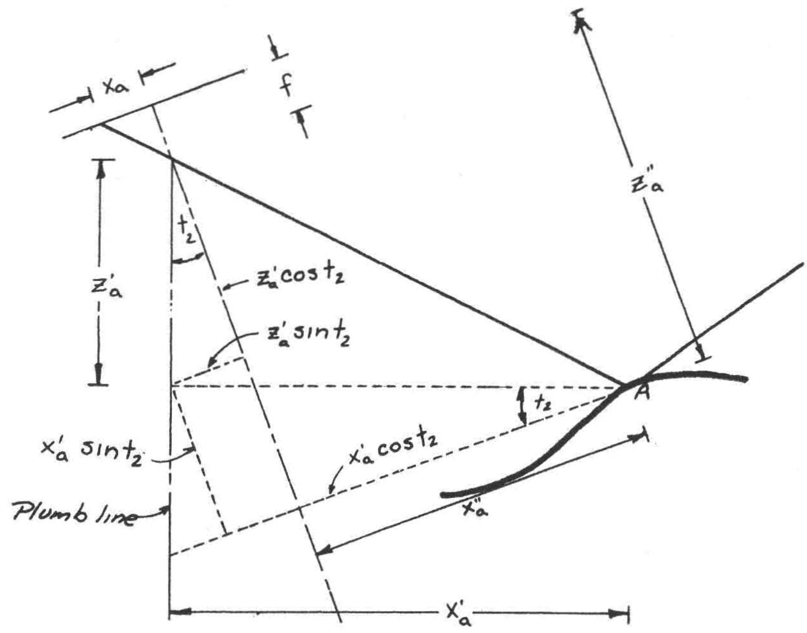

FIG. 7.

focal-length of the camera with which the photograph was obtained. This eliminates many of the possible magnification factors which could be obtained with monocular viewing. The second is that in order to set the measuring mark on any point in question it is necessary to move the intersection of the space-rods either up or down, as is dictated by the relief of the model. To do this requires a change in the z' co-ordinate and therefore the magnification factor is no longer a constant. It would then be necessary to convert the machine co-ordinates to plate co-ordinates by a different factor for each point of different elevation. As a result of this, the accuracy of the plate co-ordinates is variable. i.e.—If the machine co-ordinates are recorded to 0.01 mm. and at one point $z'=3f$, then the plate measurement can be recorded to 0.003 mm., while if at another point $z'=2f$, the measurements at that point could only be reliable to 0.005 mm.

Now for the more difficult case of tilted photography. If the pair is oriented as was first suggested, with one photo-plane level and aligned with the machine axes and with the other oriented to it, the solution of the level photo would be the same as described in the preceding paragraph. The solution of the second plate would involve the recording of and correction for the rotations of orientation as described below for a photo tilted only about the y axis.

By similar triangles (Figure 7):

$$x_a : f = x_a'' : z_a''$$

by rotation of the system about point A:

$$x_a'' = x_a' \cos(t_2) - z_a' \sin(t_2)$$

and

$$z_a'' = x' \sin(t_2) + z_a' \cos(t_2)$$

therefore:

$$x_a = f \frac{x_a' \cos(t_2) - z_a' \sin(t_2)}{x_a' \sin(t_2) + z_a' \cos(t_2)}$$

It follows that if the photo were tilted about the x axis and were subject to swing as well, the solution of that particular photo would be so complicated that, unless an electronic computer was available, it would be extremely time consuming. However, with the aid of a computer a matrix multiplication for the transformation of axes will yield the required co-ordinates.

Weighing the advantages and disadvantages of both methods of measurement, it is obvious that for speed and efficiency in both measuring and calculation, monocular viewing is far superior to the binocular system when using the A-7.

ACCURACY

The accuracy of the A-7 used as a comparator was investigated on a comparison basis. The standard control used was a glass-plate on which was an etched grid with a nominal

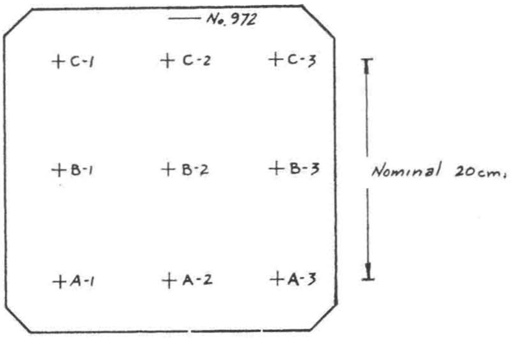

FIG. 8.

2×2 cm. separation. This plate was provided by Wild Heerbrugg, as a calibration-plate to be used when adjusting the A-7. The deviations from the theoretical positions of the nine primary points of a square 20×20 cm. were provided to an accuracy of 0.001 mm. as shown in Figure 8. It was these nine points upon which the comparison was made.

The plate was first measured with a Mann Comparator which has an accuracy of 0.001 mm. The method of observation was that described in "Photogrammetry" by F. H. Moffitt. Secondly the grid-plate was measured with the A-7, using the method of monocular measurement described in this paper. This method was chosen because of its speed and simplicity.

It must be kept in mind that the operator was totally inexperienced in the use of either instrument, and that one with greater knowledge of them could possibly obtain much better results. Table II shows the results of these measurements for the reader's comparison. All machine co-ordinates have been translated and rotated, as necessary, using the readings at point *B-2* as $x=0$ and $y=0$.

CONCLUSION

With an accuracy of ±5 microns the A-7 Autograph would be able to perform well as a comparator, should a more accurate instrument be unavailable or occupied with more important work. The monocular method of viewing, in conjunction with the electronic printout, would undoubtedly provide the most efficient use of the A-7 and therefore free the instrument in the shortest period of time to continue its usual duties.

When the measurements with the A-7 were made, the focal-length was set at 150.00 mm. and the constant z' plane was 480 mm. from the projection center as set on the z column of the instrument. These values result in a magnification factor (f/z') of 0.3125.

The co-ordinates determined by the A-7 varied from those of the standard by a mean error of 0.005 mm. and were distributed over a span of from 0.010 to 0.001 mm. Those determined by the Mann Comparator were in error by not greater than 0.002 mm. with a mean of 0.001 mm. Should the error in the A-7 measurements be introduced in standard six-inch photography taken at 2,000 feet, the horizontal position of the point on the ground would be in error by an amount not greater than one-tenth of a foot.

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TABLE II

PLATE CO-ORDINATES AS OBTAINED FROM:

Point	*A-7*		*Mann Comparator*		*Wild Heerbrugg Standard*	
	x	y	x	y	x	y
A-1	−99.994	−99.994	−100.001	−100.002	−100.000	−100.003
A-2	−0.003	−99.997	+0.001	−100.002	0	−100.002
A-3	+100.006	−99.994	+100.002	−99.999	+100.000	−100.000
B-1	−99.991	+0.003	−100.003	+0.002	−100.001	0
B-2	0	0	0	0	0	0
B-3	+100.000	+0.006	+99.999	+0.002	+100.001	0
C-1	−99.994	+99.991	−100.000	+100.001	−100.001	+100.000
C-2	−0.003	+99.997	−0.001	+100.001	0	+100.000
C-3	+100.003	+100.003	+99.999	+99.998	+100.000	+100.000