

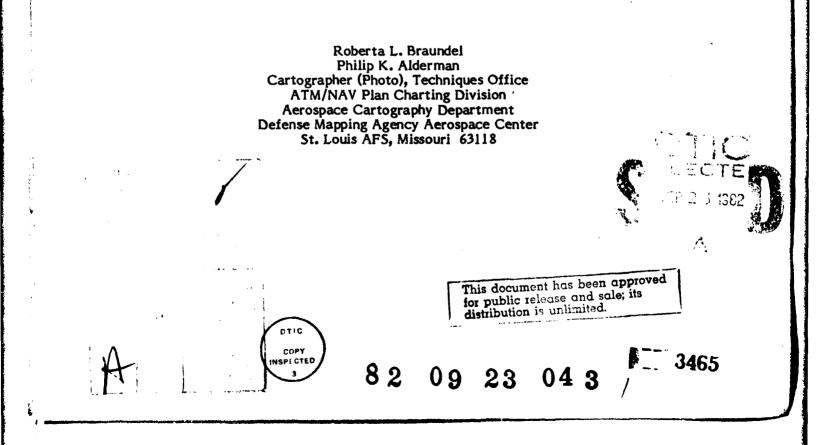
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### TILT DETERMINATION OF

### NON-VERTICAL PHOTOGRAPHY

#### USING A HANDHELD PROGRAMMABLE CALCULATOR

By



Abstract

A system has been developed which allows the photo interpreter to determine the tilt of an aerial photograph. Input consists of image measurements made using a calibrated template and tube magnifier, and three geodetic control points scaled from large scale map source. Church's resection is used to compute the camera parameters on the Hewlett-Packard HP 41C programmable calculator. Tilt determination allows computation of lengths, widths, and heights from a single image. These calculations follow naturally from the resection and are included in the system.

The system incorporates several desirable features. It is easy to learn and to use, and the resection converges within five minutes. The basic equipment is inexpensive and the calculator may be used for other applications.

#### **I. INTRODUCTION:**

A photo interpreter or photogrammetrist occasionally is presented nonvertical or oblique photography as his primary source for photogrammetric measurement. Poor flying conditions or inexpert photographic technique frequently result in undesired nonverticality. Oblique photography may be chosen because a larger area of coverage can be achieved, and a look at the side of a feature to be analyzed permits a more reliable interpretation.

Whatever the source of tilt, the relatively simple measurements of vertical photography become extremely complicated and, without the assistance of a computer, prohibitively time-consuming.

A variety of disciplines rely upon on-the-site field measurements. For many, the level of sophistication does not warrant full-time use of a nonportable computing system. Recent developments in handheld programmable calculators make it possible to quickly resolve the tedious computations needed to determine the tilt of an aerial photograph. These instruments are precise and easy to use. Simple operating instructions and programmed prompts lead the operator through the procedure step-by-step with virtually no opportunity for blundërs.

A computer program (Appendix B) was developed at the Defense Mapping Agency Aerospace Center (DMAAC) for the Hewlett Packard 41C calculator which determines the tilt of an aerial photograph using Church's Resection (Church, 1945). Horizontal and vertical ground measurements may then be computed for features on that photograph.

#### 2. SOFTWARE:

Church's Resection was chosen because the math model, computation algorithm, and pre-tested data were readily available. Professor Earl Church developed the procedure and published it in 1945 in a Syracuse University technical paper. Virtually every theoretical photogrammetry student has cranked out the solution on a desk calculator or has programmed it in FORTRAN. The desk calculator procedure reputedly takes about six hours, assuming no blunders. Present day students, after struggling through the first iteration, opt for the FORTRAN version (possibly an exercise designed to make students more receptive to the collinearity and coplanarity equations).

Professor Church's solution is iterative, and uses matrices and determinates to derive the exposure station coordinates and the swing and tilt of the aerial photograph (see American Society of Photogrammetry <u>Manual of Photogrammetry</u>, 1980). These values are defined in a rather unique coordinate system. He presents the solution in a "cookbook" form, and provides checks throughout to identify blunders.

Heights (Appendix A.II) and lengths (Appendix A.III) are computed by three digital rectification algorithms. One subroutine computes the direction cosines (Appendix A.I) of vectors from the principal point to the imaged nadir and to the base and top or the end points of the feature being measured. Image coordinates are then projected onto a horizontal plane passing through the nadir image. The vector passing from the principal point through the nadir is substituted for focal length in the conventional single image height and length equations (figures 1, 2, and 3).

The software design features repeated use of the direction cosine algorithm to reduce programming steps and conserve storage.

#### 3. HARDWARE:

The HP 41C programmable calculator (Hewlett-Packard, 1979) was chosen because it had memory expandable to the requirements of the solution and because of the authors' familiarity with the programming language. (Choice of this calculator does not constitute endorsement by DMAAC of Hewlett Packard or the HP 41C calculator.) The HP 41C features continuous memory, LED display, and magnetic card reader. With memory modules, the calculator is expandable to more than 300 registers (250 with card reader attached). It is battery operated with very low power consumption, and accessories include rechargeable batteries. The system is suitable for office or field applications.

#### 4. PROCEDURE:

Computing heights or lengths with this system consists of measuring map coordinates, measuring image coordinates, and operating the calculator program. The system concept was developed to increase accuracies with a minimum of operator training and a minimum of opportunity for operator error.

Map derived control is scaled from large scale map source such as United States Geological Survey (USGS) 1:24000 scale topographic maps. The user reads the Northing and Easting from the Universal Transverse Mercator (UTM) grid with, for example, the Metric Coordinate Reader (CR-2) (USGS, 1973), manufactured by USGS. The Geological Survey reports that 15 meter accuracies are expected with their 1:24000 maps.

A 1-centimeter grid aligned to the fiducials of the photo is fixed in place. To measure photo coordinates, the user counts the grid lines to determine centimeter values. Using a Bausch & Lomb calibrated tube magnifier, he reads x and y coordinates to a least count of 0.1 millimeter. (Choice of the Bausch & Lomb calibrated tube magnifier does not constitute endorsement by DMAAC of Bausch & Lomb or its products.) Paper stretch of the photo, image quality, and other factors will contribute to error; however, 0.2 millimeter accuracies are expected as a worst case.

To operate the calculator program, the user first runs the routines for Church's Resection (Appendix B, Line 01). Algorithms for length or height determination are then applied.

Church's Resection requires as input: 1) UTM Easting, Northing and height of three widely spaced, non-collinear photoidentifiable control points; 2) the x and y image coordinates of the control; 3) focal length of the camera; and 4) approximate UTM coordinates of the exposure station. These values are input into the calculator's storage registers. The user then starts the program to compute corrections to exposure station coordinates. With reasonable approximations (less than 1000 meters away from the true values), the solution converges after three or four iterations. Corrections to the revised coordinates of the exposure station will be less than one meter.

The operator then executes the command to compute tilt - the angle n O p, imaged nadir, principal point, and imaged principal point; swing - the angle in the photo plane measured clockwise about the optical axis from the + y-axis to the imaged nadir; and azimuth of the principal plane - the UTM azimuth of the direction of tilt. These values are automatically stored for use in the following algorithms.

A subroutine called Direction Cosines (DC) (Appendix B, Line 413) computes the vector algebra common to the height and length determinations. The user must input into the storage registers the x, y of the feature of interest and focal length of the camera. That is, the base and top of a vertical feature or the end points of a horizontal feature.

The final step is to command the calculator to execute the height (Appendix B, Line 471) or the length (Appendix B, Line 491) subroutine.

The software was designed for practical photo interpretation applications and will give results comparable to those obtained with conventional vertical photography. Obviously, the geometry is strongest with a 152.43 cm focal length camera and control widely spaced to form a strong three-sided pyramid.

Distance measurements are considered to be small, such as the length of a bridge, the edge of a building, or a plot boundary. As with conventional vertical photography, no compensation is made for displacement due to elevation differences.

#### 5. CONCLUSION:

No.

The use of tilted aerial photography until now has been largely limited to qualitative applications. A photogrammetrist can use slightly tilted photography on a stereo plotter or the photo interpreter can send it to the photo lab for rectification. However, these procedures require elaborate optical equipment, are time consuming, and require highly skilled technicians.

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The tools and procedures for the digital rectification described in this paper open new opportunities for the use of tilted photography. The components are inexpensive, reliable, and virtually maintenance free. The system is easily learned and can be used in either the office or field. Furthermore, a photo interpreter with access to a powerful programmable calculator will develop his own algorithms to make his time more productive.

#### REFERENCE

- American Society of Photogrammetry (1980), "Manual of Photogrammetry Fourth Edition", American Society of Photogrammetry, Page 62, 105 Virginia Ave., Falls Church, VA 22046.
- Church, Earl (1945), "Revised Geometry of Aerial Photography", Syracuse University Bulletin 15, Syracuse, New York.
- Hewlett-Packard (1979), "Owner's Handbook and Programming Guide HP-41C", Hewlett-Packard Company, 1000 N.E. Circle Blvd., Corvallis, OR 97330
- United States Department of the Interior Geological Survey (1973), "Metric Coordinate Reader CR-1", United States Department of the Interior Geological Survey, 1340 Old Chain Bridge Road, McLean, VA 22101

#### APPENDIX A

#### Math Model

#### I. **Direction Cosines:**

Image coordinates of nadir  $x_n$ ,  $y_n$  and  $z_n$ 

$$x_{n} = \overline{pn} \cos (90 - s) \tag{1}$$

$$y_{n} = \overline{pn} \sin (90 - s)$$
 (2)

$$z_{p} = -f \tag{3}$$

where 
$$\overline{pn} = f$$
 tan t,  
s is swing,  
f is focal length,  
t is tilt, and  
 $\overline{pn}$  is the vector from the imaged principal point to the imaged padir.

Computation of direction cosines l, m, and n.

$$l_{i} = x_{i}/d_{i}, \quad m_{i} = y_{i}/d_{i}, \quad n_{i} = z_{i}/d_{i}$$
 (4)

where  $d_i = x_i^2 + y_i^2 + z_i^2$ (5)

Angles between vectors are computed using the cosine law:

$$< v_1 o v_2 = \cos^{-1} (l_1 l_2 + m_1 m_2 + n_1 n_2)$$
 (6)

where  $\langle v_1 o v_2 \rangle$  is the angle at the principal point o between two vectors.

The value on is used in computing both heights and distances.

$$\overline{\text{on}} = f/\cos t$$
 (7)

Refer to Figures 1, 2, and 3 for graphic representation of variables.

#### II. Height Determination:

b' and t' are points where vectors from the principal point to the base and top of the object being measured would intersect a horizontal plane passing through the imaged nadir.

$$\frac{nb'}{nt'} = \frac{on}{on} \tan < nob$$
(8)  
(9)

d;' is the rectified image displacement.

 $d_{i}' = \overline{nt'} - \overline{nb'}$ (10)

r' is the rectified radial distance from the imaged nadir to t :ctified image of the base of the object.

$$\mathbf{r}' = \mathbf{n}\mathbf{b}' \tag{11}$$

H is the height of the exposure station above the object.

$$H = Z_{o} - H_{F}$$
(12)

where  $Z_{\rm c}$  is the height of the exposure station above the datum (computed in Church's resection), and

 ${\rm H}_{\rm F}$  is the elevation of the object above the datum.

Substituting the values into the conventional height determination equation

•••

height =  $d_i' H/r'$  (13)

#### III. Length determination:

The equation for the length of an object on a conventional vertical aerial photograph is

$$L = I(Z_0 - H) / f$$
(14)

where L is the length of the object l is the imaged length of the object and the other parameters are as defined before.

Using the horizontal plane passing through the imaged nadir we can substitute the rectified image values:

$$L = l' (Z_0 - H) / \overline{on}$$
(15)

where l' is the rectified image length.

l' is the vector subtraction of the vectors  $\overline{ce_1}$ ' and  $\overline{oe_2}$ ', where  $e_1$ ' and  $e_2$ ' are the rectified image points of the ends of the object being measured.

$$l' = \overline{oe}_{2}' - \overline{oe}_{1}'$$
(16)

$$= \overline{\operatorname{oe}}_{1}^{2} + \overline{\operatorname{oe}}_{2}^{2} - 2 \overline{\operatorname{oe}}_{1} \overline{\operatorname{oe}}_{2} \cos \langle e_{2} \operatorname{oe}_{1} \rangle$$
(17)

$$\overline{oe}_{1}' = \overline{on} / \sin < noe_{1}$$
 and (18)

$$\overline{oe}_{2}' = \overline{on} / \sin < noe_{2}$$
(19)

## APPENDIX B

# Program Listing

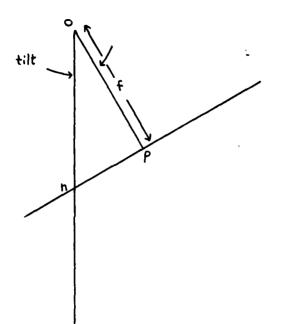
01	LBL <sup>T</sup> Y CF 00 .00201 STO 56 48.05001 STO 57 XEQ 15 00099	41	XEQ 14 27.02601 STO 56 -1 STO 57 XEQ 04 26.03801 STO 57	81	LBL 15 CLX LBL 50 RCL IND 56 X / 2 + ISG 56 GTO 50 SQRT
10	STO 59 39.04101 STO 57 XEQ 03 9.01701 STO 57 XEQ 06 XEQ 09 LBL 58 18 STO 56	50	.00801 STO 56 XEQ 13 27.03501 STO 57 XEQ 06 XEQ 12 27.02901 STO 57 54.05001 STO 58	90	1/X 1 E5 X <>Y * STO IND 57 LAST X 3 ST- 56 RDN LBL 51
20	36 STO 57 .00201 STO 58 STO 59 XEQ 08 .00201 STO 56 48.05001 STO 57	60	42.04401 STO 56 52 STO 59 55 STO 60 43 STO 61 XEQ 07 BEEP	100	STO IND 56 ISG 56 GTO 51 .003 ST+ 56 ISG 57 GTO 15 RTN LBL 02 RCL 39 PCL 51
30 40	XEQ 15 FS? 00 GTO 10 00099 STO 59 51.05301 STO 57 XEQ 03 XEQ 02 42.04701 STO 56	70 80	View 44 PSE View 43 PSE View 42 STOP XEQ 11 GTO 58 SF 00 GTO 58 STOP	110	RCL 51 1000000 * STO 51 RCL 40 RCI 52 100,000 * STO 52

121 RCL 41 RCL 53	161	RCL IND 57 RCL IND 58	201	ISG 56 X <>Y
100000		* STO IND 56 RCL 57		LAST X R *
STO 53		3		STO IND 56
RTN				RDN
LBL 03		9		ST- IND 56
0		MOD		LAST X
130 STO IND 57	170	STO 57	210	ENTER /
.003		ISG 58		ISG 56
ST + 59		RCL IND 57 RCL IND 58		RTN RTN
LBL 52 RCL 59				LBL 06
3		STO IND 56		RCL 01
+		ISG 58		RCL 03
9		ISG 56		RCL 00
MOD		GTO 53		RCL 04
STO 58		RCL 56		XEQ 05
140 RCL IND 59	180	35	220	
RCL IND 58		X > Y?		RCL 03
*		GTO 04		RCL 00
STO IND 57		RTN		RCL 05
ISG 59		<u>LBL</u> 14		XEQ 05
GTO 52		RCL 48		RCL 02
ISG 57		ENTER /		RCL 04
GTO 03		ENTER /		RCL 01
CLX		RCL 39		RCL 05
STO 42	100	RCL 49		XEQ 05
150 STO 44	190	XEQ 54	230	
STO 46		RCL 40		RCL 06
		RCL 50 XEQ 54		RCL 00 RCL 07
<u>LBL</u> 04 .003		RCL 41		XEQ 05
STO + 56		RCL 41 RCL 48		RCL 02
1		LBL 54		RCL 06
STO + 57		ST-IND 56		RCL 08
42.04801		RDN		RCL 00
STO 58		*		<b>XEQ 05</b>
160 LBL 53	200	ST + IND 56	240	RCL 07
********				

241 RCL 02 RCL 01 RCL 08 XEQ 05 RCL 06 RCL 04 RCL 03 RCL 07 XEQ 05 250 RCL 05 RCL 06 RCL 03	290	ISG 57 GTO 57 RCL IND 60 ST/IND 56 .003 ST+ 57 8.003 FS? 00 ST- 57 3 ST+ 58 6	321 330	ST+ 57 ISG 59 GTO 08 .003 ST+ 59 3 ST- 57 ISG 58 GTO 08 RTN LBL 09
RCL 08 XEQ 05 RCL 05 RCL 07 RCL 04 RCL 08 LBL 05		FS? 00 ST+ 58 ISG 56 GTO 56 RCL IND 61 CHS STO IND 61		RCL 09 RCL 08 * RCL 12 RCL 05 * -
260 * STO IND 57 RDN * ST - IND 57 ISG 57 RTN RTN LBL 07 RCL IND 59	300	RCL IND 59 CHS STO IND 59 FC? 00 RTN 1 ST+ 58 ST+ 59 9.01703 STO 57	340	RCL 15 RCL 02 * STO 54 RTN LBL 10 -1.00901 STO 57 18.02601
270 CHS STO IND 59 LBL 56 0 STO IND 56 <u>LBL 57</u> DSE 58 RCL IND 57 RCL IND 58 *	310		350	
280 ST+ IND 56	320	1	360	54

		-		
361 STO 60	401	RCL 07	442	STO 56
1.00703		1		3.00901
STO 61		ATAN		STO 57
XEQ 07		X<0?		12.01301
GTO 16		+		STO 55
LBL 11		<sup>+</sup> STO 40		LBL 18
$\frac{LBL}{RCL}$ 44		RCL 00		CLX
		RCL 03		STO IND 55
ST+ 36				LBL 17
RCL 43	410	· · · ·	451	RCL IND 56
370 ST+ 37	410		471	RCL IND 57
RCL 42		STO 41		
ST+ 38		STOP		
RTN		LBL <sup>T</sup> DC		ST+ IND 55
LBL 12		RCL 14		ISG 57
RCL 27		RCL 40		ISG 56
RCL 08		TAN		GTO 17
*		*		ACOS
RCL 28		STO 15		STO IND 55
RCL 07		RCL 40		.00201
380 *	420	CHS	461	STO 56
-		90		ISG 55
RCL 29		+		GTO 18
RCL 06		STO 16		<b>RCL 14</b>
				CHS
*		COS		RCL 39
+		*		COS
STO 55		STO 00		Ĩ
RTN		RCL 15		STO 17
KIN		RCL 16		
T DT 12		SIN		STOP
LBL 13 ISG 57		*		LBL <sup>T</sup> H
	421		472	
390 RCL IND 57	431		47 2	TAN
STO IND 56		RCL 14		*
ISG 56		STO 02		STO 13
GTO 13		STO 05		
RTN		STO 08		RCL 17
<u>LBL</u> 16		0.00201		RCL 12
RCL 06		STO 56		TAN
ACOS		48.05001		*
STO 39		STO 57		STO 12
360		XEQ 15		RCL 13
400 RCL 08	441	.00201	482	-

483	STO II	520	*
	RCL 38		2
	RCL 28		+
	-		CHS
	*		RCL 12
	RCL 12		X / 2
	/		+
490	STOP		RCL 13
470			X / 2
	RCL 17		:
		620	+ 5007
	RCL 12	<b>530</b>	
	SIN		STO 19
	1		RCL 38
	STO 12		STO 19
	RCL 17		<b>RCL 27</b>
	RCL 13		RCL 28
	SIN		-
500	1		*
	STO 13		RCL 17
	3.00501		1
	STO 56	540	STOP
	6.00901		END
	STO 57		
	CLX		
	STO 18		
	LBL 19		
	RCL IND 56		
510			
210	*		
	STO 18		
	ISG 57		
	ISG 56		
	GTO 19		
	RCL 12		
	RCL 13		
	*		
	RCL 18		



np = f tan∠t

Low oblique photo viewed in the plane nop

Figure 1

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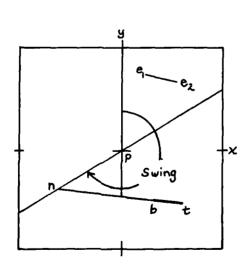


Photo plane of tilted aerial photograph showing swing, imaged nadir, and imaged vertical feature.



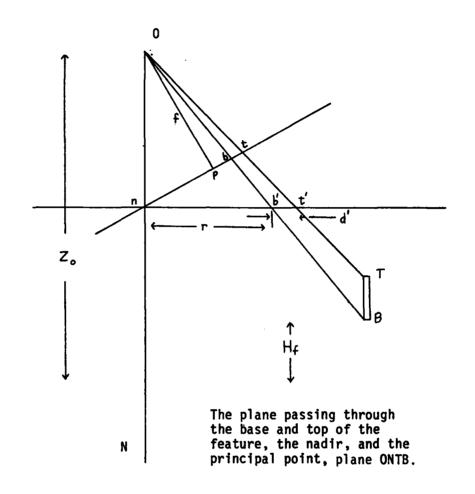
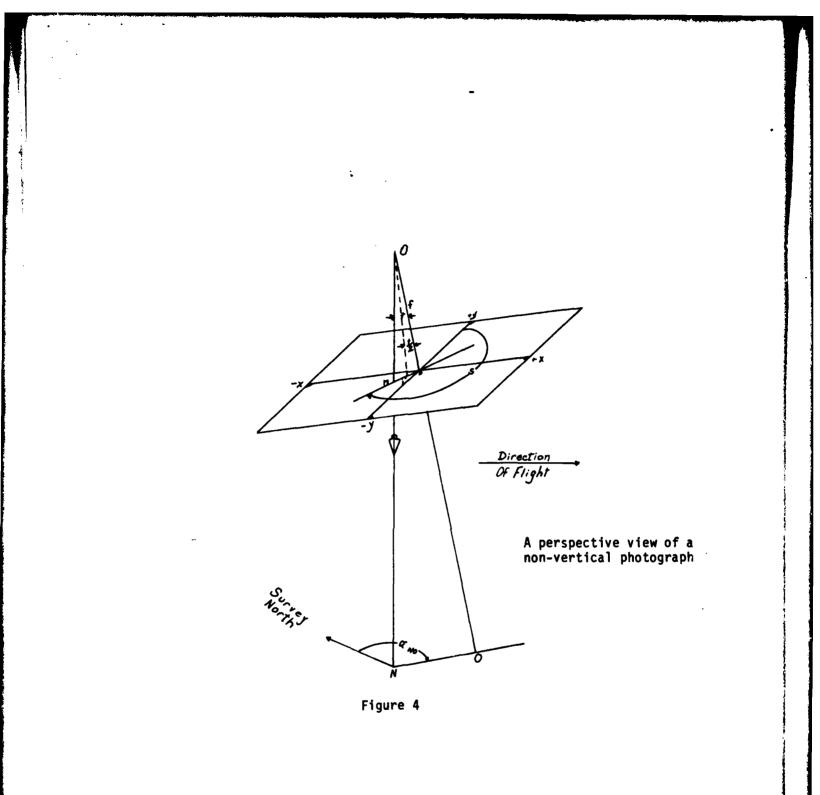


Figure 3



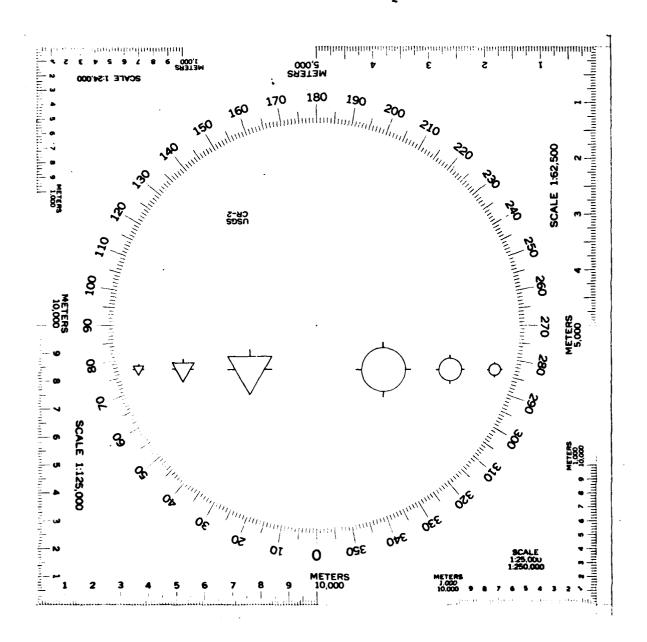


FIGURE 5. The CR-2 Metric Coordinate Reader

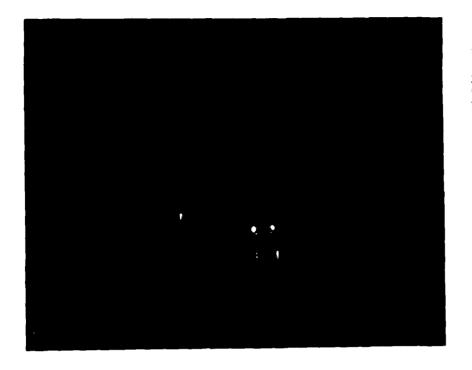


FIGURE 6. Bausch & Lomb Tube Magnifier



FIGURE 7. Measuring Photo Coordinates

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#### Biographical Sketch

Roberta L. Braundel is a Cartographer (Photogrammetry) in the Techniques Office of the Air Target Materials/Nav-Plan Charting Division of the Aerospace Cartography Department at the Defense Mapping Agency Aerospace Center. She received her bachelors degree in Data Information Systems from Tarkio College and is currently working on her masters degree in Computer Science at the University of Missouri/Rolla. She is currently assisting in the development of various automated techniques associated with map and chart production as well as in the development of automated methods of chart production scheduling and control. Mrs. Braundel is a member of the American Congress on Surveying and Mapping and serves as Secretary of the St. Louis Section - ACSM.

Philip K. Alderman received his bachelors degree in mathematics in 1967 from Southern State College in Arkansas. He received his masters degree in Civil Engineering (Photogrammetry) in 1971 from the University of Illinois. His mapping career includes experience as a cartographer, analog and analytical Stereo Plotters, Aerial Photo-Inspector, instructor at the DMAIAGS Cartographic School and project engineer in the DMAIAGS Bolivia Project. He is currently assigned to the Techniques Office of the Air Target Materials/ Nav-Plan Charting Division of the Aerospace Cartography Department at the Defense Mapping Agency Aerospace Center. Mr. Aldernan is a member of the American Society of Photogrammetry and the American Congress on Surveying and Mapping.

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