AFAL-TR-79-1171

TRI-BAR READING CORRECTION FOR OBLIQUE IMAGERY

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Reconnaissance & Weapon Delivery Division

July 1979

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Final Report for Period December 1978 - July 1979

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This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

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Image Quality

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tri-Bar resolution targets are geometrically distorted when photographed at oblique angles. One of the effects of this distortion is the changing of the aspect (length to width) ratio of the bars. Targets parallel to the line of flight (crossline) at large oblique angles to nadir of the aircraft produce images with apparent increased aspect ratios due to the foreshortening of the bar/space width. Perpendicular targets to the flight direction (inline) at an oblique angle have their lengths foreshortened, thus reducing the aspect

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) ratios. At 70°, original 5:1 aspect ratio tri-bar targets have apparent ratios of 14.6:1 crossline and 1.71:1 inline.

A laboratory experiment was set up simulating oblique imagery to determine what effects the changing aspect ratio has on the accuracy of tri-bar readings, after the insertion of normal geometrical corrections. Different target contrast ratios, target orientations, and cameras were used. Analysis of variance showed that for crossline targets, resolution readings corrected by the normal cosine geometrical factor provide accurate results for any contrast ratio or target orientation. A highly significant finding of this study was that inline target resolution readings, where previously no geometrical or other corrections have been used, need to be adjusted. This is required for any contrast ratio, although the magnitude of the correction factors depend on target orientation. Normalized polynomial regression equations were used to obtain these correction factors.

FOREWORD

This report was prepared by the Air Force Sensor Evaluation Center, Dynamics & Environmental Evaluation Branch (AFAL/RWF) of the Reconnaissance & Weapon Delivery Division, Air Force Avionics Laboratory. This report is concerned with the correction factors needed to obtain accurate resolution readings from tri-bar targets which have been photographed from positions other than vertically. CMSgt Raymundo Viramontez, Mr. Thomas M. Scanlon, and Mr. Wayne A. Harlow of RWF assisted in the test set-up and data acquisition. Mr. Ralph Pinney of Mead Corporation performed the precise microdensitometer tracing, from which contrast ratios were obtained. Mr. Fred Hoffman of Mead Corporation and SSgt A. Killinen of RWF provided the film processing. Mr. Alfred J. Bowling supplied most of the data processing support.

This report has been reviewed and approved.

Richard M. Smith

RICHARD M. SMITH, Major, USAF
Deputy Chief, Dynamics & Environmental
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

I. PURPOSE

The purpose of this study was to determine how tri-bar resolution readings are affected by changing aspect ratio, like that caused by oblique aerial imagery, and to determine the factors needed to obtain accurate results.

II. INTRODUCTION

A. In evaluating photographic reconnaissance systems from airborne platforms, ground based tri-bar targets are often used. Despite arguments against this method and the generation of new equipment utilizing other techniques, Tri-bar Resolving Power remains the most readily accepted method of evaluating image quality. This method has a national certification system that insures that all qualified readers obtain on a statistical basis, equal readings, within small limits. Military Standard 150A, "Photographic Lenses", provides for the evaluation of lens imaging characteristics against a standardized stimulus, the tri-bar target. The target is described as follows:

> "The standard target element shall consist of two patterns (two sets of lines) at right angles to each other. Each pattern shall consist of three lines separated by spaces of equal width. Each line shall be five times as long as it is wide."

B. Successive patterns decrease in line (bar) width in a constant proportion, usually according to the sixth-root-of-two (1.1225). A standard AF tri-bar target is shown in Figure 1.

C. For vertical targets, the photo resolution is calculated with the formula:

$$R = \frac{(.1)}{(X)}\frac{(h)}{(f)} \qquad (1)$$

where:

- R = Photo resolution (lines/mm)
- h = Height above terrain (meters)
- f = Focal length (cm)
- X = Combined width of bar and space taken from the smallest ground tri-bar target resolved (meters).

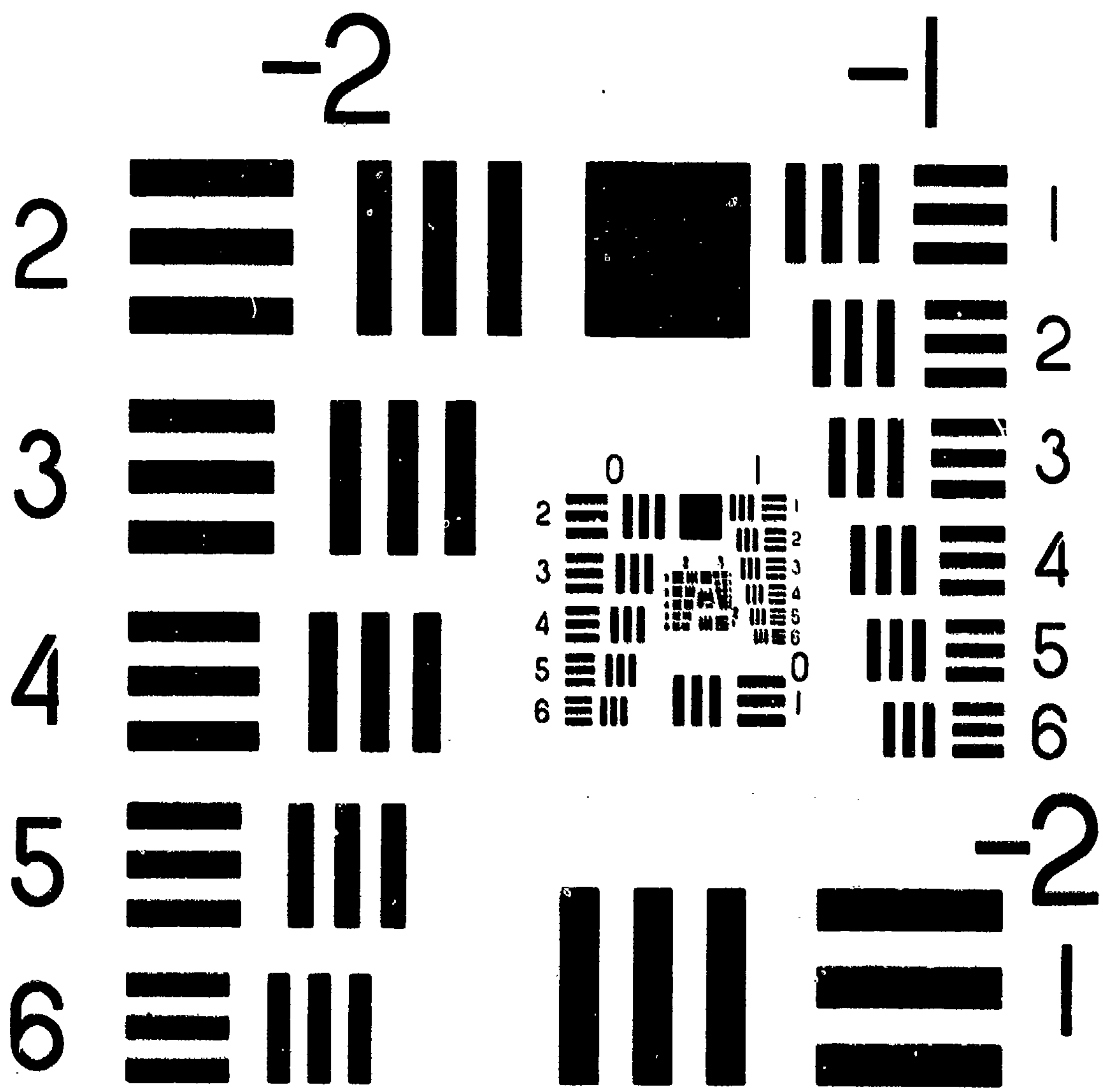


FIGURE 1
USAF 1951 RESOLUTION TARGET

This procedure is well documented and established.[1,2] However, when long range oblique (large angles) tri-bar targets are imaged, the conversion to resolution values is not as well defined. This report will discuss two considerations in the image quality evaluation of oblique photography using tri-bars, i.e., (1) Geometrical Factor and (2) an Aspect Ratio Factor.

1. The Geometrical Factor

a. The geometrical factor affecting resolution determination when tri-bar targets are photographed from oblique angles is presented herein to eliminate any confusion with what we term the aspect ratio effect. Figure 2 presents the geometry of the situation. A sensor platform is flying at a height h above the ground and is looking out at an angle "Ø" to the vertical.

b. For the crossline targets (Figure 2A), the sensor sees the perpendicular to the line of sight (angle Ø) projection of the bar space width. Thus the bar and space dimensions that are observed are equal to the bar/space width, X, multiplied by the cosine of the look angle Ø. In addition, the distance from the sensor to the target is increased from that of the vertical target case, and this distance is equal to h/cos Ø.

$$\text{For crossline, } R = \frac{(.1)}{(f)} \cdot \frac{(h)}{(\cos \emptyset)} \cdot \frac{1}{(X \cos(\emptyset))} \qquad (2)$$

where:

R, h, f, and X = as defined in equation (1)

Ø = Sensor look angle measured from the vertical

1. Niels Jensen, Optical & Photographic Reconnaissance Systems, John Wiley and Sons, Inc., New York, NY, 1968.

2. Reconnaissance Reference Manual, McDonnell Douglas, 1973.

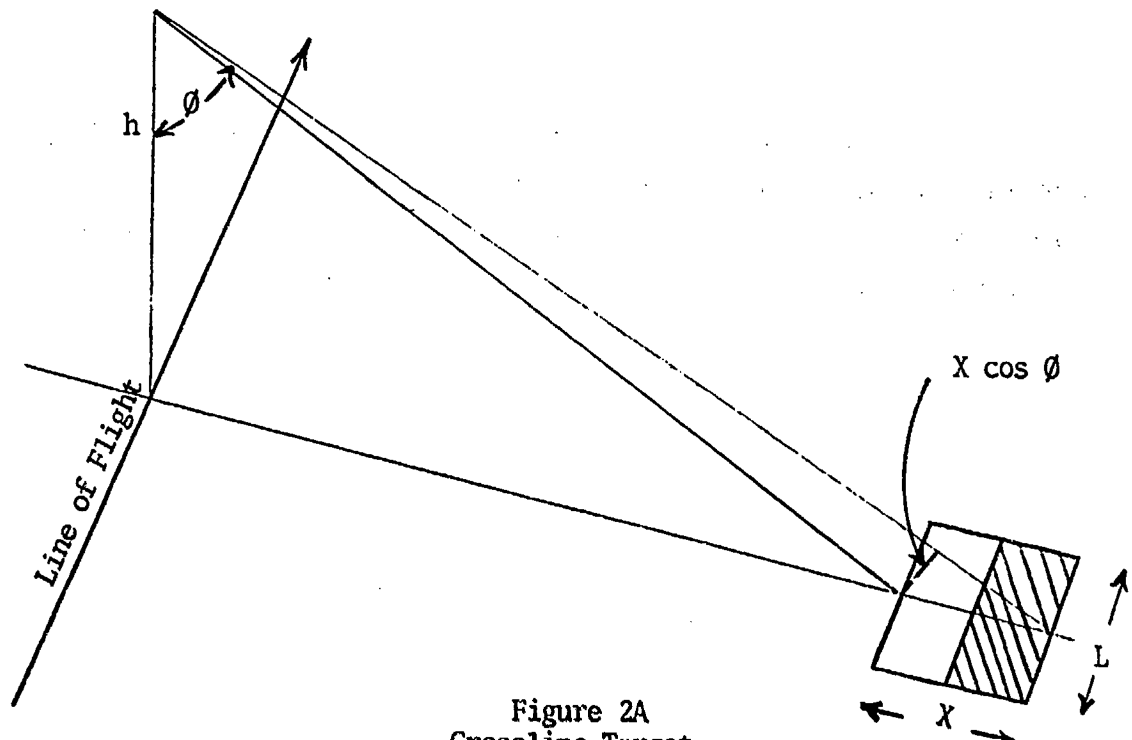


Figure 2A
Crossline Target

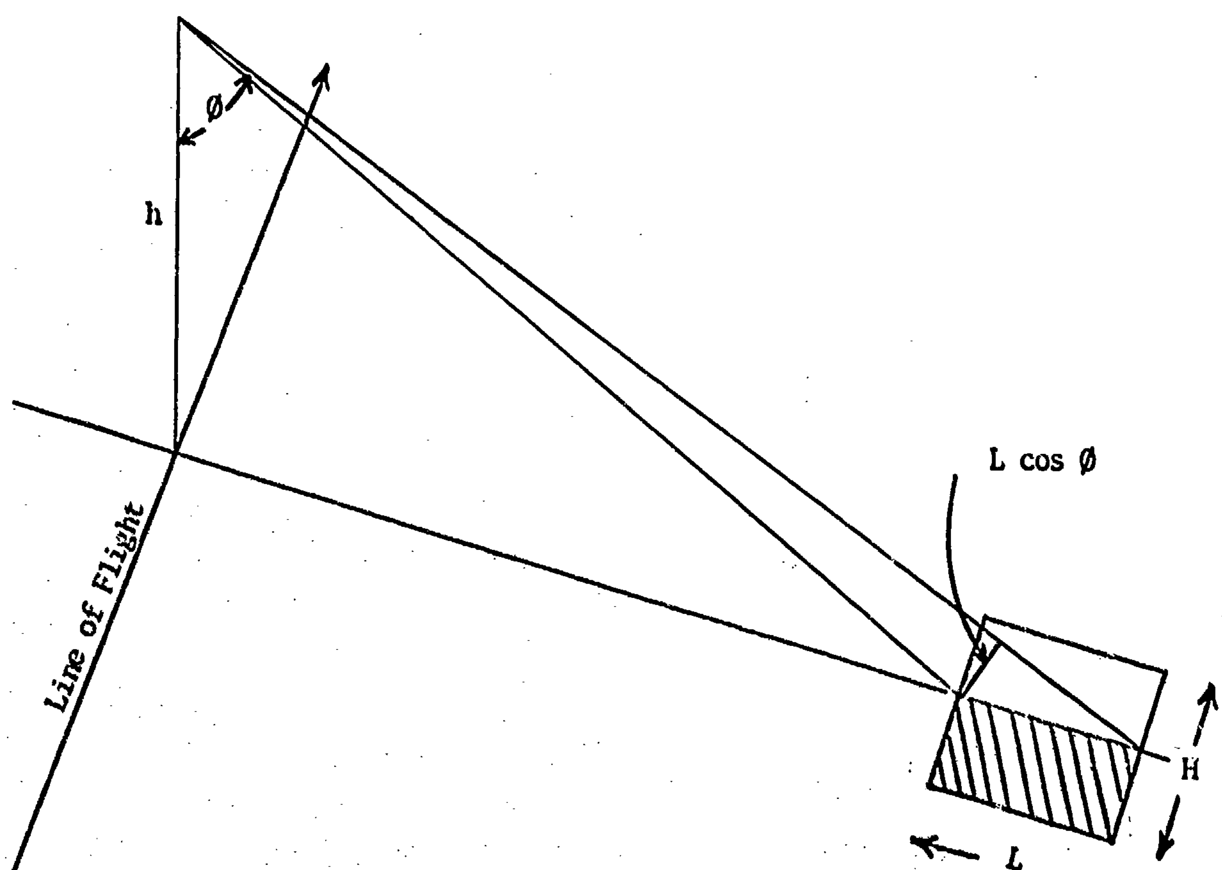


Figure 2B
Inline Target

c. For the inline targets (Figure 2B) the sensor sees the perpendicular to the line of sight (angle ϕ) projection of the bar or space length. Thus the observed bar or space length (L) which is nominally equal to five times the bar or space width is reduced to a value of L cos ϕ. Note that the bar and space dimension, X, is unchanged. Therefore, taking into account the sensor target distance and no change in the bar/space width, the equation for resolution becomes:

$$\text{For inline, } R = \frac{(.1)}{(f)} \cdot \frac{(h)}{(\cos \phi)} \cdot \frac{1}{X} \qquad (3)$$

where:

R, h, f, X, and ϕ are defined as in equation 2.

Thus, for oblique photography after determining the resolved tri-bar elements, equations 2 and 3 are used to calculate the crossline and inline resolution respectively. Note that the curvature of the Earth is ignored in this analysis.

2. Aspect Ratio Factor

a. The geometry conditions discussed previously change the apparent aspect ratio of the tri-bar targets when viewed from an oblique angle. For the crossline targets the bar and space widths are decreased by the cos ϕ while the lengths are unchanged. Thus the aspect ratio increases to a value of 5 divided by cos ϕ. In the inline direction the opposite happens, and the aspect ratio is reduced to 5 times the cos ϕ. Figure 3 is an example of this effect. This is an oblique photo, taken at scan angle of approximately 73°, of tri-bar target site 5A at Edwards AF Base. The aircraft is flying in a direction parallel to the long axis of the target site. This flight line could be imagined as along the right edge of the photograph. The tri-bar targets near the large white patch on the top of the photograph are horizontal targets laying on the ground, while the other targets are inclined 60° to the horizontal. Inspecting the horizontal

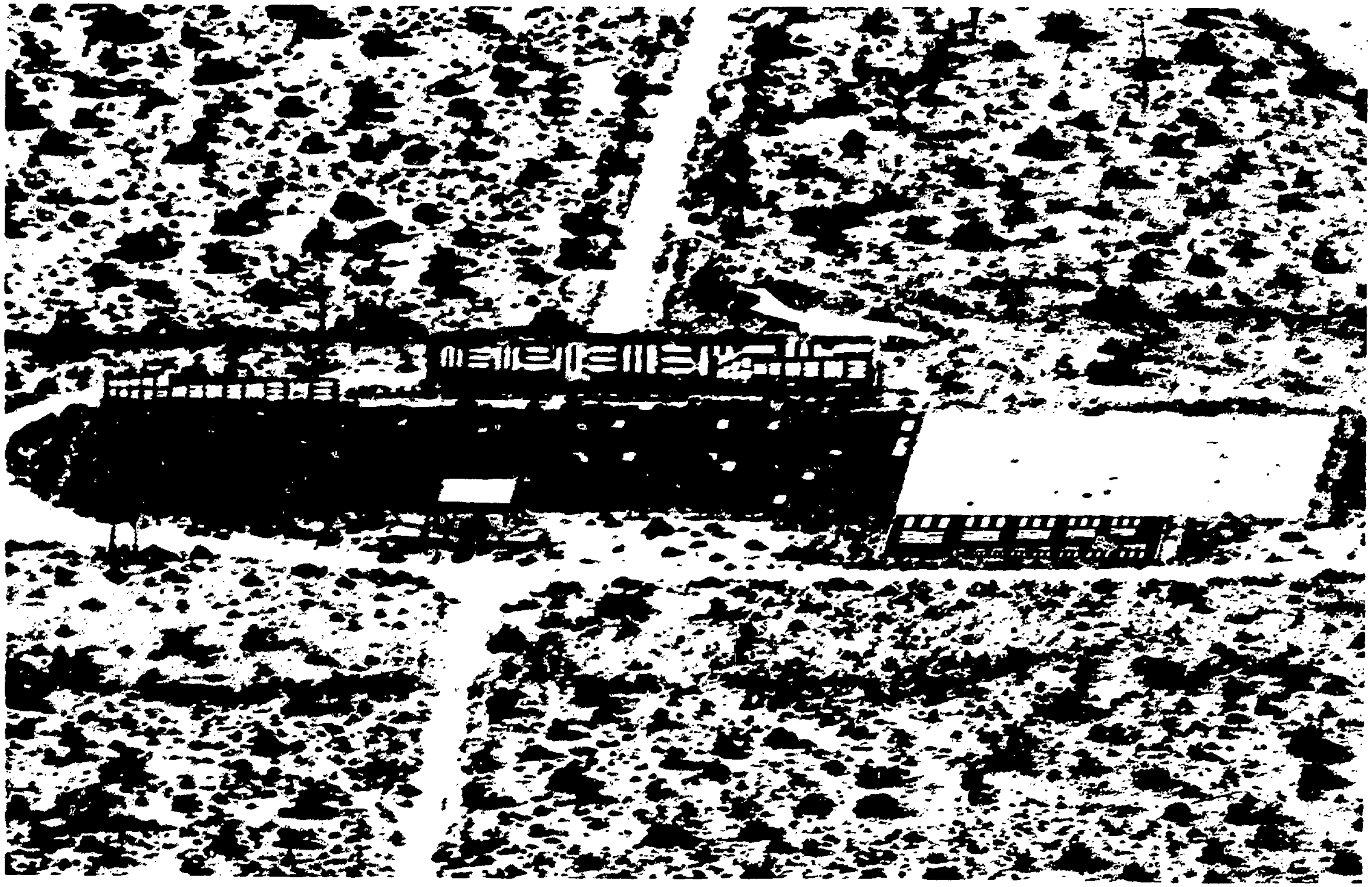


FIGURE 3
TARGET SITE 5A, EDWARDS AFB

targets, the change in aspect ratio is apparent. The crossline targets (parallel to flight line) have an increased observed aspect ratio (17.1:1) while the inline targets have a decreased observed aspect ratio (1.46:1). Also note that there is little observed aspect ratio change on the inclined targets (crossline 5.13:1, inline 4.98:1) since these targets lie at an angle of 13^{o} to the perpendicular line of sight.

3. Objectives

a. One objective of this study was to determine if the changing of aspect ratio itself affects the observer's ability to accurately obtain the smallest resolvable element from a tri-bar target. An example of how the readings may be affected is as the aspect ratio increases, a long line effect may be present which can cause optimistic readings, similar to the observation of power and telephone lines on aerial photographs. Another objective was to find what effects the decreasing aspect ratios have on reading tri-bar targets, especially if it causes observers to read less resolution than if the photograph were taken vertically. The research reported herein was designed to investigate these questions and to determine the magnitude of any effect. It was further desired to investigate how other parameters, such as contrast and target orientation, affect the tri-bar target readings on oblique photographs.

III. AFAL LABORATORY EVALUATION

A. Target Set-Up

1. A standard USAF 1951 master resolution target was printed onto 20.3 X 25.4 centimeter matte finish paper to produce resolution targets of 2:1, 3:1, and 7.5:1 contrast ratios and 5:1 aspect ratio. The prints were mounted onto 20.3 X 25.4 centimeter plastic sheets, using double sided tape over the whole sheet. The three resolution targets, and 90% and 18% reflectance cards were mounted on a single piece of plywood which was bolted onto a sturdy tripod.

2. The target set-up is shown in Figure 4. The resolution targets were placed in the corner of a room and black cloth was hung behind them to cut down on stray reflections. A single quartz lamp was placed 2.10 meters from the targets, at a height of 2.85 meters and an

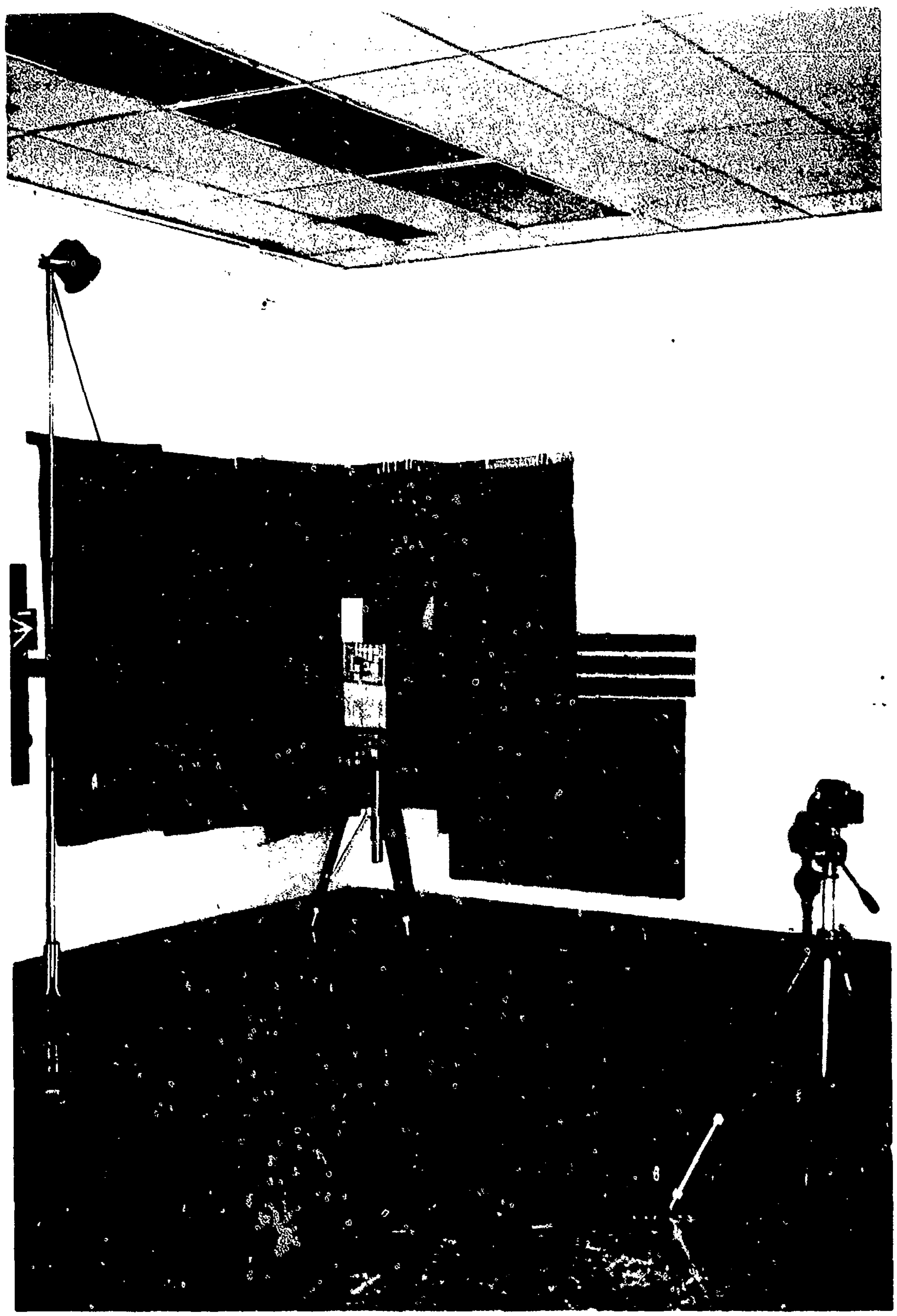


FIGURE 4
TARGET SET-UP

angle of zero degrees. A transient was used to lay out a quarter circle around the targets, with floor marks at 5 degree increments.

B. Photography

1. A 35mm Nikon camera with a 50mm lens and a 70mm Hasselblad camera with an 80mm lens were used to photograph the targets. Kodak 3414 Aerial Film was used in each camera and processed in MX-641 chemistry in a Versamat processor. The Nikon was loaded with 70mm 3414 film which had been slit down the middle and rolled into 35mm cassettes.

2. Each camera was placed on a tripod at a height of 94.0 centimeters. This lined the camera up with the middle resolution target. A plumb line was hung from the tripod so that the camera could be placed accurately over the degree marks.

3. A focus series and an exposure series were run with each camera at 0, 40, and 80 degrees. An exposure time of 1/125 second at f/8 was used for the Nikon and 1/160 second at f/5.6 was used for the Hasselblad.

4. The Nikon exposures were made with the mirror held up and with a cable release which tripped the self-timer. The Hasselblad exposures were made similarly, except a self-timer was not used. These operations helped to minimize vibration effects. Also, the exposures were made between 6:00 A.M. and 7:00 A.M. while there were no other activities in the building.

5. At least nine exposures were made at each 5^{o} increment with each camera. The camera was moved around the targets in an arc instead of in a line parallel to the targets because of space limitations in the building and to keep the scale at each angle the same. In order to determine if there was an effect from target layout, each target was rotated 90^{o} on the plywood and the photography was repeated with both cameras.

IV. IMAGE EVALUATION

A. Resolution Readings

1. The resolution target images were read by three IRARS certified readers. The limiting resolution was determined from these readings using formulas (2) and (3), with the exception that the distance

from the target to the camera is constant so the h/cos Ø term is replaced by 4.27 meters.

B. Contrast Ratio Determination

1. The contrast ratio of each resolution target was found by scanning each target image at each angle with a Mann-Data Microdensitometer, which was equipped with a 12 X 36 micron aperture and calibrated with a sensitometric strip that had been processed along with the film. The contrast ratios were determined by measuring the density differences of the bars and backgrounds on the film, using the sensitometric curve of the film and processing to determine the log exposure differences, and using formula (4).

$$CR = 10^{\Delta \log E} \quad (4)$$

where:

CR = Contrast ratio of targets

and $\Delta \log E$ = Exposure difference between target and background, measured off D log H curve.

An average contrast ratio was determined for each of the three resolution targets for each camera and target orientation.

C. Contrast Ratio Corrections

1. A slight variation in the recorded contrast ratios of the targets was seen at the different angles due to the illumination of the targets. Since resolution is dependent on contrast ratio, the resolution readings were corrected for these variations using equation (5), thereby correcting to the original contrast ratios of the targets, i.e., 7.5:1, 3:1, and 2:1. This equation is a modification of that derived by James W. Mayo in his master's thesis to the University of Arizona, Optical Science Department, in 1968 titled, "Photographic Resolving Power of Aerial Reconnaissance Lenses as a Function of Target Modulation".

$$R_{cor} = R_{uncor} \left(\frac{M_{cor}}{M_{uncor}}\right)^{1/2} \quad (5)$$

where:

R_{cor} = Equivalent Resolution at Contrast Ratio Desired

R_{uncor} = Measured Resolution at Measured Contrast Ratio

$$M_{cor} = \frac{CR_{cor}-1}{CR_{cor}+1} \qquad (6)$$

M_{cor} = Modulation at Desired Contrast Ratio

CR_{cor} = Contrast Ratio Desired

$$M_{uncor} = \frac{CR_{uncor}-1}{CR_{uncor}+1} \qquad (7)$$

M_{uncor} = Modulation of Measured Tri-Bar Target

CR_{uncor} = Measured Contrast Ratio of Tri-Bar Targets

The corrected resolution values from all readers for each contrast ratio target photographed with each camera and each target orientation were normalized to the value at zero degrees and averaged. These normalized resolution values can be seen in the Appendix.

D. Statistical Analysis

1. A polynomial regression technique was used to fit curves to the average normalized resolution readings. First through fourth order curves were fit to the data. Curves were obtained for each contrast ratio target photographed with each camera and each target orientation.

2. An expected mean square analysis of variance was performed on the data using angle, contrast ratio, target orientation, and camera as the factors, and the averaged normalized resolutions as the responses.

V. TEST RESULTS

A. Regression Analysis

1. The results of the regression analysis showed that the second and third order equations provide the best fit to the normalized data (see Appendix, Tables 6 & 8). The best fit curves are shown in Figures 5 through 8. The X-axis is labeled both in camera angle and the resulting aspect ratio of the recorded targets. If there were no aspect

ratio effects, the regression curve would essentially be a straight line at a constant normalized resolution value of one. These figures show that under all conditions of the test, crossline data is near the value of one, but the inline data shows a significant increasing departure from this value at large oblique angles. The results appear to be somewhat independent of contrast.

B. Analysis of Variance

1. Table 1 gives the results of the analysis of variance and is discussed in the following.

2. For the crossline data, the analysis showed that the angle effect was not significant. Therefore, only the cosine geometrical correction factors, and no aspect ratio correction, is required. Also the contrast ratio and target orientation effects were not significant.

3. The angle effect was significant for the inline data, showing that an aspect ratio correction is needed for this data at all angles. The target orientation was also significant, as was the target orientation-angle interaction. The reason for this is illustrated in Figure 11. The inline bars in target orientation 1 are more bunched up than in orientation 2. This makes them harder to read, so lower resolutions are reported for these targets. This effect is much more pronounced at the higher angles than at the lower ones, causing the interaction to be significant. This effect does not show up in the crossline bars because their apparent increased aspect ratio makes them easier to distinguish from one another, even at the higher angles.

4. The contrast ratio effect was not significant for the inline data, as it neither was for the crossline data. This allows all three target contrast data to be combined. Figure 9 shows the combined contrast ratio regression curves for each camera and target orientation, and the regression equations are listed in the Appendix. The inline data can be further reduced by regressing the two camera data for each target orientation, since the camera effect was not significant. These reductions provide the aspect ratio correction curves shown in Figure 10. The inline aspect ratio correction factors and the equation of the correction curves are listed in Table 2.

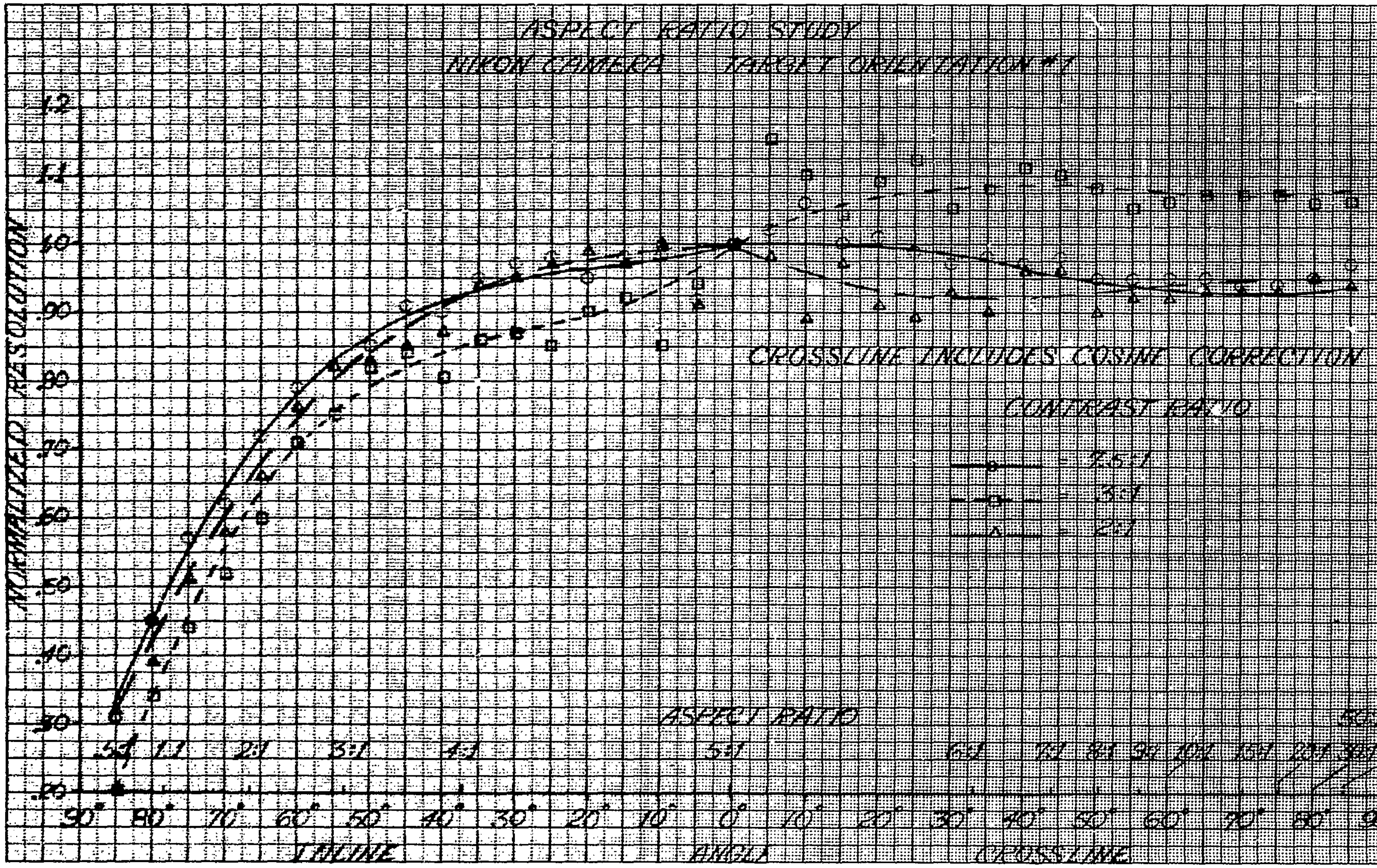

ASPECT RATIO STUDY
NIKON CAMERA TARGET ORIENTATION #1
NORMALIZED RESOLUTION
CROSSLINE INCLUDES COSINE CORRECTION
CONTRAST RATIO
2.5:1
3:1
2:1
ASPECT RATIO
INLINE
ANGLE
CROSSLINE

FIGURE # 5

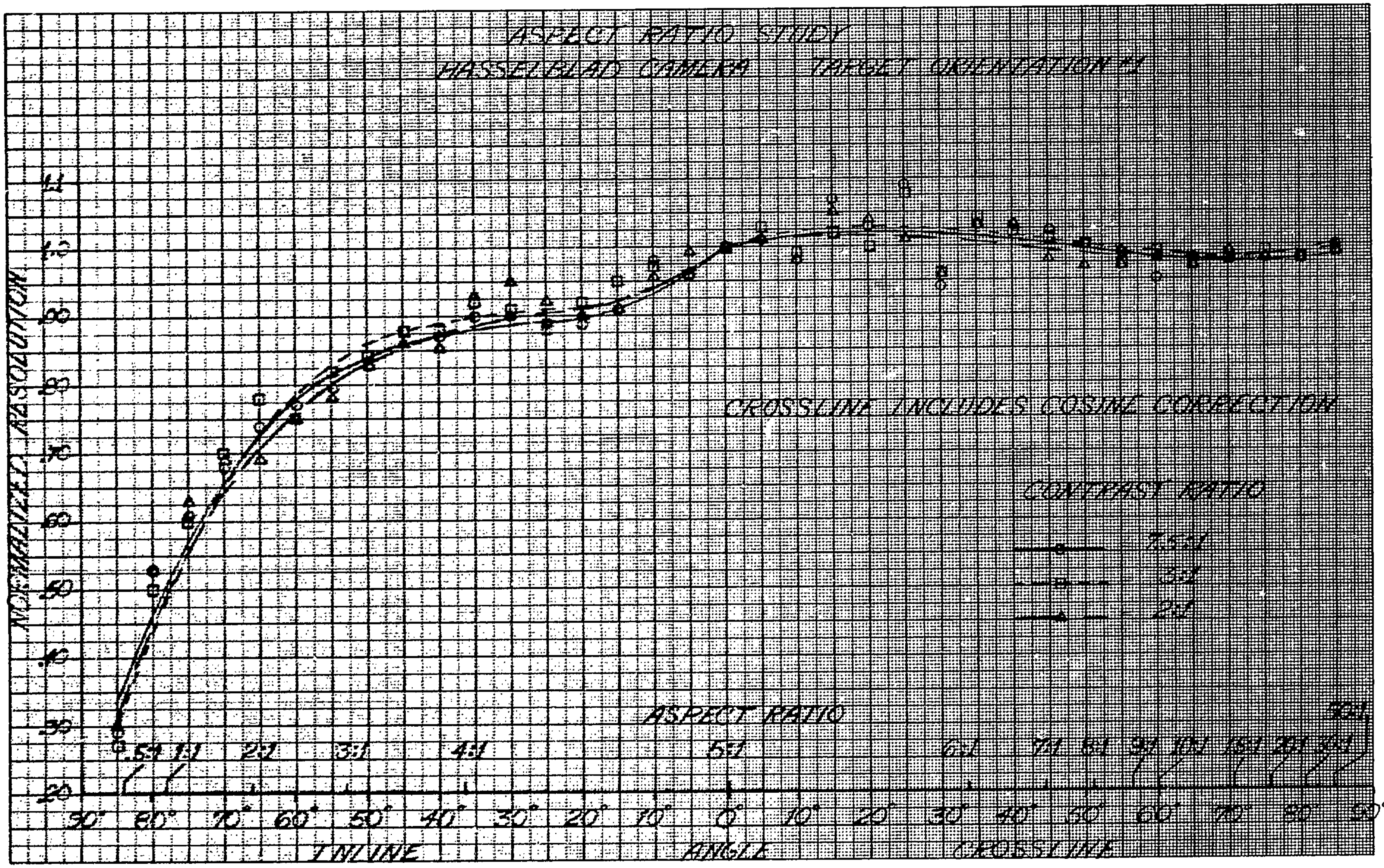

ASPECT RATIO STUDY
HASSELBLAD CAMERA TARGET ORIENTATION #1
CROSSLINE INCLUDES COSINE CORRECTION
CONTRAST RATIO
7.5:1
3:1
2:1
ASPECT RATIO
.5:1 1:1 2:1 3:1 4:1 5:1 6:1 7:1 8:1 9:1 10:1 15:1 20:1 30:1 50:1
NORMALIZED RESOLUTION
1.1 1.0 .90 .80 .70 .60 .50 .40 .30 .20
90° 80° 70° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 70° 80° 90°
INLINE ANGLE CROSSLINE

FIGURE #6

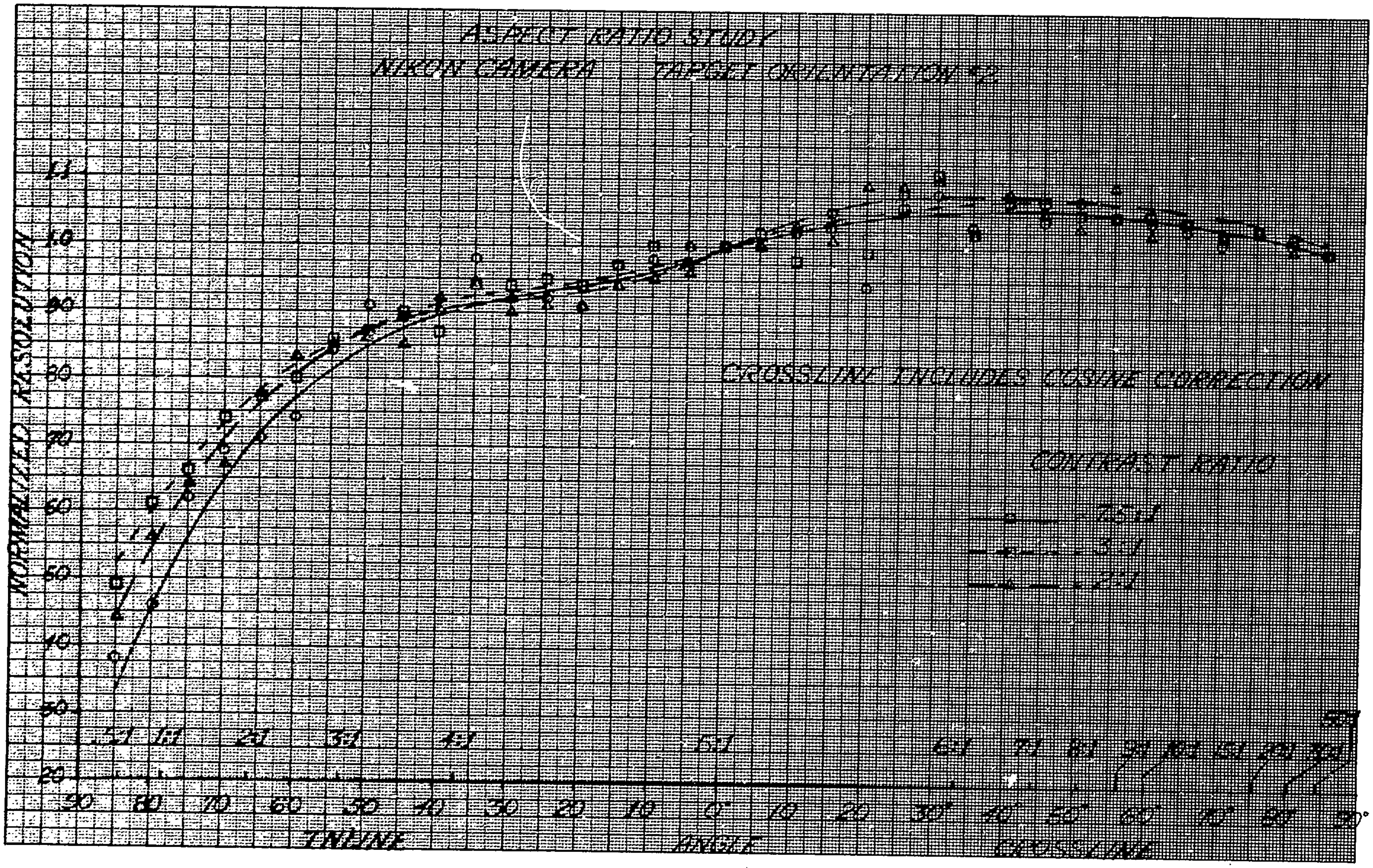
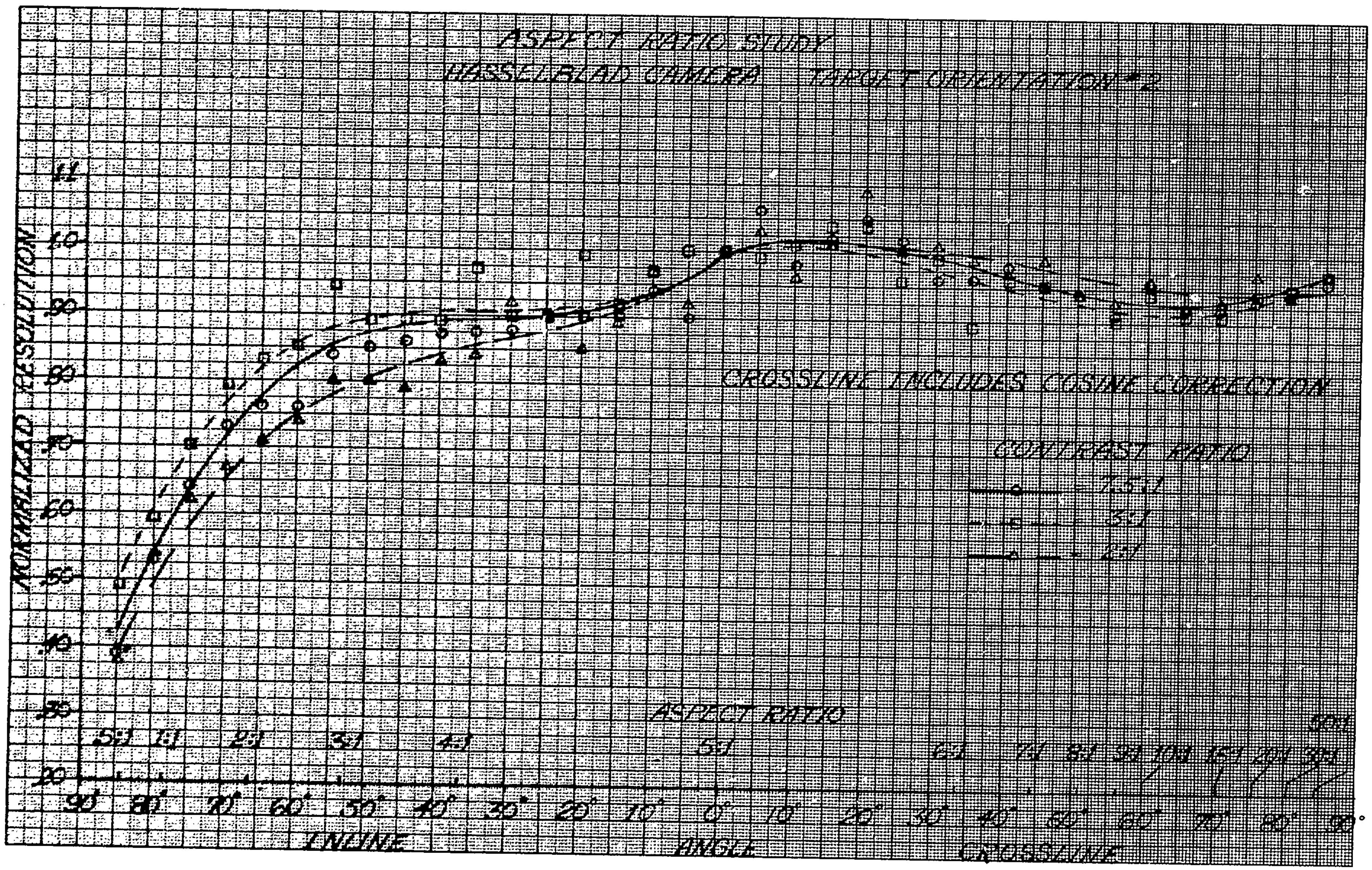

ASPECT RATIO STUDY
NIKON CAMERA TARGET ORIENTATION #2
CROSSLINE INCLUDES COSINE CORRECTION
CONTRAST RATIO
3:1
2:1
NORMALIZED RESOLUTION
ANGLE
CROSSLINE

FIGURE # 7



ASPECT RATIO STUDY
HASSELBLAD CAMERA TARGET ORIENTATION #2
NORMALIZED RESOLUTION
CROSSLINE INCLUDES COSINE CORRECTION
CONTRAST RATIO
7.5:1
3:1
2:1
ASPECT RATIO
ANGLE
INLINE
CROSSLINE

FIGURE # 8

TABLE 1

ANALYSIS OF VARIANCE

Levels of Factors:		
	Angle (A)	18
	Contrast Ratio (R)	3
	Target Orientation (T)	2
	Camera (C)	2

Crossline

* = Significant at 95% Confidence

Grand Mean 1.0000

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	Calculated F Ratio
A	.07412	17	.00436	1.61
R	.03549	2	.01774	.67
AR	.01756	34	.00052	.85
T	.00150	1	.00150	.20
AT	.02192	17	.00129	.49
RT	.06250	2	.03125	1.84
ART	.03025	34	.00089	1.65
C	.04830	1	.04830	9.31 *
AC	.04596	17	.00270	4.46 *
RC	.05256	2	.02628	43.38 *
ARC	.01316	34	.00039	.72
TC	.06934	1	.06934	16.78 *
ATC	.04455	17	.00262	4.85 *
RTC	.03394	2	.01697	31.40 *
Error (ARTC)	.01838	34	.00054	
Total	.56952	215		

Inline

Grand Mean .80921

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	Calculated F Ratio
A	6.28874	17	.36993	99.18 *
R	.00377	2	.00188	.09
AR	.02423	34	.00071	.87
T	.06033	1	.06033	10.09 *
AT	.10457	17	.00615	7.52 *
RT	.07260	2	.03630	8.01
ART	.03187	34	.00094	1.37
C	.00102	1	.00102	.18
AC	.06345	17	.00373	4.56 *
RC	.04162	2	.02081	25.44 *
ARC	.02098	34	.00062	.90
TC	.01833	1	.01833	4.05
ATC	.02111	17	.00124	1.80
RTC	.00906	2	.00453	6.58 *
Error (ARTC)	.02340	34	.00069	
Total	6.78510	215		

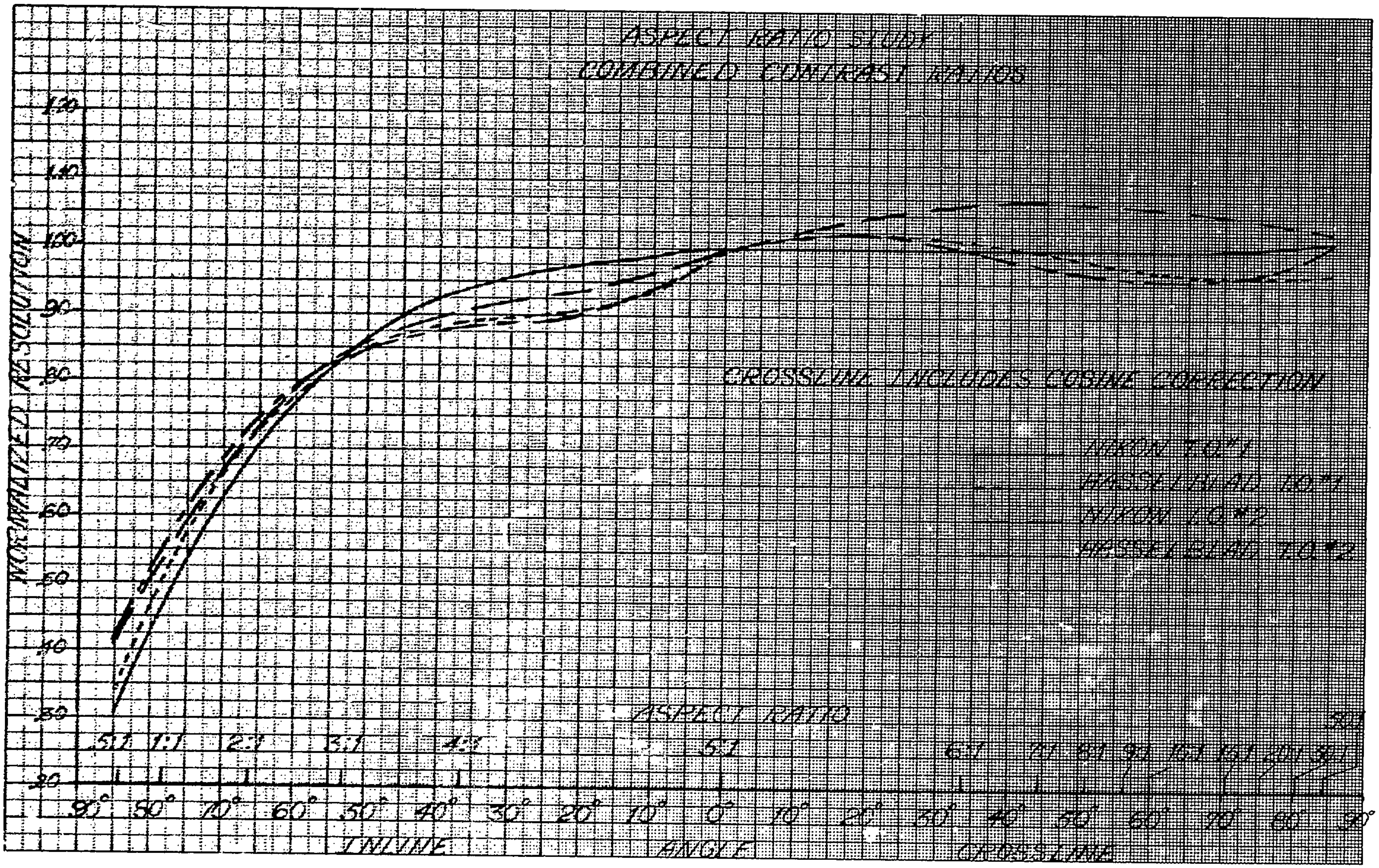

ASPECT RATIO STUDY
COMBINED CONTRAST RATIOS
CROSSLINE INCLUDES COSINE CORRECTION
NIKON T.O.#1
HASSELBLAD T.O.#1
NIKON T.O.#2
HASSELBLAD T.O.#2
NORMALIZED RESOLUTION
ASPECT RATIO
INLINE
ANGLE
CROSSLINE

FIGURE #9

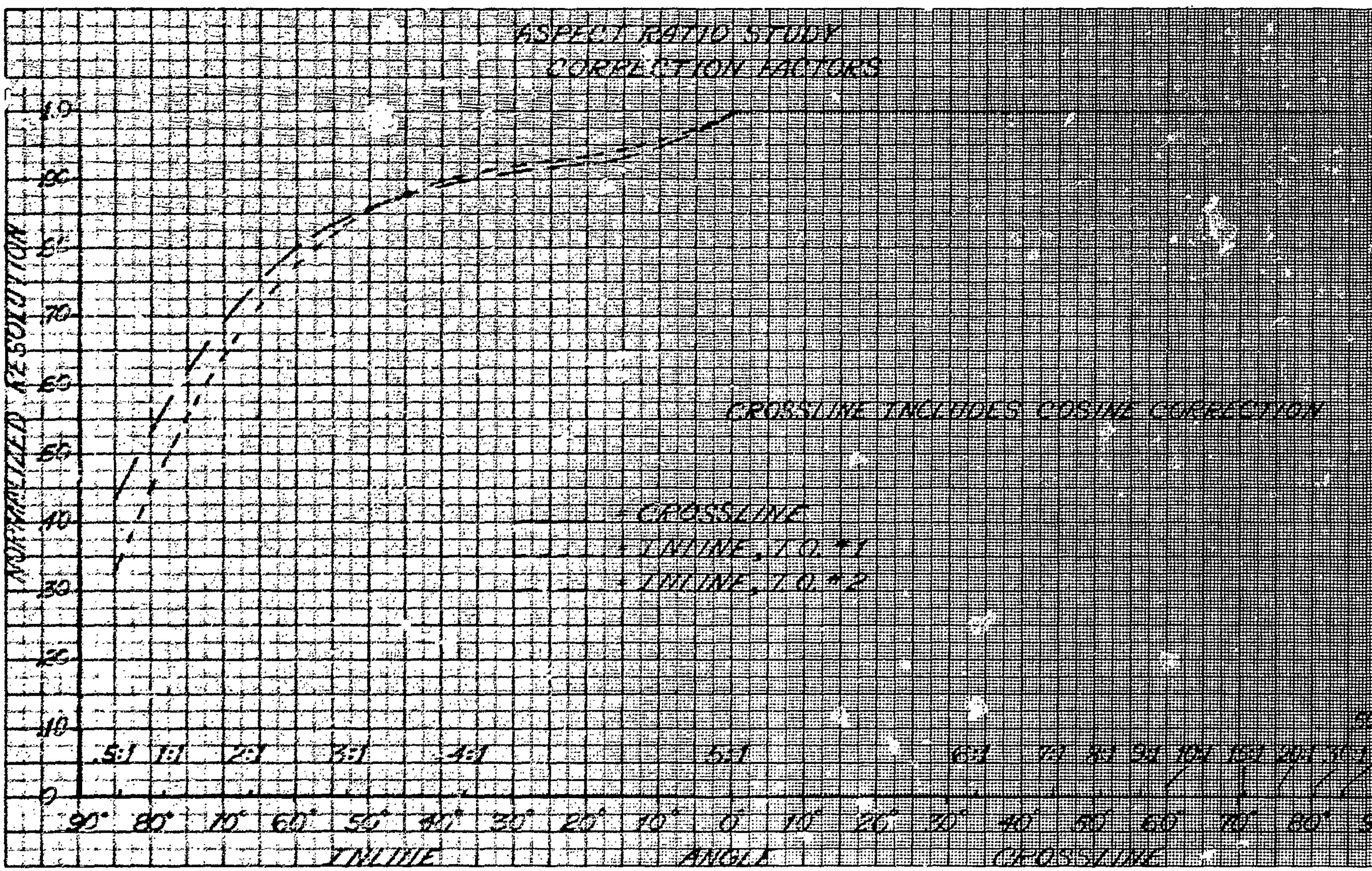
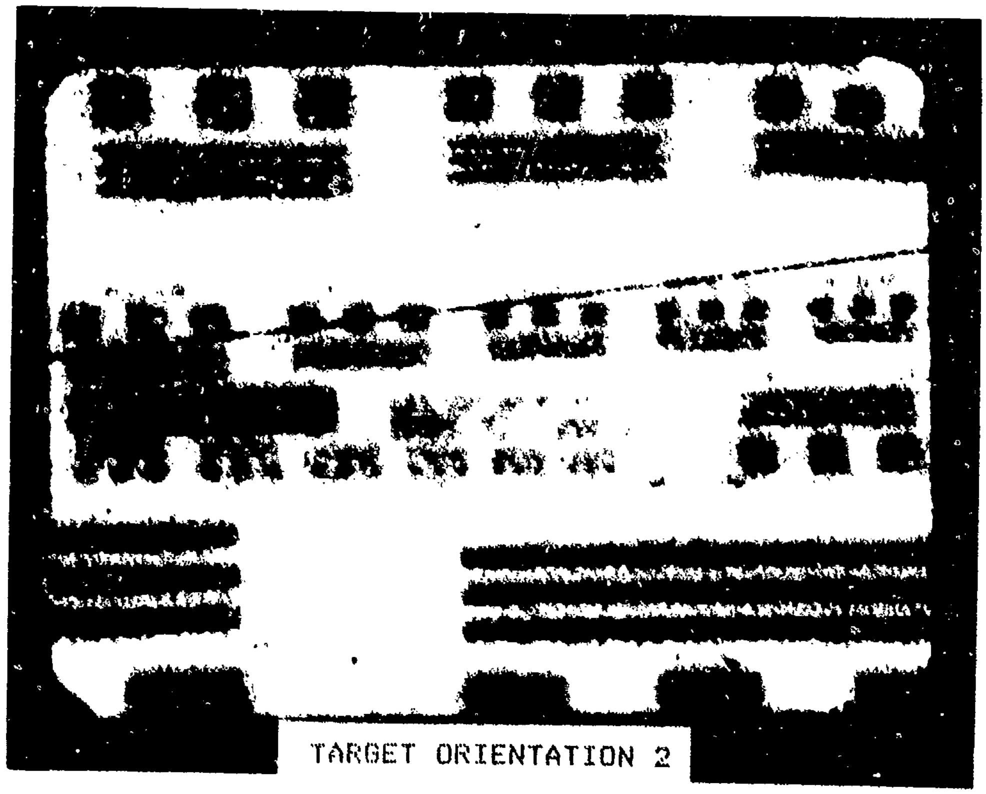
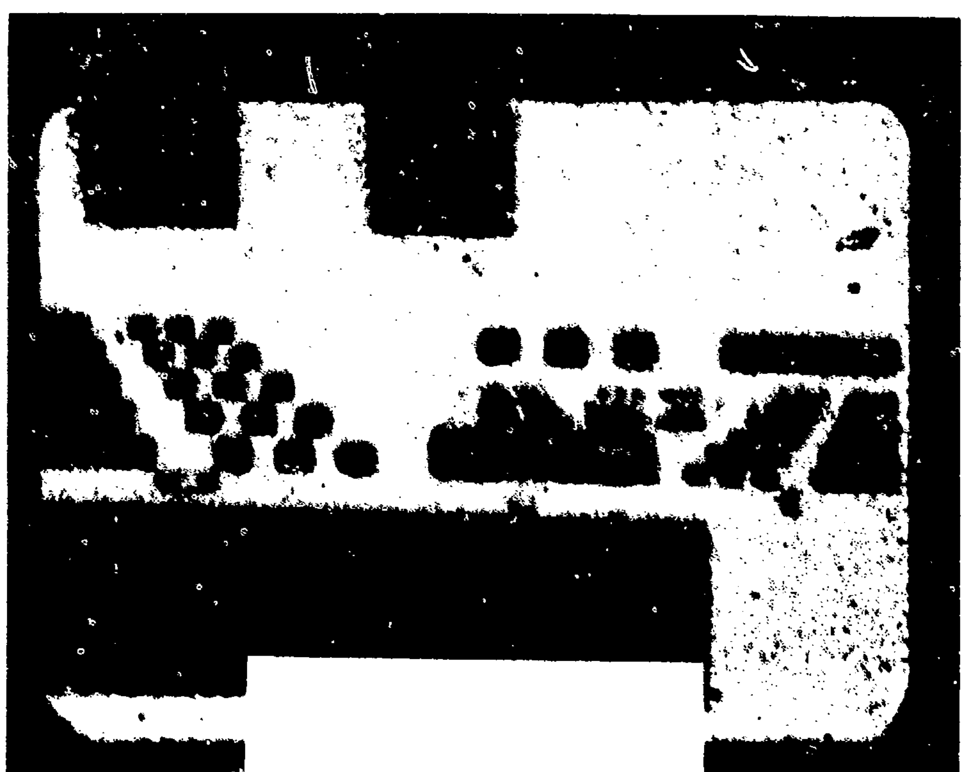

ASPECT RATIO STUDY
CORRECTION FACTORS
NORMALIZED RESOLUTION
1.0
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
CROSSLINE INCLUDES COSINE CORRECTION
CROSSLINE
INLINE, I.O. #1
INLINE, I.O. #2
.5:1
1:1
2:1
3:1
4:1
5:1
6:1
90° 80° 70° 60° 50° 40° 30° 20° 10° 0 10° 20° 30° 40° 50° 60° 70° 80° 90°
INLINE
ANGLE
CROSSLINE

FIGURE #10



TARGET ORIENTATION 2



TARGET ORIENTATION 1

FIGURE 11
TARGET ORIENTATION EFFECT

TABLE 2

ASPECT RATIO CORRECTION FACTORS

Angle	Inline Target Orientation 1	Inline Target Orientation 2
0	1.000	1.000
5	.975	.970
10	.956	.947
15	.943	.932
20	.934	.921
25	.927	.913
30	.919	.907
35	.910	.900
40	.897	.891
45	.879	.878
50	.853	.860
55	.819	.834
60	.774	.799
65	.716	.754
70	.643	.696
75	.555	.624
80	.448	.536
85	.322	.430

Regression Equations

Y = Normalized Resolution
X = Scan Angle in Degrees

Inline T.O. 1 $Y=1.00-(.00593)X+(.00018)X^2-(.2401x10^{-5})X^3$ ESE=.0458

T.O. 2 $Y=1.00-(.00704)X+(.00020)X^2-(.2307x10^{-5})X^3$ ESE=.0390

5. Tri-bar resolution readings should be corrected for aspect ratio using the normal geometrical cosine function for the crossline readings and the functions shown in Table 2 for the inline readings, using the appropriate target orientation. These corrections can be used for any contrast ratio target, and are used according to equation (8).

$$\text{Corrected Aspect Ratio Resolution} = \frac{\text{Resolution Read}}{\text{Correction Factor}} \qquad (8)$$

F. The significance of the camera effect for the crossline data and of the many camera interactions cannot at this time be explained. The Nikon camera appeared to have some astigmatism, since the inline readings were 10% higher than the crossline reading at the low angles. The Hasselblad camera had essentially the same readings for crossline and inline at the low angles. This could possibly account for the camera effects and camera interaction effects.

VI. CONCLUSIONS

A. Oblique imaged inline target resolution readings, where previously no geometric or other correction have been used, need to be adjusted for an aspect ratio effect. This effect at large oblique angles can significantly increase the computed resolution.

B. Oblique imaged crossline target resolution readings require the use of only the normal geometric (cosine) correction factors.

C. Over the contrast ratio range used, the correction factors both for geometric and aspect ratio were independent of the contrast ratio of the target.

D. Target orientation was found to significantly effect the inline aspect ratio correction factors. The two orientations tested provided slightly, but significantly different correction factors. This suggests that different type targets may have different correction factors.

VII. RECOMMENDATIONS

A. Use the resulting aspect ratio correction factors for inline imaging as discussed and given in Table 2.

B. Continue the use of the cosine factor for crossline targets.

C. Further investigate the aspect ratio effect using different type targets.

D. Confirm the results with a controlled airborne test.

VIII. Appendix TABLE 3

Normalized Resolution, Corrected for Contrast Ratio

Nikon Camera - Target Orientation 1

Target Contrast Ratio - Crossline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	1.02	1.15	.98
10	1.06	1.10	.89
15	1.00	1.04	.97
20	1.01	1.09	.91
25	.99	1.12	.89
30	.97	1.05	.93
35	.98	1.08	.90
40	.97	1.11	.96
45	.98	1.10	.96
50	.95	1.08	.90
55	.95	1.05	.92
60	.95	1.06	.92
65	.95	1.07	.93
70	.94	1.07	.93
75	.94	1.07	.93
80	.95	1.06	.95
85	.97	1.00	.94

Target Contrast Ratio - Inline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	.92	.94	.91
10	.98	.85	1.00
15	.98	.92	.97
20	.95	.90	.99
25	.98	.85	.97
30	.97	.87	.95
35	.95	.86	.94
40	.90	.80	.87
45	.91	.84	.85
50	.85	.82	.83
55	.82	.75	.82
60	.79	.71	.76
65	.72	.60	.66
70	.62	.52	.58
75	.57	.44	.51
80	.45	.34	.39
85	.31	.18	.32
Contrast Ratio on Film	3.3:1	2.3:1	1.7:1

TABLE 4

Normalized Resolution, Corrected for Contrast Ratio

Nikon Camera - Target Orientation 2

Target Contrast Ratio - Crossline

Angle	7.5:1	3:1	2:1
0	1.01	1.03	1.00
5	1.00	1.02	1.00
10	1.02	.98	1.03
15	1.05	1.03	1.01
20	.94	.99	1.09
25	1.08	1.06	1.09
30	1.08	1.11	1.10
35	1.03	1.02	1.02
40	1.08	1.07	1.08
45	1.04	1.07	1.05
50	1.07	1.05	1.03
55	1.05	1.05	1.09
60	1.04	1.05	1.02
65	1.03	1.04	1.04
70	1.01	1.02	1.03
75	1.03	1.03	1.03
80	1.02	1.01	1.00
85	1.00	1.00	1.00

Target Contrast Ratio - Inline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	1.00	.97	.96
10	.98	1.00	.95
15	.97	.97	.94
20	.91	.94	.91
25	.92	.95	.91
30	.92	.94	.90
35	.98	.94	.94
40	.90	.87	.92
45	.89	.90	.85
50	.91	.87	.86
55	.84	.86	.85
60	.74	.80	.83
65	.71	.77	.75
70	.69	.74	.67
75	.62	.66	.64
80	.46	.61	.56
85	.38	.49	.44
Contrast Ratio on Film	8.6:1	2.7:1	2.0:1

TABLE 5

Normalized Resolution, Corrected for Contrast Ratio
Hasselblad Camera - Target Orientation 1

Target Contrast Ratio - Crossline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	1.01	1.03	1.01
10	.98	.99	.98
15	1.07	1.02	1.05
20	1.03	1.00	1.04
25	1.09	1.08	1.04
30	.94	.96	.96
35	1.03	1.04	1.03
40	1.03	1.02	1.03
45	1.02	1.01	.98
50	1.00	1.00	.97
55	.99	.97	.97
60	.95	.99	.98
65	.98	.97	.97
70	.99	.98	.99
75	.98	.99	.98
80	.98	.98	.98
85	1.00	.99	.99

Target Contrast Ratio - Inline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	.96	.96	.99
10	.98	.97	.96
15	.91	.95	.91
20	.88	.92	.90
25	.89	.88	.92
30	.90	.91	.95
35	.90	.92	.93
40	.87	.88	.85
45	.88	.88	.86
50	.83	.84	.83
55	.79	.82	.78
60	.77	.75	.75
65	.74	.78	.69
70	.68	.70	.69
75	.61	.60	.63
80	.53	.50	.53
85	.29	.27	.30
Contrast Ratio on Film	5.6:1	3.0:1	2.1:1

TABLE 6

Normalized Resolution, Corrected for Contrast Ratio
Hasselblad Camera - Target Orientation 2

Target Contrast Ratio - Crossline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	1.00	.99	1.03
10	.98	1.01	.96
15	1.02	1.04	1.01
20	1.05	1.04	1.09
25	1.02	.96	1.00
30	.96	.99	1.01
35	.96	.89	.99
40	.98	.96	.97
45	.95	.95	.99
50	.94	.94	.94
55	.91	.90	.93
60	.96	.94	.96
65	.92	.91	.92
70	.92	.91	.93
75	.93	.94	.97
80	.94	.95	.94
85	.96	.97	.97

Target Contrast Ratio - Inline

Angle	7.5:1	3:1	2:1
0	1.00	1.00	1.00
5	.90	1.00	.92
10	.94	.97	.97
15	.90	.92	.89
20	.90	.99	.85
25	.90	.90	.90
30	.88	.90	.92
35	.89	.97	.84
40	.87	.89	.83
45	.86	.89	.79
50	.85	.89	.80
55	.84	.94	.80
60	.76	.85	.74
65	.76	.83	.71
70	.73	.79	.67
75	.64	.70	.62
80	.53	.59	.54
85	.39	.49	.38
Contrast Ratio on Film	5.0:1	2.6:1	1.8:1

TABLE 7

Regression Formulas for Tables 3 and 4
Nikon Camera

Y = Normalized Resolution
X = Scan Angle in Degrees

<u>Target Orientation 1</u>

Crossline	7.5:1	$Y = 1.00-(.00064)X-(.00011)X^2$	ESE = .0090
	3:1	$Y = 1.00-(.00482)X-(.00008)X^2$	ESE = .0209
	2:1	$Y = 1.00-(.00576)X-(.00029)X^2+(.1208 x 10^{-5})X^3$	ESE = .0241
Inline	7.5:1	$Y = 1.00-(.00310)X+(.00010)X^2-(.1838 x 10^{-5})X^3$	ESE = .0172
	3:1	$Y = 1.00-(.00889)X+(.00024)X^2-(.2894 x 10^{-5})X^3$	ESE = .0240
	2:1	$Y = 1.00-(.00058)X-(.1024 x 10^{-5})X^3$	ESE = .0215

<u>Target Orientation 2</u>

Crossline	7.5:1	$Y = 1.00-(.00194)X-(.00016)X^2+(.6777 x 10^{-6})X^3$	ESE = .0323
	3:1	$Y = 1.00-(.00194)X-(.00017)X^2+(.7614 x 10^{-6})X^3$	ESE = .0256
	2:1	$Y = 1.00-(.00471)X-(.00008)X^2+(.8944 x 10^{-7})X^3$	ESE = .0296
Inline	7.5:1	$Y = 1.00-(.00518)X+(.00015)X^2-(.2132 x 10^{-5})X^3$	ESE = .0324
	3:1	$Y = 1.00-(.00398)X+(.00010)X^2-(.1406 x 10^{-5})X^3$	ESE = .0190
	2:1	$Y = 1.00-(.00617)X+(.00018)X^2-(.2168 x 10^{-5})X^3$	ESE = .0214

TABLE 8

Regression Formulas for Tables 5 and 6
Hasselblad Camera

Y = Normalized Resolution
X = Scan Angle in Degrees

Target Orientation 1

Crossline	7.5:1	$Y = 1.00-(.00206)X-(00010)X^2$	ESE = .0332
	3:1	$Y = 1.00-(.00219)X-(00010)X^2$	ESE = .0259
	2:1	$Y = 1.00-(.00146)X-(.00011)X^2$	ESE = .0224
Inline	7.5:1	$Y = 1.00-(.00945)X+(.00028)X^2-(.3075x10^{-5})X^3$	ESE = .0391
	3:1	$Y = 1.00-(.00851)X+(.00027)X^2-(.3143x10^{-5})X^3$	ESE = .0458
	2:1	$Y = 1.00-(.00707)X+(.00019)X^2-(.2344x10^{-5})X^3$	ESE = .0405

Target Orientation 2

Crossline	7.5:1	$Y = 1.00-(.00251)X-(.00004)X^2-(.6249x10^{-6})X^3$	ESE = .0421
	3:1	$Y = 1.00-(.00160)X-(.00005)X^2-(.6387x10^{-6})X^3$	ESE = .0305
	2:1	$Y = 1.00-(.00159)X-(.00010)X^2$	ESE = .0307
Inline	7.5:1	$Y = 1.00-(.00883)X+(.00027)X^2-(.2891x10^{-5})X^3$	ESE = .0295
	3:1	$Y = 1.00-(.00914)X+(.00029)X^2-(.2961x10^{-5})X^3$	ESE = .0408
	2:1	$Y = 1.00-(.00849)X+(.00020)X^2-(.2164x10^{-5})X^3$	ESE = .0421

TABLE 9

Regression Formulas for Figure 9

Y = Normalized Resolution
X = Scan Angle in Degrees

Target Orientation 1

Nikon Crossline	$Y = 1.0-(.00005)X-(.00016)X^2+(.3799 \times 10^{-6})X^3$	ESE = .0275
Inline	$Y = 1.0-(.00207)X+(.00007)X^2-(.1663 \times 10^{-5})X^3$	ESE = .0246
Hasselblad Crossline	$Y = 1.0-(.00252)X-(.00008)X^2-(.1464 \times 10^{-6})X^3$	ESE = .0399
Inline	$Y = 1.0-(.00834)X+(.00025)X^2-(.2854 \times 10^{-5})X^3$	ESE = .0399

Target Orientation 2

Nikon Crossline	$Y = 1.0-(.00286)X-(.00014)X^2+(.5095 \times 10^{-6})X^3$	ESE = .0276
Inline	$Y = 1.0-(.00511)X+(.00014)X^2-(.1902 \times 10^{-5})X^3$	ESE = .0306
Hasselblad Crossline	$Y = 1.0-(.00315)X-(.00003)X^2-(.7190 \times 10^{-6})X^3$	ESE = .0306
Inline	$Y = 1.0-(.00882)X+(.00025)X^2-(.2672 \times 10^{-5})X^3$	ESE = .0399

*U.S.Government Printing Office: 1979 — 657-084/243