Apollo 15
Hasselblad Camera
Calibration
Photogrammetry

LEC/HASD No. 640-TR-007

PROJECT APOLLO

NASA CONTRACT NAS 9-10950

TECHNICAL REPORT

SYNOPSIS OF CAMERA CALIBRATION RESULTS - FOR APOLLO MISSION 15 HASSELBLAD CAMERAS

JULY 22, 1971

PREPARED FOR
MAPPING SCIENCES BRANCH
EARTH OBSERVATION DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FOREWORD

Presented here are the key results of the calibration of the Hasselblad cameras for Apollo Mission 15. The 60 mm and the 80 mm focal length cameras were calibrated using the Wild T-4 Goniometer. Stellar calibration was performed for the 250 mm and the 500 mm focal length cameras. The procedure followed in the calibration by the Wild T-4 Goniometer is outlined in the Technical Report "A Procedure for the Calibration of Finite-Focused Cameras By Wild T-4 Goniometer", LEC/HASD No. TR-676-43-01, dated March 24, 1971. Data reduction for stellar calibration was performed by DBA's SMAC program. The preprocessing was done by a modified version of the MUSAT preprocessor.

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ACKNOWLEDGEMENTS

Measurements on the Wild T-4 Goniometer were made by Mr. E. Mager and Mrs. P. Gosden of the Mapping Sciences Department. Data for computer runs was prepared by Miss E. Reynolds, who also tabulated the results.

Photography for stellar calibration was obtained at the MSC Observatory, Houston, Texas. Mr. D. Peterson of MSC Observatory helped set up the equatorial tracking mount for the cameras while taking photography of a stellar field. Messrs. R. Kassay and P. Brandow helped in taking the photography. Measurements on the Mann Comparator were made by Messrs. E. Mager and P. Brandow. Mr. M. Malone helped in preparing the data for computer runs, and also tabulated the results.

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* Flight cameras

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1031 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 5081616 S/N 1031 DATE: 5/24/71

CAMERA SETTINGS: F:5.6 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.466 ± .020 (mm)

--Calibrated Focal Length

CFL = 61.461 ± .012 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.4	0.9	3.0	-2.7	-0.0
7.1	-2.5	0.8	-1.6	-1.5	-1.2
10.6	-2.9	2.7	1.3	-2.1	-0.2
14.1	0.9	1.0	-2.2	1.5	0.3
17.7	-2.4	1.2	-0.4	-6.9	-2.1
21.2	-0.3	-3.2	-4.5	-0.2	-2.0
24.7	-2.0	0.9	-4.6	-0.2	-1.5
28.3	-5.4	-0.6	-5.2	4.1	-1.8
31.8	3.0	0.7	-4.1	5.8	1.3
35.4	5.4	3.2	0.0	9.8	4.6

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -2.33294867 \times 10^{-5}$

$k_3 = -2.85403966 \times 10^{-7}$

$k_5 = 3.28548045 \times 10^{-10}$

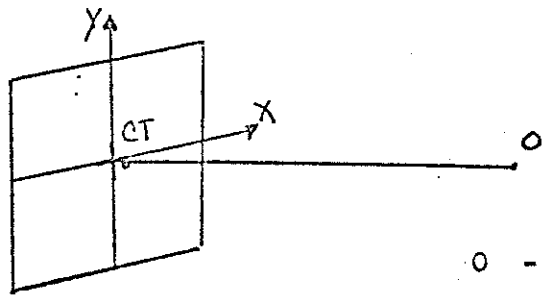
--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.384 ± .020 (mm)

Pd 61.466 without reseau
Pd 61.384 with reseau
− .082 reseau

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = .470 ± .039 (mm)

y = -.130 ± .034 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1031 FOR APOLLO MISSION 15

LENS: Carl Zeiss Nr 5081616 S/N 1031 DATE: 5/24/71

CAMERA SETTINGS: F:5.6 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.504 ± .049 (mm)

--Calibrated Focal Length

CFL = 62.499 ± .033 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.8	-1.0	-3.7	-5.5	-1.1
7.1	-2.6	-1.7	-2.4	-4.3	-2.7
10.6	-1.3	-0.1	1.1	-4.2	-1.1
14.1	1.5	-2.0	-3.2	-2.8	-1.6
17.7	0.2	-1.4	-2.6	-9.0	-3.2
21.2	1.0	-4.6	-4.7	-4.4	-3.2
24.7	0.9	-2.4	-4.4	-2.1	-2.0
28.3	0.0	-2.0	-6.1	1.2	-1.7
31.8	5.6	-0.6	-1.1	5.1	2.4
35.4	5.5	5.7	4.5	12.4	7.1

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -1.78733215 \times 10^{-4}$

$k_3 = -3.72655718 \times 10^{-8}$

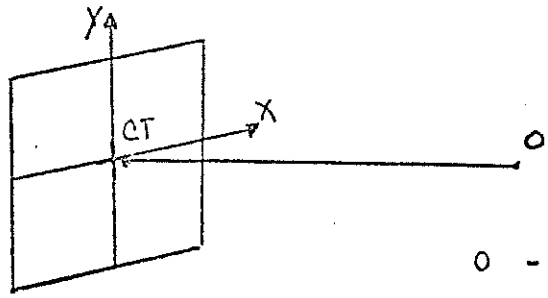
$k_5 = 2.72146168 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 62.411 $\pm$ .057 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

$x = .479 \pm .038$ (mm)

$y = -.132 \pm .034$ (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1031 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 5081616 S/N 1031 DATE: 5/24/71

CAMERA SETTINGS: f:5.6 at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.248 ± .041 (mm)

--Calibrated Focal Length

CFL = 63.246 ± .030 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-0.8	-1.3	-0.7	-3.4	-1.5
7.1	-2.6	-2.0	-6.2	-2.9	-3.4
10.6	-3.6	-1.5	-5.0	-4.4	-3.6
14.1	-1.0	-2.6	-11.3	-1.2	-4.0
17.7	-3.8	-7.8	-9.1	-10.3	-7.7
21.2	-3.4	-3.6	-12.5	-4.3	-5.9
24.7	-3.8	0.4	-11.2	-3.8	-4.6
28.3	-5.5	-0.1	-10.7	2.8	-3.4
31.8	2.2	2.9	-7.0	7.7	1.4
35.4	7.5	10.0	8.4	10.5	9.1

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -4.04234868 \times 10^{-4}$

$k_3 = 9.86227819 \times 10^{-8}$

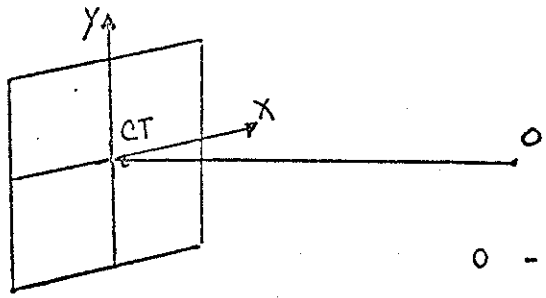
$k_5 = 3.42047857 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 63.152 $\pm$ .056 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

$x = .484 \pm .040$ (mm)

$y = -.134 \pm .035$ (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1031 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 5081616 S/N 1031 DATE: 5/24/71

CAMERA SETTINGS: f:11 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.479 ± .032 (mm)

--Calibrated Focal Length

CFL = 61.467 ± .035 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-2.0	1.7	8.1	-1.0	1.7
7.1	-2.7	0.2	3.3	-0.5	0.1
10.6	-2.4	1.3	4.5	0.2	0.9
14.1	0.3	0.8	-0.3	0.8	0.4
17.7	-0.8	0.5	2.2	-6.8	-1.2
21.2	-0.2	-2.3	0.3	-1.2	-0.8
24.7	-3.4	-0.8	-0.6	-2.6	-1.8
28.3	-6.3	-2.0	-7.0	2.5	-3.2
31.8	-0.3	-1.7	-1.9	1.8	-0.5
35.4	2.1	-0.5	0.0	4.9	1.6

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = 1.23240431 \times 10^{-4}$

$k_3 = -6.12699748 \times 10^{-7}$

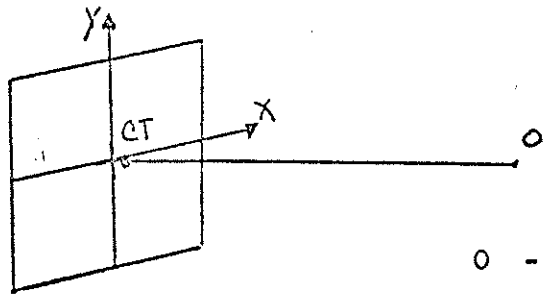
$k_5 = 4.44206170 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.386 $\pm$ .029 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

$x = .470 \pm .039$ (mm)

$y = .130 \pm .034$ (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1031 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 5081616 S/N 1031 DATE: 5/24/71

CAMERA SETTINGS: f:11 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.499 ± .039 (mm)

--Calibrated Focal Length

CFL = 62.497 ± .026 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-0.5	-1.2	2.0	-4.9	-1.1
7.1	-2.9	-3.0	-3.7	-4.1	-3.4
10.6	-3.4	0.2	-2.9	-4.8	-2.7
14.1	-1.4	0.5	-7.1	-2.0	-2.5
17.7	-3.4	-1.0	-2.6	-8.8	-3.9
21.2	-4.5	-2.7	-5.1	-3.6	-4.0
24.7	-1.9	-2.0	-5.0	-2.7	-2.9
28.3	-2.0	-1.0	-6.2	3.0	-1.5
31.8	1.7	2.5	-0.9	1.8	1.3
35.4	6.2	7.1	4.8	12.2	7.6

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -2.73157856 \times 10^{-4}$

$k_3 = 9.02491532 \times 10^{-8}$

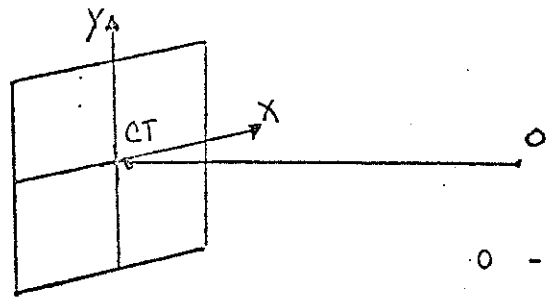
$k_5 = 2.33296386 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

$= 62.412 \pm .050$ (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

$x = .479 \pm .038$ (mm)

$y = -.132 \pm .034$ (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1031 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 5081616 S/N 1031 DATE: 5/24/71

CAMERA SETTINGS: f:11 at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.251 ± .047 (mm)

--Calibrated Focal Length

CFL = 63.244 ± .032 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.7	0.1	1.1	-4.0	-1.1
7.1	-3.8	-1.5	-5.9	-4.4	-3.9
10.6	-4.4	0.0	-3.4	-6.5	-3.6
14.1	-2.3	-2.2	-11.4	-5.8	-5.4
17.7	-3.5	-0.5	-6.1	-13.8	-6.0
21.2	-0.8	-4.5	-8.0	-8.2	-5.4
24.7	-0.6	-0.3	-3.7	-6.9	-2.9
28.3	0.0	0.2	-6.7	-2.4	-2.2
31.8	6.5	2.6	3.3	3.7	4.0
35.4	7.7	7.7	8.3	12.0	8.9

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -4.75095109 \times 10^{-4}$

$k_3 = 4.79127914 \times 10^{-7}$

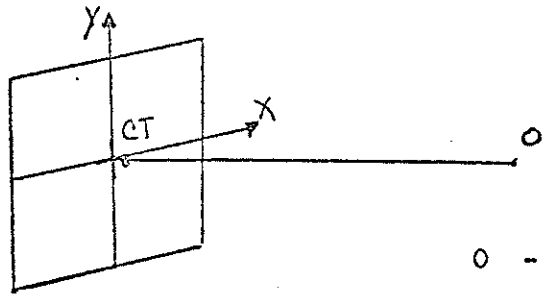
$k_5 = 8.56960683 \times 10^{-11}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 63.152 $\pm$ .051 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = .484 $\pm$ .040 (mm)

y = -.134 $\pm$ .035 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1033 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 2586540 S/N 1033 DATE: 5/24/71

CAMERA SETTINGS: f:5.6 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.501 ± .013 (mm)

--Calibrated Focal Length

CFL = 61.497 ± .014 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.7	-1.4	3.9	-5.2	-1.1
7.1	-3.7	-3.0	0.8	-3.9	-2.4
10.6	-2.9	-2.1	0.5	-5.9	-2.6
14.1	-1.1	-4.1	-4.1	-2.0	-2.8
17.7	-2.9	-4.2	1.1	-9.4	-3.8
21.2	-2.7	-7.0	-1.1	-4.3	-3.8
24.7	-2.5	-6.3	-2.2	-3.9	-3.7
28.3	-1.0	-3.5	-3.7	7.2	-0.2
31.8	2.7	-0.5	1.4	3.4	1.7
35.4	6.8	4.7	4.1	9.4	6.2

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -3.00446145 \times 10^{-4}$

$k_3 = 2.50383057 \times 10^{-7}$

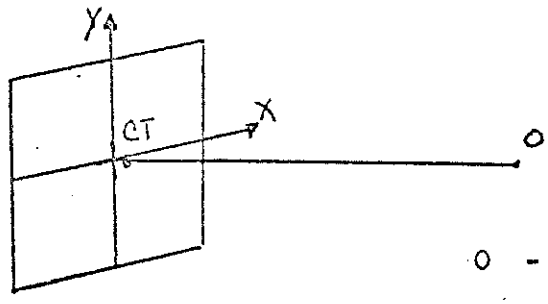
$k_5 = 1.05492160 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.390 ± .006 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.568 ± .019 (mm)

y = -.047 ± .023 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1033 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 2586540 S/N 1033 DATE: 5/24/71

CAMERA SETTINGS: f:5.6 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.526 ± .036 (mm)

--Calibrated Focal Length

CFL = 62.512 ± .028 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	0.0	-4.1	1.4	-4.2	-1.7
7.1	-3.8	-5.7	-3.9	-3.2	-4.1
10.6	-6.5	-5.2	-1.7	-2.2	-3.9
14.1	-4.6	-7.0	-6.9	0.6	-4.5
17.7	-7.7	-9.1	0.1	-7.6	-6.1
21.2	-6.1	-10.2	-3.7	-1.9	-5.5
24.7	-7.6	-8.5	-4.5	-1.8	-5.6
28.3	-6.1	-6.2	-5.3	-0.2	-4.4
31.8	-0.5	-1.3	-0.1	4.2	0.6
35.4	4.0	6.2	6.9	7.6	6.2

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -4.06762083 \times 10^{-4}$

$k_3 = 1.47780643 \times 10^{-7}$

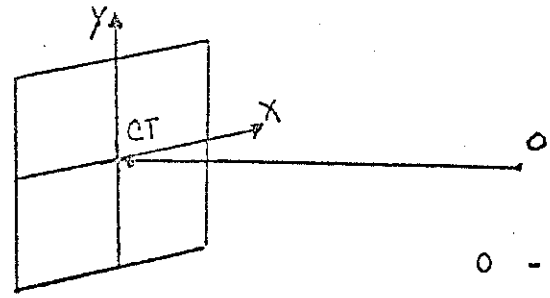
$k_5 = 2.53239681 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 62.410 ± .047 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.577 ± .021 (mm)

y = -.050 ± .024 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1033 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 2586540 S/N 1033 DATE: 5/24/71

CAMERA SETTINGS: f:5.6 at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.301 ± .044 (mm)

--Calibrated Focal Length

CFL = 63.286 ± .031 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.2	-1.7	2.5	-3.0	-0.8
7.1	-4.6	-5.7	-3.5	-4.7	-4.6
10.6	-6.5	-5.2	-1.5	-4.6	-4.4
14.1	-6.4	-8.6	-4.2	-0.3	-4.9
17.7	-9.0	-10.1	0.1	-8.9	-7.0
21.2	-7.2	-12.0	-3.1	-3.4	-6.4
24.7	-8.2	-11.0	-1.7	-1.1	-5.5
28.3	-3.9	-9.0	-2.5	5.3	-2.5
31.8	-0.3	-1.1	2.2	7.2	2.0
35.4	5.4	8.7	5.8	13.8	8.4

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -4.90727108 \times 10^{-4}$

$k_3 = 3.39501188 \times 10^{-7}$

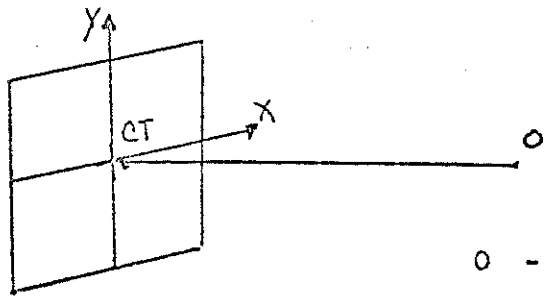
$k_5 = 1.95996543 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 63.169 ± .058 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.583 ± .020 (mm)

y = -.052 ± .023 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1033 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 2586540 S/N 1033 DATE: 5/24/71

CAMERA SETTINGS: f:11 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.512 ± .011 (mm)

--Calibrated Focal Length

CFL = 61.501 ± .022 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-2.4	-0.5	5.6	-3.2	-0.1
7.1	-4.2	-2.6	1.0	-3.0	-2.2
10.6	-4.6	-1.7	2.2	-3.5	-1.9
14.1	-3.0	-2.8	-2.5	-0.8	-2.3
17.7	-5.5	-1.1	4.5	-8.4	-2.6
21.2	-5.5	-4.9	0.4	-3.2	-3.3
24.7	-5.7	-4.1	0.2	-2.1	-2.9
28.3	-5.5	-1.4	-1.7	5.5	-0.8
31.8	-0.2	1.2	2.9	2.4	1.6
35.4	2.4	6.1	2.5	8.4	4.8

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -2.11620766 \times 10^{-4}$

$k_3 = 1.00414812 \times 10^{-7}$

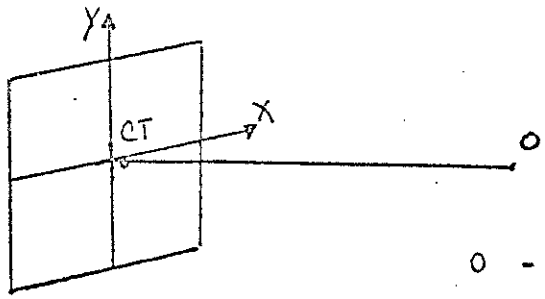
$k_5 = 1.45364465 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.392 ± .008 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.566 ± .018 (mm)

y = -.050 ± .022 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1033 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 2586540 S/N 1033 DATE: 5/24/71

CAMERA SETTINGS: f:11 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.526 ± .033 (mm)

--Calibrated Focal Length

CFL = 62.514 ± .020 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-2.6	-0.6	2.5	-3.2	-1.0
7.1	-3.8	-3.0	-2.5	-3.3	-3.1
10.6	-4.2	-1.5	-1.0	-4.9	-2.9
14.1	-3.0	-2.8	-6.0	-1.2	-3.2
17.7	-6.0	-2.4	-0.1	-10.8	-4.8
21.2	-7.7	-4.6	-3.8	-2.6	-4.7
24.7	-5.6	-2.2	-1.6	-2.0	-2.8
28.3	-2.0	2.7	-4.5	3.3	-0.1
31.8	1.0	-15.6	2.2	4.2	-2.0
35.4	3.2	15.6	6.0	10.8	8.9

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -2.76683896 \times 10^{-4}$

$k_3 = 5.28696274 \times 10^{-9}$

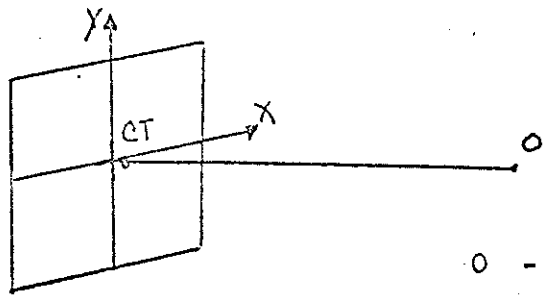
$k_5 = 3.09558444 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 62.410 $\pm$ .044 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.576 $\pm$ .021 (mm)

y = -.051 $\pm$ .023 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1033 FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 2586540 S/N 1033 DATE: 5/24/71

CAMERA SETTINGS: f:11 at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.293 ± .056 (mm)

--Calibrated Focal Length

CFL = 63.281 ± .030 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-3.3	-3.0	3.3	-6.5	-2.4
7.1	-7.3	-5.9	-2.9	-6.9	-5.8
10.6	-8.2	-6.5	-0.4	-6.0	-5.3
14.1	-9.6	-12.1	-6.3	-3.7	-7.9
17.7	-11.2	-13.6	-2.0	-14.2	-10.2
21.2	-10.6	-15.1	-2.0	-4.4	-8.0
24.7	-8.3	-12.2	-2.4	-3.7	-6.6
28.3	-4.5	-10.7	-3.3	-4.2	-5.7
31.8	-0.4	-7.0	3.6	6.7	0.7
35.4	8.1	12.9	9.7	14.2	11.2

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = -6.36607529 \times 10^{-4}$

$k_3 = 3.01138715 \times 10^{-7}$

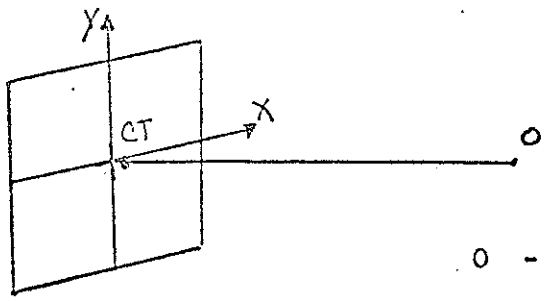
$k_5 = 3.60749406 \times 10^{-10}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

$= 63.166 \pm .052$ (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

$x = -.584 \pm .019$ (mm)

$y = -.053 \pm .023$ (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1038 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss Nr. 5081619 S/N 1038 DATE: 5/24/71

CAMERA SETTINGS: F:8 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.483 ± .018 (mm)

--Calibrated Focal Length

CFL = 61.482 ± .010 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	0.2	2.0	5.4	-3.9	0.9
7.1	-0.4	1.7	1.3	-0.3	0.6
10.6	0.1	2.2	5.3	0.5	2.0
14.1	0.8	1.0	1.8	5.0	2.2
17.7	-0.1	3.3	6.4	-5.0	1.2
21.2	1.9	-3.8	2.9	1.3	0.6
24.7	2.5	-2.9	1.5	1.0	0.5
28.3	1.9	-4.1	-1.4	1.0	-0.7
31.8	0.7	-5.9	0.1	2.7	-0.6
35.4	-2.5	-0.9	-5.4	5.3	-0.9

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

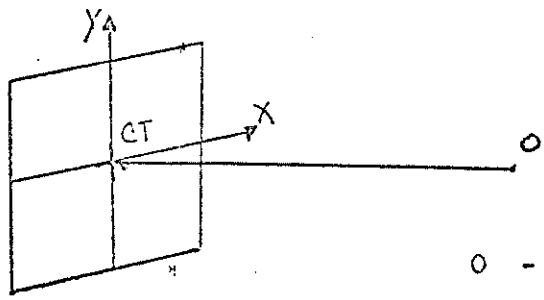
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.394 ± .011 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.225 ± .006 (mm)

y = -.085 ± .006 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1038 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss NR 5081619 S/N 1038 DATE: 5/24/71

CAMERA SETTINGS: F:8 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.491 ± .033 (mm)

--Calibrated Focal Length

CFL = 62.491 ± .020 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	0.9	-0.3	0.8	-2.8	-0.4
7.1	-1.2	-0.8	1.5	-0.4	-0.2
10.6	-1.2	1.5	2.3	0.6	0.8
14.1	-0.5	2.2	3.0	2.3	1.8
17.7	-1.1	0.6	3.8	-5.0	-0.4
21.2	-1.2	-3.1	-7.6	0.9	-2.8
24.7	-0.4	-0.6	5.3	0.2	1.1
28.3	-0.3	2.2	6.1	5.1	3.3
31.8	0.0	2.3	6.8	0.0	2.3
35.4	-0.3	3.3	7.7	5.6	4.1

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

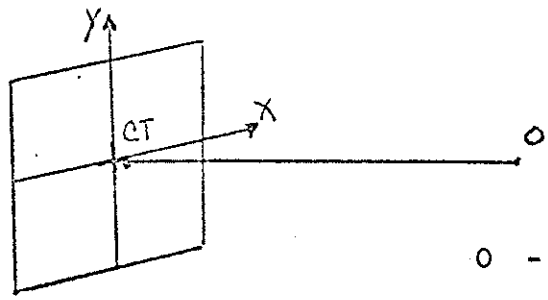
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 62.381 ± .041 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.228 ± .002 (mm)

y = -.071 ± .003 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1038 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss 5081619 S/N 1038 DATE: 5/24/71

CAMERA SETTINGS: F:8 at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.225 ± .051 (mm)

--Calibrated Focal Length

CFL = 63.218 ± .024 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.4	0.6	0.8	-2.2	-0.6
7.1	-2.0	-0.5	-1.6	-1.2	-1.3
10.6	-2.9	-2.4	1.7	-1.9	-1.4
14.1	-1.9	-0.2	-3.8	2.3	-0.9
17.7	-3.6	0.6	2.0	-5.6	-1.7
21.2	-2.0	-3.8	-1.8	-0.3	-2.0
24.7	-4.1	-1.5	-1.2	-2.7	-2.4
28.3	-1.0	-0.7	-4.8	-3.4	-2.5
31.8	1.3	0.8	-1.8	-1.0	-0.2
35.4	3.2	5.0	1.0	-0.0	2.3

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

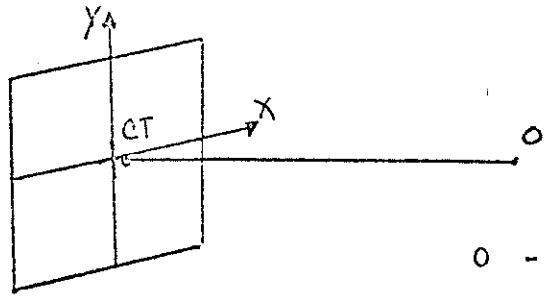
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 63.264 ± .038 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.183 ± .025 (mm)

y = -.084 ± .021 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1039 FOR APOLLO MISSION 15

LENS: Carl Zeiss Nr. 5081608 S/N 1039 DATE: 5/24/71

CAMERA SETTINGS: F:5.6 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.572 ± .014 (mm)

--Calibrated Focal Length

CFL = 61.572 ± .006 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-2.8	1.5	3.2	-1.1	0.2
7.1	-0.6	0.6	1.0	2.2	0.8
10.6	-0.5	3.5	6.3	3.0	3.1
14.1	2.3	3.9	0.2	5.7	3.0
17.7	1.2	4.9	5.3	-1.9	2.4
21.2	0.6	-0.8	2.2	3.4	1.4
24.7	-0.4	-1.0	0.8	2.1	0.4
28.3	1.4	-0.1	-1.6	2.4	0.5
31.8	2.8	-3.0	-1.8	-0.6	-0.7
35.4	1.5	-1.9	-6.3	0.0	-1.7

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = —

k_3 = —

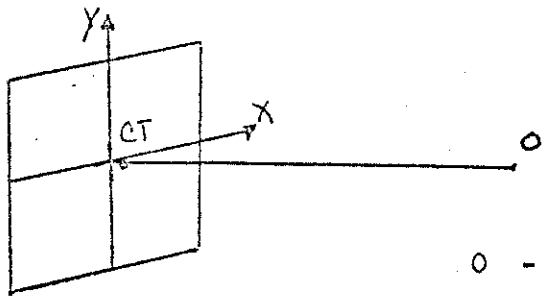
k_5 = —

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.461 ± .010 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.201 ± .008 (mm)

y = -.158 ± .009 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1039 FOR APOLLO MISSION 15

LENS: Carl Zeiss Nr. 5081608 S/N 1039 DATE: 5/24/71

CAMERA SETTINGS: F:5.6 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.566 ± .041 (mm)

--Calibrated Focal Length

CFL = 62.557 ± .030 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	0.0	-2.2	2.2	-1.3	-0.3
7.1	-2.3	-2.5	-1.0	0.2	-1.4
10.6	-0.1	0.0	2.9	1.4	1.1
14.1	2.8	-0.4	-1.4	6.9	2.0
17.7	0.3	0.0	3.8	-4.2	-0.0
21.2	0.8	-2.0	1.6	2.7	0.8
24.7	-0.7	-3.3	0.1	0.7	-0.8
28.3	-1.3	-4.5	-2.8	4.4	-1.1
31.8	0.2	-3.2	-2.2	-1.8	-1.8
35.4	0.0	3.1	-0.2	0.0	0.7

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

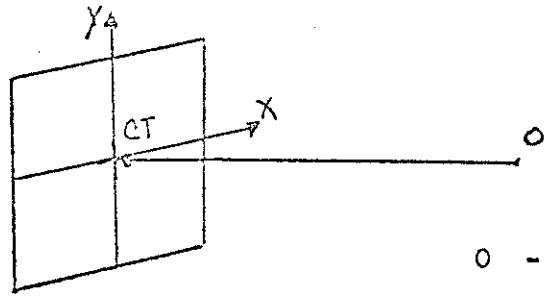
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 62.456 ± .041 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.194 ± .014 (mm)

y = -.182 ± .016 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1039 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss Nr. 5081608 S/N 1039 DATE: 5/24/71

CAMERA SETTINGS: F:5.6 at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.313 ± .067 (mm)

--Calibrated Focal Length

CFL = 63.311 ± .032 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-2.0	-0.2	2.9	-2.3	-0.4
7.1	-3.8	-1.1	-1.4	-1.0	-1.8
10.6	-4.7	1.4	-0.9	-0.7	-1.2
14.1	-0.5	-1.0	-8.2	4.4	-1.3
17.7	-3.1	-0.8	-5.0	-5.7	-3.7
21.2	-1.6	-2.9	-9.1	0.8	-3.2
24.7	-2.8	-0.5	-14.3	1.9	-3.9
28.3	-3.9	-2.3	22.4	-2.4	3.5
31.8	-2.0	-0.9	-21.2	6.4	-4.4
35.4	-0.0	4.2	-22.4	9.6	-2.2

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

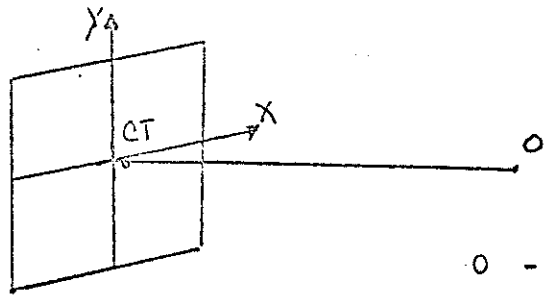
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 63.204 ± .061 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.193 ± .013 (mm)

y = -.184 ± .015 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1039 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss Nr. 5081608 S/N 1039 DATE: 5/24/71

CAMERA SETTINGS: F:11 at 70 ft.

--Principal Distance (inner lens node to the film plane)

PD = 61.570 ± .019 (mm)

--Calibrated Focal Length

CFL = 61.572 ± .011 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.2	0.4	3.5	-2.1	0.1
7.1	-0.2	0.5	1.0	0.7	0.5
10.6	0.0	2.0	6.1	1.0	2.3
14.1	2.7	3.5	2.0	6.5	3.7
17.7	0.5	2.3	6.9	-5.0	1.2
21.2	1.3	-0.2	2.6	1.1	1.2
24.7	0.7	1.5	1.5	-1.0	1.2
28.3	-0.4	0.2	-1.2	-1.2	-0.7
31.8	1.2	-0.5	-0.4	-2.7	-0.6
35.4	-2.4	0.0	-3.5	-6.5	-3.1

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

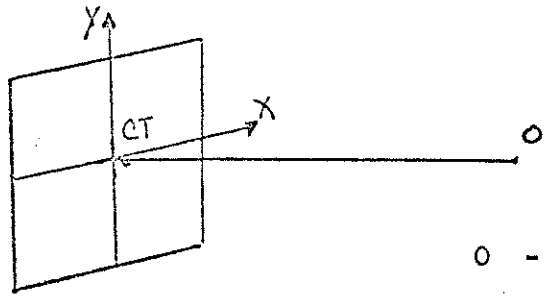
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 61.459 ± .016 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.202 ± .008 (mm)

y = -.158 ± .007 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1039 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss 5081608 S/N 1039 DATE: 5/24/71

CAMERA SETTINGS: F:11 at 10 ft.

--Principal Distance (inner lens node to the film plane)

PD = 62.555 ± .055 (mm)

--Calibrated Focal Length

CFL = 62.547 ± .020 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-1.7	0.3	-2.4	0.3	-0.9
7.1	-2.1	-1.2	-4.1	-0.6	-2.0
10.6	-1.6	2.3	-1.0	-0.2	-0.1
14.1	0.8	-1.0	-3.9	5.8	0.4
17.7	-2.1	0.7	1.1	-5.2	-1.4
21.2	-1.0	-3.7	-1.3	0.0	-1.5
24.7	-1.0	-1.9	0.6	-1.8	-1.0
28.3	0.1	-2.6	-2.1	-4.6	-2.3
31.8	3.0	-2.3	0.1	-3.1	-0.6
35.4	0.0	0.0	0.0	-5.8	-1.5

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

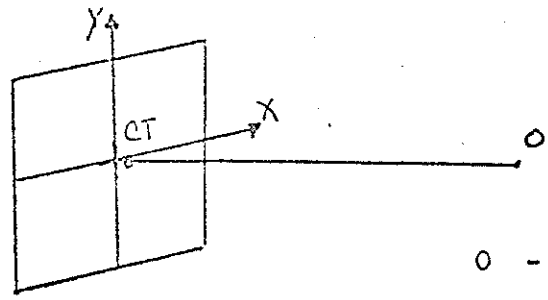
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 62.455 ± .039 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.193 ± .012 (mm)

y = -.183 ± .014 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad S/N 1039 (60 mm) FOR APOLLO MISSION 15

LENS: Carl Zeiss 5081608 S/N 1039 DATE: 5/24/71

CAMERA SETTINGS: Fill at 7 ft.

--Principal Distance (inner lens node to the film plane)

PD = 63.314 ± .049 (mm)

--Calibrated Focal Length

CFL = 63.305 ± .019 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	-0.2	-0.7	5.2	-3.4	0.2
7.1	-0.5	-2.4	0.7	-1.7	-1.0
10.6	-3.6	-1.3	3.3	-2.4	-1.0
14.1	-0.6	-1.6	-3.3	2.1	-0.9
17.7	-0.7	-2.4	3.6	-8.4	-2.0
21.2	0.6	-5.2	0.3	-2.8	-1.8
24.7	-0.3	-4.1	-0.6	-1.6	-1.7
28.3	2.8	-3.2	-5.2	4.6	-0.3
31.8	2.1	-0.9	-1.2	0.0	0.0
35.4	0.0	4.2	2.1	0.0	1.6

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

k_1 = ——

k_3 = ——

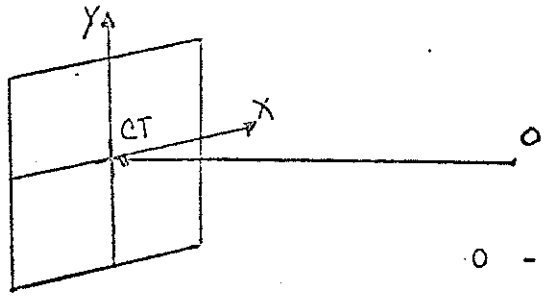
k_5 = ——

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= 63.200 ± .056 (mm)

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = -.193 ± .013 (mm)

y = -.186 ± .015 (mm)

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad (non reseau) S/N 1054 FOR APOLLO MISSION 15

LENS: Carl Zeiss S/N 1054 DATE: 5/24/71

CAMERA SETTINGS: f:5.6 at ∞

--Principal Distance (inner lens node to the film plane)

PD = 80.761 $\pm$ .014 (mm)

--Calibrated Focal Length

CFL = 80.755 $\pm$ .014 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	31.5	30.0	33.8	31.0	31.6
7.1	58.9	58.6	57.7	60.3	58.9
10.6	79.9	84.0	82.6	85.6	83.0
14.1	97.8	97.1	96.3	98.1	97.3
17.7	99.8	103.2	98.9	100.8	100.7
21.2	93.5	93.0	92.4	95.6	93.6
24.7	67.3	71.8	68.4	70.5	69.5
28.3	27.3	33.0	25.6	31.6	29.4
31.8	-29.6	-24.7	-29.1	-25.6	-27.2
35.4	-99.8	-99.1	-102.6	-100.6	-100.5

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = 9.002550 \times 10^{-3}$

$k_3 = -1.077444 \cdot 10^{-5}$

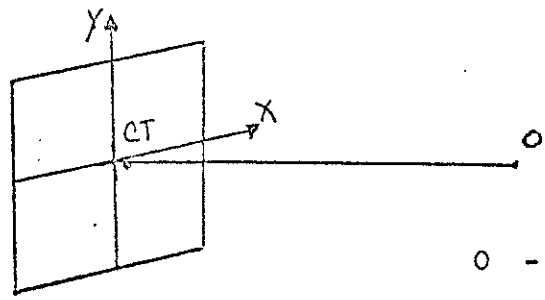
$k_5 = 1.048022 \times 10^{-9}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= Not Applicable

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = ——

y = ——

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad (non reseau) S/N 1054 FOR APOLLO MISSION 15

LENS: Carl Zeiss S/N 1054 DATE: 5/24/71

CAMERA SETTINGS: f:11 at ∞

--Principal Distance (inner lens node to the film plane)

PD = 80.761 ± .014 (mm)

--Calibrated Focal Length

CFL = 80.751 ± .012 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	31.3	31.3	32.2	30.3	31.2
7.1	59.0	58.8	58.5	58.6	58.7
10.6	82.2	83.5	84.0	83.4	83.3
14.1	99.6	97.6	97.7	97.3	98.0
17.7	102.7	101.7	102.1	101.3	102.0
21.2	95.3	90.6	95.3	93.9	93.8
24.7	72.2	69.2	73.3	70.0	71.2
28.3	32.5	28.9	26.8	30.9	29.8
31.8	-26.4	-30.3	-27.2	-28.0	-28.0
35.4	-105.9	-105.9	-106.2	-105.5	-105.9

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = 8.979062 \times 10^{-3}$

$k_3 = -1.043666 \times 10^{-5}$

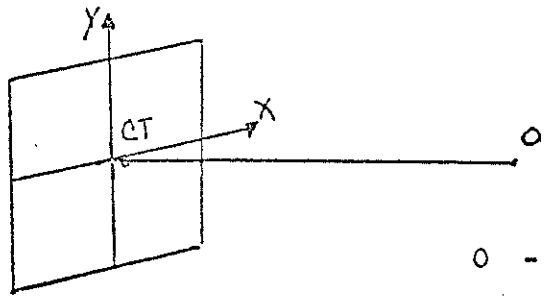
$k_5 = 0.699330 \times 10^{-9}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= Not Applicable

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = ——

y = ——

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad (non reseau) S/N 1057 FOR APOLLO MISSION 15

LENS: Carl Zeiss S/N 1057 DATE: 5/24/71

CAMERA SETTINGS: f:5.6 at ∞

--Principal Distance (inner lens node to the film plane)

PD = 80.657 ± .006 (mm)

--Calibrated Focal Length

CFL = 80.644 ± .010 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	30.8	29.2	31.0	30.6	30.4
7.1	58.1	56.0	56.5	58.6	57.3
10.6	80.8	80.5	82.6	82.3	81.6
14.1	98.5	92.8	96.5	98.7	96.6
17.7	101.8	99.5	100.2	100.9	100.6
21.2	91.7	87.3	95.8	94.0	92.2
24.7	69.9	65.5	72.4	68.8	69.2
28.3	30.1	25.7	29.4	29.3	28.6
31.8	-24.5	-31.5	-27.8	-28.7	-28.1
35.4	-101.1	-102.5	-103.4	-105.1	-103.0

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = 8.858504 \times 10^{-3}$

$k_3 = -1.043391 \times 10^{-5}$

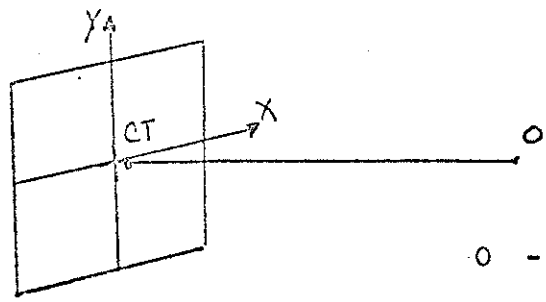
$k_5 = 0.822164 \times 10^{-9}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= Not Applicable

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = ——

y = ——

CAMERA CALIBRATION

WILD T-4 GONIOMETER

CAMERA: Hasselblad (non reseau) S/N 1057 FOR APOLLO MISSION 15

LENS: Carl Zeiss S/N 1057 DATE: 5/24/71

CAMERA SETTINGS: f:11 at ∞

--Principal Distance (inner lens node to the film plane)

PD = 80.657 ± .006 (mm)

--Calibrated Focal Length

CFL = 80.656 ± .018 (mm)

Radial Lens Distortion:

Radial Dist. (mm)	Distortion (μm)				Average
	Diag. I		Diag. II		
	L	R	L	R	
0.0	0.0	0.0	0.0	0.0	0.0
3.5	29.7	30.6	33.4	30.0	30.9
7.1	57.1	56.1	58.1	61.2	58.1
10.6	79.4	80.5	84.4	85.3	82.4
14.1	96.4	94.5	94.5	100.7	96.5
17.7	99.7	100.1	99.9	104.0	100.9
21.2	93.8	89.2	93.4	96.7	93.3
24.7	69.9	68.2	68.8	73.9	70.2
28.3	31.8	28.1	21.6	35.9	29.4
31.8	-23.6	-28.5	-26.5	-22.6	-25.3
35.4	-99.8	-102.6	-104.4	-99.3	-101.5

--A least squares curve-fitting to the distortion values was carried out according to the formula:

$$\delta = k_1 r + k_3 r^3 + k_5 r^5 + \ldots .$$

where, δ = distortion (mm)

r = radial distance (mm)

and, $k_1, k_3, k_5 \ldots$ = distortion coefficients

The distortion coefficients are:

$k_1 = 8.884987 \times 10^{-3}$

$k_3 = -1.039303 \times 10^{-5}$

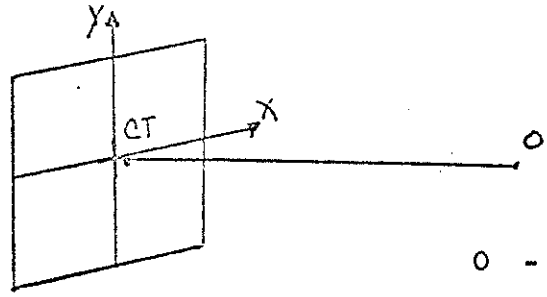
$k_5 = 0.807452 \times 10^{-9}$

--Location of the Principal Point, PP, (with respect to the built-in reseau):

A. Principal Distance (inner lens node to the reseau plane)

= Not Applicable

B. Principal Point Location



O - Lens Node (inner)

CT - Central Target

x, y - Axes defined by the reseau crosses.

x = ——

y = ——

(Pre-set for 70 fr.)

STELLAR CAMERA CALIBRATION

CAMERA: Hasselblad S/N 1026 APOLLO MISSION 15

LENS: 500 mm S/N 1006 DATE OF EXPOSURE: 5/28/71

DATE OF CALIBRATION: 7/9/71

The analytical photogrammetric interior orientation calibration of the Hasselblad camera S/N 1026, lens S/N 1006 system was performed using image measurement data derived from a stellar exposure made on the evening of 28 May 1971. The availability of a calibrated reseau grid system within the camera and its exposure simultaneously with the stellar images provided a basis for data refinement due to film distortions. By refining the stellar image data in the manner, the calibration results tabulated will relate to a plane coinciding with that of the reseau plate in the camera.

The mathematical solution was ultimately performed with only 74 stellar images as usable input. This factor coinciding with the image measurements residual mean error of 8.1 micrometers is considered extremely detrimental to the integrity of the solution.

1. CALIBRATED FOCAL LENGTH

$f = 504.184$ mm $\qquad \sigma_f = \pm 0.110$ mm

2. PRINCIPAL POINT LOCATION

$X_p = +0.004$ mm $\qquad \sigma_{X_p} = \pm 0.081$ mm

$Y_p = +0.002$ mm $\qquad \sigma_{Y_p} = \pm 0.081$ mm

3. RADIAL LENS DISTORTION COEFFICIENTS

$K_1 = +0.1977190 \times 10^{-1} \qquad \sigma_{K_1} = \pm 0.4412113 \times 10^{-5}$

$K_3 = -0.1752154 \times 10^{-4} \qquad \sigma_{K_3} = \pm 0.6853863 \times 10^{-6}$

$K_5 = +0.7124664 \times 10^{-9} \qquad \sigma_{K_5} = \pm 0.4851065 \times 10^{-9}$

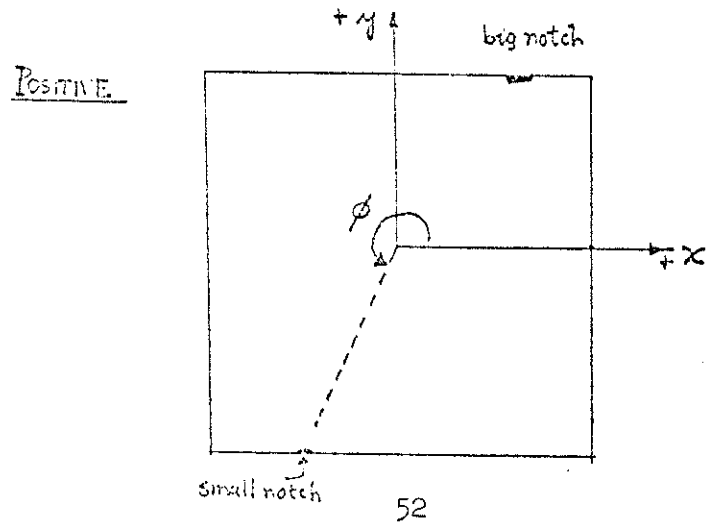
$K_7 = -0.2070659 \times 10^{-24} \qquad \sigma_{K_7} = \pm 0.8284579 \times 10^{-18}$

4. DECENTERING LENS DISTORTION COEFFICIENTS

$J_1 = +0.6005235 \times 10^{-5} \qquad \sigma_{J_1} = \pm 0.1159237 \times 10^{-5}$

$J_2 = +0.2751371 \times 10^{-38} \qquad \sigma_{J_2} = \pm 0.4878625 \times 10^{-23}$

$\phi = +261^{\circ}.4381 \qquad \sigma_\phi = \pm 11^{\circ}.42690$



STELLAR CAMERA CALIBRATION

CAMERA: Hasselblad S/N 1028 APOLLO MISSION 15

LENS: 500 mm S/N 1003 DATE OF EXPOSURE: 5/28/71

DATE OF CALIBRATION: 7/9/71

The analytical photogrammetric interior orientation calibration of the Hasselblad camera S/N 1024 - lens S/N 1003 system was performed using image measurement data derived from a stellar exposure made on the evening of 28 May 1971. The availability of a calibrated reseau grid system within the camera and its stellar image provided a basis for data refinement due to film distortions. By refining the stellar image data in this manner, the calibration results tabulated will relate to a plane coinciding with that of the reseau plate in the camera.

The mathematical solution was ultimately performed with only 56 stellar images as usable input. This factor coinciding with the image measurements residual near error of 9.8 micrometers is considered extremely detrimental to the integrity of the solution.

1. CALIBRATED FOCAL LENGTH

$f = 504.984$ mm $\qquad \sigma_f = \pm 0.175$ mm

2. PRINCIPAL POINT LOCATION

$X_p = 0.000$ mm $\qquad \sigma_{X_p} = \pm 0.001$ mm

$Y_p = 0.000$ mm $\qquad \sigma_{Y_p} = \pm 0.001$ mm

3. RADIAL LENS DISTORTION COEFFICIENTS

$K_1 = +0.1799903 \times 10^{-1} \qquad \sigma_{K_1} = \pm 0.6337937 \times 10^{-5}$

$K_3 = -0.2060471 \times 10^{-4} \qquad \sigma_{K_3} = \pm 0.1274422 \times 10^{-5}$

$K_5 = +0.3786803 \times 10^{-8} \qquad \sigma_{K_5} = \pm 0.1098170 \times 10^{-8}$

$K_7 = -0.4017195 \times 10^{-24} \qquad \sigma_{K_7} = \pm 0.9941123 \times 10^{-18}$

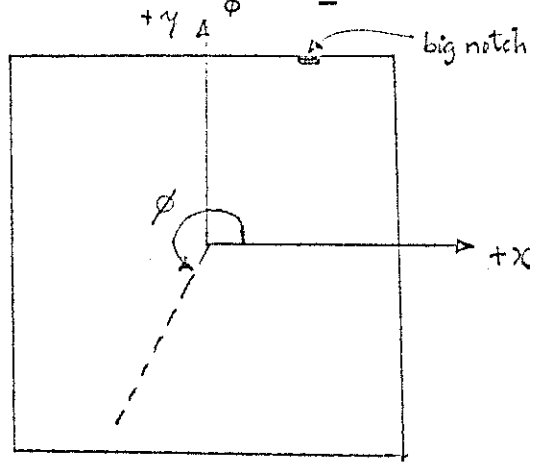
4. DECENTERING LENS DISTORTION COEFFICIENTS

$J_1 = +0.3959108 \times 10^{-5} \qquad \sigma_{J_1} = \pm 0.2257016 \times 10^{-5}$

$J_2 = -0.8839593 \times 10^{-39} \qquad \sigma_{J_2} = \pm 0.3866210 \times 10^{-23}$

$\phi = +227^{\circ}.9693 \qquad \sigma_{\phi} = \pm 27^{\circ}.31219$

POSITIVE



STELLAR CAMERA CALIBRATION

CAMERA: Hasselblad S/N 1054 APOLLO MISSION 15

LENS: 250 mm S/N 1016 DATE OF EXPOSURE: 5/13/71

DATE OF CALIBRATION: 6/9/71

The camera calibration herein documented was performed with data derived from a stellar exposure made on the evening of 13 May 1971 with the Hasselblad camera S/N 1054 and the 250 mm lens cone S/N 1016.

The analytical reduction was performed with 274 star image measurements well distributed over the format of the image frame. The least squares mathematics of the solution indicated a final mean error of 4.6 micrometers from the residual values of the image measurements.

The attached table is a synopsis of the interior orientation values as computed for this camera - lens system. The figure attached illustrates the orientation of the image plane relative to the camera format during the calibration procedure.

1. CALIBRATED FOCAL LENGTH

$f = 249.414$ mm $\qquad \sigma_f = \pm 0.014$ mm

2. PRINCIPAL POINT LOCATION

$X_p = 0.000$ mm $\qquad \sigma_{X_p} = \pm 0.0007$ mm

$Y_p = 0.000$ mm $\qquad \sigma_{Y_p} = \pm 0.0007$ mm

3. RADIAL LENS DISTORTION COEFFICIENTS

$K_1 = +0.9472912 \times 10^{-2} \qquad \sigma_{K_1} = \pm 0.5520711 \times 10^{-6}$

$K_3 = -0.9123677 \times 10^{-5} \qquad \sigma_{K_3} = \pm 0.1627360 \times 10^{-6}$

$K_5 = +0.8352030 \times 10^{-9} \qquad \sigma_{K_5} = \pm 0.1039468 \times 10^{-9}$

$K_7 = +0.4794406 \times 10^{-23} \qquad \sigma_{K_7} = \pm 0.6594446 \times 10^{-18}$

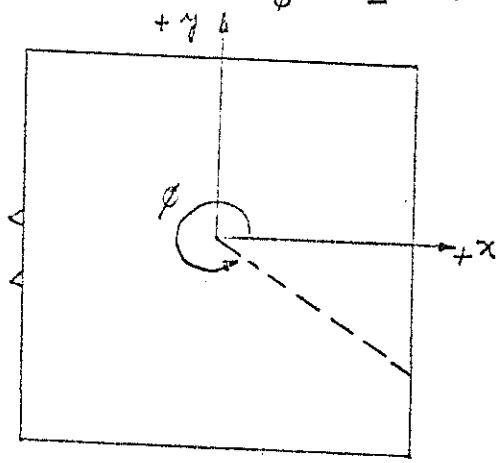
4. DECENTERING LENS DISTORTION COEFFICIENTS

$J_1 = +0.1244650 \times 10^{-5} \qquad \sigma_{J_1} = \pm 0.3678752 \times 10^{-6}$

$J_2 = -0.1709946 \times 10^{-39} \qquad \sigma_{J_2} = \pm 0.8130756 \times 10^{-24}$

$\phi = 320.^{\circ}7031 \qquad \sigma_\phi = \pm 13.^{\circ}65082$

POSITIVE



STELLAR CAMERA CALIBRATION

CAMERA: Hasselblad S/N 1057 APOLLO MISSION 15

LENS: 250 mm S/N 1017 DATE OF EXPOSURE: 5/13/71

DATE OF CALIBRATION: 6/9/71

The camera calibration herein documented was performed with data derived from a stellar exposuse made on the evening of 13 May 1971 with the Hasselblad camera S/N 1057 and the 250 mm lens cone S/N 1017.

The analytical reduction was performed with 327 star image measurements well distributed over the format of the image frame. The least squares mathematics of the solution indicated a final mean error of 4.8 micrometers from the residual values of the image measurements.

The attached table is a synopsis of the interior orientation values as computed for this camera-lens system. The figure attached illustrates the orientation of the image plane relative to the camera format during the calibration procedure.

1. CALIBRATED FOCAL LENGTH

$f = 249.650$ mm $\qquad \sigma_f = \pm 0.014$ mm

2. PRINCIPAL POINT LOCATION

$X_p = 0.000$ mm $\qquad \sigma_{X_p} = \pm 0.0007$ mm

$Y_p = 0.000$ mm $\qquad \sigma_{Y_p} = \pm 0.0007$ mm

3. RADIAL LENS DISTORTION COEFFICIENTS

$K_1 = +0.9193490 \times 10^{-2} \qquad \sigma_{K_1} = \pm 0.5157790 \times 10^{-6}$

$K_3 = -0.8474799 \times 10^{-5} \qquad \sigma_{K_3} = \pm 0.1709313 \times 10^{-6}$

$K_5 = +0.5546985 \times 10^{-9} \qquad \sigma_{K_5} = \pm 0.1196325 \times 10^{-9}$

$K_7 = -0.7674422 \times 10^{-24} \qquad \sigma_{K_7} = \pm 0.6859644 \times 10^{-18}$

4. DECENTERING LENS DISTORTION COEFFICIENTS

$J_1 = +0.6178938 \times 10^{-5} \qquad \sigma_{J_1} = \pm 0.3221639 \times 10^{-6}$

$J_2 = -0.9709413 \times 10^{-37} \qquad \sigma_{J_2} = \pm 0.4199920 \times 10^{-23}$

$\phi = 92^{\circ}34537 \qquad \sigma_{\phi} = \pm 2^{\circ}974806$