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NRO

National Reconnaissance Office

CAMERA
MANUAL

THE KH-9 MAPPING CAMERA SYSTEM MANUAL

PUBLISHED BY
NATIONAL PHOTOGRAPHIC INTERPRETATION CENTER
FEBRUARY 1973

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WASHINGTON, D.C.

MEMORANDUM FOR RECIPIENT

SUBJECT: KH-9 Mapping Camera System (MCS) Manual

This camera manual has been prepared to provide you with technical information for advanced planning within the exploitation community. Should conflicts arise in connection with this publication and the preliminary data published on the MCS in the KH-9 Camera Manual (TCS-22571/70), this manual takes precedence.

This information may be disseminated to persons having (1) a TALENT-KEYHOLE clearance and (2) a clearly specified need-to-know.

John E Kulpa Jr
JOHN E. KULPA, JR.
Colonel, USAF
Director, NRO Staff

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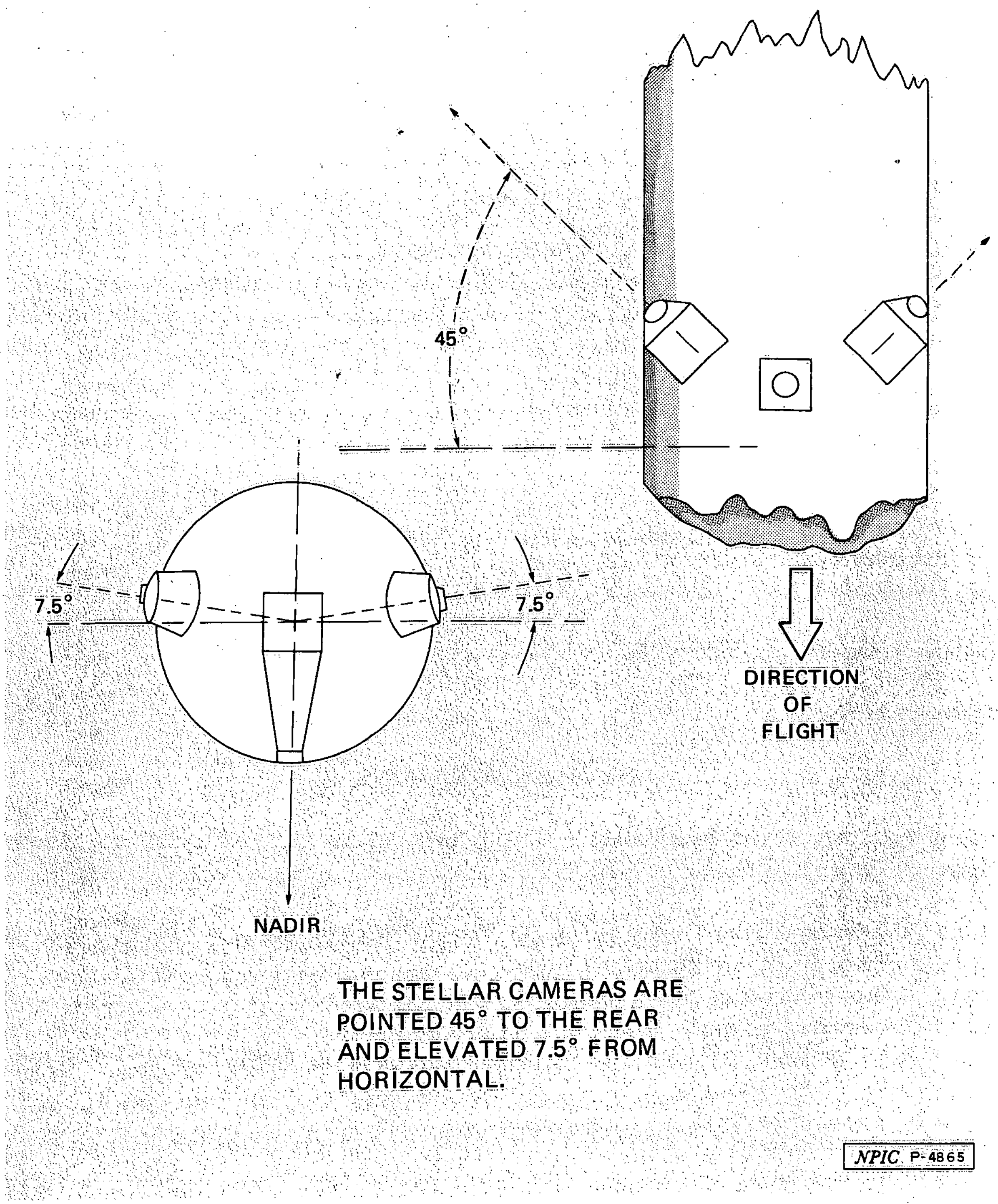

Figure 1. Camera System Relationship

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INTRODUCTION

The KH-9 mapping camera system is designed to provide accurate attitude, timing, and calibrated imagery to establish a data base suitable for the production of 1:50,000 scale maps and other topographic products. It is also designed to provide geodetic point positioning to an accuracy of 250 feet. The KH-9 mapping camera system is operated separately from the KH-9 panoramic camera system, whose search and surveillance requirements should remain relatively stable.

The mapping camera system is composed of a vertical terrain camera with a 12-inch focal length lens, and twin stellar cameras with 10-inch focal length lenses. The camera system relationship is diagramed in Figure 1. The terrain and stellar cameras operate simultaneously with the mid-point of terrain and stellar exposures coincident within four milliseconds.

Conjugate coverage between the panoramic system and the mapping camera system is possible but a majority of mapping camera coverage will be independent.

TERRAIN CAMERA

Camera Data

The terrain lens points downward on orbit and images the scene on a 9- by 18-inch format with 12-inch focal length, f/6 optics. The camera contains approximately 3,300 feet of 9.5-inch-wide film with a 19.25 inch cycle spacing. This will provide approximately 2050 frames per mission. A summary of terrain camera characteristics is given in Table 1. Figure 2 shows a view of the terrain camera.

The terrain lens is protected from loss of heat to the environment by a thermal shutter. The thermal shutter is designed to open just prior to exposure, remain open during exposure, and close immediately following exposure. A failsafe lock-spring mechanism is built into the terrain thermal shutter so that upon command, the terrain thermal shutter can be permanently opened. The thermal shutter has heater elements integrated into the assembly to constantly maintain the terrain lens cell temperature at the required thermal level.

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The rear surface of the lens or reseau plate, contains a grid of tick marks which are normally imaged when the frame is exposed. This reseau is used during map production and other mensuration jobs that need high precision to compensate for film distortion. The reseau plate is attached to the lens body by flexures which maintain precise axial and lateral alignment but allow the plate and film to be moved along the flight path for forward motion compensation (FMC).

TABLE 1

TERRAIN CAMERA DATA

Optical Parameters	
Focal Length	12 inches
Relative Aperture	f/6; T 12
Format Size	9" x 18"
Filter	Wratten 21
Field of View	
In-Track	73.7°
Cross-Track	41.1°
Diagonal	80.0°
Antivignetting Filter	First surface of Window Element
Reseau	10mm grid (Intersections only)
Frame Advance	19.25"
Platen	0.65 plano - parallel plate
Film	
Type	3400
Width	9.5"
Supply	3300'
Shutter	
Type	Continuously rotating discs (3) and one semaphore
Exposure	3, 6, 12 msec
Cycle Time	7.8 sec to 87 sec
Orientation	Vertical, downward
Forward Motion Compensation	.0165 to .0566 Rad/sec (V/h control)
Resolution (Dynamic)	36-lines/mm minimum 54-lines/mm on axis

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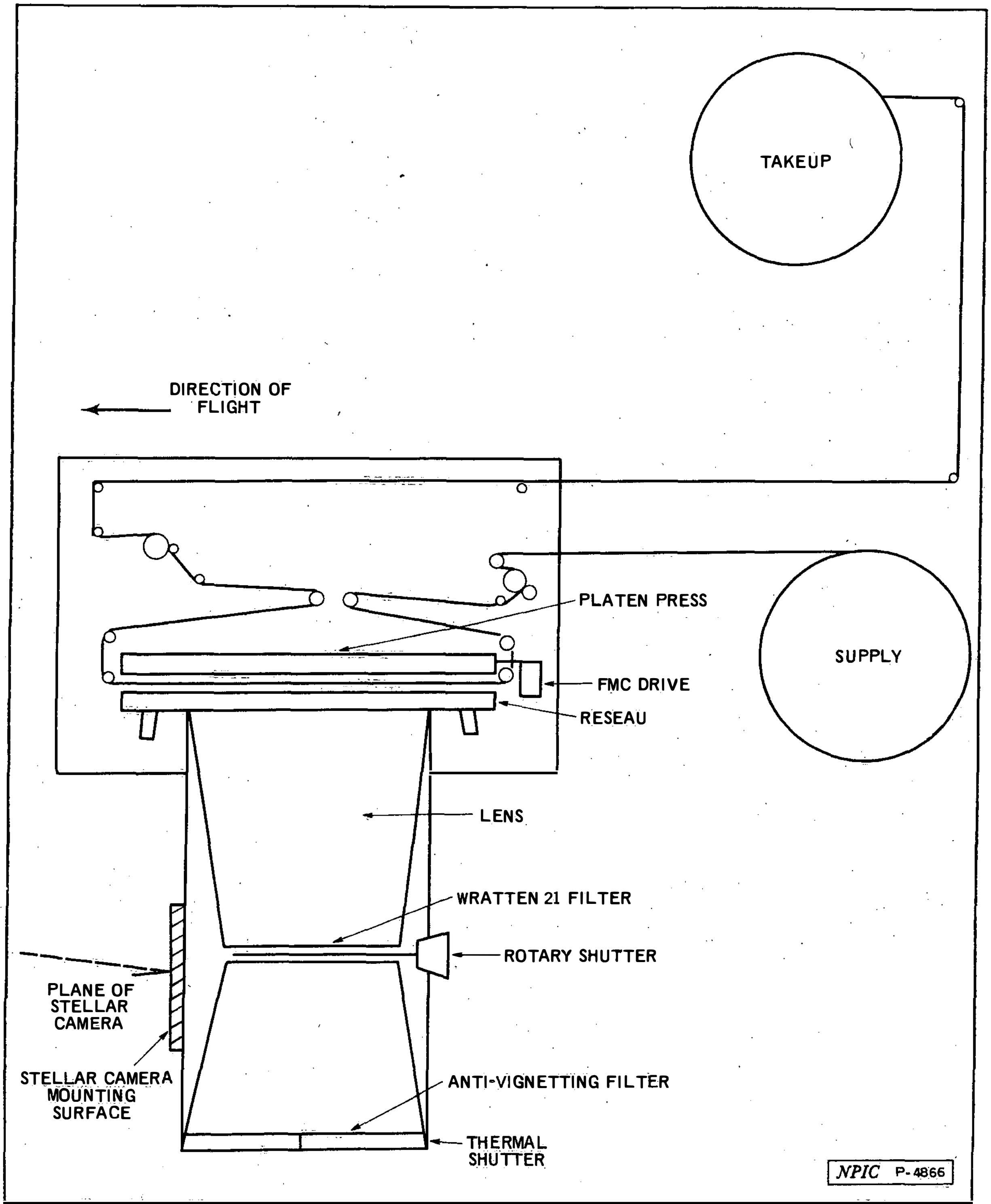

Figure 2. Terrain Camera

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Overlap

The camera can operate in 10, 70, or 78 percent overlap modes. The 78 percent overlap mode can only be used for altitudes higher than 100nm. Figure 3 is a diagram of the three overlap modes.

Resolution

The system's design criteria states that the dynamic resolution will be a minimum of 54 lines/mm on axis with no point in the format less than 36 lines/mm. The camera's performance has been analyzed to predict the actual resolution of the system. The resolution in lines/mm at one-inch intervals over the 9- by 18-inch format is shown in Figure 4. The ground resolution values which correspond to Figure 4 are given in Figure 5.

Coverage

Using a nominal altitude of 92.5nm and 70 percent overlap the total area of gross coverage is approximately 6 million sq. nm. Dry Land area of the earth is 43.4 million sq. nm.

Ground coverage can be approximated by using the formulas given in Figure 6. Table 2 gives the ground coverage at various altitudes and Figure 7 shows the coverage at three specific altitudes.

A comparison of ground coverage between the forward camera of the main unit and the terrain camera at an altitude of 100 nm is shown in Figure 8.

TABLE 2

TERRAIN CAMERA COVERAGE

Altitude	80	85	90	95	100	105	110	115	120
Cross-Track Coverage, nm	60.1	63.8	67.6	71.4	75.1	78.9	82.7	86.4	90.2
In-Track Coverage, nm	120.8	128.4	136.0	143.6	151.2	158.9	166.5	174.2	181.8
Area Coverage sq. nm x 10^3	7.26	8.19	9.19	10.25	11.36	12.54	13.77	15.05	16.40

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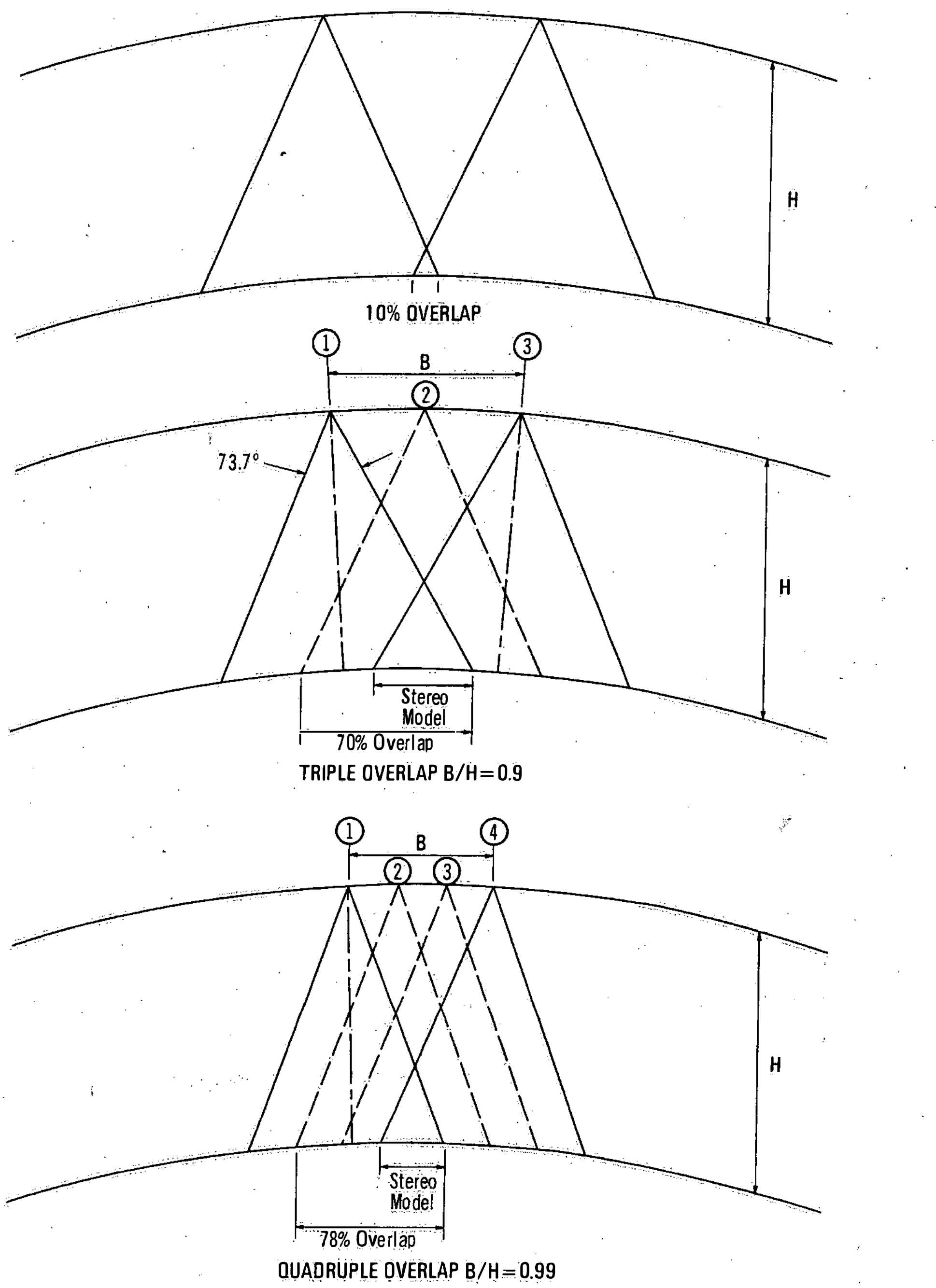

Figure 3. Overlap Modes

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9.0	37	36	36	37	38	38	37	36	36	37
8.0	37	38	40	41	42	42	41	40	38	36
7.0	41	43	44	45	45	45	44	43	42	39
6.0	44	45	46	46	46	46	45	44	43	42
5.0	46	46	47	47	47	47	46	45	43	42
4.0	47	48	48	49	49	49	47	45	43	42
3.0	48	49	51	52	53	51	49	46	44	43
2.0	49	50	53	55	56	54	50	48	45	44
1.0	50	52	55	57	59	55	52	49	47	45
0	50	52	55	57	59	58	56	53	50	47
-1.0	49	51	54	56	58	58	58	55	52	49
-2.0	49	50	52	55	56	55	55	54	52	50
-3.0	49	50	51	52	53	53	52	52	51	50
-4.0	48	49	50	50	51	50	50	49	49	49
-5.0	47	48	49	49	49	48	48	48	49	49
-6.0	46	47	48	48	48	48	47	48	48	47
-7.0	44	45	46	47	47	47	47	47	46	44
-8.0	40	42	43	44	45	44	44	43	42	41
-9.0	42	40	40	41	41	41	40	40	40	42

WRATTEN 21 FILTER, 12 MILLISECOND EXPOSURE.

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Figure 4. Predicted Terrain Camera Resolution Values (Lines/mm)

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9.0	50	51	51	50	49	49	49	51	51	50
8.0	50	48	46	45	44	44	45	46	48	51
7.0	45	43	42	41	41	41	42	43	44	47
6.0	41	41	40	40	40	40	41	42	43	44
5.0	40	40	39	39	39	39	40	41	43	43
4.0	39	38	38	37	37	38	39	41	42	43
3.0	38	38	36	35	35	36	38	40	41	43
2.0	38	37	35	33	33	34	37	38	41	42
1.0	37	36	34	32	31	34	35	37	39	41
0	37	36	34	32	31	32	33	35	37	39
-1.0	37	36	34	33	32	32	32	33	36	37
-2.0	38	37	35	34	33	33	33	34	35	37
-3.0	38	37	36	35	35	35	35	36	36	37
-4.0	38	38	37	37	36	37	37	37	37	37
-5.0	39	38	38	38	37	38	38	38	38	38
-6.0	40	39	39	39	38	38	39	38	38	39
-7.0	42	41	40	39	39	39	39	39	40	41
-8.0	46	44	43	42	41	41	42	42	44	45
-9.0	44	46	46	45	45	45	46	46	46	43

WRATTEN 21 FILTER, 3400 FILM, 2:1 CONTRAST,
12 MILLISECOND EXPOSURE, 2 SIGMA RATES,
ALTITUDE 92.5 NM.

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Figure 5. Predicted Ground Resolution Values

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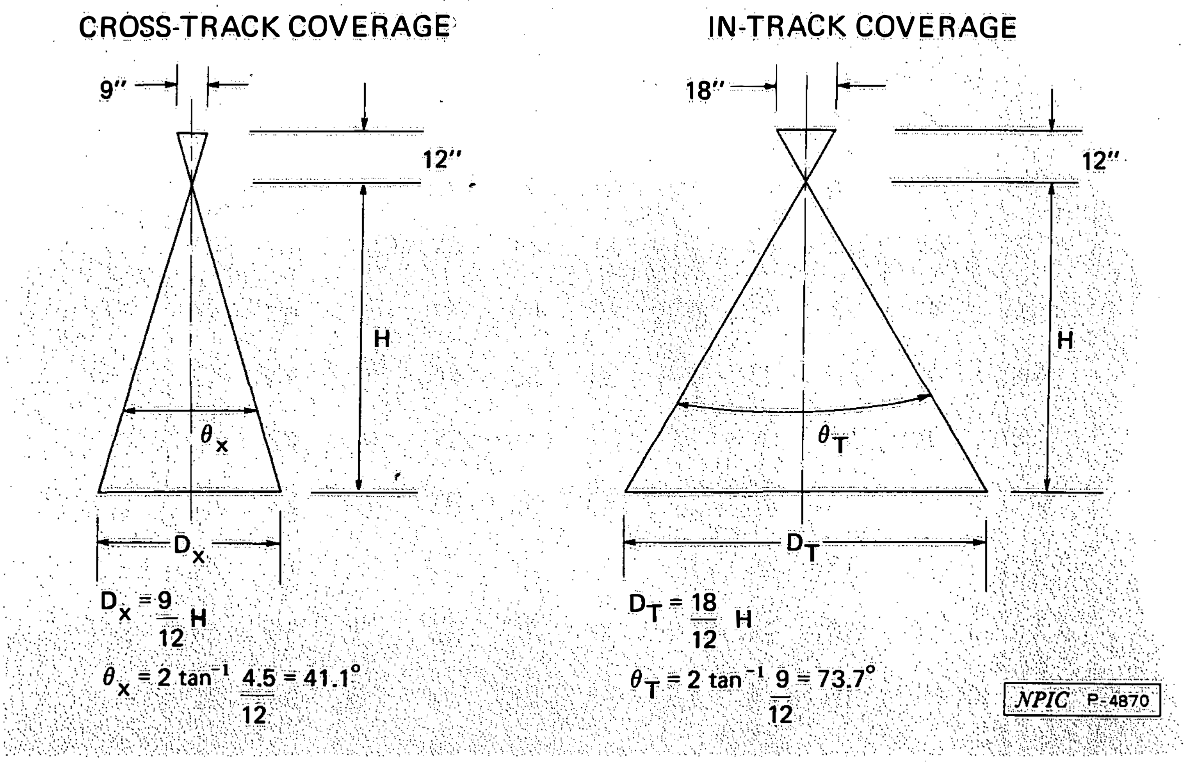

Figure 6. Ground Coverage

Image Motion Compensation

The terrain camera is designed to compensate for the motion of the image that is caused by the forward motion of the vehicle. However, this compensation is only totally effective if the film plane is perfectly parallel to a flat ground. The forward motion compensation (FMC) assembly drives the terrain platen press during exposure parallel to and in the same direction of flight. The forward motion compensation is controlled by the velocity/height ratio and compensates for altitudes between 80 and 240nm. The velocity/height range is from .0165 to .0566 radians/second with an accuracy of .00108 radians/second. This equates to a platen velocity of 4.72 to 17.25 millimeters/second with a minimum and maximum platen displacement during the exposure interval of .020 and .22 millimeters respectively.

The across-track component of image motion due to earth rotation will be compensated for by crabbing the mapping camera system. That is, the camera will be aligned in yaw so as to make the across-track components equal in magnitude but opposite in direction to the average between the two boundaries of a latitude band of interest within the northern or southern hemisphere. The required crab angle is approximately 1.9°.

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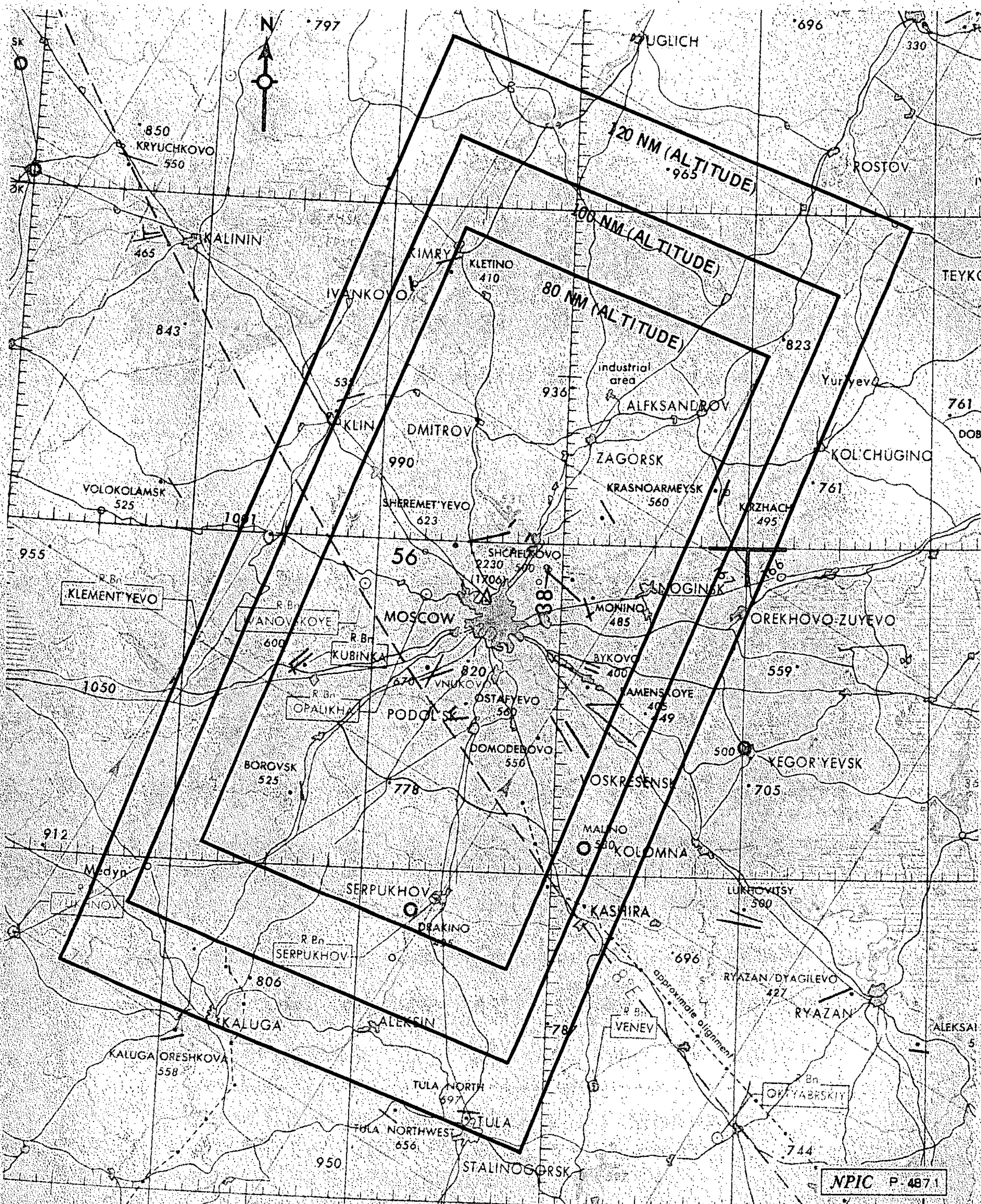

Figure 7. Coverage Diagram

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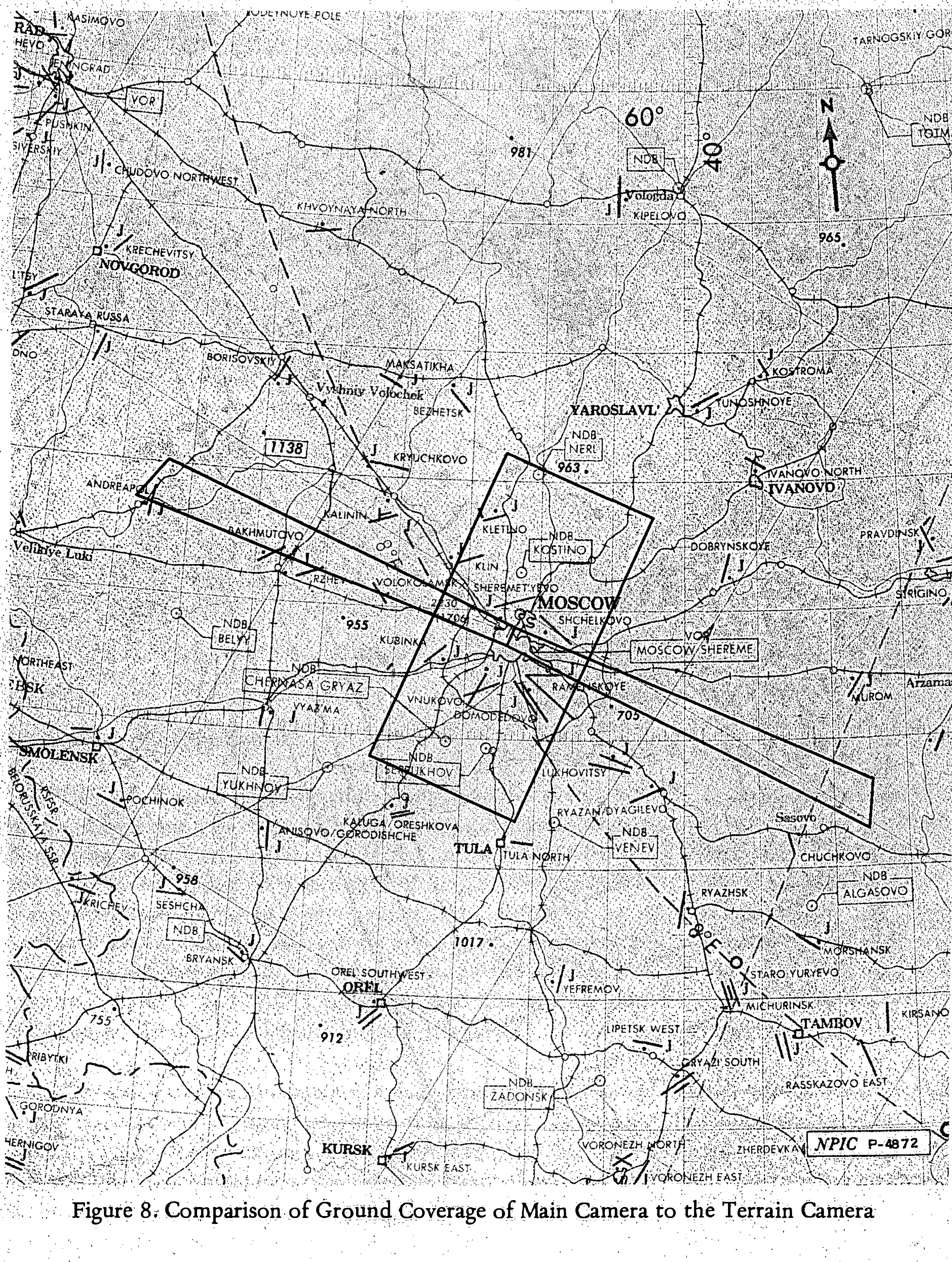

Figure 8. Comparison of Ground Coverage of Main Camera to the Terrain Camera

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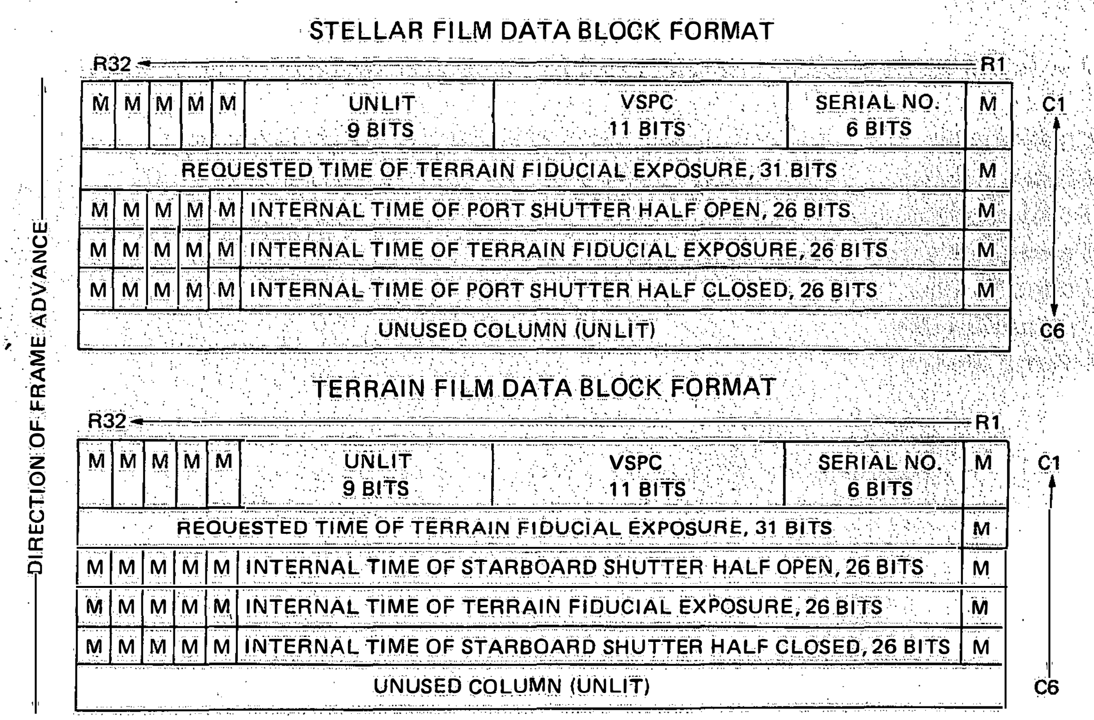
Recorded Data

A data block is recorded on the terrain film for each frame and contains information relative to exposure time, serial number of the system, and the setting of commands used in making the exposure. A data block is also recorded for each pair of stellar frames. The two data blocks are essentially identical. The difference between them is that the data block on the stellar film contains information on the port stellar shutter and the data block on the terrain film contains information on the starbord stellar shutter. Both data blocks are shown in Figure 9.

As indicated in Figure 9, the columns are numbered from one through six vertically. The bits in the rows are numbered from one through 32 from right-to-left (the least significant bit being on the right). Note that column six is not used, and that row one is exposed on every frame and rows 28 through 32 except in column two are exposed in every frame.



NOTES:
1. M = Marker bit, exposed on all frames for interpretation reference.
2. View shows original negative, emulsion down.
3. Columns numbered 1 through 6 from top bottom.
4. Rows numbered 1 through 32 from right to left.
5. The Data Blocks are in complimented logic.

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Figure 9. Data Block Formats

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The VSPC (Variable Stored Program Command) word contains (from right to left) two bits for the overlap mode, two bits for the exposure (nominal shutter time) and seven bits for the FMC rate.

The entire data block array presents the data bits in complimented logic, i.e., a lighted bit is a 'zero'; an unlighted bit is a 'one'.

Four fiducial marks are exposed on the terrain film to provide a firm reference point which locates where the principal point of calibration intersects the frame format, i.e., these marks precisely locate the moving terrain image with respect to the calibrated reference frame of the optics. The four fiducial marks are arranged on the sides of the format, one in each corner, as shown in the terrain format diagram, Figure 10.

Frame marks and start of operation marks are also exposed on the film.

Titling Information

The following data will be optically titled on the original negative of the terrain film:

Classification
Mission Number
Revolution Number
Operation Number
Frame Number
Acquisition Date
Overlap Mode

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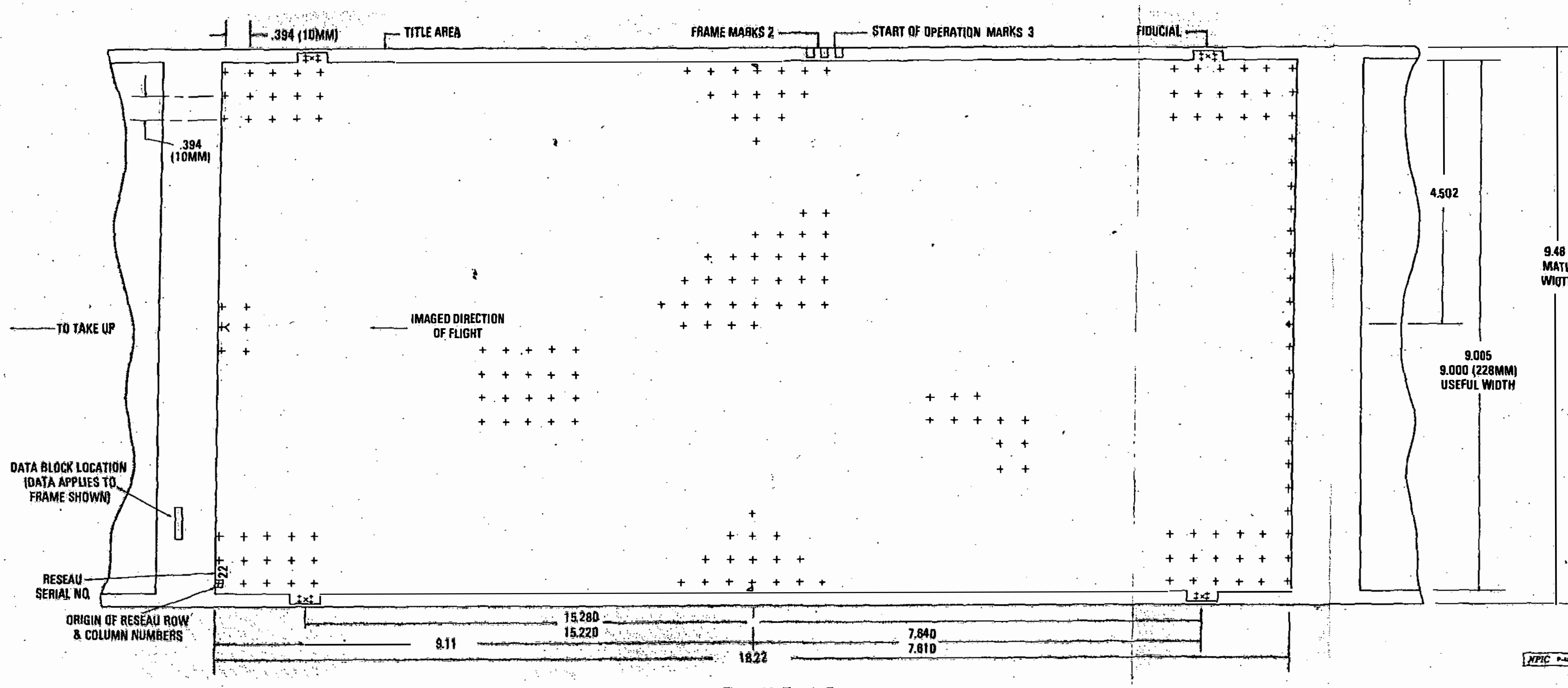

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Figure 10. Terrain Format

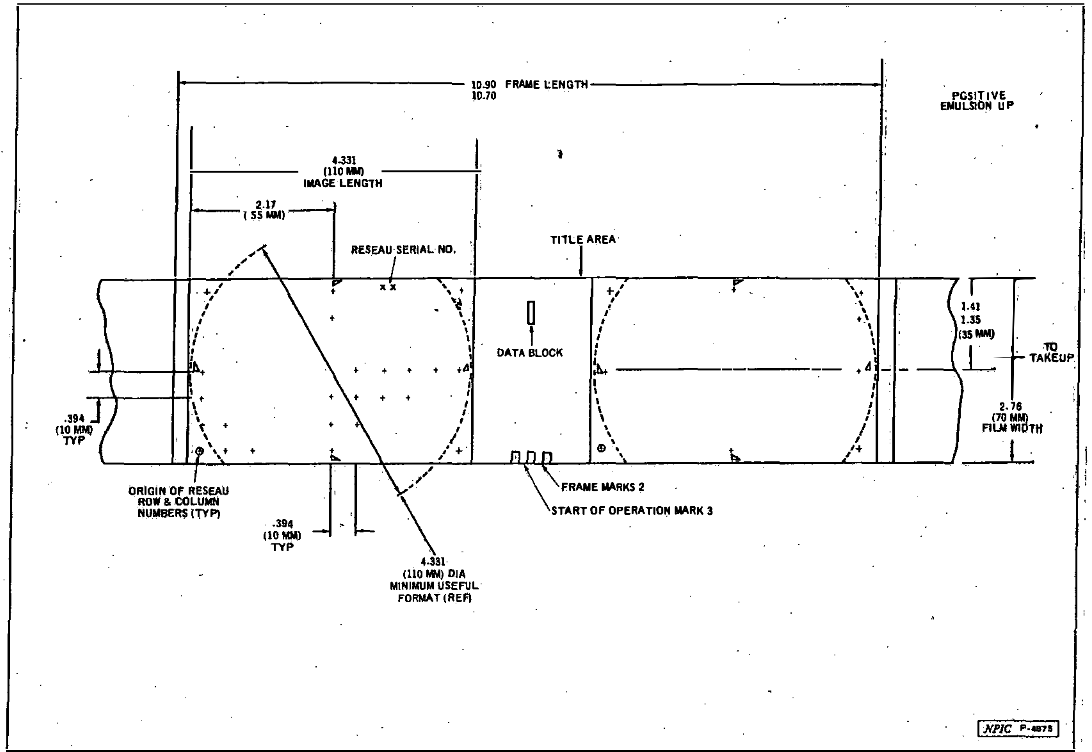

Figure 11. Stellar Format

STELLAR CAMERA

Camera Data

The purpose of the stellar camera is to provide a means for accurate determination of attitude for the terrain camera. Also, the stellar camera can be useful in monitoring the stability of the vehicle.

The stellar camera comprises two lenses of 10-inch focal length, f/2 optics, pointed 45° aft and 7.5° above the horizontal. This alignment was selected to reduce sun and albedo problems in recording stars. The camera will record stars of sixth magnitude and brighter. The stellar format (Figure 11) contains two adjacent (one left and one right) 70x110mm images of the star field on a 70mm film strip. A summary of the stellar camera data is given in Table 3.

Double-blade 'barn door' shutters are located in front of the lens to both gate the exposure and limit the thermal load on the lens between exposures. Figure 12 shows a view of the stellar camera.

TABLE 3

STELLAR CAMERA DATA

Optical Parameters	
Focal Length	10.0"
Relative Aperture	f/2.0
Format Size	110x70mm each image
Field of View	25° x 16°
Filter	None
Platen	Plano-concave element
Reseau	10mm grid (intersections only)
Frame Advance	10.75"
Film	
Type	3401
Width	70mm
Supply	2,060'
Shutter	
Type	Barn Door (before the lens)
Exposure Time	200 milliseconds
Cycle Time	Synchronized with terrain camera
Orientation	Aft-looking 45 degrees either side of flight path 7.5° above horizontal
Star Imagery	Up to the sixth magnitude

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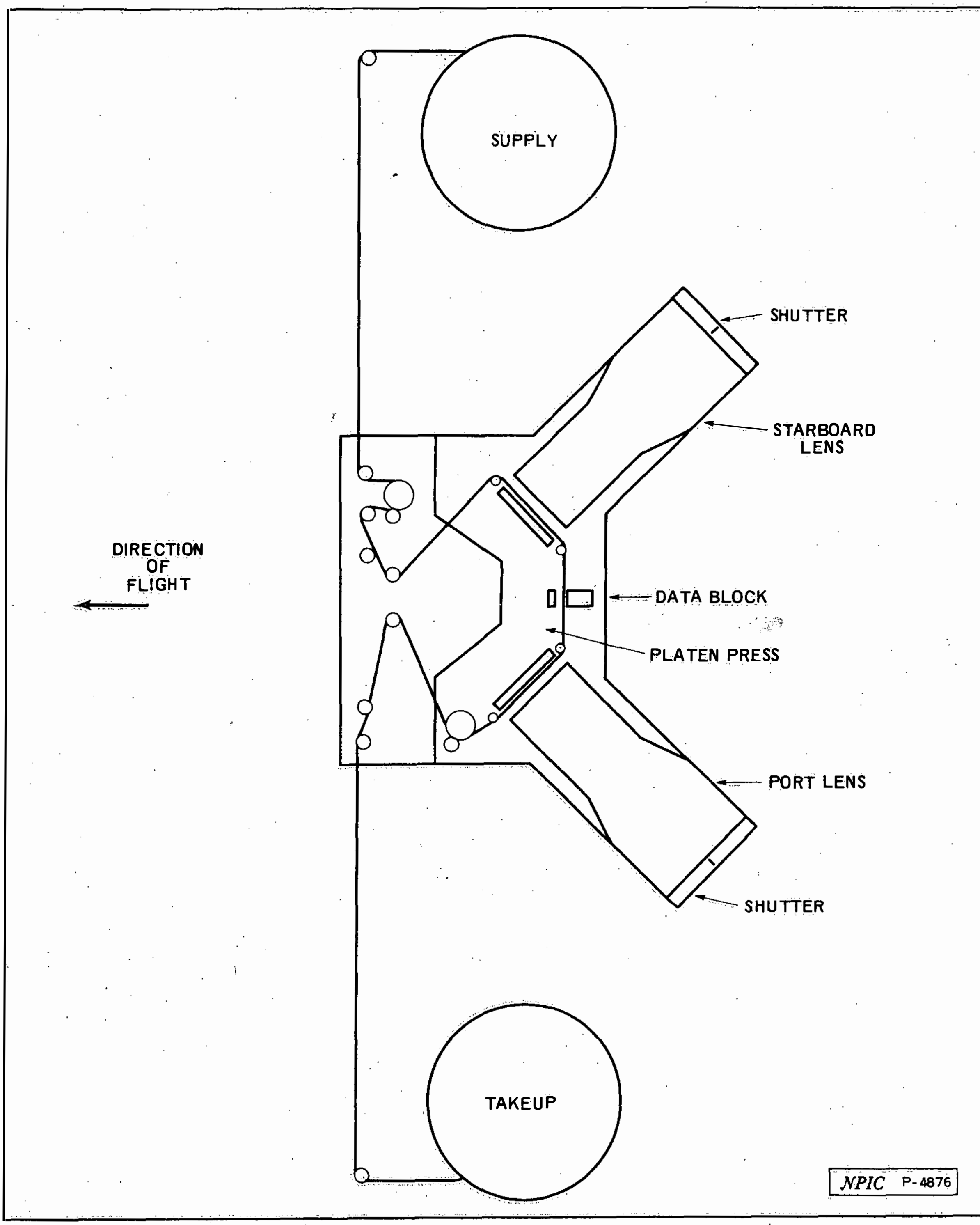

Figure 12. Stellar Camera

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Light Baffle

A light baffle is mounted externally to each lens of the stellar camera. The light baffles absorb stray light incident from outside the specified angular field-of-view. In addition, the baffles contain over-illumination photo cells to temporarily inhibit the associated stellar lens in the event that the sun comes into its field-of-view. Each baffle has a light-tight safety shutter which permanently caps the lens aperture upon command in the event that a stellar shutter fails open.

Reseau

There is a 10mm grid (intersections only) superimposed on the stellar format for calibration and mensuration purposes. However, there is insufficient background illumination to expose the reseau when pointed at the celestial sphere. Consequently, the reseau must be exposed artifically by pre-fogging the film with a flashing light-source through the reseau plate. This raises the image density except where shadowed by the reseau.

Recorded Data

One data block is exposed for each pair of stellar frames and is located between the two. The data block was explained under the terrain camera and shown in Figure 9. A reseau serial number will also be exposed within the frame format.

Frame marks and start of operation marks are exposed on the stellar film. These marks are to be sensed at an intermediate stage of photographic processing to permit location of optical titles adjacent to each frame.

Titling Information

The following data will be otpically titled on the original negative for each pair of stellar exposures:

Classification
Mission Number
Revolution Number
Operation Number
Frame Number
Port and Starboard indicators

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CALIBRATION REPORT

A calibration report will be compiled and disseminated by the Topographic Center of the Defense Mapping Agency prior to each mission. The contents of the report will include:

1. Introduction

2. Background Information

   2.1 Procedures
   2.2 Distortion Correction Equations
   2.3 Relative Orientation
   2.4 Definitions of Angular Orientation Systems

3. Calibrated Fiducials

4. Terrain Camera (Calibration Results)

   4.1 Interior Orientation Values and Distortion Coefficients
   4.2 Distortion Profile Tabulated Values (Balanced Curve)
   4.3 Distortion Profile Tabulated Values (Gaussian Curve)
   4.4 Distortion Profile Tabulated Values (Decentering Curve)
   4.5 Correlation Matrix (of Interior Orientation Parameters)
   4.6 Calibrated Reseau

5. Port Camera (Calibration Results)

   5.1 Interior Orientation Values and Distortion Coefficients
   5.2 Distortion Profile Tabulated Values (Balanced Curve)
   5.3 Distortion Profile Tabulated Values (Gaussian Curve)
   5.4 Distortion Profile Tabulated Values (Decentering Curve)
   5.5 Correlation Matrix (of Interior Orientation Parameters and Relative Orientation Angles)
   5.6 Relative Orientation Matrix
   5.7 Angular Orientation Systems
   5.8 Calibrated Reseau

6. Starboard Camera-Same as Port Camera

7. Resolution Data

   7.1 Terrain Resolution Results

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EPHEMERIS INFORMATION

A daily Mission Performance Report (MPR), developed for the stellar/terrain camera system, contains all the data necessary for exploitation except the targeting information.

Data	Frequency
1. Camera ID (terrain and stellar)	Report
2. Film type for each camera	Report
3. Filter	Report
4. Focal lengths	Report
5. Lens serial numbers	Report
6. Time correlation parameters	Report
7. Initial conditions	Report
8. Physical earth constants	Report
9. Rev Number	Revolution
10. GMT date	Revolution
11. GMT time (in seconds) of ascending mode	Revolution
12. Longitude of ascending mode	Revolution
13. A 20 point ephemeris	Revolution
a. GMT time of ephemeris point in seconds	Revolution
b. XYZ components of vehicle position	Revolution
c. XYZ components of vehicle velocity	Revolution
d. XYZ components of vehicle acceleration	Revolution
14. Operation number	Operation
15. Data	Operation
16. GMT time of first and last frame of the operation	Operation
17. Total number of frames	Operation
18. Operation overlap mode	Operation
19. Rev number	
20. Latitudes and Longitudes of the four corners of the operation	Operation
21. Frame, rev, and operation number	Frame
22. System time at center of format	Frame
23. Vehicle time at center of format	Frame
24. V/H ratio	Frame
25. Commanded FMC	Frame
26. Vehicle altitude	Frame
27. Vehicle yaw, pitch and roll	Frame
28. Latitude and Longitude of nadir	Frame
29. Vehicle inertial velocity and azimuth	Frame
30. Ground velocity and azimuth	Frame

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31.	Sun elevation and azimuth	Frame
32.	Attitude data source (live or nominal)	Frame
33.	Vehicle yaw, pitch, and roll rate	Frame
34.	Right ascension and declination of stellar cameras	Frame

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