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PRELIMINARY ENGINEERING DESCRIPTION of the SURVEY CAMERA for the APOLLO MAPPING AND SURVEY SYSTEM

Volume 1 of 2 Volumes

Prepared by

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for

HEADQUARTERS SPACE SYSTEMS DIVISION
(SAFSP)

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GLOSSARY

AF	Air Force
AGC	Apollo Guidance Computer
AGE	Aerospace Ground Equipment
A/S	Aerospace Corp.
ASE	Aerospace Support Equipment
CM	Command Module
C/P	Camera Payload (Survey)
CSM	Command Service Module
DEI	Design Engineering Inspection
EKC	Eastman Kodak Company
EMI	Electromagnetic Interference
G & N	Apollo Guidance and Navigation
IMC	Image Motion Compensation
IMU	Inertial Measuring Unit
LEM	Lunar Excursion Module
MSD	Multiple Speed Drive
NAA	North American Aviation
NAA/S & ID	North American Aviation Space and Information Systems Division
NASA	National Aeronautics and Space Administration
P/L	Payload (General)
SAFSP	Secretary of the Air Force Special Projects
S/C	Space Craft
SCT	Low Power Scanning Telescope
SIC	Stellar Index Camera
SM	Service Module
SXT	Sextant
TM or TLM	Down Link Telemetry
V/h or Vg/h	Ratio of Vehicle Nadir Velocity to Altitude

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SECTION 1

SUMMARY

The purpose of the Apollo Mapping and Survey (M&S) system is to photograph the surface of the moon in preparation for a manned landing. The survey Camera Payload (C/P) is that part of the M&S system whose purpose is to detect hazards to the manned landing craft by means of very high resolution stereo photography. A camera system well suited to this task has been developed by Eastman Kodak Company (EKC) under the sponsorship of the Director of Special Projects, Office, Undersecretary of the Air Force (SAFSP). This C/P has been proven to be extremely reliable, it produces photographs of exceptional quality, and it will satisfy all the survey requirements of the M&S mission.

Reported in this document are studies of the modifications which will be required to adapt the C/P for service in the Apollo vehicle. These studies show that the existing payload can be modified and installed in the #1 bay of the Apollo Service Module (SM) with a minimum of modification to the SM itself. Furthermore, the basic simplicity of the C/P makes it readily adaptable to either very high resolution strip and stereo pair photography or to wide coverage high resolution panning service. Predictions of performance appear in summary form in Section 3.10; these predictions are predicated on an advance in film manufacturing which is required to increase the exposure index of type 4404 film from 3.6 to 6.0. While the necessary advance in the state-of-the-art is by no means certain, it is considered very probable. (An advance in film characteristics to the "optimized" levels indicated by the customer-required study of ection 3.10.3.3 is much less likely). The M&S program will also benefit significantly from other

EKC sponsored research and development activities such as that devoted to ultra thin base (UTB) films which may increase coverage by 60% at no increase in film weight.

Realistic simulations of photographic resolution and scale are furnished in section 3.6.4. Several of these simulations show the Lunar Excursion Module as it will appear when photographed on the lunar surface by the EKC system.

The conclusions drawn from the study effort are that the existing EKC payload can be easily modified to:

(1) Provide maximum resolution of the lunar surface in strip, stereo pair, or panning service in a simple, flexible, highly reliable system.

(2) Cover all of the selected landing sites in either a 2-day (panning) or a 4-day (stereo pair) mission.

(3) Provide a maximum growth potential for follow-on lunar and space exploration.

(4) Provide optimum cost effectiveness by using existing facilities and AGE together with qualified flight hardware.

SECTION 2
INTRODUCTION

2.1 BACKGROUND

This document describes a study conducted by Eastman Kodak Company to evaluate the design modifications and interfaces necessary to adapt an existing Photographic Reconnaissance Payload to an Apollo spacecraft.

Project Elba, the designation for this project, was first revealed to EKC by the Director of Special Projects Office Under Secretary of the Air Force (SAFSP) and the National Aeronautics and Space Administration (NASA) in late December 1963. Subsequently, a feasibility study was conducted by Kodak and a report (SP-114-009) submitted. In June of 1964, EKC, in cooperation with North American Aviation Space Information Systems Division (S&ID) initiated a study specifically aimed at:

(1) Integration of the payload into the Apollo spacecraft, and
(2) Missions which could be accomplished using the resulting Apollo Mapping and Survey System.

As a parallel effort, EKC, supported by NASA and/or NAA/S&ID, conducted payload design and performance studies, and in coordination with NASA and NAA/S&ID, developed payload interface specifications.

Initially, completion of the study was required in December 1964. However, redirection was received on 17 July 1964 (CCN-1) requesting that EKC present the study results at a Design Engineering Inspection (DEI) on 30 September 1964. To accomplish this effort in the shortened time, several areas of investigation were delayed for completion after the DEI. These areas include studies related to V/h devices, requirements for operational testing on earth orbits, test equipment interface studies and a special photo-visual lunar exploration study.

This report, which is presented as a backup for the DEI, must be considered as a preliminary effort and will be further enhanced in detail with publication of a final study report in January 1965.

2.2 SCOPE

The primary objectives of this study were to:

(1) Establish the interface necessary to physically adapt an existing photographic reconnaissance payload to the Apollo vehicle, and

(2) Determine the ability of the payload to photograph lunar landing site hazards.

The ground rules upon which this study was based were established by SAFSP and NASA and include the following:

Lunar orbiting would be at 30 and 80 nautical mile altitudes.

Orbital inclination angle was not to exceed ten (10) degrees

Stereo coverage of the ten prospective lunar landing sites over a one degree lunar square is required.

Mission duration is a maximum of eight (8) days as a design goal, but may be only four (4) days on the first mission.

Goal for photography is:

Measurement of ±2 degrees of slopes up to 12 degrees and detection of two standard NASA cone hazards with base angles of 38.6 degrees and 26.5 degrees respectively.

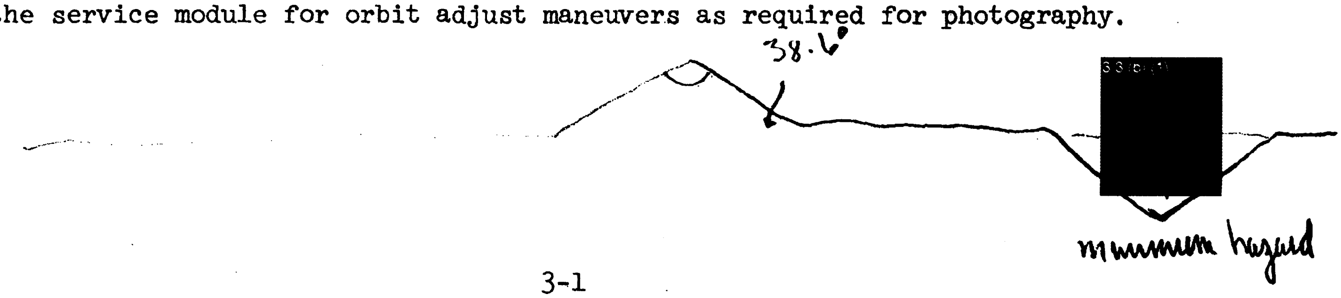
SECTION 3

SYSTEM AND SUBSYSTEM CONCEPTS

3.1 INTRODUCTION

The primary objective of the survey portion of the Apollo Mapping and Survey Mission is to acquire stereo photography adequate for certifying the topography of LEM landing sites. The survey camera **subsystem** must (1) provide best possible lunar surface resolution for detection of protuberances or holes represented as right circular cones of 38.6° and 26.5° base angles, and (2) measure to an accuracy of ±2°, surface slopes in the range from 0° to 12° relative to the local horizontal for circular areas 30 feet in diameter. The Apollo M and S Work Statement specifies a requirement for detection of an [redacted] diameter right circular cone, [redacted] in height. This specific requirement **was** removed and items (1) and (2) above substituted. However, the [redacted] cone dimensions have been used in this report as an indication of the minimum size cone which constitutes a hazard.

The nominal, primary mission is specified as having a 4-day lunar stay time. Orbital altitudes are specified as 30 ±1.1 n.mi. (2 sigma) and 80 ±1.1 n.mi. (2 sigma), the maximum orbit inclination is 10°, and maximum orbit eccentricity is 0.0009. In accordance with the Work Statement furnished EKC, a manned lunar landing is not to be attempted on the primary survey mission. Spacecraft attitude in lunar orbit is to be controlled by the Apollo service module reaction control system. A limited amount of fuel will be carried in the service module for orbit adjust maneuvers as required for photography.



The basic problems in lunar photography arise from the surface characteristics. The albedo (i.e. surface reflectance) is very low, particularly in the flat maria areas which appear to be desirable landing sites. Contrast (determined by geometric factors) is also low and the photometric properties of the surface are such that low-to-low moderate sun elevations are requred for contrast enhancement. Long exposure times, compared to normal earth photography, are necessary for verification of the lunar landing sites because of the low albedo combined with the moderate solar altitudes needed for contrast enhancement. Photography at sun elevations less than 15 degrees must be avoided because of long sharp shadows. Shadows are sharp and black, and hazards within shadow regions cannot be detected photographically because, unlike earth, the lack of atmosphere eliminates scattered light as a source of illumination in shadows. The nominal good lighting band is taken to be 15° to 45° in sun elevation.

The lunar photometric function taken from Eimer's curves of Fedoret's observational data has been used to establish exposure criteria for photographic dtection of surface hazards. The exposure criteria accounts for cones of various base angles, sun elevations from 15° to 60°, and camera line of sight orientations, and has been computed for an advanced version of 4404-type film having an exposure index of 6 instead of the actual value of 3.6.* The exposure criterion developed in this manner is the basis for determination of dynamic performance of the photo subsystem. Lens performance has been proven and the effects of smear on resolution are predictable. Thus, great confidence is placed in the system performance estimates presented in this section of the report.

* Advanced type 4404 film (EI = 6) is not a current production item but, based on current company sponsored research and development, high probability exists that this film will become a standard production item during the Apollo lunar flight period.

Type 4404 film (EI = 6) requires longer exposure times with resultant higher smear.

The method of obtaining stereo photographic coverage of the lunar landing sites at highest possible resolution within mission constraints is explained. The coverage modes stress simplicity in camera operational concepts and in mission conduct with the aim of preserving the superior resolution capabilities of the photo subsystem.

If the reader has not already done so, he should turn now to the photographic simulations in Section 3.6, view the demonstrations of [redacted] ground resolution of the lunar surface (with a LEM model), and see the striking ability of stereo to probe down into the tiny craters on the moon. After viewing the simulations, the reader should return to this section and read about the photographic subsystem and methods which make this type of photography possible.

3.2 CAMERA PAYLOAD SUBSYSTEM DESCRIPTION

This section provides a brief description of the camera payload and also a description of the various photographic modes in which it can be operated. A complete description of the camera payload will be found in Section 4.0.

3.2.1 C/P

Refer to Figure 3-1, a schematic diagram of the payload. Light rays from a point on the moon passes through the open viewport doors, is redirected by the stereo mirror, and is focused on the film by the lens. The film proceeds from a supply reel to a take-up reel by way of the looper assembly. The film velocity is stabilized at the exposure station by a platen of large inertia; as the film passes a narrow slit in the focal plane of the lens

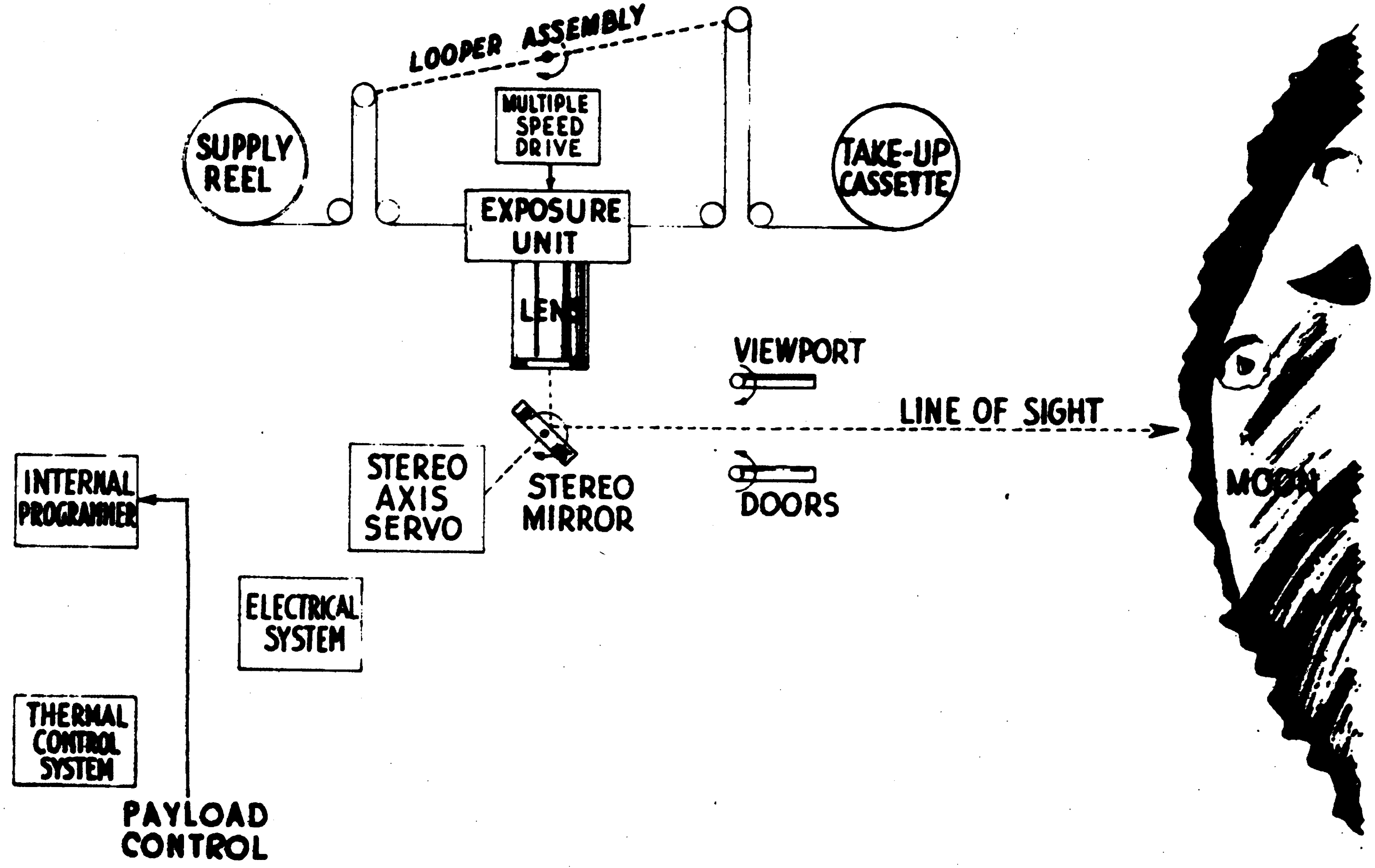


Figure 3-1. Preliminary Payload Schematic

a latent image is imposed on the film. The looper assembly and the multiple speed drive both contribute to proper exposure of the film, the multiple speed drive by advancing the film at the same rate that the lunar image advances due to the motion of the vehicle and the looper assembly by permitting most of the photography to take place when supply and take-up reels are motionless.

The C/P design philosophy utilizes on board systems to the maximum extent possible. However, an internal programmer can receive commands to initiate photography and control subsequent camera functions. The programmer will require orbital information for proper selection of a program; it also requires periodic synchronization of its clock with an orbital reference, for example an occulation signal.

The thermal control concept is based on establishing values so that temperature is controlled adding heat to a thermally isolated payload. This system consists of thermistor temperature measuring devices, strip-heater elements, and both conductive and radiative insulation. A complete description of the C/P thermal control system appears in Section 4.9 of this report. The electrical system includes mirror positioning servo control circuitry, power supplies, cables, timing mark generators for coding the film, instrumentation circuitry, a command processing unit, V/h, exposure control, and automatic focus devices as required.

3.2.2 Modes of Operation

The basic modes of C/P operation are:

Monoscopic Strip Photography - This photo is a monoscopic strip of in-track coverage obtained by operating the camera continuously for a significant period of time. The stereo mirror position and obliquity (vehicle roll) angle may be set, within limits, to obtain the most favorable photometric function compatible with coverage and performance.

Alternate Orbit Strip Stereo - Alternate orbit strip stereo is a special case of strip photography. See Figure 3-2. On odd numbered orbits, for example, photos are obtained using a forward stereo angle. On even numbered orbits a rearward angle is used. An overlap pattern of successive orbits places the center of one strip at the edge of the adjacent strip thus assuring one on-axis high resolution picture in each stereo strip pair. (An obliquity angle may be employed, if desired, to minimize redundancy at high altitude, improve coverage at low altitudes or to enhance the photometric function.)

Stereo Pair - The stereo pair, unlike alternate orbit stereo, achieves convergent stereo coverage of a finite in-track area with one pass over the area. The stereo pair is obtained by first photographing an area with a forward looking stereo angle and then, after moving the mirror to the aft stereo position, the same area is photographed again. The geometry of a stereo pair is given in Figure 3-3. The in-track coverage of a single stereo pair for a fixed convergence angle is set by the operational altitude; the higher the altitude the larger the in-track coverage. (An obliquity angle may be used during photography to improve the photometric function if it is compatible with coverage requirements.)

Stereo/Mono Pair - The stereo/mono pair is an extension of the stereo pair employed to provide greater in-track coverage per pair at the lower altitudes. It is a forward looking strip photo which is partially overlapped, in-track by an aft looking strip photo. See Figure 3-4. (An obliquity angle may be employed within limits, to obtain the best photometric coverage compatible with coverage requirements.)

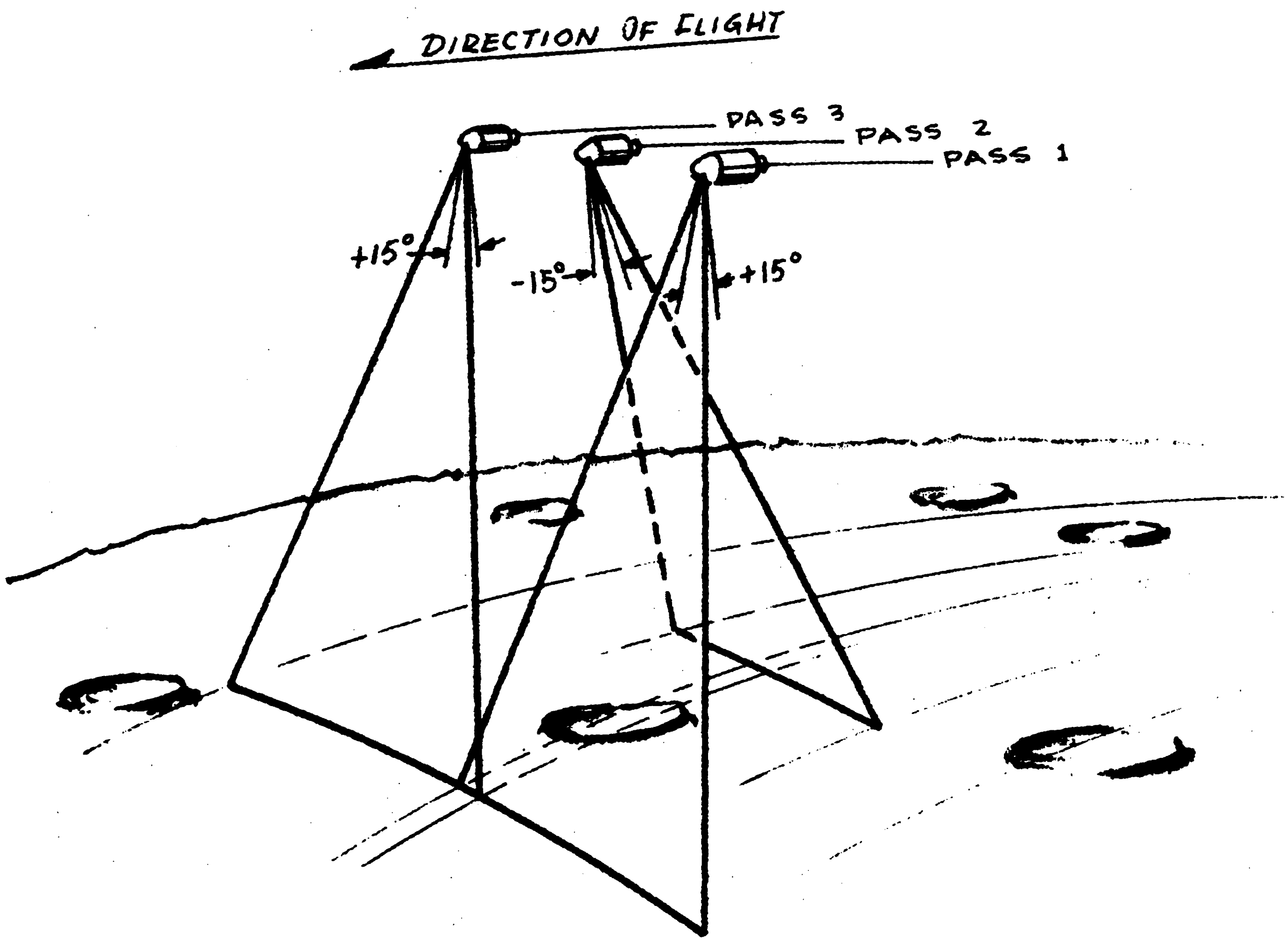


Figure 3-2. Continuous Strip Coverage, Alternate Orbit Stereo

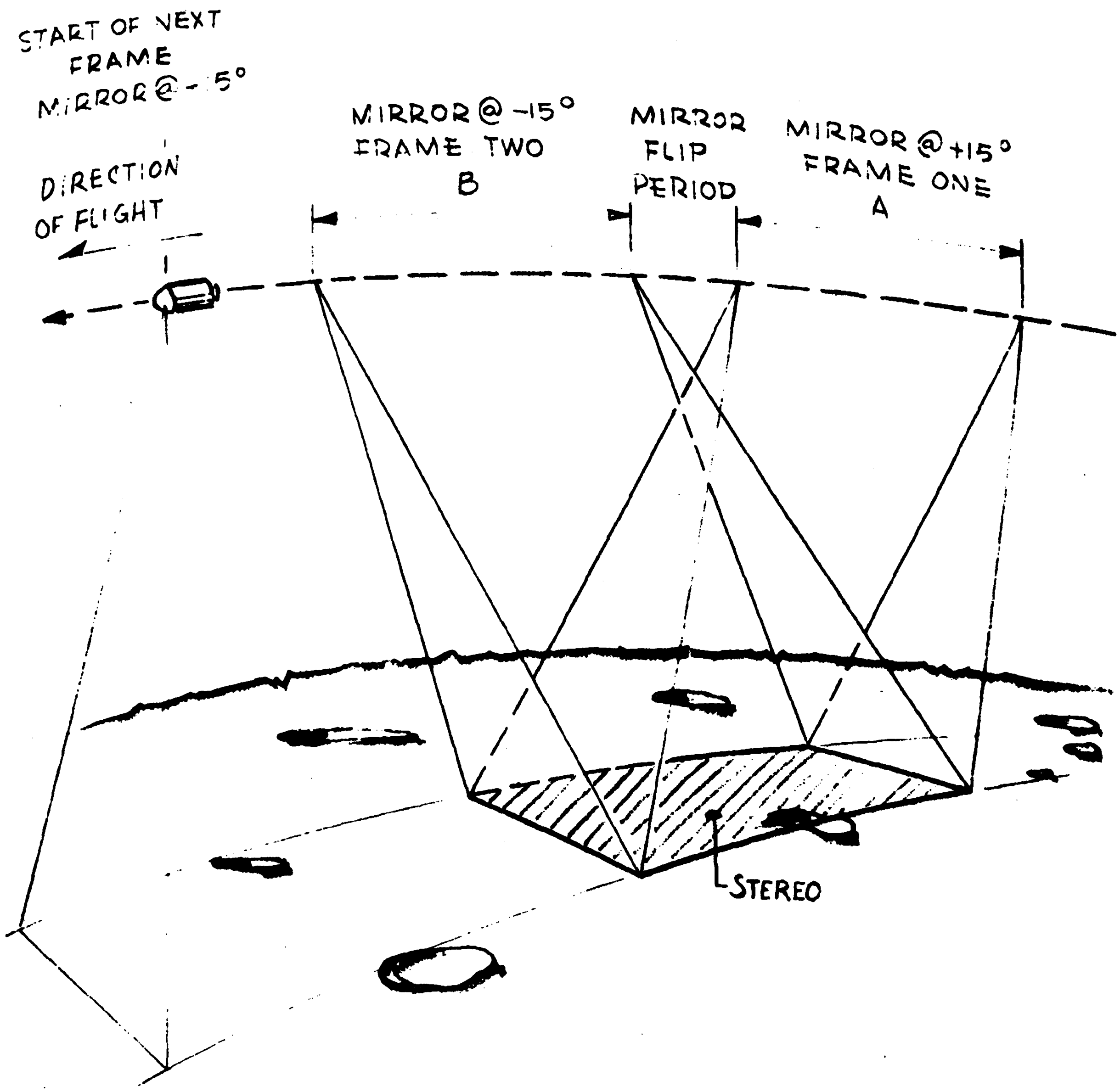


Figure 3-3. Stereo Pair (Strip Coverage)

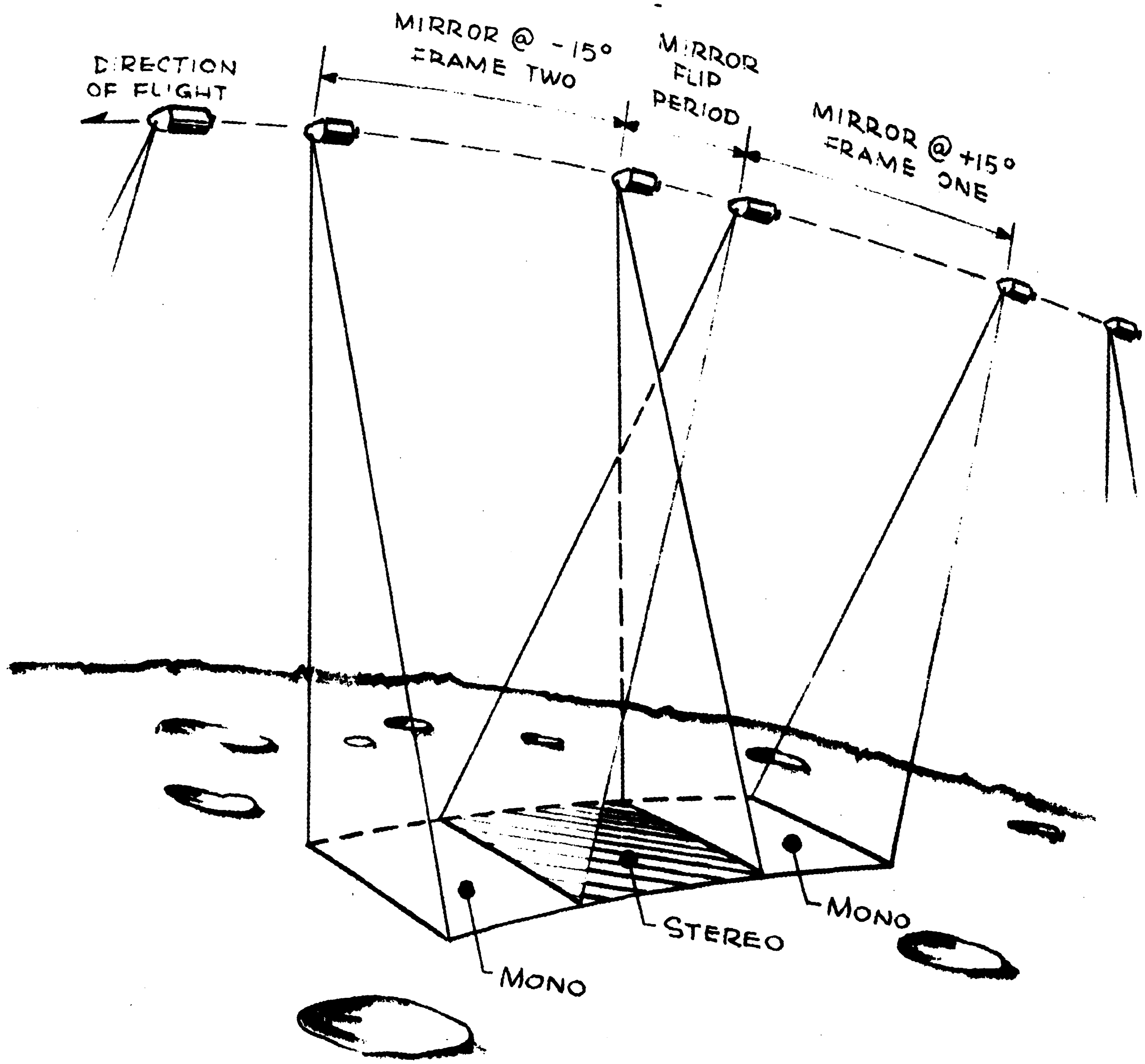


Figure 3-4. Stereo/Mono/Pair (Strip Coverage)

Stereo Pair Sampling Mode of Operation - Stereo pair sampling represents an auto-cycle mode of C/P operation used when contiguous strip coverage is not required of the survey system. This arrangement provides random high resolution sampling of the terrain instead of complete coverage. The operation of the C/P in this mode is similar to that described for stereo pairs. One example of the coverage produced by this mode of operation is given in Figure 3-9.

Panning with Stereo Mirror - A complete discussion of the adaptation of the strip camera to a panning mode by using the stereo mirror as a panning mirror appears in Section 6.0 of this report.

3.3 MISSION COMMENTARY AND OPERATION CONCEPTS

3.3.1 Mission Commentary

This commentary is predictated on mission profiles (supplied by the Air Force) in which a 4-day lunar stay time is nominal for early missions. Although the first mission may permit only 2 days of lunar orbital photography, later missions may allow up to 8 days of lunar photography. The goal of early missions is to certify photographically, in stereo, ten specific landing sites, that is, to detect small hazards and low slopes that constitute a hazard to manned LEM landings. Inclination of lunar orbits is restricted to 10° or less.

The extreme bounds of sites I and X are separated by 79.5° in longitude, which exceeds by 49.5° the 30° good lighting band. If advantage is taken of lunar surface progression of 13.2° in 1 day, the 49.5° can be reduced in 2 days to 23°. Regardless of coverage method, the 10 sites cannot be photographed in 2 days without a sacrifice of good lighting at 3 of the 10 sites. All sites can be photographed in good lighting in 4 days if a sufficient number of plane changes are made. The important advantage in the 4-day nominal mission (over a 2-day mission) is that small hazards will be detected in all ten of the areas of interest.

Because of stated command module return weight limitations, there is a maximum film load which can be carried to earth, and resolution must be traded for greater coverage, whether the coverage comes from higher altitude or from a wider field camera. For 4-day or longer missions, this report considers coverage to be poor trade-off for resolution. For a 2-day mission, an adaptation of the high quality optics to a panning mode should be considered for greater coverage although there will be a modest 20 percent loss in resolution.

3.3.2 Operational Concepts

The best operational concepts employed for lunar photography will emphasize extreme simplicity. The basic mode recommended for the nominal four day mission photography consists of in-track stereo pairs (or stereo/mono pairs) taken from an altitude of 30 n. mi. without roll or yaw maneuvers. This mode of operation provides the ultimate in photographic quality and imposes minimum space and weight demands on the Apollo vehicle. The operational sequence and coverage capability for the nominal mission are described in Section 3.4.

Two basic concepts of lunar photography from low inclination orbits are illustrated in Figures 3-5 and 3-6. In the first concept (Figure 3-5), photography is taken at and near the orbital node. Due to progression of the lunar surface (0.55°/hour easterly), each successive orbit passes over a new area to be photographed. This operational concept is ideally suited to optics of moderate field angle because contiguous strips can be photographed without excessive redundancy and without roll maneuvers or plane (node) changes. The nominal 4-day mission photography (Section 3.4) utilizes this concept - however, one significant node shift (a plane change without change of inclination) is suggested to avoid a long, photographically inactive period

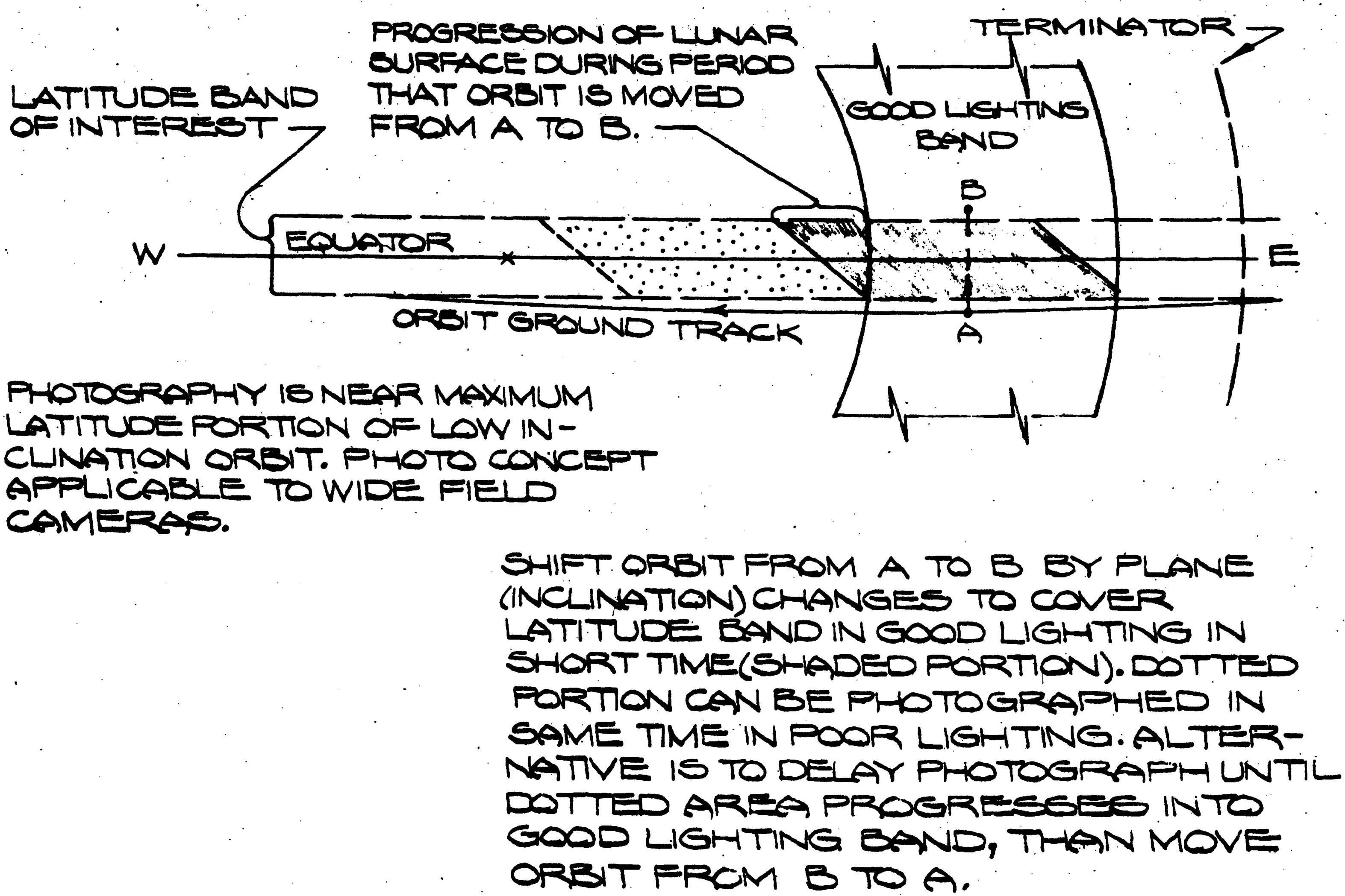


Figure 3-5. Photography at Low Inclinations - Inclination Change Concept

3.6

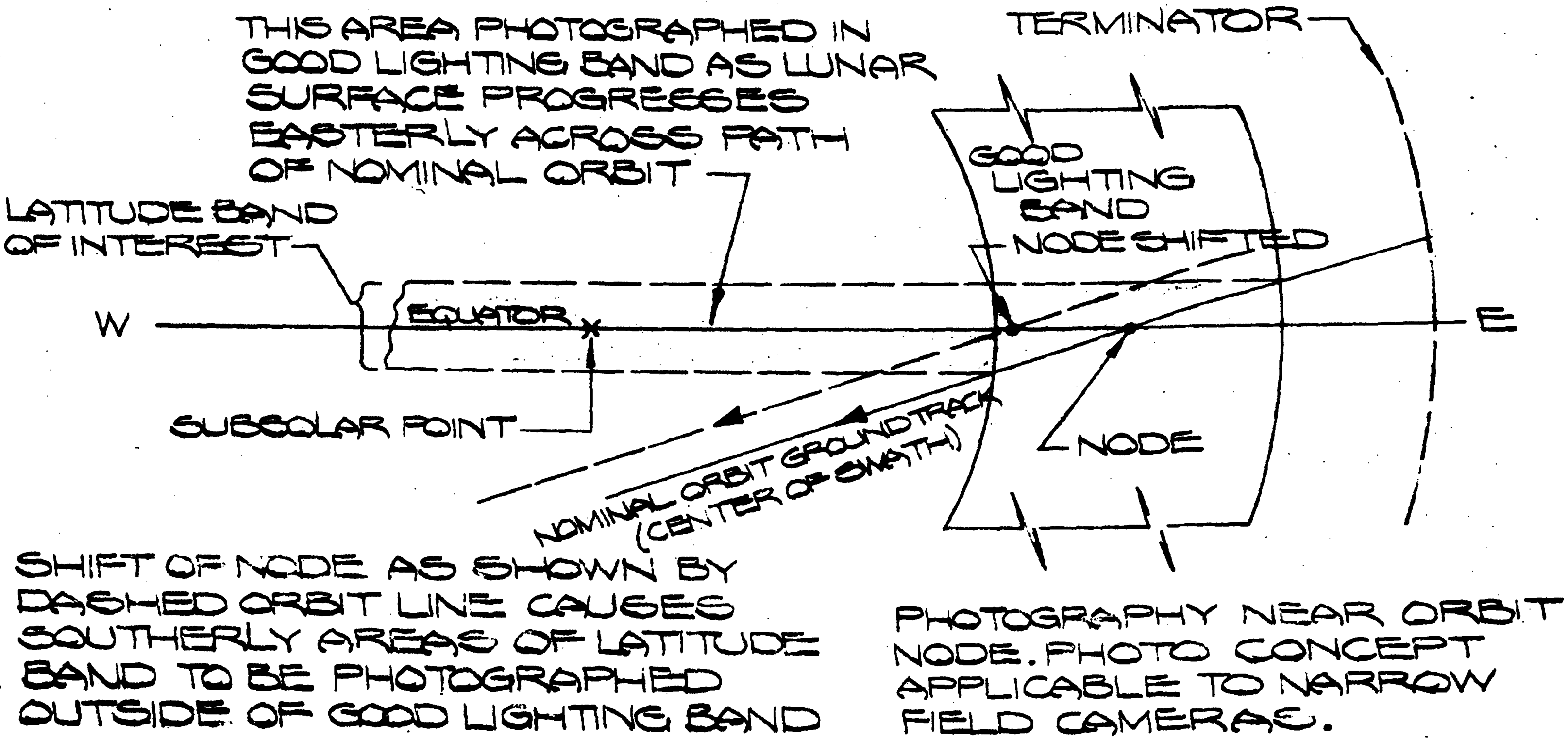


Figure 3-6. Photography at Low Inclinations - Lunar Surface Progression Concept

3.5

during which the next site progresses to the suborbital ground track. As Figure 3-5 indicates, a large westerly node shift causes southerly areas to depart from the optimum 30° lighting band, for photography. The concept of Figure 3-5 also applies to photography when the subsolar point is east of the node.

Figure 3-6 shows a second operational concept. In this concept inclination changes and (possible) obliquity changes of the line of sight are used to move successive photographic swaths across the area of interest. Photography occurs near the maximum latitude of the appropriately inclined orbit. If there were not severe lighting restrictions, this method would be useful for wide coverage of the entire equatorial area because wide field cameras would cover a wide latitude band in a short time, that is, in relatively few orbits. However, for coverage of the wide longitude band which includes the Apollo landing sites, a waiting period is required to allow new area to move into optimum lighting. A degradation of cone resolution is the consequence of photography outside the optimum lighting band.

A narrow field camera operating in the mode of Figure 3-6 and incorporating vehicle roll (obliquity) changes (one per orbit) can cover a strip about 25 n. mi. wide cross-track with a series of contiguous swaths. After an inclination change to move the orbit in latitude, the procedure is repeated. Such a procedure can be carried out from a 30 n. mi. altitude with a maximum obliquity of 20°. This concept is not recommended for the nominal mission because ground resolution is reduced somewhat from pure in-track strip photography and because vehicle roll is required.

3.4 SITE COVERAGE MISSION AND SUPPLEMENTARY PHOTOGRAPHY

The Apollo survey mission has high resolution photography of ten potential landing sites as its most important requirement. The EKC camera payload can achieve this goal in several modes of operation and these modes are described in this section. The mode which appears most attractive is described in paragraph 3.4.1 and alternative modes are analyzed in subsequent paragraphs.* Supplementary photography can be obtained in any of the coverage modes.

3.4.1 Site Coverage, Recommended Mode

The primary objective of the survey mission is certification of 10 landing sites (Figure 3-7) by means of high resolution stereo photography. At 30 n. mi. altitude and 10° orbit inclination, the ground swaths photographed are contiguous for successive orbits. The ground swath is 3.44 n. mi. wide and the progression of the lunar surface in the cross track direction is 2.95 n. mi. per orbit. Thus, the overlap of successive strips is 3.4-2.95 = 0.49 n. mi., which allows a vehicle roll error of 1° before a gap occurs. The stereo pair mode of photography, in which fore and aft photographs cover the same area on the lunar surface, is recommended for high resolution site coverage. At 30 n. mi. altitude, 6 to 8 contiguous stereo pair strips 13.3 n. mi. in length can be used to cover each site. If greater in-track picture length is desired, monoscopic photography can be taken immediately before and after the stereo pairs. Figure 3-8 shows an example of typical site coverage (stereo/mono pairs) with 8 orbits (24 n.mi. cross track coverage). If the mission is film limited, 6 orbit traversals per site should give sufficient cross track coverage (18 n. mi.).

* A complete discussion of the adaptation of the strip camera to a panning mode by using the stereo mirror as a panning mirror appears in Section 6.0 of this report.

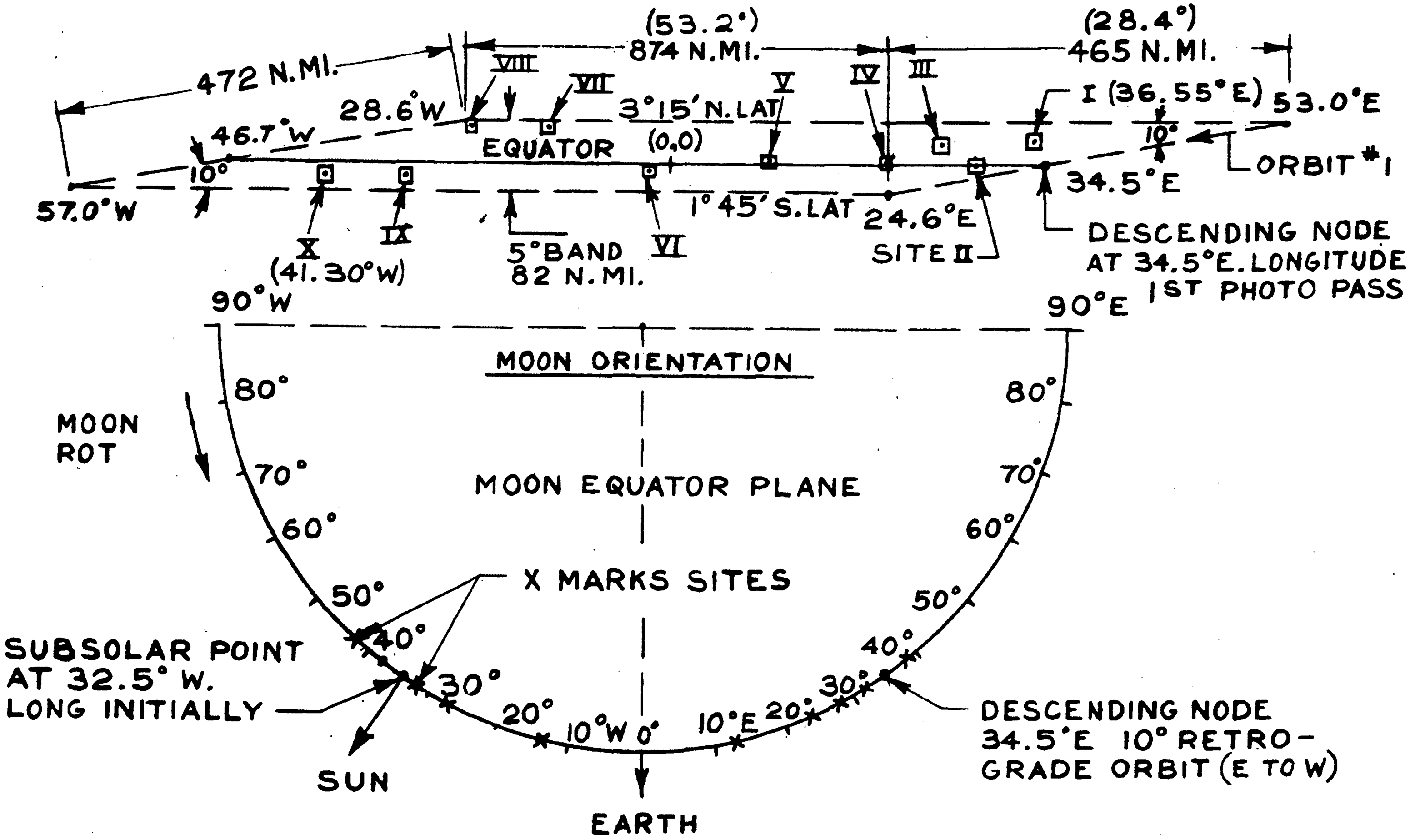


Figure 3-7. Operational Area for Site Coverage; 10-Degree Retrograde Orbit at 30 n.mi. Altitude

41.30
36.55
18

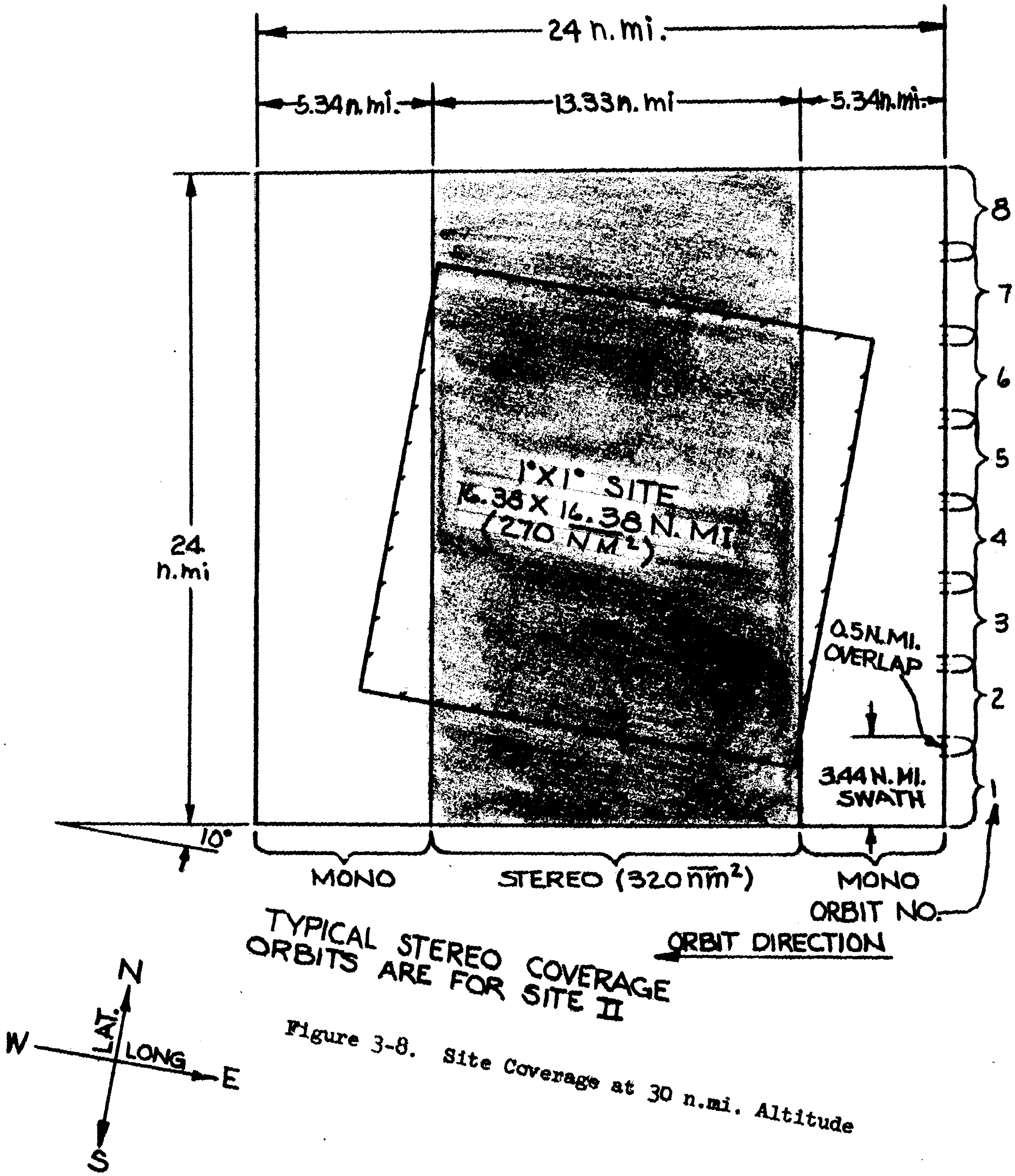


Figure 3-8. Site Coverage at 30 n.mi. Altitude

The ten sites can be covered in four days (52 orbits) with in-track stereo photography and no roll maneuvers. For the example shown in Figure 3-8, camera operation is as follows: camera ON for 21.6 seconds, camera OFF 3.2 seconds while the stereo mirror is turned from the 15° forward to 15° aft position, camera ON 21.6 seconds, camera OFF and stereo mirror return to forward position in 3.2 seconds. This sequence is the same for each orbit which crosses one or more sites. Film consumption is 7.4 feet for each traversal of a site.

During the 4-day mission, 73 traversals are made for a total of 540 feet of film weighing 9.3 pounds. Total coverage of 2930 n.mi.^{2} of non-redundant stereo photography on 300 feet of film and 2380 n.mi.^{2} of non-redundant monoscopic photography on 240 feet of film. Total area of the ten 1° x 1° sites is 2680 n.mi.^{2}.

With a total film load of 3000 feet, 45 additional potential sites can be verified in the same manner. If stereo pairs only are used (without monoscopic borders), 90 additional potential landing sites can be photographed with 3000 feet of film.

The first photographic orbit for the 4-day mission has its descending node at 34.5°E. longitude so that photography of site II starts immediately after the equator crossing. The subsolar point is chosen to be at 32.5°W longitude. Table 3-1 shows the sequence of site photography with elapsed time and longitude for each equator crossing. To accomplish the required coverage in 4 days, 3 plane changes are made, the one of greatest significance being made after photography on orbit 31. This is calculated to be a plane change of 3.6° to move the descending node west from 0.86°W (orbit 31) to 22.70°W (orbit 32) without a change of inclination. It is estimated that this change requires a Δ V of about 340 ft./sec. In conversations with NAA/S&ID, EKC has been informed that plane changes are permissible with Δ V up to 400 feet/second.

TABLE 3-1

FOUR DAY SITE COVERAGE SEQUENCE - 30 N. Mi. ALTITUDE

Orbit No.	Descending Node Crossing Hours	Descending Node Crossing Longitude	Sites Covered	
1	0	34.50°E	II	Orbit is 10° retrograde
2	1.89	33.46°	II	
3	3.78	32.42°	II	
4	5.67	31.38°	II	
5	7.56	30.34°	I, II	
6	9.45	29.30°	I, II	
7	11.34	28.26°	I, II	
8	13.23	27.22°	I, II	
9	15.12	26.18°	I, IV	
10	17.01	25.14°	I, III, IV	
11	18.90	24.10	I, III, IV	
12	20.79	23.06°	I, III, IV	
13	22.68	22.02°	III, IV	
14	24.57	20.98°	III, IV	
15	26.46	19.94°	III, IV	
16	28.35	18.90°E	III, IV	0.7° plane change after
17	30.24	13.70°E	V	orbit 16 photography.
18	32.13	12.66°	V	Move node from 18.90°E to
19	34.02	11.62°	V	13.70°E. Retain 10°
20	35.91	10.58°	V	inclination.
21	37.80	9.54°	V	
22	39.69	8.50°	V	

Orbit No.	Descending Node Crossing Hours	Descending Node Crossing Longitude	Sites Covered	
23	41.58	7.46°	V	
24	43.47	6.42°	-	
25	45.36	5.38°	VI	
26	47.25	4.34°	VI	
27	49.14	3.30°	VI	
28	51.03	2.26°	VI	
29	52.92	1.22°	VI	
30	54.81	0.18°E	VI	
31	56.70	0.86°W	VI	3.6° plane change after orbit 31 photography. Move node from 0.86°W to 22.70°W. Retain 10° inclination.
32	58.59	22.70°W	IX	
33	60.48	23.74°	IX	
34	62.37	24.78°	IX	
35	64.26	25.82°	VII, IX	
36	66.15	26.86°	VII, IX	
37	68.04	27.90°	VII, IX	
38	69.93	28.94°	VII, IX	
39	71.82	29.98°	VII	
40	73.71	31.02°	VII, X	
41	75.60	32.06	VII, X	
42	77.49	33.10°	VII, X	
43	79.38	34.14°	X	
44	81.27	35.18°	X	
45	83.16	36.22°	X	

Orbit No.	Descending Node Crossing Hours	Descending Node Crossing Longitude	Sites Covered	
46	85.05	37.26°W	X	0.5° plane change after
47	86.94	41.42°W	VIII	orbit 46 photography.
48	88.83	42.46°	VIII	Move node from 37.26°W
49	90.72	43.50°	VIII	to 41.42°W. Retain 10°
50	92.61	44.54°	VIII	inclination.
51	94.50	45.58°	VIII	
52	96.39	46.62°	VIII	End of 4-day mission.

Because of plane changes, the 4-day mission is accomplished only at some sacrifice in good lighting. However, the exceptionally good system resolution and stereo acuity over every site make it possible to satisfactorily verify the sites and detect the hazards.

Table 3-2 shows sun elevations as calculated for photography at the center of each site, considering the initial longitude of the subsolar point, the lunar progression, and the 1° per day change in sun elevation due to earth/moon rotation about the sun. From the start of photography of a site (swath across northern-most edge), there is a sun elevation change of about 5° caused by the 0.55°/hour equatorial progression of the site. Thus, ±2.5° must be added to each of the tabular values. Column A represents the nominal 4-day mission in which westerly node changes of 28° were made. Sun elevations are higher than desired for sites IX and X, but performance estimates shows that a [redacted] diameter, 41.6° cone, a [redacted] diameter, 38.6° cone and a 47-inch diameter, 26.5° cone can be detected with the basic film (speed of 6), 1/150 second exposure time, at 60° sun elevation. At 65° sun elevation, 27-inch diameter cones of 38.6° base angle can be detected.

Columns B and C of the table show that favorable lighting is maintained in a longer (6.2-day) mission which can be conducted without plane changes. The difference between columns B and C is the initial longitude of the subsolar point. Coverage of each site is identical to that of the 4-day nominal mission.

TABLE 3-2

SUN ELEVATION FOR PHOTOGRAPHY OF SITE CENTER

Sites in Order of Photography	A Nominal 4-day mission (subsolar point at 32.5°W)	B A 6.2-day mission (subsolar point at 97.5°E)	C A 6.2-day mission (subsolar point at 29.5°W)
II	23.3°	26.7°	26.3°
I	13.7°	36.3°	16.7°
IV	22.9°	27.1°	35.9°
III	17.4 °	32.6°	20.4°
V	26.9°	27.1°	25.9°
VI	32.3°	21.7°	31.3°
IX	59.8°	16.4°	36.6°
VII	38.5°	37.7°	15.3°
X	61.0°	15.2°	37.8°
VIII	42.5°	36.5°	16.5°

NOTES:
(1) 10° retrograde orbit with initial descending node at 34.5°E. lingitude.
(2) 30 N. Mi. altitude
(3) At each site, sun angle variation from the start of photography to the end of photography is about ±2.5° from sun elevation at site center (tabular values).
(4) Sun elevations are measured from horizon.

Site coverage at altitudes substantially higher than 30 n. mi. is not recommended because of the loss in resolution due to change in scale of photography. Mission duration cannot be reduced significantly and plane changes are still required at higher altitudes.

3.4.2 Stereo Pairs

The previous section suggested the use of contiguous stereo pairs for supplementary photography of potential landing sites. Sampling of areas in stereo can be done in a variety of other ways. One example is shown in Figure 3-9, in which none of the pairs are contiguous. If wider cross-track samples are desired, a series of adjacent pairs can be used as required. Maximum length of a stereo pair strip ranges from 13.3 n. mi. at 30 n. mi. altitude to 40.5 n. mi. at 80 n. mi. altitude. Swath width of a single pair ranges from 3.4 n. mi. at 30 n. mi. altitude to 9.2 n. mi. at 80 n. mi. altitude.

The camera operation sequence for stereo pairs at 30 n. mi. altitude is as follows: camera ON 15.45 seconds, camera OFF 3.2 seconds for turning stereo mirror aft, camera ON 15.45 seconds for second half of pair, camera OFF 3.2 seconds for turning mirror forward, and repeat ON/OFF sequence as desired for additional pairs. An 18.9 n. mi. gap in coverage occurs in-track between each pair. Each pair covers 46 n. $mi.^2$ and consumes 5.3 feet of film.

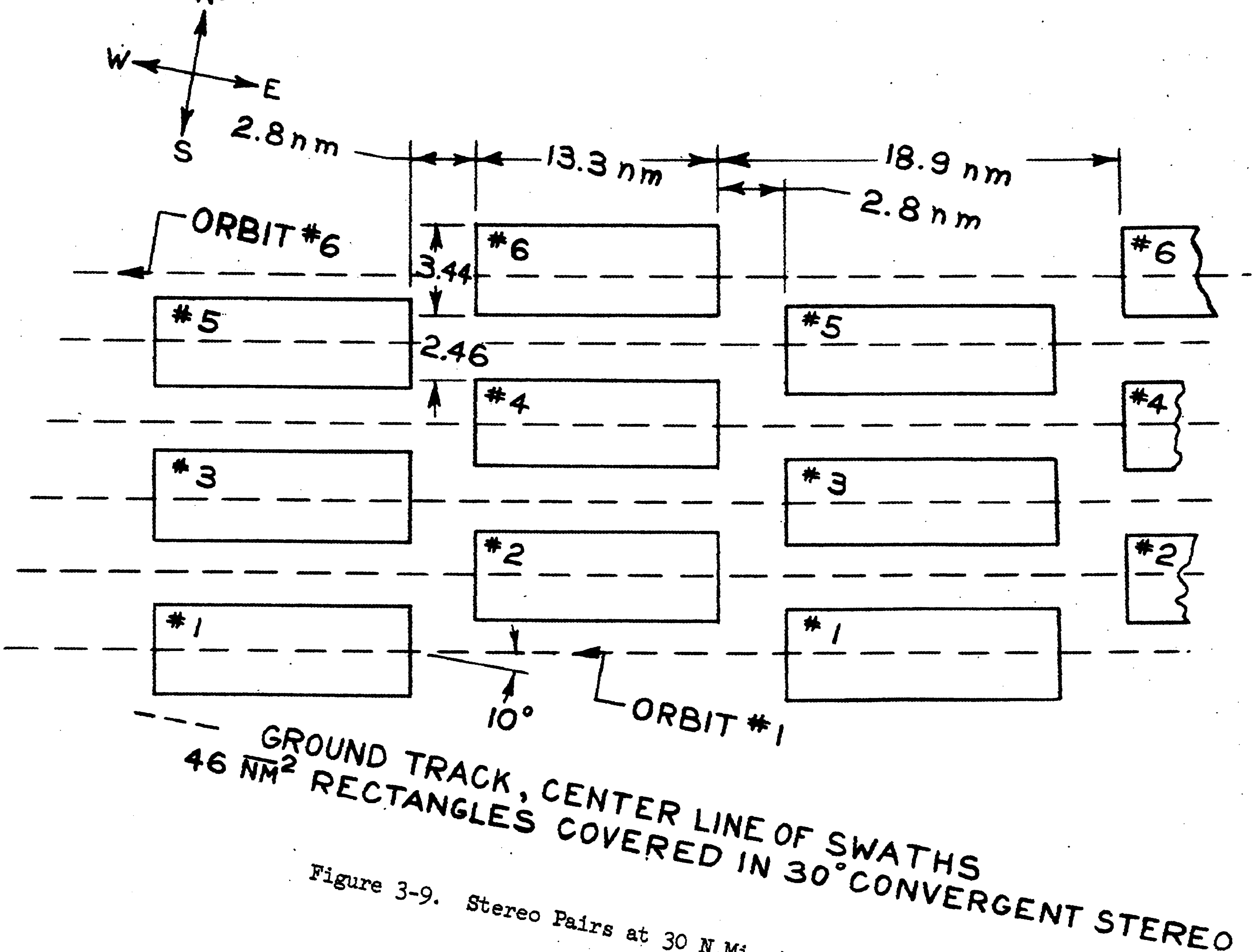


Figure 3-9. Stereo Pairs at 30 N.Mi. Altitude

At higher altitudes, coverage of the maximum length stereo pair increases approximately as the square of the altitude. Pair length can be reduced any desired amount by reducing camera ON time appropriately. Because stereo pairs (or monoscopic swaths) are contiguous for successive orbits of 10° inclination at 30 n. mi. altitude, efficient and versatile high resolution coverage patterns can be produced. Higher altitudes in general are not recommended for the strip stereo pair mode unless strips longer than 13.3 n. mi. are required.

3.4.3 Contiguous Monoscopic Strips

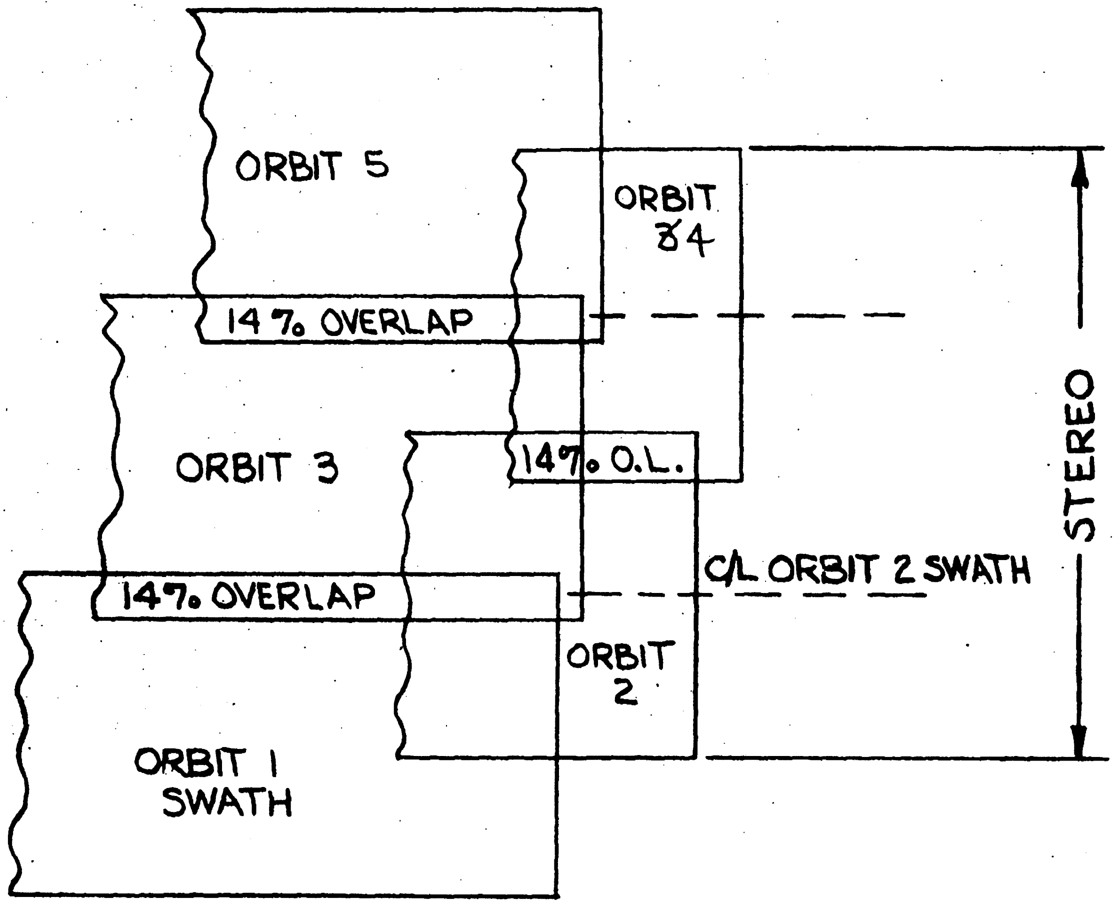
Contiguous monoscopic strips can be photographed from 30 n. mi. altitude in a 10° inclined orbit by ulilizing only the natural rotation of the lunar surface. As the altitude is increased, the swath widths become larger, overlap increases, and more and more redundant photography is obtained. At 62 n. mi. there is about 57% overlap, and 100% stereo photography can be taken by turning the stereo mirror to look forward on one orbit and aft on the next orbit. Monoscopic photography can still be taken at this altitude,if desired, by operating the camera every other orbit only. In the monoscopic mode the mirror can either look fore or aft, depending on which direction is the most favorable photometrically.

At altitudes greater than 62 n. mi., the overlap becomes substantially larger than 50% and redundancy increases. There is no coverage benefit in increasing the altitude above 62 n. mi. unless roll maneuvers and occassional plane changes are utilized to take advantage of the wider ground swaths. If inclinations higher than 10° were permitted, the lunar rotation would allow efficient coverage at the higher altitudes without roll maneuvers or plane changes. However, monoscopic strips are not advised at high altitude because of reduced ground resolution.

3.4.4 Alternate Orbit Strip Stereo

In this mode, swaths from even numbered orbits overlap 14% and odd numbered orbit swaths also have 14% side overlap. In addition, centers of the odd orbit swaths are at the overlapping edges of the even orbit swaths, as shown in Figure 3-10. Alternate orbit strip stereo can be used at 30 n.mi. altitude with a 5° orbit inclination. At 62 n. mi., a 10° inclination is required for proper overlap. The required inclination is calculated from the formula: $2 \Delta \lambda \sin i$ = path width-overlap, where $\Delta \lambda$ is the equator crossing spacing of consecutive orbits and i is orbit inclination. The overlap is 14% of the swath width.

This mode is not as appearling for low altitude site coverage as the stereo pair mode because twice as many orbits (and twice the time) per site are required. The longer time causes a greater sun angle variation during photography of each site and a greater sun angle variation over the total site coverage mission. However, at a 62 n. mi. altitude, the maximum allowavle inclination of 10° is compatible with the swath width and lunar progression. Though resolution is reduced from that at 30 n.mi. altitude, coverage is maximized and excellent contiguous stereo photography of gross lunar areas can be taken in this mode of operation - without the use of roll maneuvers or plane changes. Gains in coverage for altitudes greater than 62 n.mi. are not significant unless roll (obliquity) maneuvers and plane changes are used to shift the ground swaths and take advantage of the wider swath widths.



STEREO STRIPS ARE FORMED BY SWATHS 2 AND 1, 2 AND 3, 3 AND 3, 3 AND 5
1 + 2, 2 + 3, 3 + 4, 4 + 5

Figure 3-10. Alternate Orbit Strip Stereo

3.4.5 Coverage Comparisons

Figures 3-11 and 3-12 show coverage attainable in a 30° good lighting band by stereo pairs and alternate orbit strip stereo, each as a function of altitude. Contiguous monoscopic strips are not shown but this coverage is approximately twice that of the alternate orbit stereo mode. Coverage per orbit would increase in proportion to an increase in the longitude band over which the photography is taken. Table 3-3 was compiled to show coverage for a given film load. The number of orbits, mission time, and the latitude and longitude bands covered are restricted by the 30° sun angle variation limit, that is, the film would be used up in fewer orbits if each orbit traversed a longitude/lighting band longer than 30°. The camera operates about 10 minutes of each orbit during the traversal of the 30° longitude band which is the band that has been used for calculation of the tabular values. Coverage per foot of film or per pound of film is independent of the lighting band.

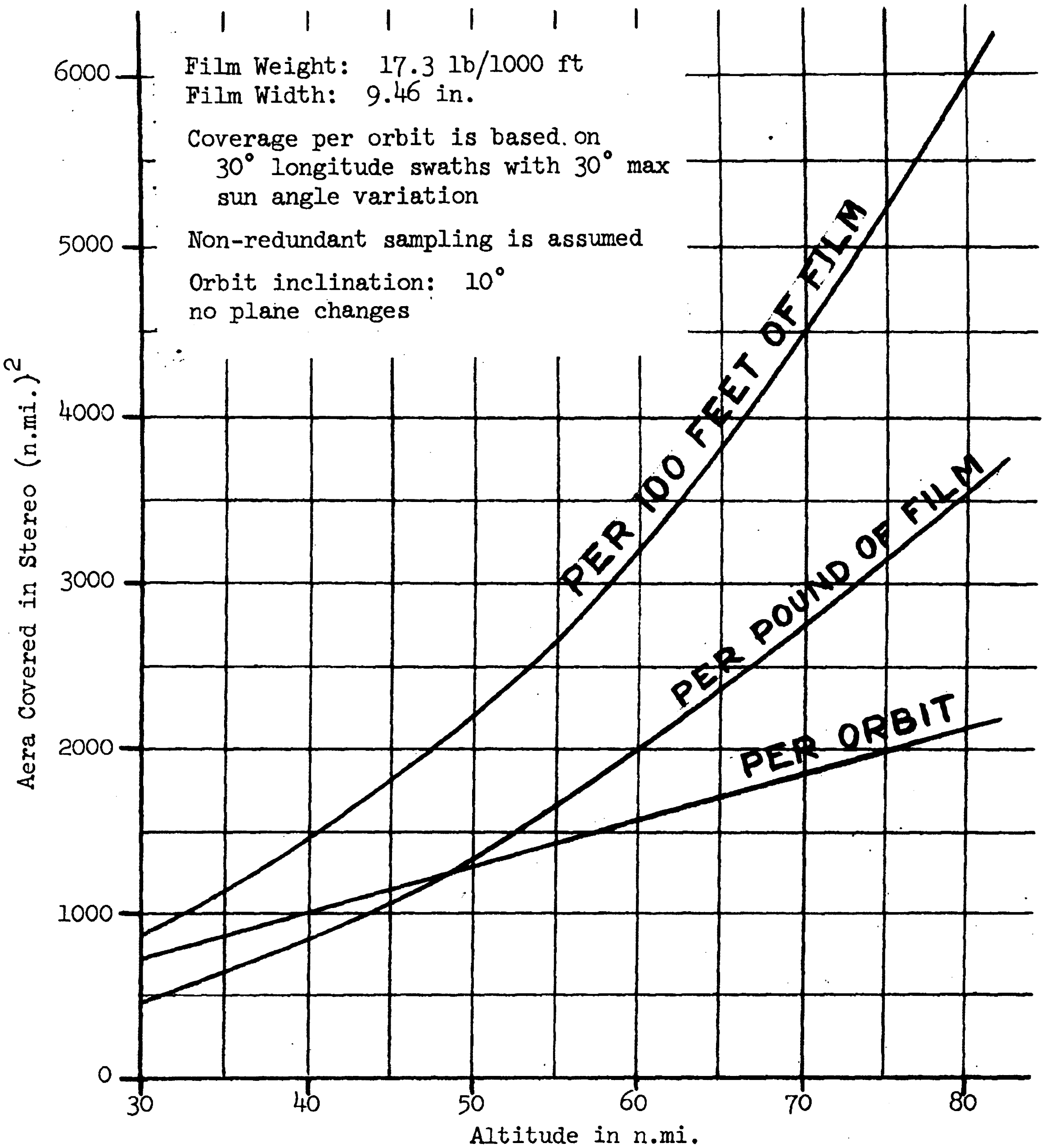


Figure 3-11. Stereo Pair Coverage vs Altitude

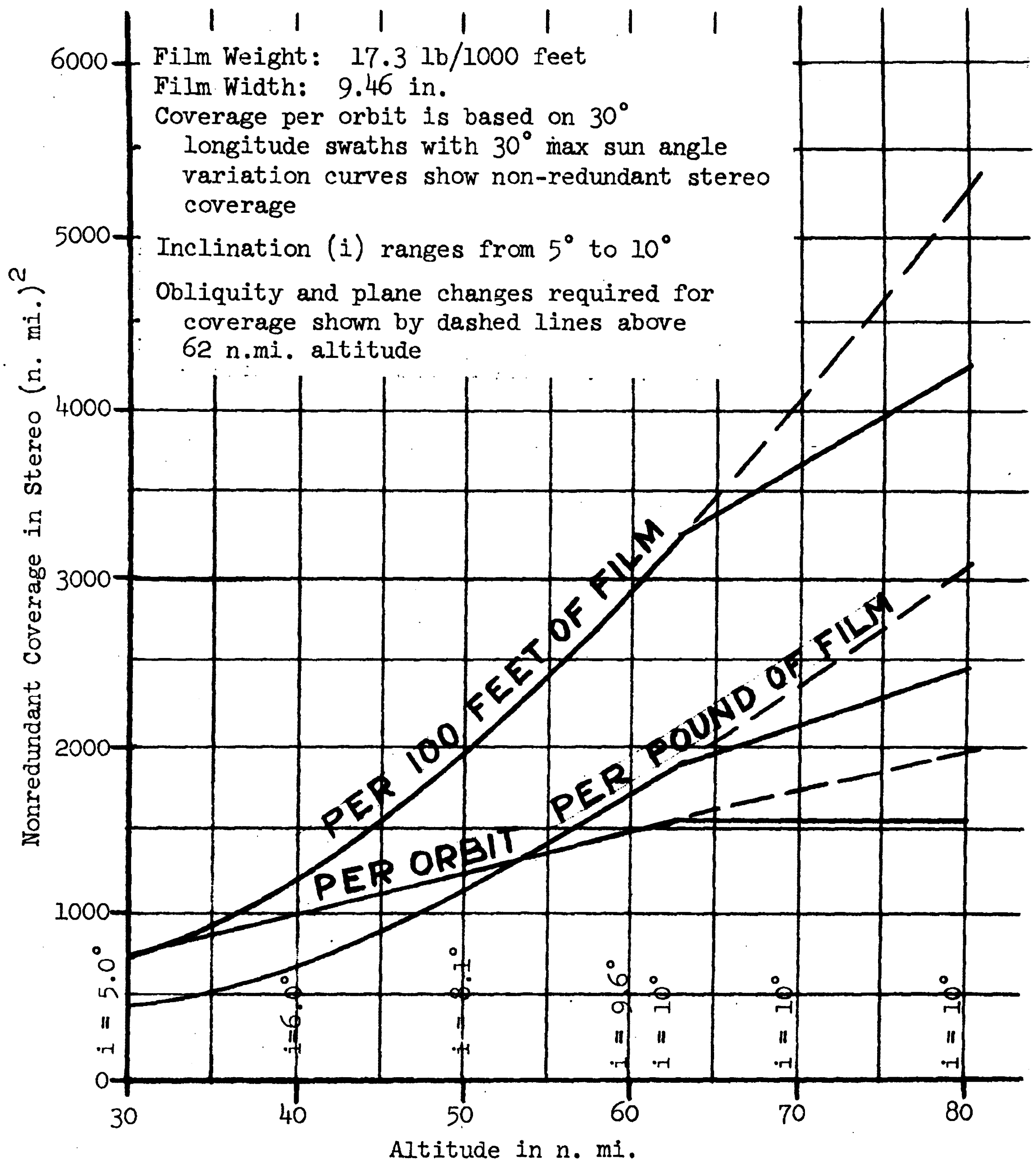


Figure 3-12. Alternate Orbit Strip Stereo Coverage vs Altitude

TABLE 3-3

COVERAGE BASED ON 50-LB. FILM LOAD AND 30° SUN VARIATION LIMIT

	Stereo Pairs		Alternate Orbit Strip Stereo			Contiguous Mono Strips
	30 N.M.	80 N.M.	14% overlap 30 N.M.	31% overlap 80 N.M.	14% overlap 80 N.M. (See Note 1)	14% overlap 30 N.M.
Coverage Type	Stereo	Stereo	Stereo	Stereo	Stereo	Mono
Non-redundant coverage (nm^2)	24,100	178,500	21,100	123,500	153,500	43,000
Redundant coverage (nm^2)	None	None	3,500	55,000	25,000	7,000
Number of Orbits	35	83	29	78	78	29
Mission Hrs.	66	168	55	158	158	55
Mission Days	2.7	7.0	2.3	6.6	6.6	2.3
Lat. Band coverage	5.3°	5.3°	2.6°	5.3°	5.3°	5.3°
Longitude band coverage	36°	92°	30°	87°	87°	30°
Orbit Inclination	10°	10°	5°	10°	10°	10°

(The 50 lb. film load is chosen as an example only. Coverage for other loads is directly proportional to weight ratio.)

Note 1: Obliquity change required once per orbit to reduce stereo redundancy; e.g., vehicle roll can be changed from +8° to -8° in 12 orbits (1 day), then a node change of 3.3° can be made, and then the cycle repeated.

3.5 EXPOSURE CRITERIA

The "exposure criterion" for lunar photography has been established. The "average"[1] scene luminance for each sun elevation range is placed at a density of 1.0 on the density vs log exposure (log E) curve. This is commonly called the H and D curve. The density range on type 4404 film which yields a resolution of 3.3(b)(1) [redacted] is 0.70 to 1.70. The photo sub-system will require three exposure times (1/100, 1/140, and 1/200 sec.) to place the "average" scene luminance at the optimum position on a film similar to type 4404 but with an exposure index of 6.0. Table 3-5 lists exposure times as a function of sun elevation and film speed.

3.5.1 Background

Photography of the lunar surface from an orbiting vehicle is considerably different from similar photography of the earth's surface, since:

(1) As determined from the earth the variation of brightness with changing sun elevation, camera angle and lunar surface slope follows a photometric function considerably different from a Lambert reflector.

(2) The moon is without an atmosphere to scatter light into the shadow areas.

---

[1] Average scene luminance is defined as the median for that segment of the luminance distribution containing 95% of the points calculated for the conditions of this study.

(3) The normal reflectances[2] based on measurements from the earth are:

Dark plains (maria) - 6.5% reflectance
Average lunar continents - 12% reflectance
Average of lunar surface - 9% reflectance

A reflectance of 7% is taken to be representative of the reflectance of the proposed site areas, and will be used in the calculations of this section.

The range of brightness for the elements of a cone on the lunar surface have been determined by a computer program written for the IBM 7044 computer. The results of this determination have been plotted as a function of sun elevation, camera angle and cone angle. These curves are included in Appendix R.

3.5.2 Analysis

The distribution of scene luminances (Figures 3-13, 3-14, 3-15, and 3-16) in the image plane of the camera has been determined using the following method:

(1) The scene luminance in the image plane was calculated for 243 conditions using the data of Appendix R. The variables included in the calculation were as follows:

(a) Sun elevation angles 15°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°.

(b) Cone base angles 15°, 30°, 45° and 60°.

(c) Camera angles from nadir -15°, 0, +15°.

2. "Natural Environment and Physical Standards for Project Apollo", Pg. 37, NASA Document M-DE 8020.008A, August 26, 1963.

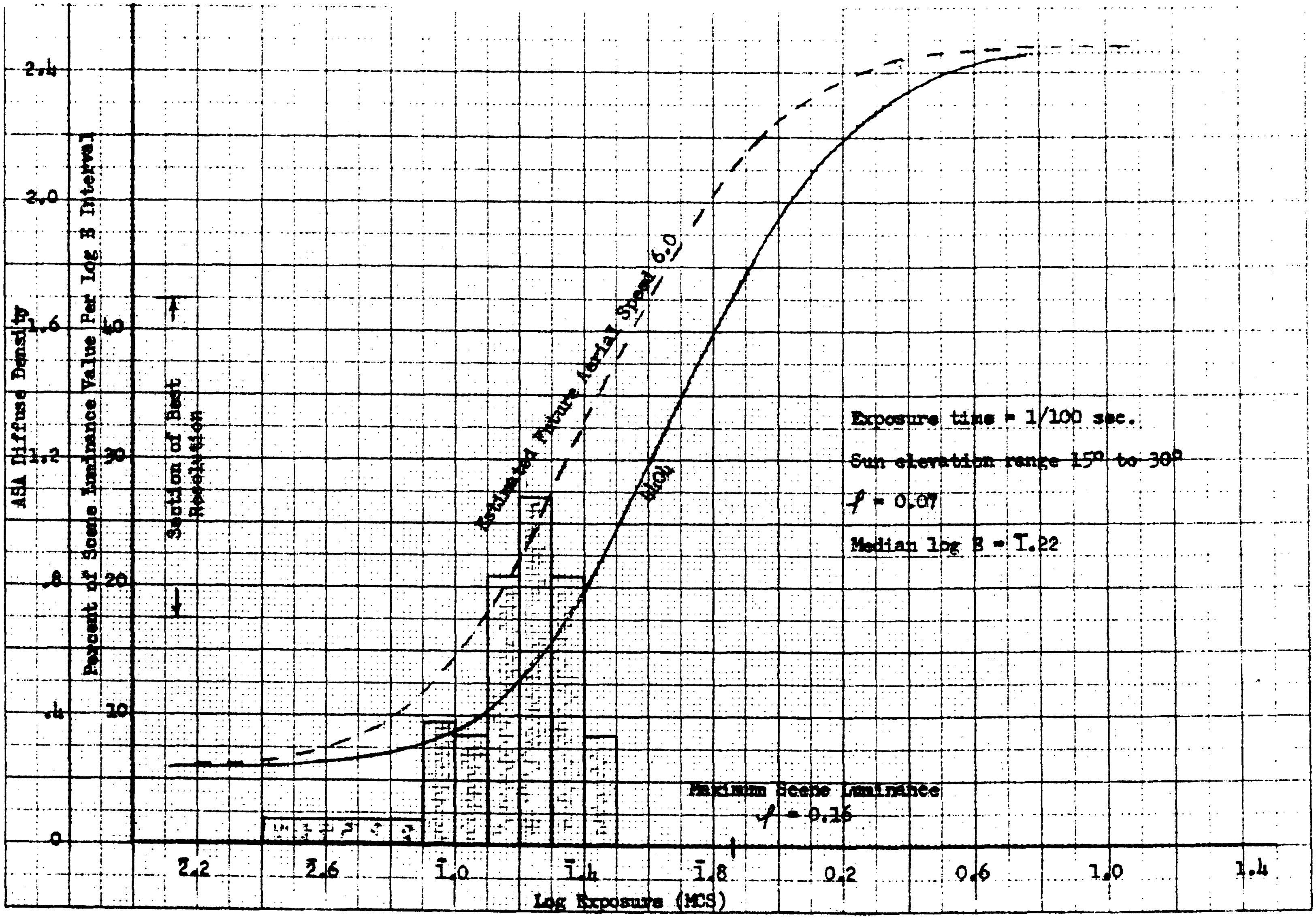


Figure 3-13. Scene Luminance Distribution at the Image Plane-Sensitometric Curves for 4404 Films

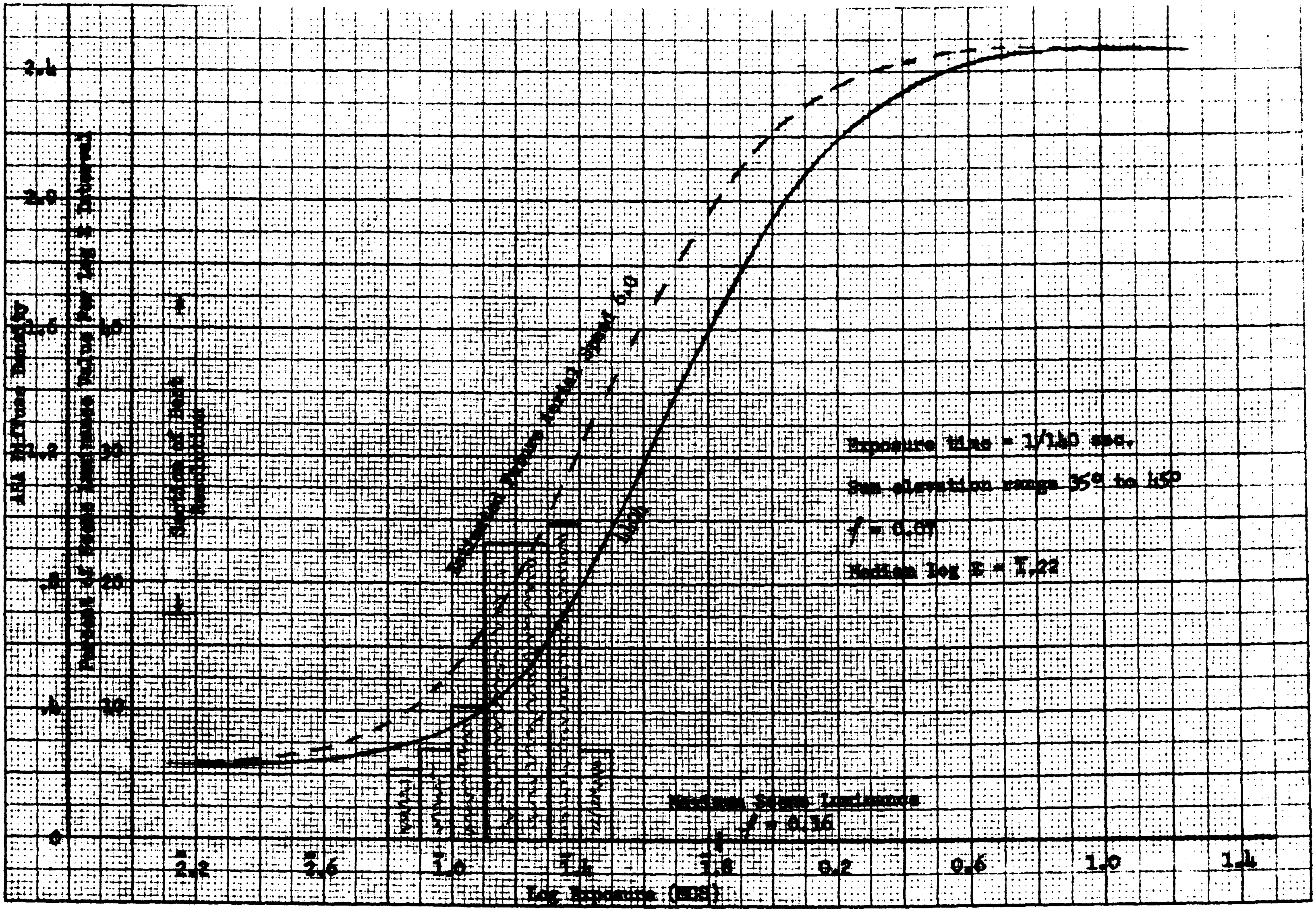


Figure 3-14. Scene Luminance Distribution at the Image Plane-Sensitometric Curves for 4404 Films

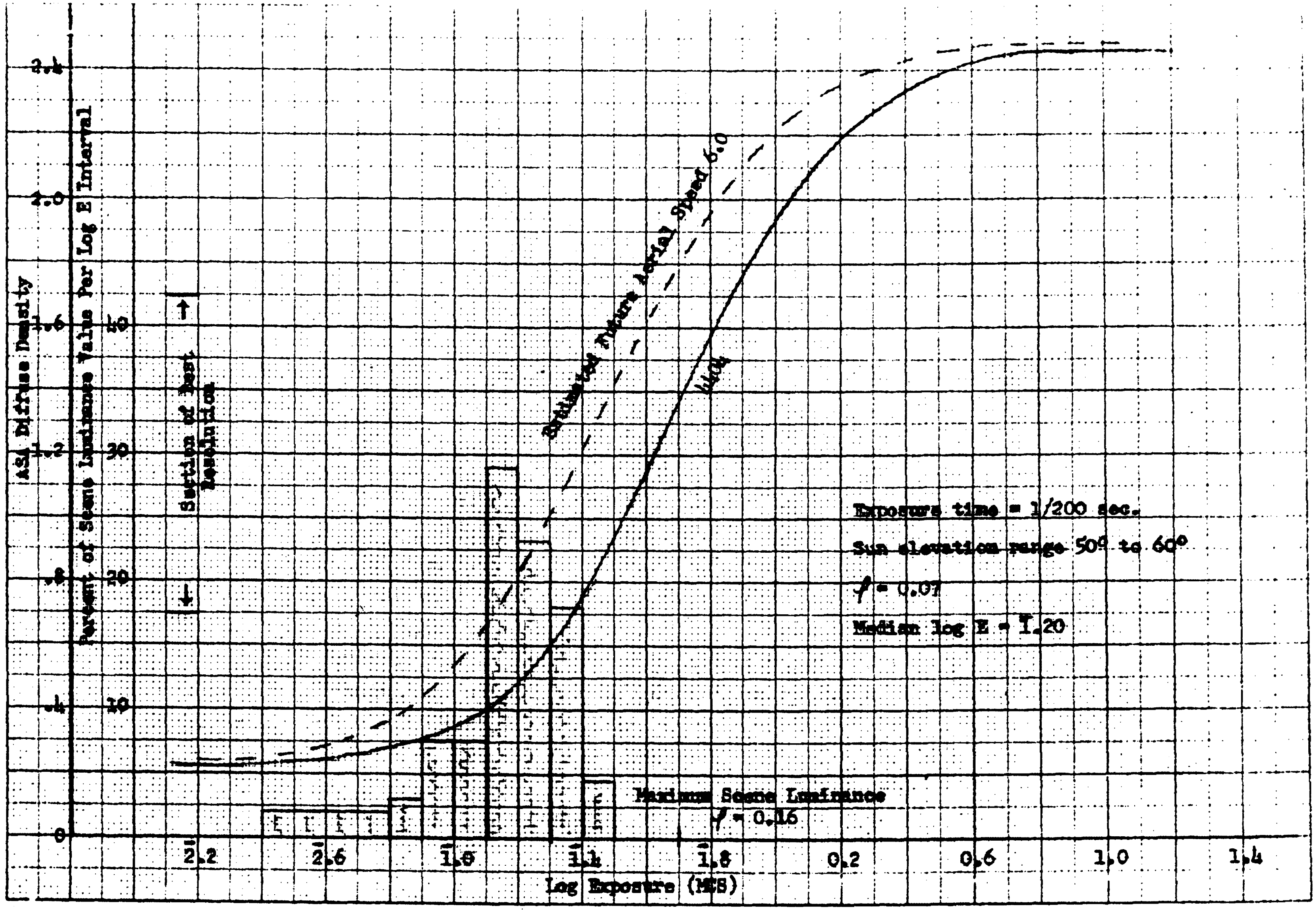


Figure 3-15. Scene Luminance Distribution at the Image Plane-Sensitometric Curves for 4404 Films

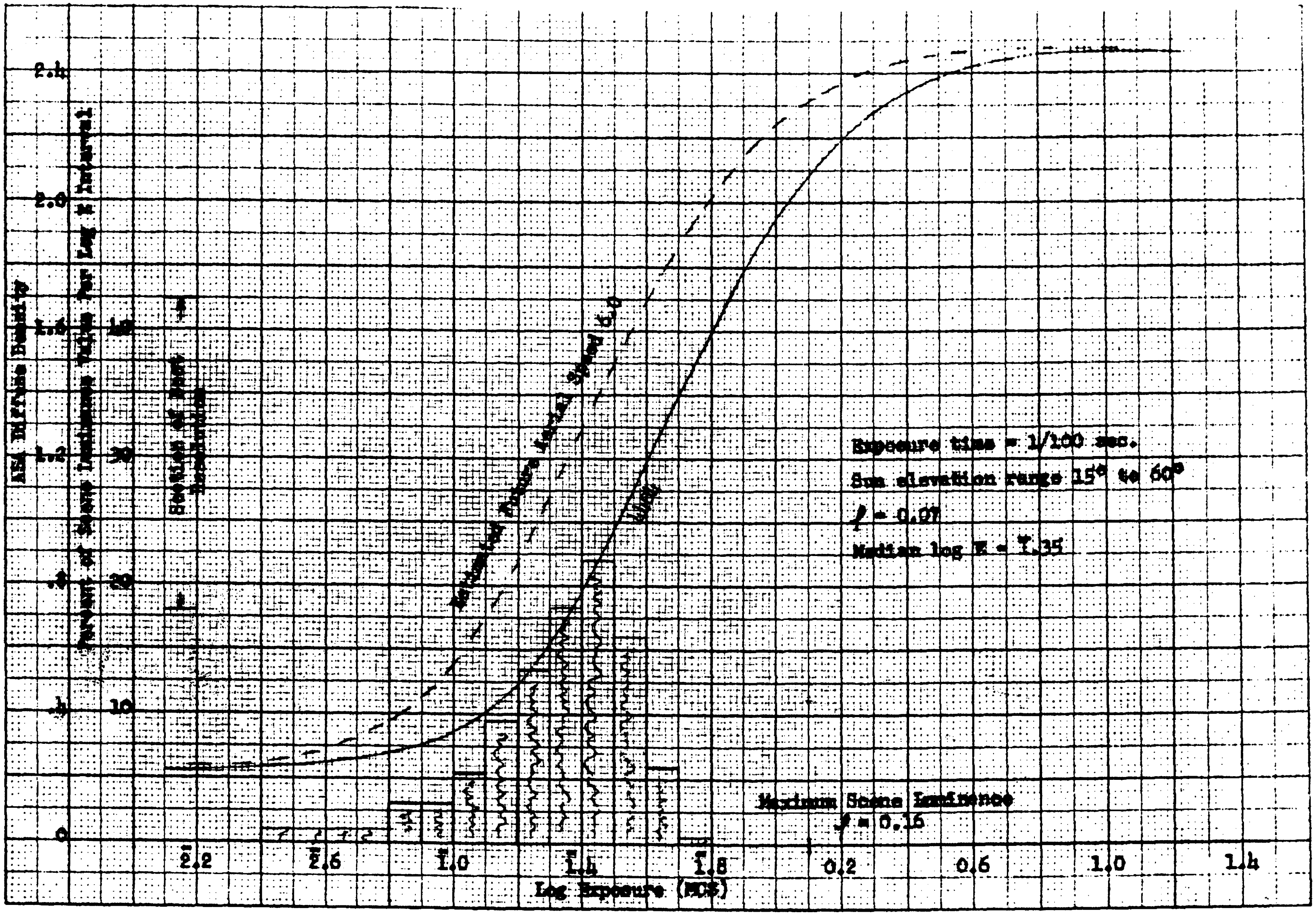


Figure 3-16. Scene Luminance Distribution at the Image Plane-Sensitometric Curves for 4404 Films

(d) Cone maximum and minimum illumination

(e) Background illumination

(f) Albedo (ρ) = 0.07

(2) The scene luminance and corresponding log E values were determined for each point assuming an exposure time of 0.010 seconds for all sun elevations. This assumption is modified later to optimize the image rendition.

(3) The 60 conditions for which the minimum scene luminance is less than 0.025 meter-candle-seconds are not included in the distribution, since exposure for scene illuminated by star light and earth shine is not a design parameter for this system.

(4) The scene luminance distributions are plotted as a function of percent occurrence for three ranges of sun elevations. The ranges of sun elevation angle used are 15° to 30° (Figure 3-13), 35° to 45° (Figure 3-14) and 50° to 60° (Figure 3-15). The distribution of luminance for the entire range is shown in Figure 3-16. This distribution curve is subject to the following limitations:

(a) The reflectance (or albedo) at all points of the lunar surface is 0.07.

(b) The information content of the photographic format is dependent on recognition of illumination variation caused by the various slopes of the lunar surface.

(c) The background illumination was not weighted in proportion to its occurrence in the photograph format. The background represents only 11% of the points considered.

(d) The photometric function for lunar fine detail is as found by earth based measurements.

The distribution of scene luminances in the film plane for each of the three ranges of sun elevation angles shows that 80 to 90 percent of the points fall within a log E range of 0.60.

To optimize image resolution and tone reproduction, the distribution of luminances for each sun altitude range was shifted along the log E axis by an amount which accounts for the proper exposure time:

(1) Sun elevation angle range 15° to 30°. "Average" log E value is $\bar{1}.22$. (exposure time = 0.010 sec.).

(2) Sun elevation angle range 35° to 45°. "Average" log E value is $\bar{1}.22$. (exposure time = 0.007 sec.)

(3) Sun elevation angle range 50° to 60°. "Average" log E value is $\bar{1}.20$ (exposure time = 0.005 sec.).

Since dynamic resolution is improved by reduced smear as exposure time is decreased, a short exposure time is desirable. Dynamic resolution for the photo subsystem as a function of exposure time is shown in Table 3-4. Resolution is based on the nominal smear budget (see Section 3.10.5.2).

TABLE 3-4

EXPOSURE TIME VERSUS DYNAMIC RESOLUTION AT 30 N.Mi. ALTITUDE (2:1 CONTRAST TARGET)

Exposure Time (sec.)	Geometric Mean Dynamic Resolution 1/mm	Geometric Mean Ground Resolution inches
1/100	[redacted]	[redacted]
1/150		
1/200		

The density range for [redacted] resolution with a 2:1 contrast target is 0.70 to 1.70.

If the photographic image is to contain the maximum information, the average scene luminance from Figures 3-13, 3-14, 3-15 and 3-16 should have a log E value of approximately $\bar{1}.25$ for a film with an Aerial Exposure Index of 6.0* (The standard type 4404 film of index 3.6 is shown as a reference only.) This places the average scene luminance at a density of about 1.00, which is slightly lower than the mid-density of the density range for [redacted] resolution. This point (D = 1.00) was deliberately chosen below the mid-density point as it has been found that the highest resolution is located near the toe of the curve. A slight speed advantage of 0.10 log E is also obtained.

Table 3-5 lists the exposure times for optimum exposure as a function of elevation.

TABLE 3-5

EXPOSURE TIME OF OPTIMUM EXPOSURE OF LUNAR SURFACE

Exposure Index	Sun Elevation	Exposure Time
6.0 (improved 4404)	15° - 30°	1/100 sec.
	35° - 45°	1/140 sec.
	50° - 60°	1/200 sec.

* The Aerial Exposure Index is given by 1/2 Es, where Es is the exposure at the 0.6 gamma point (speed point) of the density - log E curve.

3.5.3 Conclusions

The "Exposure Criterion for Lunar Photography" is that:

(1) The "average" scene luminance as determined from the distribution of scene luminance at the film plane for a given range in sun altitude be exposed to yield a density of 1.00.

(2) The lunar photographic system exposure times be varied as a function of sun elevation. The exposure times required are listed in Table 3-5.

3.6 PHOTOGRAPHIC OUTPUT

The following paragraphs describe the proposed film format and the auxiliary data to be contained therein. Edge data requirements are based on maximum post flight support.

3.6.1 Image Format

The photographic frame is divided laterally into five principle areas:

(1) Data side area
(2) Yaw slit A area
(3) Scene image area
(4) Yaw slit B area
(5) Title side area

Fiducial lines form a border between the yaw slit areas and the scene image area.

The data side area contains two data tracks: track A, a 400 cps pulse chain and track B, a 10 cps pulse chain with time, location, and attitude labels encoded in binary form periodically recorded between the pulses. All pulses are of 400 cps equivalent size, thus the proximity of the 400 cps time track (data track A) can assist in visual label decoding. All pulses are recorded in real time during lunar photography. Density levels of the recorded pulses will be compatible with machine reading techniques.

The title side area contains a series of pre-launch exposed gray scales to assist in calibration of the photometry. This area is also available for post-flight titling of the photographic frame. See Figure 3-17 for a dimensioned picturial presentation of the image format.

All data track information is recorded on the film through the use of electrically keyed lamps. The yaw slit images* and fiducial lines are formed directly from the scene image.

3.6.2 Data Recording

As mentioned in the previous paragraphs two data tracks are recorded on the photographic record during lunar photography. The proposed format employs a 400 cps pulse chain or time track in data track A and a 10 cps time track in data track B. The 10 cps time track is obtained by a C/P counting circuit utilizing the 400 cps pulse train. Three data words obtained from an associate's subsystem encoded in serial binary form are required to produce the proposed data labels which will assist in the post flight analysis of the photographic record and index the survey and mapping photography. A breakdown of the requirements set by the labels is outlined as follows.

* Yaw slits are used to enable a direct optical/film recording of camera roll and yaw attitude and IMC error.

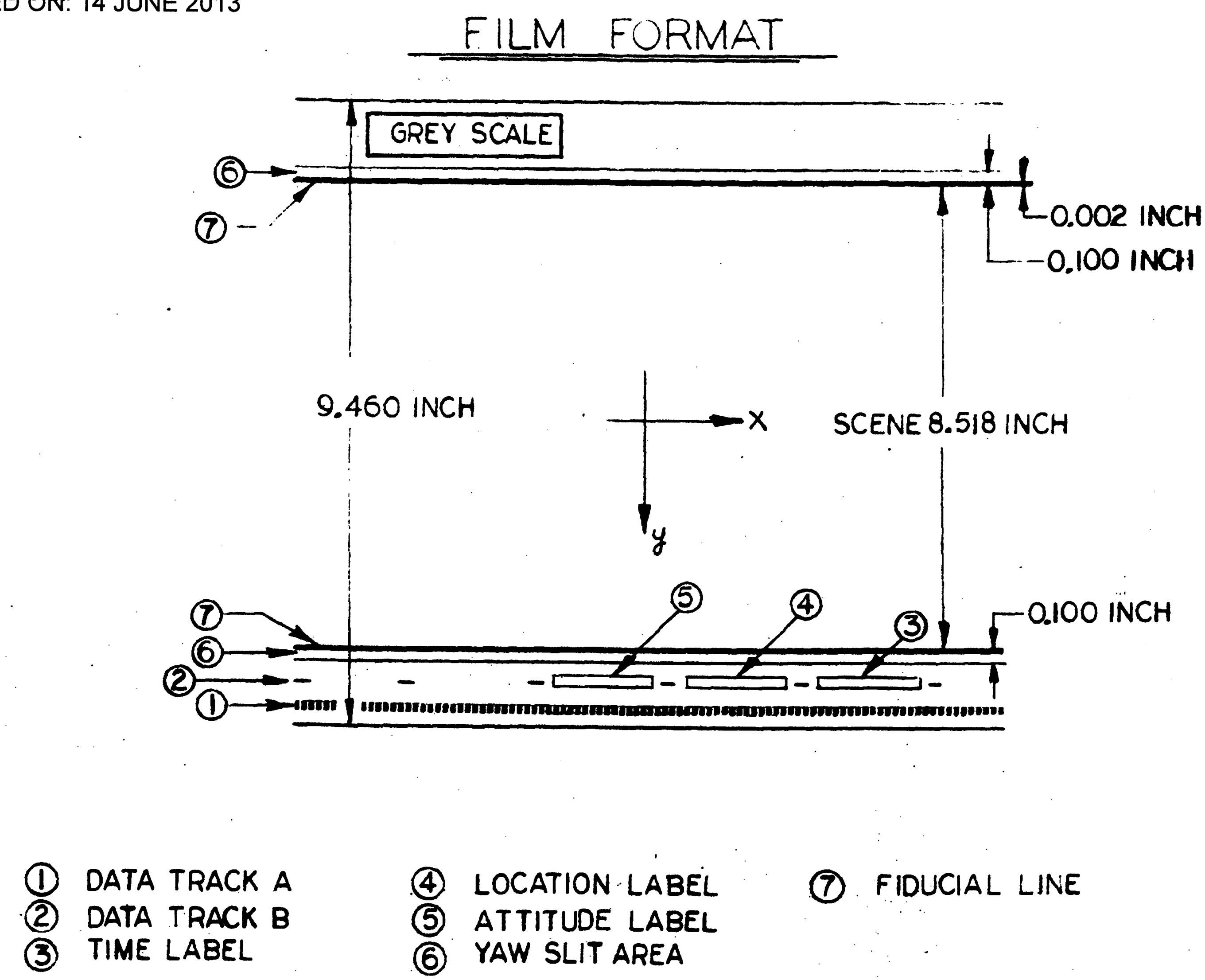


Figure 3-17. Film Format

Time Label:

(a) 23 bit binary code

(b) Granularity of 0.1 seconds

(c) Provided every 1.6 seconds during photography

(d) Bit frequency 400 cps

Location Label: The location label contains three elements of vehicle location which are latitude of nadir, longitude of nadir, and altitude of vehicle. The three elements combined form a 36 bit binary coded word. All bit frequencies are at 400 cps. The label should be provided every 1.6 seconds during photography.

Longitude:

(a) 15 bit binary code

1 bit direction (East/West)
14 bit magnitude

(b) Granulaity of 1 minute of arc

(c) Range of 180°E to 180°W

Latitude:

(a) 11 bit binary code

1 bit direction (North/South)
10 bit magnitude

(b) Granularity of 1 minute of arc

(c) Range 16°N to 16°S

Altitude:

(a) 10 bit binary code

(b) Granularity 0.1 n. mi.

(c) Maximum altitude approximately 125 n. mi.

Attitude Label: The attitude label contains three elements of vehicle attitude which are roll, pitch, and yaw with respect to a local vertical, vehicle coordinate system. The three elements combined form a 20 bit binary coded word. All bit frequencies are at 400 cps. The label should be supplied every 1.6 seconds during photography.

Roll:

(a) 8 bit binary code

1 bit direction (+ or -)
7 bit magnitude

(b) Granularity 0.1 degrees

(c) Range ±10 degrees

Pitch:

(a) 6 bit binary code

(b) Granularity 0.1 degree

(c) Range ±3 degrees

Yaw:

(a) 6 bit binary code

1 bit direction (+ or -)
5 bit magnitude

(b) Granularity 0.1 degree

(c) Range ±3 degrees

A sketch of the label format is given in Figure 3-18. Note that each label follows successive 10 cps pulses which are also recorded in data track A. The information contained in each label represents the described function at the time represented by the one-tenth second pulse it follows.

Should the requirements set forth by the proposed data recording section prove to be incompatible with the Block II Apollo System, trade-offs and adjustments can be made.

3.6.3 Mapping Mission Support

The ability of a mapping system to generate high quality topographical maps is dependent primarily upon knowledge of control points, photographic resolution, and stereo acuity. Contour mapping based on standard plotting and mapping techniques requires a ground resolution which is about 10 times better than the desired contour interval. That is, a contour interval of 100 meters would require a ground resolution of 10 meters. Recent mapping advances have developed a plotting technique which allows associated high resolution photos to be used with the basic mapping photography to improve the obtainable contour interval. This mapping improvement can be achieved on the Apollo mapping mission by employing the survey camera high resolution stereo photography in conjunction with the SIC mapping photography. Therefore, it is very advantageous to the total mapping and survey mission if the survey photography and mapping photography are compatible.

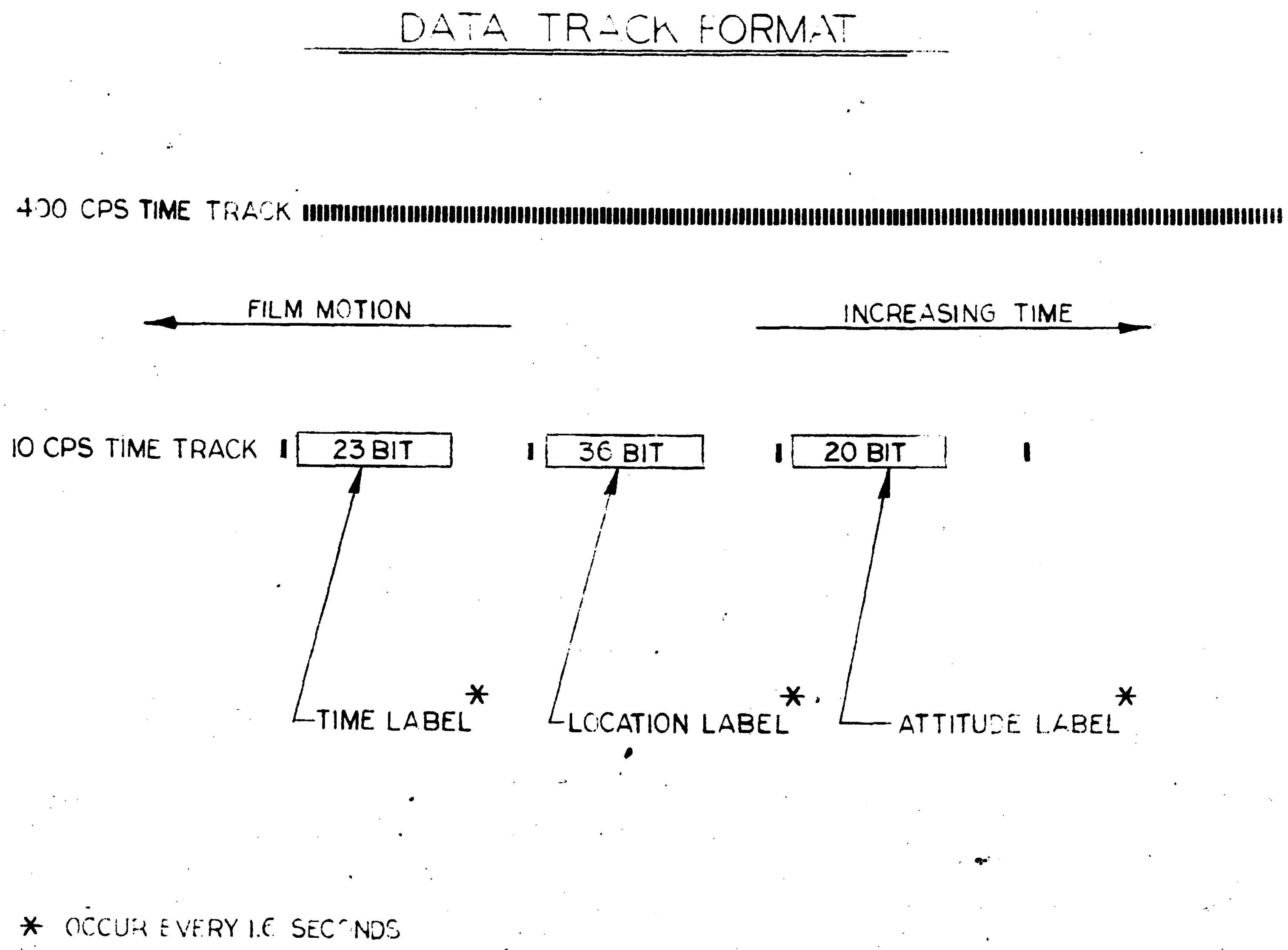


Figure 3-18. Data Track Format

The following desirable properties of the proposed camera lend themselves to this mapping support application:

(1) The photography output has a constant scale in the X direction and Y direction, therefore, rectification of photography can be accomplished by standard techniques.

(2) The proposed camera system provides high acuity contiguous stereo coverage of site areas.

(3) Cross-track overlap of site photography permits bridging cross-track.

(4) High resolution, about 3 3 (b) (1) [redacted] ground resolution is obtained for 2:1 contrast at 30 n. mi. altitude.

(5) Edge data and yaw slit images determine attitude of camera during photography.

(6) Neglecting radial errors which will be a function of the vertical mapping control, in-track distance measurements are accurate to about 1%.

(7) Lens distortion less than 0.1% across the field.

3.6.4 Simulations

The following simulations are submitted to better convey to the reader a feeling for the scale, ground resolution and stereo effect of our proposed survey-camera photography. All simulated ground resolutions are based on a 2:1 contrast.

3.6.4.1 <u>Simulation of Resolution and Stereo Effect</u>. The stero prints * shown in Figure 3-19 simulate the resolution performance of the C/P for an orbital altitude of 30 n. mi. and a stereo convergence angle of 30°. The original negatives were obtained by photographing a 1/80 scale LEM (type)

* Stereo viewer attached to front cover

Set A

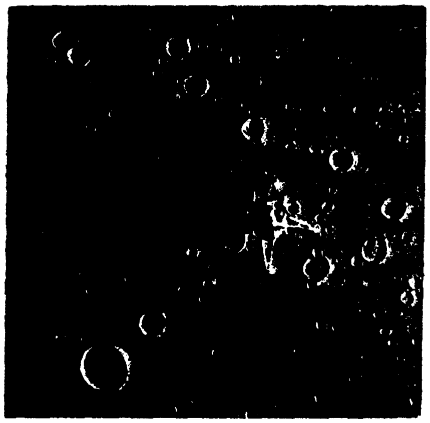
In-track stereo (30°)
at 30 n.mi. altitude
(20° sun angle)

|←—— 195 feet ——→|

Figure 3-19. 3.3(b)(1) [redacted] Simulation of Ground Resolution on Lunar Surface

Set B

Cross track
stereo at
30 n.mi.
altitude



model positioned on a relief model of the lunar surface. The resulting print simulates a performance of approximately [redacted] ground resolution. Stereo set A simulates this level of performance for in-track stereo coverage as produced by stereo pairs, stereo-mono pairs, and alternate orbit strip stereo. Stereo set B simulates this level of performance for cross-track stereo coverage as obtained with panoramic or oblique coverage.

To better portray the level of performance [redacted] resolution represents, Figure 3-20 has been included. Print A shows a photograph of an earth scene which simulates [redacted] ground resolution. As related earlier, this represents approximately the performance of the C/P from an altitude of 30 n. mi. (about 182,000 feet). Print B simulates the maximum resolution obtained to date of the lunar surface. This level of resolution was achieved by the last Ranger VII photograph from an altitude of 0.17 n. mi. (about 1000 feet). A visual comparison of the two prints conveys the relative enhancement of scene detail which can be expected with the Apollo photographic flights. However, of even more importance, print A conveys the C/P performance level in terms of images that our eyes more readily understand.

Figure 3-21 contains a stereo pair which simulates the C/P performance at an orbital attitude of 80 n. mi. and a stereo convergence angle of 30°. The ground resolution portrayed by this simulation is about 24 inches.

Referring back to Figure 3-19 for a moment, an interesting point can be brought out. The four aspects related by the four photographs allow examination on all sides of a common target such as the LEM model. These four aspects are obtainable with the proposed C/P configuration when accompanied by a vehicle roll capability. Thus, when a lunar target is encountered about which maximum information is required, this four aspect approach to photography can be available.

Print "A"

[redacted] Ground
Resolution

(Appollo at
30 n.mi.)

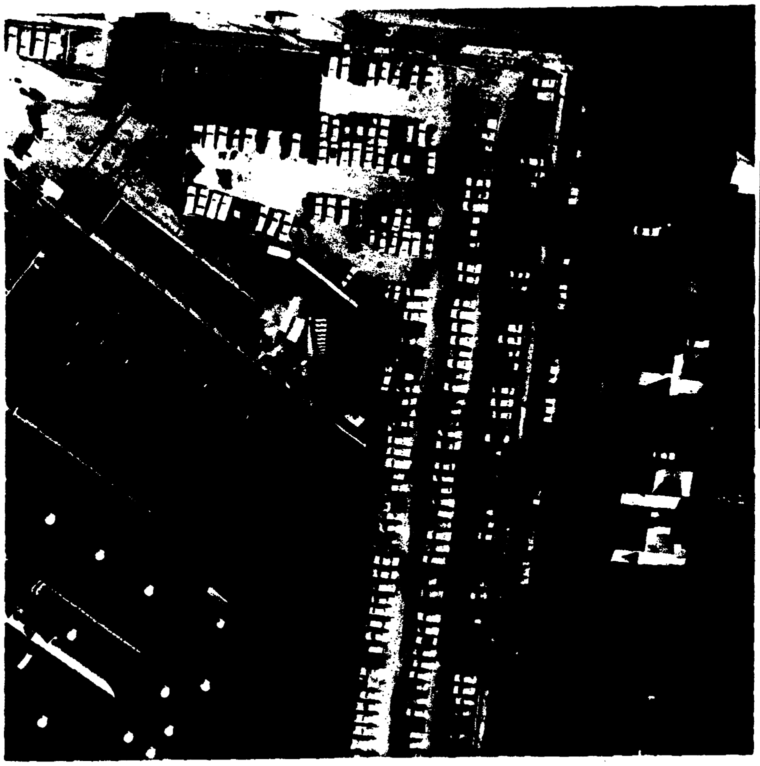
Figure 3-20. Earth Scene Simulation of Apollo and Ranger Resolution

Print "B"

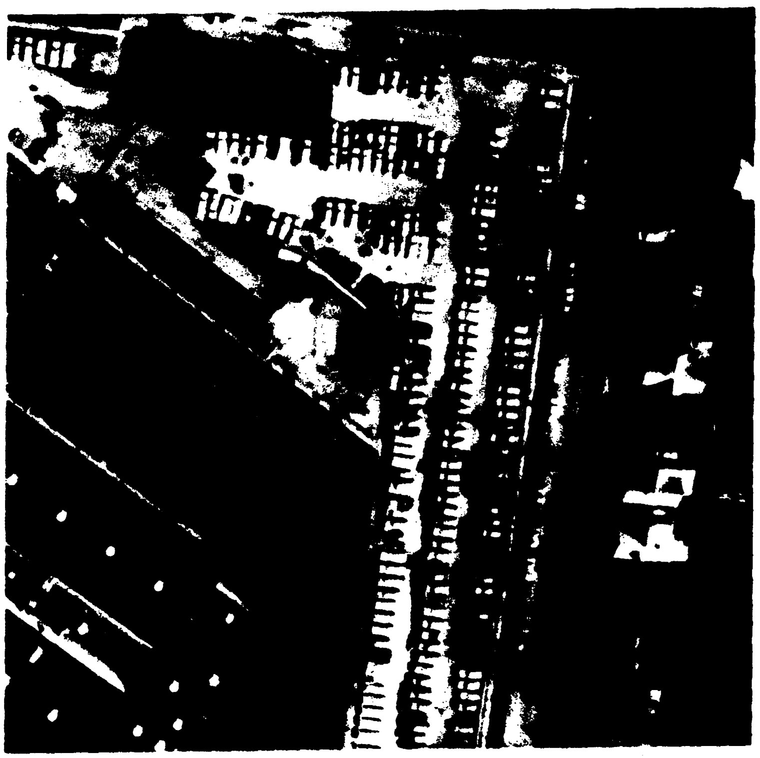
36" Ground
Resolution

(Ranger at
0.16 n.mi.)

NRO APPROVED FOR RELEASE
DECLASSIFIED BY: C/IRRG
DECLASSIFIED ON: 14 JUNE 2013



3.3(b)(1) [redacted]



In track stereo at 80 n.mi.

20° Sun Angle

30° Stereo Angle

|←—— 195 feet ——→|

Figure 3-21. Simulation of 24-Inch Ground Resolution on Lunar Surface

3.6.4.2 Simulation of Scale. The scale simulations included as Figure 3-22 and Figure 3-23 are provided to relate to the reader a visual presentation of the lateral camera coverage contained on the photographic plane. This is presented as the long dimension on each print which is scaled to the proposed image format. On these scale simulations no attempt has been made to simulate performance.

Figure 3-22 is composed of two prints which simulate the lateral coverage at an orbital altitude of 30 n. mi. Print A shows this coverage as a section of Ranger Photo 2B16062-9 which simulates the required 3.4 n. mi. swath width at the film plane. For those of us who have a better feel for distances when confronted with earth images, print B is provided which simulated the same lateral coverage as a section of Washington, D.C., area.

Figure 3-23 is also composed of two prints which now simulate the lateral coverage of the high end of the altitude range 80 n. mi. Print A employs Ranger Photo 2B16062-8 to convey the lateral swath coverage of 9.8 n. mi. at the film plane while print B shows this same coverage as a section of the Washington D.C., area.

The in-track coverage, short dimension of each print, is not simulated and will depend on the mode of C/P operation employed.

3.6.4.3 Smear Simulations

Figure 3-23.1 is provided to give the reader a visual simulation of the effect of image smear. The quality of the photographs are comparable to the performance of the survey camera operating at an altitude of 80 n. mi. although a direct simulation of quality is not intended.

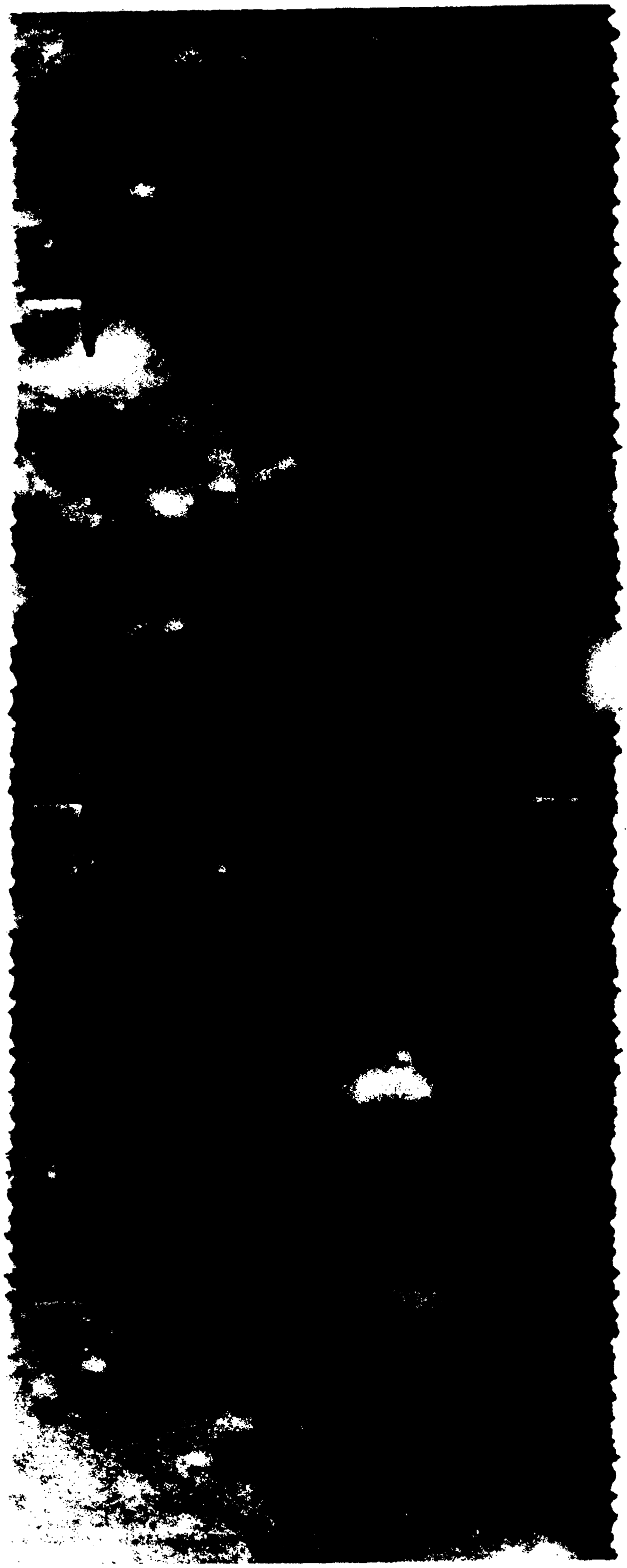
Print A: Ranger Photo 2B16062-9

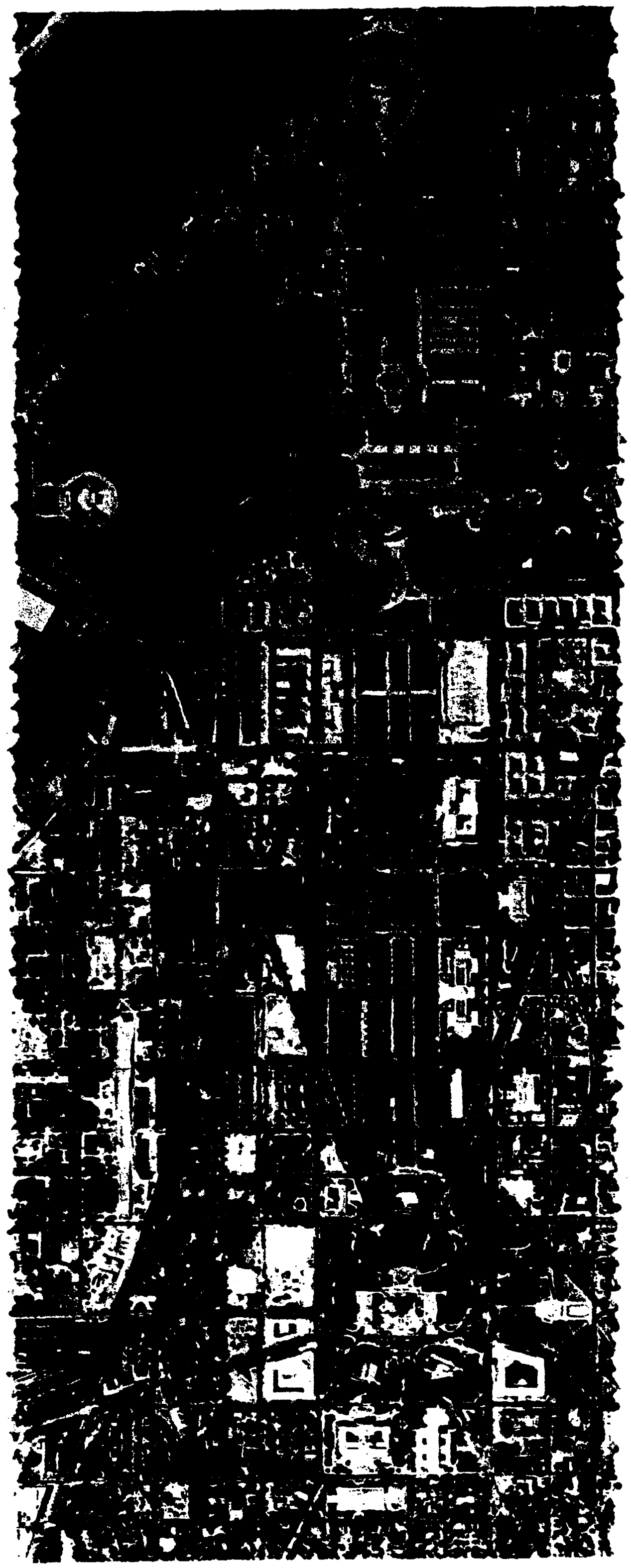
Print B: Washington DC Scene

3.4 n.mi.

Figure 3-22.1. Scale Simulation for 30 N.Mi. Altitude Photography

In-track Direction ⟶





Print A: Ranger Photo 2B16062-8

Print B: Washington DC Scene

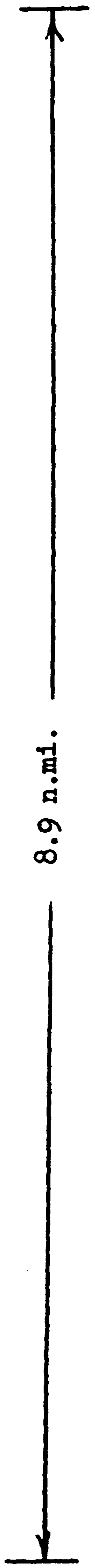


Figure 3-22.2. Scale Simulation for 80 N.Mi. Altitude Photography

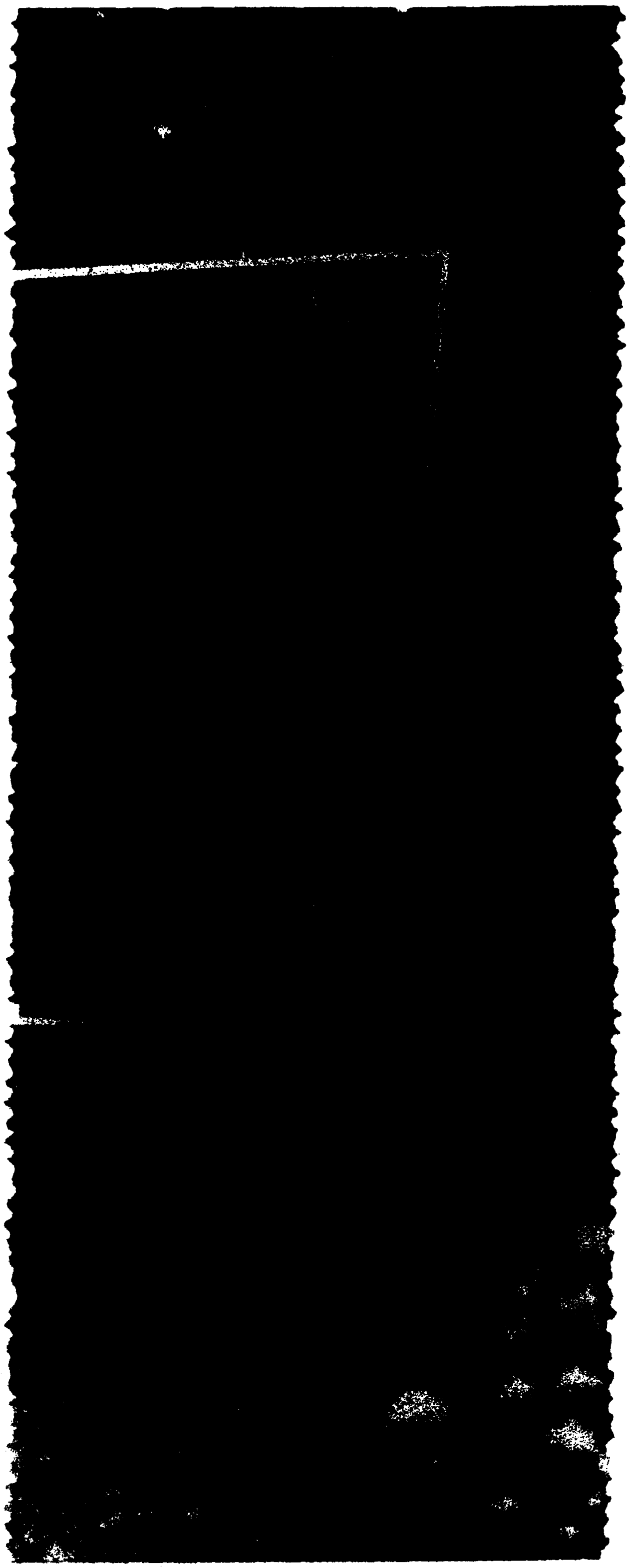
In-track Direction →

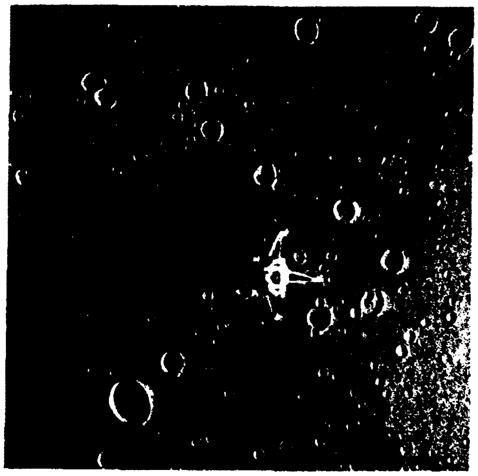
Illustration A
Zero Smear

Illustration B
One foot smear

Illustration C
Three feet smear

Figure 3-23.1. Smear Simulations





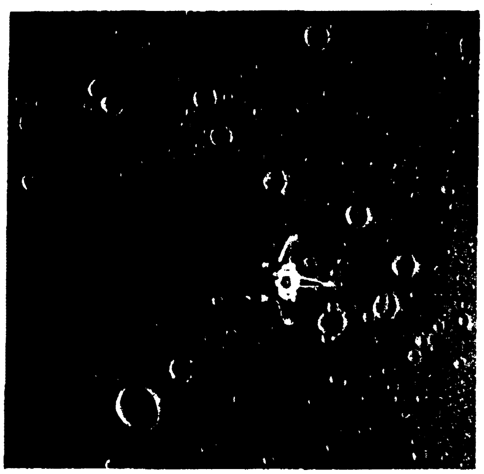
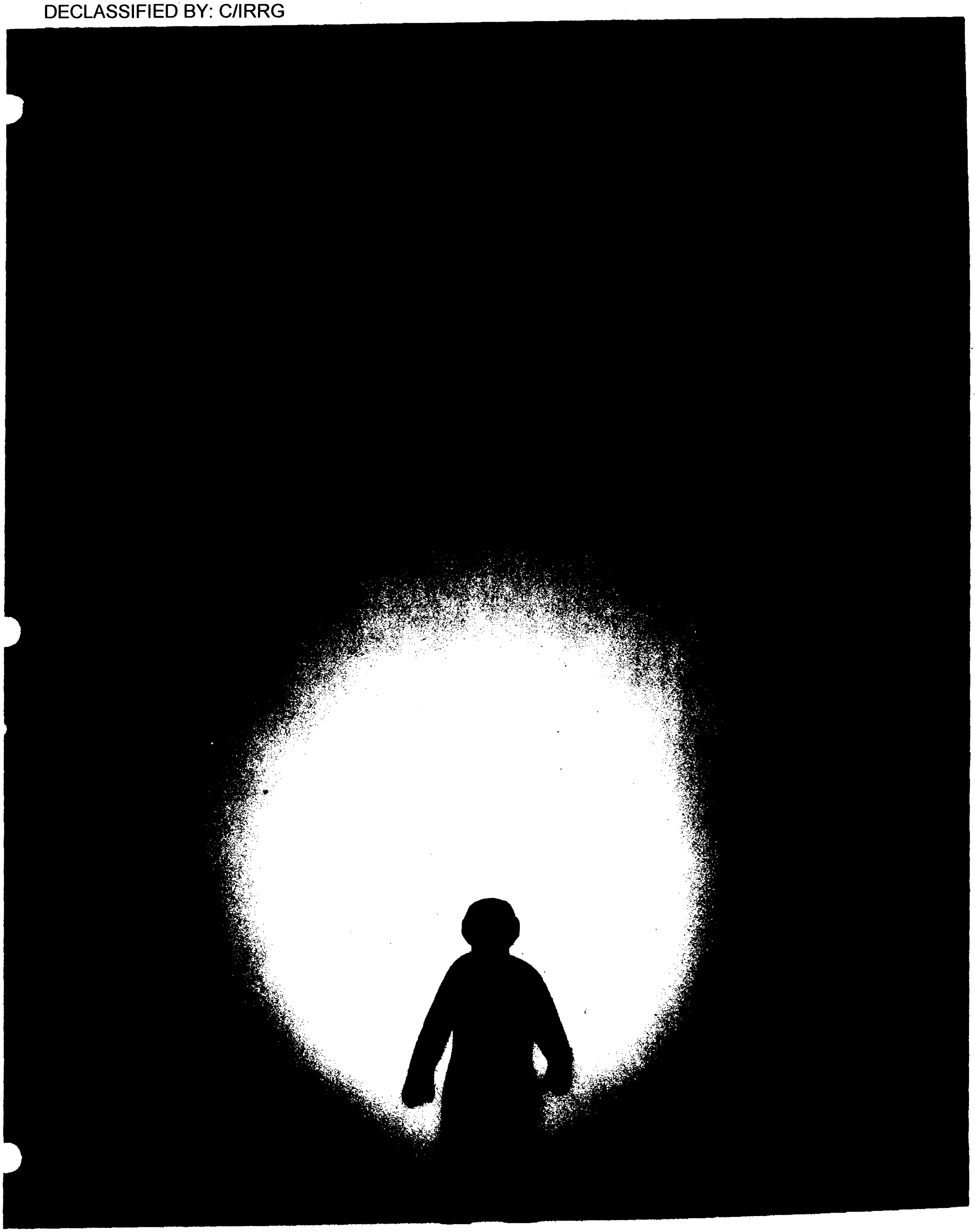


Figure 3-23.2. Lunar Photometric Simulation



Example A represents a zero smear level of photography and acts as a base for comparison.

Example B represents a nominal level of smear (1 ft. on the ground).

Example C represents a level of smear 3 times greater than set as a nominal in Example B (3 ft.).

Two points of discussion are introduced by this series of prints. First, a comparison of Example A and Example B shows that a certain level of smear (in this case 1 ft.) is obtainable before measurable degradation of the photograph is detected. Many of the design goal tolerances are based on this minimum detectable smear. Second, a comparison of Example B and Example C shows the effect of increasing the smear level above 1 ft. Note that a level of degradation is now quite apparent. This factor of 3 increase in smear is not unrealistic with regard to the Apollo System since it is comparable to the increase in system smear obtained by increasing the 2 roll rate from .004 degrees/sec (design goal) to .019 degrees/sec (present CSM w/o LEM).

3.6.4.4 Simulation of the Lunar Photometric Function. Figure 3-23.2 relates pictorially the effect of the lunar photometric function on what might be considered a typical observation - a man viewing his own shadow which is projected in front of him/horizontal, on a flat, uniform surface. The illuminating source is behind the observer and at an elevation of 45° with respect to the projection surface. Note that the apparent surface brightness decreases as the observer looks away from the shadow of his head. Maximum brightness is at the observers head shodow since it lies on a line between the point of observation (the man's eyes) and the illuminating source.

3.7 EARTH ORBIT FLIGHT TESTS

The careful NASA step-by-step approach to the manned lunar mission calls for a program of earth-orbiting test vehicles prior to launching the first manned lunar spacecraft. This section concerns the problems of testing the lunar survey camera in an earth-orbiting environment.

The differences between earth and its moon, such as atmosphere, albedo and terrain, present two basically different photographic problems. Two alternate approaches to earth orbit testing of the survey camera are possible. The C/P can be modified to permit the attainment of high resolution earth photography or the C/P can be kept in its proposed lunar configuration. The basic modifications are not severe, and can be further simplified if the inclination and/or nominal altitude of the earth testing orbit can be selected on the basis of photographic considerations. For example, a very low orbital inclination will minimize the cross track image velocity due to the earth's rotation and thereby minimize the crab angle modification. A higher altitude testing orbit, on the order of 150 nautical miles, will produce a lower Vg/h level and thus minimize the IMC modifications.

With either C/P configuration, modified or unmodified, the basic task of the earth orbit test program should be to establish the compatibility of the spacecraft and subsystem in both prelaunch and orbital phases and also to establish operational readiness of the total system. Final performance, based on lunar mission requirements, can only be partially satisfied by earth orbit testing. Several units, such as the Vg/h sensor and the focus electronics, operate from a ground image, thus C/P performance based on earth images can be established. However, performance based on lunar images will be unresolved until an actual lunar operation is conducted. Likewise, thermal differences between the two missions will lend some uncertainties to earth orbit testing. For example, higher albedo energy inputs to the stereo mirror will result in larger mirror differential temperatures than predicted for lunar missions. Absolute temperatures, for the most part, can be compensated by coating (α/ϵ) changes.

In spite of these problems, earth orbit testing can establish confidence in the lunar mission readiness of the C/P design. For example, satisfactory operation of the following C/P units can be demonstrated.

(1) Film transport
(2) Camera IMC
(3) Optics - (modified C/P only)
(4) Crab and stereo drives
(5) Platen drive
(6) Programmable slit positioning
(7) View-port door
(8) Command response
(9) Instrumentation and down telemetry
(10) Edge data
(11) Cut/separation
(12) Film retrieval

The basic C/P design can be validated, operational experience can be obtained, and subsystem compatibility can be established. A plan for earth orbit testing should reflect photo testing requirements. This plan should have as its goal the following tasks:

a) To set a series of flight test objectives aimed at examining the operational readiness of the system.

b) To examine the trade-offs between C/P configuration and possible earth orbit.

c) To establish an earth orbit test mission profile based on the results of (a) and (b).

3.8 C/P UTILIZATION OF APOLLO SUBSYSTEMS AND ASTRONAUTS

3.8.1 C/P Control Philosophy

As an introduction to the application of other Apollo subsystems to C/P use, let us examine basic C/P control requirements. Proper performance of the camera payload during a photographic operation requires active control over several of the camera's functions. A list of these functions reads as follows:

1) Timing - Camera events must be initiated at the right place and in the right sequence.

2) Exposure - The correct programmable slit must be positioned in the image field.

3) Focus - The focus setting must be compatible with the camera to object distance.

4) Mode - The desired mode of operation must be selected.

5) IMC - The proper film velocity and crab setting must be maintained during photography.

6) Temperature - Thermal control must be maintained to optimize the performance of the optics.

7) Attitude - Camera attitude must be maintained to ensure coverage and minimize image smear.

For discussion purposes these seven tasks can be divided into three basic groupings: (1) those which can be internally controlled by the C/P, (2) those which at present can not be internally controlled, and (3) those which appear to be sitting right on the fence.

Comprising the first group are those functions which can be predicted in advance, and/or follow a well defined principle which lends itself to automated controls, such as IMC, thermal control, focus control, and several of the mode sequences. Thus a degree of automatic control can be built into the camera subsystem without repeating capabilities presently available in the CSM subsystem.

The second group represents those tasks which can not be predetermined, and/or do not follow a well defined principle or do not lend themself to automation. The prime member of this group is timing. Camera ON and OFF events are dependent upon vehicle location; due to the wide range of orbits and uncertainty in the J_2 and J_3 force field terms, automatic programming of a lunar mission is not advisable at this time. Thus, a reliance on an updatable memory such as that contained in the AGC unit is required. This requirement does not extend to stereo sampling-photo modes of operation.

The third grouping is comprised of the fence sitters of which exposure is the prime example. Exposure determination is basically a function of three factors: (1) film velocity, (2) slit width, and (3) scene brightness. The slit width-film velocity relationship is well understood and lends itself readily to internal C/P logic. However, scene brightness determination, if automated, requires some sort of photometer device, (potentially available in the V/h sensor). Thus, the problem becomes very similar to that of automatic exposure in earth orbiting cameras except we have traded problems created by white clouds for problems created by deep shadows. Any photometer is an integrator over some finite area, and therefore, it can be deceived by the presence of either deep shadows or by the presence of white clouds. It is, therefore, recommended that initial missions base their exposure setting on the photometric function as we know it now and not on an automatic exposure determining device. Therefore, a computer is useful to assist in exposure slit selection during lunar orbit.

3.8.2 Utilization of Apollo Subsystem Capabilities

As related in the previous paragraphs, the C/P can utilize other Apollo subsystems to advantage as a source of edge data, down link telemetry, power, and back-up to the automated C/P internal controls. The following paragraphs outline these basic applications.

3.8.2.1 Command System Utilization. A command system is necessary to initiate and terminate photographic operations at a predetermined location, to select the mode of photography, to make real time platen position adjustments, and to initiate separation sequences. This need can be satisfied in two ways: (1) the AGC can be told when, where, and what is to be requested of the C/P and allow it to perform the complete control task, or (2) a ground computer can calculate when, where, and what, then transmit the generated commands to the AGC memory with a time request, and let the AGC initiate action based on a time request/vehicle time correlation. Either approach should allow both a real time and future time command capability.

3.8.2.2 Computer Program Uses. Potential C/P utilization of the spacecraft problem-solving computer stems from two needs: (1) the need to determine scene brightness and (2) the need for an IMC back-up control.

As mentioned previously the determination of scene brightness based on the moon's photometric function is an important part of exposure determination and therefore, exposure slit selection. Based on a firm mission plan, the correct exposure slit for each of the ten sites can be selected by a ground computer and sequenced into the variable memory of the AGC for later programming. However, if the mission plan is not firm or the orbit/lighting variability is high, it may be advisable to store the slit selection program in the AGC's fixed memory to be called upon as needed. The inputs to the program will be based on data readily available to the AGC logic. Both approaches should allow for the expanding knowledge obtained in this area by currently planned lunar probes with the eventual goal of internal C/P exposure control.

The primary mode of IMC control is through a V/h sensor.* Operation of this type of control device in lunar orbit is at present based on engineering judgement. Should some undetected facet of the lunar environment impair operation of this type of IMC control, it could degrade the photography seriously. Therefore, it is essential that a back-up control be available. The back-up control could be obtained by two possible methods.

One, because of the relatively level terrain of the site area, a nominal IMC could be employed at each site with some loss in resolution. This best IMC speed for each site could be stored in memory to be called upon as a back-up should difficulty with the internal IMC control be detected.

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* For a complete description of the V/h sensor, see Section 4.6.

Two, the basic film velocity equation could be placed in the memory of an earth based computer. The primary data inputs to the equation are focal length, altitude, vehicle inertial velocity, stereo angle and obliquity angle. Each data input except altitude is either known or can be calculated to the required accuracy with minimum effort. However, altitude above the lunar terrain is not readily available. Therefore, a moon profile or an accurate altitude sensor would be required. It appears advantageous to employ a moon profile. The total profile and an orbit track determination program are then combined within an earth based computer. The required film drive speeds based on time or location for several orbits as calculated by the computer are then transferred to the AGC variable memory which initiates changes in film velocity based on the time or location label. The up link telemetry updates the AGC memory as required based on the available amount of variable AGC memory. The second back-up approach is more complex, but it can determine film drive speed requirements at any charted point on the lunar surface. Should facilities be available to provide this level of back-up, this method is preferred.

3.8.2.3 Data Needs. To assist in post-flight analysis and to provide an index with SIC photography, several bits of spacecraft data are required by the C/P to be placed on the edge of the photographic frame. These data include attitude, location, and time and are available to the AGC; when recorded on the photographic frame they provide an invaluable tool to the photogrammatist and photometrist.

3.8.2.4 Power and Down-Telemetry Needs. The need for raw power and a down-telemetry link for the determination of payload health are obvious; the magnitude of these requirements is discussed in another part of this report.

3.8.3 Apollo Subsystem Utilization Summary

In summary, the camera payload can call upon other Apollo subsystems for the following:

(a) A command control system to initiate events based on time, location, and selection.

(b) A computer type control to provide a selection capability based on stored memory or equated relationships (scene brightness - film drive speed back-up)

(c) A down telemetry link to permit monitoring of payload health.

(d) An attitude control system to provide camera stability.

(e) Knowledge of position, attitude, and time required for edge data.

3.8.4 C/P Utilization of Astronauts

Because the astronaut is present when orbital events are taking place, he has the ability to simplify the mechanics of many events such as film retrieval. However, his most valuable feature is his ability to evaluate unusual situations, to make decisions based on experience, and to take first hand action. Based on these capabilities it is proposed that the astronaut be considered for the following:

(a) Be trained to understand the operation of the C/P, to monitor selected payload functions and assist in a determination of payload health.

(b) Be given a capability to photograph scenes of interest by aiming the camera through the vehicle attitude control system. Visual observations by the astronauts are the key to this task.

(c) Be provided with focus adjust capability so that he may back-up exercises aimed at optimizing focus.

(d) Assist with film retrieval.

(e) Conduct a series of photometric experiments to assist in establishment of an updated lunar photometric model.

The degree to which the astronauts should participate in these five tasks requires further evaluation.

3.9 RADIATION SUSCEPTIBILITY

During earth-lunar transfer, lunar orbit, and the return to earth, the Apollo lunar survey payload and more particularly the photographic film is exposed to radiation. The following paragraphs discuss the response of the proposed film to various types of radiation and the characteristics of the expected types of radiation.

3.9.1 Film Response

Silver halide emulsions are capable of storing an image because of the absorption of energy, usually from visible light. If the same material is exposed to other photon or particle radiation, some of this radiation will be absorbed and the material will receive an over-all exposure (fog) just as if the absorbed energy were light. The ability of electromagnetic or charged particles to alter the halide structure is greater than that of neutral particles. Photographic films generally have greater sensitivity to low energy photon radiation than to very high energies. Figure 3-24 shows the shape of a typical X-ray and gamma-ray sensitivity for a reconnaissance film.

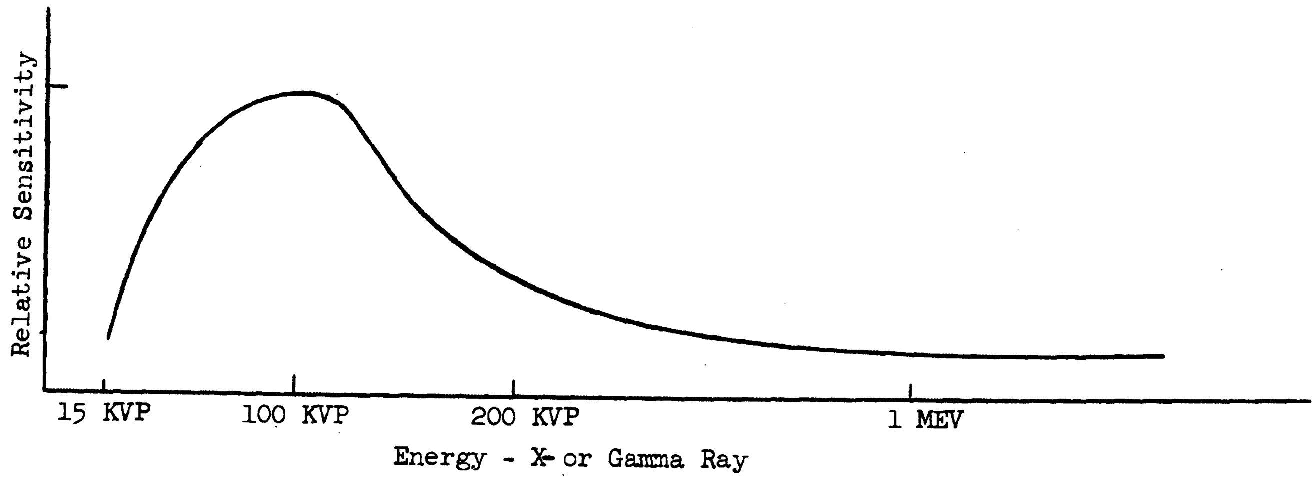

Figure 3-24. Typical X- and Gamma Ray Sensitivity

It can be seen that very high energies have a constant, but relatively small, effect on the film whereas low energies are much more effective. The ratio of peak to minimum sensitivity varies from about 20:1 to as high as 2000:1. This points out that evaluation of a particular film requires knowledge of the energy distribution of the radiation source. The energy dependence of film sensitivity is less severe for exposure with particles such as protons.

The effect of high energy X-ray exposure on the type 4404 film characteristic (H&D) curve is shown in Figure 3.25. The exposure produced by gamma rays and protons in SO243 film (an emulsion similar to type 4404) is shown in Figure 3-26. Notice that Figure 3-26 plots net radiation-produced density whereas Figure 3-25 gives total density. When comparing high energy photon exposure to high energy proton exposure, a useful simplification is that one roentgen is about as harmful as 1 rad.

The data of Figures 3-25 and 3-26 shows that 50 rads or roentgens is a threshold of noticeable Type 4404 film fogging, and that increasingly serious loss of photographic quality occurs for exposures from this level up to 1000 rads or roentgens, where all information is effectively lost.

It will be shown in the following section that only proton exposure is of significance in the lunar mission.

3.9.2 Radiation Sources

The major radiation sources considered in lunar mission analysis are:

(1) Galactic cosmic radiation
(2) Geomagnetically trapped radiation (Van Allen)
(3) Solar wind
(4) Solar flare particle radiation

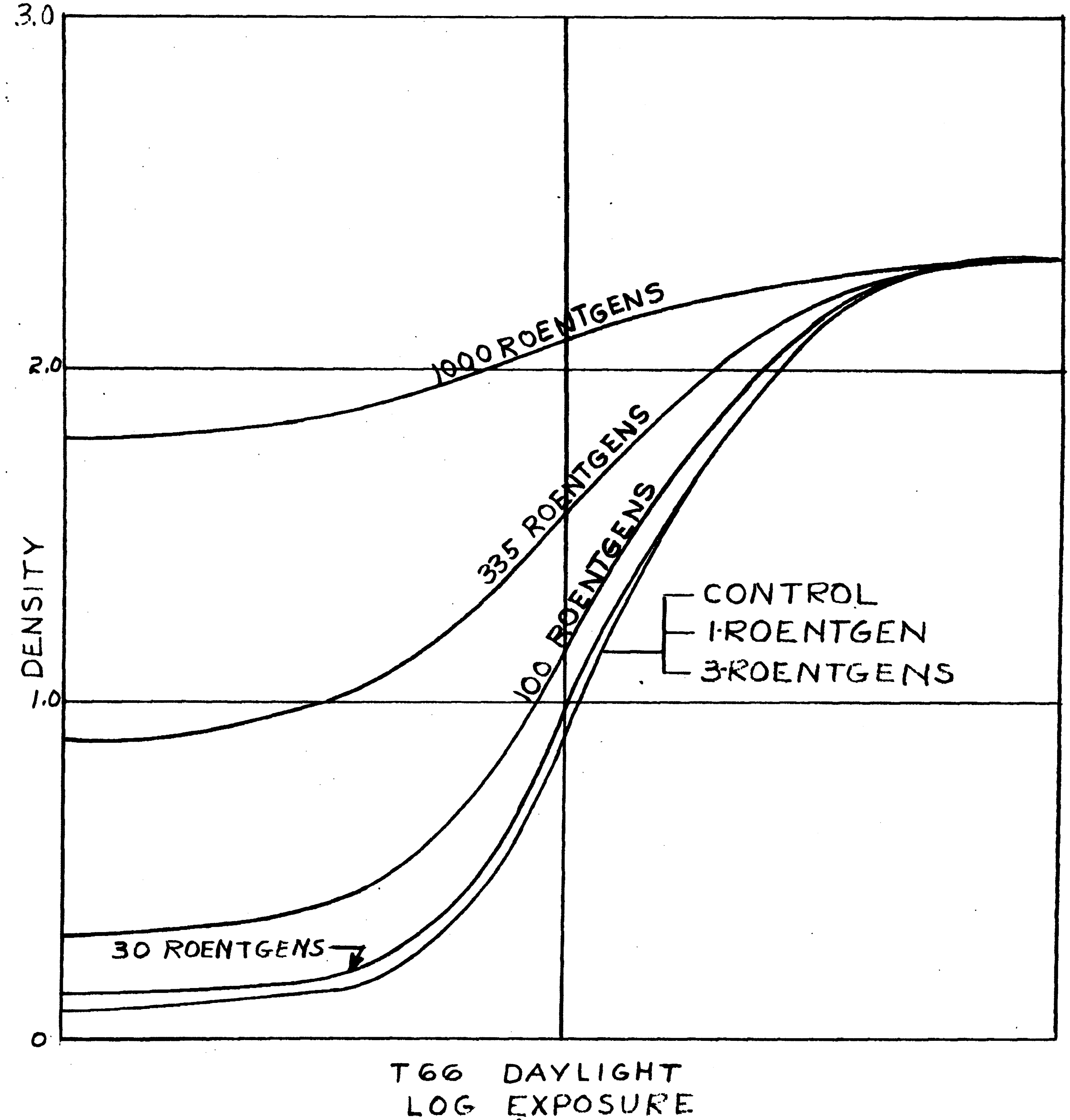

Figure 3-25. Effect of X-Ray Exposure on 4404 Film

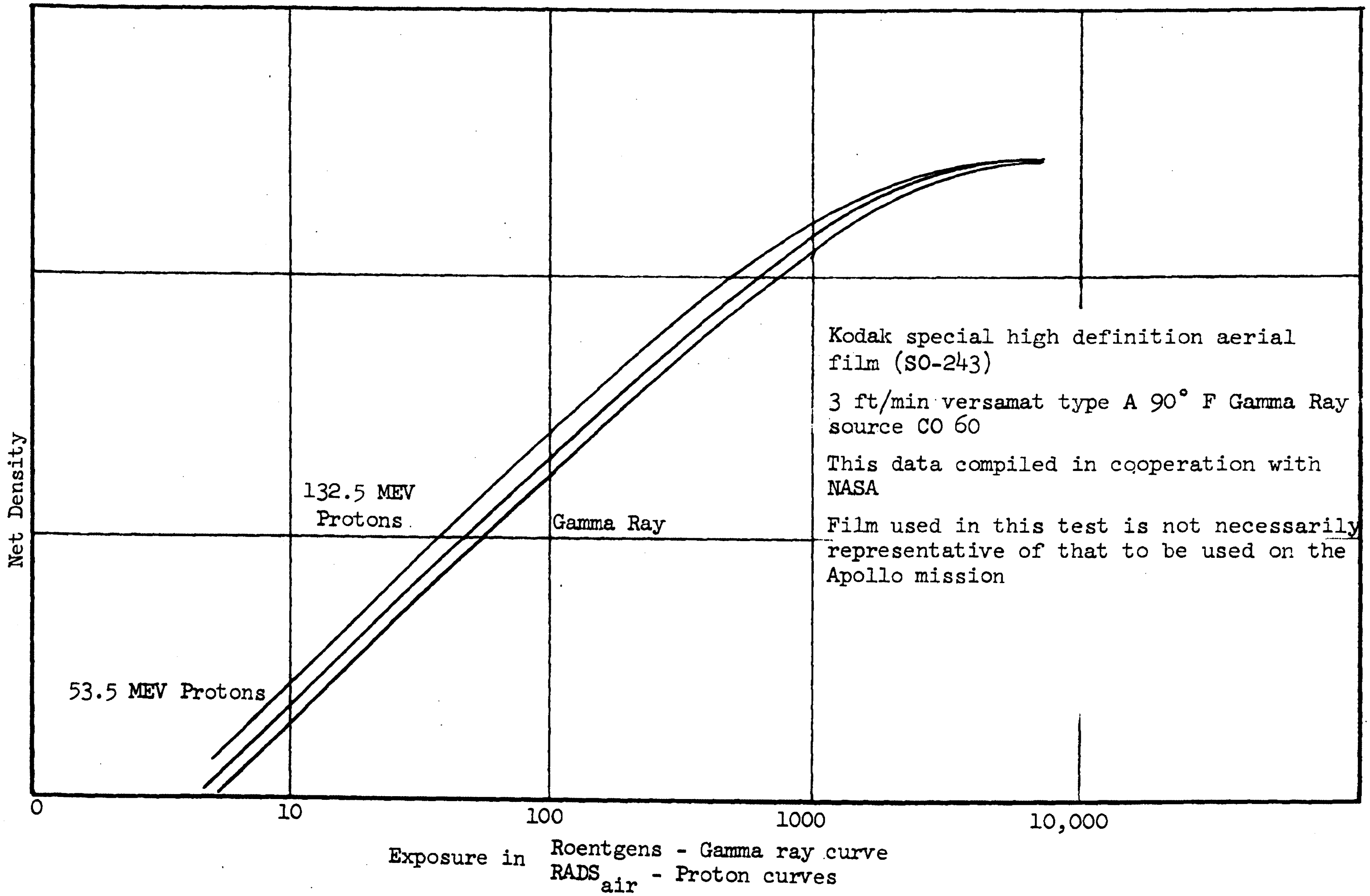

Figure 3-26. Effect of Gamma Rays and Protons on SO-243 Film

A brief description of the characteristics of these radiation sources is given below.

3.9.2.1 Galactic Cosmic Radiation. Galactic cosmic radiation consists of completely ionized atomic nuclei and is distinguished from other radiation in the vicinity of the earth by its slow time variation (11 year cycle in anticorrelation to sunspot cycle), its flat energy spectrum, and its origin from outside the solar system. The radiation dose from galactic cosmic radiation inside a lunar vehicle is approximately 0.5 to 1.0 rad per month, which can be neglected in film fogging analysis.

3.9.2.2 Geomagnetically Trapped Radiation. Geomagnetically trapped radiation, often referred to as the Van Allen belts, consists of charged particles trapped in the earth's magnetic field. There are two spatially separated regions of high flux, referred to as the inner and outer belts. The particles are predominantly protons in the inner belt and electrons in the outer belt. Trajectory analysis indicates that the worst accumulated dose for one Van Allen belt passage is eight rads, which can also be neglected.

3.9.2.3 The Solar Wind. Solar wind and storm estimates have been obtained from observations of the ripples in certain comet tails, whistlers, time lag between the onset of solar flares, and magnetic storms, etc. Solar wind is estimated to consist of 85% protons, 15% alpha particles, with some very small amounts of heavy element ions. Recently, direct measurements from space probes have been made available with the most extensive data coming from Mariner II. The electrostatic spectrometer on this probe showed that a plasma flux from the direction of the sun was nearly always present at energies of 1664 and 2476 eV. This corresponds to proton velocities of 563 and 690 km/sec respectively. The radiation dose to the film of a lunar vehicle is expected to be negligible from this source.

3.9.2.4 Solar Particle Event Radiation. Solar particle event radiation refers to the energetic particles ejected from the sun during or subsequent to a solar flare. The particles reaching the earth in these events have been found to be primarily protons with smaller concentrations of alpha particles and heavier nuclei present. In a few events, the alpha particle concentration has been quite large.

Early in an event, the low energy particle density is small. Later, the relative number of low energy to high energy particles increases. Unfortunately, the time behavior of an event is often very complicated, especially in the case of multiple events.

The time delay between flare occurrence and the arrival of the first particles depends on flare location. Particles from east limb flares may take 3 to 5 hours to reach the earth while particles from west limb flares typically require at most a few minutes to one-half hour. The transit time of particles is much longer than would be required for a straight trajectory. This is a result of the twisted, weak magnetic field that exists between the sun and the earth. This field is equivalent to a scattering medium through which the particles must diffuse. The outward streaming of the solar wind pulls the field out from the sun while the rotation of the sun coils it into a spiral. The east limb particles must diffuse across the coiled field lines while the west limb particles can more closely follow the field lines to reach the earth, which explains the dependence of transit time on flare location.

Since the magnitude and time of solar flare film exposure is a pseudo-random phenomenon, it is necessary to assign probabilities to the likelihood of obtaining a proton exposure of a given level. This is done in Figure 3-27, for 3 different 3.3 (b) (1) [redacted] for 30 day missions occurring during solar cycle 19. [redacted] 3.3 (b) (1) [redacted] This data is considered applicable to the solar cycle 20 conditions since, as Figure 3-28 shows, predicted cycle 20 activity is somewhat lower.

3.9.3 Relative Sensitivity - Film vs Crew

The preceeding data describes the finite probability of radiation affecting photographic quality. It must be pointed out, however, that the Apollo crew is as sensitive as the type 4404 film. This is shown in Table 3-6 where a rem is approximately equivalent to a photographic rad or roentgen.

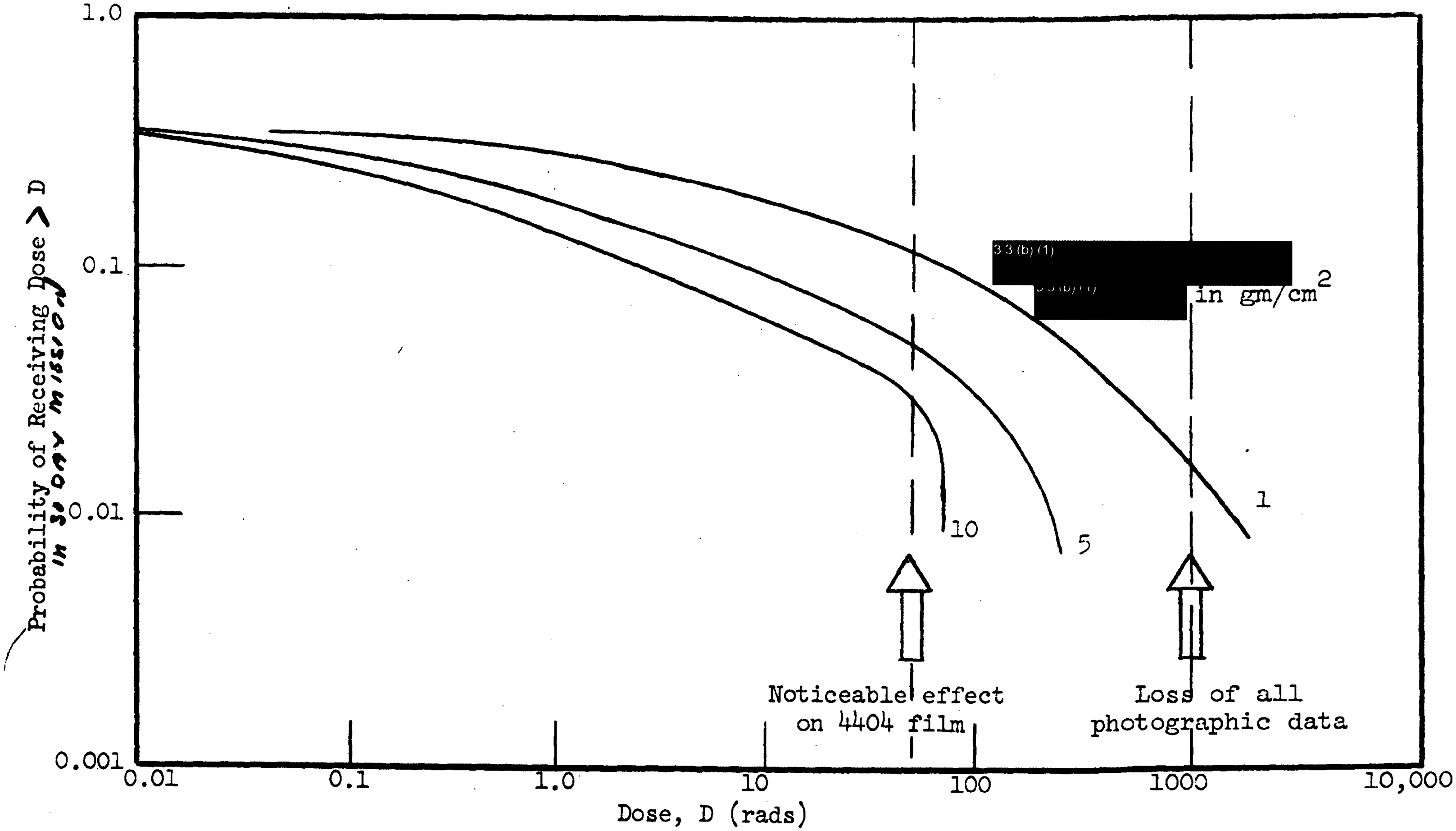

Figure 3-27. Cumulative Probability - Dose Curves for 30-Day Mission

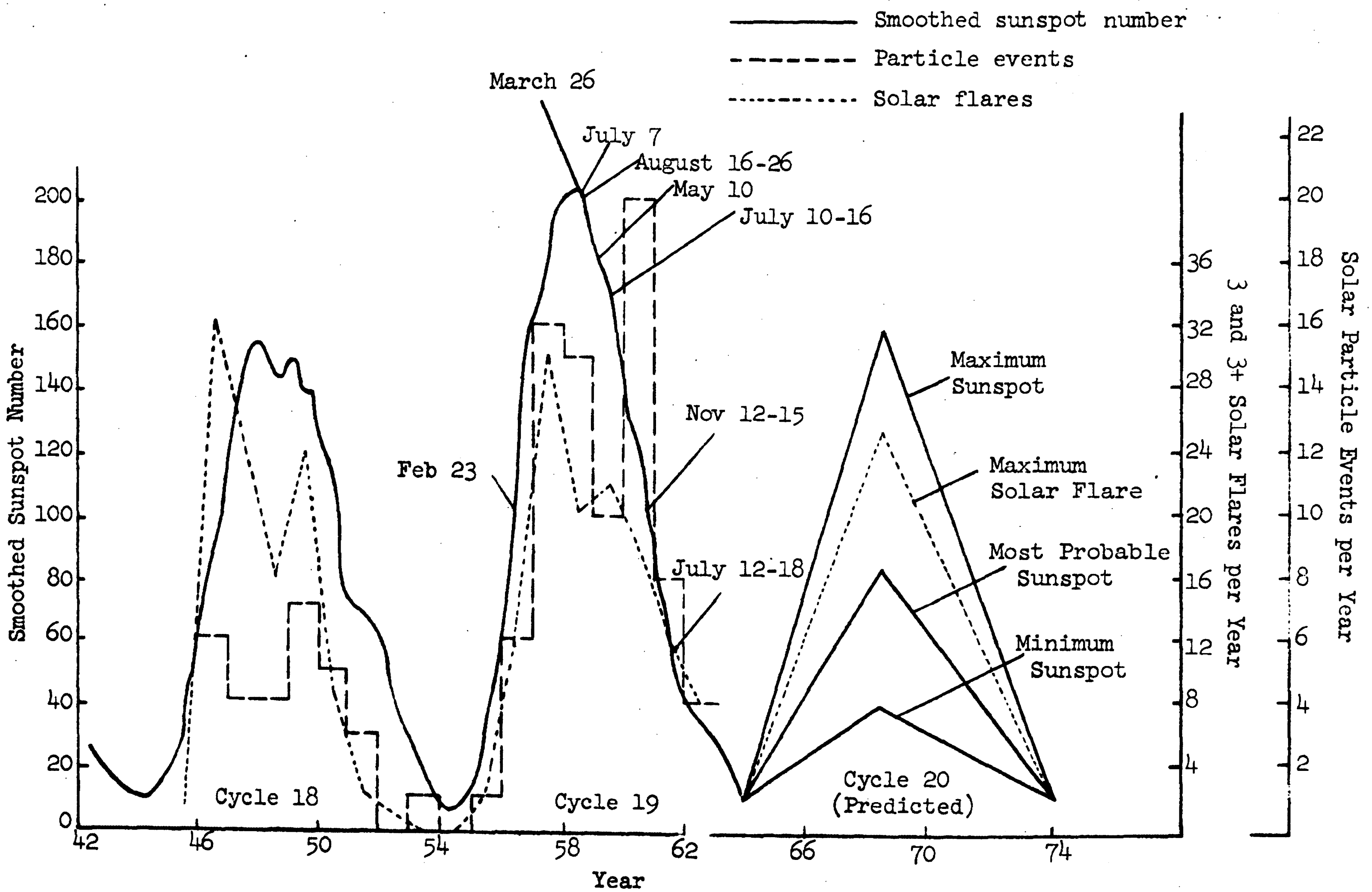

Figure 3-28. Solar Activity

3.10 System Performance Estimate

A summary of system performance (strip and panning) for cone detection is as follows:

Minimum Detectable Cone Diameter (Inches)

Smear Budget:		Nominal Smear Budget			Integral V/h Smear Budget		
Sun Angle:		15°	30°	45°	15°	30°	45°
38.6° Cone	Alt. (nm)						
Strip Stereo	30	[redacted]					
Strip Stereo	80	31.3	37.1	40.5	29.0	33.9	39.1
Panning Stereo	30	[redacted]			(Integral V/h not feasible with panning)		
26.5° Cone							
Strip Stereo	30	[redacted]					
Strip Stereo	80	32.5	38.5	54.5	30.2	36.1	50.4
Panning Stereo	30	[redacted]		24.7	(Integral V/h not feasible with panning)		

Slopes

Slopes in the range from 1° to 12° can be detected with an accuracy of ±2° or better for contrasts of 1.2 or greater.

THE PARAGRAPHS THAT FOLLOW ILLUSTRATE THE PROCEDURE USED TO ESTIMATE SYSTEM PERFORMANCE. THE GRAPHS PRESENTED ARE BASED ON USE OF THE NOMINAL SMEAR BUDGET (WITH NADIR V/h SENSING), WHEREAS POTENTIAL STRIP CAMERA PERFORMANCE IS REPRESENTED BY USE OF INTEGRAL V/h SENSING. THE PANNING SYSTEM ADAPTATION IS DISCUSSED IN SECTION 6.

3.10.1 Assumptions

There are two areas of uncertainty in predicting the ability of a photographic system to detect a small object on the surface of the moon. One has to do with the photometric characteristics of an object on the moon's surface, and the other with the detectability of a photographic image in the eye of an observer. With regard to the first, the assumption is made that it is permissible to extrapolate the characteristics of gross lunar areas and to give to small objects the same brightness and contrasts as large objects observable from the earth. An analysis of photographic performance is presented below, it is quite speculative since no reliable basis for calculation is known, but the analysis is believed to be conservative. Thus, predictions based on gross lunar photometric data are not necessarily the actual limit of performance.

Table 3-6 *

EXPOSURE TOLERANCE VALUES FOR MAN

WHOLE-BODY RADIATION DOSES

Dose	Probable Effect
0.001 rems/day	Natural background radiation
0.01 rems/day	Permissible dose range 1957
0.1 rems/day	Permissible dose range 1930-50
1 rems/day	Debilitation in 3 to 6 months; death in 3 to 6 years (projected from animal data)
10 rems/day	Debilitation in 3 to 6 weeks; death in 3 to 6 months (projected from animal data)
100 rems in one day 150 rems in one week 300 rems in one month	Survivable emergency exposure dose but permitting no further radiation exposure for life.
25 rems	Acceptable single emergency exposure
100 rems	Twenty-year career allowance in nuclear powered vehicles
500 rems	Maximum permissible twenty-year career allowance in nuclear powered vehicles.

For reference, exposure definitions are:

One <u>r</u> (Roentgen) is the quantity of gamma or X-radiation that ionizes one cubic centimeter of dry air at STP to one electrostatic unit of charge.

One <u>rep</u> (Roentgen equivalent-physical) is the quantity of radiation that produces an energy absorption of 93 ergs/gm of aqueous tissue.

One <u>rad</u> is the quantity of radiation that deposits 100 ergs/gm in any material.

One <u>rem</u> (Roentgen equivalent per man) is the quantity of particle radiation that produces tissue damage equivalent to that produced by the absorption in biological tissues of 93 ergs/gm of 200 Kev X-rays.

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* From STL "SPACE DATA" handbook.

The photometric properties of the gross lunar areas are well established and are based upon observations made by telescope from the earth. These data have been reduced to an empirical relation of the form:

$$B = B_o \rho \phi,$$

where B is the brightness of an observed surface, B_o is a constant equal to 12,560 foot-lamberts, ρ is the measured albedo, and ϕ is a function dependent on the position of the sun, the surface normal, and the direction of observation. Values of ρ are given in Section 3.5. Values of ρ are taken from Eimer's curves of Fedoret's observational data, which relates ϕ to the geometric variables, and apply to lunar maria areas. The main source of uncertainty in this approach is considered to be the extrapolation of the data from large to small objects.

In the second area of uncertainty, detectability, measured values of performance on the basis of tri-bar detection are available for an existing system and can be calculated with precision for the proposed system. It remains, however, to translate tri-bar performance into cone and slope detectability. The formula that has been provided by NASA for calculating cone detectability is:

$$E.M. = \frac{BM - Bm}{9.5\ Bg},$$

where E.M. is the equivalent modulation of a cone of diameter D, BM and Bm are the maximum and minimum brightness of the cone's surface, and Bg is the brightness of the background. The equivalent modulation, E.M., represents the modulation that has to be assigned to a tri-bar target of spatial frequency 1/.886 D in order that it possess the same detectability as the cone. This formula, although not exact, forms a convenient basis for discussion cone detectability. The detectability of slopes is considered in the low resolution limit only and depends on (1) the contrast of a slope against its background, and (2) the stereo acuity of the system.

3.10.2 Method of Calculating Photographic Performance

In the following paragraphs a discussion of the method used for estimating photographic performance based on the standard Air Force resolving power targets of 2:1 contrast is presented. Cone detection is estimated by the same method, using the cone to tri-bar conversion outlined in Section 3.10.1

3.10.2.1 Definition of Resolution. Resolution is a measure of the ability to distinguish between closely spaced objects under specific viewing conditions. For example, a photograph is said to have 2-foot ground resolution at a specified contrast ratio when light stripes 1-foot wide, 1-foot apart, and 5-feet long, with a contrasting dark background are distinguishable in the developed negative.

Resolving power depends not only on the quality of the optics, but also on the contrast of the target being photographed. Contrast of a bar-chart test object is defined mathematically as the ratio of the brightness of the light bars to the brightness of the dark background. A contrast ratio of 2:1 represents an appropriate test condition and the resolving power of the C/P is measured in the laboratory by photographing a series of test charts at 2:1 contrast, as designated in Figure 7 of MIL-STD-150A, using a 300-inch focal length collimator which will be available for this program.

3.10.2.2 Measurement of Photographic Quality. The use of solid bars and contrasting backgrounds is the familiar form of specifying resolution. This method does not lend itself to any known, well-defined method of analyzing or synthesizing of photographic systems component by component. Photographic-image quality may be measured and analyzed, however, by transfer functions frequently called sine-wave response. This method is analogous to the determination of the transfer function of electronic circuitry, each element in the photographic system is treated as a low-pass filter. The sine-wave response gives the bandpass characteristics of each element as a function of spatial frequency. As is done in electronic circuitry, the subsystem can be divided into elements such that the output of each individual element is independent of the charateristics of the next element; for example, the image formed by the lens at the film plane is independent of the smear caused by the IMC errors. Under this condition and with the assumption that the system is linear, the output of one element can be treated as the input of the next element. Therefore, the sine-wave response of each element can now be multiplied to obtain the combined effect of two or more elements; i.e., the total sine-wave response of the system. This is then operated on mathematically to obtain a measure of photographic quality.

Since the output of the C/P is survey information, the measure of photographic quality should be related to information capacity. It is theoretically possible to calculate the information capacity from measurements of the sine-wave response. Such measurements are tedious, however, and would not be suitable as a production test. It is felt that with proper consideration given to the scale and contrast of the detail to be recorded, the measurement of system resolution will give an adequate indication of information capacity or photographic quality.

3.10.2.3 Sine-Wave Response. The static lens sine-wave response curves used for determining system resolution is shown in Figure 3-29.

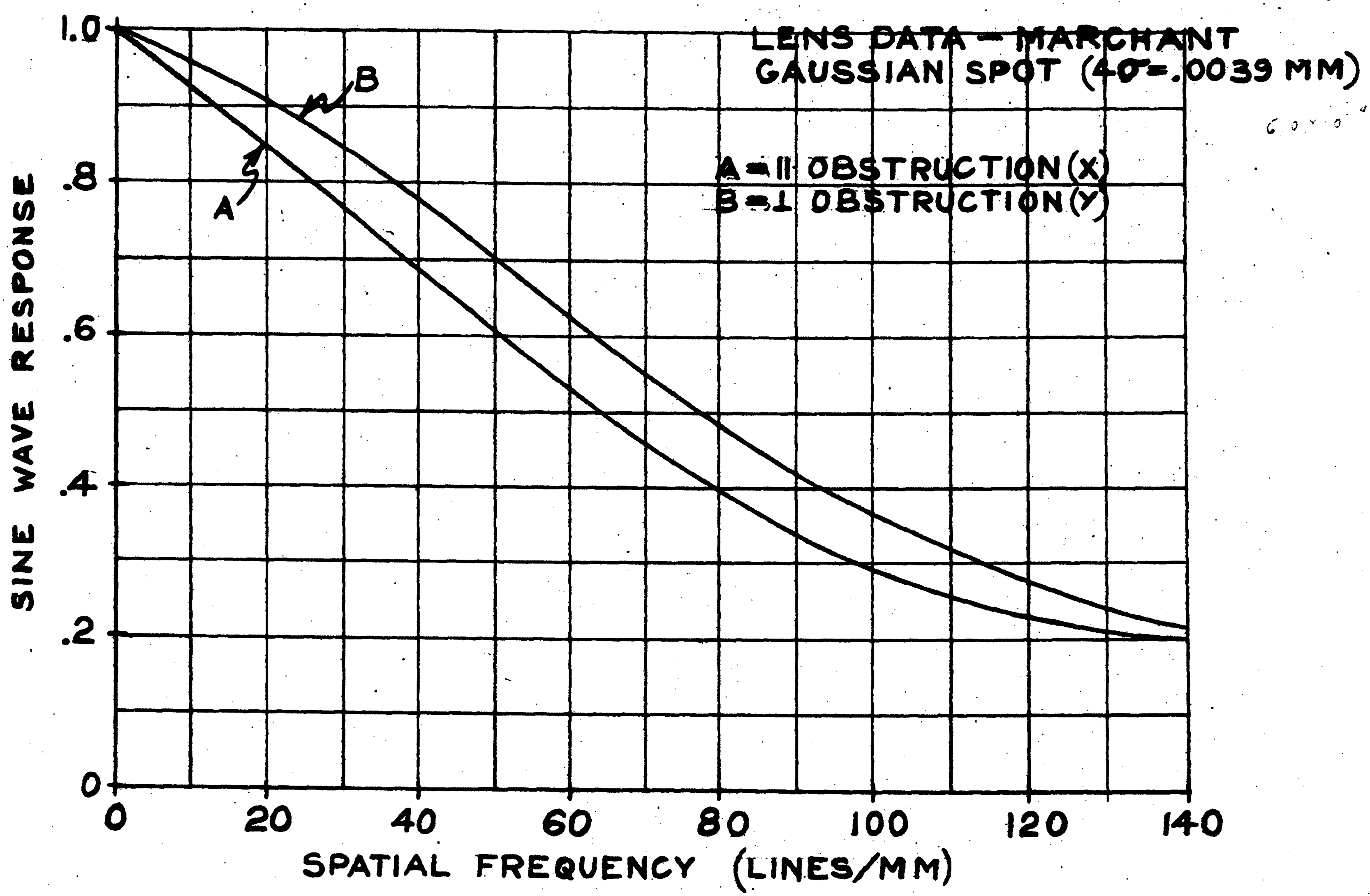

Figure 3-29. Sine-Wave Response for Lens

A general discussion of the concepts used in sine-wave response analysis is given in Appendix A. The assumptions involved in establishing the magnitude of the smear and the method of conversion from linear smear on the ground to the corresponding sine-wave response are given in Appendices B and C.

3.10.2.4 System Resolution. Using the technique outlined in Appendix D, "Exposure, Modulation, and Resolution," the resolution of the photo subsystem may be calculated for various smear values. System resolution in terms of cones is calculated by changing the .33 value of modulation (2/1 contrast) used in Figure D-1 of the Appendix to the appropriate equivalent tri-bar modulation of the cone, and accounting for the scale factor between cone and tri-bar dimensions.

3.10.2.5 Smear. The total S/C smear is made up of the contributions of smear production by the C/P, and the CSM.

There are several smear tables considered in Appendix C. The smear budget used in this section for calculating photographic performance is the nominal budget shown in Table C-2 of Appendix C. Once an exposure time and altitude have been chosen, the total smear may be calculated by the smear formula and the method of combining smear components given in Appendix C.

3.10.2.6 Computer Utilization for the Performance Estimate. The photographic performance analysis to follow has been carried out with extensive utilization of the IBM 1620 and 7044 computer systems. The smear equations and 2:1 tri-bar resolution predictions are combined into one program for use on the 1620. Photometric function, contrast, and illumination calculations are combined into a second program for use on the 7044. A third program for the 7044 makes use of the output from the first two and predicts cone detection. The formulas in Appendices A-D, as well as the cone to tri-bar conversion formulas of Section 3.10.1, are utilized in these programs.

3.10.3 Photographic Performance - Customer Ground Rules

This section deals with estimating photographic performance by the ground rules established by the customer.* These ground rules are summarized in the following table.

Table 3-7

CUSTOMER GROUND RULES FOR ESTIMATING PHOTOGRAPHIC PERFORMANCE

(1) Cone to tri-bar equivalence as outlined in Section 3.10.1.

(2) Cones having an angle with respect to the local horizontal surface of 26.5° and 38.6°.

(3) Incident illumination = 12,560 lumens per square foot.

(4) Albedo = 0.065, photometric function defined by Fedorets data.

(5) The local vertical, the sun, and the camera, are on the same plane.

(6) Total system performance to be calculated by convolution of the appropriate modulation transfer functions representing optics, film, objects, and smear terms.

(7) System performance based on a film which has a resolution of [redacted] at 2:1 contrast and a speed of 6.0 as measured at the 0.6° gamma point.

Tables 3-8 and 3-9 show data used in this report. Points from the customer's curves are shown for comparison.

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* Payload Performance Criteria, 31 August 1964, Letter from Lt. Col. John K. Hansen, M and S System Program manager, USAF.

Table 3-8

BRIGHTNESS VS. SUN ELEVATION

Brightness (Ft. - Lamberts), 30 n.mi. Altitude

	+15° Stereo		-15° Stereo	
Sun Elevation	E.K.	Customer	E.K.	Customer
0°	0	0	0	0
10°	61.2	69	42.2	37
20°	128.6	136	88.8	84
30°	201.4	206	135.8	131
40°	279.1	282	185.6	185
50°	362.5	360	240.7	240
60°	469.1	461	299.7	296
70°	673.8	619	362.3	357

Table 3-9

EQUIVALENT MODULATION VS. SUN ELEVATION, CONE ANGLE = 26.5°

	Equivalent Modulation			
	+15° Stereo		-15° Stereo	
Sun Elevation	E.K.	Customer	E.K.	Customer
15°	.220	.194	.192	.192
20°	.192	.182	.164	.164
30°	.141	.135	.118	.114
40°	.095	.087	.077	.074
50°	.067	.061	.054	.052
60°	.039	.036	.038	.038
70°	.010	.012	.012	.027

Table 3-10

EQUIVALENT MODULATION VS. SUN ELEVATION, CONE ANGLE = 38.6°

	Equivalent Modulation			
	+15° Stereo		-15° Stereo	
Sun Elevation	E.K.	Customer	E.K.	Customer
15°	.248	.225	.220	.217
20°	.206	.200	.183	.185
30°	.162	.156	.150	.150
40°	.138	.125	.129	.128
50°	.101	.099	.092	.090
60°	.065	.067	.068	.067
70°	.019	.024	.051	.051

With regard to item (7), film similar to type 4404 with a speed of 6.0 is assumed. With regard to item (6), the aerial image modulation curve of type 4404 film shown in Figure D-1 of Appendix D will be used for calculating system performance, along with the methods described in Appendices A-D. This approach is believed to be consistent with the intent of the customer.

3.10.3.1 Brightness and Modulation. Three curves representing brightness and modulation were received by EK from the customer on 11 September 1964. Slight discrepancies exist between this data and that calculated by EK. Due to the advanced stage of analysis at the time the data was received, EK was not able to revise its calculations to conform exactly to the customer's data. There is, however, excellent agreement between the two sets of data. One factor influencing the discrepancy is that EK has accounted for the curvature of the lunar surface in its calculations. At an altitude of 30 n. miles and a stereo angle of 15°, for example, the angle alpha of the background is increased 0.491°. A second factor is that EK has made all its calculations by computer, thereby increasing the significant figures carried in the calculations.

3.10.3.2 Photographic Performance. A considerable amount of information has been presented in this section concerning the details of how the photographic performance of type 4404 film is estimated in terms of tri-bar and cone detection. This information can be summarized as follows:

Tri-bar resolution is predicted by finding the intersection of the system dynamic response vs spatial frequency curve with the aerial image modulation vs spatial frequency curve for type 4404 film. The system dynamic response is the product of each spatial frequency of the static lens response, the degradation due to image smear, and the modulation of a 2:1 contrast Air Force target (33%). The aerial image modulation curve represents the experimental threshold aerial image modulation required to resolve an Air Force target. The intersection of the two curves represents the resolution capability of the photographic system in terms of lines/mm on the film. Ground resolution is expressed as the inverse of spatial frequency, scaled to ground dimensions.

Cone diameters are calculated in a similar manner, except that the target modulation is given as:

$$E.M. = \frac{Bm - Bm}{9.5\ Bg}$$

Once the photographic resolution in lines/mm has been found, the cone diameter in the image plane is calculated by the formula,

$$\text{Cone Diameter} = 1/.886V,$$

where V is spatial frequency in lines/mm. The cone diameter in the image plane is then scaled to ground dimensions.

Several figures are presented to show the expected resolution of the system in terms of cone diameter. Figures 3-30 (1) and 3-30 (2) plot cone diameter vs sun elevation for the 26.5° base angle cone for an altitude of 30 n. miles. Figures 3-31 (1) and 3-31 (2) show the same information for the 38.6° base angle cone. Exposure times of 1/75, 1/100 and 1/150 second are shown. The 1/100 second is appropriate for sun elevations from 35° to 45°. The 1/75

3.3(b)(1)

[redacted]

SUN ELEVATION (DEGREES)

(1)

3.3(b)(1)

[redacted]

SUN ELEVATION (DEGREES)

(2)

Figure 3-30. Detectable Cone Diameter vs Sun Elevation-26.5° Cone Angle

3.3(b)(1) [redacted]

SUN ELEVATION (DEGREES)

(1)

3.3(b)(1) [redacted]

SUN ELEVATION (DEGREES)

(2)

Figure 3-31. Detectable Cone Diameter vs Sun Elevation - 38.6° Cone Angle second is shown for comparison, however, this exposure time is not required by our exposure criteria. The gain in resolution with decresing exposure time is due to the reduced smear, which decreases linearly with exposure time.

Figures 3-32 through 3-33 show how ground resolution is degraded with increased altitude for the two cone angles. Sun elevations of 15° and 30° at 1/100 second and 45° sun elevation at 1/150 second exposure time are shown.

In Section 3.5, an exposure time of 1/100 second was determined to be acceptable for a sun angle range of 15° to 30°, and an albedo of 0.07. At 30 n. miles, this represents a range in detectable diameters of [redacted] for the 26.5° cone, and a range of [redacted] for the 38.6° cone. At 35° sun elevation, an exposure time of about 1/150 second is used. For this sun elevation, a diameter of [redacted] for the 26.5° cone, and a diameter of [redacted] for the 38.6° cone can be detected.

There are two thougts which must be held in mind when viewing these figures. The first is that stereo pairs of each target are taken, and resolution at both stereo angles is shown. Although resolution is usually quoted as the best of the two values, there is actually a resolution enhancement due to the second picture. The improvement in resolution due to the second picture and to stereo acuity has not been accounted for. Therefore, the figures do not imply the limiting resolution of the system.

3.10.3.3 Film Optimization by Customer Ground Rules. The preceding discussion on the detection of cones is based on the use of an advanced type 4404 film. This basic film is assumed to have a speed of 6.0 (current production material has a speed of 3.6) at the 0.60 gamma point and it has a limiting resolution of [redacted] at 2/1 contrast. In Section 3.5, an exposure time of 1/100 second was chosen to obtain optimum

3.3(b)(1)

[redacted]

Altitude (nautical miles)

3.3(b)(1)

[redacted]

Altitude (nautical miles)

Figure 3-32. Detectable Cone Diameter vs Camera Altitude for Cone Angle of 26.5 Degrees

3.3(b)(1) [redacted]

3.3(b)(1) [redacted]

Figure 3-33. Detectable Cone Diameter vs Camera Altitude for Cone Angle of 38.6°

exposure for an albedo of 0.07 and a sun elevation range of 15° to 30°. For the same albedo and a sun elevation range of 35° to 45°, the optimum exposure is about 1/150 second. At an altitude of 30 nautical miles, the nominal smear budget (Table C-2 of Appendix C) predicts 5.15 microns of smear across the slit for 1/100 second, and 3.43 microns of smear across the slit for 1/150 second exposure time. As this is a considerable amount of smear, an advantage might be gained if a new film were developed where the exposure time could be reduced at the expense of the limiting resolution. The customer has specified that this trade-off be made using the following relation:

$$lS^{1/2} = C,$$

where l is the limiting resolution of the film, S is the aerial speed of the film, and C is a constant equal to 808 for the basic film. The customer has requested that this trade-off be performed for two hypothetical films having C equal to 950 and 1250. The trade-off is also performed for the basic film for comparison.

3.10.3.3.1 <u>Assumptions for Film Optimization</u>. For the purpose of this study, the following assumptions have been made:

(1) An exposure time of 1/100 second covers the sun elevation range of 15° to 30°, and an exposure time of 1/150 second covers the sun elevation range of 35° to 45°. These exposure times are for an albedo of 0.070 and a film speed of 6.0.

(2) Exposure time is inversely proportional to film speed, other factors held constant.

(3) $lS^{1/2}$ = constant.

(4) System resolution is given by the relation,

$$\left(\frac{R_g}{h}\right)^2 = \left(\frac{1}{R_f F}\right)^2 + \left(\frac{6.75 \times 10^{-5}}{D}\right)^2 + \left(\frac{St}{F}\right)^2$$

where R_g = ground resolution in ft.

h = altitude in ft.

R_f = resolving power of film in l/mm

F = focal length in mm

D = lens aperture diameter in inches

S = smear rate in mm/second

t = exposure time in seconds

(5) System performance will be optimized for the nominal smear budget in the across the slit direction, at altitudes of 30 to 80 nautical miles.

3.10.3.3.2 Results of Film Optimization Study. The equation for system resolution in the preceding paragraph was used to optimize the trade-off between speed and resolution. The following table summarizes the results at 30 nautical miles altitude.

Table 3-11

OPTIMIZATION OF SPEED AND LIMITING RESOLUTION, 30NM ALTITUDE

$1S^{1/2}$	*Aerial Film Speed 15°-30°	*Aerial Film Speed 35°-45°	Limiting Resolution (l/mm) 15°-30°	Limiting Resolution (l/mm) 35°-45°	Across the slit ground resolution (inches) 15°-30°	Across the slit ground resolution (inches) 35°-45°
808	10.8	8.2	[redacted]		[redacted]	
950	12.0	9.1				
1250	14.4	11.0				
**808	6.0	6.0				

* Film speed as measured at the 0.60 γ point.

** Basic Film

At an altitude of 80 nautical miles the linear smear is reduced, due primarily to reduced film velocity. The smear in the across the slit direction, for example, is decreased from 5.15 to 3.17 microns using the basic film at a 1/100 second exposure time. The following table shows that the reduction in smear with altitude significantly reduces the aerial film speed needed for optimum performance.

Table 3-12

OPTIMIZATION OF SPEED AND LIMITING RESOLUTION, 80NM ALTITUDE

$1S^{1/2}$	Aerial Film Speed 15°-30°	Aerial Film Speed 35°-45°	Limiting Resolution (line/mm) 15°-30°	Limiting Resolution (line/mm) 35°-45°	Across the slit ground resolution (inches) 15°-30°	Across the slit ground resolution (inches) 35°-45°
808	7.8	6.0	[redacted]		25.04	24.2
950	8.7	6.6			24.35	[redacted]
1250	10.4	8.0			[redacted]	
**808	6.0	6.0			25.54	24.2

** Basic Film

To optimize each film for altitudes from 30 to 80 nautical miles and sun elevations from 15° to 45°, a compromise has to be made. For the film having an $1S^{1/2}$ of 808, the ranges of altitude and sun elevations represents a range in aerial speed of 10.8 to 6.0. An aerial speed of 8.2 would be optimum for this film. For a film having an $1S^{1/2}$ of 950, there is a range in aerial speed of 12.0 to 6.6. For this film, a speed of 9.1 is optimum. Similarly, a speed of 11.0 would optimize total performance for a film having an $1S^{1/2}$ of 1250. The following table shows the ground resolutions which would be obtained for each of the 3 films at 30 and 80 nautical miles altitude and sun elevations from 15° to 45°, using the optimum speeds chosen above.

Table 3-13

GROUND RESOLUTION FOR OPTIMIZED AERIAL FILM SPEEDS

$1S^{1/2}$	Optimum aerial film speed	30 NM Altitude		80 NM Altitude	
		15°-30°	35°-45°	15°-30°	35°-45°
808	8.2	[redacted]	[redacted]	25.05	24.4
950	9.1	[redacted]	[redacted]	24.36	[redacted]
1250	11.0	[redacted]	[redacted]	[redacted]	[redacted]

The film characteristics appeariang in Table 3-13 above are believed to be optimum for the conditions imposed; it must be noted, however, that the study was just an exercise and probably does not reflect values attainable in the near to immediate future.

3.10.4 Additional Performance Studies

Annex I of the Work Statement for the Apollo Mapping and Survey System states that "The lunar surface resolution of the survey photography must be adequate for:

(1) Detection of protuberances (or holes) which could be just contained within an [redacted] diameter right circular cone [redacted] in height.

(2) Measurement to an accuracy of ±2° of surface slopes in the range from 0° to 12° relative to the local horizontal for circular areas 30 feet in diameter. Measurement by both photometry and stereo is desirable.

Sections 3.10.4.1 and 3.10.4.2 give an estimate of performance for these two hazards.

3.10.4.1 Detection of [redacted] Diameter [redacted] High Cones. Table 3-14 shows the equivalent modulation for a 41.63° base angle cone, which has the shape of the hazard. The orbit inclination is 10° with respect to the lunar equator, consistent with other sections of this report.

Table 3-14

MODULATION VS SUN ELEVATION, 41.63° CONE

Sun Elevation	Modulation +15° Stereo	-15° Stereo
10°	.3307	.3224
20°	.2053	.1891
30°	.1624	.1527
40°	.1411	.1376
50°	.1085	.1038
60°	.0722	.0776

Figure 3-34 shows the diameters of this cone which are detectable, as a function of sun elevation for an altitude of 30 n. miles. Three exposure times (1/75 second, 1/100 second, and 1/150 second) are included. It is evident from these curves that the [redacted] diameter is detectable through the 15° to 45° sun elevation range for stereo photography at the 1/100 and 1/150 second exposure times. (No attempt has been made to account for stereo acuity in these calculations, although it is known that stereo acuity will improve detectability.) For sun elevations from 50° to 60°, an exposure time of 1/200 second is recommended. Extrapolation at computer data indicates that the [redacted] diameter cone can be detected at a sun elevation of 56°.

Figure 3-35 shows the variation in detectable cone diameter with altitude for the 41.63° base angle cone, at an exposure time of 1/100 second (sun elevations of 15° and 30°) and at 1/150 second (sun elevation of 45°), for stereo angles of +15° and -15°. These curves show that the [redacted] diameter is detectable up to 45 n. miles altitude at 15° sun elevation, 36 n. miles at 30° sun elevation, and 36 n. miles at 45° sun elevation.

3.10.4.2 Detection of Slopes. The measurement of the inclination of a flat surface with respect to the local horizontal can be made by two methods. The first method relies on the photometric properties of the lunar surface, while the second depends on the stereo acuity of the system. Both of these methods will be discussed in the following paragraphs, but first it is worth while to define the word slope.

[redacted]

SUN ELEVATION (DEGREES)

[redacted]

SUN ELEVATION (DEGREES)

Figure 3-34. Detectable Cone Diameter vs Sun Elevation for Cone Angle of 41.63°

3.3(b)(1)

[redacted]

Altitude (nautical miles)

3.3(b)(1)

[redacted]

Altitude (nautical miles)

Figure 3-35. Detectable Cone Diameter vs Camera Altitude for Cone Angle of 41.63 Degrees

In this section, a slope is a uniformly flat circular area of surface, 30 feet in diameter, inclined at some angle ϵ with respect to the local horizontal and oriented at another angle δ with respect to the direction of motion. These angles are shown in Figure 3-36. The angle δ will vary from 0° to 360°, and is taken positively in a counter-clockwise direction.

3.10.4.2.1 Detection of Slopes by Photometry. The measurement of the inclination of surface slopes by photometry involves 5 basic steps. These are:

(1) The establishment of local geometry.

(2) The charting of a plot of brightness ratio vs ϵ for values of δ between 0° and 360°, from the data established in step 1.

(3) The measurement (by densitometer, for example) of the brightness ratio between the surface slope in question and the local horizontal.

(4) The measurement (probably visual) of the angle δ for the surface slope in question.

(5) Looking up the angle ϵ of the slope inclination for the values taken in steps (3) and (4), in the plot made in step (2).

The following information must be gathered in Step (1):

(a) The longitude and latitude of the sub-solar point.

(b) The longitude, latitude, and inclination of the orbit.

(c) The line of sight of the C/P (stereo and obliquity angles).

(d) The inclination of the local horizontal with respect to some reference plane.

(e) The photometric properties of the area of interest.

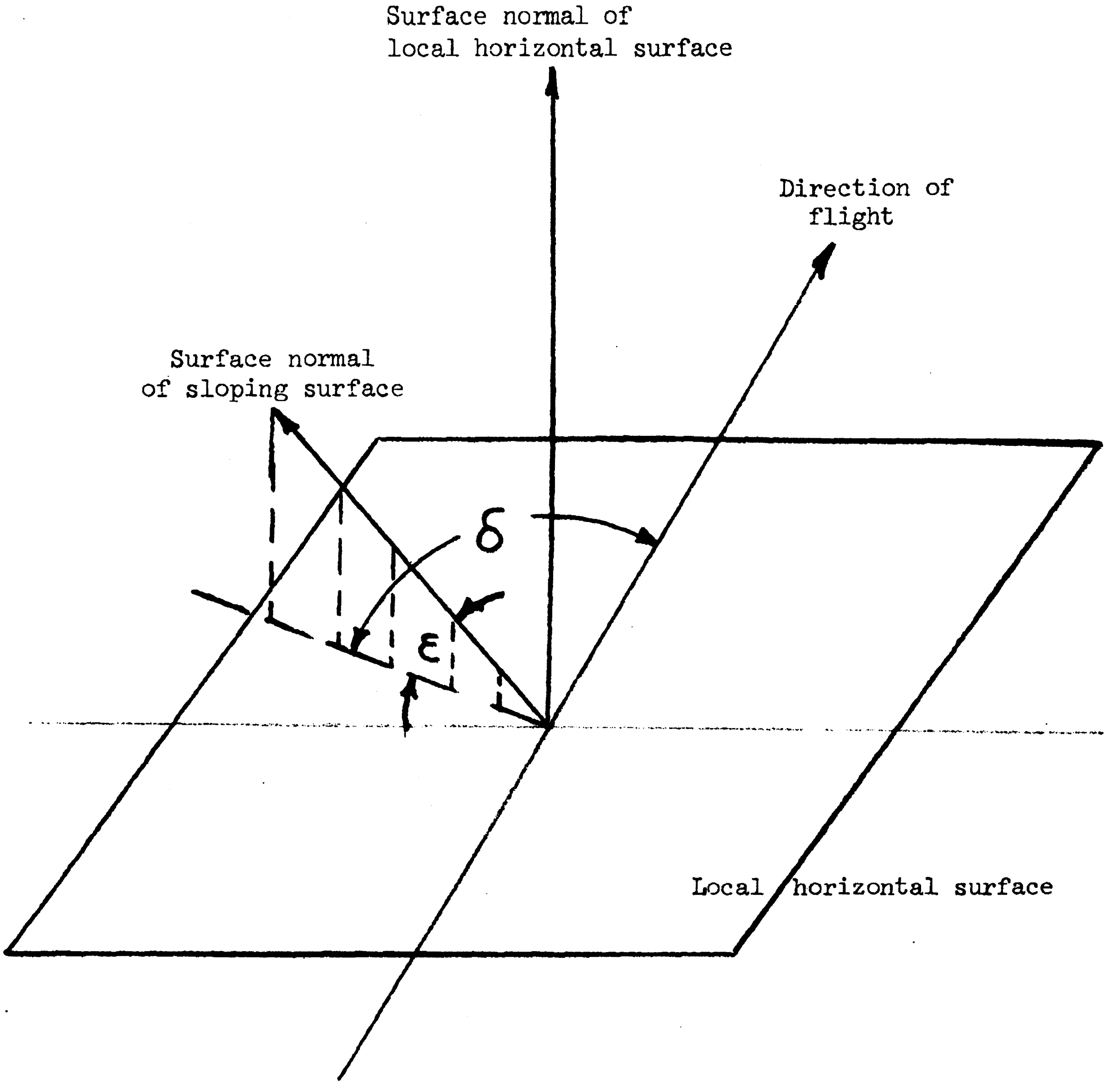


Figure 3-36. Slope Geometry

Figure 3-37 is a sample plot obtained by step (2), for the following conditions:

(a) Sub-solar point longitude = 60° East
Sub-solar point latitude = 0°

(b) Vehicle longitude = 0°
Vehicle latitude = 0°
Vehicle inclination = 0°, retrograde

(c) Stereo angle = +15° (away from sun)
Obliquity angle = 0°

(d) The local horizontal is contained in a plane perpendicular to the nadir.

(e) Eimer's curves of Fedoret's data applies to the area in question.

The accuracy of the measurement is obviously dependent on two major factors. These are the accuracy with which low brightness ratio can be measured, and the angle δ . A good density measurement is accurate to about ±0.02. Assuming that this represents the accuracy of the measurement and assuming that the slope of the H&D curve for Kodak Type 4404 film is 2.0 at the target density, the corresponding error in the brightness ratio is about ±2%. Referring to Figure 3-37, this means that slopes can be measured to an accuracy of ±2° in the ϵ = 0° to 12° range for all δ's from 0° to 65°, 115° to 245°, and 295° to 360°. Slopes whose surface normals lie within 40° of the line of flight can be measured to an accuracy of better than one degree. No slopes less than about one degree can be detected.

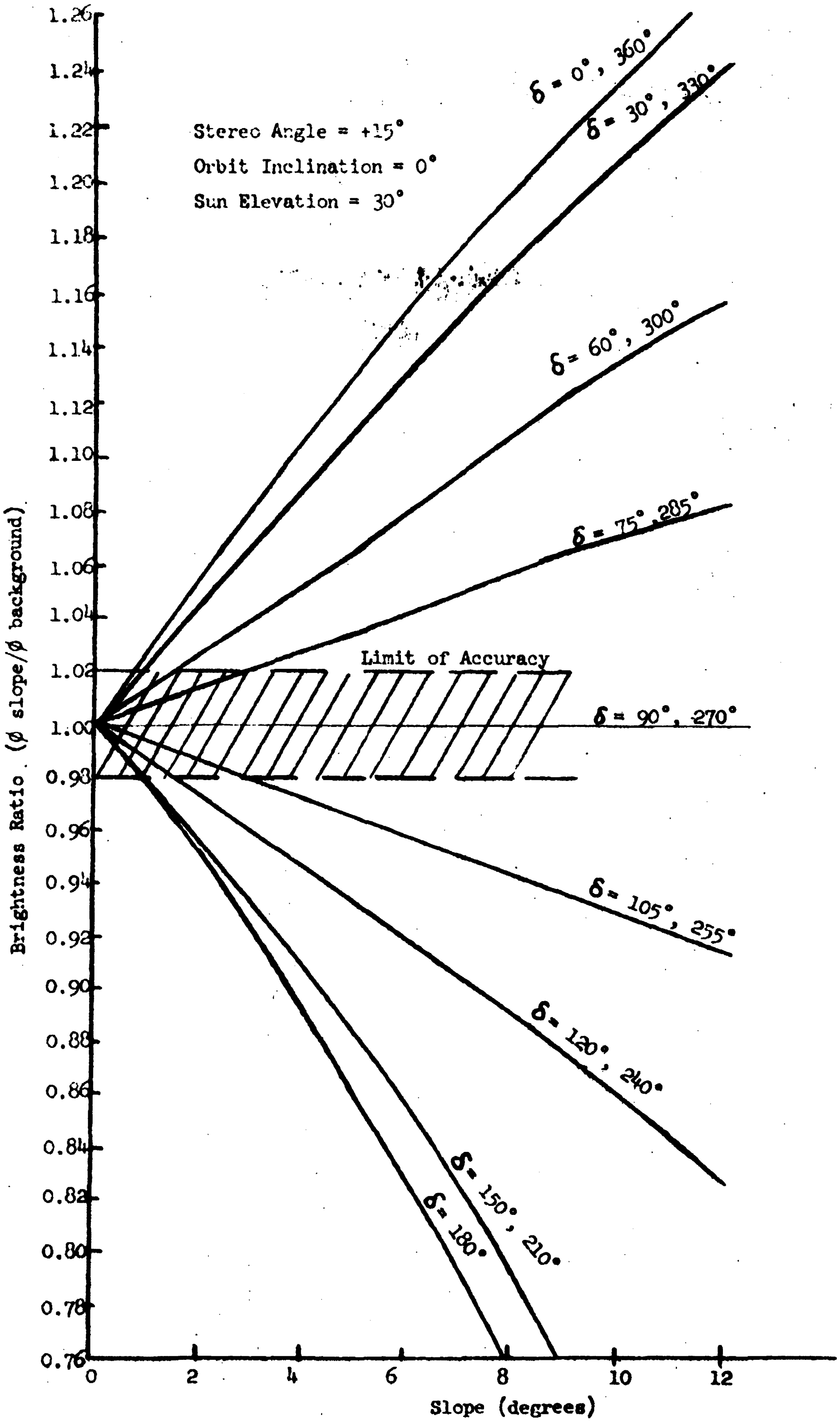


Figure 3-7. Brightness Ratio vs Slope

3.10.4.2.2 Detection of Slopes by Stereo Acuity. The stereo acuity of a photographic system is given by the equation,

$$\text{Stereo Acuity} = \frac{\text{K X Ground Resolution}}{\text{Stereo Base-to-Height Ratio}},$$

where K is empirical and in the range from 0.25 to 0.4. It was shown previously in Section 3.10 that ground resolution is a function of the modulation of the target, all other factors held constant. It is obvious that stereo acuity will vary with the geometry of target, the sun, and the C/P. To avoid complications in this area, Figure 3-38 was developed by the methods discussed in this section. This figure plots ground resolution as a function of target contrast at an altitude of 30 nautical miles and an exposure time of 1/100 second.

A second curve, which plots minimum detectable slope inclination vs ground resolution, is shown in Figure 3-39. This curve was derived for the 30 foot diameter using the stereo acuity equation with K=0.25 and base-to-height ratio = 0.54. Thus, minimum detectable slope inclination (degrees) = $\text{TAN}^{-1} \left(\frac{\text{Stereo acuity}}{\text{30 ft.}}\right)$.

To illustrate the use of Figures 3-38 and 3-39, assume that the contrast between a surface slope and its background is found to be 1.2. From Figure 3-38, the ground resolution at this contrast is [redacted]. From Figure 3-39, the minimum detectable slope inclination is 1.4 degrees. If the contrast was measured to be 1.09, the minimum detectable slope inclination would be 3.4 degrees. The term minimum detectable slope inclination implies that a slope 30 feet in diameter can not be detected by stereo acuity methods if its inclination with respect to the local horizontal is less than the value found from Figure 3-39. If the diameter of the slope is larger than 30 feet, the minimum detectable slope inclination for a measured contrast will be smaller than the value found in Figure 3-39.

3.3 (b) (1)

[redacted]

Contrast of Slope with Local Horizontal

Figure 3-38. Ground Resolution vs Contrast

3.3(b)(1)

[redacted]

Figure 3-39. Slope Inclination vs Ground Resolution

It is difficult to estimate the accuracy to which stereo acuity can predict the inclination of surface slopes. If the stereo acuity is considered accurate to ±10%, then the slope inclination has a maximum error in the 0° to 12° range of about ±1 degree. There is also the error in measuring the contrast between the slope and the background of about 2% mentioned in the previous section, but as the error does not directly enter the calculation, its effect is difficult to estimate. The desired accuracy of ±2° can probably be achieved by this method, providing the slope possesses sufficient contrast with the background.

3.10.5 Effect of Attitude Rates and Smear on System Resolution

3.10.5.1 Attitude Control. The nominal smear tolerances and smear allocations are given in Table C-2 of Appendix C. The 2 sigma variability on vehicle attitude displacement errors is 0.5° in roll, pitch and yaw. These are also the current NAA variabilities. The nominal 2 sigma attitude rate error is 0.01°/second in roll, pitch, and yaw rate. The largest smear contributors are yaw angular error and roll rate. Both contribute to smear in the y (cross track) direction. To find the effect of roll rate errors, total y smear and y system resolution were computed with varying roll rate errors inserted in the smear budget. All other smear contributions were held constant. The results are shown in Figure 3-40 for 30 n. mi. altitude and Figure 3-41 for 80 n. mi. altitude. Roll rate does not contribute to smear in the x (in-track) direction, thus x resolution does not change. Of significance is the fact that smear from most contributors decreases as altitude increases, but smear due to attitude rates is independent of altitude. It is readily seen from the curves that resolution in the y direction is degraded severely as roll rate error increases. An error larger than 0.01°/second is considered excessive. The design goal for roll rate is 0.004°/second, 2 sigma, but the current roll rate error for Apollo attitude control is 0.019°/second, 2 sigma.

ADVANCED 4404 FILM, SPEED 6.0
2:1 CONTRAST
0.01 SEC EXPOSURE
Y IS CROSS TRACK DI
X IS IN TRACK

3.3(b)(1)

[redacted]

Figure 3-40. Y Resolution vs Roll Rate Error, 30 N.Mi. Altitude

4404 FILM-ADVANCED
2:1 CONTRAST
0.01 SEC EXPOSURE
Y IS CROSS TRACK DIRECTION
X IS IN TRACK

3.3(b)(1)

[redacted]

Figure 3-41. Y Resolution vs Roll Rate Error; 80 N.Mi. Altitude

A similar degradation exists for yaw angle error. The y smear from a 0.7° yaw error is the same as that from a 0.02°/second roll rate error. The Apollo vehicle yaw attitude tolerance of 0.5° is considered reasonable, although significant gains could be made through reduction of this tolerance. The design goal for yaw error is 0.4°.

The effect of any smear contributor on the total system smear and on system resolution at any contrast and exposure time can be obtained through computer programs which have been set up for smear and resolution calculations. Trade offs between contributors can be examined and smear reduction efforts can be applied where they are most needed.

3.10.5.2 Smear Budgets. The effect of smear on the dynamic system resolution in the x and y directions is shown in Figure 3-41 for the existing system using type 4404 film and operating at 2:1 tri-bar contrast. Although this contrast does not apply specifically to the lunar surface, the curves are valuable for examination of smear contributor trade-offs and effects of exposure time variations on resolution.

Table 3-15 summarizes x and y image smear, ground resolution, and dynamic lens/film resolution in lines/mm for the nominal smear budget and other possible smear budgets which are included in Appendix C. Exposure time is 1/100 second for all budgets. At 1/140 second, all smear values are 7/10 of those shown, and at 1/200 second all smear values are 1/2 of those shown. Resolution for the reduced smear can be determined by Figure 3-42, System Resolution vs. Smear.

[redacted]

IMAGE SMEAR MICRONS

Figure 3-42. System Resolution vs Smear

Table 3-15

RESOLUTION AND SMEAR SUMMARY,
2:1 CONTRAST TRI-BAR

Possible Smear Budgets	Image Smear x microns	Image Smear y microns	Ground Resolution x inches	Ground Resolution y inches	Ground Resolution Geometric mean inches	Dynamic Lens/Film Resolution x 1/mm	Dynamic Lens/Film Resolution y 1/mm	Dynamic Lens/Film Resolution Geometric mean 1/mm
30N.MI.								
1. Nominal	5.13	6.54	[redacted]			[redacted]		
2. Integral V/h	4.43	1.76						
3. Ground Program	8.54	6.56						
4. Design Goal Att.	4.89	4.73						
5. NAA w/o LEM	5.13	8.57						
No Smear	0	0				Static Lens/Film Resolution [redacted]		
80 N.MI.						Dynamic Lens/Film Resolution		
1. Nominal	3.15	4.01	25.5	[redacted]	[redacted]	[redacted]		
2. Integral V/h	3.05	0.61	25.4					
3. Ground Program	4.76	4.05	28.2	25.0	26.5			
4. Design Goal Att.	3.10	2.13	25.4	[redacted]	24.0			
5. NAA w/o LEM	3.15	6.71	25.5	30.1	27.5			
No Smear	0	0	[redacted]			Static Lens/Film Resolution [redacted]		

NOTE: 1/100 sec exposure time; advanced 4404 film of speed 6.

Nominal Smear Budget

This budget was established early in the study phase as representing the minimum smear which would be compatible with the photo subsystem's potential for high resolution photography. Logically enough, many of the smear contributors retain the same tolerances that are allotted to the existing hardware - these are the tolerances on stereo servo positioning, roll, pitch and yaw alignments (camera to attitude control reference), mounting of the stereo mirror in crab and stereo, and knowledge of focal length. These tolerances, with the exception of mirror mounting in crab, are the same in all the smear budgets. The film drive speed steps have been reduced in size from 1% to 0.5% to reduce smear without any significant complication to payload hardware. The error due to film velocity steps has been combined with that due to MSD oscillator drift to produce a combined 2 sigma variability of ±0.30%. The tolerance on film drive oscillation or platen vibration has been reduced from 0.8% to 0.53% (2 sigma). This value represents the amplitude (0 to peak) of the film velocity oscillation as a percentage of the film drive speed. At 30 n. mi. altitude, 0.53% represents a smear rate of 0.27 mm/second that is, 0.53% of the film drive speed of 2 inches/second. With film drive system modification, this smear rate is considered as a conservative estimate of potential improvement in smoothness of the drive.

The attitude control tolerances listed, 0.5° in angular displacement and 0.01°/second in rate, are considered well within the state of the art. Pitch rate variability does not contribute to smear because a V/h sensor measuring V/h at nadir is assumed for this budget. The sensor output that is used to set film drive speed (proportional to V/h) includes the angular pitch rate of the vehicle. Elimination of other attitude errors cannot be accomplished unless the sensor is integral with the camera and views the same ground scene that the camera photographs. The V/h sensor error is specified as 0.5%, 3 sigma. This error enters the smear budget as an error in altitude determination since the percentage variation in vehicle velocity and nadir velocity is negligible during V/h sensor operation.

Contributions from the 2 sigma variability of all smear contributors were calculated by means of the smear equations and added statistically to give total x and y image smear for the photo subsystem at 2:1 tri-bar contrast. The nominal exposure time of 1/100 second was used. Smear rate in microns/second at the film plane is image smear times 100, and smear rate in radians/second is the micron/second rate divided by the focal length. The latter is calculated as 2.6×10^{-4} radians/second in x, or 1.1% of the V/h rate at 30 n. mi. altitude. Such a rate is conservative for future payloads and improvements in this rate are expected through equipment modification and V/h techniques.

Integral V/h Budget

This budget incorporates the capability of a V/h sensor integral with the camera. The use of the Bolsey sensor in this application is under study and currently appears feasible. The sensor looks at the same scene which is being photographed via the stereo mirror. In-track smear components due to vehicle pitch, pitch rate, and roll are sensed and eliminated by the film drive speed setting obtained from the the in-track V/h measurements. Cross track smear due to vehicle yaw, roll rate, and yaw rate are sensed because of the sensor's ability to measure cross track image velocity. Crab of the stereo mirror is used to correct for this image smear velocity component. All attitude control errors are then eliminated, but a sensor in-track error and a sensor error in crab measurement must be in the smear budget. In addition, there is a sensor-to-camera alignment error in crab, and a crab servo "following" error. Mirror mounting error in crab is eliminated from the budget. Other tolerances are the same as in the nominal budget. Integral V/h sensing provides minimum smear, virtually eliminating by y smear component, and appears promising at this time.

Ground Programming of Film Drive Speed

Knowledge of the vehicle altitude and velocity in orbit as obtained from earth tracking or astronauts' sightings can be used to program V/h for setting the film drive speed. This is a back up to the V/h sensor measurement. Uncertainty in the knowledge of altitude produces a serious smear, particularly at 30 n. mi. altitude, and for this reason V/h sensing is recommended for determination of altitude above the lunar surface. An altitude prediction error of 0.5 n. mi. (3 sigma) has been assumed and entered in the smear budget. Mainly because of this error, total x smear increases to 8.5 microns, compared to 5.1 microns for the nominal budget. Since the V/h sensor is not used, pitch rate error of the vehicle must also be in the smear budget. It is of interest to note that a 0.5% V/h error is equivalent to an altitude error of 0.15 n.mi. which is much lower than the altitude prediction error assumed for ground tracking.

Design Goal Attitude Control

This budget differs from the nominal only in the size of attitude control tolerances, which are reduced to ± 0.4° (2 sigma) in angular displacement and ± 0.004°/second (2 sigma) in rate, each for all axes. These tolerances were established as a goal for the SCM reaction control system. Geometric mean ground resolution at 2:1 contrast is improved over the nominal by 0.5 inch at 30 n. mi. and 1.2 inches at 80 n. mi. for this budget.

N.A.A. Attitude Control Without LEM

This budget differs from the nominal only in attitude control rates. Because of the high roll rate error when the CSM is used without the LEM (0.028°/second, 3 sigma error) total y smear increases from 6.5 microns (nominal) to 8.6 microns. The y ground resolution is degraded by 3 inches at 30 n. mi., and the geometric mean resolution is degraded by 1.9 inches, for 2:1 contrast.

3.10.5.3 Ground Resolution Versus Contrast and Attitude

The effect of contrast of a tri-bar target on ground resolution of the photo subsystem is shown in Figure 3-43 for 30 n. mi. altitude and in Figure 3-44 for 80 n. mi. altitude. The film is advanced typed 4404 with an aerial exposure index of 6. Both the nominal smear budget (which incorporates Nadir V/h sensing), and the smear budget with V/h sensing integral with the camera payload were used for computing data for the graphs.

Figure 3-45 contains plots of ground resolution versus altitude for tri-bar target contrasts of 1.3:1 and 2:1, for the same two smear budgets. Exposure time for this and the two preceding plots was 1/100 second, which is the exposure for lunar photography at sun elevations of 15° to 30°.

[redacted]

Figure 3-43. Ground Resolution vs Tri-Bar Contrast

[redacted]

Figure 3-44. Ground Resolution vs Tri-Bar Contrast

3.3(b)(1)

[redacted]

Figure 3-45. Altitude vs Ground Resolution

3.11 GROWTH POTENTIAL

The survey camera subsystem is based on minimal modification to current hardware. However, the first program requirements are several years in the future. Within this time span, growth potential exists in several areas. Typical are coverage, performance, additional capabilities, and other modes of operation. The following paragraphs discuss these and other potential areas of growth.

3.11.1 Performance

The existing photo subsystem uses a Maksutov lens designed with spherical surfaces, and employing all glass elements. Experience gained in manufacturing this lens and designing lenses for other programs indicates that further improvements are feasible. On-axis dynamic system performance with this lens is currently specified as [redacted] for a 2:1 low contrast target. Occasional performance numbers are as high as [redacted] Such a performance level is not unrealistic to establish for photo systems with lenses manufactured in the near future. Further design modifications would also enhance performance. The substitution of a two element meniscus lens for the present single element meniscus lens is an example of the type of design change possible.

Other lens designs are also being investigated. For example, a Ross corrector type lens that uses an aspheric primary mirror without a meniscus has been designed. This lens may produce on-axis performance levels in the [redacted] region. If based on current designs, it would have a slightly reduced field angle. This restriction, however, is also subject to further development and might be overcome within the time period involved.

Such changes to the optical system would allow performance to be increased as much as 40 per cent over the currently specified levels. These changes are all within predictable state-of-the-art advances.

3.11.2 Coverage

The present system configuration uses a lens half-field angle of 3.2 degrees to cover 9-inch wide film (8.5-inch image width). If the film width were increased to 12-inches the corresponding half-field angle would be about 4.25 degrees. This represents a per pass coverage increase of about 30 percent. Although the required lens modifications have not been investigated in detail, this also is an area of potential system growth.

3.11.3 Additional Payload Capabilities

In the proposed mode of operation, the survey camera is intended to photograph areas of the lunar surface using black-and-white aerial film. This film is stored in the payload section of the service module until the termination of the lunar orbit portion of the mission. It is then transferred to the command module and returned to earth with the astronauts. Several variations can be made in this basic capability. A brief description of some of these follows:

a. Other Films - Although type 4404 film is the optimum black-and-white film for high resolution photography, other film can be used on some missions or portions of missions for special types of information. Various infrared films can record differences in surface temperatures or emissivity that may indicate additional data concerning the lunar surface material. Color films can also record the presence and/or lack of color in the surface detail. Such information would provide metallurgists and geologists with additional data concerning the composition of potential landing surfaces. The color correction of the present lens is excellent.

Company sponsored research and development is being conducted on very thin (Estar) base films. The results of this research will be available to this program. Increased film lengths of 60% would be possible within the same weight budget with use of this material.

b. Processing and/or Readout - Should the astronaut desire to view the photographic material to obtain more detailed information concerning certain areas, a film processing capability can be added. As proven on other programs, the use of Kodak Bimat Film is completely compatible with the expected space environment. This processing can be accomplished automatically in the payload section of the service module or special cassettes can be provided to transfer selected quantities of film to the service module for processing.

In addition to processing, the film can be read out selectively using flying spot scanners and photo detectors or other techniques. The readout film could be displayed in the command module to alleviate the film transport problem or more probably would be transmitted to earth to provide rapid return of selected photographic data and an opportunity for further mission planning.

c. Panning Adaptation - If it is desired to increase coverage at the expense of resolution in order to obtain photography over broader areas of the lunar surface, the EKC C/P can be adapted to a panning configuration. A preliminary discussion of this arrangement appears in Section 6.0 of this report.

3.11.4 Other Modes of Operation

As described in the previous paragraph, a processing and readout capability can be added to the photographic payload to provide an alternate means of data return. This suggests the possibility of an automatic operation that could be utilized to extend the useful life of the photographic system. If a payload module were provided with attitude control and a command system, it could be left in lunar orbit to photograph, process, and transmit to earth the resultant photographs. In this way, the payload life and capability could exceed the limits presently imposed by the manned system. This capability would be separate from the primary recovery technique and would be initiated after the normal mission sequence was completed.

3.11.5 Other Applications

In addition to growth potential in the area of hardware changes, growth potential also exists in the mission goals themselves. The present goals are to survey an area of the lunar surface bounded by ±40° longitude and ±5° latitude. Several specific LEM landing sites within this area are to be surveyed as a primary mission goal.

Scientific information can also be gathered from an orbiting lunar satellite at the same time information important to the selection of a landing site is recorded. Although many sensors may be appropriate for making measurements from a satellite, our attention is focused on photo-visual techniques.

An outstanding characteristic of aerial photography is that vast quantities of information are gathered at an enormous rate, stored in the latent image, and made available for more leisurely study at a later time. Photographic analysis frequently takes two forms, photogrammetry or measurement of objects via their scaled images, and photo interpretation or the drawing of inferences about the nature of objects from the nature of their images.

The analysis of black-and-white photographs depends on pattern and intensity of tones augmented by stereo effects; color photographs add another variable, hue, which may be especially effective for lunar photography where there is no dulling atmosphere to reduce color saturation. Although low resolution photographs of the moon shown no color (except for the recently observed "red spots"), it is contrary to normal experience to expect that the lack of color in low resolution photographs will be extrapolated to high resolution photographs.

As described earlier, film can be developed in flight using simple modern techniques for processing high resolution film in a gravitationless space environment. Photographs processed by these techniques, together with simple viewing or projection apparatus, can provide the Apollo crew with a basis for in-flight study and analysis of the lunar surface.

Analysis of photography during lunar missions would permit the crew to take action based on the results of their analyses. The action taken may be one or more of the following: change orbit, augment black-and-white photography with color shots, introduce color filters into black-and-white optical path for spectrozonal optimization, change exposure, or modify the mission.

The crew can also take action of another sort; specifically, the placement of special devices on the lunar surface. Examples might be: explosive changes, the effects of which would be photographed on impact with the surface or when radio controlled detoration was induced on a subsequent orbit, surface dyes whose rate of disappearance would be recorded, objects ejected from the satellite to mark the surface, or flares to illuminate polar valleys forever hidden from sunlight.

In addition to reconnaissance prior to landings on the lunar surface it is reasonable to expect that the initial manned lunar landing will be followed by further exploration. Because of the many inhospitable characteristics of the moon, and the difficulty of establishing and maintaining people there, it is probable that we will want to develop techniques for further exploration from orbiting vehicles. These techniques will also be of great value to future planetary expeditions, and the moon will be an excellent "practice field" for developing our space exploration abilities. A first step toward further lunar exploration is to send men to observe and record, photographically, the entire lunar surface including the hidden side. This record will provide the information needed to classify the lunar surface in accordance with various criteria and then to select from these classes those areas to be explored photographically in greater detail. (For example, an important criterion for further manned mission will be the accessibility of the area from a suitable LEM landing site.)

Complete coverage of the moon will require a rather lengthy mission (27 days) and during this time the astronauts would tape record their observations and interpretations of what they see, and photograph unusual events they observe visually.

Complete photographic coverage of the lunar surface can be readily accomplished from a polar orbit. The illumination below the satellite is a function of both longitude and latitude; the optimum orbital longitude with respect to the sub-solar meridian is not known and will probably not be known until better exposure information is available.

Programming a lunar survey mission for complete coverage, however, may be a complex affair. For example, by programming a controlled roll maneuver from pole to equator two benefits are derived: the first is a variable ground swath which can be widest at the equator and thus convert monoscopic to stereoscopic coverage, the second benefit is derived from an improved solar phase angle and consequent increase in illumination and reduction in exposure time.

3.12 NUMERICAL SUMMARY

3.12.1 Photographic Output Data

A. Ground Resolution (at 1/100 second exposure, basic film, 2:1 contrast)

1. Nominal (Nadir V/h sensing)

30 n. mi.	[redacted]
80 n. mi	25.2 inches

2. Integral V/h sensing

30 n. mi.	[redacted]
80 n. mi.	

B. Lens Film Resolution (Dynamic, 2:1 contrast)

1. Nominal (Nadir V/h)

30 n. mi.	[redacted]
80 n. mi.	

2. Integral V/h

30 n. mi.	[redacted]
80 n. mi.	

C. Scale of Photography (cross-track)

1. 30 n. mi.	1:29500
2. 80 n. mi.	1:78700

D. Width of Ground Strip

1. 30 n. mi.	3.44 n. mi.
2. 80 n. mi.	9.19 n. mi.

E. Scene Width on Film	8.518 inches
F. Scene Length on Film	Variable
G. Scene Length on Ground	
1. Strip mode	Variable
2. Alternate orbit stereo	Variable
3. Stereo/mono pair	Variable

4. Stereo pair
   30 n. mi. 13.33 n. mi. (max.)
   80 n. mi. 40.45 n. mi. (max.)

H. Stereo Acuity

1. 30 n. mi.
2. 80 n. mi.

I. Area Coverage per 100 feet of film (non-redundant-stereo)

1. 30 n. mi. 860 n. mi.^{2}
2. 80 n. mi. 6050 n. mi.^{2}

3.12.2 Survey Package

A. Weight (estimated)

1. C/P (without film) 1158 lbs.
2. Film (3000 feet) 52 lbs.
3. Total 1210 lbs.

B. Dimensions of C/P (estimated)

1. Length 146 inches

3.12.3 Survey Camera

A. Camera Type Strip

B. Lens

1. Type Maksutov
2. Focal length 77-inches
3. Aperture stop [redacted]
4. Half field angle 3.2 degrees

C. Programmable slit

1. Number of slits 7
2. Transistion time between positions 3.2 sec.
3. Drive

D. Slit Domensions

1. Length (including yaw slit) — 8.718 inches

2. Slit-to-film distance — 0.007 inch

3. Width

Slit 1	0.0292 inch
Slit 2	0.0207 inch
Slit 3	0.0146 inch
Slit 4	0.0104 inch
Slit 5	0.0073 inch
Slit 6	0.0052 inch
Slit 7	0.0037 inch

E. Exposure

1. At nominal IMC speed

15°-30° sun elevation	1/100 second
35°-45° sun elevation	1/140 second
50°-60° sun elevation	1/200 second

F. Focus System

1. Type — Single grid, single detector, dual channel with rotating focus shifter

2. Range — ±0.010 inch

3. Rate — 0.00025 inch/sec. (Nominal)

4. Drive (Platen) — D-C motor

3.12.4 Survey Film (Basic)

A. Type — High Definition Aerial Film, Estar thin base

B. Exposure Index — 6.0

C. Dimensions

1. Width — $9.460^{+0.010}_{-0.005}$ inches

2. Length	3000 feet
3. Thickness	0.0030±.0003 inch
D. Roll dimension	
1. Core diameter	6 inches
2. Roll diameter	13.6 inches
E. Weight (nominal)	52 lbs.
F. Film Handling Tension	2.5 to 5 lbs.

3.12.5 Image Motion Compensation

A. Film Drive	
1. Type	Synchronous
2. Film velocity range	
30 n. mi. nominal alt.	1.76 to 2.59 inch/sec.
80 n. mi. nominal alt.	0.68 to 0.78 inch/sec.
30/80 n. mi. range	0.68 to 2.59 inch/sec.
3. Number of steps (fixed % diff.)	
30 n. mi.	84
80 n. mi.	30
30/80 n. mi.	291
4. Speed change per step	0.5 percent
5. Drive tolerance	0.2 percent
6. Control - V_g/h	Internal to C/P
Command	Serial binary from AGC
B. IMC design parameters	
1. Altitude range	
30 n. mi. nominal alt.	23.9 to 35.2 n. mi.
80 n. mi. nominal alt.	73.9 to 85.2 n. mi.
2. Crab angle	
Range	±1.5 degrees

C. V/h Sensor

1. Type (Mfr.)	Bolsey
2. Output	Binary
3. V/h range	0.008 to 0.05 rad/sec.
4. Sensor Error (3)	
(a) In track V/h	0.5%
(b) Cross track (yaw)	0.1

3.12.6 Optical Aiming

A. Stereo Mirror Servo

1. Positions (line of sight)	+15 & -15 degrees
2. Transition time	3.2 seconds

B. Crab Servo

1. Range	±1.5 degrees
2. Transition time	0.6 degrees/sec.

C. Obliquity Aiming (not determined)

1. Range
2. Rate
3. Settling time

3.12.7 Data Recording

A. Data Tracks

1. Track width	0.005 inch
2. Pulse width	Equivalent 400 cps square wave size
3. Track B	
Pulse chain	10 cps
*Time label	23 bit binary

4. Track A

Pulse chain	400 cps

B. Yaw Slit Recordings

1. Length	0.1 inch
2. Spacing	0.108 inch
3. Width	
Leading slit	2/3 photo slit width
Lagging slit	1/3 photo slit width

C. Fiducial Line Width — 0.002 inch

D. Gray Scales (pre-exposed)

1. Location	Title side edge
2. Number of	One every 3 feet

*See paragraph 3.12.9

3.12.8 General Data

A. Site Locations

1.	E 36° 55'	N 1° 55'
2.	E 31°	N 0°
3.	E 28° 22'	N 1° 10'
4.	E 24° 10'	N 0° 10'
5.	E 12° 50'	N 0° 20'
6.	W 1° 22'	S 0° 30'
7.	W 13° 15'	N 2° 45'
8.	W 28° 15'	N 2° 45'
9.	W 31° 30'	S 1° 5'
10.	W 41° 30'	S 1° 10'

B.	Launch Parameters	
	1. C/P temperature	70°F (nominal)
	2. RH of film	40±5%
	3. Film enclosure pressure diff.	2.5 psi (max.)
C.	Earth Parking Orbit	
	1. C/P temperature	70°F (nominal)
	2. Film enclosure pressure	0.1 psi (nominal)
D.	Trans-lunar	
	1. C/P temperature	70°F (nominal)
	2. Film enclosure pressure	0.05 psi (minimum)
E.	Lunar Orbit	
	1. C/P temperature	70°F (nominal)
	2. Film enclosure pressure	0.05 psi (minimum)
	3. Stereo mirror diff. temp.	±0.2 F (maximum)
	4. Inclination of orbit	10 degrees (maximum)
	5. Eccentricity of orbit	Near circular
	6. Mission length (lunar orbit)	8 days (maximum)
	7. Sun elevation range (good)	15 to 45 degrees
	(acceptable)	10 to 60 degrees
	8. Orbital Period	
	(a) 30 n. mi.	113.4 min.
	(b) 80 n. mi.	121.9 min.
	9. V_g/h	
	(a) 30 n. mi.	0.029 rad/sec.
	(b) 80 n. mi.	0.010 rad/sec.
F.	Number of Instrumentation Points	

3.12.9 Photographic Requirements on Other Subsystems

A. Vehicle location (2 sigma)

1. Intrack	0.1 n. mi.
2. Cross track	0.4 n. mi.
3. Altitude	0.33 n. mi.

B. Attitude (2 sigma) nominal

1. Yaw	±0.5 degree
2. Pitch	±0.5 degree
3. Roll	±0.5 degree
4. Yaw rate	±0.01 degree/sec.
5. Pitch rate	±0.01 degree/sec.
6. Roll rate	±0.01 degree/sec.

C. Obliquity Aiming (not determined)

1. Range	degrees
2. Rate	degrees/sec.
3. Settling time	seconds

D. Electrical Power

1. Voltage level (nominal)	28 vdc
2. Watt hours (est.)	
Environmental	10,000
Operational	2,000

E. Timing and Recording Data

1. Pulse chain	400 cps
2. Time label	
Bits	23
Granularity	0.1 sec.
Number of	Every 1.6 sec.

3. Location label

Bits	36
Latitude	11 bit binary
Longitude	15 bit binary
Altitude	10 bit binary
Granularity	Lat/long 1 min; alt 0.1 n. mi.
Number	Every 1.6 sec.

4. Attitude label

Bits	20
Roll	8 bit binary
Pitch	6 bit binary
Yaw	6 bit binary
Granularity	1 minute of arc
Number	Every 1.6 sec.

SECTION 4

PAYLOAD DESIGN/CONFIGURATION

Adaptation of the existing EK camera P/L for use in the Apollo vehicle requires modifications in P/L mounting, film take-up, and control circuitry. The configuration illustrated in Figure 4-1 is the result of a repackaging of existing P/L components, some of which are modified, in a manner which will most efficiently utilize the available space in the SM without impairing or jeopardizing the capability of the P/L to meet the mission objectives of Section 3.0.

One of the ground rules established in the original feasibility study was to adapt the existing P/L to the Apollo SM with a minimum of modification to either unit, thus preserving the proven reliability of the existing hardware. Further study and additional systems and vehicle requirements have established the need for more extensive hardware redesign and modifications than were originally conceived. However, these modifications have maintained the original design concepts, have significantly improved P/L performance and have preserved reliability.

One of the major changes affecting payload hardware was the decision to package the C/P in the SM at a 37°45' angle to the bay centerline. This change resulted in substantial alterations to specific hardware designs (not the design concepts). Major alterations were to the primary mounting rings and film handling equipment; the bay cross section was not large enough in the 37°45' orientation to accept the C/P without change. The change in orbital operating range from one range at 80 n. miles to two ranges centered at 30 & 80 n. miles requires changes in the multiple speed drive (MSD), camera slit plate, and film handling system. Resolution requirements for the lunar mission during strip mode photography

Figure 4-1. Camera Payload Configuration

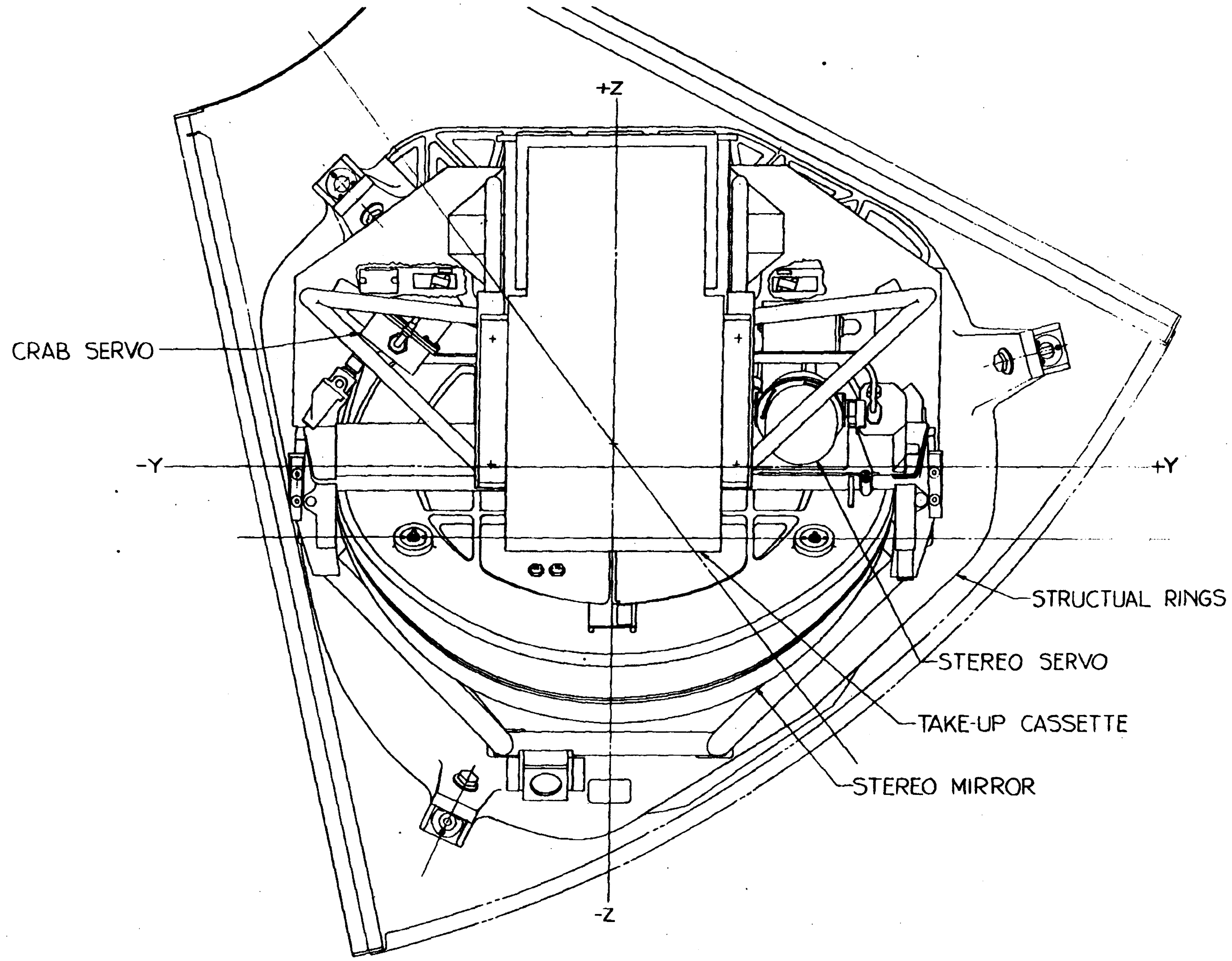
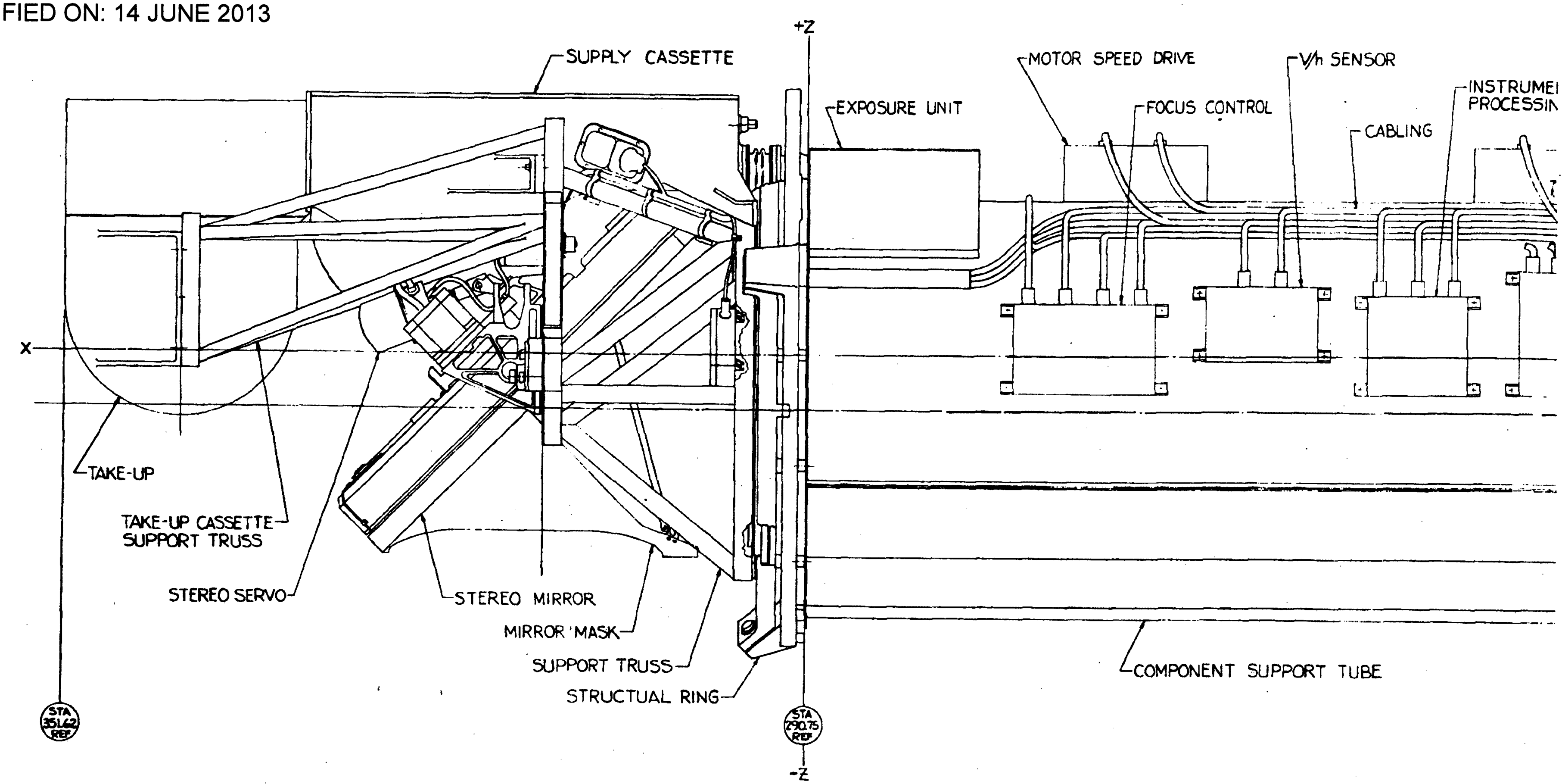
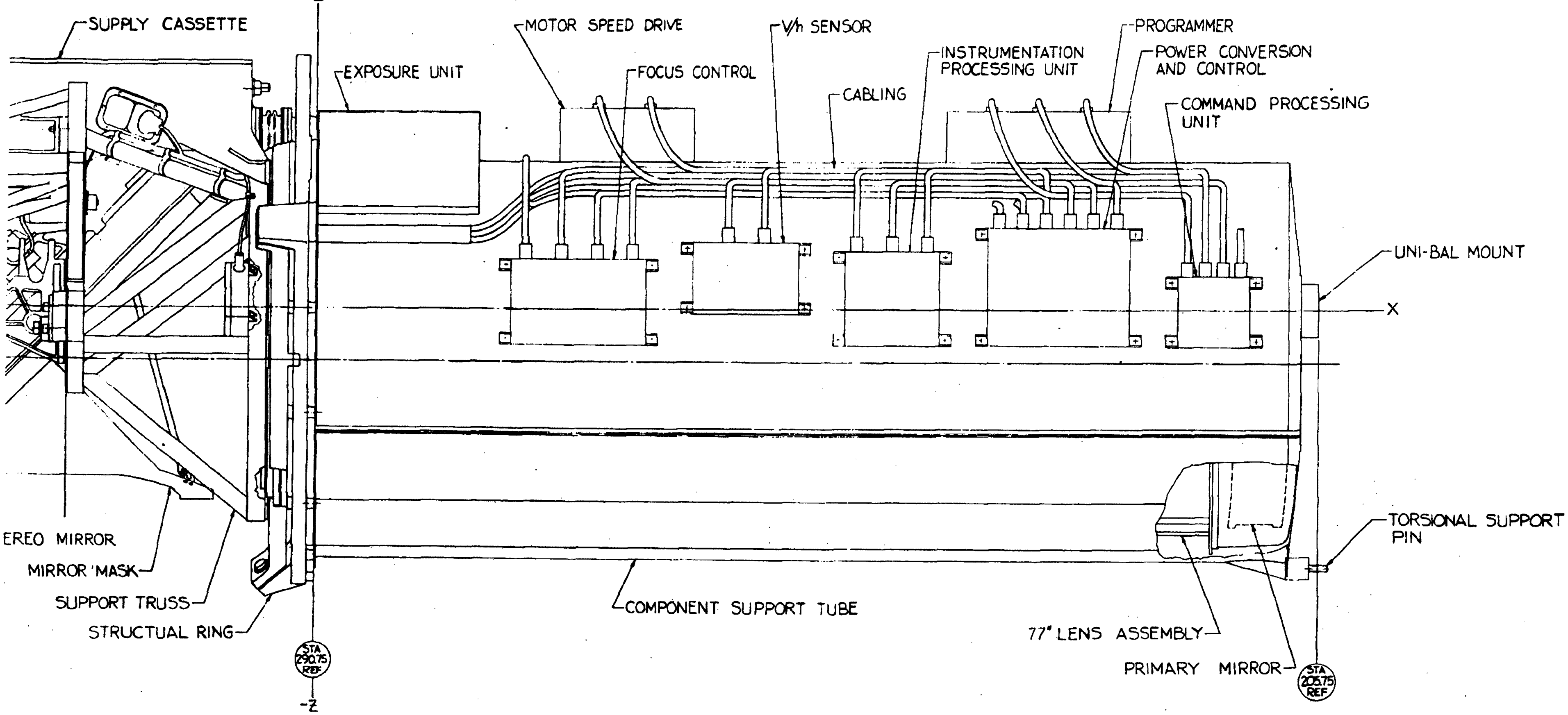

+Z
-Z
-Y
+Y
CRAB SERVO
STRUCTUAL RINGS
STEREO SERVO
TAKE-UP CASSETTE
STEREO MIRROR

Figure 4-1 (continued)


+Z
SUPPLY CASSETTE
MOTOR SPEED DRIVE
V/h SENSOR
INSTRUME
PROCESSIN
EXPOSURE UNIT
FOCUS CONTROL
CABLING
X
TAKE-UP
TAKE-UP CASSETTE
SUPPORT TRUSS
STEREO SERVO
STEREO MIRROR
MIRROR MASK
SUPPORT TRUSS
STRUCTUAL RING
COMPONENT SUPPORT TUBE
STA 351.62 REF
STA 290.75 REF
-Z


+Z
SUPPLY CASSETTE
EXPOSURE UNIT
MOTOR SPEED DRIVE
FOCUS CONTROL
V/h SENSOR
CABLING
INSTRUMENTATION PROCESSING UNIT
PROGRAMMER
POWER CONVERSION AND CONTROL
COMMAND PROCESSING UNIT
UNI-BAL MOUNT
X
TORSIONAL SUPPORT PIN
EREO MIRROR
MIRROR MASK
SUPPORT TRUSS
STRUCTUAL RING
COMPONENT SUPPORT TUBE
77" LENS ASSEMBLY
PRIMARY MIRROR
STA 290.75 REF
-Z
STA 205.75 REF

necessitate additional design changes in the film handling system in order to reduce vibration and velocity transients during photography. Because of weight limitations on the maximum recoverable load to be brought back in the C/M, the take-up cassette must be redesigned to enable jettisoning of the take-up drive and cassette end plates just prior to transfer of the exposed film into the C/M. This redesign permits the film retrieval load to be maximized. Apollo vehicle requirements for ejection of the C/P prior to film retrieval have also increased the complexity of the mechanical interface. Many of these changes effect the electronic and electrical P/L systems.

Existing AGE will also be affected by these design alterations.

The proposed survey camera (C/P) (See Appendix Y for preliminary Flight Module Specification) is designed about a diffraction limited f/3.95 Maksutov-type lens which has a focal length of 77-inches and a field view of ~~4.6~~ 6.4 degrees. The exposure unit employed is an adjustable speed "strip camera" which utilizes an in line, constant tension film handling system for 9.5-inch wide film; the film is fed from an enclosed supply cassette, through the exposure unit (camera) with associated loopers to the take-up cassette. Exposure settings, image motion compensation and focus settings are all adjustable over ranges dictated by mission requirements. A plano mirror (stereo mirror) is positioned forward of the lens aperture to reflect the camera field-of-view down toward the lunar surface. The stereo mirror can be positioned by command or logic to provide a forward or aft look angle, thus providing high acuity convergent stereo capability. A structure assembly supports, orients, and maintains alignment of the various P/L components relative to each other while maintaining a configuration compatible with mission objectives and interface requirements. Various "black boxes" are positioned for reliability of cabling as well as convenience of access.

Documentation supporting the payload design will include the Photographic Payload Subsystem Specification, outlined in Figure 4-2.

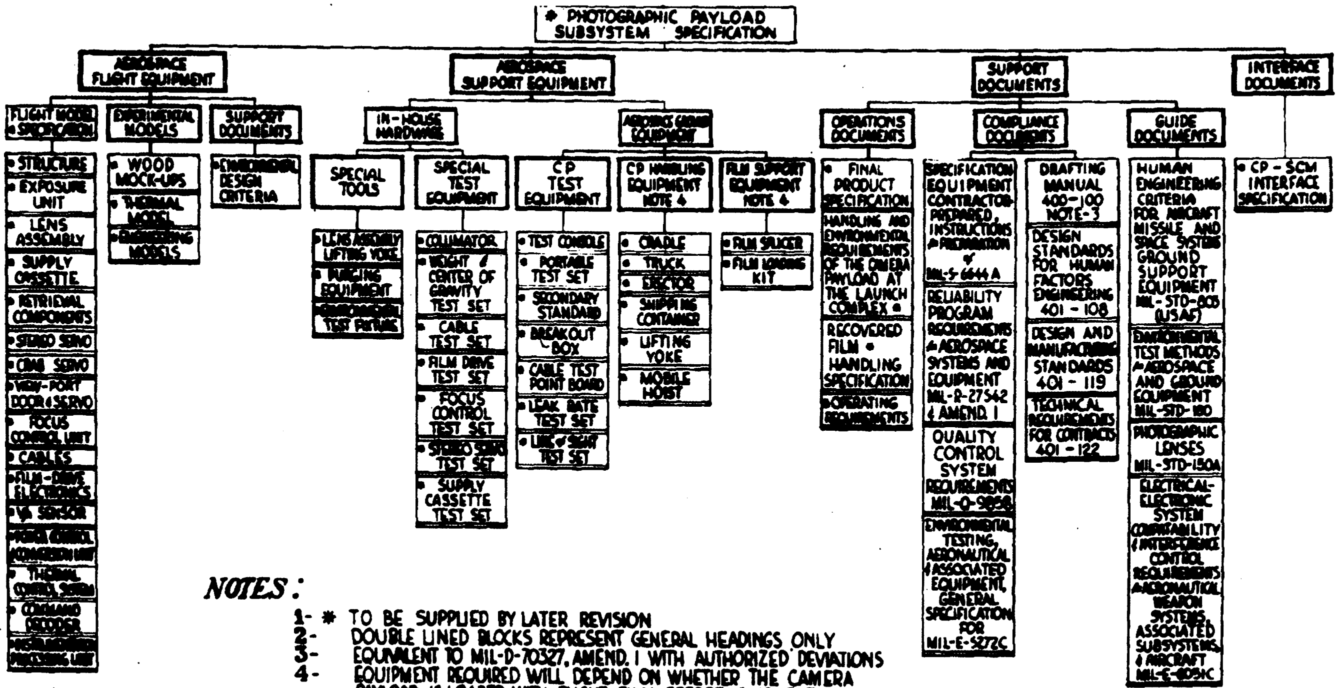
The following paragraphs describe the payload components and their relationships in greater detail.

4.1 STRUCTURE

Component mounting and orientation are dictated by function, available space, accessibility and environmental criteria; the C/P structure provides the mechanical linkage and support for all C/P components in the service module. Each of the structural components described below, with the exception of the take-up cassette support truss, will require minor modification to adapt the existing design to the requirements of this program. The truss will be a new item requiring structural qualification. All other structural mounting concepts employed in supporting and maintaining the alignment have demonstrated their ability to withstand launch forces equal to those expected in the launch environment of the Apollo vehicle. Payload mounting to the service module is covered in detail in Section 5.0 on Interfaces.

4.1.1 Component Support Tube Assembly, Lower and Upper

The component support tube assembly surrounds the lens and exposure unit assembly except in the area of the optical path and provides both support



NOTES:

1- * TO BE SUPPLIED BY LATER REVISION
2- DOUBLE LINED BLOCKS REPRESENT GENERAL HEADINGS ONLY
3- EQUIVALENT TO MIL-D-70327, AMEND. I WITH AUTHORIZED DEVIATIONS
4- EQUIPMENT REQUIRED WILL DEPEND ON WHETHER THE CAMERA PAYLOAD IS LOADED WITH FLIGHT FILM BEFORE SHIPMENT.

Figure 4-2. Specification Tree

for the electronic packages, cabling and heater control system, and also an isothermal environment for the lens. An access door allows unobstructed access to exposure unit parts for alignment and testing.

4.1.2 Socket Mounting Ring Assembly

This assembly provides the main support and mounting surface between the camera payload and service module. It contains three curved mounting pads, spaced about the ring, which establish the main mechanical interface at station 290.75 with NAA. When assembled to the primary structural ring assembly, these pads form a spherical joint, which prevents any external bending forces applied to the payload package from being transferred to the lens.

4.1.3 Primary Structural Ring Assembly

This ring provides the main structural support and reference surface for the camera payload. It carries all longitudinal loads (and those lateral loads not carried by the uni-bal mount) imposed upon the payload by environmental conditions and transfers these loads, through the spherical joint, to the service module. It provides mounting surfaces for the component support tube assembly, the 77 inch lens, film supply cassette, and support truss assembly.

4.1.4 Uni-Bal Mount Assembly

The uni-bal mount, positioned in the area just aft of the 77-inch lens, provides an interface mounting between the camera payload and the service module aft bulkhead. It transfers all lateral loads, not borne by the primary structural ring, to the service module bulkhead. The housing contains a uni-bal bearing which engages a stud of slightly undersized diameter extending forward of the aft bulkhead of the service module. The uni-bal and stud combination allow for longitudinal expansion or contraction of the service module resulting from thermal differentials during various phases of test, launch and orbit. This assembly also provides thermal isolation of the camera payload from the service module bulkhead.

4.1.5 Primary Structural Support Assembly

The primary structural support assembly consists of a support truss assembly, socket mounting ring assembly, primary structural ring assembly, male crabbing bearing track, stereo mirror crab pivot, and mounting surfaces for the stereo mirror pivot bearing blocks, stereo control and drive assembly, and the crabbing control and drive assembly. It aligns the stereo mirror relative to the lens assembly and provides mounting surfaces for the film supply cassette and take-up cassette. After initial alignment, it maintains parallelism of the pivot axis of the stereo mirror to the plane of the reference surface of the primary structural ring within 0.010 inches over the length of the pivot axis. This tolerance applies after initial alignment and testing, but does not apply when loads, other than gravitational, are being applied to the assembly.

4.1.6 Insulating Pads

These pads provide thermal isolation of the payload from the service module at the three forward mounting pads.

4.1.7 Take-Up Cassette Support Truss

The support truss for the take-up cassette, a magnesium weldment, maintains the alignment of the take-up cassette to the rest of the film handling system by means of a rigid tie to the primary structure ring assembly. Thus, the entire film handling system is referenced to the spherical joint formed by the socket mounting ring and primary structural ring and isolates film tracking and alignment from thermal distortions of the service module.

4.1.8 Reliability

The structural configuration to be used on the Survey C/P is nearly identical to an existing, qualified structural design. Although a minor hardware change will be necessary to adapt the C/P to sector I of the service module, the reliability and qualification status of this system will be comparable to that demonstrated by the existing structural design. A significant characteristic of this structural system is its ability to isolate the C/P optical and film handling systems from structural distortions.

4.2 OPTICAL SYSTEM

The fundamental design objective of the C/P is to photograph lunar scenes with a maximum of detail. A second, but basic requirement is to minimize the size and weight of the C/P. To accomplish these requirements, the lens used must approach diffraction limitations; therefore, the lens designer must consider the tradeoffs in lens aperture once focal length and utilize a knowledge of manufacturability to achieve optimum results. The lens proposed for this program is reliable and proven both from the standpoints of design, manufacturability, and test.

4.2.1 Optical Design

4.2.1.1 Lens Aperture. Lens aperture diameter is determined by the altitude from which the lens is to be used and the minimum ground dimensions to be resolved. These factors establish an angular resolving power requirement. Angular resolving power of a perfect lens is a function of aperture and wavelength of the light to be focused and is given by

$$\text{Angular Resolution (High Contrast)} = \frac{C}{D}$$

where D is the diameter of the lens aperture, is the wavelength, and C is a constant depending on the criterion used to determine resolution (C = 1.22 in the case of the Rayleigh criterion). The most efficient aperture, in terms of size and weight, is an aperture just large enough to resolve the size object required where the theoretical minimum aperture for the lens alone is given by the above expression.

In actual design, the lens aperture is always made larger than this theoretical minimum to allow for loss of resolution as a result of geometrical lens aberrations, moderate scene contrast, and the effects of other system elements. The minimum aperture diameter capable of meeting the resolution requirements of this system is 3.3(b)(1) [redacted] To guarantee that this minimum aperture will be obtained after assembly, the lens is designed with an aperture diameter of 3.3(b)(1) [redacted]

4.2.1.2 Focal Length. The focal length of the lens is determined by the desired relationship or scale between the ground and image size. Optimum focal length is found by studying the ground resolution for a range of focal lengths, each having a 3.3(b)(1) [redacted] effective aperture. Based on such a study, a 77-inch focal length is considered optimum under ideal conditions for photography with Kodak type 4404 film or its equivalent.

4.2.1.3 Relative Aperture and f-Number. Relative aperture is defined as the ratio of the diameter of the effective aperture (entrance pupil) to the focal length of the lens. This ratio, together with the transmittance of the lens, determines the illumination of the image or the speed of the lens. The notation most commonly used to indicate the relative aperture or speed of a lens is the *f*-number, written as *f*/4, where the *f*-number, 4, is the reciprocal of the relative aperture. Thus, as the *f*-number decreases, the relative aperture and speed of the lens increases. The *f*-number of the lens used (aperture = 3.3(b)(1) [redacted] 3.3(b)(1) [redacted] is 3.95 (or *f*/3.95).

4.2.1.4 T-Number of Optical System. The f-number must be combined with the lens transmittance, t, when used for exposure calculations. The lens speed is stated in terms of a T-number which is defined as follows:

$$\text{T-Number} = \frac{f\text{-number}}{t}$$

The transmittance, t, is determined photometrically and, therefore, takes into account all light losses including those attributable to obstructions in the aperture. Approximately 54 percent of the incident light flux in the 450 to 700 mm region is transmitted. Therefore, the

$$\text{T-number} = \frac{3.95}{0.54} = 5.4$$

4.2.1.5 Lens Type. The lens chosen is a Maksutov-type which has the advantage of using only spherical surfaces. It is a 77-inch focal length f/3.95 lens with a half-field angle of 3.2 degrees. The depth of focus is ±0.0005 inches at the image plane. It is shown schematically in Figure 4-3, expanded schematic of camera payload optical components. The stereo mirror indicated is part of the total C/P optical assembly.

4.2.1.6 Image Quality and Lens Accuracy. The quality of the aerial image produced by the lens is demonstrated by photographic resolution tests conducted on the lens alone and as an integral part of a C/P. Sine—wave-response techniques (described in Appendix A) are used to relate these resolution measurements to the predicted theoretical performance of the lens.

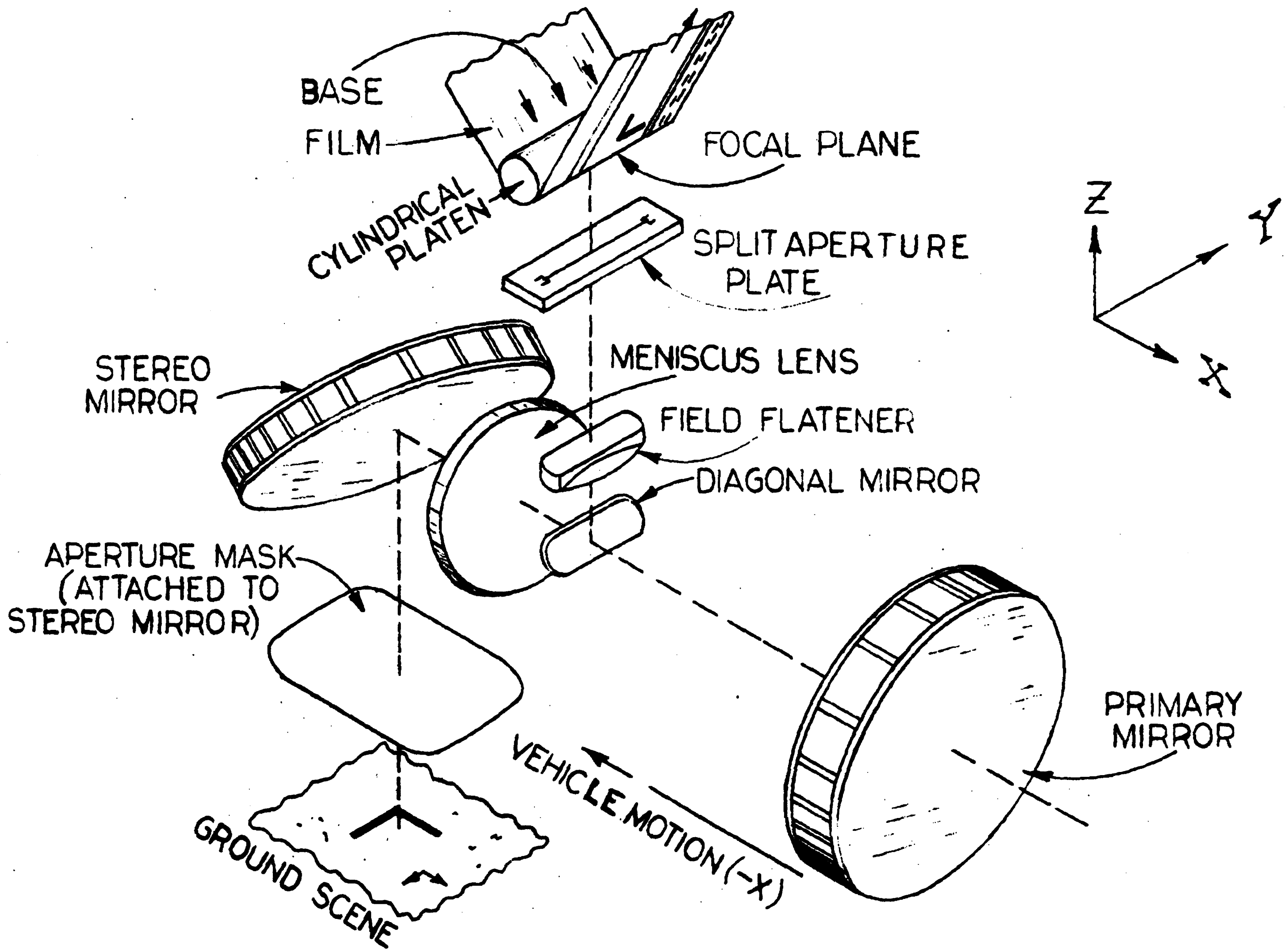


Figure 4-3. Expanded Schematic of Camera Payload Optical Components

To achieve the required image quality, the optical elements are precisely located and retained to prevent distortion of lens and mirror surfaces. The lens must maintain the best focus position within 0.0010 inch*, or loss of resolution results. To maintain this critical focus position throughout the mission, close controls are placed on the range of temperatures and temperature gradients. Careful consideration must also be given to mounting the lens and to choice of materials used in the lens components.

4.2.1.7 Image Orientation and Film Motion. The ground scene image, while passing through the camera payload lens assembly, undergoes a complete inversion. This simply means that the ground scene is inverted in the y plane. Since several changes in orientation of the image are involved, Figure 4-3 is included to illustrate the relationship between the initial ground scene and the final image recorded on the film. Figure 4-3 also shows schematically the various elements of the lens system involved. The relative directions of film motion for image motion compensation and vehicle motion over the ground scene are also shown in this figure. A detailed description of the film format is shown in Figures 3-17 and 3-18.

*This value was determined from calculations based on arbitrary criteria that included film response, film process control, and the manufacturability of the lens.

4.2.2 Lens and Mirror Elements

The elements of the optical assembly include both mirrors and lenses. In the order that a light ray passes through the optical assembly, these elements are: the stereo mirror, the meniscus lens, the primary mirror, and a group of lenses known collectively as the field flattener group.

4.2.2.1 Stereo Mirror. The stereo mirror is a plano mirror which is mounted separately from the lens assembly. It reflects light ray into the main lens assembly. The stereo mirror is positioned for stereo photography, and is also positioned in crab to compensate cross-track image motion.

4.2.2.2 Meniscus Lens. The meniscus lens is a concave-convex element with very little optical power. This lens serves as a window for the lens assembly and is used to correct the spherical aberration of the primary mirror. At the level of performance required for this lens system, the quality of the meniscus has a very significant affect.

4.2.2.3 Primary Mirror. The primary mirror is a first surface spherical mirror the rear surface of which is made parallel to the polished concave front surface to aid thermal and structural stability. The primary mirror provides the principal focusing action in the folded optical path of the 77-inch lens.

4.2.2.4 Diagonal Mirror. The diagonal mirror is a rectangular flat mirror, mounted in the center of the lens barrel on a hub supported by Invar tubular arms welded into the front of the lens barrel. The diagonal mirror reflects the light rays coming from the primary mirror through a 90° angle to allow them to fall at the film plane in the exposure unit which is mounted on the side of the lens barrel.

4.2.2.5 Field Flattener. The field flattener consists of two lens elements in a cell near the film plane. As the name implies, a flat image plane is produced. Chromatic aberrations are also corrected by the field flattener elements.

4.2.2.6 Flare Light. Baffles are incorporated in the Invar lens barrel and the field flattener assembly to shield the focal plane from stray light rays. Experience indicates that the amount of extraneous light should not exceed 1.5 percent of total.

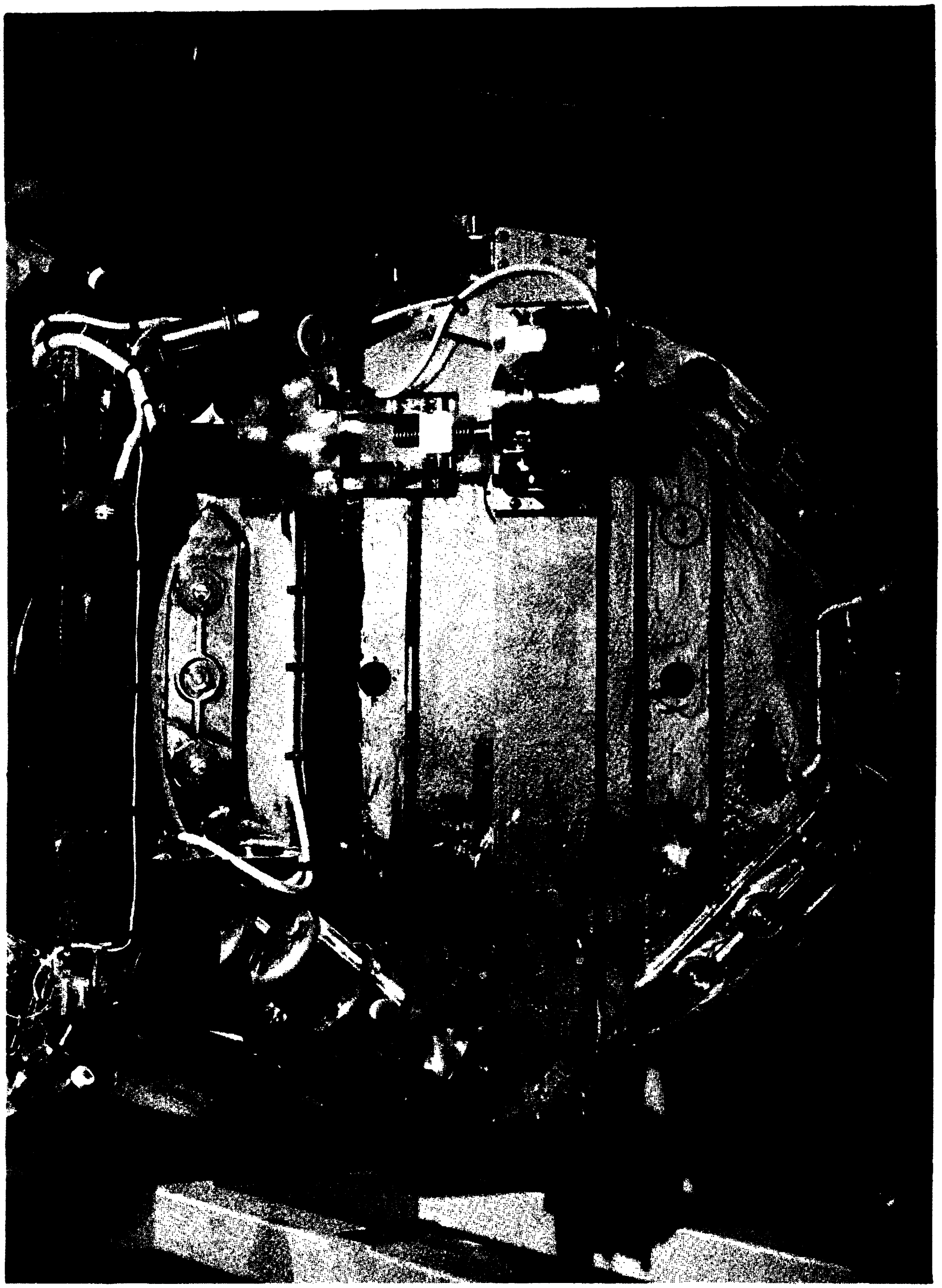
4.2.3 Optics Mounting

The 77 inch lens is rigidly attached at its forward end to the primary structural ring. This mounting restricts the lateral and longitudinal movement of the lens. The aft end of the lens barrel contains the unibal mount that engages with the stud on the aft bulkhead of the service module. This mounting arrangement provides complete lateral support but allows freedom for differential longitudinal movement.

The stereo mirror assembly is mounted to the stereo mirror support by means of bearing blocks supported on a movable bridge. This mounting arrangement permits the mirror two degrees of freedom for controlled movement about the optical stereo and crab axes. Stereo movement is achieved by rotating the mirror in the bearing blocks about a transverse axis. The movable bridge, pivoted at one end, is moved in bearing tracks at the other end by the crab-servo lead-screw mechanism to achieve crabbing movement. It is designed so that the pivot point and the crab-servo attachment can be interchanged; therefore, either positive or negative rotations can be obtained. This movement of the bridge physically occurs about the vehicle X axis, but optically represents crab movements about the Z axis (see Figure 4-4).

4.2.4 Reliability

The optical system described in the previous paragraph is identical to an existing, qualified optical design concept. No modifications will be necessary for adaptation to lunar photography. As a result, the reliability and qualification status of this system will be identical to that demonstrated by the existing optical design.



1. Crab Servo
2. Alternate Crab Servo Mounting Point
3. Stereo Servo
4. Bridge

Figure 4-4. Stereo Mirror (Back)

4.3 CAMERA AIMING

4.3.1 Stereo Obliquity and Crab

The C/P primary mission is one of high resolution site verification. This can be accomplished with the proposed payload by means of in-track stereo photography. The line-of-sight of the existing optical system can be moved to a fixed forward or aft position by means of a stereo mirror rotation of $\pm 7.5^\circ$ about the vehicle pitch axis, corresponding to $\pm 15^\circ$ line of sight angles. Although best resolution is obtained "in-track" (zero obliquity angle), in some cases it may be desirable to aim the camera to the right or left of the ground track. The line of sight, can be moved in obliquity by means of a vehicle roll maneuver. Stereo photographs can be made at any obliquity position of the vehicle up to a recommended maximum of 40° (scale distortion and increased smear at field edges become excessive beyond this value).

A crab adjustment is also provided in the camera payload. This adjustment was designed to compensate the cross track component of image motion, that is, to align the image velocity vector perpendicular to the camera slit and parallel to the film velocity vector. Rotation of the image velocity vector (crab) is accomplished by a rotation of the stereo mirror about the roll axis of the vehicle. For earth photography, crab compensates the earth's rotational velocity. This is not required in lunar photography because moon rotation is very slow. However, crab can also be used to compensate cross track components of image smear due to vehicle yaw and vehicle roll rate, as discussed in the section on V/h. As an example, 0.5° of vehicle yaw can be compensated by a 0.5° crab rotation of the stereo mirror. The line of sight is also rotated 0.5° in roll by the crab movement.

4.3.2 C/P Aiming Drives

4.3.2.1 Stereo Servo. The stereo aiming drive is a digital servomechanism which drives the stereo mirror by means of a lead-screw and nut combination having a 0.2 inch-per-inch pitch. As a result of this lead-screw pitch, the servomechanism does not need to be locked in position during powered-flight sequences. (A lead-screw, whose pitch is below a critical angle determined by the coefficient of friction, will not convert thrust loading into rotational loading.) The servo output is delivered by means of a rotating shaft which is mechanically coupled to the lead-screw and nut combination. In addition, the servo contains a potentiometer which is geared so that the output voltage corresponds to the stereo mirror position.

The stereo servo is a simple d-c drive controlled by the agreement or disagreement of the input command with a code generated by the shaft encoder. It receives two electrical power inputs:

(1) +28 volts dc unregulated for operational power

(2) +5 volts dc for the load position instrumentation circuit.

The stereo command is a one bit word command presented to the servo from the spacecraft. This command is satisfied by rotating the servo output shaft until the internal position code, generated by the encoder, matches the input command. The commands and associated mirror positions are as tabulated below:

Stereo Position Codes

Stereo Mirror Position	Command Codes
0°	0
+15°	1

The stereo servo is capable of positioning the stereo mirror in any one of two discrete positions. Under worst conditions of low voltage and maximum anticipated load, the stereo servo can move the mirror between positions within 4 seconds. The average electrical power required by the servo when driving the stereo mirror is 32 watts. No operational power is required after a given command has been satisfied.

Means are included to automatically disable the servo in the event it does not satisfy a command within 7.5 seconds. Should this occur, the servo is reconnected whenever the digit of the one bit command word is changed. The servo has an electrical limiting action which prevents the load from being driven more than 0.277 degree beyond the two extreme required positions. Mechanical stops are also provided to cage the mirror, in the event a malfunction of the servo should attempt to drive the mirror outside its normal operating range.

4.3.2.2 Crab Servo. The crab servo is capable of continuously positioning the stereo mirror for crab correction during photography. The crab motor drives the stereo mirror through a gear reduction train and a lead screw, similar to that for the stereo servo. This gear train also drives a potentiometer providing voltage for crab angle monitoring and an encoder whose purpose is described in Section 9.4.

The crab servo sets any crab angle from +1.5 degree to -1.5 degree by command signal. The command signal is an analog voltage supplied from the V/h sensor as described in Section 9.4. Under conditions of maximum load and low supply voltage, the servo can drive the stereo mirror from one crab extreme to the other in 5 seconds. The electrical power required to drive the servo depends on the crab angle difference between the mirror and V/h sensor. Since the crab correction system is a nulling system, the crab angle difference is usually small and the power requirements are low. During maximum crab angle change, the power requirement is about 30 watts.

4.3.3 Servo Mechanism Mounting

The stereo servo is mounted to the bridge portion of the stereo mirror support and moves in crab with the mirror and bridge assembly. The crab servo is mounted to the truss portion of the stereo mirror support assembly. Each is mounted on a pivot bearing which allows the servo and lead-screw mechanism to follow the motion of the mirror. Bending moments in the lead screw are thereby avoided. A secondary effect of this mounting arrangement is to convert the linear movement of the lead screw to an approximately linear rotational movement of the mirror (see Figure 4-4).

4.3.4 Reliability

Two minor changes will be made to existing qualified servo designs. Two servo positions will be used instead of the present three position servo design for the stereo unit. It is anticipated that continuous analog crab compensation will be attained through the use of a V/h sensor output. The second change will be the incorporation of transistor switching circuitry to replace the relays used in existing designs. This type of switching circuitry has been qualified as a part of a positioning servo, although not specifically this one. It is expected that the reliability of the existing servo designs will change very little as a result of these minor changes which are deemed desirable from an EMI standpoint.

4.4 FILM HANDLING SYSTEM

The film handling system design concept has been based on the photographic system requirements as outlined in Section 3.0 of this report. It is physically composed of those drivers, rollers, tension mechanisms, loopers, and film alignment devices necessary to accurately and smoothly transport the photographic film from the supply cassette through the exposure unit and into the take-up cassette. Despite close control of manufacturing tolerances and assembly, independent mounting of these units to the primary structural assembly may introduce errors in the alignment path both from the tolerance errors and mechanical flexure. In order to accommodate these errors, suitable transition mechanisms and rollers are introduced at appropriate places in the film path. Pivot rollers, pivoting about an axis parallel to the on-coming film plane, are inserted as idlers between the supply/exposure unit, exposure unit/supply, and supply/take-up. Functioning as displacement compensators, these "pivot"/"wobble" compensating rollers have been successfully employed in the existing hardware thus providing a firm basis for confidence in anticipating precise film tracking and guiding in the proposed C/P. The film handling system design concept is based on the capability of performing strip or stereo pair photography of equal quality; either mode is accomplished by control of the duration of the photographic burst.

Figure 4-5 schematically shows the path of the photographic film through the system, starting at the supply cassette and ending at the take-up cassette. A detailed description of the film handling system is presented in the following paragraphs.

NOTE: $T_2 > T_1$ DURING STRIP PHOTOGRAPHY
$T_2 = T_1$ DURING STEREO PHOTOGRAPHY

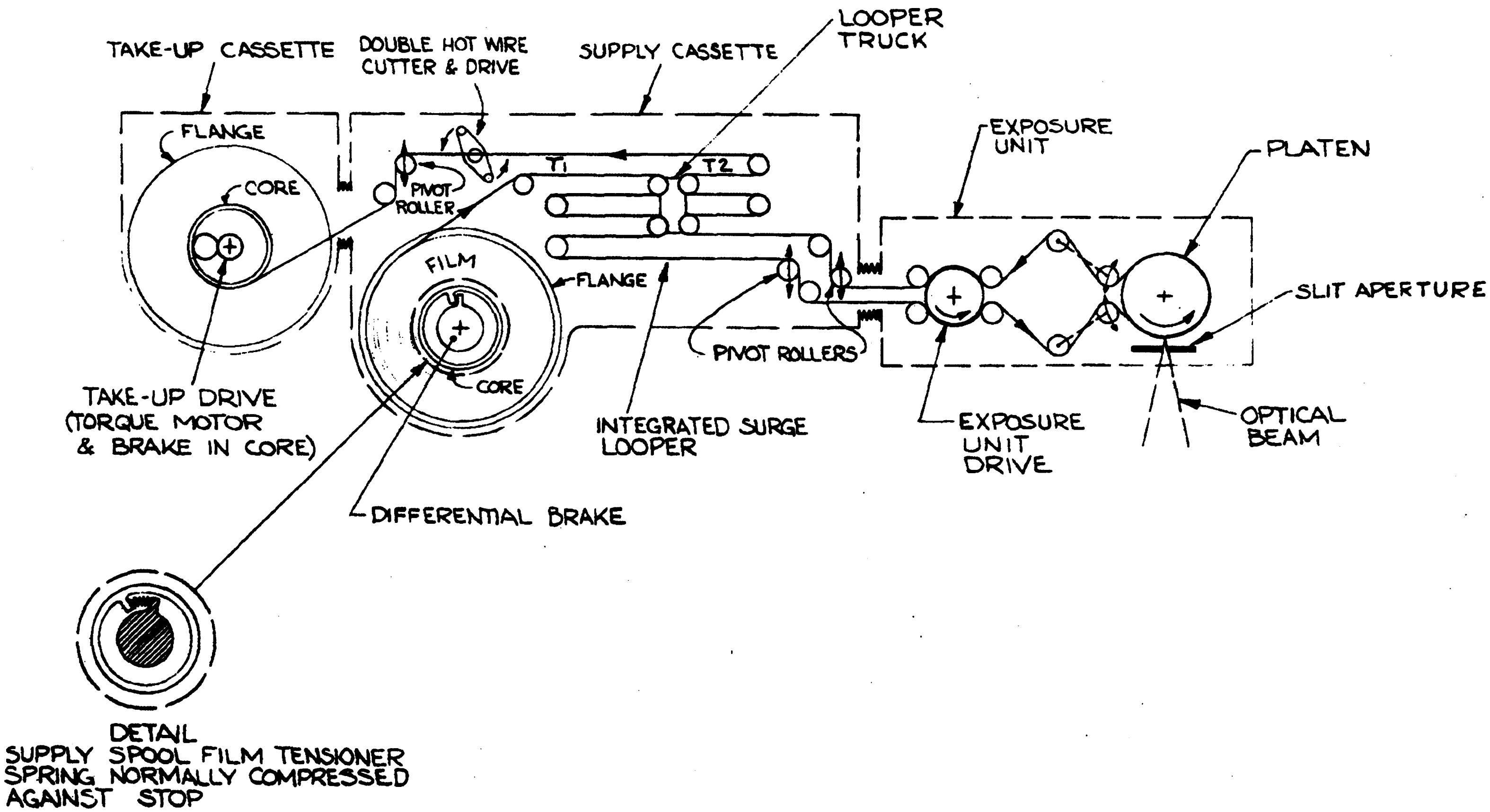


Figure 4-5. Film Path Schematic

4.4.1 Supply Cassette

The film, wound on a suitable spool is contained within a lighttight supply enclosure of sufficient strength and rigidity to provide structural mounting provisions and satisfactory mechanical alignment under the anticipated environmental conditions. Rotational restraint is imposed on the spool as necessary to provide film tension for proper film tracking and guiding. The restraint is provided by a drag or friction brake. Figure 4-6 shows the relationship of core diameter to convolution diameter of the spooled film. It is evident, for driving and braking reasons, that a large core provides the most favorable O.D. to I.D. ratio. Further, for large footages of film, core diameter has a small effect on the ultimate convolution diameter (see 3000 feet to 6000 feet range bracketed in the diagram). An additional advantage provided by large spool cores is the capability of including brakes and drive motors inside the cores.

In the design, see Figure 4-5, three-thousand-feet of film on a standard Kodak 6-inch aero spool core (13.57 inches convolution diameter, 14-inch diameter standard honeycomb flanges) is loaded into the supply cassette about a concentric differential drag-brake contained inside the core. The drag-brake is a multiple disc type containing alternate plates of metal and lubricated felt. One half of the metal plates are keyed to the rotating spool core and therefore rotate when the film is drawn from the spool. The remaining metal plates are keyed to a non-rotating central shaft. The laminated stack of metal and felt discs is axially spring loaded to initiate friction between the several members of the laminate. An appropriate reduction gear train rotates a lead-screw as film is consumed, causing a nut to bias the axial spring loading at the rate needed to maintain uniform film tension as the convolution diameter changes.

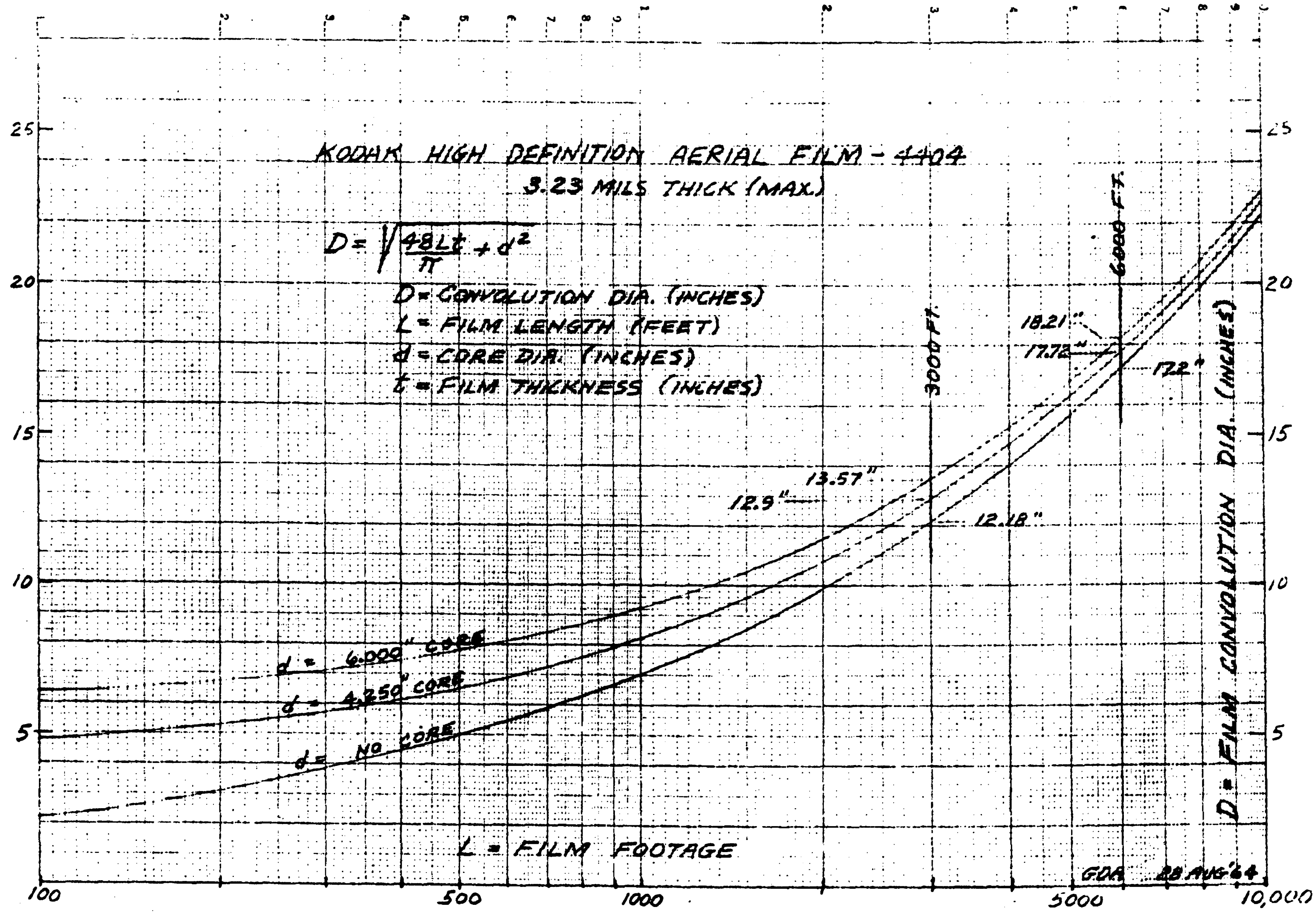


Figure 4-6. Film Footage vs Convolution Diameter of Spooled Film

As a precaution against creep slippage of the brake under conditions of severe environmental vibration, allowing film to go slack, the supply reel is spring coupled to the brake. Normal film tensions (2.5 to 8 pounds tension on the film is suitable to maintain good tracking) hold the spring in compression such that the spool core is in positive mechanical contact with the internal brake at all times. The spring prevents slack film between the supply spool and the supply drive in the event that brake creep occurs. Such a spring can be made to act through as many spool revolutions as required to obviate the effects of brake creep.

The integrated looper system is designed with sufficient capacity to store up in advance one stereo frame length of film and provides the capability of exposing the frame without requiring supply and the take-up spool rotation. In this way the supply and take-up drive cannot cause vibration during photography. Film tensions are equal on both sides of the looper truck during exposure of the stereo frame.

Between stereo frames, exposed film is drawn from the take-up side of the looper by the take-up drive. Simultaneously, the supply side of the looper is automatically filled in anticipation of the next stereo frame exposure.

During monoscopic strip photography the looper truck is held against a stop on the take-up end of the looper system by the continuously energized take-up drive. Variations in film tension do not reach the platen because of the drive system employed in the exposure unit. See Section 4.5.

4.4.2 Exposure Unit

The exposure unit consists of a lighttight housing which accepts incoming film from the supply cassette, passes the film over an exposure unit drive roller, around the platen, back over the drive roller (180° from the original position) and returns the film through the supply cassette housing from which it is transmitted to the take-up cassette. The drive roller is powered by a hysteresis synchronous motor to maintain a precise peripheral speed. The film drive in essence is the type known as a "Davis Drive", noted for smoothness of operation. The platen is preceeded and followed by a fluid-damped, variable rate spring idler rollers which provide a considerable degree of auto-damping as a contribution to film velocity smoothness. A complete analysis and description of the exposure unit appears in Section 4.5 of this report.

4.4.3 Take-Up Cassette

4.4.3.1 Take-up Film Handling. Film from the exposure unit is routed back through the supply housing and looper by appropriate guide rollers, through a film cutter device and lighttight flexible chute into the take-up housing and on to the take-up spool. The film cutter is an adjunct which ensures that the film and leader have been completely separated from the remainder of the film handling system at the end of the mission, or which permits command termination of photography and the salvaging of exposed material without the necessity of winding up the remaining unexposed film. It consists of a pair of wires running athwart the film plane near the exit of the supply housing adjacent to the take-up. The wires are attached to the ends of two double-ended arms pivoted about an axis passing through the film plane. The act of cutting is accomplished by heating the wires by virtue of their internal resistance and subsequently rotating the support arms, causing the film to be severed in two places.

The take-up spool is driven by a torque motor of sufficient power to take up film at the maximum photography rate and to maintain suitable film tension. In a power OFF condition, the take-up spool is locked to prevent rotation and loss of film tension.

4.4.3.2 Retrieval Weight Restrictions. The maximum load able to be returned with the command module has been established at 80 lbs. To maximize the quantity of exposed film which can be returned, serveral take-up cassette designs have been investigated. The most favorable approach is one in which the drive core and cassette ends are jettisoned prior to transfer to the command module, leaving a light-trap periphery skin around the reel flanges as shown in Figure 4-7. Approximately 20 lbs. of the total 30 lb. cassette weight can be removed by this method. This, in effect, allows an increase in "take hence" film of 20 lbs. an approximately 1200 feet.

4.4.4 Reliability

The film handling system to be employed consists of a number of proven film handling elements. No problems of integrating these elements are anticipated since the fundamental concepts associated with these proven qualified elements are well understood. The goal of this system is to minimize the number of moving and ON and OFF cycles during actual photography in order to obtain the desired high resolution photographs.

4.5 EXPOSURE UNIT

4.5.1 General

The exposure unit controls the exposure of the film on which the lunar image

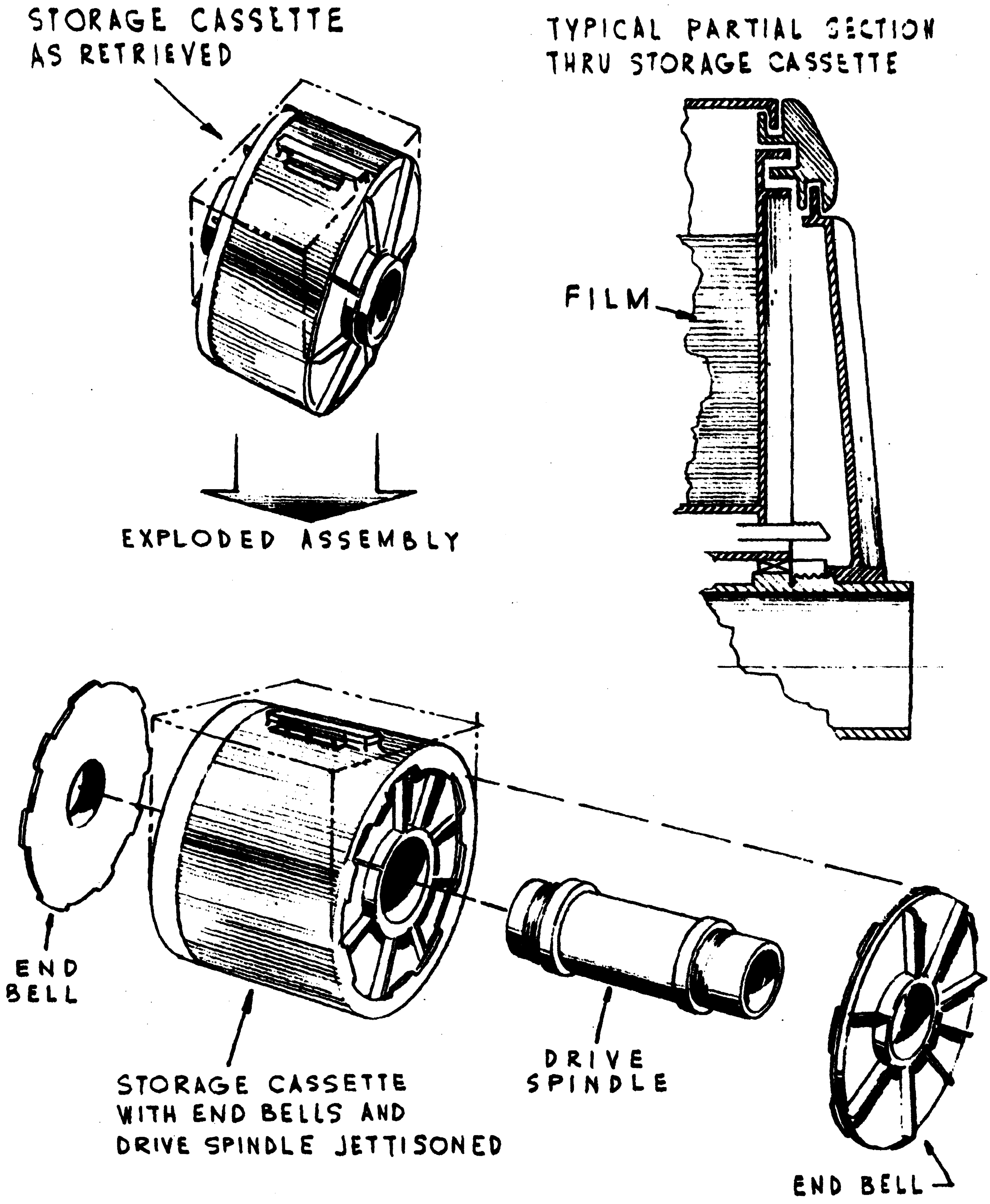
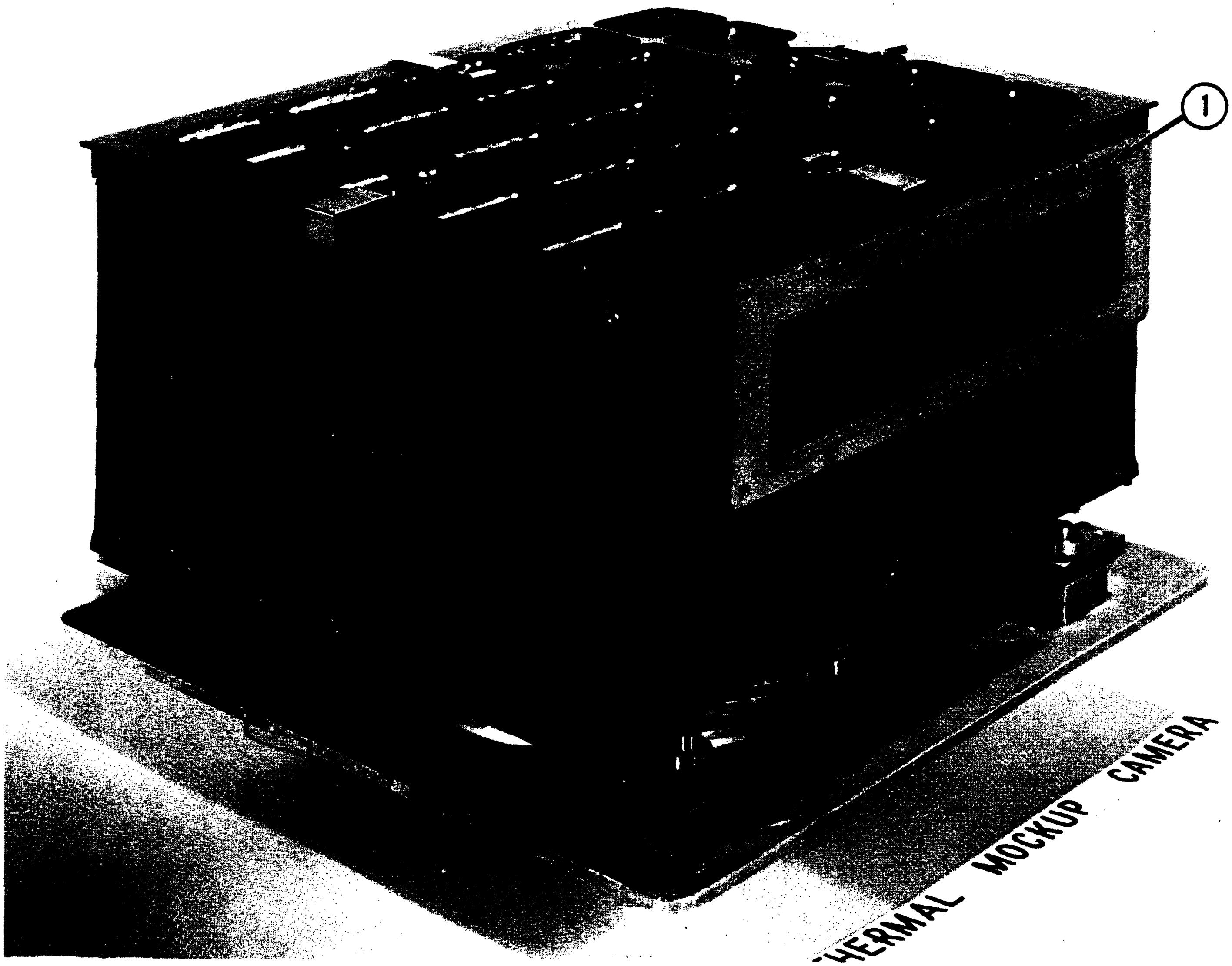


Figure 4-7. Storage Cassette

is recorded. In spacecraft photographic applications the high velocity of the spacecraft with respect to the scene necessitates the use of image motion compensation (IMC) techniques to control image smear in addition to the requirements for maintaining the sensitive surface of the film at the image plane and establishing the exposure times, as in the case with the more familiar camera systems. IMC is provided by moving the film at the same velocity as the scene image during the exposure period, the precision of synchronism determining the amount of smear, or blurring, which will occur. The external structure of the exposure unit provides a light-tight enclosure for the exposure mechanism. A typical exposure unit of the type to be described is illustrated in Figures 4-8 and 4-9. The exposure unit consists of a film drive and platen mechanism, the focus detector and drive assemblies, a programmable slit mechanism and data recording assemblies.

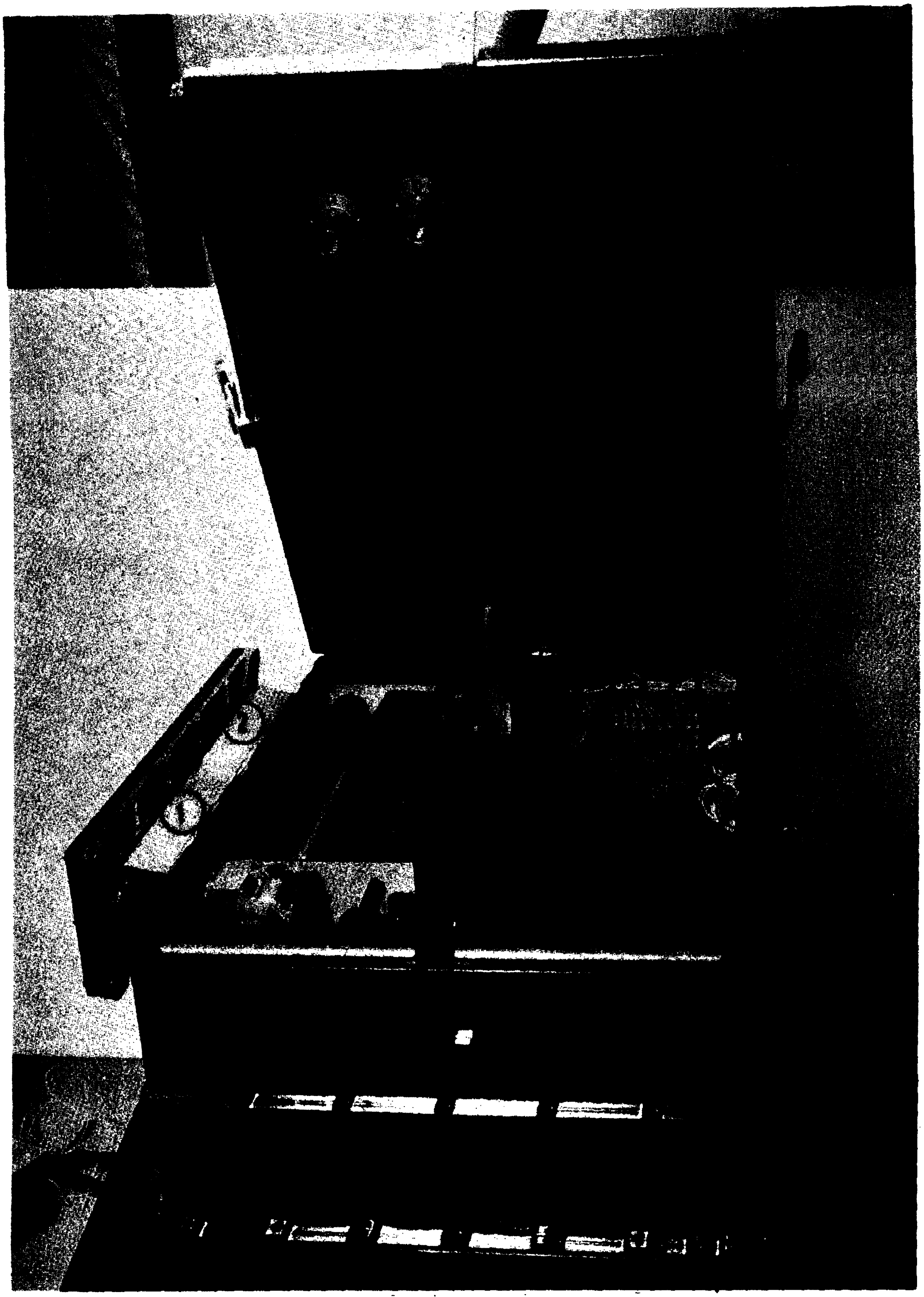
The exposure unit is a strip-type, or slit, camera which continuously exposes a narrow strip across the film as the spacecraft passes over the area being photographed. The image is focused through a programmable-slit aperture onto the moving strip of film. Exposure of the film is determined by the choice of the slit width and the speed at which the film moves past the slit. The forward velocity component of the spacecraft relative to the object plane is compensated for by the IMC correction introduced as a variable film speed. The yaw and roll contributions to the image velocity vector established by the spacecraft motion relative to the object plane is more readily compensated by controlling the stereo mirror position in crab attitude than it would be to provide two dimensional IMC correction. Crabbing the mirror causes the image to remain stationary in a direction along the slit.

The film is held firmly on a cylindrical drum (platen) whose diameter (4.625 inches) is large enough to provide the necessary film flatness in



1. Flexible Joint Mating Face

Figure 4-8. Exposure Unit, Exterior



1. Drive Roller
2. Idler Roller
3. Platen

Figure 4-9. Exposure Unit, Cover Open

the narrow area behind the slit. The film is wrapped around the platen and moved past the slit aperture at a rate determined by the IMC requirements. Mechanical power to move the film through the exposure unit is supplied to a film drive roller by a hysteresis-synchronous motor, whose speed is established by the motor speed drive unit (MSD).

The field of the camera payload lens covers about 8.5 inches of the 9.5 inch width of the photograph. Because lens aberrations increase rapidly with field angle, the strip-type exposure unit will give better performance over a given format than a frame-type exposure unit whose lens must cover the diagonal of the field.

The programmable slit assembly consists of a slit plate containing slits of various widths. The correct slit is moved into position by a slit drive motor and associated electronics. The slit selection is a function of the film drive speed, which bears a definite and known relationship to spacecraft altitude, and hence, exposure time. The effect of the photometric functions upon slit selection is adequately defined by knowledge of prevailing lunar longitude with respect to the subsolar point to approximately a 5 degree tolerance. The appropriate slit is selected in response to a slit position command received from the spacecraft.

Focus control is provided by the focus control system which consists of a focus detector assembly, focus control unit and focus drive assembly. A detailed description of the focus control is provided in Section 4.8 of this report.

Also contained within the exposure unit are two data track printing heads. The data tracks, which consist of 400 cycle per second and 10 cycle per second timing marks together with a periodically occurring binary time label word, are generated from data signals supplied to the C/P interface. The data signals are diplexed and amplified in the payload and the resultant signals are used to pulse neon lamps to an illumination level sufficient to expose the film. Figure 4-10 illustrates the basic data track printing head electronics in schematic form. The circuit illustrated provides sufficient light output and has fast rise and fall times to permit exposure of the film in a manner suitable for machine readout of the exposed data tracks.

4.5.2 Film Drive and Platen

4.5.2.1 Image Motion Compensation (IMC). During photography the camera drive must provide a constant film drive velocity to prevent variation in exposure which would produce bands of non-uniform density (banding) and differential movement of the aerial image and film which results in smear. In order to compensate for image motion over the expected range of altitudes and camera aiming angles, provision is made for film speed adjustment in film drive velocity steps varying in one-half percent, or smaller, steps. The range and step increments are derived from the altitude and aiming parameters specified for the lunar mission. Changes of film drive velocity are achieved by varying the power supply frequency of the hysteresis synchronous film drive motor. The film drive motor power supply frequency and associated voltages are altered step-wise from the nominal response to binary-coded command signals.

Two sources of IMC commands are available, the V/h sensor in the C/P and discrete IMC commands received from the spacecraft. The command source is

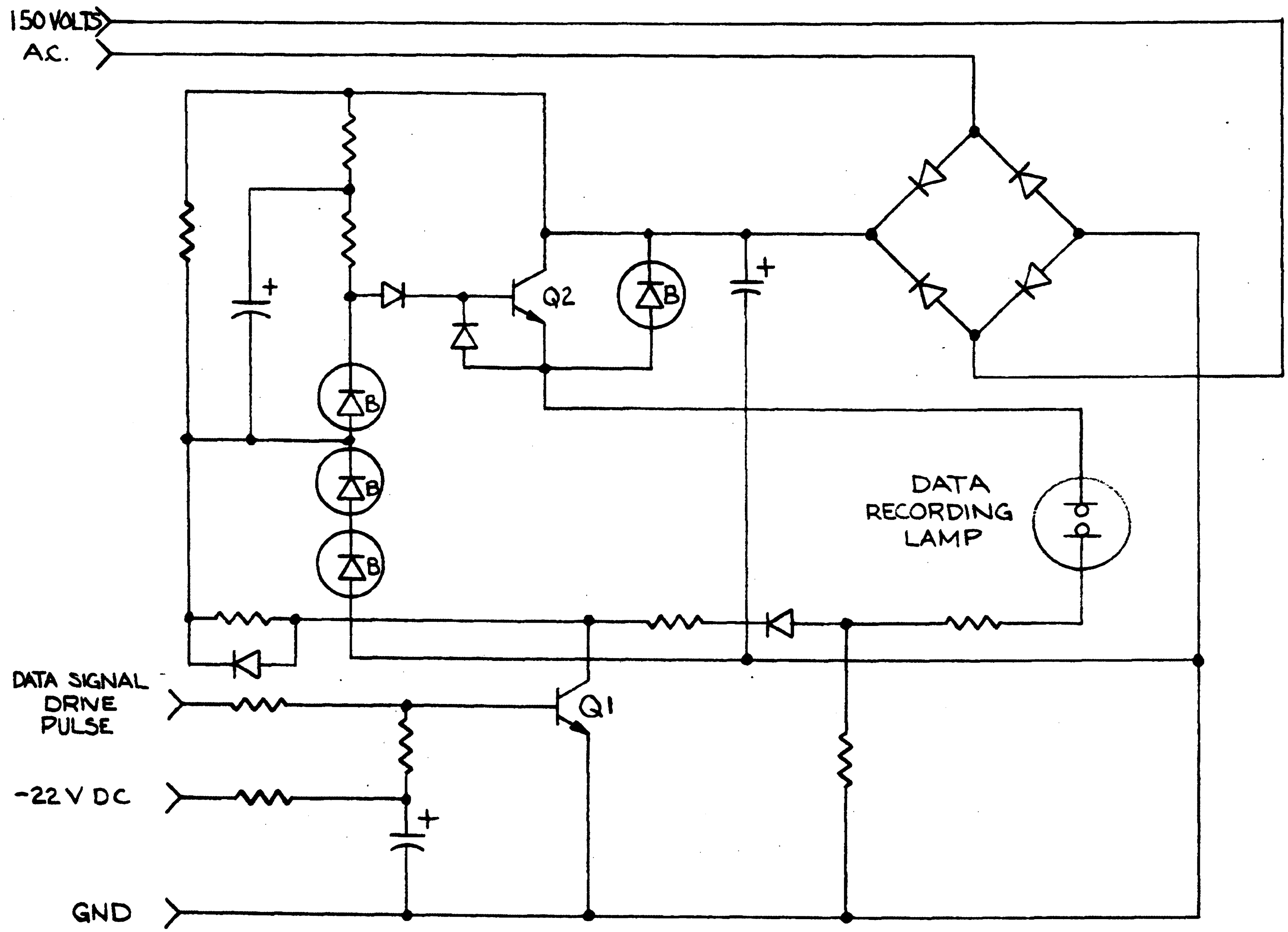


Figure 4-10. Data Recording Assembly Schematic Diagram

selectable using the IMC automatic-manual command. The film drive system is normally controlled by the C/P's V/h sensor. However, the C/P will require that its command input be from the spacecraft if -

(1) The V/h sensor fails to provide a properly correlated output due to a lack of sufficient scene bit density, or

(2) An anomaly occurs in the V/h sensor which causes the V/h malfunction signal to occur.

If the V/h sensor fails to provide a valid output due to a lack of scene information content, and the C/P receives its commands from the spacecraft for a period of time, the return to automatic operation will occur automatically upon resumption of valid V/h sensor correlation. In the instance of a V/h sensor anomaly which causes the malfunction signal to occur, a return to automatic operation will not take place since the anomalies which establish the malfunction signal are catastrophic in nature (e.g. failure of the photomultiplier tube, failure of the V/h sensor drive motor, etc.). It is therefore desirable that the IMC command applicable to each of the 10 LEM landing sites be stored in the on-board computer and that the IMC command to the C/P be updated as each site is acquired. In this manner a failure of the V/h sensor will not cause a loss of photography of any site to occur. In fact, if the command to be stored is able to be determined with sufficient accuracy, there will be no evidence of a discontinuity.

A detailed description and theory of operation of the V/h sensor is contained in Section 4.6 together with a discussion of its adaption to provide IMC commanding of the film drive system.

4.5.2.2 <u>Film Drive Electronics (Motor Speed Drive - MSD)</u>. Variable frequency power for the film drive motor is supplied by the MSD. A simplified block diagram of the MSD is shown in Figure 4-11. The MSD receives binary commands from the V/h sensor in the automatic IMC mode or from the spacecraft in the manual IMC mode. The binary commands gate the output of a pure binary counter which is driven by a high stability, high frequency reference clock. The gated counter outputs are applied to a single shot multivibrator which resets the counter and initiates a new counting cycle. The counter is reset at a rate corresponding to a multiple of the desired frequency. The period of the output pulses of the single shot multivibrator defines the period of a multiple of the commanded frequency. The single shot multivibrator outputs drive a flip-flop whose output frequency is, therefore, a multiple of the desired output frequency. The flip-flop's two outputs are in turn individually counted down by additional flip-flops which produce two-phase, fundamental frequency outputs which are power amplified and applied to the motor windings. The proper phase shift is obtained directly in this system since the first flip-flop's outputs occur at double frequency and with exactly 180 degree phase difference which corresponds to a 90 degree phase shift when fundamental frequency is reached in the next countdown. Also, the phase shift will be precise and constant for all frequencies. Push-pull power amplifiers directly coupled to the film drive motor, are utilized for power amplification to eliminate the need for output transformers and their attendant weight and volume. The power amplifier gain is adjusted as a function of frequency to provide an output voltage to the film drive motor defined by the equation.

$$V_{out} = \frac{16 \times \text{frequency}}{400}$$

which defines the zero to peak output voltage required as a function of frequency in cycles per second.

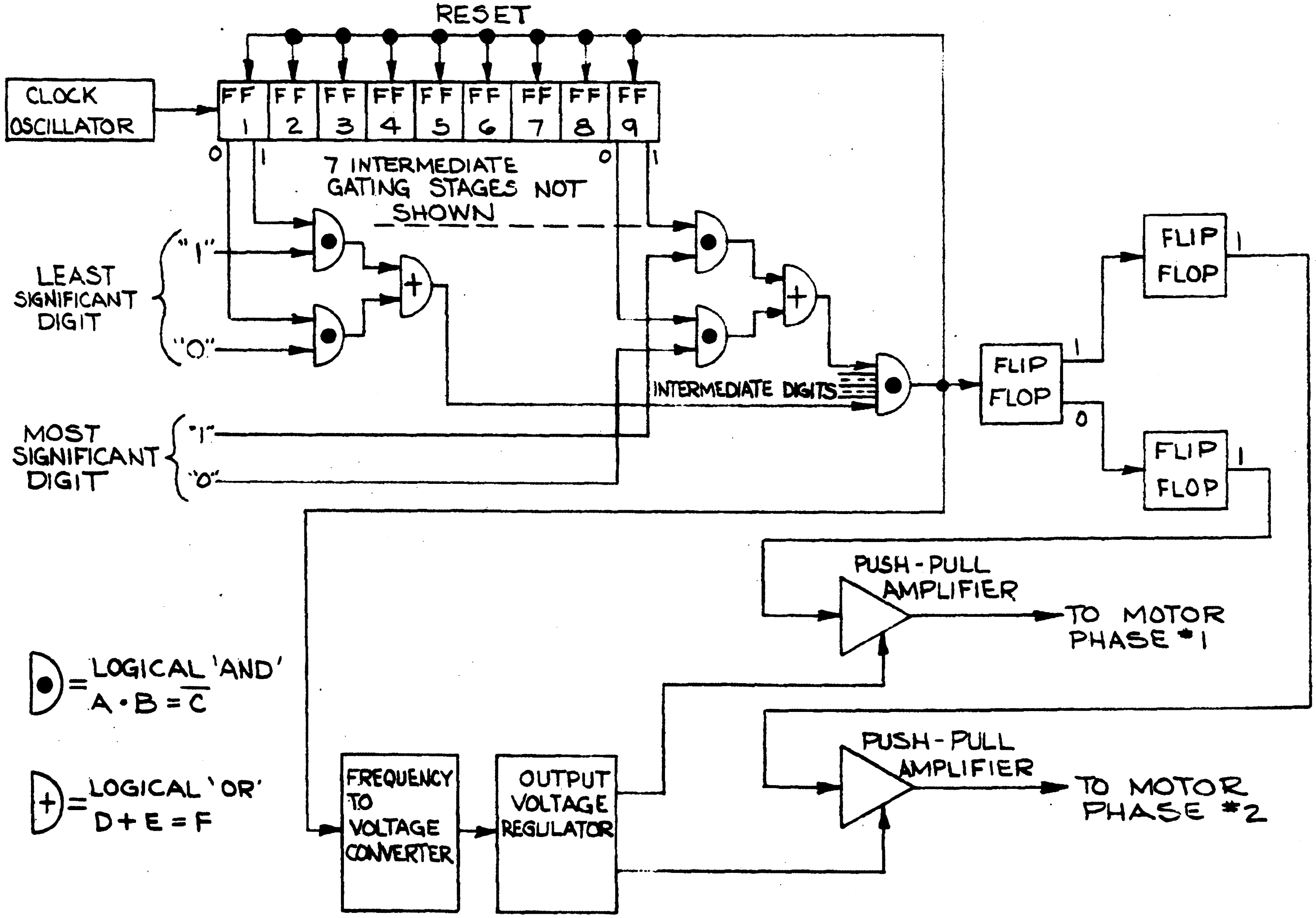


Figure 4-11. MSD Block Diagram

In addition to the MSD outputs required for film drive motor operation, an auxiliary ac output is generated for use in supplying power to the data track recording assemblies located in the exposure unit (see Section 8.1).

4.5.2.3 Platen and Drive Roller. As indicated in the preceeding sections, proper IMC requires that the film be transported past the exposure slit as smoothly as possible. The major factors affecting image smear and "banding" are: 1) accuracy in determination of actual V/h ratio required for IMC: 2) error in the adjustment of the film drive system to the proper speed for IMC due to the step-wise adjustment employed; 3) film drive mechanism smoothness; and 4) externally generated disturbances which are reflected into the exposure unit film handling mechanism. As shown in Section 3.0, there are several other factors which contribute to image smear; but, in general, they are minor contributors or related to attitude and attitude rate factors over which the C/P has no effective control. In this section the latter two major factors affecting image smear and "banding" are considered.

In the absence of slippage of the film with respect to the drive roller and/or the platen, the principal source of film velocity variation is variation of drive roller velocity due to gear noise and bearing noise associated with the drive motor to drive roller mechanical coupling. Externally generated disturbances which can be reflected to the platen arise principally from starting and stopping the film supply and take-up reels which can induce large instantaneous tension transients.

The exposure unit film handling system to be employed is illustrated schematically in Figure 4-12 in equivalent "circuit" form. The film enters the exposure unit and feeds through the drive capstan, through an input

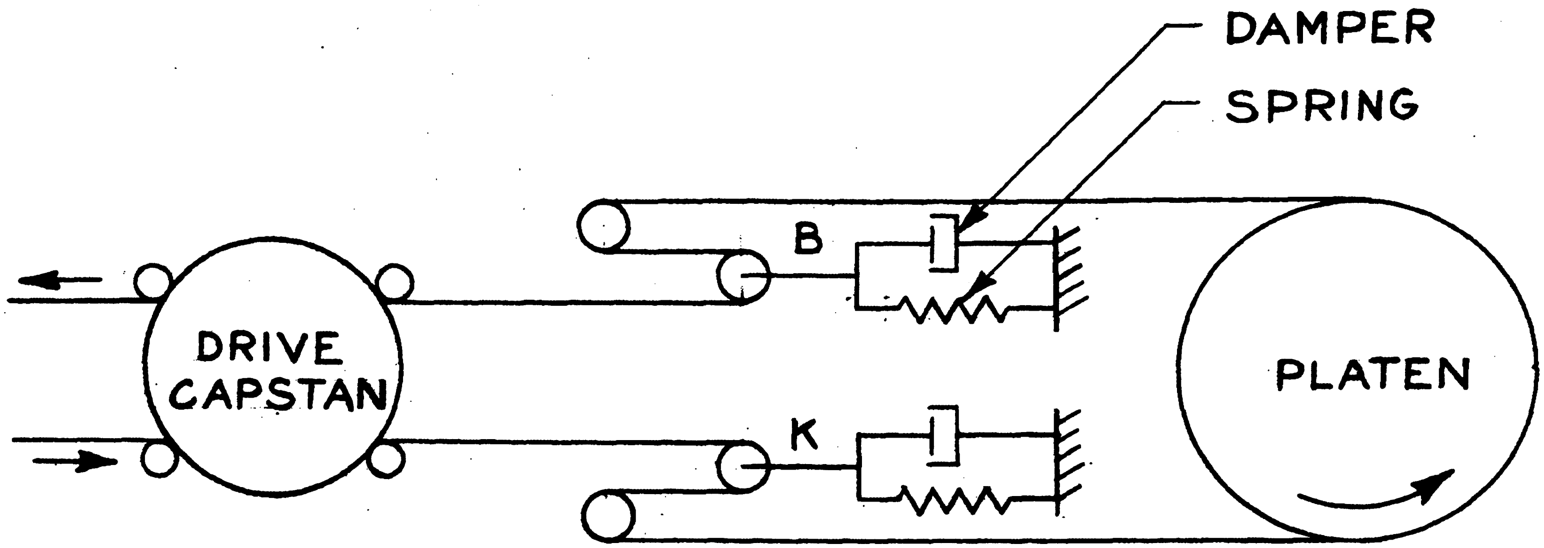


Figure 4-12. Exposure Unit Schematic Diagram

damper, around the platen, through an output damper and back through the drive capstan where it exits. The principal feature of this system is that the film at the platen is isolated from both the supply and take-up film handling components by the drive capstan and dampers. Since differential tension between the film external to the drive capstan and the film on the platen side of the capstan, on both the input and output sides, can exist up to the slip point of the film and the capstan, tension transients are not readily transmitted to the platen. Furthermore, any transient disturbances which might be transmitted to the platen side of the drive capstan are attenuated effectively by the dampers. Thus, the potential problem of film tension transients is essentially eliminated.

The film speed noise introduced by the mechanical coupling of the film drive motor to the drive roller, the capstan, is determined by the damping mechanism employed. As a part of the analysis required to determine the design changes necessary to adapt the existing hardware to the lunar mission, an analog computer study was undertaken to study the starting, stopping and noise characteristics of the film drive system equivalent circuit illustrated in Figure 4-12. The object of the computer study was to optimize the damping element characteristics for various platen inertias and investigate the response of the platen to a noise input at the capstan as a function of platen inertia and damper characteristics. The computer study was based on the following parameters:

Platen Inertia (variable)	.01797, .04000, .16000 and .32890 ounce-inch-seconds^2
Film Speed	2.0 inches per second
Start Time	0.5 seconds maximum
Noise Input	0.5 percent, 10 cycles per second and 2.0 percent, 100 cycles per second simultaneously applied
Platen Noise	0.2 percent, zero to peak, 2 sigma value, maximum

The selected inertia values define platen constructions ranging from solid steel through annular aluminum design for comparative purposes. The two noise inputs selected are representative of the noise inputs somewhat in excess of those to be expected from the output gear and high speed input shaft of an actual drive motor output gear train. Figures 4-13 through 4-20 are reproductions of the analog computer study results for the four platen inertia values studied. Figures 4-13, 4-14, 4-15, and 4-16 show the effect of varying spring and damper constants upon the platen starting characteristic. The optimum combination of the spring and damper constants was then selected and the noise characteristic investigated in each case. The results obtained are illustrated in Figures 4-17, 4-18, 4-19, and 4-20. The noise characteristics of the platen are shown to be directly related to the platen inertia, the zero-to-peak noise amplitudes being 0.49, 0.31, 0.25, and 0.14 percent of the average platen speed in the order of increasing platen inertia. Based upon the results of the computer study and data obtained from existing hardware, the exposure unit drive mechanism parameters contained in the exposure unit specification of Appendix E have been established.

4.5.3 Programmable Slit Servomechanism

The programmable slit mechanism is a digital servomechanism which controls, on command, the film exposure by accurately positioning the desired slit of the slit aperture plate.

The servo is a simple dc drive controlled by the agreement or disagreement of the input command with a code generated by the shaft encoder. It receives two electrical power inputs:

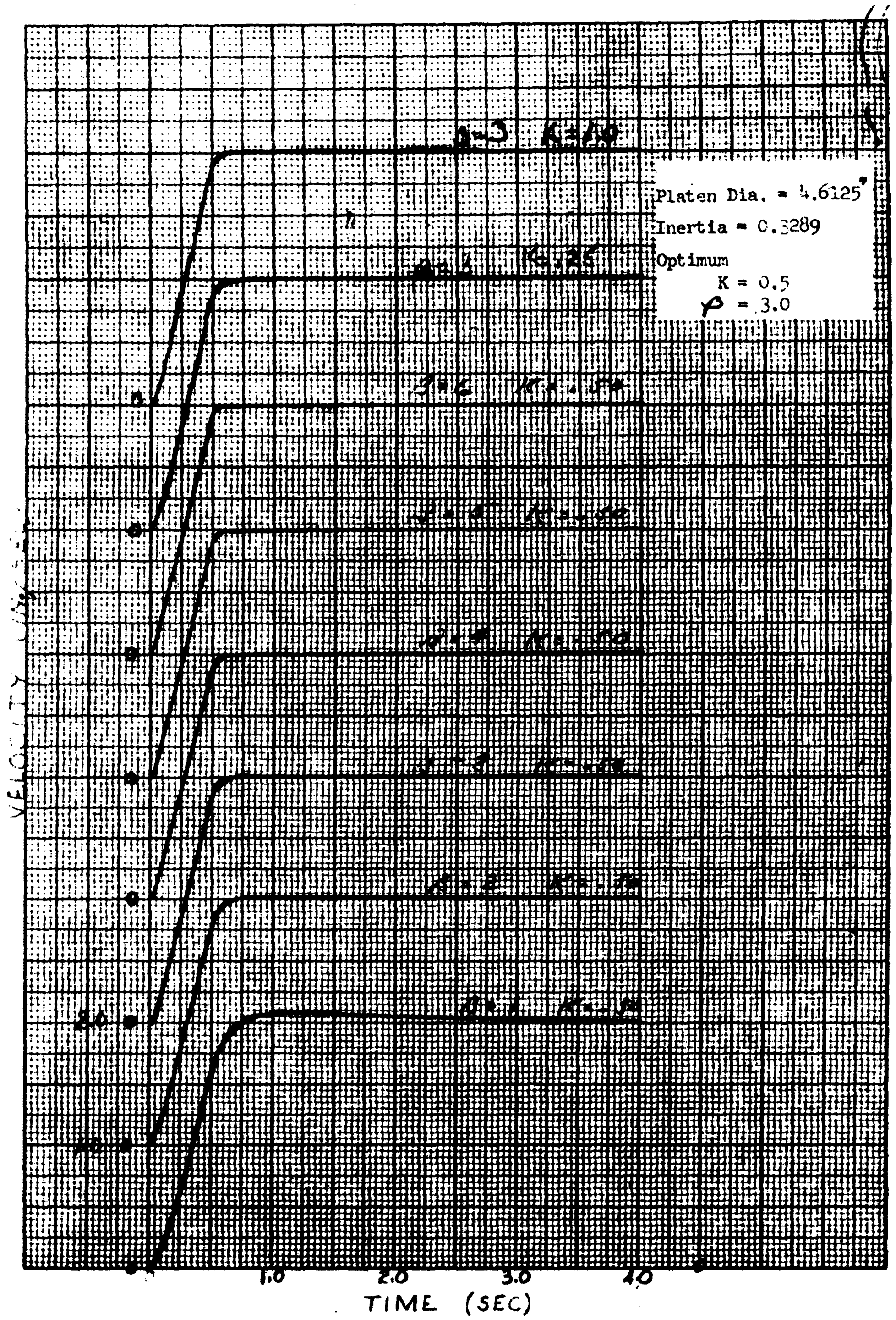


Figure 4-13. Effects of Varying Spring and Damper Characteristics on Platen Starting

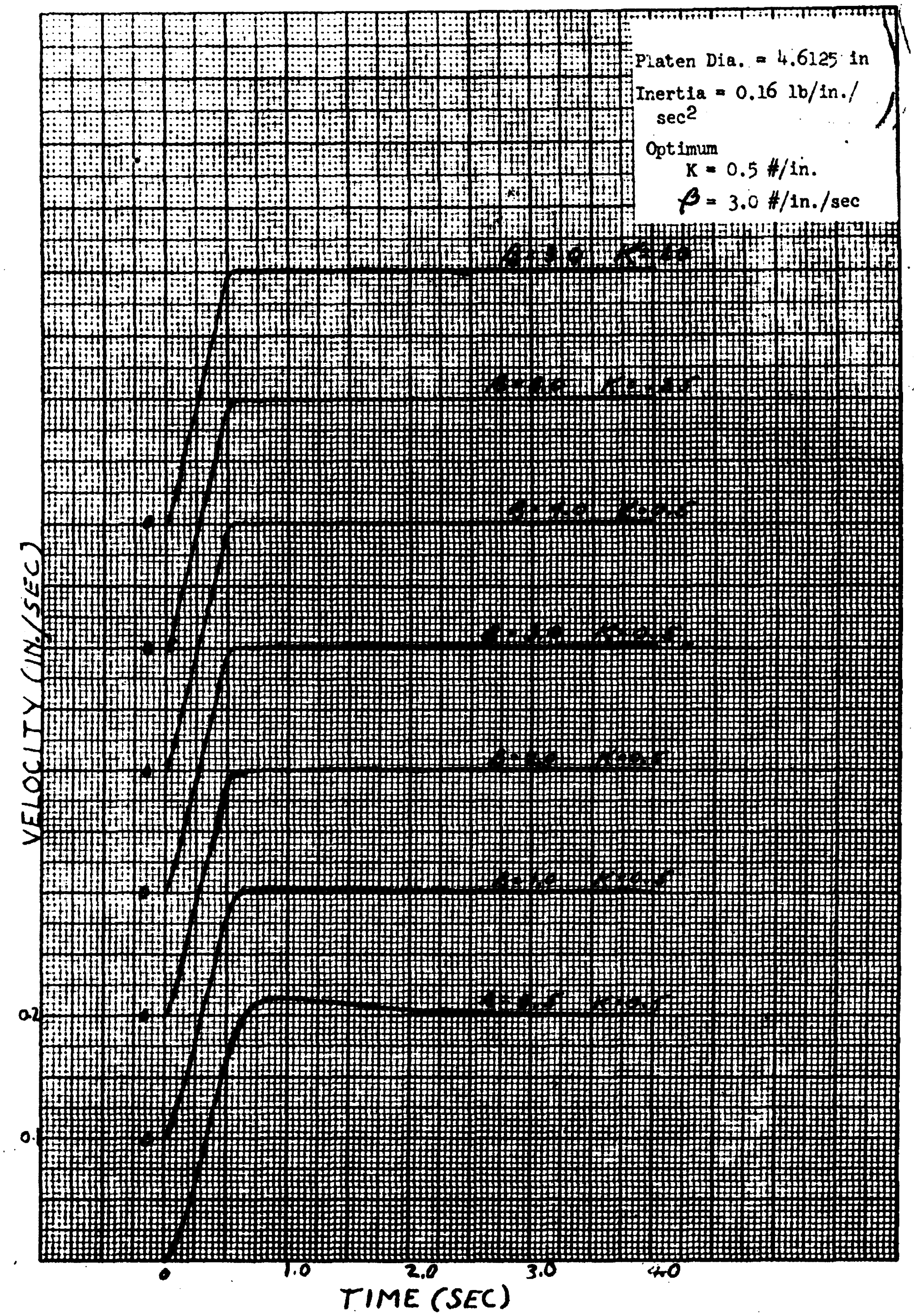


Figure 4-14. Effects of Varying Spring and Damper Characteristics on Platen Starting

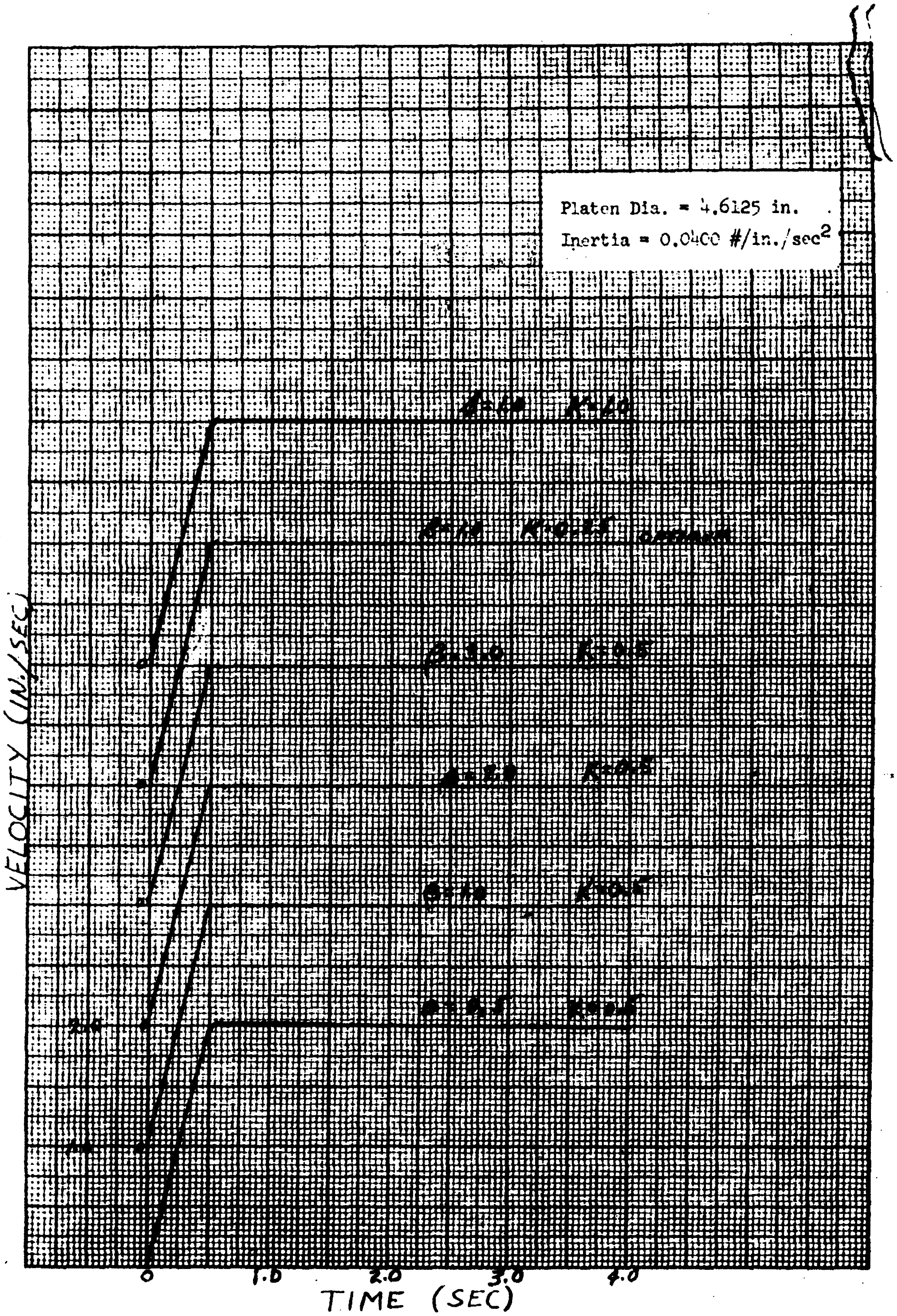


Figure 4-15. Effects of Varying Spring and Damper Characteristics on Platen Starting

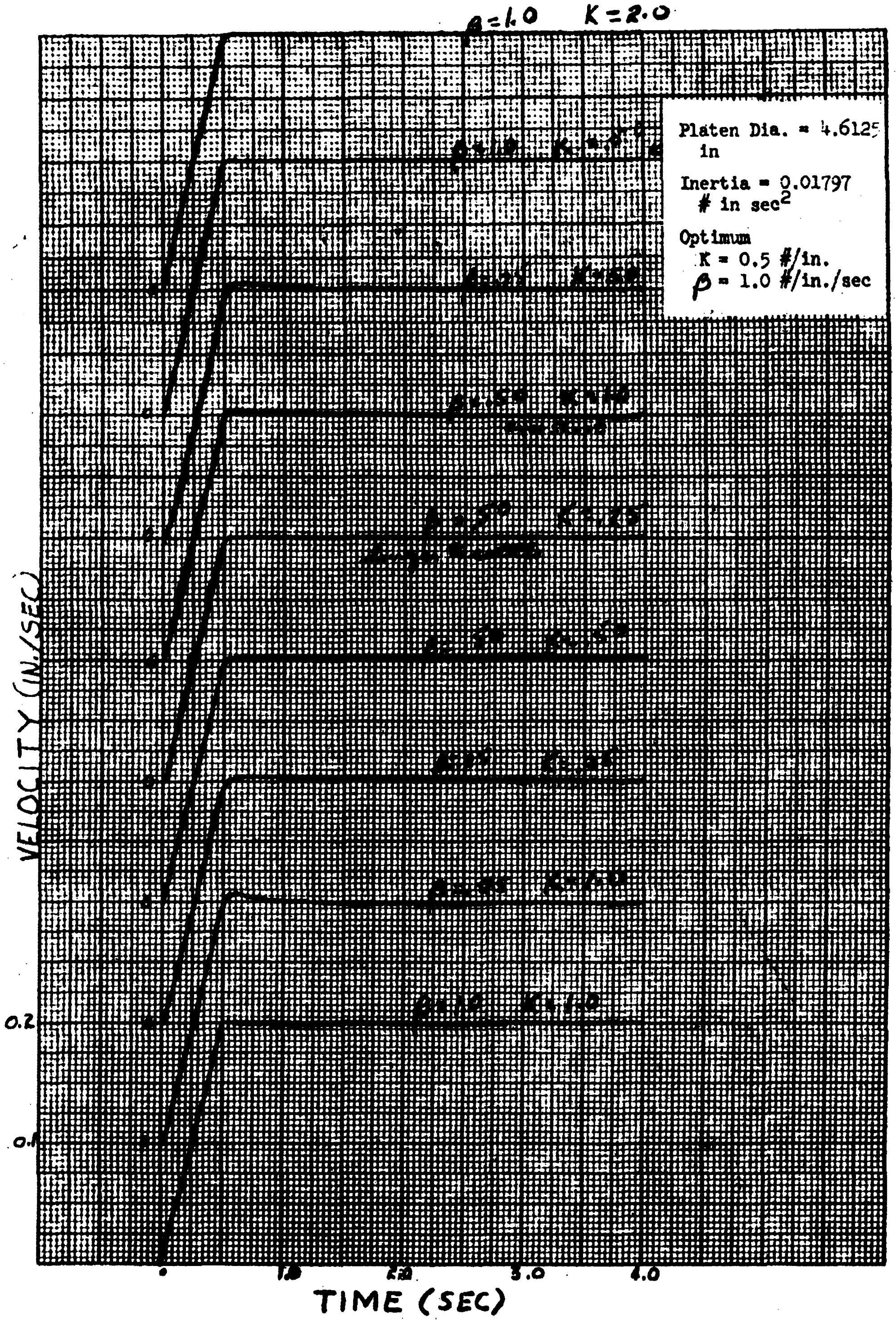


Figure 4-16. Effects of Varying Spring and Damper Characteristics on Platen Starting

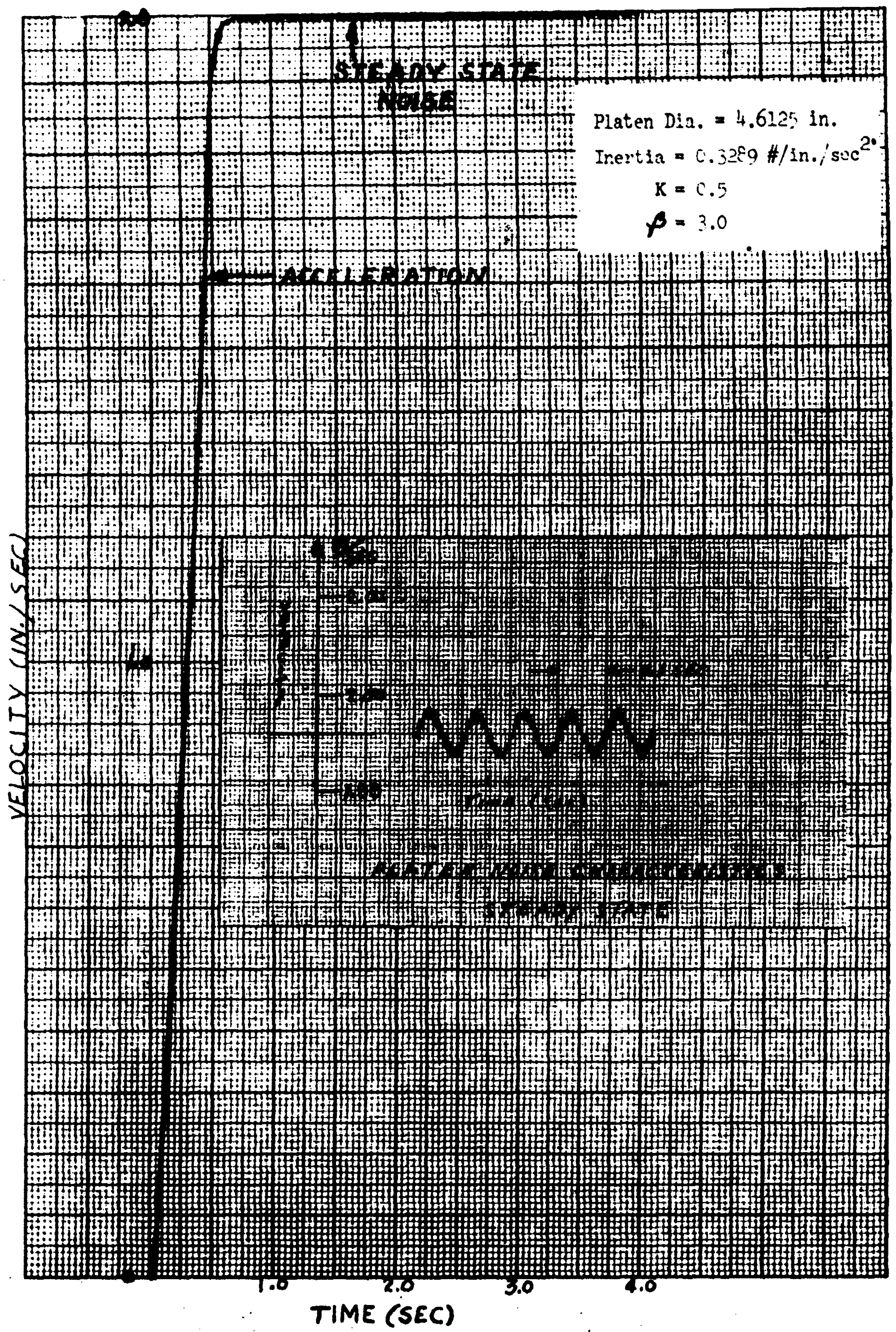


Figure 4-17. Platen Acceleration and Noise Characteristics

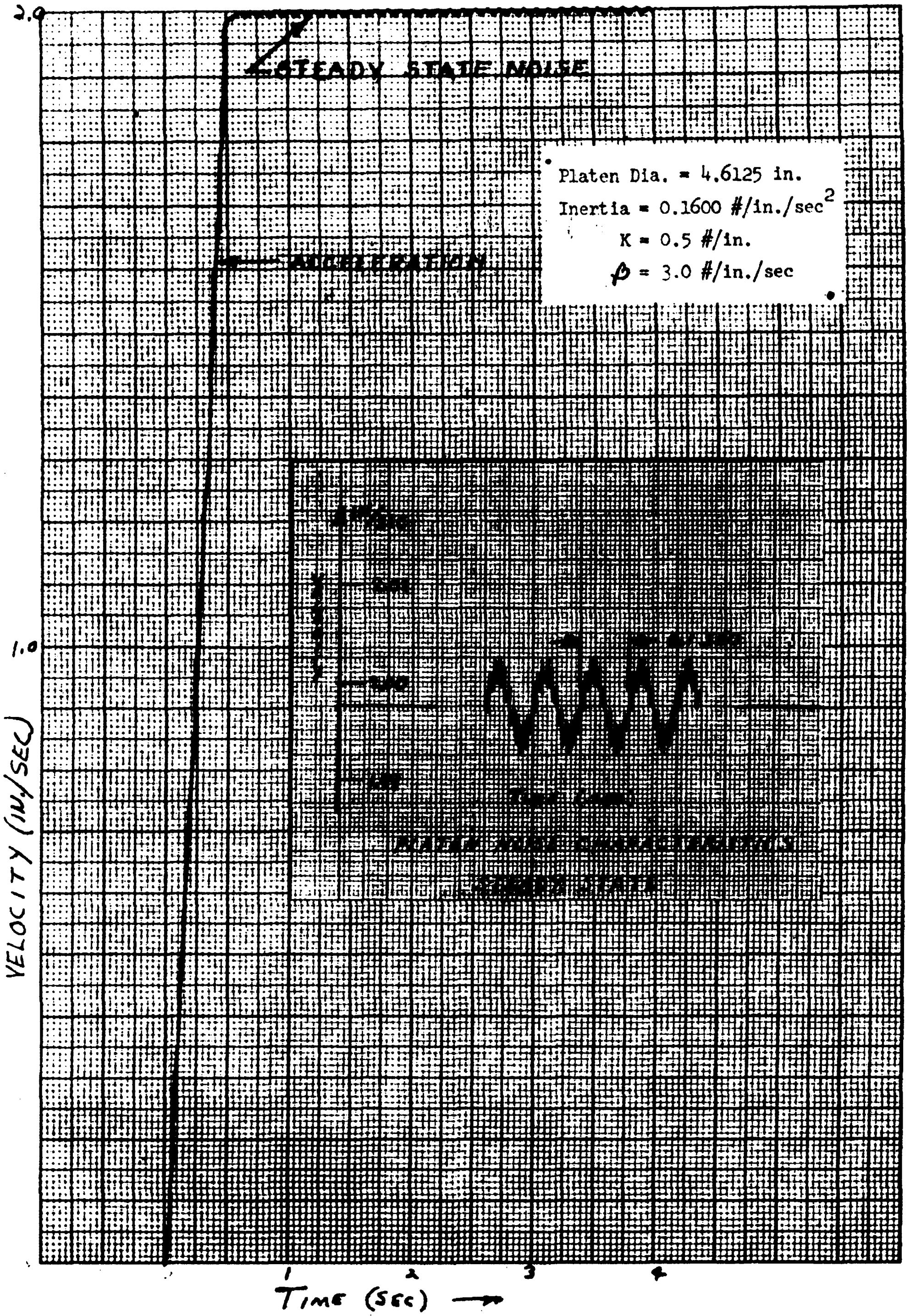


Figure 4-18. Platen Acceleration and Noise Characteristics

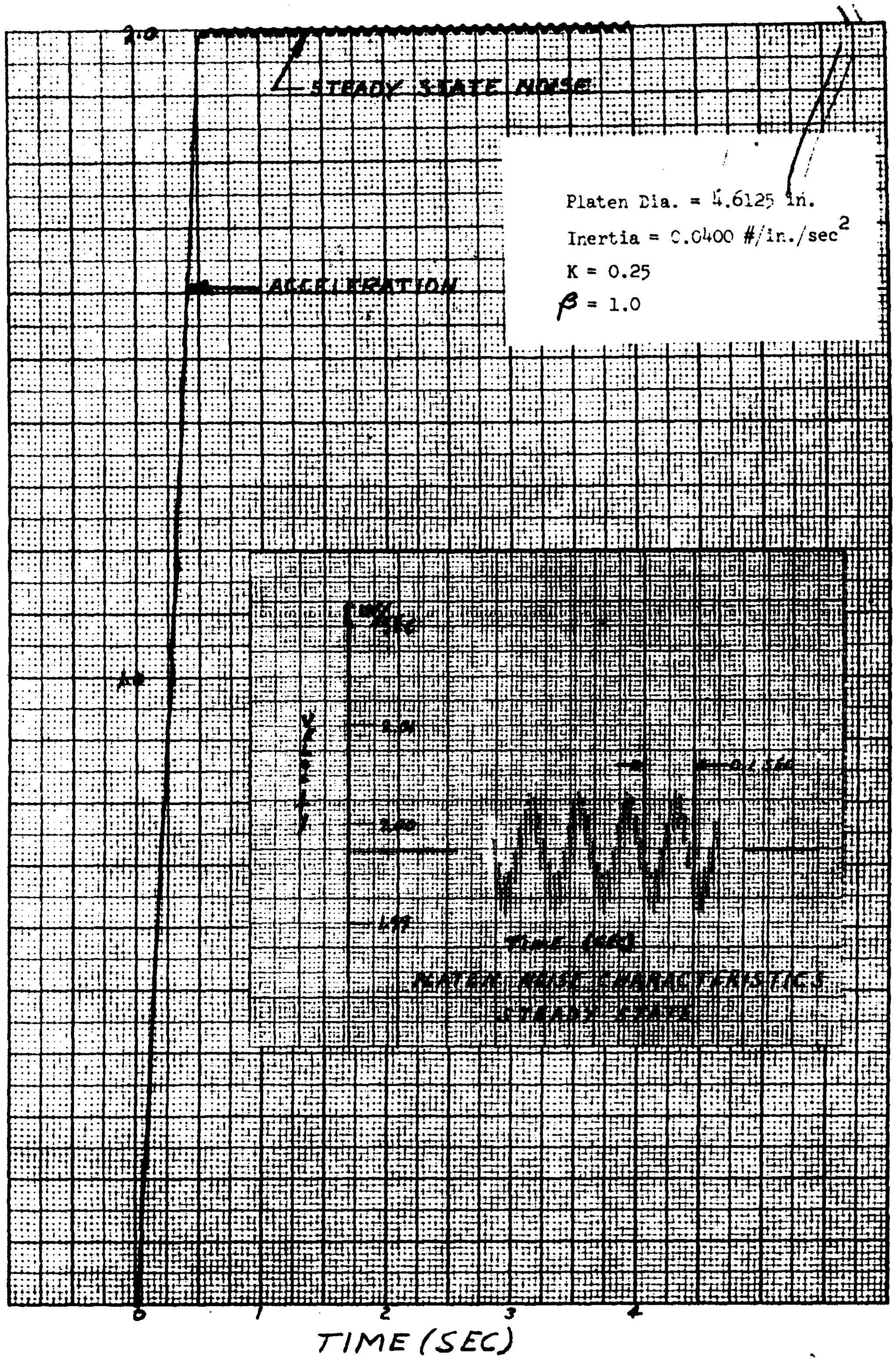


Figure 4-19. Platen Acceleration and Noise Characteristics

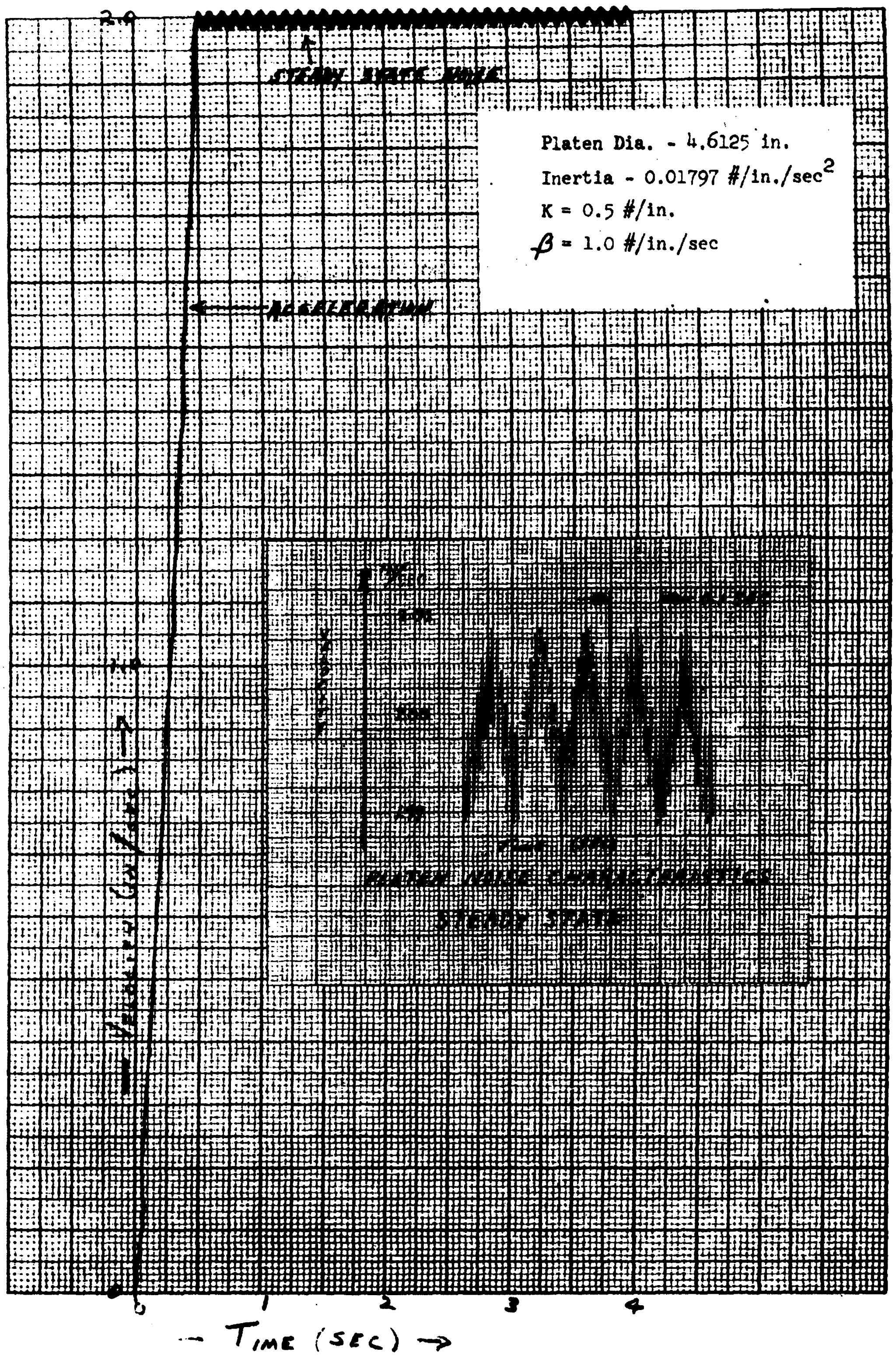


Figure 4-20. Platen Acceleration and Noise Characteristics

(1) +28 volts dc unregulated for operational power

(2) +5 volts dc for the load position instrumentation circuit

The programmable slit commands consist of a three bit word command presented to the servo. The two least significant bits are received from the spacecraft. The most significant bit is derived from the prevailing IMC command by the C/P logic. These commands are satisfied by rotating the servo Geneva drive wheel until the internal position code, generated by the encoder, matches the input command. The commands and associated slit openings are as tabulated below:

SERVO POSITION CODES

Slit Opening	Command Codes
1st	000
2nd	001
3rd	010
4th	011
5th	100
6th	101
7th	110
8th (test)	111

Two sets of slit openings are presently considered: one for low altitude and the other for high altitude. The low altitude uses an "0" for its most significant bit and the high altitude a "1". From the eight possible commands allowed by a three bit word, four are used for the low altitude, with a different slit opening for each command, and three are used for the high altitude, with also a different slit opening for each command. The eighth command (eighth position on the encoder) controls a slit opening that is to be used for testing only.

The programmable slit servo is capable of positioning any one of the slit openings upon receipt of the appropriate command. Under conditions of low voltage and maximum anticipated load, the servo can move the slit plate from one slit to an adjacent slit in less than four seconds upon receipt of a command. The average electrical power required by the servo when driving the slit plate is 9 watts. No operational power is required after a given command has been satisfied.

The servo has an electrical limiting action which prevents the slit plate from being driven much beyond the first and last slit openings.

The complete mechanism is composed of the following major subassemblies:

(a) Slit aperture plate
(b) Potentiometers
(c) Encoder
(d) Drive mechanism
(e) Switching circuitry
(f) Detent clamps

(A) The slit aperture plate is a glass plate of required size made of optical glass or yellow filter glass. It has suitable slit openings engraved in a metallic coating on its surface. The function of the slit openings is to control the film exposure.

(B) A potentiometer is used to indicate which slit opening has been positioned for photography. The potentiometer is coupled to the output shaft as shown on the schematic, Figure 4-21.

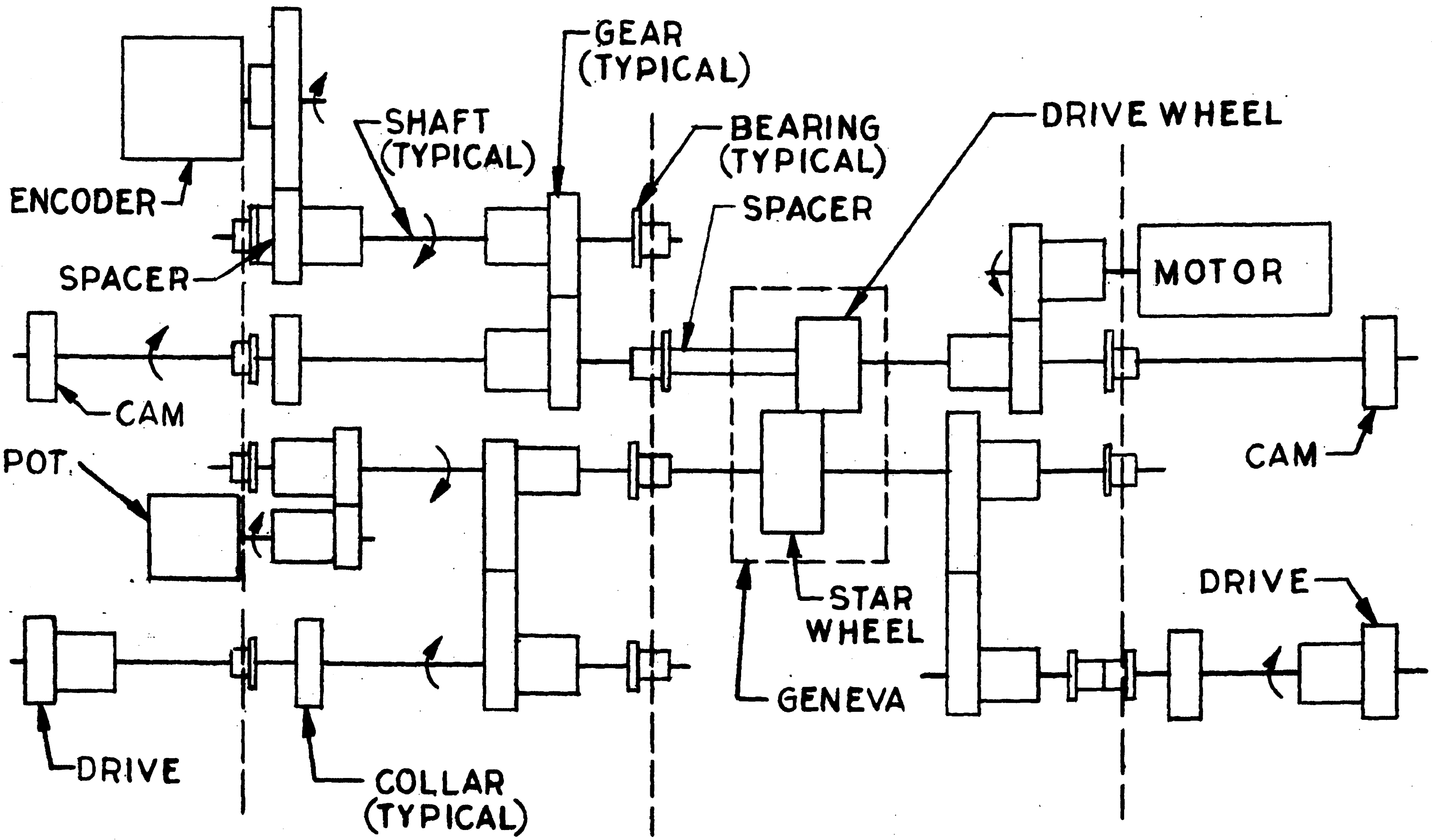


Figure 4-21. Mechanical Schematic of the Programmable Slit Mechanism

(C) The encoder is used to decode digital signals coming to the camera from an external source and to control the power which moves the slit plate to a commanded slit position. It is coupled to the drive wheel of the Geneva mechanism through a gear train.

(D) The drive mechanism consists of a drive motor, gearing and indexing devices which provide approximate positioning of the slit plate. The motor is a permanent magnet dc motor with an output torque of 30-inch-ounces under noted conditions. The servo output is delivered to the slit plate by means of two gears which are mechanically coupled to the star wheel of the four station Geneva movement.

(E) The switching circuitry consists of a solid state electronic package which provides switching of drive motor power with a minimum generation of electromagnetic interference (EMI). The complete circuit is as shown on the schematic, Figure 4-22.

(F) The detent clamps provide the necessary accuracy in the positioning of the slits and hold the slit plate securely when the drive mechanism is not operating. Sequencing of the detent clamps is provided by the cams coupled to the drive mechanism.

4.5.4 Reliability

The exposure unit consists of five basic subunits:

(1) Film Drive Mechanism
(2) Programmable Slit Mechanism
(3) Focus Detector Assembly
(4) Focus Drive Assembly
(5) Data Recording Assembly

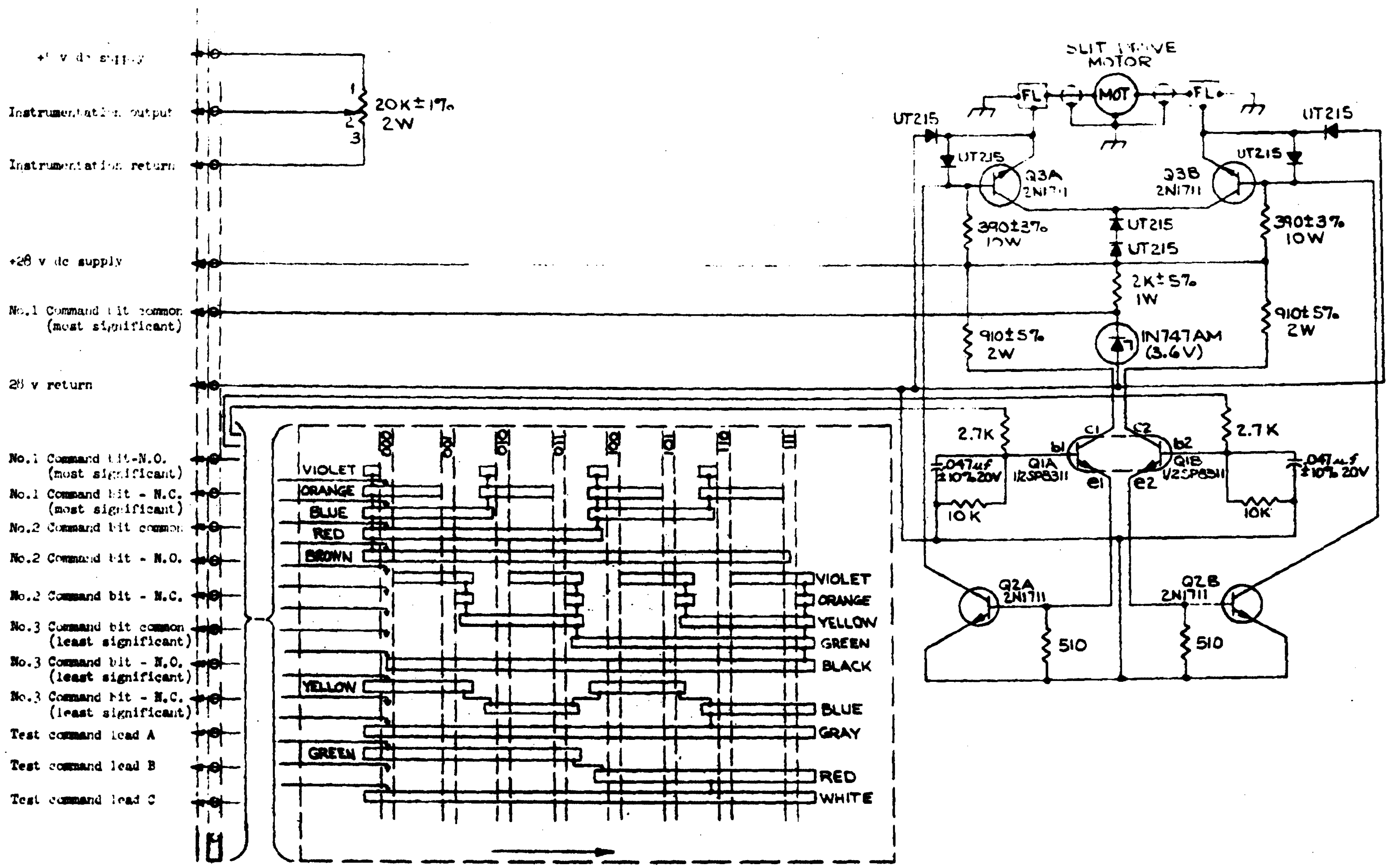


Figure 4-22. Electrical Schematic for the Slip Plate Mechanism

The method of transporting the film through the camera and exposing the film uses existing qualified design concepts. The film drive mechanism to be used will be very similar to one being developed on another program which will be subjected to the complete reliability program discussed in Section 4.10. This experience will provide considerable background information. The programmable slit mechanism will be identical to an existing qualified system. The only change required to adapt this system to the Survey C/P is the use of a different qualified encoder, that will provide eight slit positions. Only one minor modification will be necessary to adapt an existing qualified focus detector to the Survey C/P. The focus drive to be used will be identical to an existing qualified design approach. All systems used in the exposure unit are similar to existing designs. As a result, it is expected that the reliability of the exposure unit will be equivalent to those highly reliable results achieved on similar designs.

4.6 V/h SENSING DEVICE

If the image of an object being photographed has a significant relative motion with respect to the film during the exposure, the resultant photograph of the object loses sharpness or definition and is said to be "smeared". If the smear-free, or static, resolution of the system is better than the design goal, smear can be tolerated up to that point where the dynamic resolution (including smear) equals the design goal. Of the many smear contributors (for the smear budget see Appendix C), two major factors, knowledge of altitude and knowledge of ground speed, can be compensated for by a device which senses the altitude/ground speed ratio or V/h. By appropriate control action, film speed is adjusted and any yaw angle is compensated.

The Bolsey V/h sensing device (similar to devices described in ASD-TDR-63-791) requires a ground scene view which can be provided either by viewing the scene reflected by the stereo mirror or by a direct view of the nadir point. At present, stereo viewing appears preferable; however, further studies are being made in order to be certain that this is the better approach. For this reason, space allocation has been made in the drawings to allow nadir V/h measurement.

4.6.1 Smear - V/h Relationship

Smear is defined by the vector equation:

$$\bar{S} = (\bar{V}_i - \bar{V}_f)t$$

But $\bar{V}_i = \frac{D}{H}(\bar{V}_g)$ for vertical photography

Thus $\bar{S} = (\frac{D}{H}\bar{V}_g - \bar{V}_f)t$

The components of $\bar{V}_g$ are $\bar{V}_{gx}$ and $\bar{V}_{gy}$; $\bar{V}_{gx}$ is generated by vehicle velocity and $\bar{V}_{gy}$ is generated by yaw angle, yaw rate, and roll rate.

The smear components at the film are then given by:

$$\bar{S}_x = (D\frac{\bar{V}_{gx}}{H} - \bar{V}_f)t$$

and

$$\bar{S}_y = D\frac{\bar{V}_{gy}}{H}t$$

Where: $\bar{S}$ = total smear
$\bar{V}_g$ = ground velocity
$\bar{V}_i$ = image velocity

$\bar{V}_f$ = film velocity

t = exposure time

D = image distance (slit to film)

H = altitude or object distance

To eliminate $\bar{S}_x$, it is necessary to have the film speed equal to D $\frac{\bar{V}_{gx}}{H}$. To eliminate $\bar{S}_y$, it is necessary to reduce the y component of the image velocity at the film slit to zero. This is done by crabbing the mirror at an angle which is a function of $\frac{\bar{V}_{gx}}{H}$ and $\frac{\bar{V}_{gy}}{H}$.

Smear reduction is accomplished by means of a V/h sensor set to view the ground through the stereo mirror on the same line of sight as the camera. The V/h unit generates both a parallel binary number proportional to $\frac{\bar{V}_{gx}}{H}$ which controls the IMC through Motor Speed Drive (MSD) and also a dc voltage proportional to $\frac{\bar{V}_{gy}}{H}$ which sets the mirror crab angle through a nulling system.

4.6.2 V/h Description and Operation

The Bolsey sensor offers a direct method of measuring $\bar{V}_{gx}/H$ and $\bar{V}_{gy}/H$. This device offers a high accuracy (0.4%, which is within the ±0.5% necessary to keep x direction smear smaller than 1.75 microns). The primary principle employed in the Bolsey sensor is that of an area "optical contrast correlation tracker". This device is an automatic, electro-optical, tracking system employing a scanner, a data memory, and signal matching correlation techniques.

The optical tracking device scans a target on the vehicle ground track. The device tracks this target for a short time period. It then rapidly recycles to a new point forward of the first, and repeats the cycle. To hold the particular target in its field of view, the tracker is driven by its servo system at an angular rate that is proportional to V/h.

Scanning is accomplished by a compact opto-mechanical assembly. A radial-slit aperture, rotating about the axis of the scanner, dissects an image of the target scene. The light transmitted through this scanning aperture is collected and applied to a standard photomultiplier. As the slit rotates, an annulus in the image plane, corresponding to an annulus in the target scene is dissected. This dissected spatial scene information is converted by the photomultiplier into a narrow bandwidth video signal as a function of time. The video signal represents the area-integrated instantaneous light flux passing through the slit and does not represent a coherent "image" in the ordinary sense of the word. This video signal is amplified and then quantized into two levels (binary form) for further data processing. The video analog of the dissected image of any particular scene is unique and cannot be duplicated except by scanning the identical image from precisely the same vantage point. The video signal may therefore be pictured as a kind of "target signature".

A rotating magnetic memory drum is driven by the scanner shaft. On command, the quantized video signal that corresponds to a complete revolution of the scanning aperture is recorded on the drum, element by element, to provide a "reference", or remembered scene. On subsequent scans, the quantized reference video is played back and correlated with subsequent quantized video signals from the photomultiplier. From this comparison, pattern-matching error signals are derived. The error signals take the form of relative-time displacements between the compared patterns and may be used to reorient the tracking system to match the patterns perfectly.

Rotational displacements between compared images result in a time shift of the new quantized video pulses with respect to the original quantized reference video pulses. A correlator measures this time shift to detect rotational image displacement error signals.

Translational displacements between sequential images result in a periodically varying time shift of the new video pulses with respect to the original reference pulses having a periodicity equal to the scanner rotation frequency. Two mutually orthogonal translational displacements can therefore be determined by synchronously detecting the quadrature component of this periodicity. The detection is done by using synchronizing pulses that occur when the scanning slit position coincides with each of the two chosen coordinate axes (the translation error axes) in the image plane.

The rotational error and two translational errors are amplified and applied to the servo system to orient the sensor to that all errors are nulled to zero. Since the servo is a closed-loop feed-back system, it is drift-free and extremely accurate.

As a safety feature, the V/h sensor has two outputs that indicate failures. One output indicates a major failure such as photomultiplier tube failure. The other output indicates a temporary malfunction such as lack of sufficient information to give good results. These signals are used to override the V/h output. A major malfunction will permanently override the V/h signal, while a temporary malfunction will override the V/h until good information is again obtained.

4.6.3 Adaptation of V/h to IMC

The IMC speed is established by a hysteresis-synchronous motor whose speed is controlled by the frequency generated by the MSD as described in Section 4.8. The V/h sensor output supplied to the MSD is the primary source of IMC information. As a backup to the V/h sensor, and IMC command word is maintained in storage in the MSD at all times. This back-up command word is supplied to the C/P by either the spacecraft computer or via the spacecraft real time command link. Both inputs to the MSD are in 9 bit parallel binary form.

The manner of adaptation of the V/h sensor to IMC control is shown in Figure 4-23. Switch 1 determines whether the IMC signal is derived from the V/h sensor or from the spacecraft generated command word in accordance with Table 4-1.

TABLE 4-1

DERIVATION OF IMC SIGNAL

A	B	Output
0	0	V/h
0	1	Spacecraft Command
1	0	Spacecraft Command
1	1	Spacecraft Command

where

A = 1 malfunction of V/h

A = 0 no V/h malfunction

B = 1 override V/h

B = 0 return to V/h

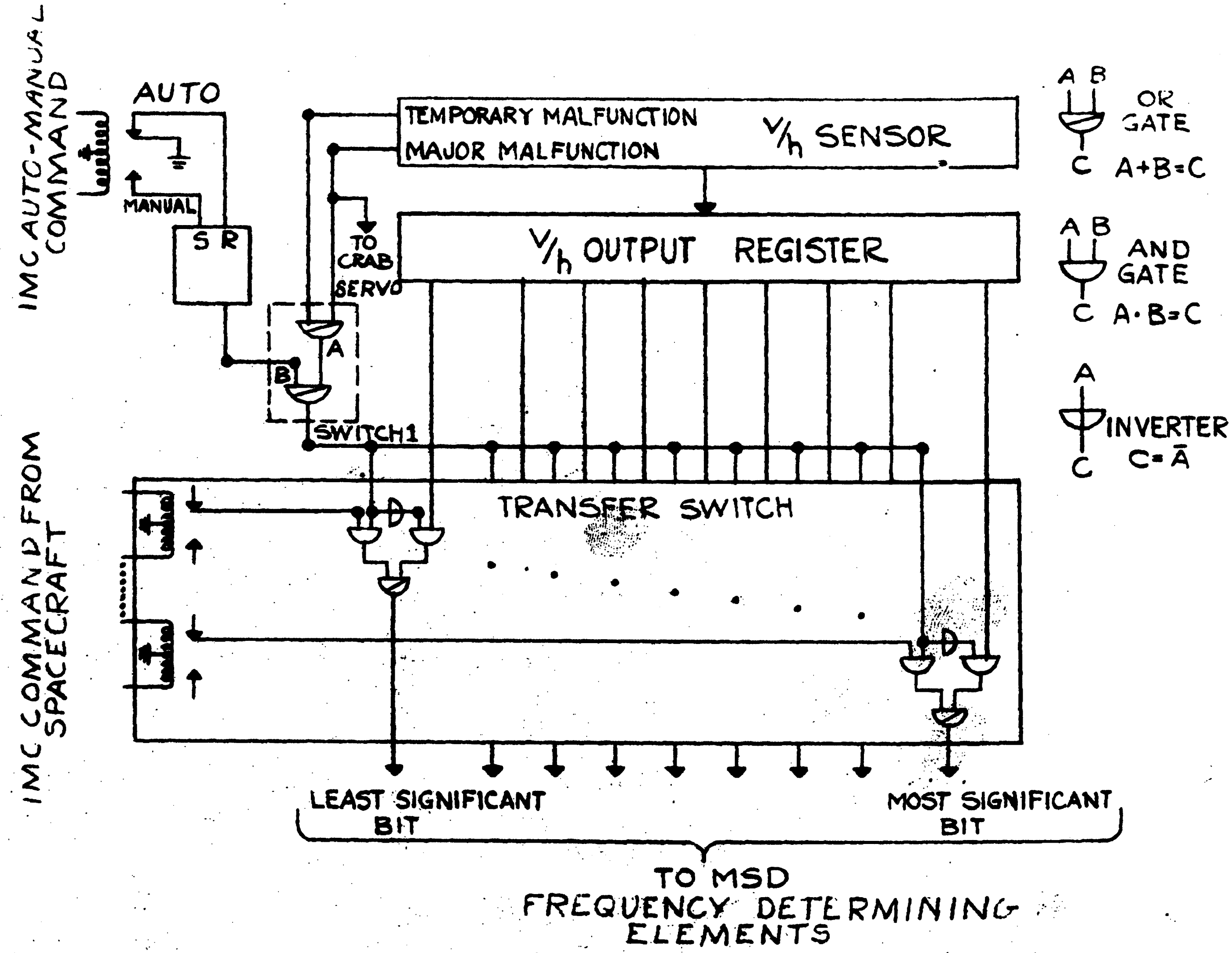


Figure 4-23. V/h to IMC Block Diagram

Spacecraft - generated IMC information is stored in latching relays. The relay driving requirements are such that the memory is insensitive to noise. If a malfunction of the V/h sensor should occur, the A input becomes "1" and switch 1 sets the OR gates to pass the stored IMC command to the frequency determining elements. If the V/h malfunction is only temporary, as would be the case when insufficient information is supplied to the V/h sensor for proper operation, the override signal from the V/h sensor will transfer the source of the IMC command from the V/h sensor to the stored command for the duration of the override signal.

In addition to the malfunction and override signals provided by the V/h sensor, a one bit IMC auto-manual command is available from the spacecraft which also transfers IMC control from the V/h sensor to the stored command. This command is provided to permit the option of real time commanding of IMC even though the V/h sensor has not malfunctioned.

4.6.4 Adaptation of V/h to Crab Correction

The system used for crab correction is shown in Figure 4-24. The velocity component $\overline{V}_{gy}$ reflected through the stereo mirror generates a signal output from the V/h sensor. This signal is presented as an analog voltage available at two wires. Wire A is positive with respect to ground, and wire B is at zero for positive crab angles; for negative crab angles, wire A is at zero and wire B is positive. The magnitude of the voltage is proportional to the magnitude of the crab angle.

This voltage is amplified and fed to the crab servo. The crab servo drives the stereo mirror in a direction to decrease the apparent crab angle. The

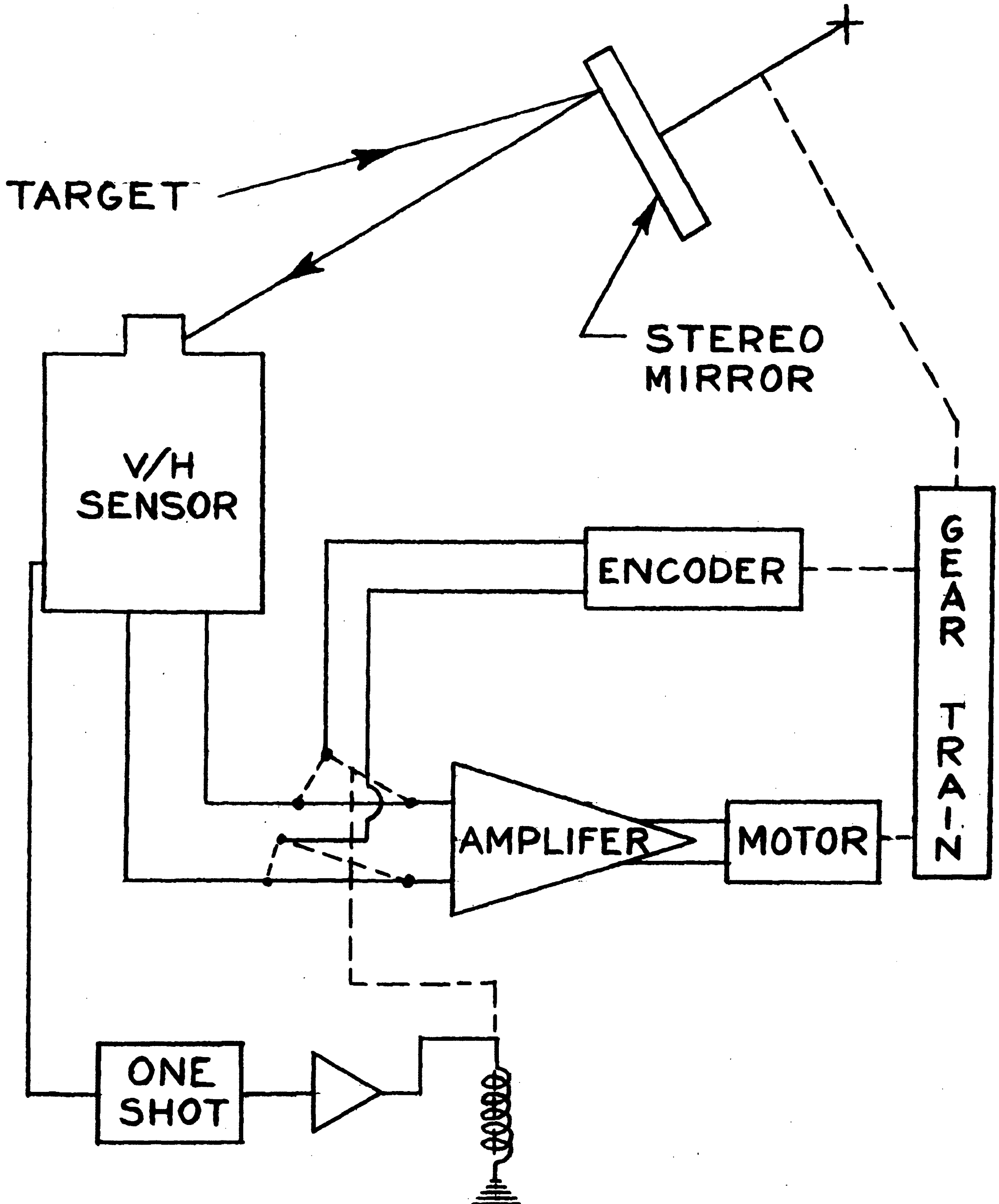


Figure 4-24. Crab Correction System

rate at which the mirror is driven depends on the magnitude of the instantaneous crab angle. When $\frac{\overline{V}_{gy}}{H}$ is finally nulled, there is no V/h output voltage and the system is in equilibrium.

The null system takes advantage of minimum V/h sensor error which occurs at zero output voltages.

If the V/h has a major malfunction, the stereo mirror is returned to the neutral (0°) position. The return system consists of an encoder driven by the crab servo gear train. This is shown in Figure 4-24.

The V/h malfunction signal, applied to a one shot multivibrator and amplified, drives a latching relay. This relay disconnects the V/h sensor output and connects the encoder output to the motor amplifier. The encoder, shown in Figure 4-25, applies a positive voltage to wire A and zero voltage to wire B if the V/h malfunctions when the stereo mirror is at a positive crab angle. If failure occurs at negative angle, wires A and B are reversed. The motor will drive at a controlled speed to the 0° position where all voltage is removed and the mirror stops.

4.6.5 Reliability

The basic V/h sensor described in the preceeding paragraphs is presently employed in the EKC Lunar Orbiter Program. As such, it is presently being subjected to the complete reliability design review program (see Section 4.10). This experience will provide considerable background information and insight into the study associated with the integration of this sensor into the Survey camera payload. Reliability evaluation of this unit is continuing.

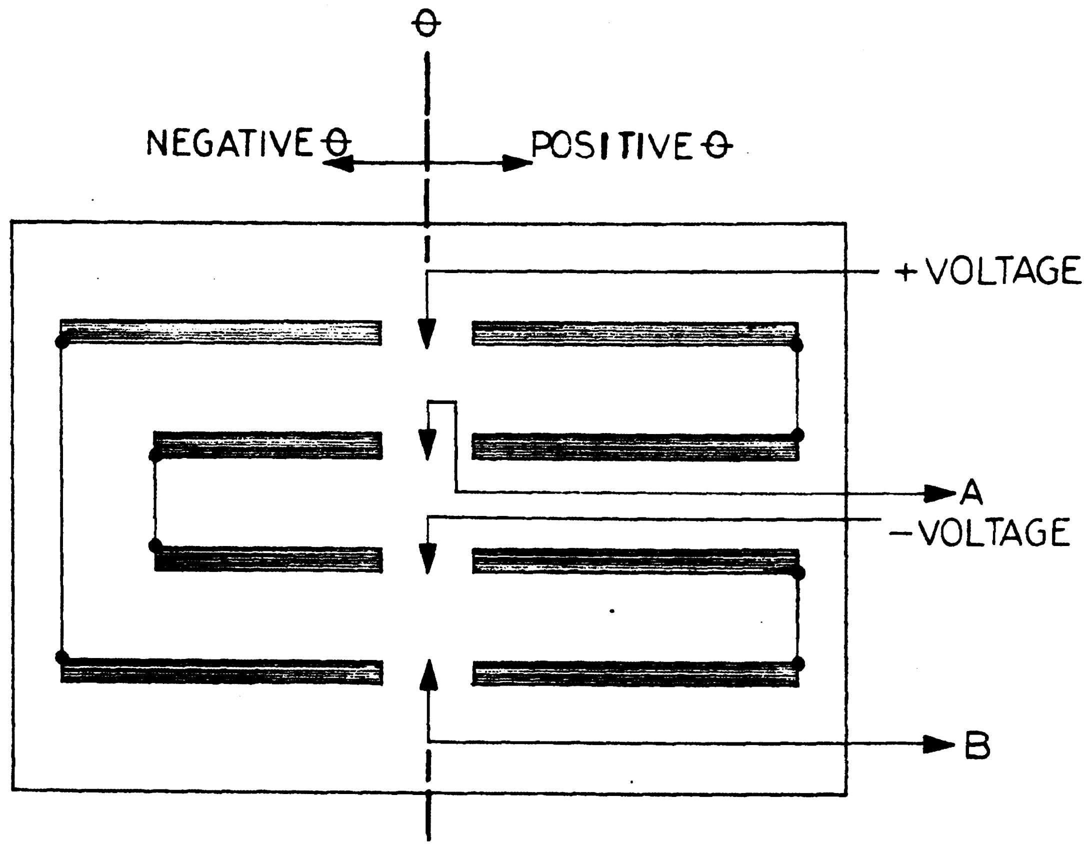


Figure 4-25. Encoder

4.7 FOCUS CONTROL

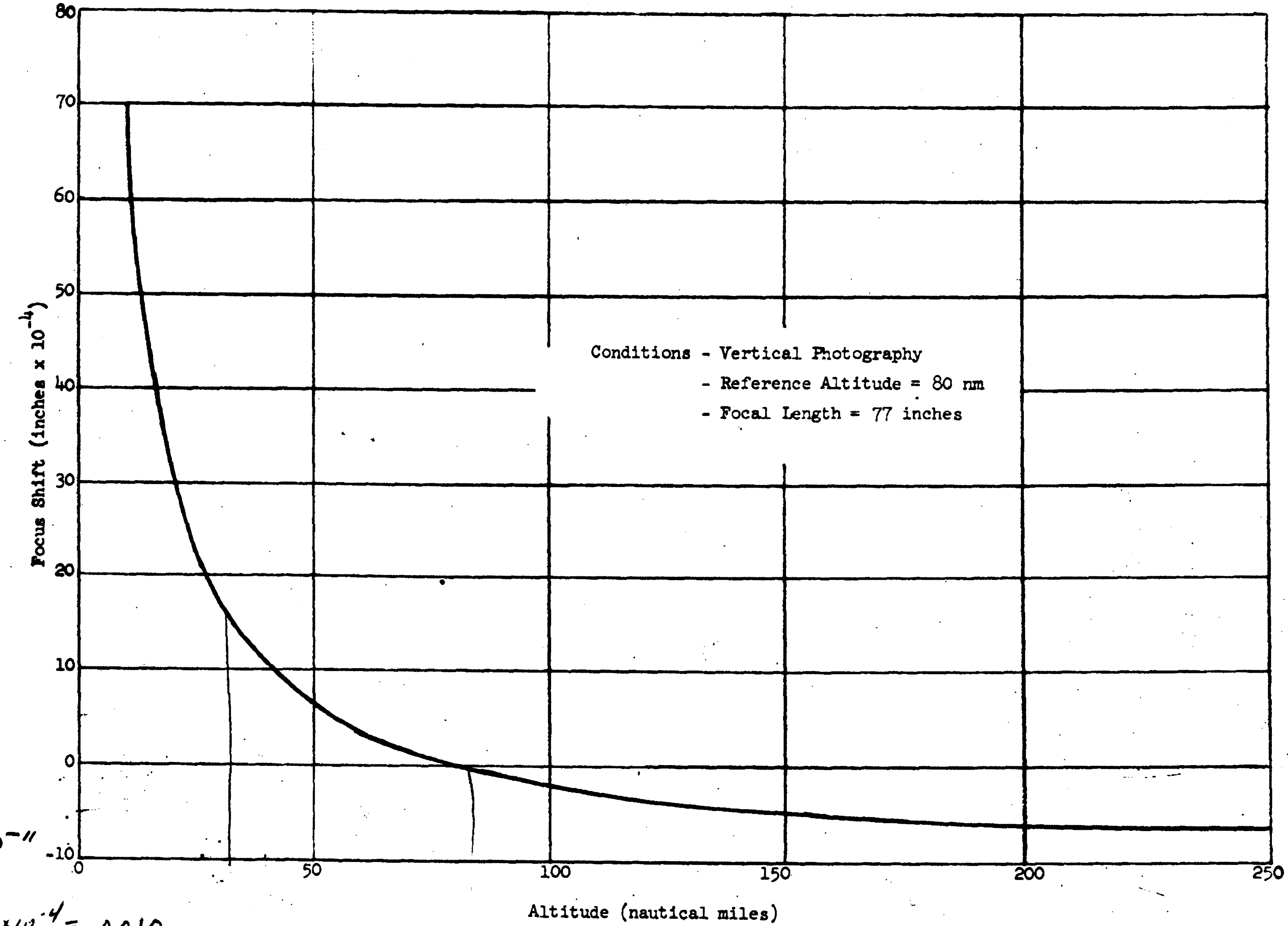
4.7.1 General

The C/P is designed to place the best image plane of the 77-inch lens at the sensitized surface of the film, and under normal in-flight conditions there will be no need to change focus unless the spacecraft changes orbital altitude. Nevertheless, as a back-up, the payload incorporates a focus control capability. The primary mode of focus control is an automatic focus control system operating as a closed loop servomechanism. A secondary mode of focus control provides focus adjustment by astronaut command. In this mode the focus control system operates as an open loop servomechanism with visual feedback to the operator. A third mode of control can be readily provided to permit real time commanding of the focus system from a ground command facility in conjunction with the spacecraft real time command system.

The focus control system will position the sensitized surface of the film to within ±0.0005 inch of the plane of best focus. To accommodate a mission profile which includes operation at widely divergent nominal orbital altitudes (such as 30 and 80 nautical miles) during the same mission, it is essential that the system be refocused when changing altitude, as evidenced by Figure 4-26. At 30 nautical miles, depth of focus of the optical system is sufficient to accommodate anticipated lunar topographic variations providing that focus is established for the mean orbital altitude and the orbit is both circular and concentric with the moon's center. However, to maintain a high probability of optimum focus, refocusing capability is desirable and necessary.

SPECIAL HANDLING

~~SECRET~~



$\pm .0005''$

$10 \times 10^{-4} = .0010$

Figure 4-26. Focus Shift vs Altitude

~~SECRET~~
SPECIAL HANDLING

The C/P is designed to minimize distortion caused by launch or orbital thermal environments which could change focus. In spite of the precautions taken, the possibility exists that a slight shift in the image plane might occur because of a variation of environmental conditions beyond the anticipated limits. The focus control system will detect such shifts and maintain critical focus in the presence of such variations.

A block diagram of the focus control system is given in Figure 4-27. The method of operation is detailed in the following paragraphs. Detail specifications establishing the design parameters for the focus system components are contained in Appendices F and G.

4.7.2 Theory of Operation

Camera payload focus is determined by using an electro-optical system which is sensitive to the changes in spatial frequency content of a progressively defocused image. The elementary system is schematically diagrammed in Figure 4-28. Light from a moving scene enters the lens and is brought to focus at a reticle. Image motion across the reticle causes the scene to be chopped, the reticle acting as a spatial band-pass filter which transmits part of the scene's spectral energy through the condensing lens to a photoelectric transducer. The filtered energy is converted into a corresponding ac electrical signal, e_o, whose frequency depends upon the product of image velocity relative to and the spatial frequency passed by the reticle. As the image is progressively defocused, the spectral energy reaching the detector changes, and thus a corresponding change in the output voltage, e_o, occurs.

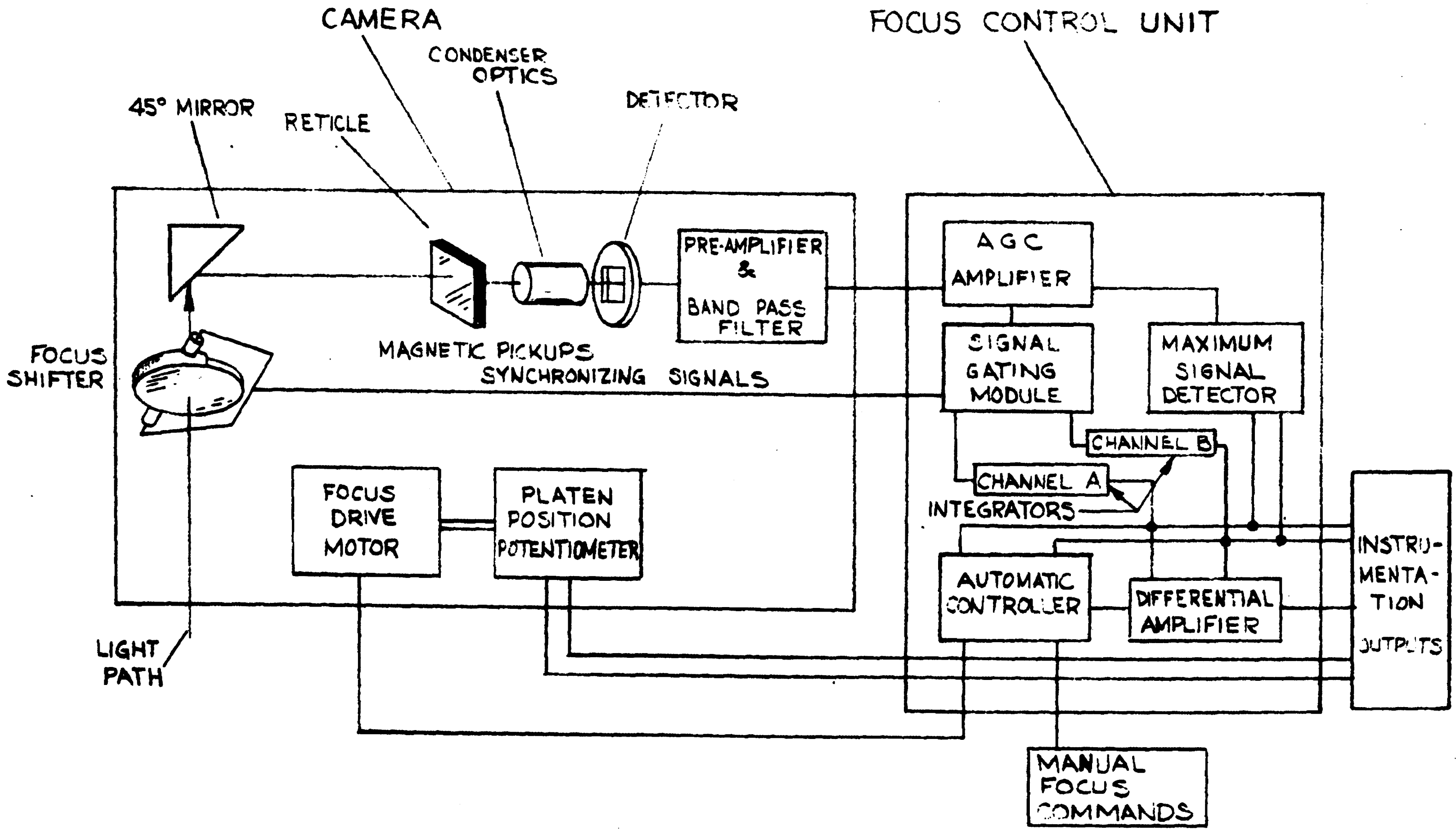


Figure 4-27. Focus Control System Block Diagram

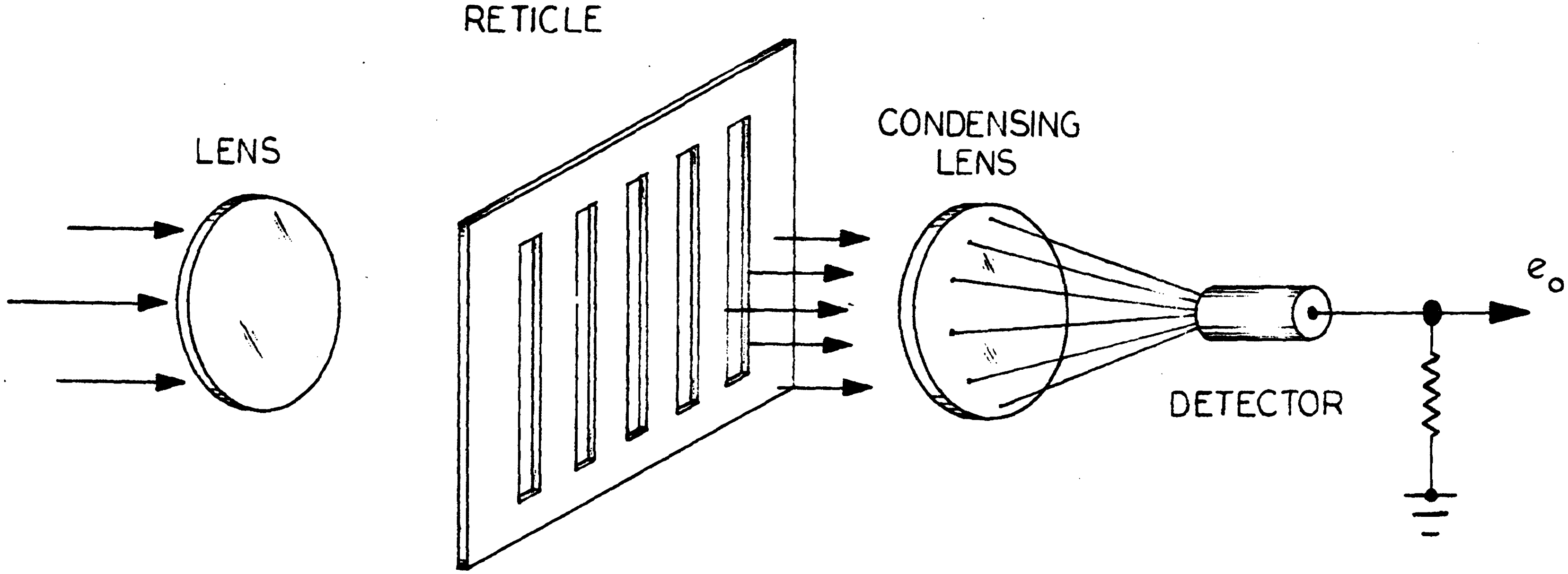


Figure 4-28. Elementary Focus Detector

With the basic system described above, the plane of best focus would be defined when the amplitude of the output signal, e_o, is a maximum and progressive defocusing would result in fall-off in the output voltage similar to that shown in Figure 4-29. Thus, the use of a single reticle and detector would necessitate the use of as high a pitch reticle as possible to provide sufficient sensitivity at the peak to permit critical focusing. However, the transmitted energy is inversely proportional to reticle pitch. This suggests that a coarse reticle pitch is desired so as to maintain as large a signal-to-noise ratio as possible. This apparent conflict of requirements is readily resolved by utilizing a dual detector system and presenting identical images to the two detectors such that the difference in voltage between the two detector outputs will indicate true focus by a null. The null is unaffected by any statistical variation by using the signal $\frac{(a-b)}{(a+b)}$, where "a" is the "a" channel signal and "b" is the"b" channel signal amplitude. Then the absolute sensitivity of the two-detector system is relatively independent of the reticle selected since operation is now based on the energy-focus curve's slope which is insensitive to reticle pitch.

The focus detector utilized in the camera payload is based upon the same principle of operation as a two-detector system, but in practice, it is preferable to utilize a "single reticle" optical system and single detector. (Synchronously detecting the "a" and "b" signals while passing a focus shifting disc through the image path creates the effect of a "two detector" system). The schematic representation of the system used is illustrated in Figures 4-27 and 4-30.

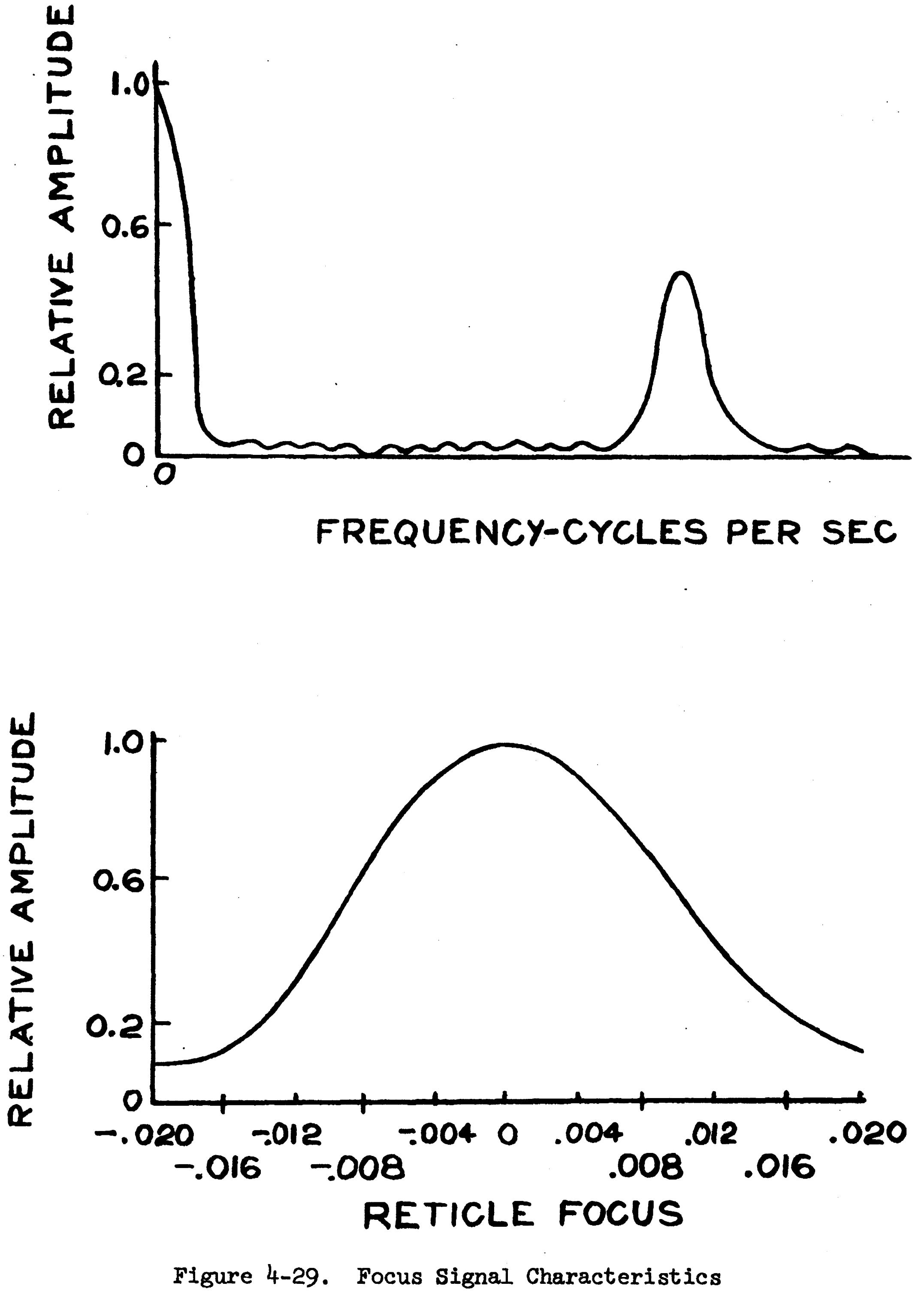


Figure 4-29. Focus Signal Characteristics

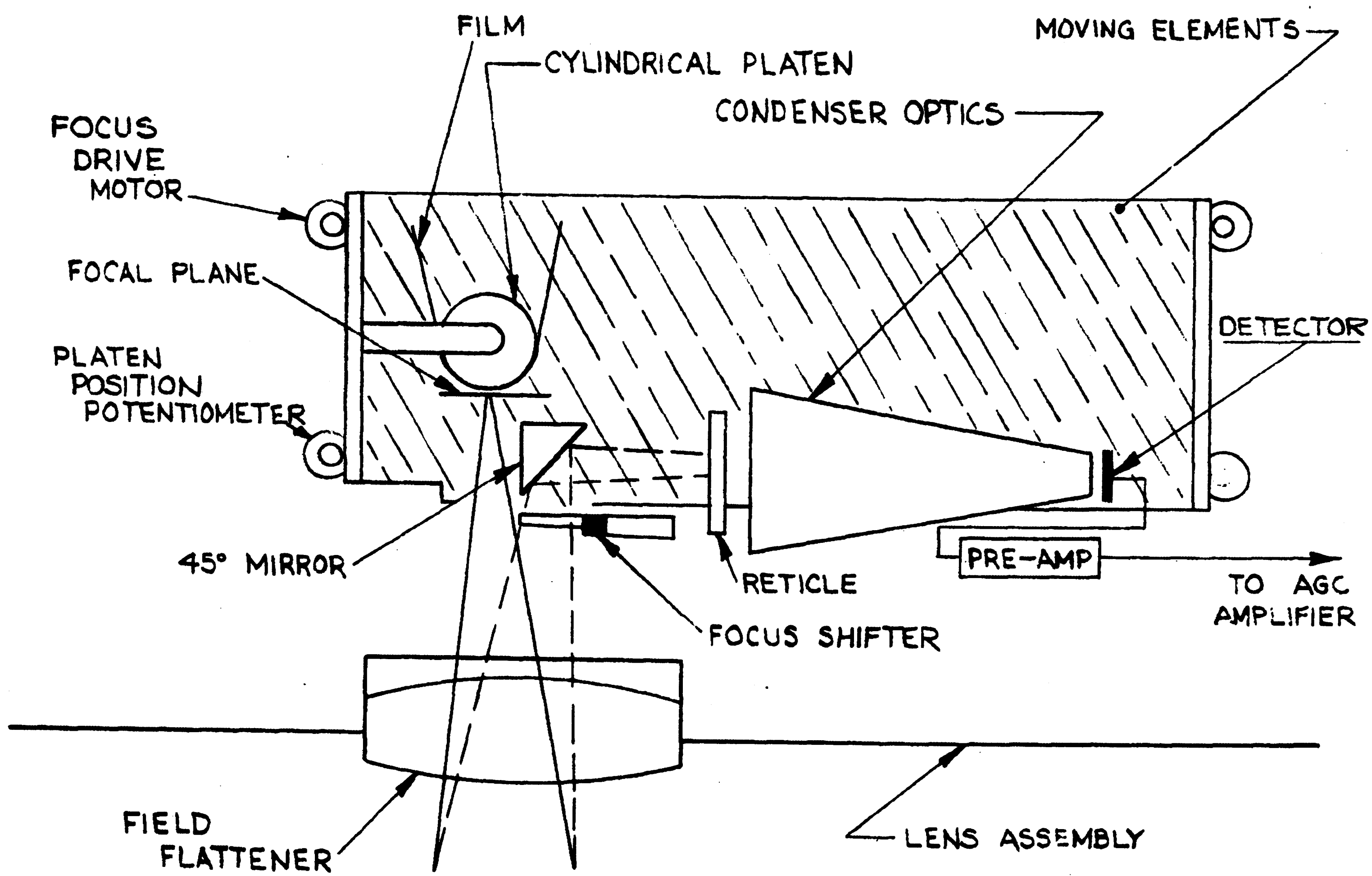


Figure 4-30. Focus System Components in Exposure Unit

The adjustment of camera payload focus by these means is particularly useful in a lunar orbital mission. Unlike an earth orbital mission the lunar surface provides an essentially optimum input to the electro-optical focus system because of the absence of clouds, atmospherics and ocean expanses. As has been demonstrated by the recent Ranger lunar probe, lunar mare are characterized by considerable surface irregularities. These irregularities are of such magnitude and frequency that they provide a scene bit density in excess of the minimum required to operate the camera payload focus system.

The C/P focus system uses a 45-degree mirror, which is located near the camera optical axis, to direct a small portion of the ground scene through a rotating focus shifter disk onto a recticle. The image movement across the reticle chops the gound scene, generating an amplitude-modulated light signal which is a function of the frequency content of the image and the sharpness of image focus at the reticle. The focus shifter, by sequentially introducing two different thicknesses of glass in the optical path, causes the image to be alternately focused in two planes. The components are arranged so that the reticle is between, and equidistant from, these two focal planes when the plane of best focus is coincident with the sensitive surface of the film. In addition, the film platen and the reticle are mounted to the same assembly so that there can be no differential movement between them.

Because the focus sensor image focal plane changes as a result of the action of the focus shifter, two out-of-focus image conditions are alternately present at the reticle. The light output signal from the reticle is directed to a detector which produces an electrical output signal. The detector output, contains two signals on a time-shared basis.

The signals are amplified, separated by a signal-gating module, integrated to produce a d-c level, and compared in a differential amplifier. Since the effects of image content are virtually the same in both channels, they cancel. The output difference signal is then a function of the two image out-of-focus conditions. The differential amplifier output is then added to a fixed d-c level (2.5v) to form the focus output signal.

Should the sensitive surface of the film not be at the plane of best focus, two different out-of-focus conditions will exist and the signal amplitudes in the two channels will be different. The magnitude of the difference signal indicates the degree and direction that the reticle and, therefore, the film plane must be moved to be at the position of best focus. Best focus occurs when the signal amplitudes in the two channels are equal.

The peak frequency of the detector output signal is a function of the reticle spacing and the velocity of the ground image perpendicular to the reticle. A band-pass filter is provided to maximize the signal-to-noise ratio of the detector output. The film platen is driven automatically or by manual command to a position which results in a differential amplifier output between two and three volts. This corresponds to a position which is within ±0.0005 inch of best focus. The mechanism which moves the film platen is the focus drive assembly. It consists of a motor with a gear reduction head, and a worm gear driving a sector gear pinned to an eccentric shaft. Rotation of the eccentric shaft moves the platen toward or away from the lens. Two potentiometers which monitor platen position are coupled to the shaft.

4.7.3 Hardware Description

The following sections briefly describe some of the characteristics of the hardware associated with the focus control system. The arrangement of the components contained within the exposure unit is shown in Figure 4-30.

4.7.3.1 Focus Shifter. The focus shifter is a 6-inch-diameter glass disk which is divided into two semi-circular sections. The glass in one of these sections is 0.030-inch thick; in the other, it is .065-inch thick. Both of these glass plates are parallel-sided optical glass and simply change the effective air-path length and, therefore, the focus plane. The effective air-path lengths through the two halves of the disk differ by 0.012 inch.

The disk is rotated at a speed of 30 revolutions per second by a d-c motor to alternately introduce the different glass thicknesses into the optical path. The synchronizing signals for control of the signal gating module are generated by the shifter rotation.

4.7.3.2 Reticle. The reticle is a glass plate aluminized on one side and ruled and etched to form a grid pattern. This pattern contains 22.5 lines per millimeter with alternate transparent and opaque strips of equal width. In addition, a multilayer interference filter is coated on one side of the reticle plate. The band pass characteristics of this filter and the optical sensitivity of the detector allow the focus control system to react only to light in the wavelength region of 0.5 to 0.7 microns which is the lens-film operating region. Reticle installation must take place at the factory and cannot be accomplished in the field.

4.7.3.3 Focus Optics and Detector. Movement of the image of the ground scene across the reticle causes the light pattern to be chopped. This chopped optical signal is collected by condenser optics which concentrate it on a photo-voltaic cell that acts as the detector. The cell in use is a silicon cell of the type generally called a "solar cell."

4.7.3.4 Preamplifier and Bandpass Filter. The output of the detector is fed into a preamplifier which amplified the signal by a factor of 10^4. The preamplifier contains a bandpass filter which has a center frequency of (later) cycles per second and a bandwidth of (later) percent. This bandpass filter is needed to select the fundamental frequency from the total signal spectrum generated and simultaneously exclude frequencies outside the bandwidth of interest. The resulting frequency is the product of the image velocity and the spatial frequency of the reticle grid pattern.

4.7.3.5 Automatic Gain Control (AGC) Amplifier. The AGC amplifier is a a medium gain amplifier with a variable gain input stage. Input gain is controlled by a feedback loop from the larger of the two signals coming out of the signal-gating module (see Sections 4.7.2 and 4.7.3.6). The amplifier is designed to maintain this larger signal at a constant level so that the difference between the two output signals is always a reproducible function of the focus error.

4.7.3.6 Signal-Gating Module. The signal-gating module is a gating network which separates the signals corresponding to the two focus positions. It is triggered by syncronizing signals generated by rotation of the focus shifter disk. This module also blocks all signals during transition periods or during periods when synchronizing signals are not present.

4.7.3.7 Integrators and Differential Amplifier. The two signals coming out of the signal-gating module are fed into separate integrators. These are rectifiers which have short time-constant characteristics (3 seconds) for rising voltages, but long time constants (10 seconds) for decreasing voltages. The output is, therefore, a d-c signal which is approximately proportional to the level of the active portion of the input signal. These two d-c signals are then fed into a differential amplifier which compares their amplitude. The amplifier output is proportional to the difference between the two input signals. The focus output signal (0-5v) is formed by adding the differential amplifier output to a fixed d-c level (2.5v).

4.7.3.8 Closed-Loop Monitoring Logic. The logic circuits of the closed loop monitor the signal levels of the two channels. If these are beyond what are considered normal limits, the closed-loop-platen-positioning circuit is immobilized.

4.7.4 Signal Outputs

The output of the detector is a complex signal which contains many frequencies. The distribution and amplitude of these frequencies is a function of the ground scene, the scene velocity at the reticle, the grid pattern, and the sharpness of scene focus at the reticle. If this scene were examined without the bandpass filter present, it would appear as shown in Figure 4-29. The region of increased signal amplitude is a direct function of reticle grid pattern spatial frequency and the scene velocity and is referred to as the system fundamental frequency. The bandpass filter attenuates signal frequencies above and below the fundamental frequency.

The relative amplitude of the passed signals, when integrated, can be plotted as a function of focus at the reticle. This curve is also shown in Figure 4-29.

The signal versus focus curves for each channel are plotted and shown in Figure 4-31 with their maximum values separated by a distance corresponding to the difference between the two focus positions (Section 4.7.3.1). The focus position can be determined from this curve if the two signals or the difference signal and its polarity are known. Because the AGC amplifier is included in the circuit, the scale associated with the difference signal is reproducible. A direct relationship between focus error and difference signal is, therefore, maintained. It should be noted that although the reticle is viewing a continuously changing ground scene the focus shifter rotates fast enough to allow both channels to contain virtually the same scene distribution. Scene focus, therefore, is the only parameter in which the two channels differ.

4.7.5 Focus Instrumentation and Commands

The following two sections give a brief description of the instrumentation and commands uniquely associated with the focus control system.

4.7.5.1 Focus Instrumentation. The ability of the C/P to perform its intended function of obtaining high resolution photographic coverage of the lunar surface is dependent, upon the maintenance of focus. Focus system instrumentation is considered "A" priority instrumentation, i.e., focus system instrumentation is necessary to the normal commanding of the payload and requires mandatory action be taken based upon unfavorable instrumentation indications. Focus system instrumentation is, therefore, constructed in a redundant manner.

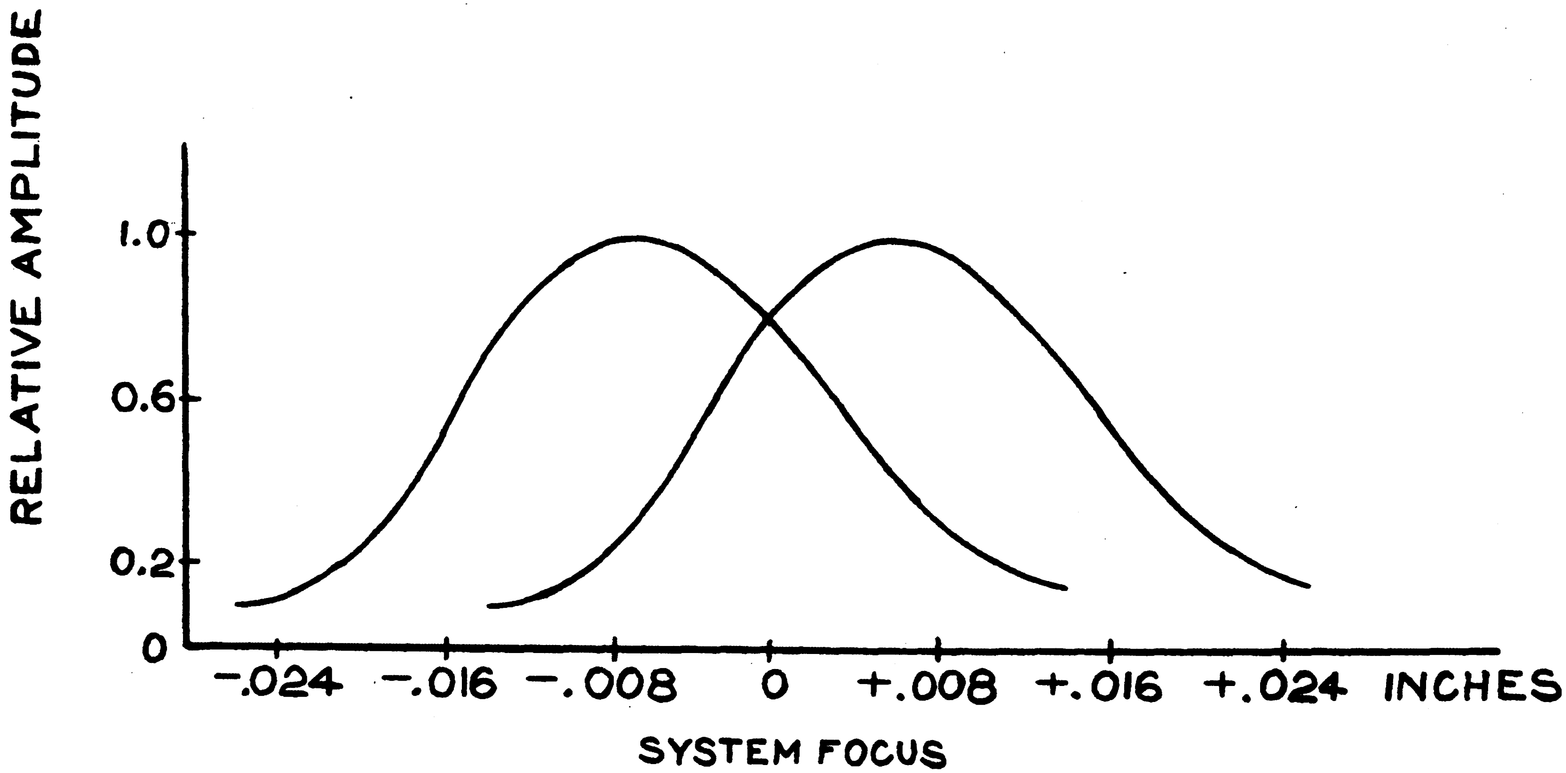


Figure 4-31. Integrator Output Signal Amplitude vs System Focus Position

Three focus signals are instrumented. The amplitude of signals at the output of each of the two focus position channels and the amplitude of the focus output signal. The focus output signal indicates the existing degree of focus. The two focus channel signals show the information which determines magnitude and validity of the difference signal.

Two instrumentation points, coarse and fine platen position, are used to establish platen position. The platen position instrumentation points are used in conjunction with the payload calibration charts to focus the system if the need arises.

Since astronaut manual control of focus is the secondary focus system operating mode, focus instrumentation is presented to the CM control center panel.

4.7.5.2 <u>Focus Commands</u>. Three commands are used for focus adjustment. They are:

1. Focus Control Mode (Manual-Automatic)
2. Focus Drive - Forward
3. Focus Drive - Reverse

In the automatic mode, focus motor is controlled by the focus control system, in the manual focus mode an astronaut initiates forward and reverse commands which cause the focus motor to run for the period of direct command application. When no direction command is present, the platen position is maintained at the last commanded position. The focus system is so designed that the platen position will not respond to either automatic or manual commands during the active photographic period.

4.7.6 Reliability

The preceding paragraphs describe the operation of an existing focus control method. Only minor modifications will be necessary to adapt a qualified existing focus control design to the Survey Camera Payload.

4.8 CAMERA PAYLOAD ELECTRICAL DESIGN

The C/P electrical assembly consists of the electrical components, cabling, and packaging necessary to transmit power and commands to, and derive instrumentation data from, the C/P. A block diagram of the C/P electrical assembly is shown in Figure 4-32. Figure 4-1 shows the location of the primary electrical packages.

4.8.1 Payload Power

Electrical power for the C/P is supplied by the SM. Two separate power supplies are required; operational and environmental power supplies which provide the following dc voltage levels:

Operational Power	+28 volts nominal (unregulated)
Environmental Power	+28 volts nominal (unregulated)

4.8.1.1 Operational Supply. The unregulated +28 volt dc operational supply is the primary power source for the C/P. Under normal operation, the energy consumption of the C/P components drawing power from this supply is 1500 watt-hours based on an 8 day (96 orbit) lifetime and an 800 stereo-pair mission. An analysis of the energy consumption of the C/P, by components, is given in Table 4-2. A power profile is shown in Figure 4-33. The operational supply voltage measured at the interface between the C/P and the SM is between 25.0 and 32.0 volts when the steady state load current is less than 7.0 amperes, and surge transients decay to normal load currents in less than 0.5 second. The application of operational power to the C/P is controlled by the C/P in accordance with commands received from the spacecraft. The operational circuits are isolated by at

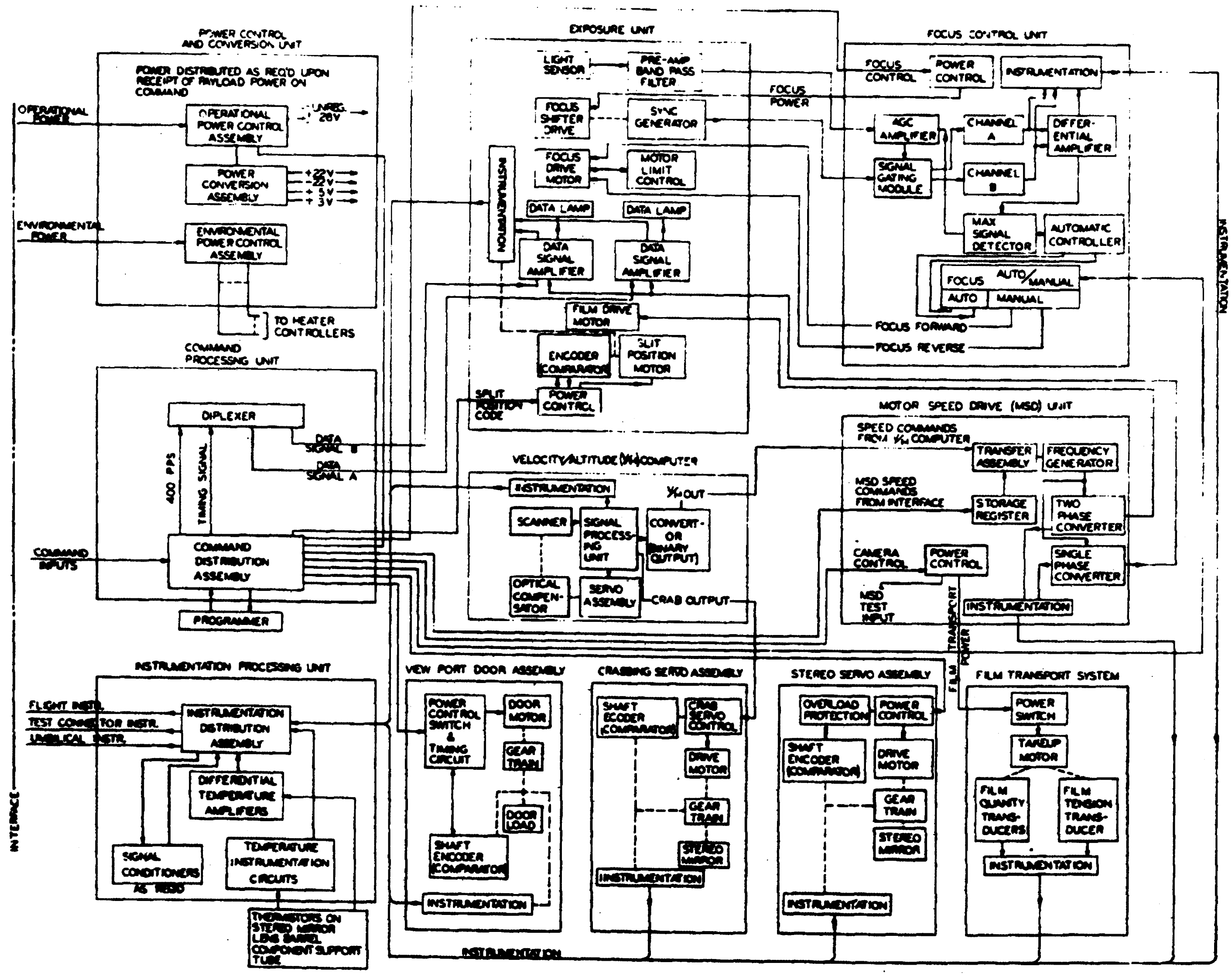
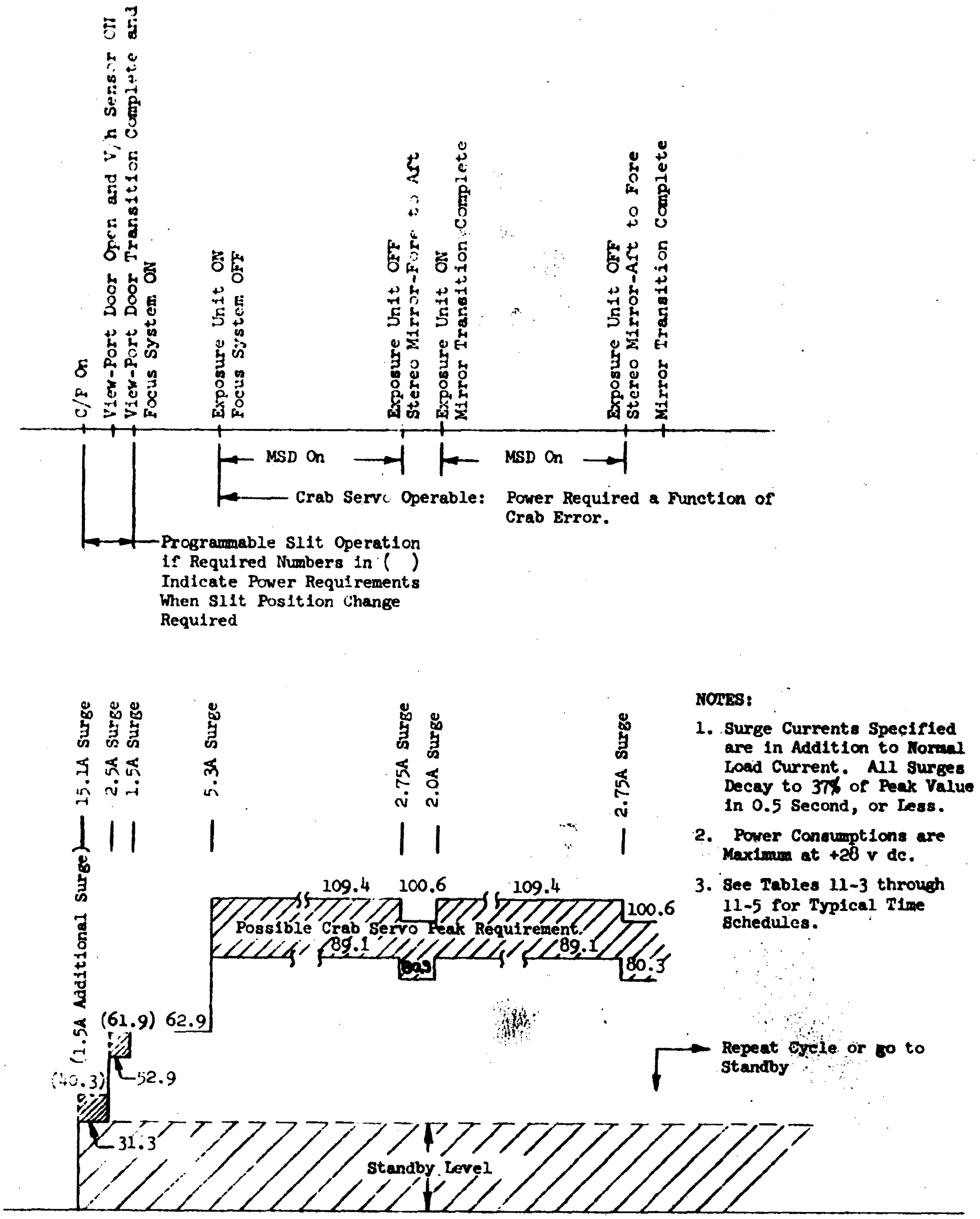


Figure 4-32. Camera Payload Electrical Block Diagram



NOTES:

1. Surge Currents Specified are in Addition to Normal Load Current. All Surges Decay to 37% of Peak Value in 0.5 Second, or Less.
2. Power Consumptions are Maximum at +28 v dc.
3. See Tables 11-3 through 11-5 for Typical Time Schedules.

Figure 4-33. Power Profile for Stereo Mode Photography Based on Maximum Power Consumption

TABLE 4-2

ESTIMATED C/P POWER CONSUMPTION

C/P Component	Power Supply	C/P ON "Standby" Steady State			C/P ON "Operational" Steady State		
		1	2	Surge	1	2	Surge
Stereo Servo	+28	15	0.42	0	750	21.0	2.75A
	+5	0.25	0.001	0	0.25	0.001	0
Crab Servo	+28	1.43	0.04	0	725	20.3	3.0A
	+5	0.25	0.001	0	0.25	0.001	0
Programmable Slit	+28	15	0.42	0	320	9.0	1.5A
	+5	0.25	0.001	0	0.25	0.001	0
Focus Drive Assembly	+28	0	0	0	200	5.6	0.2A
	+22	0	0	0	1.3	0.364	0
	+5	0.5	0.002	0	0.5	0.002	0
Focus Detector Assembly	+28	0	0	0	200	5.6	1.0A
	+22	0	0	0	2	0.44	0.15A
Film Drive Motor	AC	----(NOTE 1)------			------(NOTE 1)---------		
Data Signal Amp.	AC	----(NOTE 1)------			------(NOTE 1)---------		
	-22	0.50	0.002	0	0.50	0.002	0
View-Port Door Servo	+28	15	0.42	0	320	9.0	1.5A
	+5	0.25	0.001	0	0.25	0.001	0
Focus Control	+28	0	0	0	40	1.12	0
Unit	+22	0	0	0	120	3.36	0.15A
	-22	0	0	0	90	2.52	0
Motor Speed Drive (Note 1)	+28	3.6	0.10	0	750	18.6	2.0A
Supply Cassette	+28	0	0	0	400	11.2	1.5A
	+5	0.25	0.001	0	0.25	0.001	0

C/P Component	Power Supply	C/P ON "Standby" Steady State 1	2	Surge	C/P ON "Operational" Steady State 1	2	Surge
Take-Up Cassette	+28	0	0	0	550	15.4	1.8A
	+5	0.50	0.002	0	0.50	0.002	0
V/h Sensor	+28	0	0	0	450	12.6	1.0A
Temperature Probes	+22	2.5	0.05	0	2.5	0.05	0
Inst. Proc. Unit	+28	107	3.0	0	107	3.0	0
	+22	120	2.64	0	120	2.64	0
	-22	120	2.64	0	120	2.64	0
Power Conv. & Control	+28	4000	11.2	15A	400	11.2	0
Command Proc. Unit	+28	50	1.40	.1A	50	1.40	0
	+3	3000	9.0	0	3000	9.0	0

NOTE:

1. AC power dissipated by film drive motor and data signal amplifiers is included in motor speed drive, the unit of origin.
2. Column 1 is steady state current in milliamperes.
3. Column 2 is steady state power in watts.
4. Surge current is in amperes. Surge current is in addition to steady state current. Surge current decays to 37% of peak value in 0.5 second, or less.
5. "Standby" powers may be added to determine total standby dissipation. "Operational" powers may not be added directly. Units are time sequenced in their operation during "Operational" Phase.
6. A 1% cable loss has been allowed in all figures.

least 30 K ohms from the environmental circuits except for a common "dc return" when the C/P is installed in the SM.

The plus 28 volt dc operational power supply is modified in the C/P to supply the various input voltages necessary for operation of the C/P electrical components. The plus 28 volts is inverted, transformed, rectified, and regulated to provide ±22.0 volts dc for a portion of the instrumentation circuitry and the focus control electronics, +5.0 volts dc for the remainder of the instrumentation circuitry, and 3.0 volts dc for operation of logic circuits.

The motor speed drive (MSD) unit is a variable frequency power supply which furnishes power for film drive motor. The MSD also supplies a limited amount of ac power to the data signal printing heads in the exposure unit for printing the data tracks on the film.

Aside from these power control functions, the C/P generally utilizes unregulated operational power.

4.8.1.2 Environmental Supply. The environmental supply provides power for the environmental heaters within the C/P. Energy demands are dependent on the SM thermal control. The maximum current drain is 3.6 amperes, and the voltage measured at the interface is between 25.0 and 32.0 volts. Under nominal operating conditions, environmental power is supplied from launch until the photographic portion of the mission has been completed. In unusual situations, environmental power must be removed or applied by command by the SM. All environmental power inputs to the C/P have some form of overload protection within the C/P.

4.8.2 C/P Commands, Control, and Programming

The command requirements of the C/P are intimately related to the mission profile. It is evident that command requirements for the several mission profiles discussed in Section 3.0 required definition of the astronaut and spacecraft computer roles. The command requirements should be based upon providing as flexible a command capability as is practicable without resulting in requirements which restrict the mission profiles which can be accommodated. The electrical interface defined by Figure 5-10 and Appendix T delineate the commands required at the C/P - C/SM interface.

C/P commands fall into two categories: those which must be received from the spacecraft for normal control of the C/P and those which are "back-up" commands for functions normally controlled by systems integral to the C/P. The commands divide into the two categories as shown in Table 4-3. The sequence of command execution is basically the same for either stereo or strip mode photography. Only the timing of command delivery to the C/P changes.

The command sequence is based upon three distinct phases of operation: C/P run-up, C/P operation and C/P shut-down. The sequence required for mission termination and film retrieval is considered separately.

The C/P run-up phase occurs each time the view-port door is opened. The C/P thermal design assumes that the view-port door opens only once per orbit and stays open through completion of photography for that orbit. Normally it is necessary to execute the run-up phase only once per orbit.

TABLE 4-3

C/P COMMANDS

PRIMARY COMMANDS	CODE	BACK-UP COMMANDS	CODE
Payload Power	COD 1	MSD Speed Most Sig. Bit ON	COD 6
Camera Control	COD 2	MSD Speed Most Sig. Bit OFF	COD 7
Stereo Mirror	COD 3	MSD Speed 2nd Most Sig. Bit ON	COD 8
Door Control (View-Port Door)	COD 4	MSD Speed 2nd Most Sig. Bit OFF	COD 9
MSD Auto-Manual	COD 5	MSD Speed 3rd Most Sig. Bit ON	COD 10
Focus Control	COD 24	MSD Speed 3rd Most Sig. Bit OFF	COD 11
Slit Most Sig. Bit ON	COD 27	MSD Speed 4th Most Sig. Bit ON	COD 12
Slit Most Sig. Bit OFF	COD 28	MSD Speed 4th Most Sig. Bit OFF	COD 13
Slit Least Sig. Bit ON	COD 29	MSD Speed 5th Most Sig. Bit ON	COD 14
Slit Least Sig. Bit OFF	COD 30	MSD Speed 5th Most Sig. Bit OFF	COD 15
Supply Brake Control	COD 31	MSD Speed 6th Most Sig. Bit ON	COD 16

Focus Auto-Manual	COD 32	MSD Speed 6th Most Sig. Bit OFF	COD 17
Empty Supply	COD 35	MSD Speed 7th Most Sig. Bit ON	COD 18
Strip-Stereo	COD 25*	MSD Speed 7th Most Sig. Bit OFF	COD 19
Panning	COD 26*	MSD Speed 8th Most Sig. Bit ON	COD 20
		MSD Speed 8th Most Sig. Bit OFF	COD 21
		MSD Speed Least Sig. Bit ON	COD 22
		MSD Speed Least Sig. Bit OFF	COD 23
		Focus Forward	COD 33
		Focus Reverse	COD 34
		Cut Film	COD 36
		Separate	COD 37

*COD 25 and COD 26 required only to accomodate both stereo-strip mode and panning mode in single payload configuration or it common components used in two payload designs.

The time relationship between commands during the run-up phase is referenced to the time to initiate photographic exposure for the orbit in progress. Table 4-4 establishes the run-up phase command sequence.

In the operation phase, the time sequence is established by the photography desired for the orbit being flown. Table 4-5 illustrates a typical stereo pair cycle and a typical strip mode operation.

The shut-down phase consists of closing the view-port-door and de-energizing the C/P. This time sequence is established in Table 4-6.

When the photographic mission is complete, and film retrieval is to be initiated, the retrieval sequence must be executed. The normal retrieval sequence is illustrated in Table 4-7. Since film retrieval is critical to the success of the mission, redundancy is essential to the command structure. In the event the retrieval sequence fails to progress in accordance with the C/P programmed schedule and the cutting and sealing operation does not occur automatically, the cut film command from the spacecraft is executed which causes cutting and sealing to occur immediately. The C/P components are by-passed when the command is initiated by the spacecraft. The cut film command is a +28 volt dc command capable of operating the cutter mechanism directly. A similar redundancy will be provided for the cassette separate command if this function is performed by the C/P system.

It is important to consider the impact of limited mission profiles upon the C/P command requirements. If the mission profile becomes stereotyped and a specific and repetitious operating sequence emerges, the necessity for certain commands to be based upon navigational data for

TABLE 4-4

C/P RUN-UP COMMAND SEQUENCE

Time (Seconds) (Relative to time t_o)	Command	
t_o-X-5	Payload Power	- ON (COD 1)
	Stereo Mirror	- FORWARD POSITION (COD 3)
	MSD Auto-Manual	- SELECT (COD 5)
	MSD Speed	- SET (COD 6 thru COD 23)
	Slit Position	- SELECT (COD 27 thru COD 30)
t_o-X-2	View-Port Door Control	- OPEN (COD 4)
t_o-X	Focus Control	- ON (COD 24)
	Focus Auto-Manual	- SELECT (COD 32)
t_o-X through t_o	Automatic focus control occurs if auto-focus selected - OR - Focus Forward (COD 33) and Focus Reverse (COD 34) commanded as required to establish "best" focus.	
t_o	C/P Run-up complete	

NOTE: Period X is defined as follows:

1st orbit of mission: X = 120 seconds minimum
1st orbit following altitude change of more than 40 n. m.: X = 75 seconds minimum

All remaining orbits: X = 60 seconds minimum

TABLE 4-5

C/P OPERATIONAL COMMAND SEQUENCE

Stereo Mode

Time (Seconds) (Relative to time t_o)	Command	
t_o	Focus Control	- OFF (COD24)
	Camera Control	- ON (COD 2)
t_o+y	Camera Control	- OFF (COD 2)
	Stereo Mirror	- AFT POSITION (COD 3)
t_o+y+4.0	Camera Control	- ON (COD 2)
(t_o+y+4.0)+y	Camera Control	- OFF (COD 2)
	Stereo Mirror	- FORWARD POSITION (COD 3)
(t_o+y+4.0+y)+4.0	Stereo Cycle Repeats; internal between stereo pairs a function of mission requirements.	

NOTE: Period y is the exposure unit on time associated with the stereo pair. This interval may range from a minimum of 15 seconds to a maximum of 50 seconds for the mission profiles described in Section 3.0.

TABLE 4-5
(cont'd.)

Strip Mode

Forward Looking Strip

Time (Seconds) (Relative to time t_o)	Command	
t_o	Focus Control	- OFF (COD 24)
	Camera Control	- ON (COD 2)
t_o+y'	Camera Control	- OFF (COD 2)

Aft Looking Strip

Time (Seconds) (Relative to time t_o)	Command	
t_o	Focus Control	- OFF (COD 24)
	Stereo Mirror	- AFT POSITION (COD 3)
$t_o+4.0$	Camera Control	- ON (COD 2)
$t_o+4.0+y'$	Camera Control	- OFF (COD 2)
	Stereo Mirror	- FORWARD POSITION (COD 3)

NOTE: Period y' defined by the length of strip mode photography required by mission. More than one strip per orbit may be acquired by initiating COD 2 at any time later than t_o+y' or $t_o+4.0+y'$.

TABLE 4-6

C/P SHUT-DOWN COMMAND SEQUENCE

Time (Seconds)	Command	
t_1	Camera Control	- OFF (COD 2)
	If required - Stereo Mirror	- FORWARD POSITION (COD 3)
$t_1+4.0$	View-Port Door Control	- CLOSE (COD 4)
$t_1+7.0$	Payload Power	- OFF (COD 1)

NOTE: Time t_1 corresponds to the time of completion of photographic coverage for the orbit being flown.

TABLE 4-7

C/P RECORD RETRIEVAL COMMAND SEQUENCE
(Assumes C/P OFF at Initiation of Sequence)

Time (Seconds)	Command	
t_2	Payload Power	- ON (COD 1)
t_2+3.0	Empty Supply	- ON (COD 35)
t_2+3.0+z	Cut Film	- ON (COD 36)
	- OR -	
	Take-up Cassette ready for retrieval (See Note Below)	

NOTE: Receipt of COD 35 by the C/P initiates the following actions:

(1) Supply cassette is emptied of remaining film.

(2) Upon completion of (1), film cutter automatically actuated as back-up to insure that leader has been separated from supply reel. Take-up cassette is automatically sealed. If cutter fails to operate, COD 36 must be initiated from spacecraft upon cutter failure indication.

TABLE 4-7
(cont'd.)

(3) Responsibility for separation of take-up cassette from payload has not been definitely defined. If responsibility is EKC's, separation will occur automatically in sequence. If C/P command fails to cause separation, Separate Command, COD 37, must be initiated from the spacecraft.

Interval Z is a function of unexpended film supply at termination time t_2. Supply empty rate will be 2.5 inches per second.

their timing disappears. A typical example might be the case of operation in a stereo sampling mode with a fixed time stereo pair. In this case such commands as stereo mirror position commands and exposure unit ON and OFF commands can be programmed by the C/P rather than the spacecraft. In establishing command requirements for the C/P - C/SM interface, it is essential that a specific class of mission profiles be studied.

Control of camera payload internal functions can be accomplished in either of two ways, one way is to use the SCM AGC, another way is to use an internal programmer. The camera payload can be controlled using an internal programmer for a wide variety of mission profiles. The command functions which the programmer would be required to control are: exposure unit on-off control, stereo mirror position, door control and slit position selection. The command requirements of tables 4-4 and 4-5 illustrate that if the variable time intervals cited are fixed to a relatively small number of values and a definite time sequence for stereo pairs is established, the command sequence for the functions listed above becomes programmable using a fixed memory system such as a tape programmer. The flexibility of the camera payload is then limited only by the number of programs which are stored in the programmer for a given mission. The remaining payload commands (IMC speed selection and focus control) are normally commanded by the integral V/h sensor and focus control system and no additional provisions for these functions would be required.

A programmer which meets the requirements of the camera payload mission is the Fairchild Type VI Programmer. The basic programmer is an off-the-shelf device. This programmer has the following characteristics:
1) Capacity to control up to six on-off functions simultaneously,
2) Storage capacity for a maximum of 256 subcycles of up to 96 minutes duration per subcycle and 24,576 minutes (409.6 hours) total program capacity. Programs are stored on a pre-punched tape.

The internal programmer will be energized by the application of payload power which is a spacecraft input to the C/P. The programmer can be synchronized to the orbit by an occultation signal supplied from the spacecraft. The required subcycle period can be advanced or retarded or reset to the reference point by spacecraft input.

The supply brake control command, COD 31, is required by the camera payload to lock the film supply spool during powered flight portions of the mission. The film supply reel is braked to prevent rotation and consequent loosening of film on the supply reel. The command must be established at least one second prior to disconnection of the fly-away umbilical to permit positive verification from umbilical instrumentation that the command has been received by the C/P. The command must remain applied through the period of powered flight during ascent to earth orbit. The command should also be present when powered flight commences to achieve transition to the translunar phase of the mission, or at any time the vehicle acceleration exceeds 0.5g. Upon insertion into a lunar orbit, the spacecraft must discontinue the supply of this command to the C/P since the C/P will provide supply reel braking control during this phase of the mission.

4.8.3 Instrumentation and Astronaut Monitoring

4.8.3.1 Instrumentation. C/P instrumentation is divided into three categories: test connector instrumentation, umbilical instrumentation and flight instrumentation. Figure 4-34 illustrates the flow of C/P instrumentation in the above categories.

Test connector instrumentation is used for manufacturing system-type tests (including acceptance testing), C/P health checks upon payload delivery, post-installation checks in the service module and checks during initial on-pad operations. The instrumentation circuits included in test connector instrumentation include all flight instrumentation points and all command inputs to the C/P. This approach provides

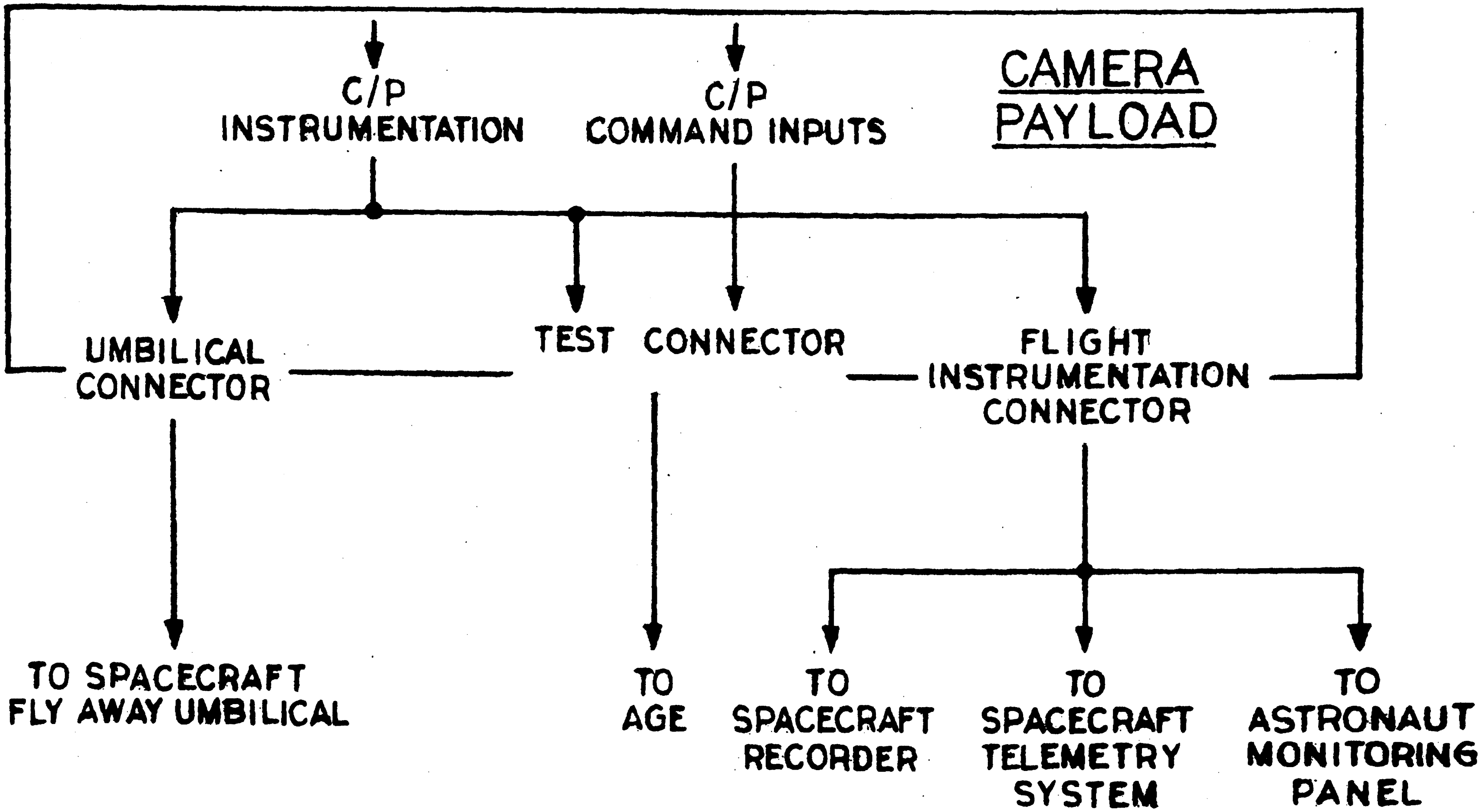


Figure 4-34. Camera Payload Instrumentation Flow Diagram

capability to conduct, by hardwire connection to the instrumentation points and command inputs, complete C/P performance and diagnostic evaluations.

Umbilical instrumentation consists of a limited number of instrumentation circuits which monitor critical C/P parameters during the count-down period. These instrumentation points are just sufficient to certify health until the instant of launch or to recognize occurrence of an anomaly which could be cause for a hold in the count-down.

Flight instrumentation consists of three levels of instrumentation: that which is necessary to the normal commanding of the C/P, that which permits commanding of the C/P on an optical basis, and that which is diagnostic in nature.

The C/P instrumentation points in the three major categories are listed in Figure 5-10. The instrumentation philosophy followed in the C/P design is that for each commandable and dynamic payload function there exists instrumentation capable of verifying the execution of the command and status of dynamic functions. Based upon this philosophy the instrumentation requirements for the C/P are as outlined in the following paragraphs.

Test connector instrumentation must be accessible for use in conjunction with ASE and AGE at all times from delivery of the C/P to the assembly point through at least that period in the count-down sequence when the pad area must be cleared. Removal of the test connector prior to three hours before launch is not advised. (It is not necessary that test connector instrumentation be available up to actual launch since umbilical instrumentation is provided for this purpose). A minimum of 78 hardline test circuits to the AGE will be required. Buffering requirements will be determined at a later date.

Umbilical instrumentation must be available from the time the test connector is removed until actual lift-off of the boost vehicle. A minimum of seven umbilical hardlines are required. Umbilical instrumentation within the C/P is electrically isolated and independent of all other C/P instrumentation. Therefore, accidental short circuiting of umbilical instrumentation circuits or accidental application of voltage to these circuits will not cause failure of the C/P. No buffering of umbilical instrumentation circuits will be required by the C/P.

Flight instrumentation requirements are a function of the particular instrumentation point's priority. The three priorities established are defined as follows:

"A" Priority - Instrumentation necessary to the normal commanding of the C/P or which indicates conditions requiring mandatory action.

"B" Priority - Instrumentation available for command of the payload on an optional basis.

"C" Priority - Diagnostic instrumentation.

Table 4-8 segregates the flight instrumentation points in accordance with the assigned priorities. Instrumentation in the "A" priority category must be available in real time. Points defined as "B" priority must be available in near real time, and real time availability is acceptable.

TABLE 4-8

FLIGHT INSTRUMENTATION PRIORITY ASSIGNMENTS

"A" Priority		
Slit Position	IMP	12
Film Take-Up Quantity Fine	IMP	16
Platen Position Coarse		19
Platen Position Fine		20
Focus "A" Channel		21
Focus "B" Channel		22
Focus Output		23
Port Open Tell Tale		25
V/h Output		32
"B" Priority		
Camera Film Path Temp		1
Stereo Mirror Differential Temp		3
Lens Barrel Differential Temp		5
Component Support Tube Temp		11
Film Take-up Quantity Coarse		14
Film Take-up Quantity Medium		15
MSD Frequency		18
Calibration		28
V/h Malfunction		29
Crab Position		34

"C" Priority

Forward Record Storage Temp	2
Stereo Mirror Temp	4
45° Mirror Temp	6
Component Support Tube Temp	7 thru 10
Stereo Position	13
Film Tension	17
Supply Cassette Film Path Temp	24
Environmental 28V	26
Take-up Motor Current	27
Data Signal "A"	30
Data Signal "B"	31
Crab Output	33

Priority "C" instrumentation is required in a form suitable for post flight evaluation.

The foregoing flight instrumentation availability requirements may be satisfied in a number of ways. For example, real time may be either via down-line telemetry in real time or via astronaut real time monitoring. Near real time processing may be accomplished by delayed astronaut monitoring. Astronaut monitoring in this case could take place during the period of flight around the "dark" side of the moon. In any event, storage of the instrumentation data until readout is accomplished will be required since the instrumentation signals of interest are available only during C/P photographic operations. Instrumentation required for post flight evaluations will require onboard storage facilities.

The flight instrumentation points have the following basic characteristics at the C/P - C/SM interface:

Source Impedance	Ranges from 0 to 5,000 ohms
Voltage	5.0 ± 0.1 volt full scale
Data Frequency	Ranges from 0.1 to 10 cycles per second

The accuracy required after readout is as follows:

"A" Priority Data	±3 percent, 2 sigma value
"B" Priority Data	±5 percent, 2 sigma value
"C" Priority Data	±8 percent, 2 sigma value

Recognition of the importance of instrumentation to optimum performance of the C/P involves a clear understanding of C/P operations and capabilities. The C/P is a precision photographic system whose photographic record quality is sensitive to such variables as temperature and vehicle attitude control. Therefore, while the C/P can function for the required mission period completely unattended, it is highly desirable that the parameters to which the system is sensitive be adequately monitored to increase the assurance of proper functioning. Therefore, the C/P flight instrumentation requirements are the minimum required in each priority level to maintain the C/P at the optimum performance level under the conditions expected to prevail.

4.8.3.2 Astronaut Monitoring. The role of the astronauts in the monitoring of the C/P must ultimately be determined from a systems view point. However, certain payload monitoring and control functions appear to be logically performed by the astronauts and are, therefore, presented as requirements of the C/P for monitoring and control.

Manual focus capability is a design feature of the C/P. In the manual focus mode the platen is driven in one direction or other in response to real time commands, i.e., the platen is driven in a given direction for the duration of the applied command. Since focusing of the C/P involves positioning the platen to a "best" focus position as indicated by the focus detector assembly and the focus control unit, real time instrumentation is essential to the proper execution of the focus commands, which are also real time. While this function can be accomplished using both real time up-link and down-link telemetry, local astronaut control appears preferable. The instrumentation and command requirements for manual control of the focus system by the astronaut control are detailed in Section 4.7.

A "master tell-tale" indicator is used to provide the astronauts with knowledge regarding gross C/P status. This indicator may take on any of several forms. For the purpose of illustrating the character of the required indicator function, it is assumed that a multiplexed signal having several discrete levels defining various conditions within the C/P can be displayed in a suitable manner. The functions to be multiplexed include: A C/P ON indication, an exposure unit ON indication, and three malfunction level indicators.

C/P instrumentation will include a provision for continuous monitoring of critical operating conditions. Immediate corrective action or immediate evaluation for possible corrective action can be taken by the astronaut if the instrumented parameters exceed predetermined limits.

The display of film quantity is recommended. The importance of this display is related to the ultimate decision as to the degree of astronaut participation in C/P operation and take-up cassette retrieval. Other astronaut monitoring functions relating to the retrieval sequence must be evaluated from the view point of astronaut participation to define the functions which need to be displayed. The astronaut monitoring capability must be established in relation to the Apollo system concepts and ultimate method of instrumentation processing adopted. The C/P design in this area is believed to be flexible enough to adapt to any reasonable approach.

4.8.4 EMI Control

The camera payload will be designed to meet the requirements of MIL-I-26600, for class 1b equipment, and EMI-10A, the NASA addendum to MIL-I-26600. In addition, the camera payload will meet the testing requirements of MIL-E-6051C. The existing equipment, which will be modified to meet the requirements of the lunar photographic mission, meets the EMI requirements of MIL-I-26600 except for some very minor discrepancies which have been accepted by the Air Force. The modifications required to meet the additional requirements imposed by EMI-10A are minimal. In instances where new components are required to adapt the camera payload to the lunar mission, the design, fabrication and test of such components will be governed by the requirements of MIL-I-26600, EMI-10A and the Eastman Kodak Company interference control plan prepared for this program. The interference control plan is contained in Appendix K.

The EMI control plan of Appendix K describes, in both general and specific terms, the manner in which compliance with MIL-I-26600 and EMI-10A will be accomplished. The scope of the control plan is such that all anticipated potential interference sources and susceptible components are identified and the applicable EMI control procedures delineated. In general the control plan requirements are reflected in the camera payload design in the following order of priority:

1. Circuits are designed to be EMI "free" in preference to EMI suppressed. The electronics associated with the programmable slit (see Section 8.3), in which all hard switch functions are performed at low voltage levels and high voltage (+28 volt) switching is performed using rise time-controlled transistor switching, is typical of implementation of this design feature.

2. Circuits and components which cannot be EMI suppressed at the interference source are EMI "contained" and the resulting "contained" subassembly is EMI suppressed as a whole. This condition is typical of the EMI control approach applied to certain microswitch applications and portions of dc-to-dc converter electronics.

In order that the requirements of MIL-I-26600 may reasonably be expected to be met by the camera payload as a whole, contracted components are procured qualified to MIL-I-26600. The necessity for the application of EMI suppression techniques at payload level is thereby minimized.

Electromagnetic interference testing of the entire camera payload to MIL-I-26600 and EMI-10A cannot be conducted as a formal MIL-I-26600 test due to the incompatibility of test methods and camera payload physical size. However, EMI testing of the camera payload can be performed to the extent required for informational purposes and to indicate the ability of the camera payload to perform in accordance with the testing requirements of MIL-E-6051C. In general, the procedures of MIL-I-26600 will be used in the conduct of camera payload testing although some deviations in test methods and interpretation of results will be necessary when MIL-I-26600 test procedures and conditions cannot be established realistically.

4.8.5 Thermal Control System Electrical Design

The schematic layout of the thermal control components is shown in Figure 4-35. This diagram shows the approximate location of the various thermal control elements and thermal instrumentation components. The numbered call outs are identified in Table 4-9. The heater powers specified in the table are specified at a nominal voltage of +28 volts dc. The thermistor probe temperatures specified are turn-on temperatures. Turn-off

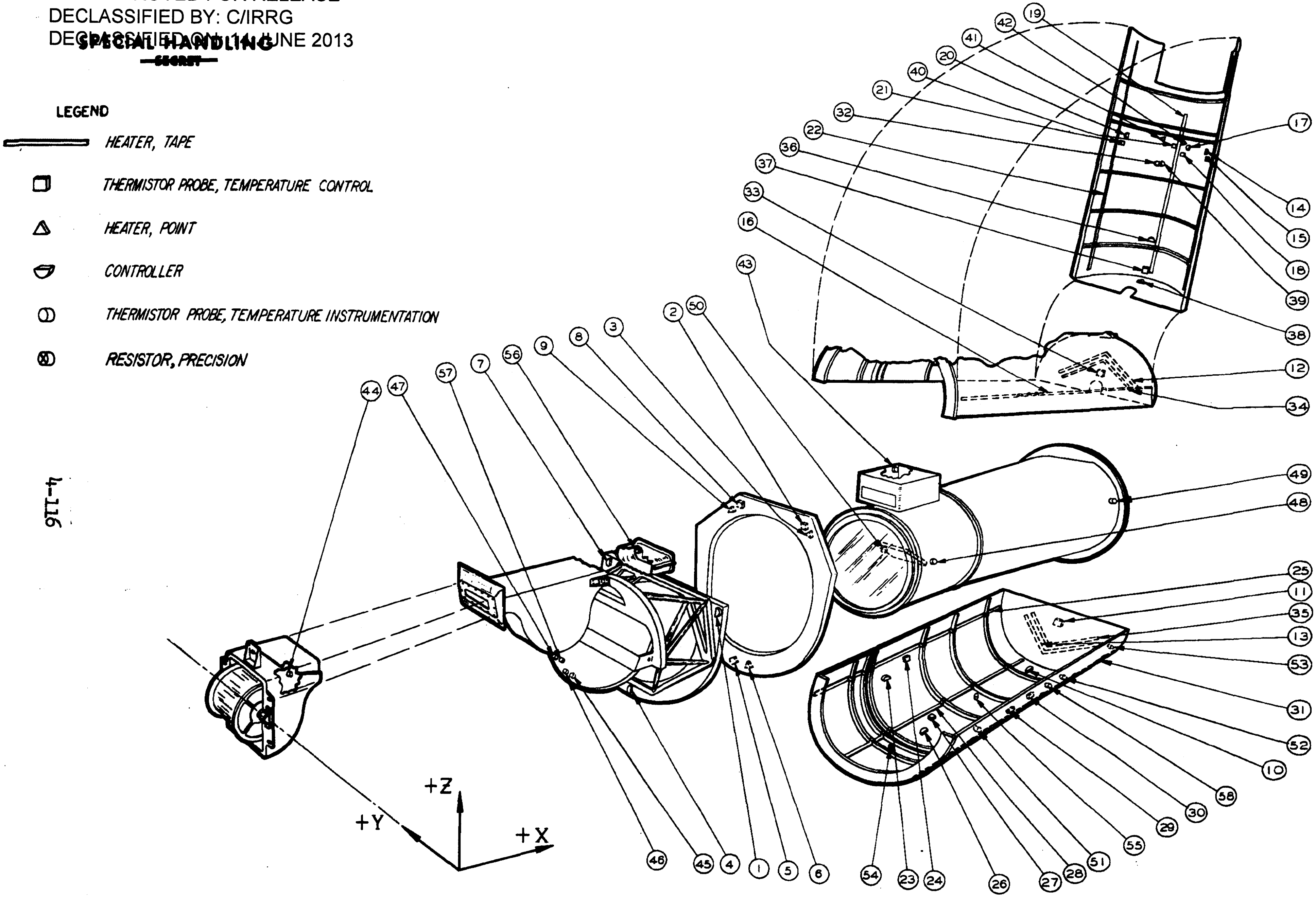


Figure 4-35. Thermal Control System Schematic

TABLE 4-9

THERMAL CONTROL SYSTEM COMPONENT IDENTIFICATION

Item	Heater System Number	Function	Location
1	3	Heater Controller	Primary Structural Ring, -Y
2	3	Thermistor Probe 69.8 F	Primary Structural Ring, -Y
3	3	Heater 5.0 W	Primary Structural Ring, -Y
4	4	Heater Controller	Primary Structural Ring, -Z
5	4	Thermistor Probe 69.8 F	Primary Structural Ring, -Z
6	4	Heater 5.0 W	Primary Structural Ring, -Z
7	5	Heater Controller	Primary Structural Ring, +Y
8	5	Thermistor Probe 69.8 F	Primary Structural Ring, +Y
9	5	Heater 5.0 W	Primary Structural Ring, +Y
10	6	Heater Controller	Component Support Tube, Rear, -Z
11	6	Thermistor Probe 69.8 F	Component Support Tube, +X
12	6	Heater 2.5W	Component Support Tube, Top, +X
13	6	Heater 2.5 W	Component Support Tube, Bottom, +X
14	10	Heater Controller	Component Support Tube, +Z
15	10	Thermistor Probe 69.8 F	Component Support Tube, +Z
16	10	Heater 5.0 W	Component Support Tube, +Z
17	11	Heater Controller	Component Support Tube, +Z
18	11	Thermistor Probe 69.8 F	Component Support Tube, +Z
19	11	Heater 5.0 W	Component Support Tube, +Z
20	12	Heater Controller	Component Support Tube, +Z

TABLE 4-9
(cont'd.)

Item	Heater System Number	Function	Location
21	12	Thermistor Probe 69.8 F	Component Support Tube, +Z
22	12	Heater 5.0 W	Component Support Tube, +Z
23	13	Heater Controller	Component Support Tube, -Z
24	13	Thermistor Probe 69.8 F	Component Support Tube, -Z
25	13	Heater 5.0 W	Component Support Tube, -Z
26	14	Heater Controller	Component Support Tube, -Z
27	14	Thermistor Probe 69.8 F	Component Support Tube, -Z
28	14	Heater 5.0 W	Component Support Tube, -Z
29	15	Heater Controller	Component Support Tube, -Z
30	15	Thermistor Probe 69.8 F	Component Support Tube, -Z
31	15	Heater 5.0 W	Component Support Tube, -Z
32	16	Heater Controller	Component Support Tube, +Z
33	16	Thermistor Probe 69.8 F	Component Support Tube, Top, +X
34	16	Heater 2.5 W	Component Support Tube, Top, +X
35	16	Heater 2.5 W	Component Support Tube, Bottom, + X
36	17	Heater Controller	Component Support Tube, +Z
37	17	Thermistor Probe 69.8 F	Component Support Tube at Torsional Restraint Pin
38	17	Heater 5.0 W	Component Support Tube at Torsional Restraint Pin
39	18	Heater Controller	Component Support Tube, +Z
40	18	Thermistor Probe 69.8 F	Component Support Tube, +Z
41	18	Heater 1.0 W	Component Support Tube, +Z
42	18	Heater 1.0 W	Component Support Tube, +Z

temperatures are nominally 0.6 Fahrenheit degree higher.

Each heater system consists of a thermistor probe, a heater controller, and a heater element. The heater systems operate as closed-loop "bang-bang" controllers, that is the heater system is either full on or full off depending upon whether the temperature at the probe is less than +69.8 F or greater than +71.4 F, respectively. Each heater system is independent of all other heater systems. When all systems are on simultaneously, the total heater power capability is 62 watts at +28 volts dc. The total power consumption of the heater controllers is 0.3 watts.

It should be noted that the environmental control system must be operative from launch through termination of the photographic mission. The total environmental control system energy budget must anticipate this requirement. It is anticipated that the environmental control system duty cycle will be considerably less than 100 percent.

Each individual heater system is independently overload protected. In this manner the existence of a fault in one system does not affect the remaining systems adversely. The heater systems locations have been so selected that the loss of one heater system in a general locale does not cause such severe thermal degredation as to necessitate mission termination.

4.8.6 Reliability

The basic elements of the P/L power design are dc-dc converters and transistor power switches. The design of the ±22 v dc, converter will be identical to an existing qualified design except for a slight transformer change necessitated by the low limit on interface operational power. A +3 v dc converter will probably be required to provide separate power to all logic circuitry. It is anticipated that the basic design of this converter will be identical to the qualified design discussed above. All +28 v dc switching functions will be accomplished with transistor switches in order to control the generation of EMI.

The use of latching relays at the C/P interface is recommended for the following reasons:

1. This system of receiving commands is qualified and proven.
2. Relays will present a universal interface in that all command bit requirements are identical.
3. This system is immune to noise below MIL-I-26600 limits.
4. The reliability of these relays has proven to be very high.
5. Relays provide good immunity to noise, transients and accidental over-voltage application.

It is anticipated that these relays will switch a maximum of +3.6 v dc which will be rise-time controlled to minimize EMI generation.

The instrumentation circuitry to be employed within the C/P will be identical to an existing qualified instrumentation design.

4.9 C/P ENVIRONMENTAL DESIGN

4.9.1 General

The high resolution required of the C/P lens necessitates close control of temperature and humidity from flight checkout to retrieval. The concept of thermal control for the C/P is based on establishing a thermally isolated payload to which heat is added to maintain the desired temperature level and distribution. The specific purposes of environmental control are:

a. To keep the lens in focus

b. To prevent condensation on, or contamination of, any optical surface.

c. To prevent condensation on any surface that comes in contact with the film.

d. To prevent environmentally caused deterioration of the film.

e. To provide a favorable thermal environment for the electronics package.

The optical surfaces of the plano stereo mirror and spherical primary mirror will be ground and polished within 1/10 wavelength of light (or 2.5 micro-inches). Distortion of these surfaces by more than 1/4 wavelength (6 micro-inches) as a result of mechanically or thermally induced stress will defocus the lens enough to degrade resolution to more than 3 feet on the ground. Asymmetric stresses may produce astigmatism in addition to defocussing, so that a focus adjustment may be inadequate to restore an infocus condition. Thus, the environmental control problem with respect to large optical elements is to prevent the creation of temperature differentials across or through the mirrors large enough to cause them to flex more than 1/4 wavelength. In addition, thermal expansion of the lens tube must be limited to a value such that the focal plane will not move out of the 0.001-inch depth of focus.

Whenever moisture condenses on a surface, it carries airborne solids with it. Inland, dust particles comprise the principal solids, but near the ocean, the air also contains considerable salt. When condensate re-evaporates, the dust and salt are left as a residue on the surface. As a film on an optical surface, such a residue reduces the transmittance and/or reflectance of the surfaces. A complex relationship exists between resolution and exposure from which it is known that a loss in exposure from the nominal will degrade resolution from the optimum value. In the case of salt residue, chemical attack on the optical surface may occur. For this reason, it is essential that no condensation take place on an optical surface at any time after the optical element has been fabricated. Care must also be taken that oily films are not deposited during environmental tests.

Condensate on the film-contacting surfaces may cause emulsion to be transferred from the film to such surfaces. This transferred emulsion may later mar, or be wiped off on other areas of film, thereby damaging these areas as well as the area from which it came. In addition, marring of the film-contacting surfaces may cause errors in film handling alignment, and film drive velocity. Therefore, the humidity within the film handling enclosure must be controlled so that condensation is eliminated at all times. The film itself normally effects this control, so that special conditioning other than temperature control is not required.

Resolution of an adequate thermal protection design depends upon definition of the operating environment parameters, knowledge of the inherent thermal properties of the C/P, and proper design of the heat flow paths such that operation occurs within acceptable temperature limits. In addition, the thermal interactions between the C/P, and its surrounding environment, SM Sector I, requires specific description of the thermal interfaces and a negotiated division of responsibilities between NAA and EKC.

4.9.2 Thermal Interface Agreement

As a means of developing an agreement on the details of the thermal responsibilities, a "Thermal Interface Drawing", (Dwg. 1600-103) has been created and is appended as Figure 5-11 (See Y-000047-KS). Parameters not resolved as of this writing will be added as the calculations and/or test data becomes available. This document is intended as a working tool which serves as a source of information for both the NAA and the EKC thermal design and which will grow into the final thermal agreement.

From the standpoints of optimizing both the thermal design and the mechanical design, the following initial division of responsibility at the interfaces is suggested:

4.9.2.1 EKC Thermal-Mechanical Interface Responsibilities

a. Provide a thermostatically controlled active heater system as part of the component support tube to protect the lens assembly.

b. Provide thermal insulators as mounting pads for the P/L which serve to limit conduction losses at the mounting points to acceptable levels.

c. Provide thermally insulated, view port doors in the mirror bay, which contain an active heater system which creates a controlled isothermal surface (when closed) toward which the stereo mirror tends to equilibrate.

4.9.2.2 NAA Thermal-Mechanical Interface Responsibilities

a. Provide insulation (such as multi-layer, aluminized Mylar) on all SM surfaces of Sector I, so as to dampen any rapid temperature oscillations at the surface as well as limit the heat flow between the P/L and the SM such that:

   (1) Under the hottest conditions of earth orbit, transfer orbit, and lunar orbit, temperatures throughout the P/L will not rise above the maximum nominal level.

   (2) Under the coldest conditions of earth orbit, transfer orbit, and lunar orbit, heat loss from the C/P will not cause the C/P temperature to fall from the nominal level.

b. Provide a thermostatically controlled active heater system on the C/P side of the insulation located in the stereo mirror bay (except for the view port doors) which is capable of maintaining an isothermal radiating surface which the stereo mirror tends to equilibrate when the view port doors are closed.

c. Perform calculations aimed at verifying the required thermal environment for all phases.

4.9.3 C/P Thermal Design

The C/P thermal design is functionally divided into two major subassemblies, the lens bay between station 203 and 290.75 and the mirror bay between station 290.75 and 355.

4.9.3.1 Lens Bay: Stations 203 to 290.75.

a. Temperature Limitations and Coupling Techniques

Allowable temperature levels in the lens assembly are ±5°F from the optimum focus temperature of 70°F. In order to minimize end-to-end gradients in the lens, and also provide a mounting surface for the electronic packages, an aluminum tube (component support tube) is provided around the Invar barrel of the lens; this will act as a heat shunt which limits end-to-end temperature gradients. Additionally, the spherical bearing mount supporting the aft end of the lens will be fabricated of Delrin, thus providing a high thermal resistance between the aft support and the lens.

Temperature gradients caused by radiative transfer between the component support tube and the lens barrel are minimized by highly polished reflective finishes on the Invar barrel and on the inside of the aluminum component support tube. Radiative coupling between the component support tube and the insulation on the SM sector surfaces will be minimized by buffing the outer tube surface as well as all electronic packages to a mirror-like specular finish.

Conductive losses and attendant thermal gradients in the lens are further minimized by the use of thermal insulators as mounting pads for the front of the lens assembly, Station 290.75.

b. Heater Locations

Although the SM Sector I surface temperatures will vary widely depending on both station and peripheral locations as well as positions in orbit, relatively constant temperatures will be seen by the C/P. The wide oscillations of the surface temperatures at a given point will be dampened by the radiative blanket insulation on the SM sector surfaces or by the conductive insulators used as mounting pads. Oscillations having periods less than 90 minutes will be completely dampened; longer periods will cause minor shifts of temperature levels on the P/L side of the insulation.

In order to minimize thermal gradients induced in the component support tube by radiative coupling with the SM Sector (which creates different potential peripheral temperatures on the sector insulation), six heater strips spaced 60° apart and parallel with the P/L axis are mounted on the inside of the component support tube. Each strip will be controlled independently by a thermistor-fed controller which operates as an ON-OFF device set for 70°F.

Two heater strips are located at the aft end of the component support tube to make up the heat flow through the spherical bearing mount. Additional heaters are located adjacent to each of the mounting pads to make up the conductive losses.

c. Power Estimation and Duty Cycle

The resolution of heater sizes requires a considerable analytical effort to determine such parameters as:

(1) Average potential radiant space fluxes for the SM vehicle surfaces for the hot and cold extremes.

(2) Determination of the required skin surface spectral character or α/E ratio on the Sector I outer skin which limits the surrounding temperatures (on a flux averaging basis) to a maximum level dictated by the choice of the blanket insulation and the required operating components power dissipation.

Clouding the calculations described above are uncertainties in the orbit parameters, uncertainties in potential fluxes, generated by insulation albedo and planetary emission, uncertainties in the α/E ratio of skin finishes, and uncertainties in the radiative resistance of the blanket insulation. In order to specify the proper heater power, it is thus necessary to overdesign the heaters based on an accumulation of tolerances. In the nominal case, heater duty cycles will be much less than 100% required for the extreme cold case. Power supplies for the environmental heater may be sized based upon peak demand for the worst possible case or for the most probable situation depending upon weight trade-offs.

A much more refined analysis is needed for precise consumable power estimates than for the heater sizing estimate; responsibility for the supply of this data logically belongs to NAA. The EKC gross heater size estimate has been set at a peak demand of 62 watts for the lens bay portion of the C/P (28.5 v dc basis).

4.9.3.2 Mirror Bay - Stations 287 to 355. As described in the interface agreement, thermal protection in the mirror bay is the responsibility of NAA except for the view port door area. NAA must essentially provide an isothermal surface in this bay in order to minimize thermal gradients in the stereo mirror.

Even delicate thermal gradients in the stereo mirror may cause loss of resolution. All C/P surfaces in the stereo mirror cavity are to be aluminized; NAA surfaces in this area will have I.R. emissivities in the order of 0.1. This multiple reflection system will minimize gradients induced in the stereo mirror by radient transfer from the complex, asymmetrical surrounding surfaces.

The EKC viewport door provides a thermal shield for the stereo mirror and stereo mirror bay during non-photographic phases of the mission. During periods of photography, upon command, the door will be driven open by a servo, Geneva drive, and mechanical linkage. The door will be hinged along one side and will be constructed of a"Z" panel, super-insulation sandwich. See Figure 4-36. In addition, a light and radiation shield or thermal boat made of aluminized fiberglass will be attached between the stereo mirror mask and the view port door.

It is expected that adequate thermal control will exist until the view port door is opened. The sudden thermal unbalance created by opening the door causes temperature gradients to develop in the mirror. However,

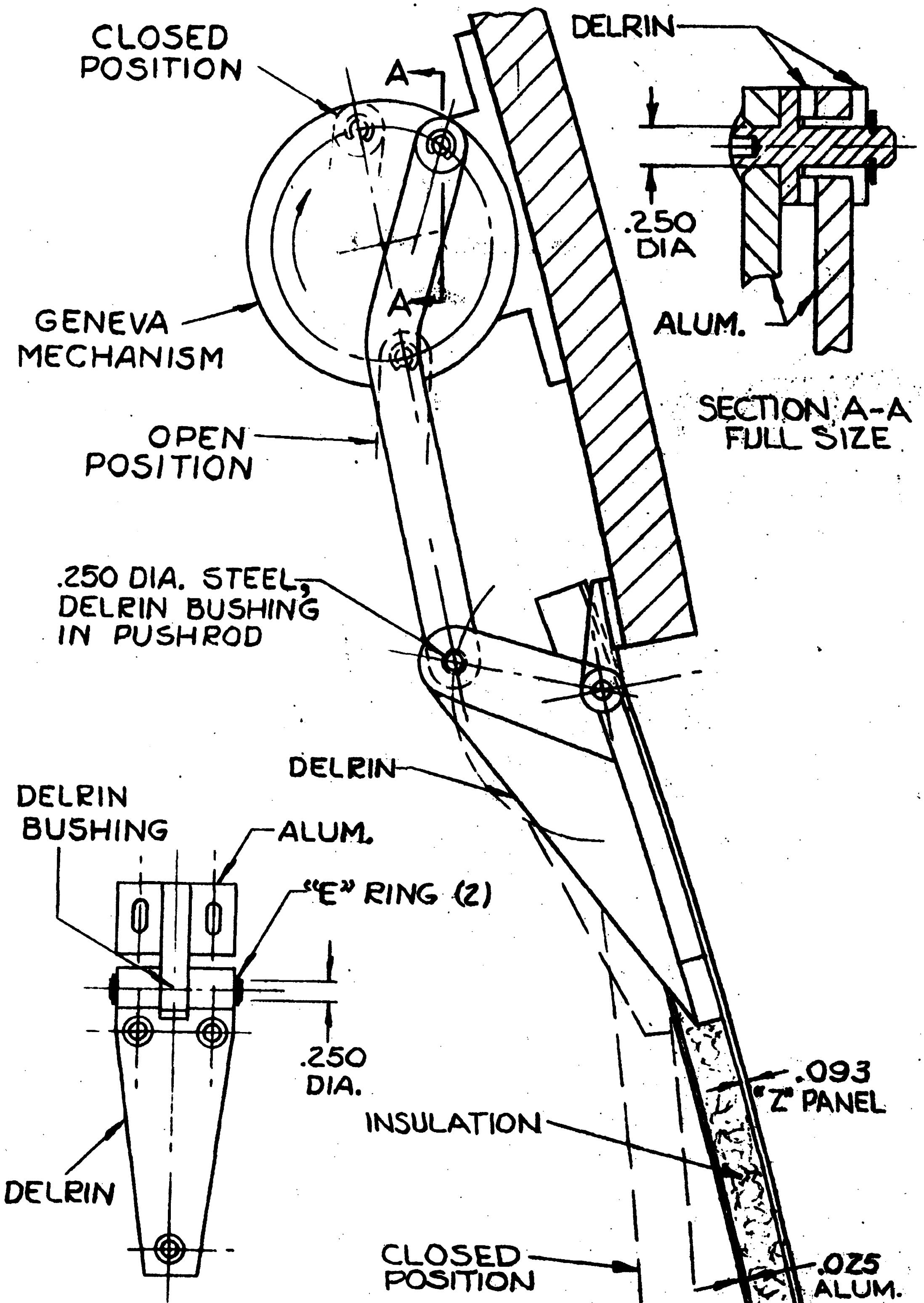


Figure 4-36. View-Port Door Drive Mechanism

calculations indicate that the non-linear gradients developed under the worst conditions of orbit will not generate overly severe optical disturbances during the short period of photography. After the door is closed, the uneven distribution of thermal energy will dissipate during the remainder of the orbit (about 80 minutes for earth orbit) so that the necessary thermal stability will exist when over target again.

As described above, EKC will provide the thermal protection for the view port door. A redundant heater system consuming a peak of 5 watts (28.5 v dc) is planned on the door.

If an optimum SM-C/P integrated thermal design indicates that heat dumping through the view port door to either space or a cold lunar surface is needed in order to meet thermal budget demands, EKC considers this to be potentially feasible providing the dumping is accomplished immediately after the photographic action, thus allowing a maximum time period for thermal stabilization of the optical system before the next photographic action.

4.9.4 Pressure and Humidity

4.9.4.1 <u>Prior to Lift-off</u>

a. Relative Humidity

Control of the ambient relative humidity will be necessary at all times from fabrication through lift-off in order to prevent moisture from condensing on any C/P optical surface. While indoors, such control will be effected by air conditioning assembly and test areas. During shipment, the payload will be contained in a pressure vessel purged with dry nitrogen to a dew point below -35°F. Under nominal controlled conditions of 70°F ± 5°F and 50 ± 5% relative humidity, the highest dew point expected is 58°F. Therefore, the minimum C/P temperature allowed will be set at 60°F. The ground handling equipment and procedures must be adequate to prevent the C/P from cooling below this temperature or from being exposed to an atmosphere having a dew point above the payload temperature.

The film handling enclosure will be closed and will not be affected by ambient humidity except when it is open during loading. The nature of the film is such that, if the film is loaded at a temperature of 70°F ± 5°F and a relative humidity of 40 ± 5%, no temperature cycle between 60°F and 90°F can produce condensation inside the enclosure.

4.9.4.2 <u>After Lift-Off</u>

a. Pressure and Humidity

There are no operating pressure requirements for the camera payload. Pressure relief valves will be incorporated to limit the pressure to a maximum of 2.5 psi above ambient during launch. On orbit, the pressure will initially be reduced to 0.1 psia by supplementary relief valves and will later be determined by system leakage.

Relative humidity control will be provided by the hygroscopic characteristic of the film emulsion since the free volume in the film enclosure is low. No active relative humidity control is required. Relative humidity is about 30% during launch. As film is unwound, the system humidity will vary depending on system leakage and velocity at which the film is unwound. Vacuum chamber tests indicate that 0.01 psia is the minimum acceptable pressure for operation of the film transport hardware. Tests at pressures down to 0.0006 psia indicate no problem with sensitometry, handling characteristics, or static charge exposures. No make-up gas will be supplied to the film handling enclosure to replenish air lost through leakage.

4.9.5 Reliability

The environmental control system, which consists of thermistor temperature probes, heater controller assemblies, tape-cable heaters, and pressure relief valves, will be employed in the same configuration as currently used on similar existing equipment. These components are completely qualified. The thermal design of the Survey C/P will minimize the use of this active heating system. A desirable feature of the proposed heating system is the fact that each heater is independent of all others. Thus, a malfunction of any particular heater will have minimum effect on the over-all thermal control.

4.10 RELIABILITY

A reliability program will support the M & S System design effort and will assure that the reliability of the existing camera systems and components will be maintained at its current high level. Reliability of the spacecraft will not be affected by the incorporation of the camera systems.

The reliability activities are intended to influence design during the design phase, prove design during the testing phase, and maintain reliability during the production phase. For a detailed discussion of the reliability program, see Appendix O.

4.10.1 Influence Design

The reliability program will influence design through all design stages by effort expended in three areas:

1. Design Review and Analysis
2. Requirements and Predictions
3. Parts Selection and Qualification

The Design Review and Analysis effort will consist of detailed review and analysis of all payload components from this inception to final design release. The Requirements and Predictions effort establishes reliability goal apportionment and a subsystem model so that all components can be designed commensurately. The Parts Selection and Qualification effort maintains a reliability approved parts list and reviews all designs from a parts standpoint.

4.10.2 Prove Design

The Reliability Testing group is responsible for proving a design through extensive component and system testing. Component reliability demonstration testing is performed early in the design stage. Component and P/L Qualification tests are performed to demonstrate the ability of the components and P/L to survive environmental and operational stress levels in excess of those expected during a normal mission. Component and P/L life (reliability) tests are performed under simulated mission conditions to demonstrate that the system will continue to function beyond normal mission life with an adequate safety factor. All design changes which result from reliability review, design analyses or changing requirements are reviewed by the Design Review and Analysis and the Testing groups to appraise the retesting effort required. Appropriate requalification tests are performed by the Testing group.

4.10.3 Maintain Reliability

The reliability program during the production phase is intended to provide continued surveillance of hardware to assure the maintenance of the inherently reliable design achieved through the effort described in Sections 4.10.1 and 4.10.2.

SECTION 5
INTERFACES

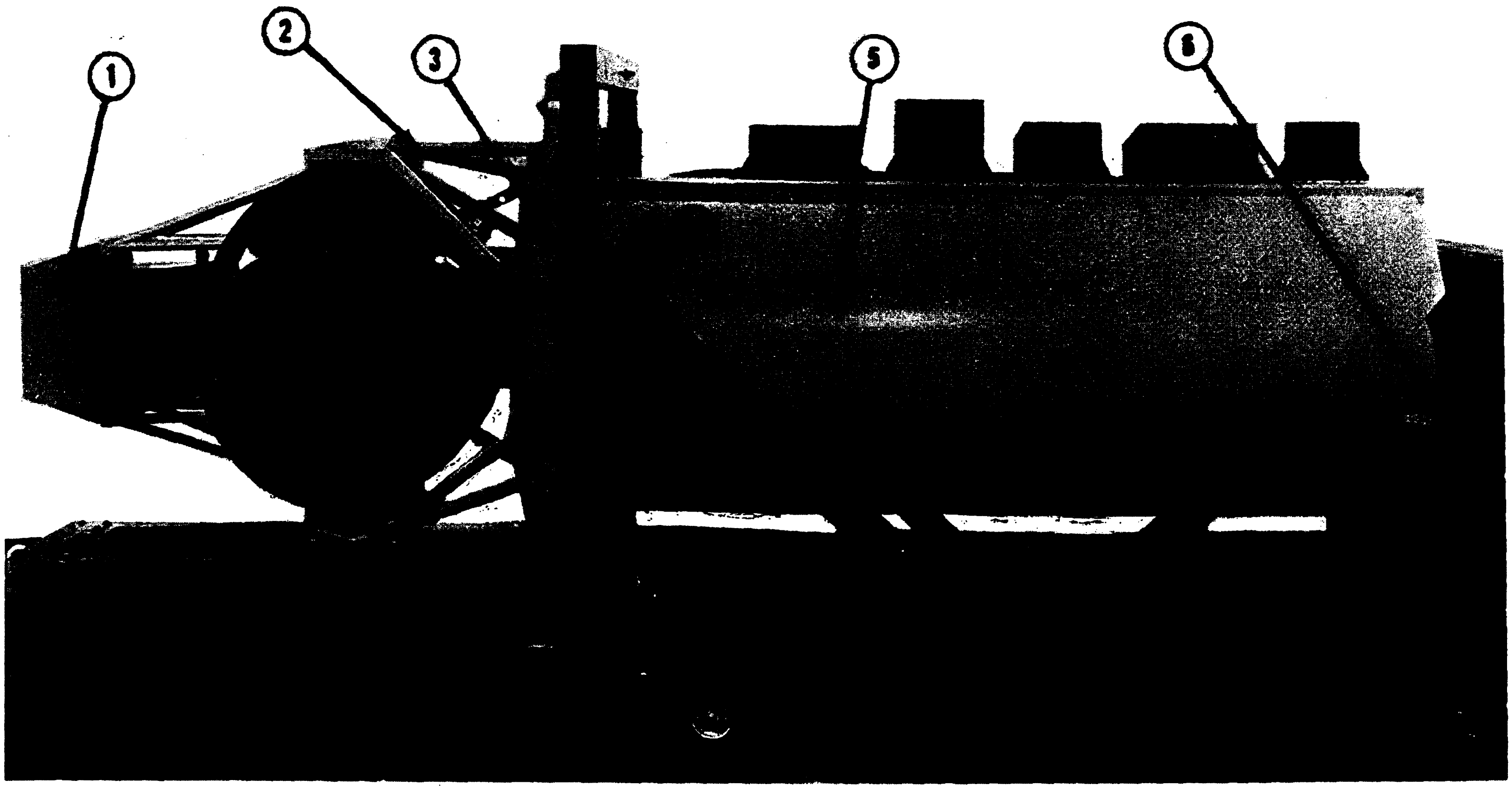
In cooperation with North American Aviation (NAA) and Fairchild Camera and Instrument Corporation (FIC) EKC has given careful consideration to the major interface areas existing between the Camera Payload (C/P) and the Spacecraft (S/C) and between the C/P and Stellar Indexing Camera (SIC). As a part of this effort, a non-functional full-scale mock-up was built and delivered to NAA on 20 September 1964. The mock-up represents the anticipated payload outline within 1/8 inch and simulates the major mechanical interfaces within tolerances consistent with standard engineering practices (see Figures 5-1, 5-2, and 5-3). All interface problem areas between the survey camera and the Apollo vehicle (and SIC) have been satisfactorily resolved.

The following paragraphs and accompanying drawing identify interface areas and define the major interfaces.

5.1 MECHANICAL

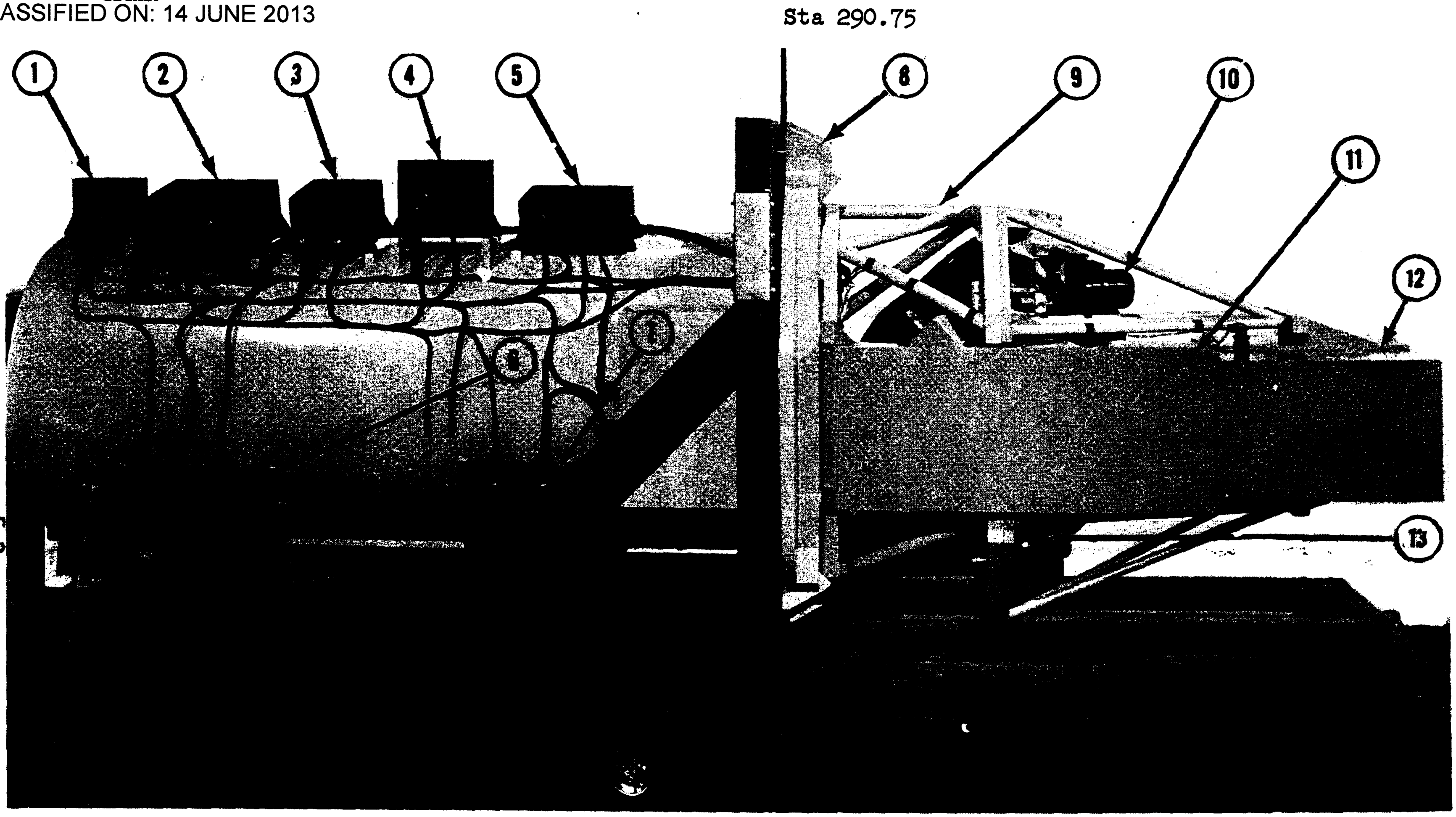
The C/P - S/C mechanical interface and space allocation is detailed in Figure 5-4, Sheets 1 through 7.

In the proposed system, the payload is installed in Bay I of the Apollo service module between stations 203 and 355. This bay is 55 degrees wide and extends radially from the inner skin (22-inch outer radius) to the outer skin (76-inch inner radius). The payload is positioned in the bay so that the payload optical line of sight for nadir photography is at a 37°45' angle to the radial line bisecting Bay I. Because of this angular offset the view-port door will appear off center in the bay.



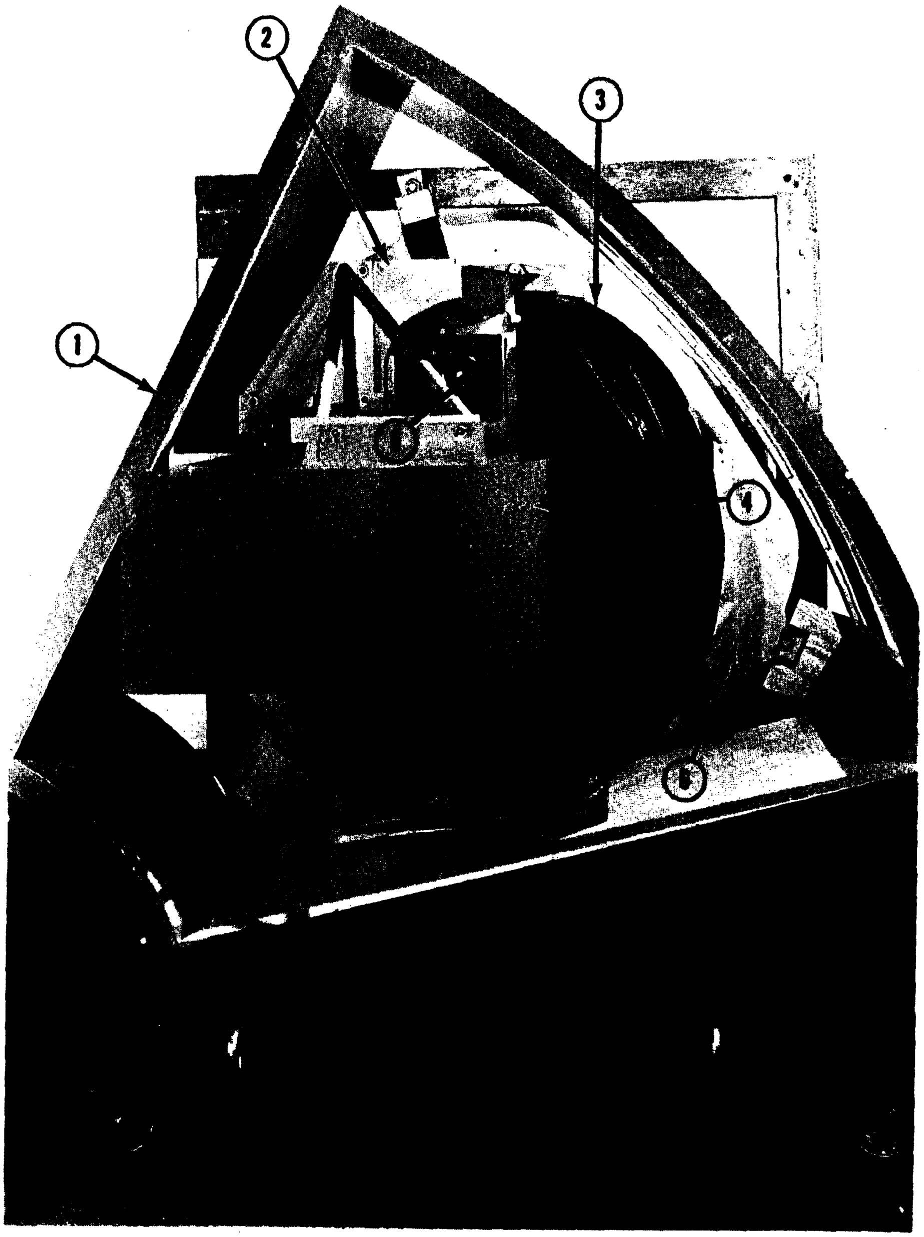
1. Take-up Cassette
2. Support Truss
3. Structural Rings
4. Stereo Mirror and Mask Assembly
5. Component Support Tube
6. Torsional Support Tube
7. Cradle

Figure 5-1. Wood Mockup, Front View



1. Command Processing Unit
2. Power Conversion and Control
3. Instrumentation Processing Unit
4. V/h Sensor
5. Focus Control
6. Programmer
7. Motor Speed Drive
8. Structural Rings
9. Support Truss
10. Elevation Servo
11. Supply Cassette
12. Take-up Cassette
13. Crab Servo
14. Component Support Tube

Figure 5-2. Wood Mockup, Back View



1. Bay Sector Mockup
2. Support Truss
3. Stereo Mirror
4. Take-up Cassette
5. Stereo Servo
6. Structural Rings

Figure 5-3. Wood Mockup, End View

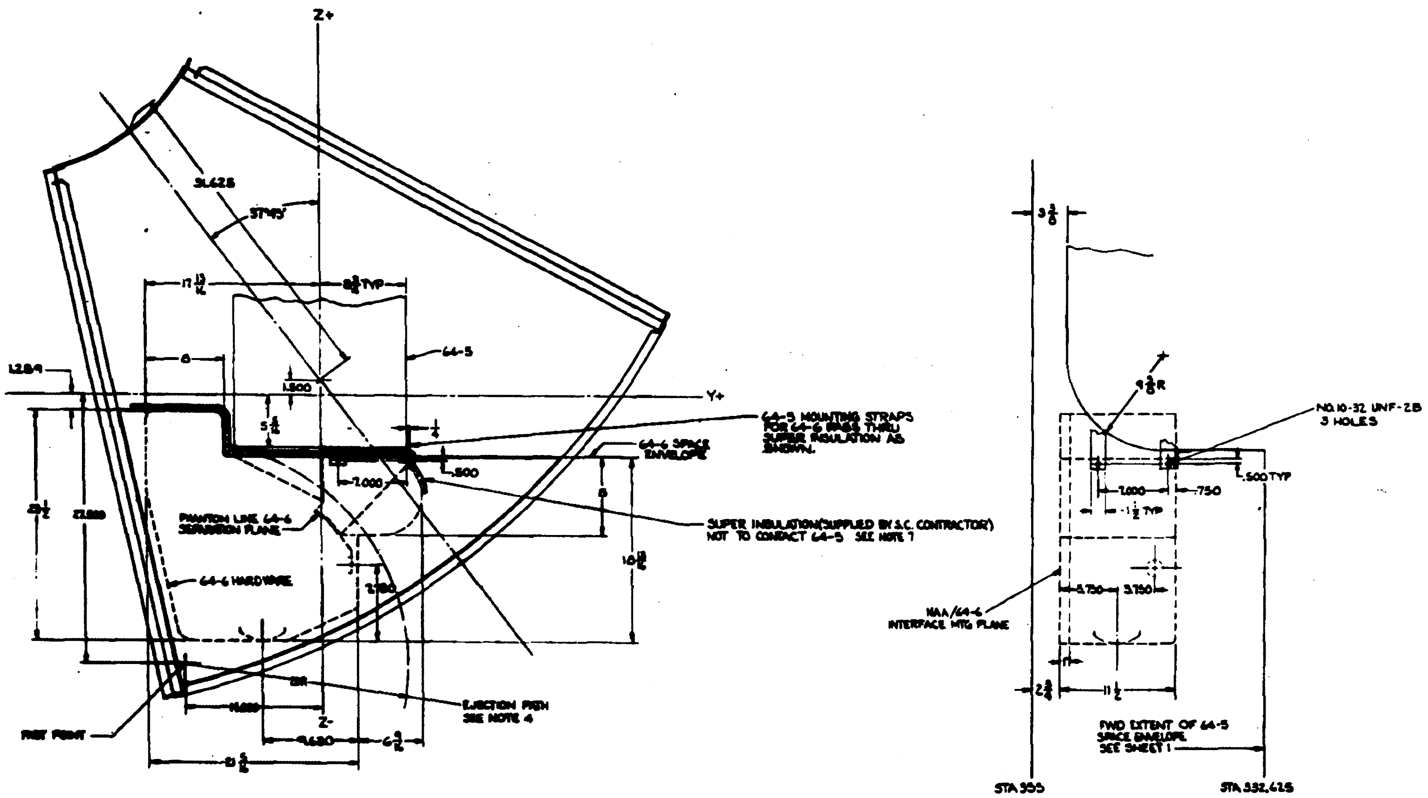


Figure 5-4, sheet 1, C/P-S/C Mechanical Interface and Space Allocation

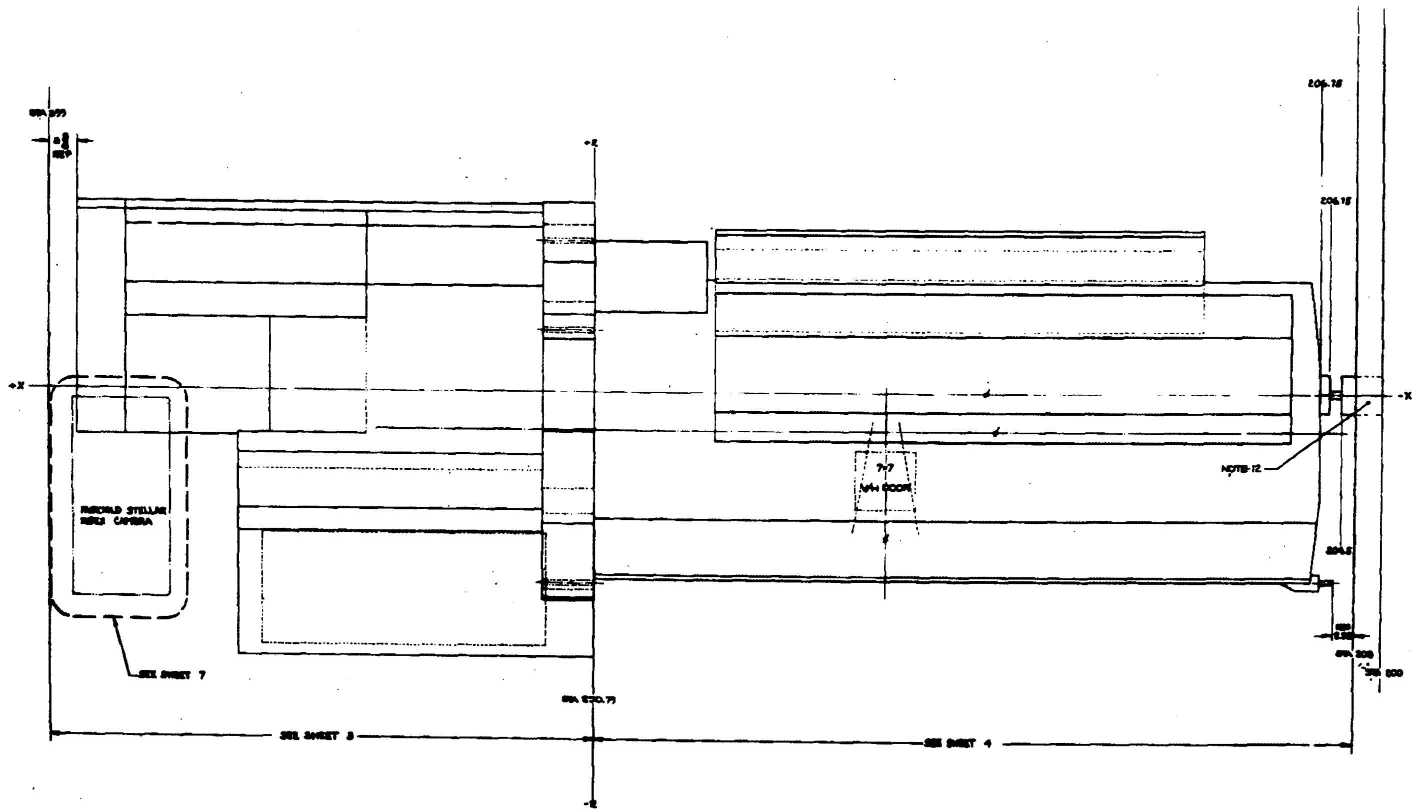


Figure 5-4, sheet 2, C/P-S/C Mechanical Interface and Space Allocation

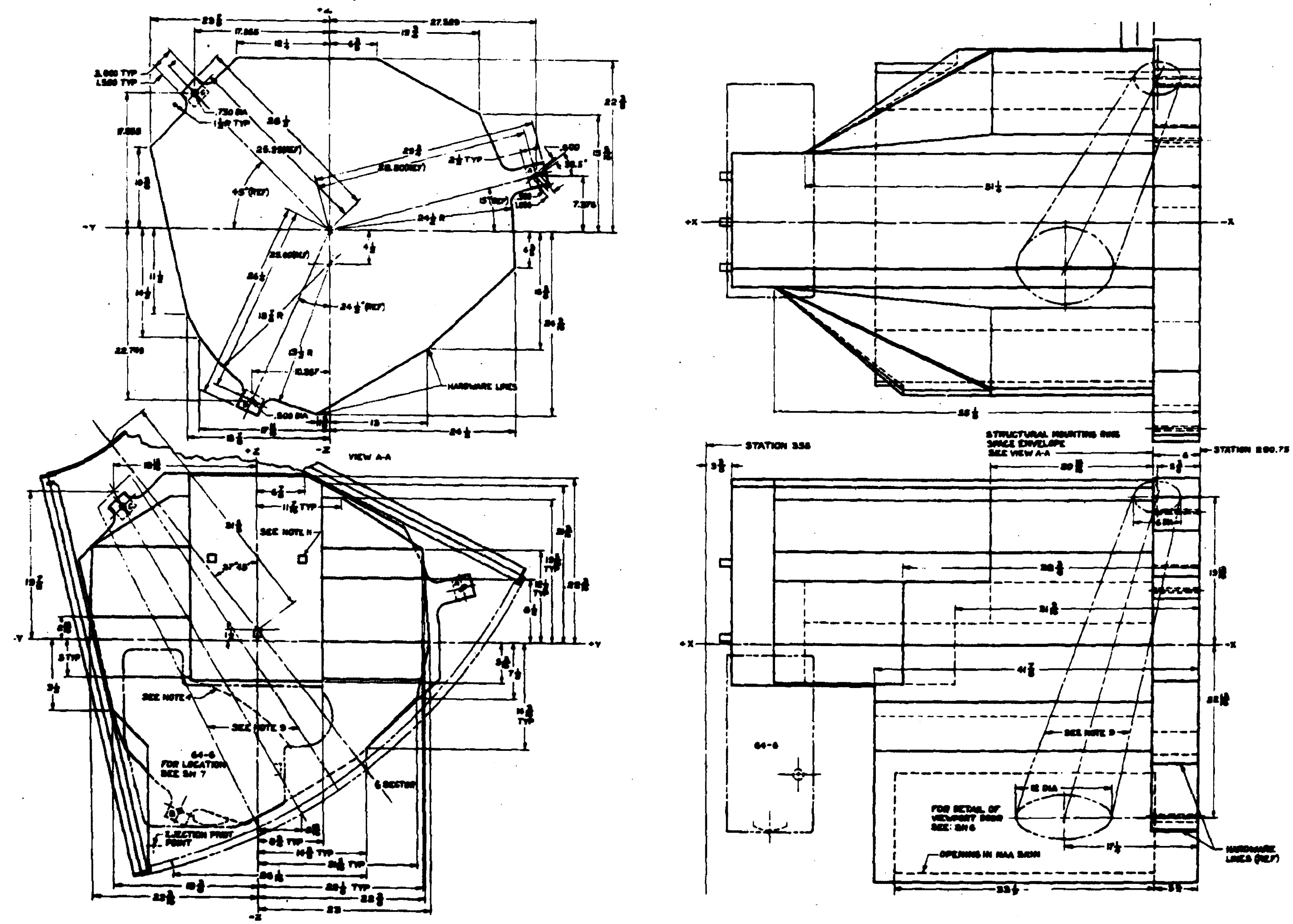


Figure 5-4, sheet 3, C/P-S/C Mechanical Interface and Space Allocation

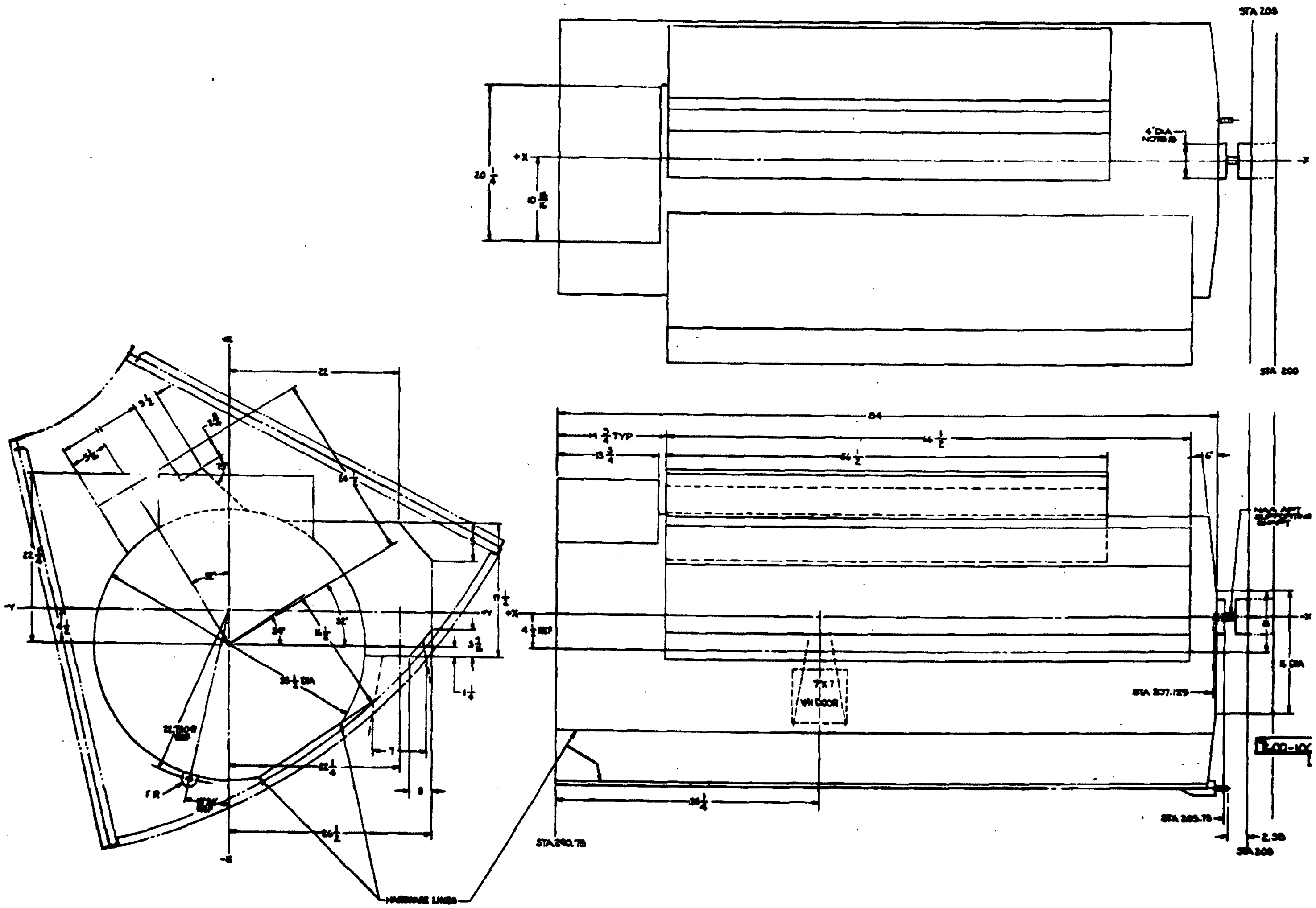


Figure 5-4, sheet 4, C/P-S/C Mechanical Interface and Space Allocation

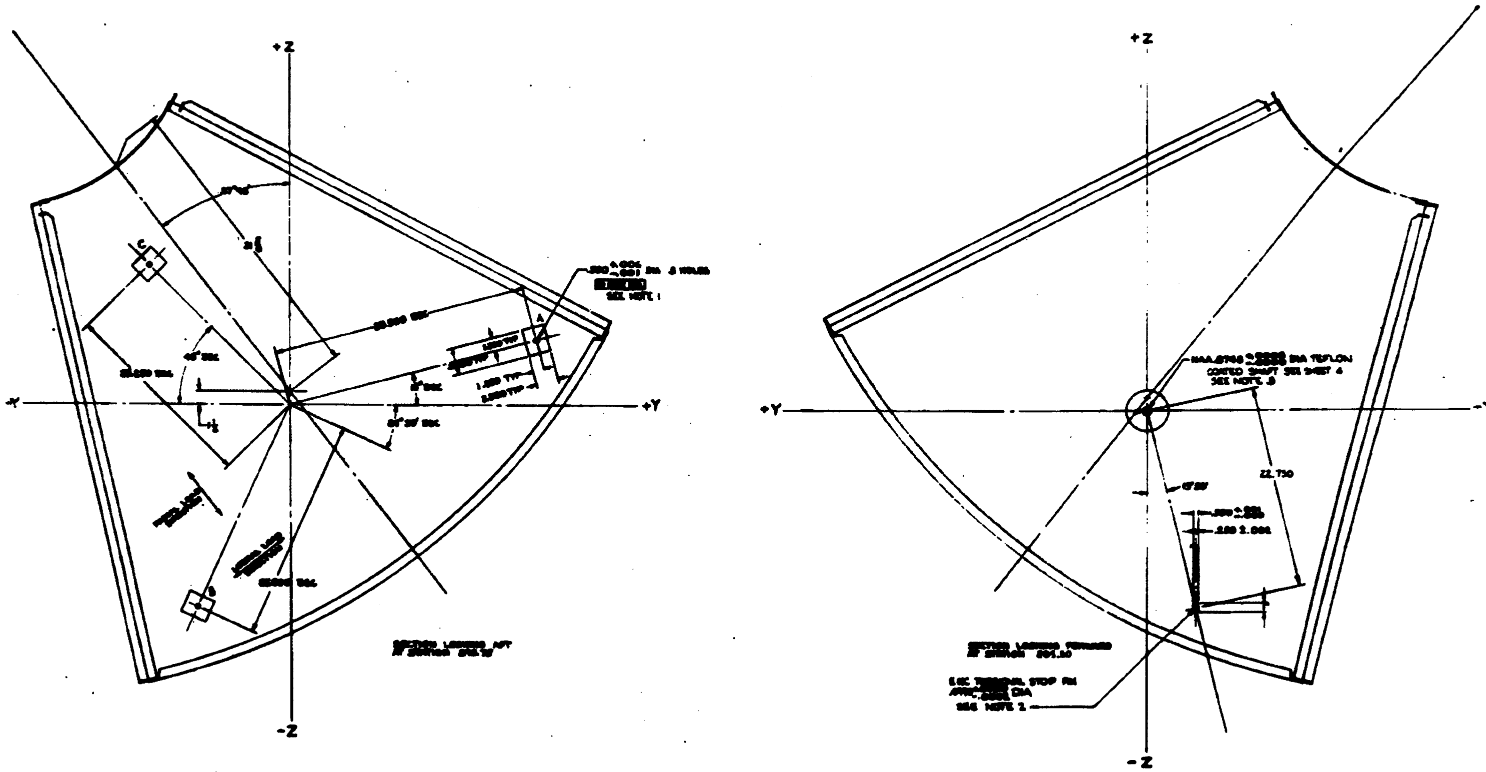


Figure 5-4, sheet 5, C/P-S/C Mechanical Interface and Space Allocation

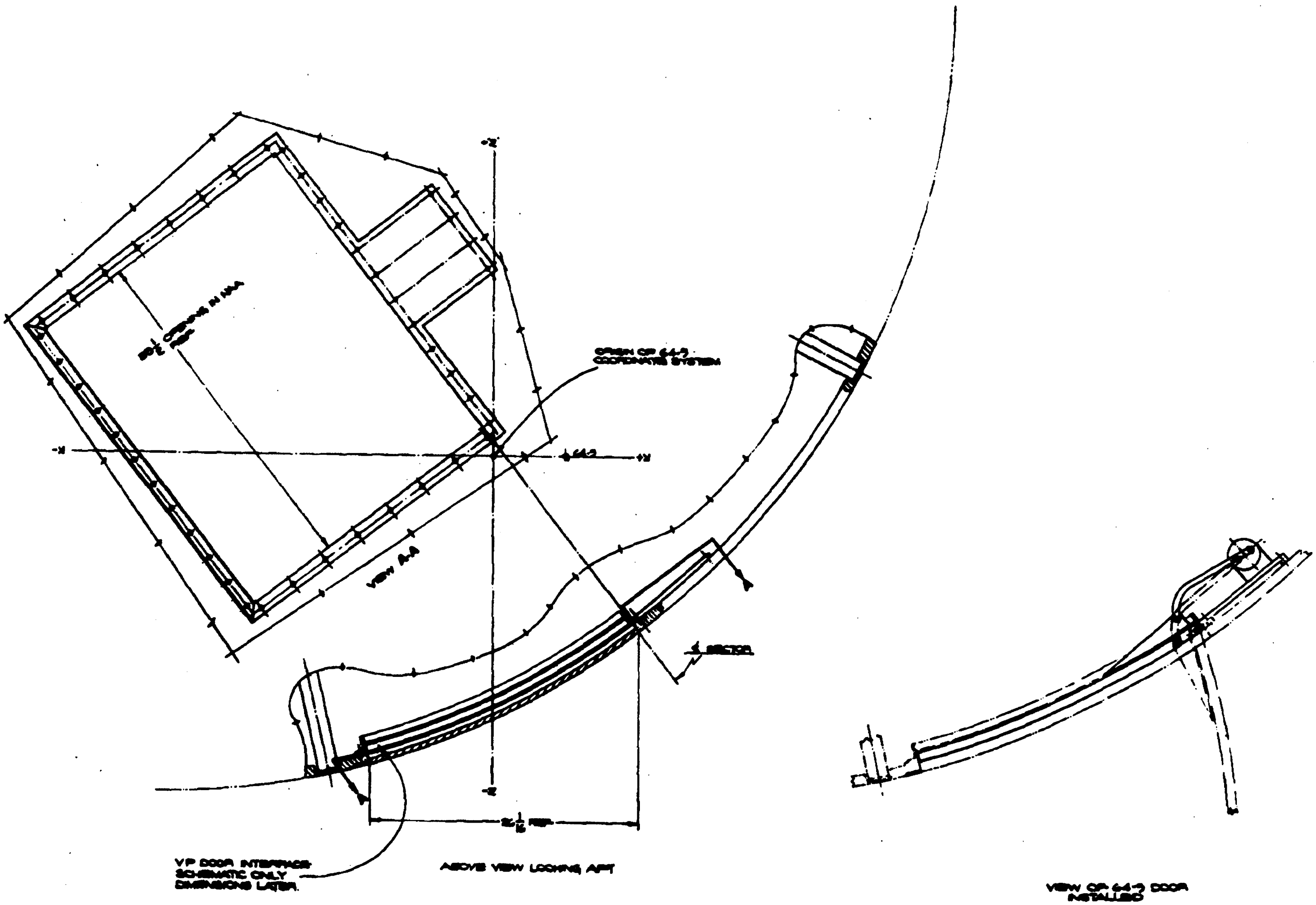


Figure 5-4, sheet 6, C/P-S/C Mechanical Interface and Space Allocation

NOTES:

1. THREE PADS DEFINE LOCATION AND SIZE OF PAYLOAD PRIMARY MOUNTING FEET AND SPACECRAFT STRUCTURE SUPPORT REQUIRED. STRUCTURAL INTERFACE BETWEEN PAYLOAD AND SPACECRAFT TO BE AS FOLLOWS:

   POINT A - BOLTED CONNECTION WITH SLOTTED HOLE IN PAYLOAD FOOT, CONNECTION TO BE TIGHT IN RADIAL DIRECTION TO TRANSMIT ALL RADIAL LOADS AND FREE TO MOVE IN SLOTTED DIRECTION WHEN PRELOAD OF 500 LBS. IS EXCEEDED.

   POINT B - BOLTED CONNECTION TO TRANSMIT LOADS IN ALL DIRECTIONS FROM PAYLOAD TO SPACECRAFT.

   POINT C - BOLTED CONNECTION WITH OVERSIZE HOLE IN PAYLOAD FOOT; BOLT TO BE TORQUED SO AS TO PRELOAD SURFACE UP TO A MAXIMUM RADIAL/LATERAL RESISTANCE OF 500 LBS. BEFORE SLIP.

2. SLOT FOR TORSIONAL STOP PIN TO BE LOCATED IN S.C. STRUCTURE. AFTER ASSEMBLY NO TORSIONAL LOAD SHALL BE IMPARTED TO PAYLOAD BECAUSE OF MISALIGNMENT. S.C. STRUCTURE TO MEET THERMAL REQUIREMENT OF DRAWING 1600-103.

3. SHAFT TO BE PART OF S.C. SUPPORT STRUCTURE.

4. ALL 64-6 HARDWARE AND S.C. INSULATION MUST BE CLEAR OF THIS PATH FOR EJECTION AND RETRIEVAL.

5. FOR THERMAL INTERFACE, SEE DRAWING 1600-103.

6. FOR ELECTRICAL INTERFACE, SEE DRAWING 1600-102.

7. ALL SUPER-INSULATION SUPPLIED BY S.C. CONTRACTOR TO CLEAR E.K. SPACE ENVELOPE BY 1/4" MINIMUM, EXCEPT IN SPECIFICALLY DEFINED AREAS.

8. THIS DRAWING IS PART OF E.K. CO. INTERFACE SPECIFICATION 1600-104.

9. NAA ACCESS THRU E.K. SPACE ENVELOPE TO MOUNTING POINT "C".

10. SPACE ALLOCATION PREDICATED ON CASSETTE RETRIEVAL AFTER 64-5 AND 64-6 CASSETTES HAVE CLEARED THE SM SKIN DURING EJECTION OPERATION.

11. NAA/64-5 CASSETTE RETRIEVAL INTERFACE TO BE DETERMINED AT A LATER DATE.

12. SPACE RESERVED THROUGH AFT BULKHEAD FOR NAA SHAFT EJECTION MECHANISM.

13. NAA EJECTION MECHANISM NOT TO CONTACT E.K. UNI-BAL MOUNT PRIOR TO EJECTION.

Figure 5-4, sheet 7. C/P-S/C Mechanical Interface and Space Allocation

A primary payload mounting plane has been established at spacecraft station 290.75; this mounting plane will provide a three point primary mounting interface for the payload. NAA will provide three tight toleranced holes at points A, B, and C as shown on the mechanical interface and space allocation drawing. EKC will provide a tight hole at point B, an oversize hole at point C, and a slotted hole at point A. The mounting tie between the C/P and S/M at these points will be by means of explosive bolts and belleville washers to provide the necessary preload as shown in Figure 5-5. Each of these mounting points will be designed to transmit full vertical load from the payload to the spacecraft during launch environments. Point B will transmit lateral and radial loading. Point A will transmit radial forces up to 500 pounds. Point C will transmit lateral and radial forces up to 500 pounds.

The aft mounting point near station 203 will take lateral loading in all directions but will not transmit any longitudinal forces to the spacecraft. Here, NAA will provide a Teflon coated pin which will engage the EKC aft uni-bal mount. A torsional stop pin, located in the aft plane near station 203 is used to provent torsional rotation of the C/P during launch.

Incorporated in the C/P are ball and socket joints at both ends. This allows the S/C to distort, within limits, without exerting any significant forces on the C/P. Such distortion of the S/C may occur because of residual stresses caused by assembly in a gravitational environment, loads imposed during launch, and orbital thermal distortions. In addition, although the ball and socket joint at the forward end supports the C/P both laterally and longitudinally, the aft uni-bal mount and longitudinal slip joint allows the C/P and SM to expand and contract in length independently. The total mounting arrangement

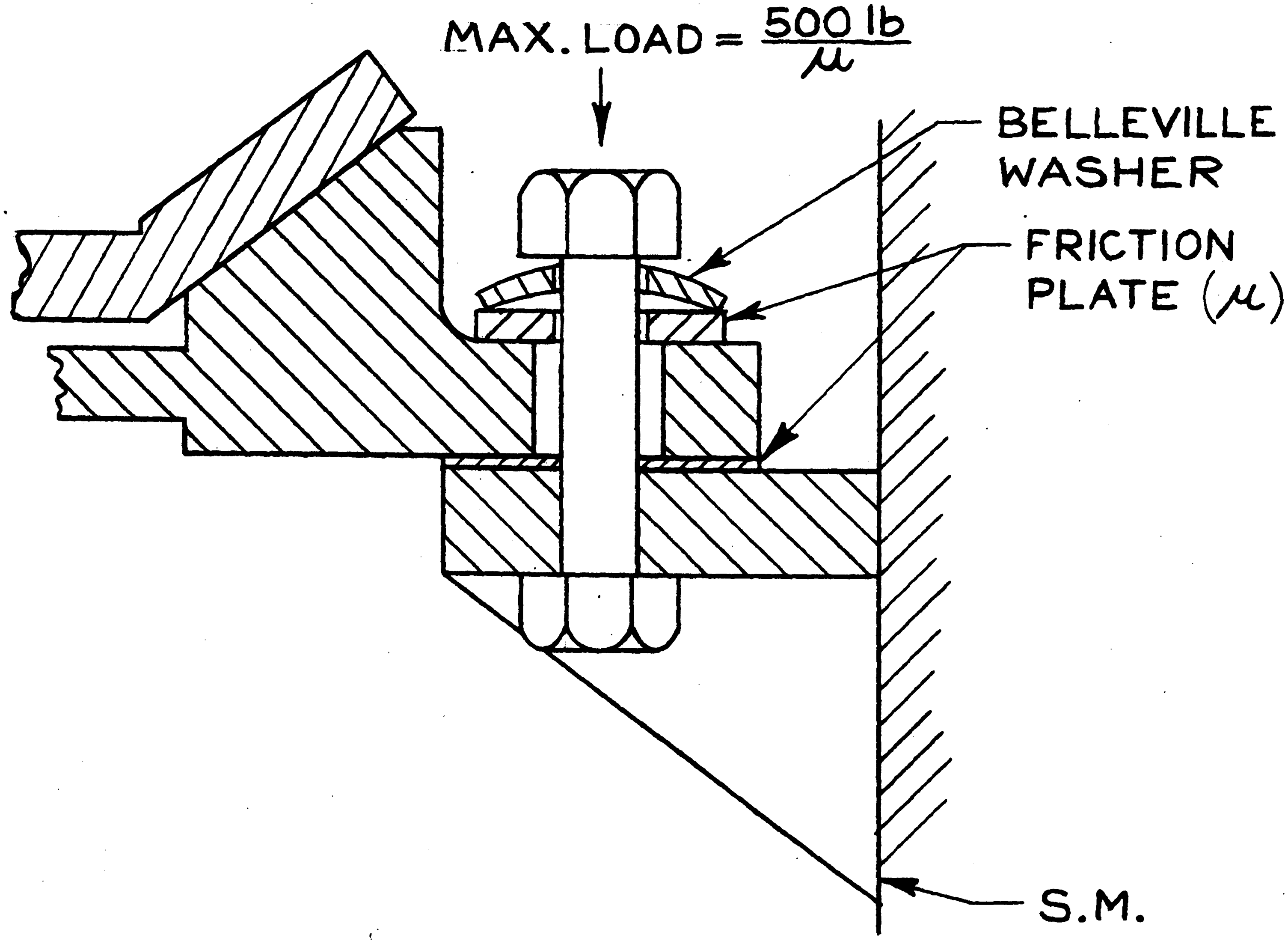


Figure 5-5. Explosive Bolt and Bellville Washer

of the 77-inch lens can be thought of as a suspension between two universal (ball and socket) joints with lateral support at each end and longitudinal restriction at only one end (See Figure 5-6). The forward universal joint is formed by the payload socket mounting ring assembly and the primary structural support ring assembly and it has a rotational capability of 0.2 degree. The aft joint contained in the uni-bal mount assembly can accommodate rotation greater than 5 degrees and a 0.5-inch longitudinal expansion or a 0.19-inch longitudinal contraction of the SM.

At the take-up cassette, two separate attachments are necessary, one with the spacecraft proper in order to attach a retrieval mechanism and the second with the Stellar Indexing Camera (SIC) take-up cassette in order to create a single package for retrieval. The C/P interface with the SIC consists of three simple separate straps, shown in Figure 5-7. The interface permits a hard mounting of each take-up cassette to its respective camera package and a soft mounting between the take-up cassettes. During ejection and recovery, each take-up will be separated from its respective payload and, being tied together, brought forward into the command module as a unit.

The view-port door to be provided by EKC and previously described in Section 4.9 of this report, will be attached to the inner surface of the Bay I sector cover. It functions as a "lens cap" and is not a structural unit. NAA will provide a structural door which will be jettisoned, the view-port door will then provide the thermal cover for the lens. This installation is detailed on Figure 5-4, Sheet 6.

The C/P will be assembled into the SM from the side with both units in a vertical position, i.e., with the "X" axis vertical. AGE will be required to support the C/P during integration.

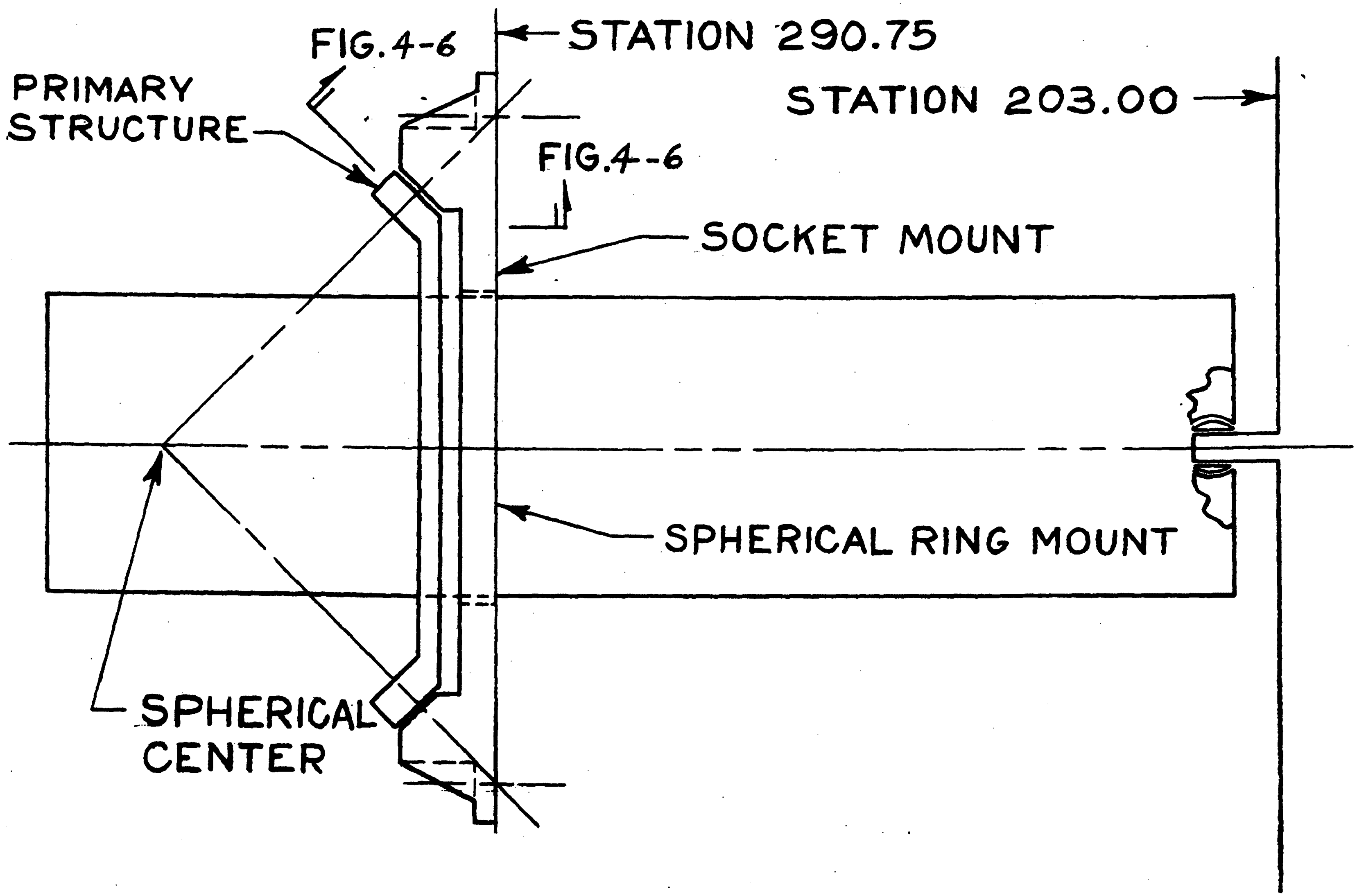


Figure 5-6. Spherical Ring and Uni-Bal Mount

NOTES
1. FOR THERMAL INTERFACE, SEE DWG NO. 1600-103
2. ALL 64-6 HARDWARE AND SC INSULATION MUST BE CLEAR OF THIS PATH FOR EJECTION AND RETRIEVAL
3. THERE IS NO 64-5/64-6 ELECTRICAL INTERFACE
4. 64-6 MOUNTING TO S.C. IS S.C. CONTRACTOR RESPONSIBILITY
5. FOR NAA/BK MECHANICAL INTERFACE AND SPACE ALLOCATION SEE DWG 1600-100

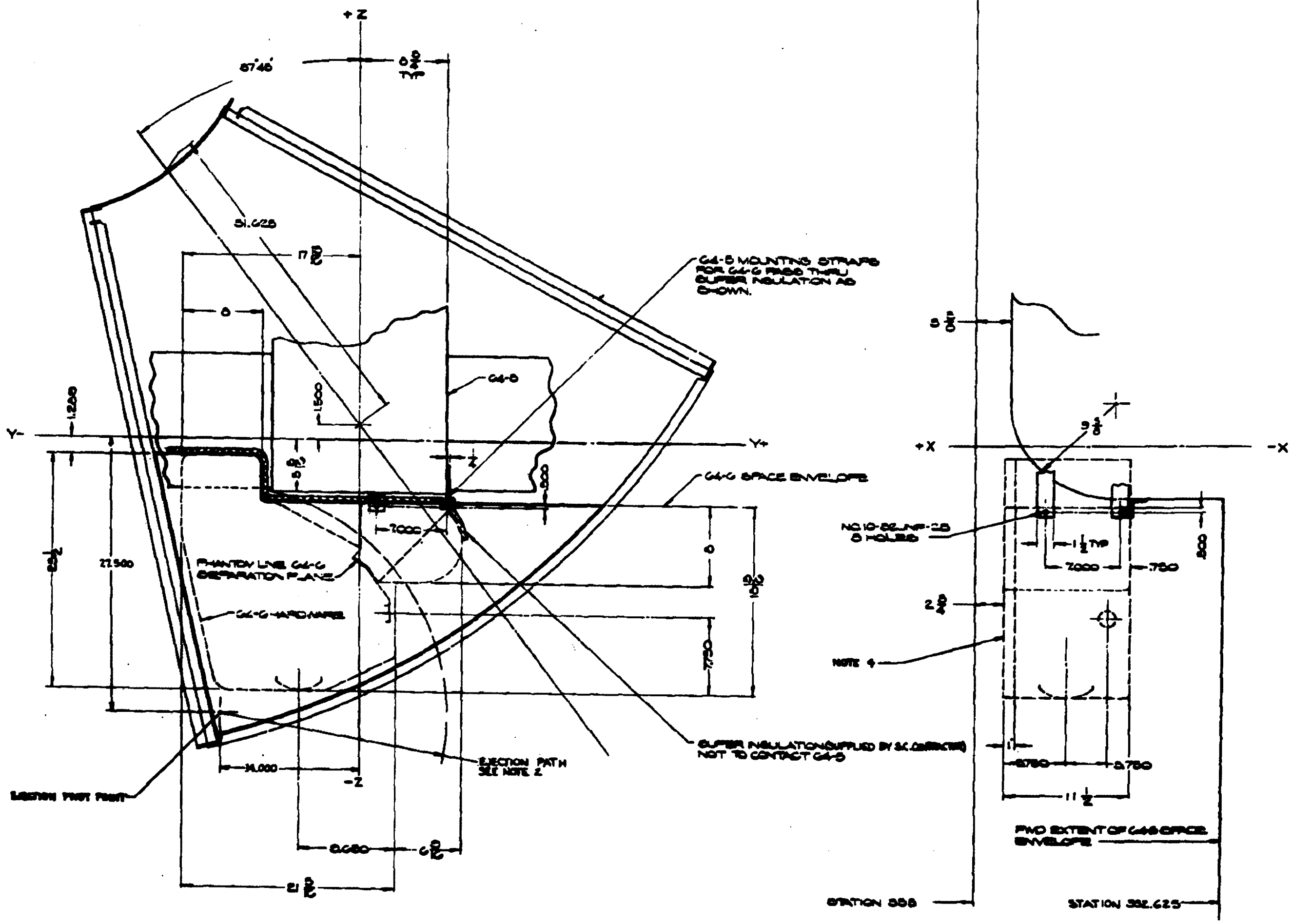


Figure 5-7. C/P - S/C Mechanical Interface

Ejection of the C/P and retrieval of the take-up cassette will be accomplished by NAA. In brief, the sector skin blows off, the camera payload rotates out of the bay, the take-up cassette separates from the C/P and transfers to the command module and the C/P ejects from the SM. In order to accomplish each of these, EKC and NAA, working in close cooperation with the SIC contractor, have arrived at a mutually agreeable mechanical interface and space allocation which has enabled the conceptual designs to be worked out and feasibility established. Although major consideration was given to concepts and spatial requirements, hardware was detailed where necessary to provide proof of this feasibility.

During the study it was demonstrated that it is possible to package the C/P in a shortened SM (143 inches long). This integration, although not shown in detail in this report, would require a smaller take-up cassette, limiting maximum film load to 3,000 feet, and more extensive modification to the payload making the approach much less desirable.

5.2 ENVIRONMENTAL DESIGN CRITERIA

The static forces which are expected at the payload interface for two cases, launch and midcourse correction are:

Case I Launch	Limit Loads (g)	Ultimate Loads (g)
Vertical Load Factor	4.7	7.0
Lateral/Radial Load Factor	0.3	0.45
Case II Midcourse		
Vertical Load Factor	2.2	3.3
Lateral/Radial Load Factor	0.8	1.2

These values were obtained from the spacecraft contractor and have been used as a basis for evaluation of the structural design concept.

A complete environmental design criteria, establishing all of the levels of environment to which the payload will be subjected, will be established at a later date. A copy of a Preliminary Environmental Design Criteria is appended in Appendix L.

5.3 C/P WEIGHT AND CENTER OF GRAVITY ESTIMATE

Table 5-1 itemizes the weight, location of the center of gravity (C.G.) and the mass moment of inertia about each of the three mutually perpendicular axes, of various C/P components, singularly and collectively.

The data is based on the proposed C/P preliminary design. The values of weight and C.G. are estimated to be within ± 5 percent of the nominal final design values. Many of these weights are actual values based on measurements taken on existing hardware.

The datum plane is assumed to be station 290.75. The X axis passes through the C/P center as defined on the mechanical interface drawing and is parallel to the SM vehicle longitudinal axis. The negative direction is from station 290.75 towards station 203.00. The Z axis is rotated clockwise 37°45' from the centerline of the SM sector I and passes through the C/P X axis. The negative direction is from the C/P centerline towards the moon (flight configuration). The Y axis is perpendicular to the X and Z axes and the negative direction is established by the right hand rule.

WEIGHT, MOMENT OF INERTIA AND CENTER OF GRAVITY OF VARIOUS C/P COMPONENTS

Component	Weight (Pounds)	Mass (Slugs)	X (Inches)	Y (Inches)	Z (Inches)	Ixx (Slug ft^2)	Iyy (Slug ft^2)	Izz (Slug ft^2)
Lens	455.0	14.1	-42.13	+ 0.03	- 4.07	17.85	357.43	355.49
Stereo Mirror	241.0	7.48	+24.33	+ 0.0	- 1.40	3.81	37.87	34.79
Structure	204.0	6.34	-15.64	0.0	- 1.78	12.36	66.20	65.33
Exposure Unit	36.2	1.09	- 5.82	0.49	+12.09	1.34	1.54	0.55
Supply Cassette	69.8	2.16	+22.76	0.18	+13.90	3.58	12.77	10.18
Take-Up Cassette	30.0	0.932	+57.00	0.0	+ 2.50	0.03	20.82	20.82
Programmer	15.0	0.465	-61.5	-10.66	+12.57	0.949	12.79	12.65
Command Processing Unit	4.0	0.124	-76.25	+20.12	- 0.0625	0.353	5.01	5.36
Power Conversion and Control	15.0	0.465	-63.25	+20.12	+ 1.9375	1.34	12.99	14.27
Instrumentation Processing Unit	6.0	0.186	-49.25	+20.12	+ 0.9375	0.537	3.14	3.66
Motor Speed Control	16.0	0.496	-22.5	+19.75	+ 0.6875	1.40	1.80	3.13
Focus Control	11.0	0.342	-26.5	-10.52	+12.354	0.667	2.07	1.96
V/L Sensor	12.0	0.372	-36.75	+21.12	+ 2.625	1.19	3.53	4.67
Cabling	30.0	0.932	-20.00	+ 7.0	0.0	0.32	2.56	2.87
View-Port Door	13.0	0.404	+22.375	+ 1.606	-24.716	1.92	3.38	1.87
Total	1158.0	35.89	-14.92	+ 0.925	- 0.867	47.65	543.9	537.56
Film (3000 Ft)	55.0	1.705	+29.25	0	+ 9.81	1.35	11.57	10.38
Total (3000 Ft)	1213.0	37.60	-12.91	+ 0.88	- 0.38	49.00	555.47	547.94
Film (6000 Ft)	110.0	3.41	+31.50	0	+11.06	3.53	27.24	24.12
Total (6000 Ft)	1268.0	39.30	-10.89	+ 0.84	+ 0.17	51.18	571.14	561.68

5.4 CAMERA PAYLOAD STATIC AND DYNAMIC INTEGRITY

Proof of the structural integrity of the camera payload mounting concept was accomplished through a series of static and dynamic tests. This testing was conducted during October, 1961, and was subsequently followed with both qualification and acceptance vibration testing of C/P's at vibration levels of the same magnitude expected from this vehicle.

The following paragraphs describe the static dynamic structural tests and results obtained.

5.4.1 Static Tests

Two static tests were performed on a structural mockup of two spherically mated rings and a support truss (similar to those proposed for this payload) using a one "g" load established as 1,000 pounds. These tests were:

(a) Longitudinal loading in 10 percent increments up to 11.25g.

(b) Longitudinal loading of 9g combined with lateral and radial loading of 3g applied in 10 percent increments.

Loads were applied to the support truss and primary structural ring in proportion to a static load analysis by means of hydraulic jacks, calibrated load cells and wiffle trees (See Figures 5-8 and 5-9). The assembly was instrumented with strain gages and dial indicators.

The maximum stress recorded on the primary structural ring was 9,450 feet psi, while the maximum deflection was recorded to be 3/16-inch. All recorded data was plotted and there was no indication of yield.

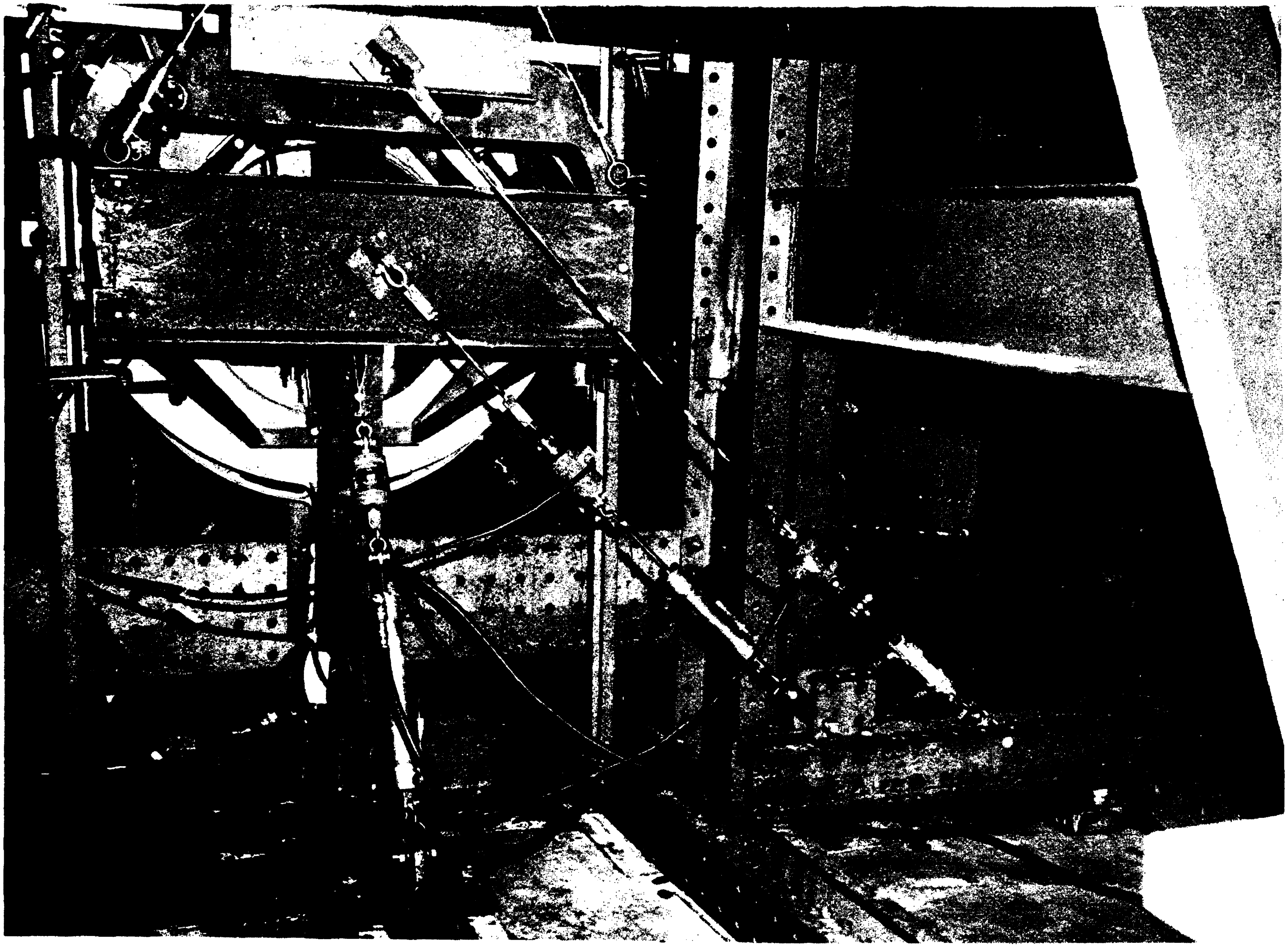


Figure 5-8. Truss assembly support loading fixtures and loading arrangement

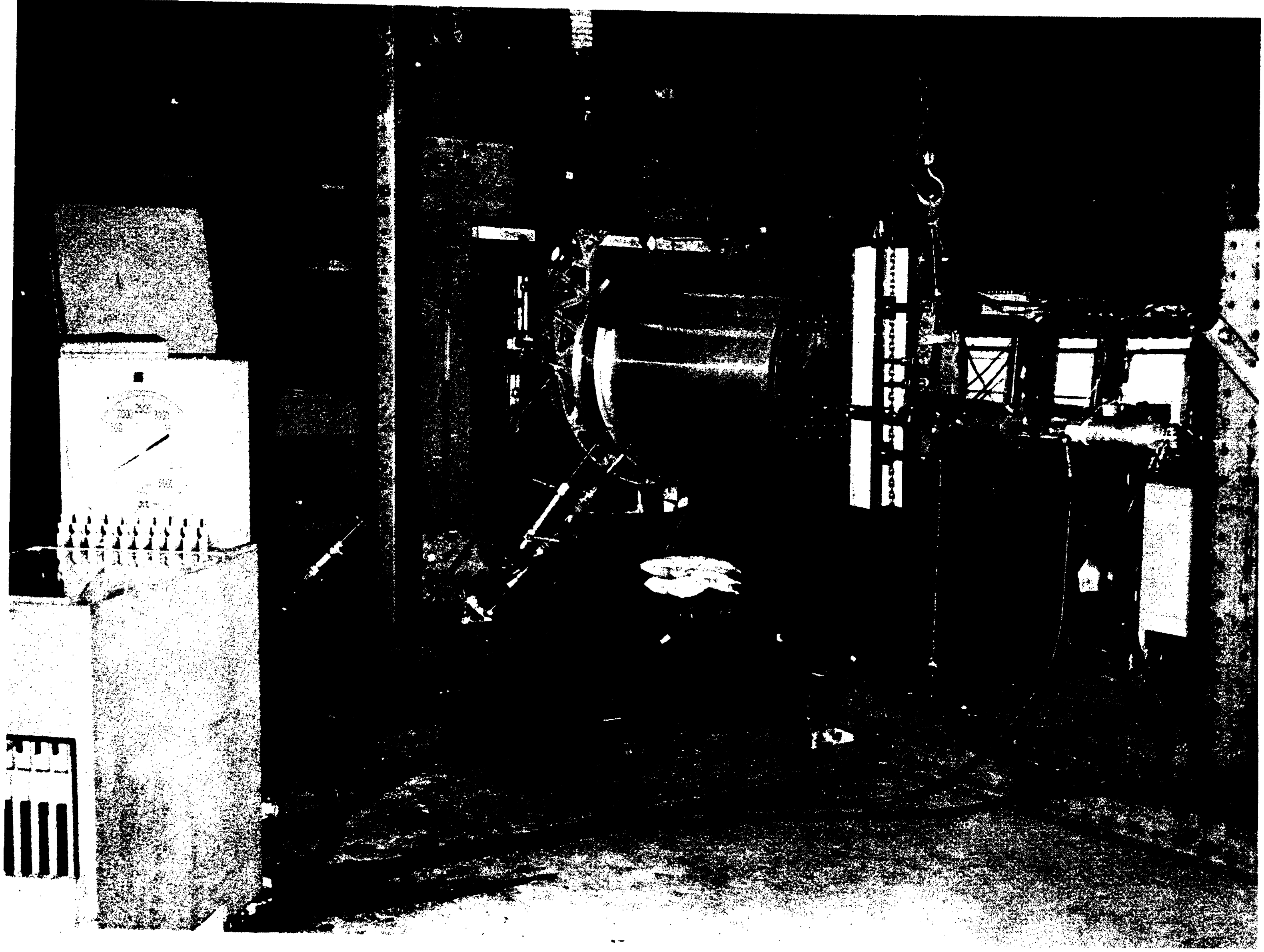


Figure 5-9. General test set-up, outer loading cylinder and loading arrangement

After completion of the static tests, the test specimen was disassembled and the parts sent to quality control inspection. No dimensional yield was found.

5.4.2 Dynamic Test

In order to verify the ability of a spherical mounting concept to withstand launch environment, a dynamic simulator mock-up was made. The dynamic simulator was full scale and simulated center of gravity location, stiffness of structural components similar to those of Section 4.2, stiffness of a 77-inch f/4 lens assembly, electronic component mounting, and the spherical mounting concepts defined in Section 4.4 for a 1,000 pound payload.

Combined sinusoidal and random vibration levels were applied in the three orthogonal axes simultaneously at the spherical mounting points of the simulator. (See Table 5-2 for level applied.) The sinusoidal vibration was applied from 5 to 2,000 cps at a rate of two minutes per octave.

Table 5-2

DYNAMIC TEST VIBRATION LEVELS

Sinusoidal Vibration (g rms)

Frequency (cps)	5-15	15-50	50-60	60-100	100-300	300-2000
Longitudinal	1.1	0.6	0.6-1.5	1.5	2.5	3.5
Lateral & Radial	1.1	1.1	1.1	1.1	2.5	3.5

Random Vibration (g^2/cps)

Frequency (cps)	20-100	100-300	300-1200	1200-2000
Longitudinal, Lateral & Radial	0	0.025	0.06	roll off at 12 db/octave

Visual inspection of all hardware was performed between tests and no catastrophic failures were noted. After completion of the test, the dynamic simulator was disassembled and the components inspected. The only failures noted were five cracked welds in the component support tube, and a sheared dowel pin in the crab servo to stereo mirror linkage. Areas of failure were redesigned and did not reoccur on re-test.

Instrumentation monitoring during test yielded a longitudinal resonance of the simulator between 23 and 26 cps. The lateral resonance was between 100 and 150 cps.

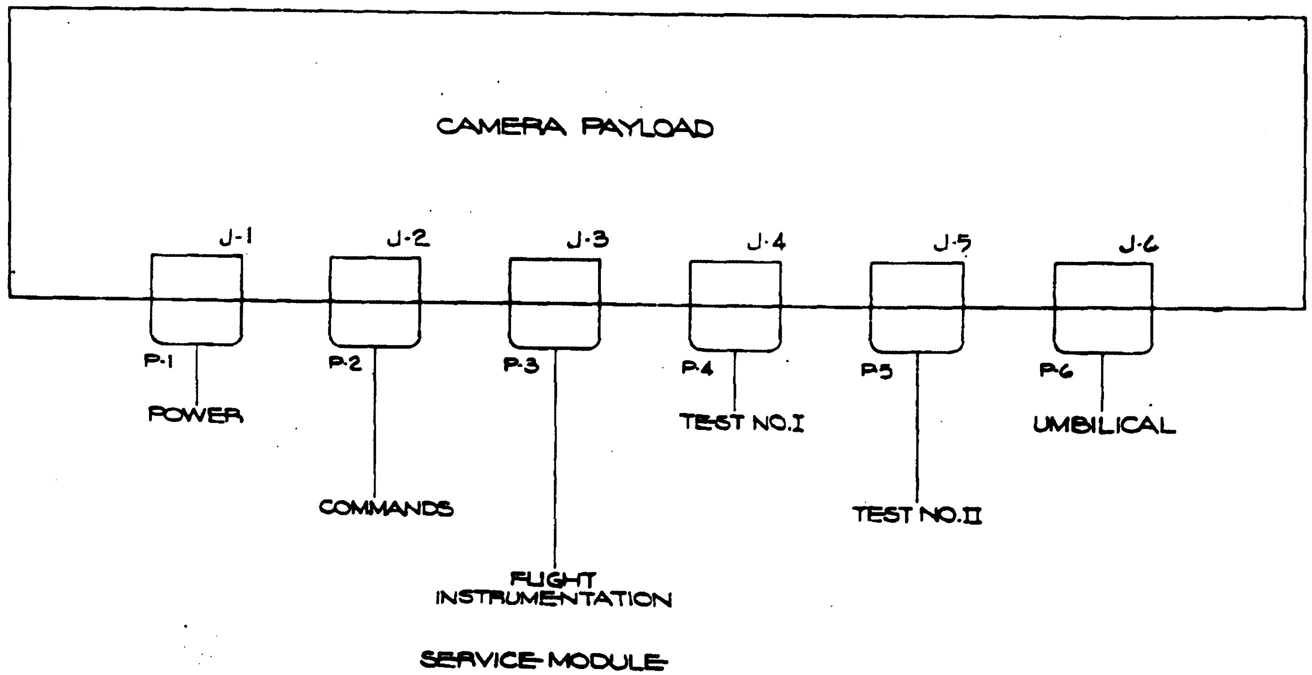
The spherical mounting concepts and structural integrity of structural mounting concepts which are very similar to those proposed in this camera payload passed the dynamic tests with flying colors.

5.5 ELECTRICAL INTERFACE

As mutually agreed upon, the electrical interface consists physically of six electrical connectors designated as follows:

Connector	No. of Pins
Power	21
Commands	55
Flight Instrumentation	41
Test No. 1	41
Test No. 2	55
Umbilical	10

Details of the signals, power, and circuit parameters, that each contractor will provide are defined in the Interface Specification, a preliminary copy of which is in Appendix IV. The Electrical Interface Drawing (See Figure 5-10) which will become a part of the Interface Agreement, describes the pin allocations for the various circuits. Spare pins designated as "No Connection" and spare circuits designated as "Spares" have been provided in accordance with the following schedule:



* TO BE SUPPLIED BY A LATER REVISION

Figure 5-10, sheet 1. Electrical Interface Drawing

NOTES –

1. J-1, J-2, J-3, J-4, J-5 AND J-6 SHALL BE DEUTSCH TYPE DTK CONNECTORS OR APPROVED EQUIVALENTS.

2. MANUFACTURERS PART NO. ON CONNECTOR SHALL BE FOR REFERENCE ONLY.

3. THE DESCRIPTIVE FUNCTIONAL DESIGNATIONS ASSOCIATED WITH POWER WIRES, COMMAND WIRES, INSTRUMENTATION WIRES, TEST POINT WIRES AND UMBILICAL WIRES SHAL BE FOR REFERENCE ONLY AND SHALL NOT CONSTITUTE A PART OF THE INTERFACE AGREEMENT.

4. A PIN LABELED "NO CONNECTION" SHALL NOT HAVE A WIRE ATTACHED TO IT WITHIN THE CAMERA PAYLOAD. A PIN LABELED "SPARE" SHALL HAVE A WIRE ATTACHED TO IT WITHIN THE CAMERA PAYLOAD. THESE SPARE WIRES SHALL BE RESERVED FOR FUTURE USE IF NECESSARY.

5. THIS DRAWING IS PART OF EASTMAN KODAK COMPANY INTERFACE SPECIFICATION ____________.

6. ABBREVIATIONS –
   MSD = MOTOR SPEED DRIVE
   V/H = GROUND VELOCITY VERSUS ALTITUDE

POWER INTERFACE

J-1 DTK**-22-21S*** (NOTE 2) — P-1 DTK**-22-21P*** (NOTE 2)

PIN	FUNCTION	CODE	PIN
A	OPERATIONAL 28 V.DC	OP. PWR	A
B	OPERATIONAL 28 V.DC.		B
C	OPERATIONAL 28 V.DC.		C
D	OPERATIONAL 28 V.DC.		D
E	DC RETURN	DC RET.	E
F	DC RETURN		F
G	DC RETURN		G
H	DC RETURN		H
J	ENVIRONMENTAL 28 V.DC	ENV PWR	J
K	ENVIRONMENTAL 28V.DC		K
L	ENVIRONMENTAL 28 V.DC		L
M	ENVIRONMENTAL 28 V.DC.		M
N	ENVIRONMENTAL RETURN	ENV. RET	N
P	ENVIRONMENTAL RETURN		P
R	ENVIRONMENTAL RETURN		R
S	ENVIRONMENTAL RETURN		S
T	SPARE		T
U	SPARE		U
V	SPARE		V
W	SPARE		W
X	NO CONNECTION		X

TEST CONNECTOR NO. I INTERFACE

J-4 DTK**-20-41S*** (NOTE 2) — P-4 DTK**-20-41P*** (NOTE 2)

PIN	FUNCTION	CODE	EQUIV.	PIN
A	CAMERA FILM PATH TEMPERATURE	TSP 1	IMP 1	A
B	STORAGE CASSETTE TEMPERATURE	TSP 2	IMP 2	B
C	STEREO MIRROR DIFFERENTIAL TEMPERATURE	TSP 3	IMP 3	C
D	STEREO MIRROR TEMPERATURE	TSP 4	IMP 4	D
E	LENS BARREL DIFFERENTIAL TEMPERATURE	TSP 5	IMP 5	E
F	45° MIRROR TEMPERATURE	TSP 6	IMP 6	F
G	COMPONENT SUPPORT TUBE TEMP. STATION ****	TSP 7	IMP 7	G
H	↕	TSP 8	IMP 8	H
J	↕	TSP 9	IMP 9	J
K	↕	TSP 10	IMP 10	K
L	COMPONENT SUPPORT TUBE TEMP. STATION ****	TSP 11	IMP 11	L
M	SLIT POSITION	TSP 12	IMP 12	M
N	STEREO MIRROR POSITION	TSP 13	IMP 13	N
P	FILM TAKE-UP QTY. COARSE	TSP 14	IMP 14	P
R	FILM TAKE-UP QTY. MEDIUM	TSP 15	IMP 15	R
S	FILM TAKE-UP QTY. FINE	TSP 16	IMP 16	S
T	FILM TENSION	TSP 17	IMP 17	T
U	MSD FREQUENCY	TSP 18	IMP 18	U
V	PLATEN POSITION COARSE	TSP 19	IMP 19	V
W	PLATEN POSITION FINE	TSP 20	IMP 20	W
X	FOCUS "A" CHANNEL	TSP 21	IMP 21	X
Y	FOCUS "B" CHANNEL	TSP 22	IMP 22	Y
z	FOCUS OUTPUT	TSP 23	IMP 23	z
a	SUPPLY CASSETTE FILM PATH TEMPERATURE	TSP 24	IMP 24	a
b	PORT DOOR TELL TALE	TSP 25	IMP 25	b
c	ENVIRONMENTAL 28V.DC	TSP 26	IMP 26	c
d	TAKE-UP MOTOR CURRENT	TSP 27	IMP 27	d
e	CALIBRATION	TSP 28	IMP 28	e
f	INSTRUMENTATION RETURN	TSP RET	IMP RET	f
g	INSTRUMENTATION RETURN	TSP RET	IMP RET	g
h	V/H MALFUNCTION	TSP 29	IMP 29	h
i	DATA SIGNAL "A"	TSP 30	IMP 30	i
j	DATA SIGNAL "B"	TSP 31	IMP 31	j
k	V/H OUTPUT	TSP 32	IMP 32	k
m	CRAB OUTPUT	TSP 33	IMP 33	m
n	CRAB POSITION	TSP 34	IMP 34	n
p	PAYLOAD MASTER TELL TALE	TSP 35	IMP 35	p
q	SPARE			q
r	NO CONNECTION			r
s	NO CONNECTION			s
t	NO CONNECTION			t

Figure 5-10, sheet 2. Electrical Interface Drawing

COMMAND AND TIME SIGNAL INTERFACE

J-2 DTK**-22-55S*** (NOTE 2) | P-2 DTK**-22-55P*** (NOTE 2)

PIN	FUNCTION	CODE	PIN
A	PAYLOAD POWER	COD 1	A
B	CAMERA CONTROL	COD 2	B
C	STEREO MIRROR POSITION CONTROL	COD 3	C
D	DOOR CONTROL	COD 4	D
E	MSD - AUTO/MANUAL	COD 5	E
F	MSD SPEED MOST SIG. BIT ON	COD 6	F
G	MSD SPEED MOST SIG. BIT OFF	COD 7	G
H	MSD SPEED 2ND. MOST SIG. BIT ON	COD 8	H
J	MSD SPEED 2ND. MOST SIG. BIT OFF	COD 9	J
K	MSD SPEED 3RD. MOST SIG. BIT ON	COD 10	K
L	MSD SPEED 3RD. MOST SIG. BIT OFF	COD 11	L
M	MSD SPEED 4TH. MOST SIG. BIT ON	COD 12	M
N	MSD SPEED 4TH MOST SIG. BIT OFF	COD 13	N
P	MSD SPEED 5TH MOST SIG. BIT ON	COD 14	P
R	MSD SPEED 5TH MOST SIG. BIT OFF	COD 15	R
S	MSD SPEED 6TH MOST SIG. BIT ON	COD 16	S
T	MSD SPEED 6TH MOST SIG. BIT OFF	COD 17	T
U	MSD SPEED 7TH MOST SIG. BIT ON	COD 18	U
V	MSD SPEED 7TH MOST SIG. BIT OFF	COD 19	V
W	MSD SPEED 8TH MOST SIG. BIT ON	COD 20	W
X	MSD SPEED 8TH MOST SIG. BIT OFF	COD 21	X
Y	MSD SPEED LEAST SIG. BIT ON	COD 22	Y
Z	MSD SPEED LEAST SIG. BIT OFF	COD 23	Z
a	FOCUS CONTROL	COD 24	a
b	STRIP-STEREO	COD 25	b
c	PANNING	COD 26	c
d	SLIT MOST SIG. BIT ON	COD 27	d
e	SLIT MOST SIG. BIT OFF	COD 28	e
f	SLIT LEAST SIG. BIT ON	COD 29	f
g	SLIT LEAST SIG. BIT OFF	COD 30	g
h	TORQUE MOTOR CONTROL	COD 31	h
i	FOCUS AUTO/MANUAL	COD 32	i
j	FOCUS FORWARD	COD 33	j
k	FOCUS REVERSE	COD 34	k
m	EMPTY SUPPLY	COD 35	m
n	CUT FILM	COD 36	n
p	SEPARATE	COD 37	p
r	COMMAND RETURN	COD RET	r
s	COMMAND RETURN	COD RET	s
t	COMMAND RETURN	COD RET	t
u	400 PPS	COD 38	u
v	TIME/POSITION LABEL	COD 39	v
w	400 PPS RETURN	400 RET	w
x	TIME/POSITION LABEL RETURN	TPL RET	x
y	400 PPS SHIELD		y
z	TIME/POSITION SHIELD		z
[illegible]	SPARE		[illegible]
AA	SPARE		AA
BB	SPARE		BB
CC	NO CONNECTION		CC
DD			DD
EE			EE
FF			FF
GG			GG
HH	NO CONNECTION		HH

*

UMBILICAL INSTRUMENTATION INTERFACE

J-6 DTK**-12-10SW*** (NOTE 2) | P6 DTK**-12-10PW*** (NOTE 2)

PIN	FUNCTION	CODE	PIN
A	FILM TENSION	BIL 1	A
B	MSD FREQUENCY	BIL 2	B
C	STEREO MIRROR TEMPERATURE	BIL 3	C
D	COMPONENT SUPPORT TUBE TEMP. STATION ****	BIL 4	D
E	TORQUE MOTOR COMMAND	BIL 5	E
F	MASTER TELL TALE	BIL 6	F
G	INSTRUMENTATION RETURN	BIL RET	G
H	SPARE		H
J	SPARE		J
K	SPARE		K

Figure 5-10, sheet 3. Electrical Interface Drawing

FLIGHT INSTRUMENTATION INTERFACE

J-3
DTK***-20-41SW***
(NOTE 2)

P-3
DTK**-20-41PW***
(NOTE 2)

PIN	FUNCTION	CODE	PIN
A	CAMERA FILM PATH TEMPERATURE	IMP 1	A
B	STORAGE CASSETTE TEMPERATURE	IMP 2	B
C	STEREO MIRROR DIFFERENTIAL TEMPERATURE	IMP 3	C
D	STEREO MIRROR TEMPERATURE	IMP 4	D
E	LENS BARREL DIFFERENTIAL TEMPERATURE	IMP 5	E
F	45° MIRROR TEMPERATURE	IMP 6	F
G	COMPONENT SUPPORT TUBE TEMP. STATION ****	IMP 7	G
H		IMP 8	H
J		IMP 9	J
K		IMP 10	K
L	COMPONENT SUPPORT TUBE TEMP. STATION ****	IMP 11	L
M	SLIT POSITION	IMP 12	M
N	STEREO MIRROR POSITION	IMP 13	N
P	FILM TAKE-UP QTY. COARSE	IMP 14	P
R	FILM TAKE-UP QTY. MEDIUM	IMP 15	R
S	FILM TAKE-UP QTY. FINE	IMP 16	S
T	FILM TENSION	IMP 17	T
U	MSD FREQUENCY	IMP 18	U
V	PLATEN POSITION COARSE	IMP 19	V
W	PLATEN POSITION FINE	IMP 20	W
X	FOCUS 'A' CHANNEL	IMP 21	X
Y	FOCUS 'B' CHANNEL	IMP 22	Y
Z	FOCUS OUTPUT	IMP 23	Z
a	SUPPLY CASSETTE FILM PATH TEMPERATURE	IMP 24	a
b	PORT DOOR TELL TALE	IMP 25	b
c	ENVIRONMENTAL 28 V.DC.	IMP 26	c
d	TAKE-UP MOTOR CURRENT	IMP 27	d
e	CALIBRATION	IMP 28	e
f	INSTRUMENTATION RETURN	IMP RET	f
g	V/H MALFUNCTION	IMP 29	g
h	DATA SIGNAL 'A'	IMP 30	h
i	DATA SIGNAL 'B'	IMP 31	i
j	V/H OUTPUT	IMP 32	j
k	CRAB OUTPUT	IMP 33	k
m	CRAB POSITION	IMP 34	m
n	PAYLOAD MASTER TELL TALE	IMP 35	n
p	SPARE		p
q	SPARE		q
r	NO CONNECTION		r
s	NO CONNECTION		s
t	NO CONNECTION		t

Figure 5-10, sheet 4. Electrical Interface Drawing

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TEST CONNECTOR NO. II
INTERFACE

J5 DTK** -22-55 SW *** (NOTE 2)

P-5 DTK** -22-55 PW *** (NOTE 2)

PIN	FUNCTION	CODE	EQUIV	PIN
A	PAYLOAD POWER	TSP 40	CCD 1	A
B	CAMERA CONTROL	TSP 41	CCD 2	B
C	STEREO MIRROR POSITION CONTROL	TSP 42	CCD 3	C
D	DOOR CONTROL	TSP 43	CCD 4	D
E	MSD AUTO/MANUAL	TSP 44	CCD 5	E
F	MSD SPEED MOST SIG. BIT ON	TSP 45	CCD 6	F
G	MSD SPEED MOST SIG. BIT OFF	TSP 46	CCD 7	G
H	MSD SPEED 2ND MOST SIG. BIT ON	TSP 47	CCD 8	H
J	MSD SPEED 2ND MOST SIG. BIT OFF	TSP 48	CCD 9	J
K	MSD SPEED 3RD MOST SIG. BIT ON	TSP 49	CCD 10	K
L	MSD SPEED 3RD MOST SIG. BIT OFF	TSP 50	CCD 11	L
M	MSD SPEED 4TH MOST SIG. BIT ON	TSP 51	CCD 12	M
N	MSD SPEED 4TH MOST SIG. BIT OFF	TSP 52	CCD 13	N
P	MSD SPEED 5TH MOST SIG. BIT ON	TSP 53	CCD 14	P
R	MSD SPEED 5TH MOST SIG. BIT OFF	TSP 54	CCD 15	R
S	MSD SPEED 6TH MOST SIG. BIT ON	TSP 55	CCD 16	S
T	MSD SPEED 6TH MOST SIG. BIT OFF	TSP 56	CCD 17	T
U	MSD SPEED 7TH MOST SIG. BIT ON	TSP 57	CCD 18	U
V	MSD SPEED 7TH MOST SIG. BIT OFF	TSP 58	CCD 19	V
W	MSD SPEED 8TH MOST SIG. BIT ON	TSP 59	CCD 20	W
X	MSD SPEED 8TH MOST SIG. BIT OFF	TSP 60	CCD 21	X
Y	MSD SPEED LEAST SIG BIT ON	TSP 61	CCD 22	Y
Z	MSD SPEED LEAST SIG BIT OFF	TSP 62	CCD 23	Z
a	FOCUS CONTROL	TSP 63	CCD 24	a
b	STRIP-STEREO	TSP 64	CCD 25	b
c	PANNING	TSP 65	CCD 26	c
d	SLIT MOST SIG. BIT ON	TSP 66	CCD 27	d
e	SLIT MOST SIG. BIT OFF	TSP 67	CCD 28	e
f	SLIT LEAST SIG. BIT ON	TSP 68	CCD 29	f
g	SLIT LEAST SIG. BIT OFF	TSP 69	CCD 30	g
h	TORQUE MOTOR CONTROL	TSP 70	CCD 31	h
i	FOCUS AUTO/MANUAL	TSP 71	CCD 32	i
j	FOCUS FORWARD	TSP 72	CCD 33	j
k	FOCUS REVERSE	TSP 73	CCD 34	k
m	EMPTY SUPPLY	TSP 74	CCD 35	m
n	CUT FILM	TSP 75	CCD 36	n
p	SEPARATE	TSP 76	CCD 37	p
q	400 PPS	TSP 77	CCD 38	q
r	TIME/POSITION LABEL	TSP 78	CCD 39	r
s	SPARE			s
t	SPARE			t
u	SPARE			u
v	NO CONNECTION			v
w	↓			w
x				x
y				y
z				z
AA				AA
BB				BB
CC				CC
DD				DD
EE				EE
FF				FF
GG	↓			GG
HH	NO CONNECTION			HH

Figure 5-10, sheet 5. Electrical Interface Drawing

Connector Pins	Spare Pins	Spare Circuits
24 or less	Not less than 2	None
24 to 61	Not less than 3	Not less than 2
61 or more	Not less than 4	Not less than 3

The power connector is to terminate C/P power circuits at the interface with the Service Module. Operational power and environmental power is to be supplied on separate circuits with separate returns.

The commands required for operation of the C/P are to be transmitted through the command connector. Each command will be presented as an electrical signal between the wire peculiar to the commanded signal and the command return. Some of the commands will be pulses; others will be represented as the absence or presence of a dc voltage on the related wires.

The commands are divided into two categories: primary and back-up. Primary commands are required for normal operation of the C/P. Back-up commands are to be used for the purpose of recovering C/P functions either partially or wholly in the event that programmed operations fail.

Data needed to monitor the operation of the C/P while in flight is transmitted through the flight instrumentation connector. Responsibility for processing flight instrumentation signals rests with NAA in accordance with the requirements established for commanding the C/P.

Two test connectors provide interface termination of C/P test points. The test connector instrumentation circuits provide a means of monitoring payload performance during the payload level tests performed prior to delivery to the integration point and during subsequent C/P health checks.

Each command and flight instrumentation circuit will have a test point which terminates in one of the test connectors. NAA will provide the hard line transmission of signals present at these connectors (See Interface Specification, Appendix N). The hardlines are defined as direct wire connections between the test connectors and the read-out instrumentation.

After disconnection of the hard lines to the test connectors prior to launch, key C/P instrumentation circuits which verify that the C/P environment and circuit operational parameters are still within tolerance limits will be carried on the umbilical connector until launch. These circuits provide information to the launch facility which is necessary to establish a launch "hold" or "abort" in the event of a C/P malfunction.

The operational power return, the environmental power return, the command return and the instrumentation return will be separate, isolated circuits within the C/P and will be brought to the interface. NAA is to connect these returns to the uni-point ground before the C/P is operated.

5.6 THERMAL INTERFACE

The thermal interface philosophy as agreed upon between NAA and EKC is described in detail in Section 4.9.

The thermal interface drawing is included as Figure 5-11.

5.7 AEROSPACE SUPPORT EQUIPMENT (ASE)

The objective of this section is to define the ASE required to support payload installation, checkout, and flight, as well as that ASE needed during the period between shipment and actual launch. In addition, special test

NOTES:

1. A PARTIAL LISTING OF ADDITIONAL DATA, DEFINITIONS, AND RESPONSIBILITY DIVISION IS GIVEN AS FOLLOWS:
2. EK WILL PROVIDE THE ENVIRONMENTAL HEATING ASSEMBLY IN THE LENS BAY AND ON THE VIEWPORT DOORS AS AN INTERNAL PART OF EK EQUIPMENT. EK TEMPERATURE CONTROLLERS WILL BE SET FOR 69±1°F (ON) TEMPERATURE WITH A (OFF) HYSTERESIS OF ±0.5°F
3. THE FLIGHT HEATER CONTROL NOMINAL TEMPERATURE IS 70°F FOR ALL ELEMENTS OF THE P/L.
4. THE NOMINAL EMISSIVITY OF ALL SM SECTOR INTERNAL RADIATION SURFACES SHALL BE 0.10
5. DURING ALL OPERATIONAL PHASES, THE DIFFERENTIAL BETWEEN THE SPATIALLY AVERAGED TEMPERATURES OF THE STEREO MIRROR BAY AND THE LENS BAY SHALL NOT EXCEED 10°F
6. CONDUCTANCE VALUES GIVEN ARE NOMINAL AND DESIGN TOLERANCE ARE ±25%.
7. GROUND CONDITIONING WHILE ON THE PAD SHALL ALLOW TEMPERATURE LEVELS OF THE P/L TO BE ESTABLISHED BY THE FLIGHT HEATER CONTROL SYSTEMS IN THE MIRROR AND LENS BAYS FOR A MINIMUM OF 24 HOURS PRIOR TO LAUNCH
8. NAA IS RESPONSIBLE FOR PREVENTING THE CONDENSATION OF MOISTURE ON ANY SURFACES OF THE EK P/L EXTERNAL TO THE FILM ENCLOSURE DURING THE PERIOD FROM INTEGRATION UNTIL LIFT-OFF. DURING FILM LOADING, THE TEMPERATURE OF THE LOADING AREA SHALL BE 70°F ± 5°F AND RELATIVE HUMIDITY SHALL BE 40 ± 5%.
9. THE DESIGN GOAL FOR THE THERMAL ENVIRONMENTAL CONTROL ASSEMBLIES IN THE STEREO MIRROR BAY IS TO LIMIT THE TEMPERATURE DIFFERENCE BETWEEN ANY TWO POINTS ON THE STEREO MIRROR TO 2.0°F MAXIMUM, EXCEPT,
   (1) THE TEMPERATURE DIFFERENCE FROM THE FRONT TO THE BACK FACE OF THE STEREO MIRROR SHALL BE 0.2°F MAXIMUM ALONG ANY LOCAL NORMAL TO THE MIRROR FRONT FACE.
   (2) THE TEMPERATURE DIFFERENCE BETWEEN THE AVERAGE FRONT AND BACK SURFACE AREA SHALL BE 0.2°F MAXIMUM AT THE START OF EACH ORBITAL PASS WITH EITHER PHOTOGRAPHIC OR FOCUSING OPERATION.
   THIS DESIGN GOAL IS BASED ON PASSIVE STEREO MIRROR TEMPERATURE CONTROL.
10. TOTAL HEAT FLOW TO THE EK P/L FROM THE AFT MOUNTING POINT AND THE TORSIONAL RESTRAINT SYSTEM SHALL NOT EXCEED 0.88 WATTS. AT ALL OTHER PHYSICAL CONTACT POINTS BETWEEN NAA AND EK, THE MAXIMUM AVERAGE TEMPERATURE AT THE NAA MECHANICAL INTERFACE SHALL NOT EXCEED 70°F.
11. FILM TEMPERATURE LIMITATIONS:
   PERIOD COVERED: FROM INITIAL INSTALLATION OF FLIGHT FILM UNTIL RETRIEVED FILM IS RETURNED TO CONTROLLED TEMPERATURE ENVIRONMENT. MAXIMUM TEMPERATURE = 125°F, BUT THE ACCUMULATION OF TEMPERATURE OVER 90°F SHALL NOT EXCEED THE FOLLOWING:
   $$\int_{t_0}^{t_R} \frac{T(t) - 90}{5}\, dt \leq 4000 \text{ HOURS}$$
   WHERE t_0 = TIME OF INITIAL INSTALLATION OF FLIGHT FILM
   t_R = TIME OF RETURN OF RETRIEVED FILM TO CONTROLLED TEMPERATURE ENVIRONMENT
   $T(t)$ = TEMPERATURE OF FILM AT TIME t IN °F.
12. NAA MOUNTING BOLTS AT C1 THRU C5 SHALL HAVE A MAXIMUM THERMAL CONDUCTIVITY OF 8.0 BTU/HR. FT °F AT 70°F.
13. THE OPERATIONAL PHASES ARE DEFINED AS FOLLOWS:
   A. FLIGHT CHECKOUT – P/L–SM INTEGRATION TO PREPARATION FOR FLIGHT
   B. PREOPERATION – BEGINNING OF FLIGHT PREPARATION TO LIFTOFF
   C. OPERATION – LIFTOFF UNTIL AFTER FINAL FILM WINDUP.
   D. POST-OPERATION – FINAL FILM WINDUP TO FILM RETRIEVAL.
14. IF IT IS DEEMED NECESSARY TO REJECT HEAT FROM THE SM SECTOR THROUGH THE VIEW PORT DOOR IN ORDER TO COMPENSATE FOR THE HEAT GAIN DURING PHOTOGRAPHY, EK STIPULATES THAT THIS ACTIVITY BE ACCOMPLISHED IMMEDIATELY AFTER PHOTOGRAPHY ENDS IN ORDER TO PROVIDE A MAXIMUM TIME PERIOD FOR THERMAL RE-EQUILIBRATION OF THE OPTICS. THIS MAY REQUIRE A ROLL MANEUVER IF THE HEAT MUST BE REJECTED TO SPACE.
15. NAA WILL PROVIDE A THERMOSTATICALLY CONTROLLED ACTIVE HEATER SYSTEM SET FOR 70°F ON THE C.P. SIDE OF THE INSULATION LOCATED IN THE STEREO BAY (R5) (EXCEPT FOR THE VIEW PORT DOOR) WHICH IS CAPABLE OF MAINTAINING AN ISOTHERMAL RADIATING SURFACE TOWARD WHICH THE STEREO MIRROR WILL EQUILIBRATE WHEN THE VIEWPORT DOOR IS CLOSED

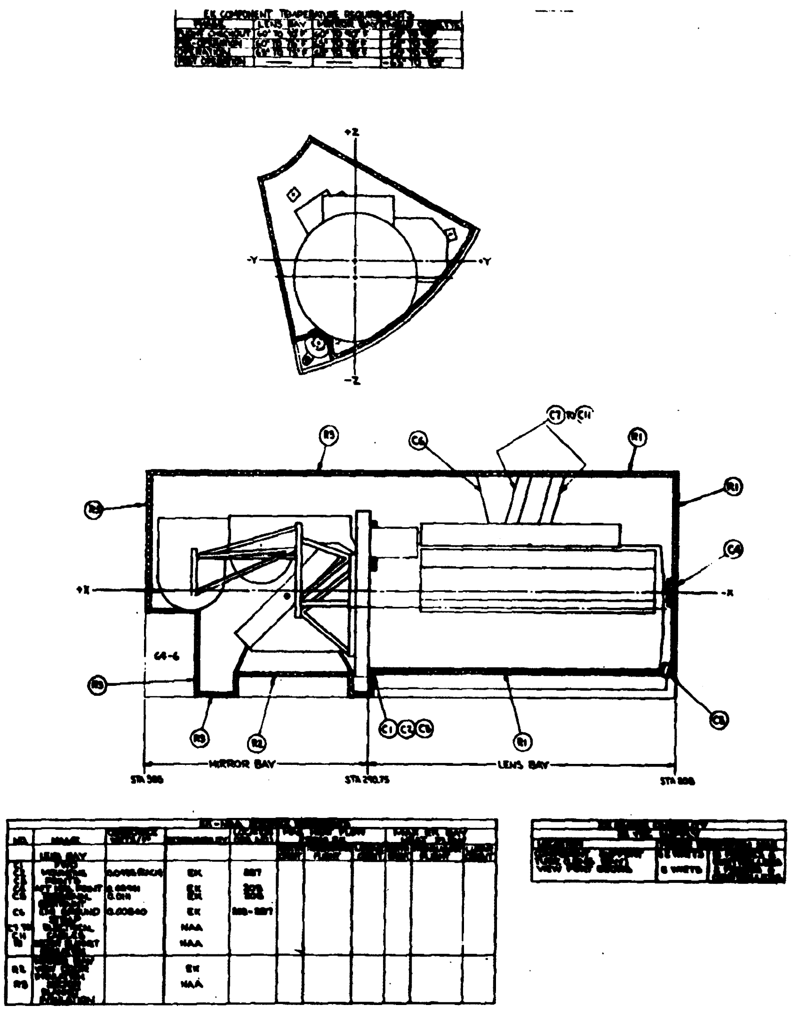


Figure 5-11. Thermal Interface Drawing

equipment, tooling, and industrial requirements which are required to support the manufacturing and test phases of the proposed program are herein defined.

For the purposes of this report, the ASE equipment definitions are subdivided into the following groups:

- (a) Test equipment
- (b) Tooling
  - (1) Handling equipment
  - (2) P/L and photographic support equipment
- (c) Industrial requirements

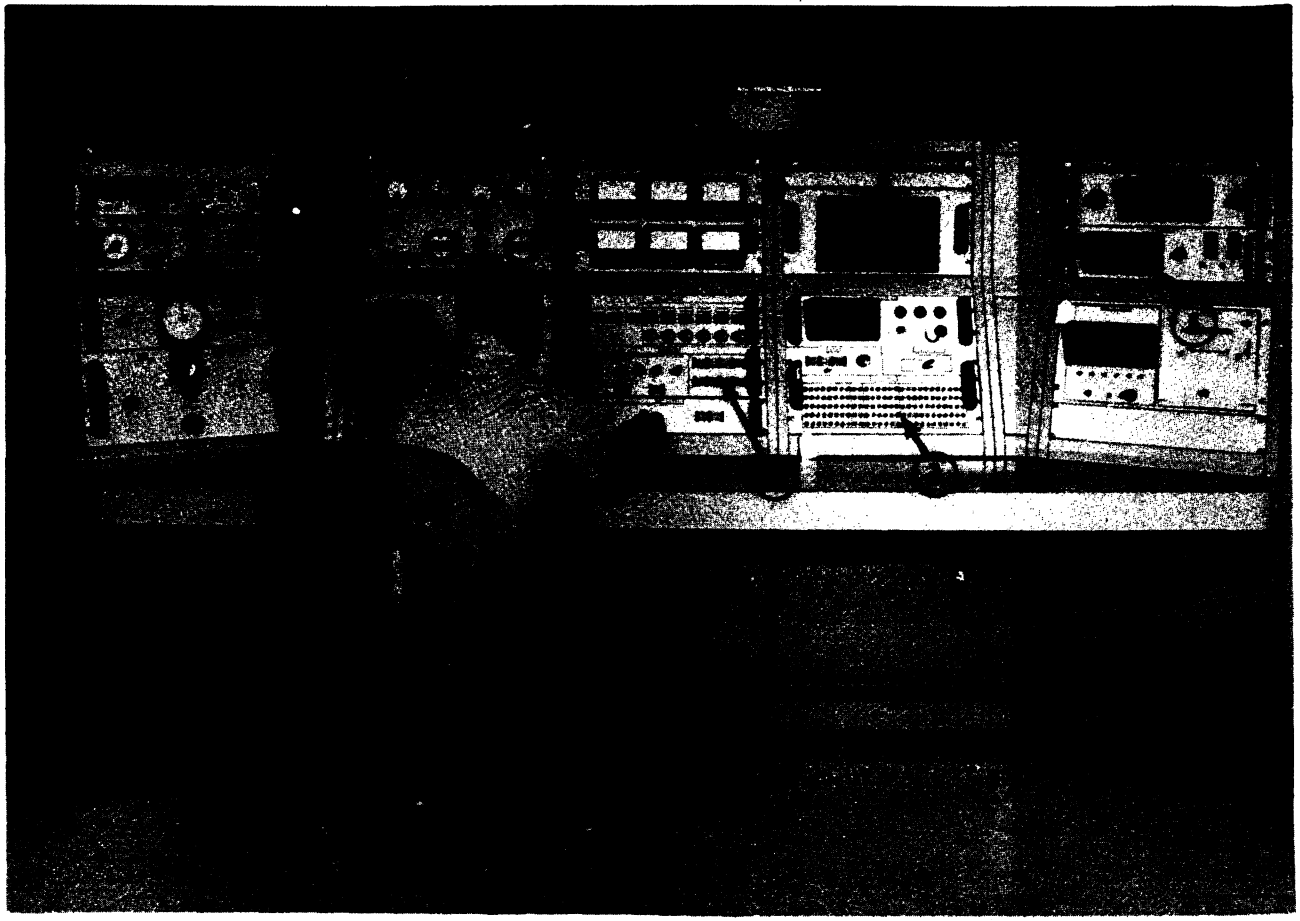
5.7.1 Test Equipment

Test equipment is that equipment required to test the electrical, mechanical, optical, or environmental performance of the P/L and/or subassemblies.

5.7.1.1 Test Consoles. The test console, as shown in Figure 5-12, supplies the power, simulates the actual impedance loads, transmits commands to and monitors the performance of the associated hardware (P/L or subassembly). In addition, portable test sets will be built for use with major subassemblies such as:

- (1) Film transport and drive system
- (2) Film supply drive
- (3) Film take-up drive
- (4) Camera
- (5) All major electronic controls

Figure 5-13 shows an existing portable test set. In addition, special test consoles shall be built as required for use with basic components such as motors, brakes, and clutches.



1. Test Drum Speed Control
2. Collimator Position Control
3. Target Illumination Control
4. Payload Power Monitor
5. Instrumentation Patch Board
6. Digital Instrumentation Monitor
7. Instrumentation Test Point Panel
8. Payload Command Control

Figure 5-12. Test Console

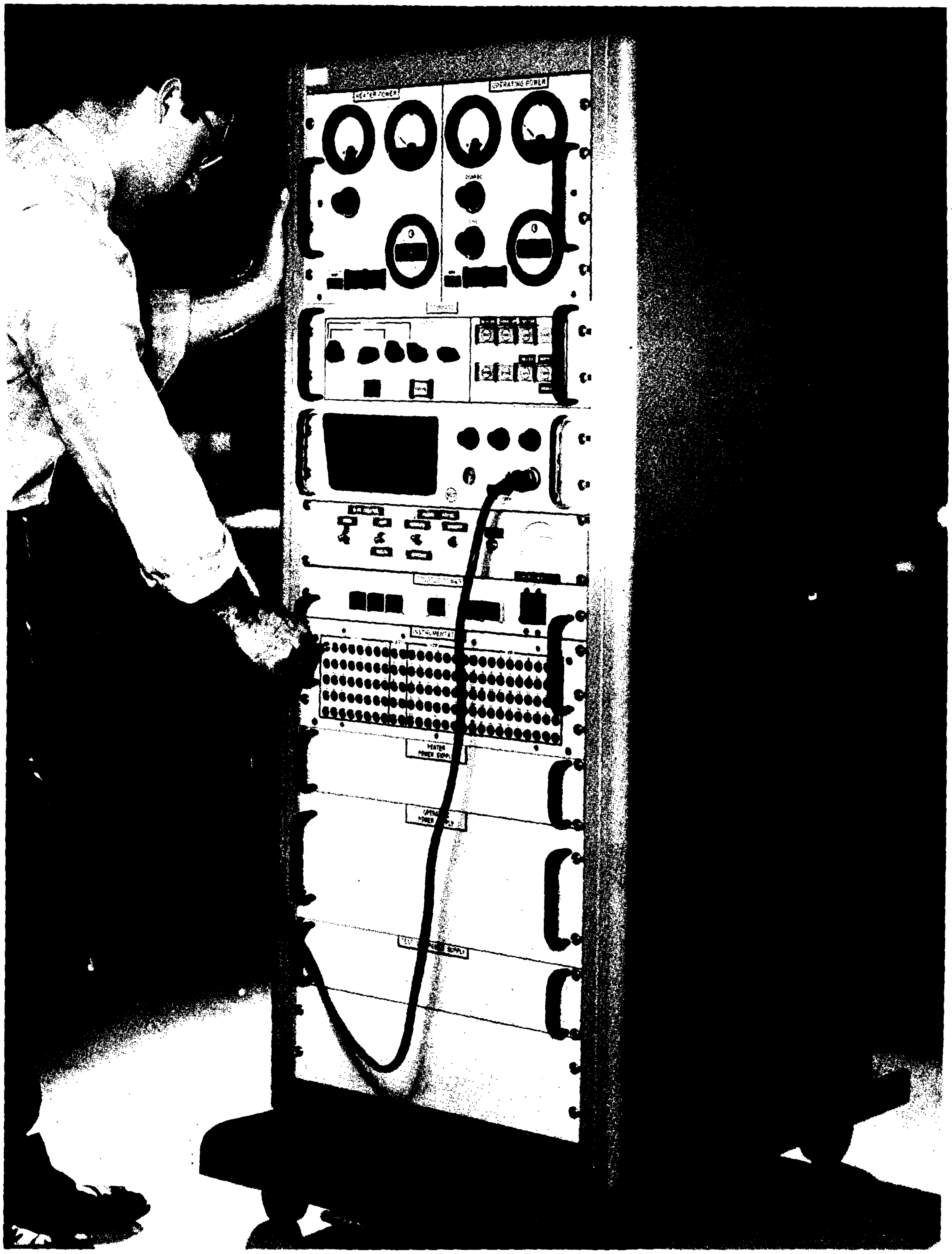


Figure 5-13. Portable Test Set

5.7.1.2 Cable Test Point Board. The cable test point board replaces standard electrical cables for test purposes. Figure 5-14 illustrates this board. The board permits non-destructive entry into any line, comprising the cable, in order to monitor the signals on the line, and to measure supply or load impedances. Cable test boards shall be built for use between:

(1) The P/L and its power and command source.

(2) Any electronic packages that are normally connected externally by cables.

5.7.1.3 Electric Simulator. The electrical simulators simulate the static and dynamic electrical parameters of the P/L or any subassembly for compatibility checks. See Figure 5-15 for illustration.

5.7.1.4 Dynamic Simulator. The dynamic simulators are used in place of, and simulate the static and dynamic mechanical parameters of the P/L or any subassembly in order to produce the appropriate load trasnferable to the actual hardware undergoing environmental testing.

5.7.1.5 Leak-rate Test Set. The leak-rate test set determines the leak-rate of any pressurized container. Several pressurized containers are:

(1) The film handling, supply, and storage system.

(2) Motor containers.

5.7.1.6 Load Box Secondary Standard. The load box secondary standard is required for the calibration of any electrical, mechanical, or optical device. See illustration on Figure 5-16.

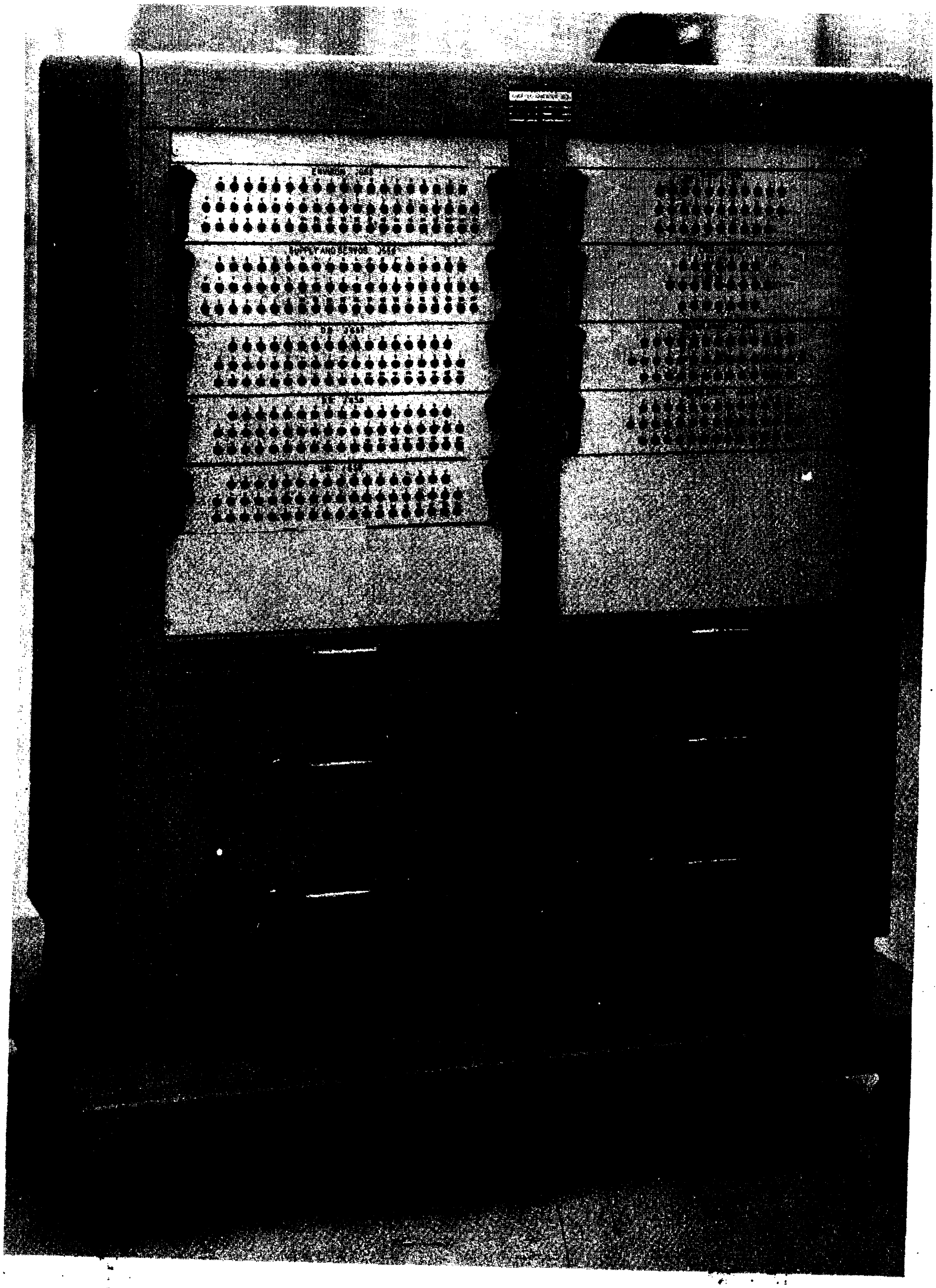


Figure 5-14. Cable Test Point Board

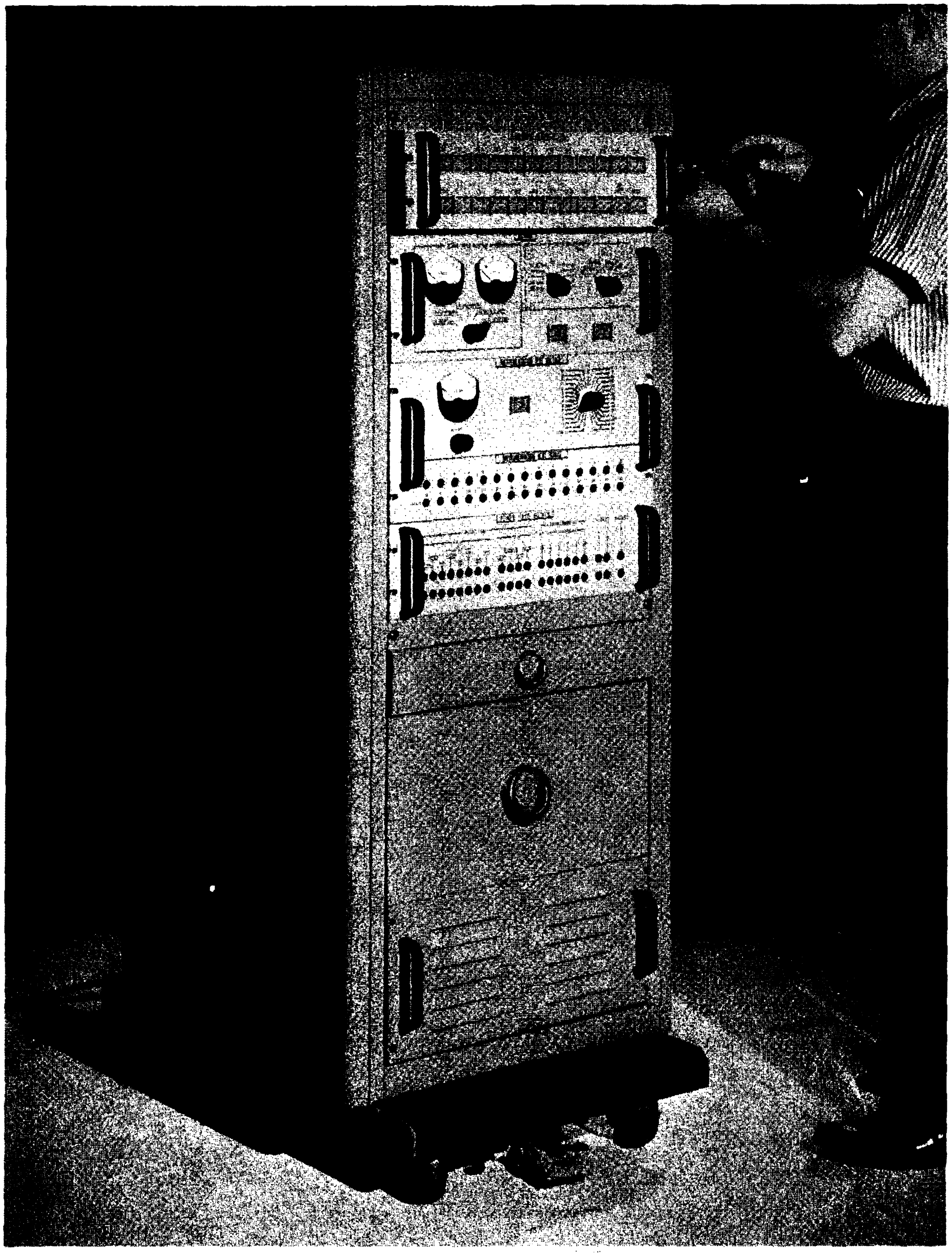


Figure 5-15. Electrical Simulator

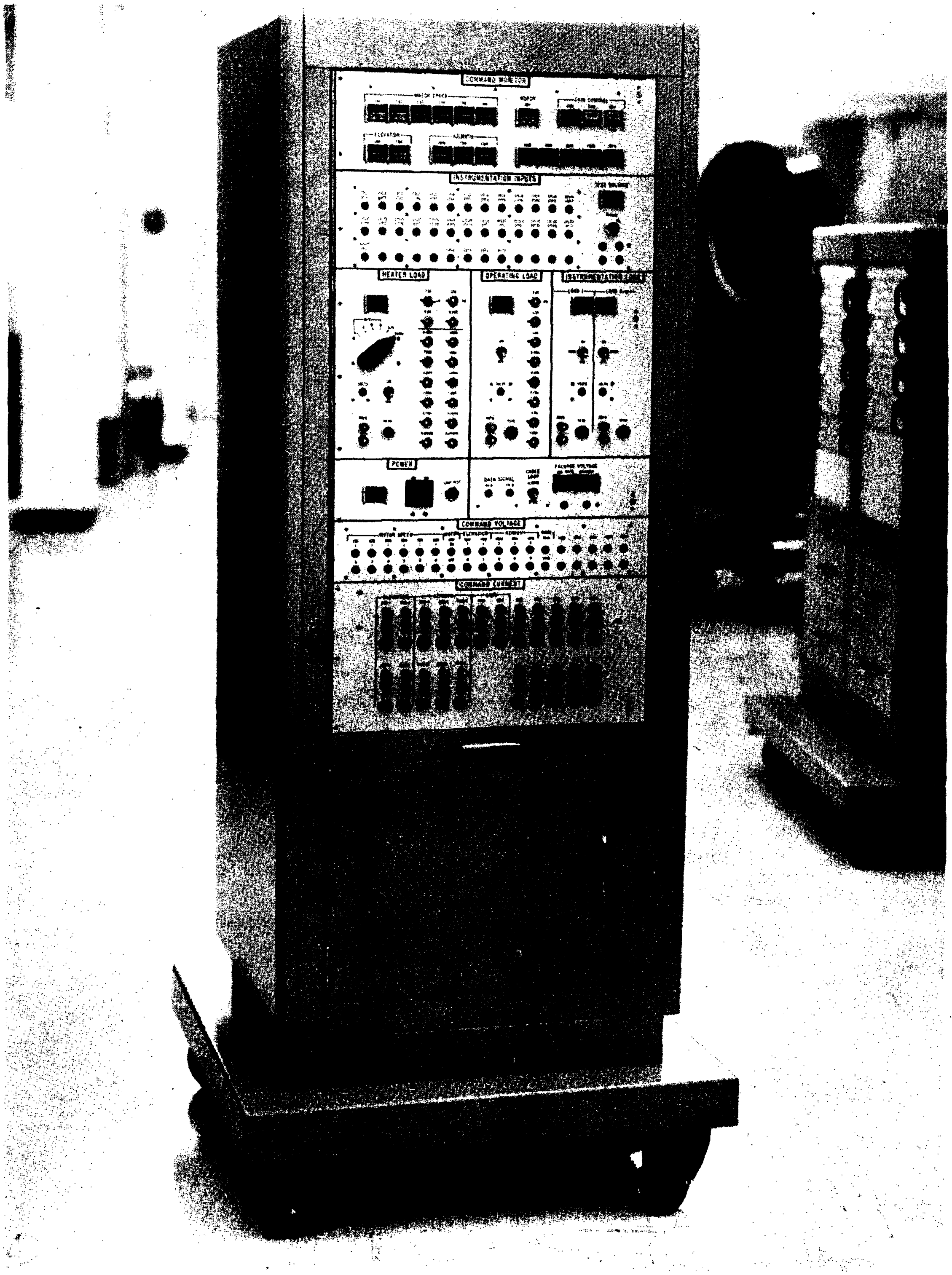


Figure 5-16. Load Box Secondary Standard

5.7.2 Tooling

Tooling is the mechanical, electrical, or optical equipment that is required for the assembly, transport, positioning or preparation of the P/L or sub-assemblies from manufacturing to launch. Tooling is divided into three major groups:

(1) Handling equipment
(2) Support equipment
(3) Assembly equipment

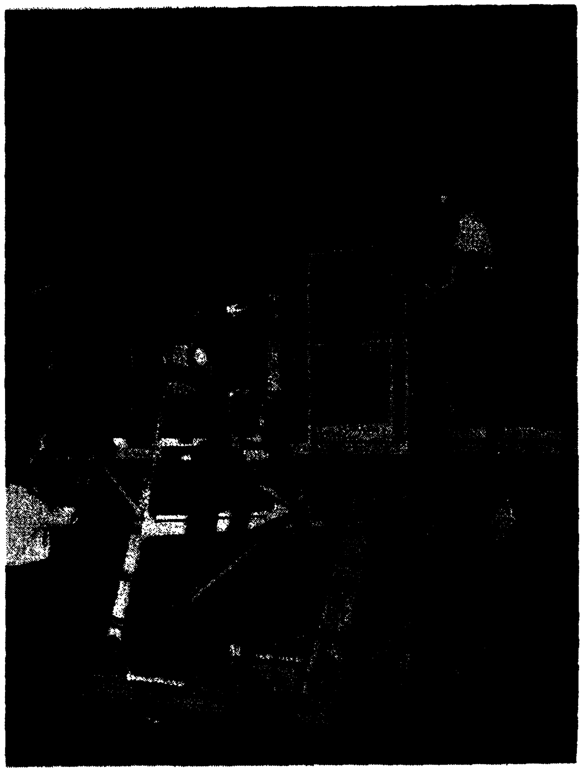
5.7.2.1 Handling Equipment. Handling equipment is defined as that ASE that is required to transport or position the P/L or any subassembly from one location or orientation to another. Included as handling equipment are the following items:

5.7.2.1.1 Cradle. The cradle supports the P/L at the P/L mounting points, eliminating any stressing of the payload due to improper support.

5.7.2.1.2 Erector. The erector rotates the P/L and cradle between the horizontal and vertical orientations. See Figure 5-17.

5.7.2.1.3 Lifting Yokes. The lifting yoke fastens to the cradle, for lifting purposes. The yoke is designed such that the lifting point lies on the line of action of the P/L and cradle center of gravity, eliminating any rotational moments. There are at least two types of yokes: one for lifting along the P/L axis, the other for lifting perpendicular to the P/L axis. See illustration of lifting yokes in Figure 5-18 and 5-19.

5.7.2.1.4 Mounting Fixture. The mounting fixture is designed to correctly support the P/L, without the cradle, in the proper orientation, permitting direct mounting of the P/L to the vehicle or the P/L environmental test fixtures.



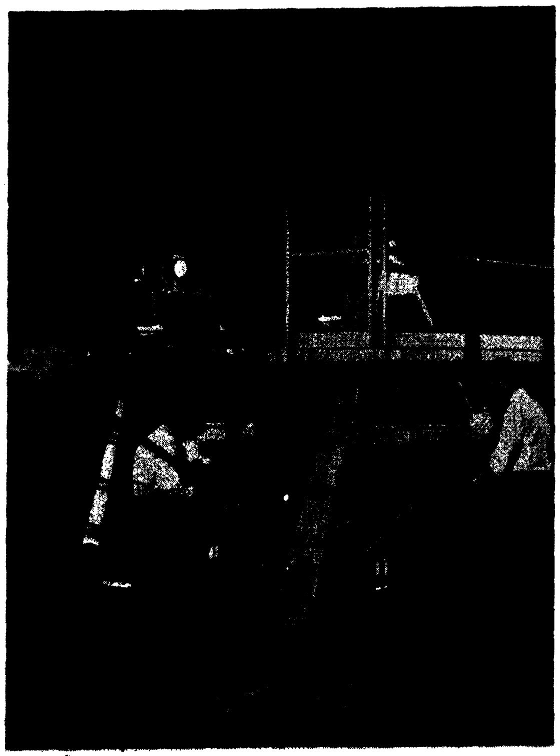


Figure 5-17. Erector

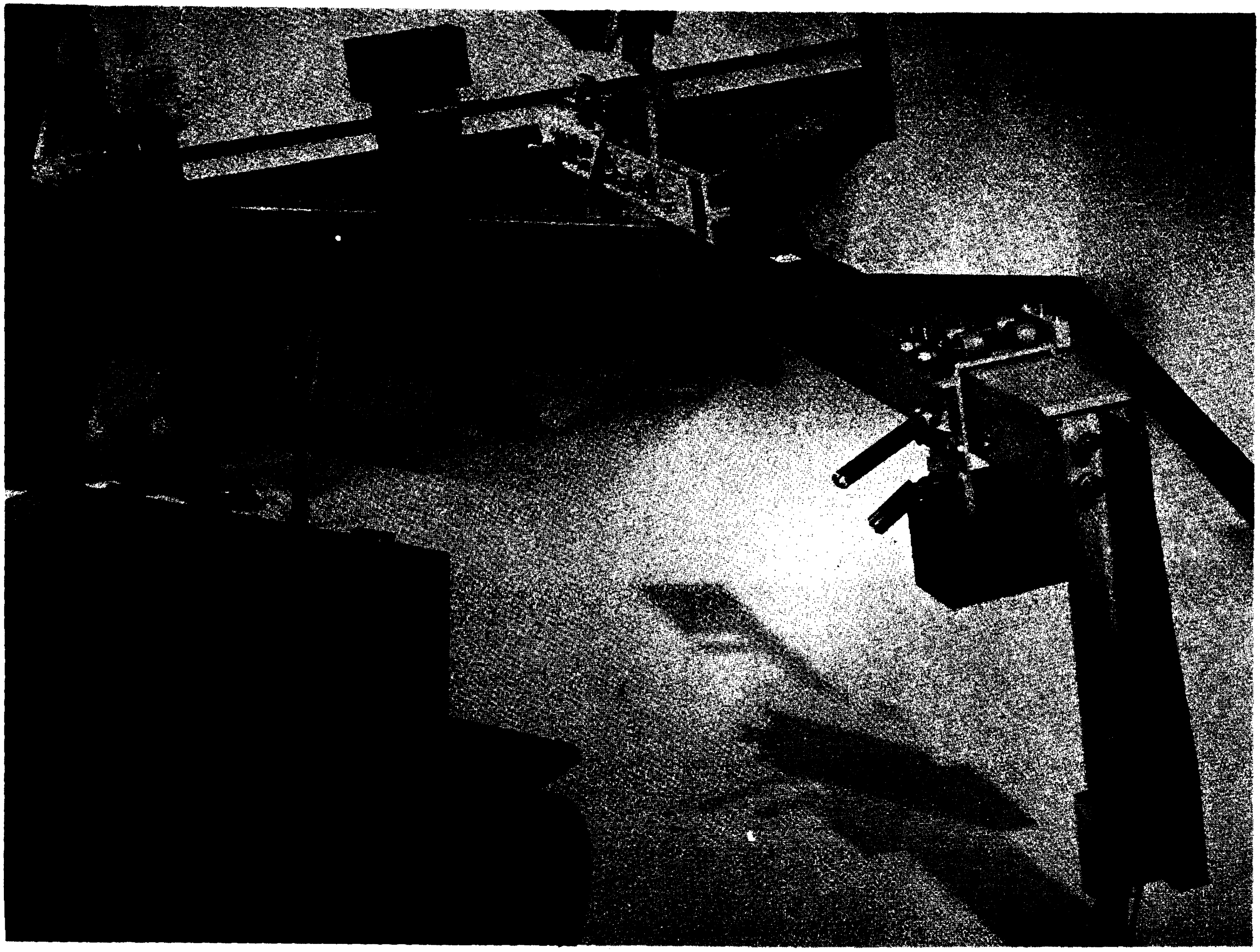
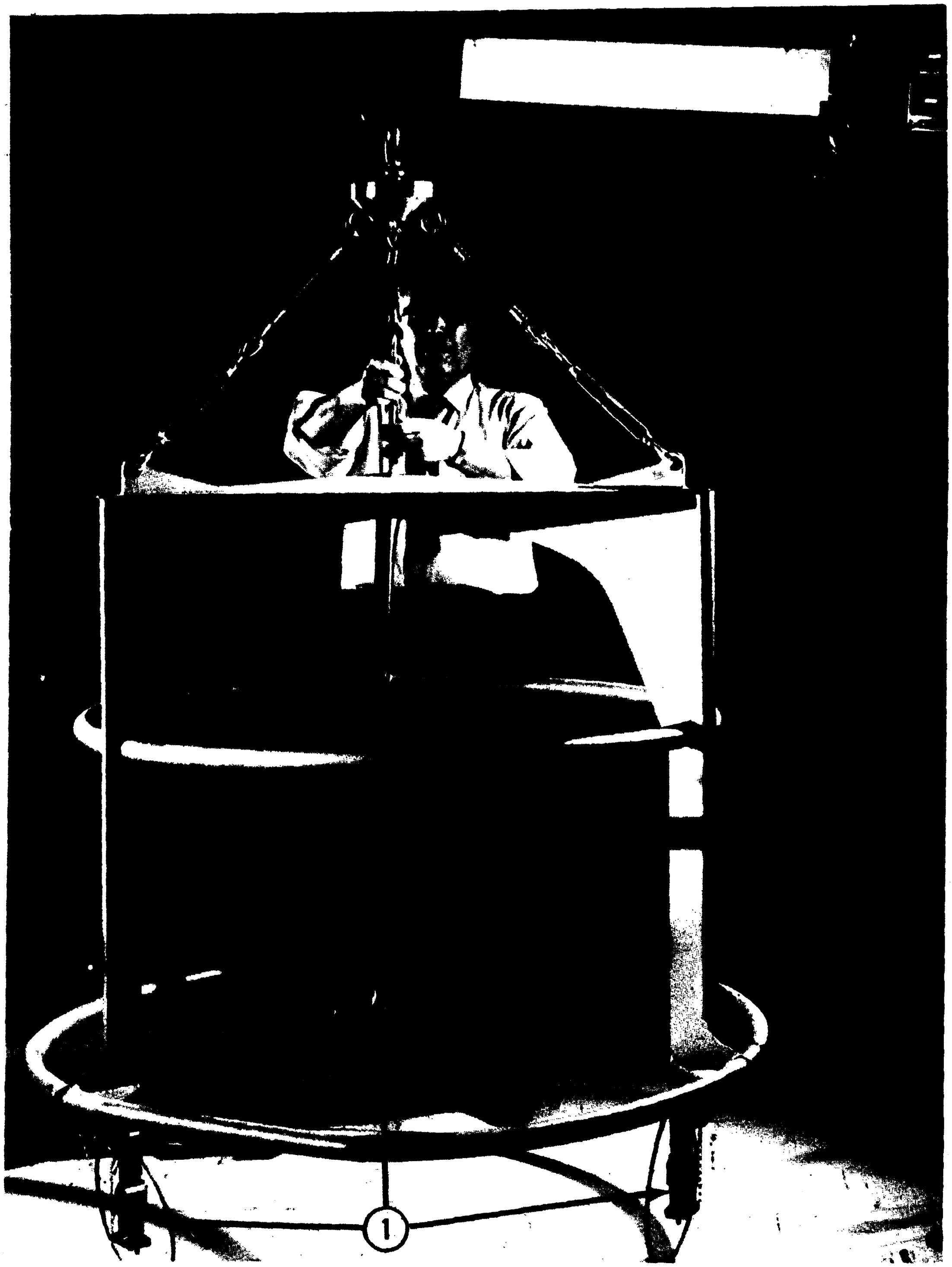


Figure 5-18. Payload Lifting Yoke



1. Payload Attachment Points

Figure 5-19. Vertical Lifting Yoke

5.7.2.1.5 Integration Fixture. The integration fixture is used to assemble the P/L into the vehicle.

5.7.2.1.6 Truck. The truck supports and moves the payload and cradle from one location to another.

5.7.2.1.7 Positioner. The positioner allows incremental positioning of the P/L prior to optical testing.

5.7.2.1.8 General Purpose Mobile Hoist. The general purpose mobile hoist is a mobile hoist used for lifting purposes.

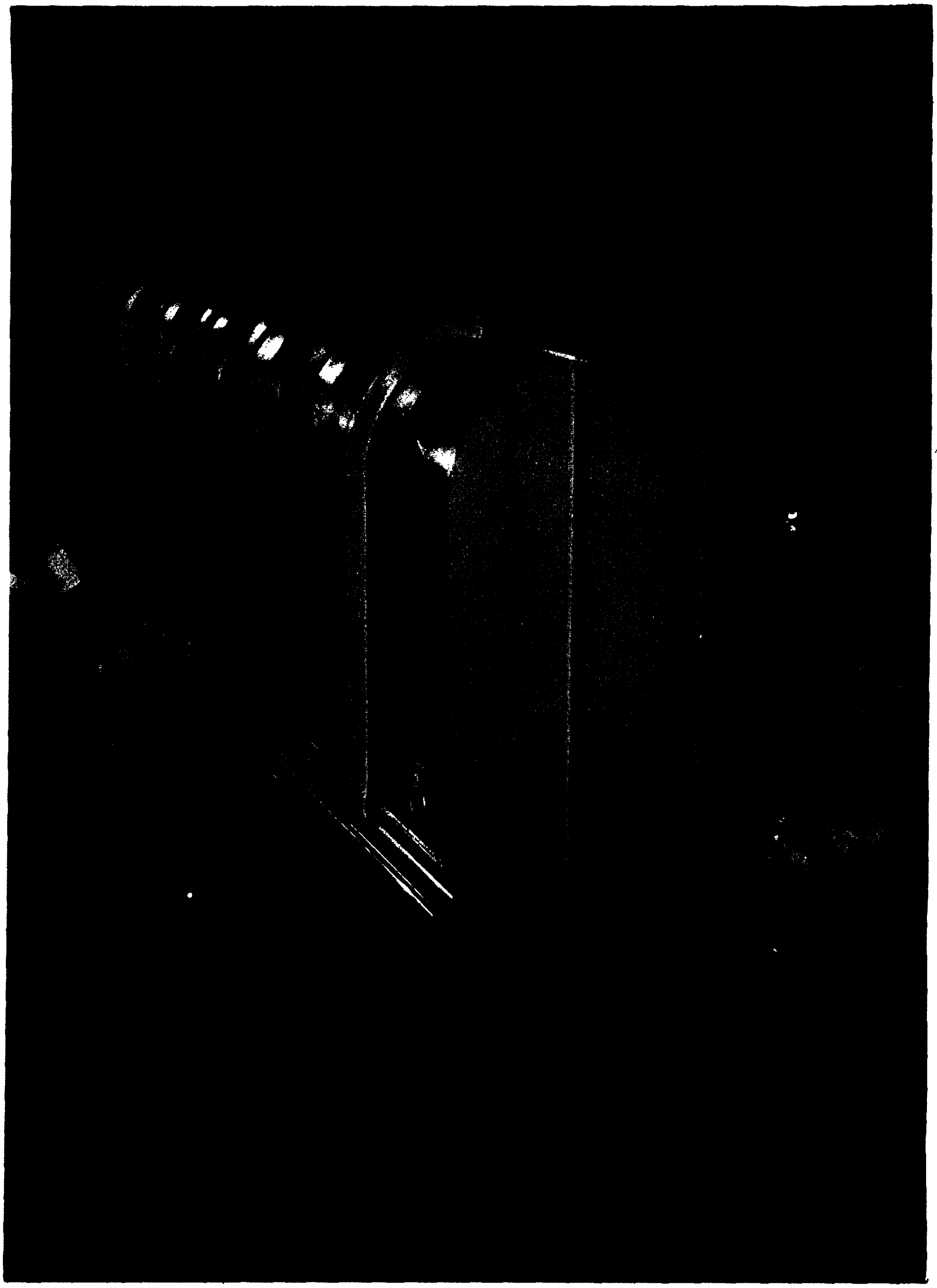
5.7.2.1.9 Shipping Container. The shipping containers are designed to protect a given subassembly or P/L during storage and shipping. A shipping container is illustrated in Figure 5-20.

5.7.2.2 Support Equipment. Support equipment is subdivided into P/L support equipment and photographic support equipment.

5.7.2.2.1 Payload Support Equipment. P/L support equipment is that ASE that is required for final flight preparation and mating of the payload.

5.7.2.2.1.1 Film Loading and Unloading Kit. The film loading and unloading kit is that equipment required to install or remove the film from the supply or the take-up cassettes. The cassettes are mounted on the P/L at this time and the loading or unloading can be performed only while the P/L is external to the vehicle.

5.7.2.2.1.2 Film Storage Container. The film storage container is used to store the film, under the proper conditions, prior to its installation in the P/L supply cassette.



1. Removable Castors

Figure 5-20. Payload Shipping Container

5.7.2.2.1.3 Film Dolly. The film dolly is used to transport the film from the storage area to the P/L.

5.7.2.2.1.4 Film Cutter and Splicer. The film cutter is used to cut the film, in order to separate one section of film from another. The film splicer is used to splice or join two sections of film together.

5.7.2.2.2 Photographic Support Equipment. Photographic support equipment is that ASE and special equipment that is required to evaluate photographic data.

5.7.2.2.2.1 Film Developing Equipment. The film developing equipment is that equipment that is required to convert a latent image on the film to a visible image.

5.7.2.2.2.2 Microdensitometer. The microdensitometer is an instrument designed to accurately measure the optical density of the developed photographic image.

5.7.2.2.2.3 Film Viewer. The film viewer is designed to provide optimum viewing conditions for viewing the developed photographic image. See Figure 5-21 for illustration of viewer.

5.7.2.3 Assembly Equipment. Assembly equipment is that special test equipment that is required for the mechanical, electrical, and optical alignment and alignment verification of the P/L or any subassembly.

5.7.2.3.1 Line-of-sight Test Set. The line-of-sight test set is used to align the optical path of the optical elements and the camera.

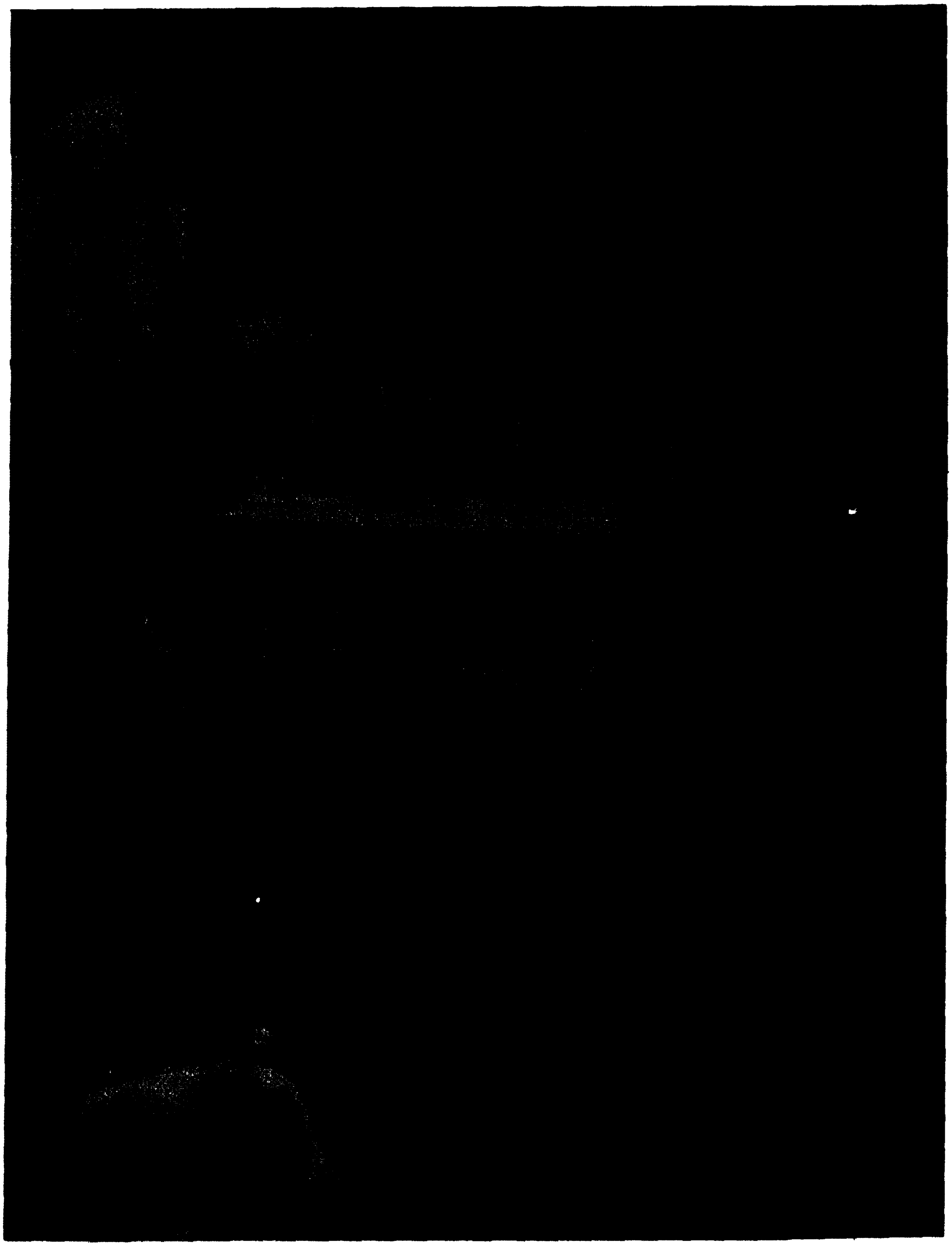


Figure 5-21. Record Viewer

5.7.2.3.2 Collimator. The collimator is an optical device that transforms, divergent or convergent light and rays to parallel light. Consequently, a target or light source located at the focal point appears to be located at infinity. The collimator is used to provide a high resolution target at the simulated altitude (effectively equal to infinity, optically speaking) for the testing of static and dynamic performance of the complete P/L (See Figure 5-22).

5.7.2.3.3 Supply and Take-up Alignment Measuring Equipment. The supply and take-up alignment measuring equipment is used to establish the correct positioning of the supply and take-up cassette axes and insure that the cassettes are co-planner.

5.7.2.3.4 Film Transfer and Support Test Equipment. The film transfer and support test equipment verifies that the film is correctly supported and moves smoothly from the supply cassettes through the system to the take-up cassette.

5.7.2.3.5 Miscellaneous Assembly Equipment. Miscellaneous assembly equipment is the mechanical, electrical, or optical tools, gages or instruments required, but not specifically stated.

5.7.3 Industrial Requirements

Industrial requirements consist of those facilities and equipment listed and defined in the following paragraphs.

5.7.3.1 Purging Equipment. The purging equipment is designed to replace the ambient atmosphere with dry nitrogen in the lens after it is assembled. The purging equipment is used to replace the ambient atmosphere in the shipping containers prior to storage or shippage.

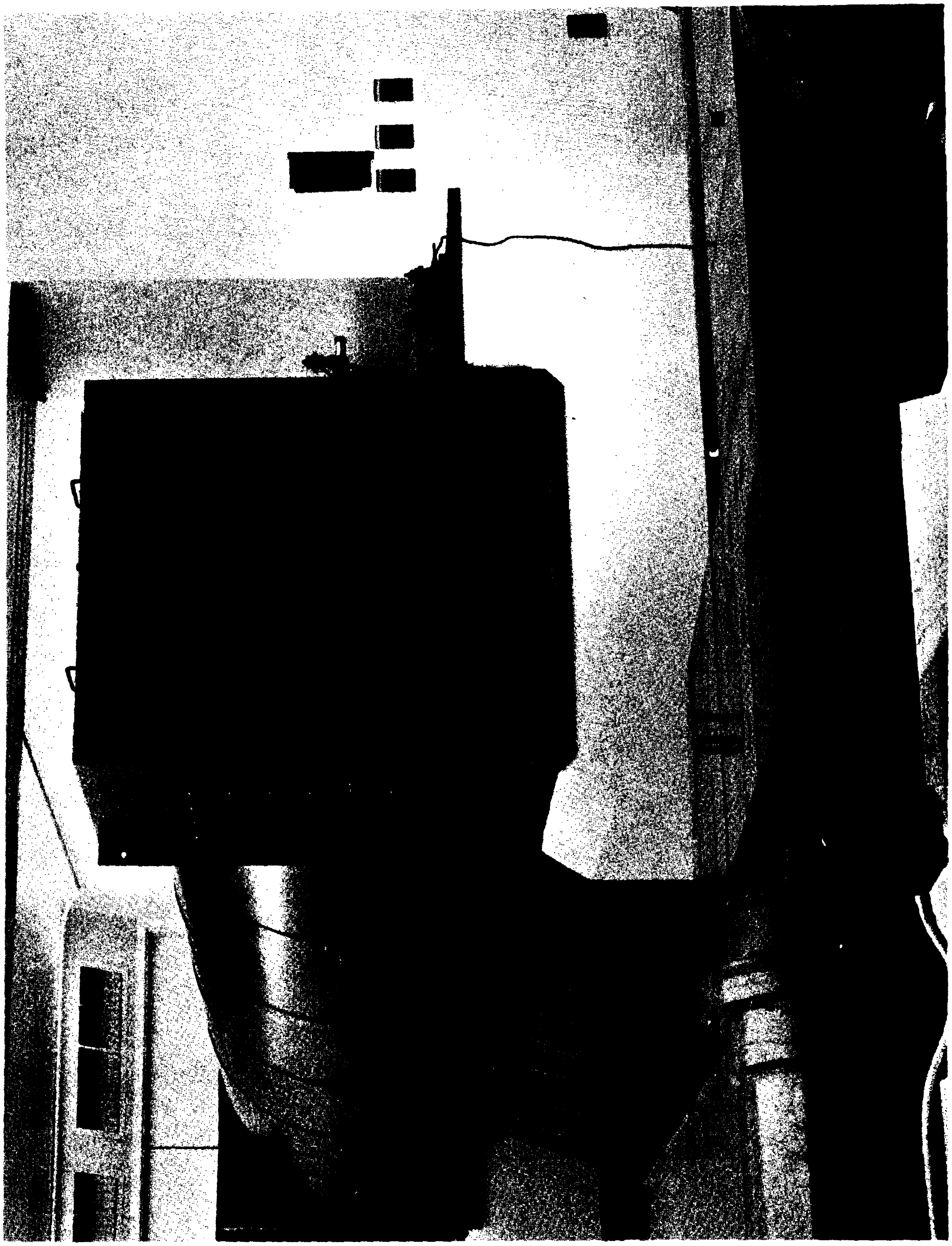


Figure 5-22. 300-Inch Collimator

5.7.3.2 Clean Room. The clean room maintains the proper environmental control of the P/L and subassemblies during manufacturing and test. Proper environmental control is defined as maintaining the optimum temperature and humidity constant. The area shall be maintained as clean as possible to minimize contamination of the P/L or subassemblies.

5.7.3.3 Environmental Test Facilities. The environment test facilities are those facilities required to separately subject a P/L, or various subassemblies to the environmental conditions as required by the quality control, reliability or qualification test specification. Environmental conditions are defined as the specified temperature, barometric pressure, vibration, acceleration shock, or operating time.

5.8 Factory-to-Pad Concept - Shipment of the completely assembled, flight ready payload from the factory to the launch pad without the need for intermediate assembly and/or test operations summarizes the "factory-to-pad" concept. This concept is desirable for the following reasons:

(a) Reliability - The proposed payload is a highly reliable unit as delivered. Implementation of "factory-to-pad" eliminates field operations and prevents compromise of the integrity of a flight-ready payload.

(b) Stability - Factory alignment of optical and film handling equipment eliminates the need for special alignment equipment at the launch site.

(c) Testing - Test results at the factory can be readily correlated at the launch site without intermediate assembly operations. Functional payload health can be demonstrated during integrated systems tests.

(d) Interchangeability - Replacement of an integral payload eliminates individual component assembly operations. This will eliminate lengthy delays and reduce the associated costs.

To incorporate this concept, the design will include considerations for performing integrated system tests, interchangeability of critical components and accessibility of electrical connectors.

Support equipment will also be designed to facilitate integration of the camera payload with the service module.

The knowledge of assembly techniques and support equipment requirements which EKC has accumulated in previous programs willprovide a firm foundation for incorporating this concept in the Apollo Mapping and Survey program.

SECTION 6

PANNING MODE OF OPERATION

By way of introduction to the panning mode of operation, we shall draw some conclusions about this mode of operation and compare its level of performance with that predicted for the strip configuration.

The first and most basic outcome of this portion of the study is the conclusion that the basic camera payload can be adapted, with moderate internal modification, to the panoramic mode of operation. No significant adjustments to the camera-service module interface agreement will be required. With respect to resolution, the system will perform (at nadir) at a predicted 80% level [redacted] when compared with the nominal strip mode of operation (nadir V/h sensor configuration [redacted], its level of comparative performance drops to about 67%. The reason for this performance loss is inherent in the dynamics of any panoramic operation; in addition, the fact is that the high velocity of image (because of panning) precludes the use of an integral V/h sensor approach to IMC control. However, the basic attribute of a panning system is not performance but coverage and, therefore, a performance loss must be expected to obtain the improvement in coverage.

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With respect to coverage, the panning system can photograph all site areas within the short two day mission. Although due to the slow translation of the good lighting band across the composite site area, some site coverage will be obtained outside the good lighting band; this is a product of the short mission - not the camera configuration. The 48 hour mission outlined for the panning system employs a near equatorial orbit with small integral changes in inclination providing the crosstrack coverage displacement.

An estimate of performance with respect to minimum cone diameter detectable for 26.5 and 38.6 degree cones is found in the performance summary at the beginning of Section 3.10. This estimate was made by the methods described in Section 3.10.2, but with the results degraded by 80% to account for the loss inherent in the panoramic operation.

6.1 PANORAMIC OPERATION OF THE C/P

The need for a panoramic system frequently arises out of a requirement for broad coverage at less-than-the-best resolution. If a broad coverage survey requirement is generated by a limited mission life (an initial 2-day mission is a possibility), the C/P can be adapted to a panoramic system to perform this task.

The basic system concept of this type of C/P operation can be described as follows. The stereo mirror of the existing strip camera will be given a dynamic drive to provide the view-sweeping panoramic action. Existing optics will remain unchanged. The vehicle will be flown in a crosstrack attitude since the mirror rotates about an axis parallel to the pitch axis of the vehicle. The faster two dimensional image motion will be compensated by first, increasing the IMC velocity and, second, optically rotating the IMC velocity vector to provide in-track and crosstrack IMC. Camera resolution on axis is predicted to be about 80 percent of that possible under nominal strip operation. No significant changes to the C/P-SM interface agreement will be required. Figure 6-1 shows the panning mode of operation pictorially.

6.1.1 Application of the Panoramic System

6.1.1.1 Philosophy. The characteristic of a panoramic system is: coverage in a hurry. Provided the initial shorter missions are planned for low altitudes, this higher coverage capability can be employed most advantageously. However, the wide longitude spread of the ten site areas accompanied by the low rotational velocity of the moon will preclude truly effective use of any high coverage capability. Even with unlimited plane change capability

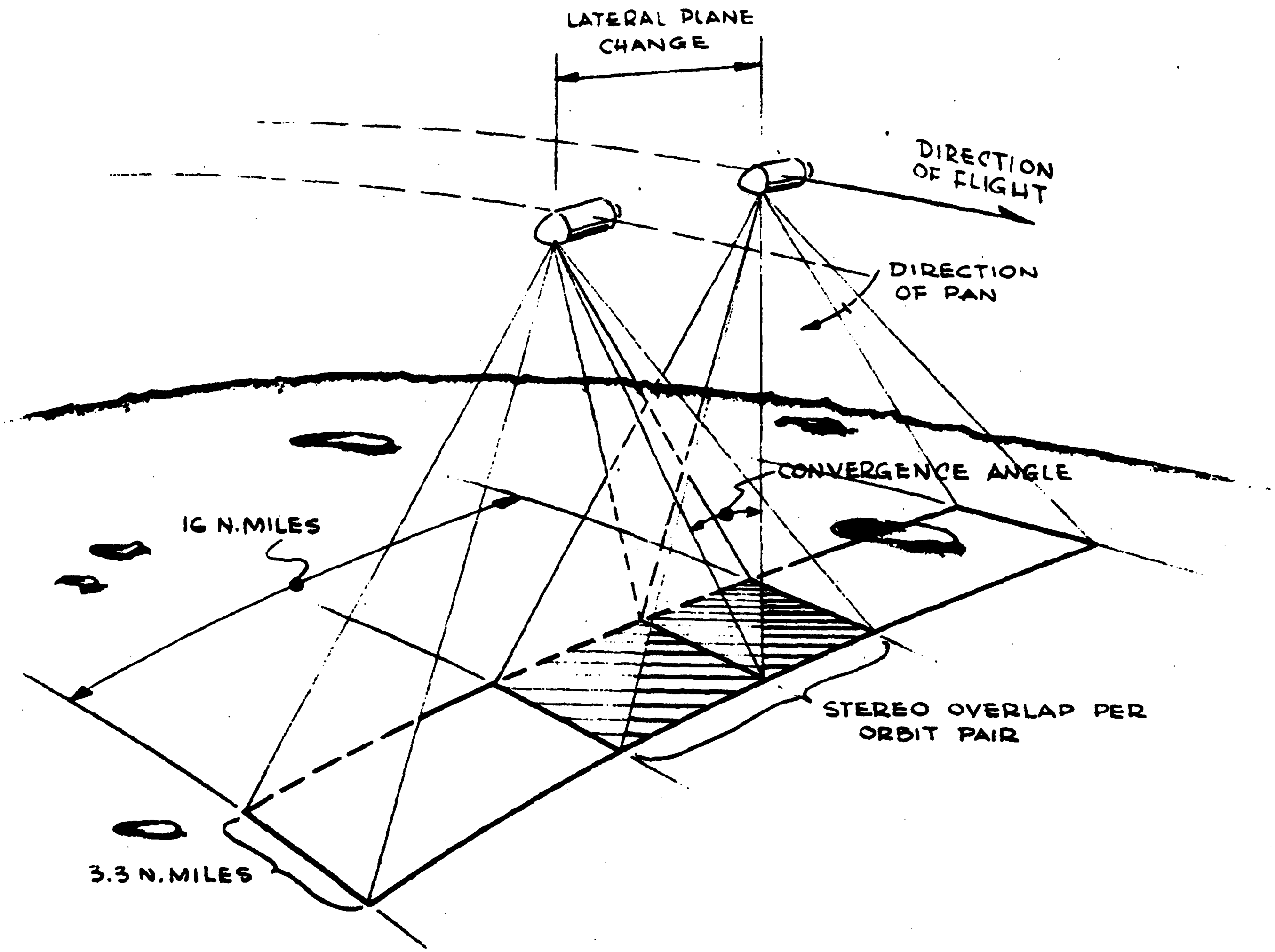


Figure 6-1. . Panoramic Coverage (Alternate Orbit Stereo)

adverse sun elevations will be encountered at some of the sites if complete site coverage is to be obtained during a short (2-day) mission.

6.1.1.2 Mission Outline. The proposed panning mission will employ a near equatorial orbit with an initial inclination of about 3° retrograde, placing the ascending node at approximately 79 degrees east longitude. The initial sub-solar point is at 49° west longitude. The ascending orbit over the site area has been chosen so that sites IX and X can be photographed as late in the mission as possible. Also, the ascending node was pushed close to the eastern border of the composite site area to permit photography of sites I and II as early in the mission as possible. Both steps were taken in an attempt to obtain the best sun angle possible at these leading and trailing sites.

Table 6-1 gives an outline of one possible two day mission. This mission employs 11 inclination changes of 0.43 degree each. The basic approach is to allow two orbits per photographic pass. The plane change is accomplished on the first orbit followed by optical and earth tracking; continued tracking, photography and preparation for the next plane adjust is accomplished on the second orbit. This sequence will then continue for the duration of the two days.

6.1.1.3 Coverage. Per pass the panoramic system sweeps out an area 16.1 n. miles wide from an altitude of 30 n.mi. In-track contiguous coverage can be any desired length. The amount of overlap in-track (swath to swath) is controlled by proper selection of the pan cycle. With the proposed low inclination orbits, the majority of the crosstrack displacement of coverage is obtained through plane changes. It is this crosstrack overlap of successive photo passes that gives the convergent stereo coverage.

TABLE 6-1

POSSIBLE TWO-DAY MISSION

Site \ Rev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Mean Sun Angle During Pho
I		P		P		P		P																		11.4°
II										P		P		P		P										9°
III						P		P		P		P														16°
IV								P		P		P		P												18°
V								P		P		P		P												29°
VI														P		P		P			P					36.6°
VII		P		P		P																				61°
VIII		P		P		P																				76°
IX																					P		P		P	60°
X																					P		P		P	71°
Inclination		176.90		177.33		177.76		178.19		178.62		179.05		179.48		179.91		0.34		0.77		1.20		1.62		

P - Photography of Site

Assending node initially at 79° east

Based on a 30 n.mi. altitude, assured stereo coverage of a site area will require 4 photo passes over each site of 7 frames each. Four passes result in a crosstrack coverage of 38 n. miles with the middle 22 n. miles in convergent stereo; seven frames provide a contiguous in-track stereo coverage of about 21 n. mi. Figure 6-2 shows this coverage format in pictorial form. Some sites, as noted in Table 6-1, were covered with only 3 photo passes. This was done primarilly to minimize the plane change requirement or optimize the sun angle. Three-pass coverage will provide a crosstrack coverage of 24 n. mi. with the middle 16 n. mi. in covergent stereo. In-track coverage will be the same.

6.1.2 Image Motion Compensation

Controlling smear in a panoramic system is alwasy a demanding problem and at the long exposure times required by lunar photography the problem is even more demanding. IMC in a panoramic system is complicated by two principal factors. One, the fast panoramic action required to maintain in-track overlap of consecutive swaths is accompanied by relatively high film velocities; two, the varying scale factor with pan angle requires the application of a drive velocity which is proportional to the cosine of the panning angle. However, it should be noted that these requirements are not new to EKC and a high level of experience exists in both areas.

The proposed system will provide in-track and crosstrack IMC by the following methods. In-track image velocity is produced by the vehicle motion over the ground. The magnitude of this component at a fixed altitude is not constant but varies by the cosine of the pan angle. Therefore, the compensating motion must also vary with pan angle. Crosstrack image velocity is produced by the panning action of the stereo mirror. By selecting an IMC velocity which is

PANORAMIC CAMERA COVERAGE

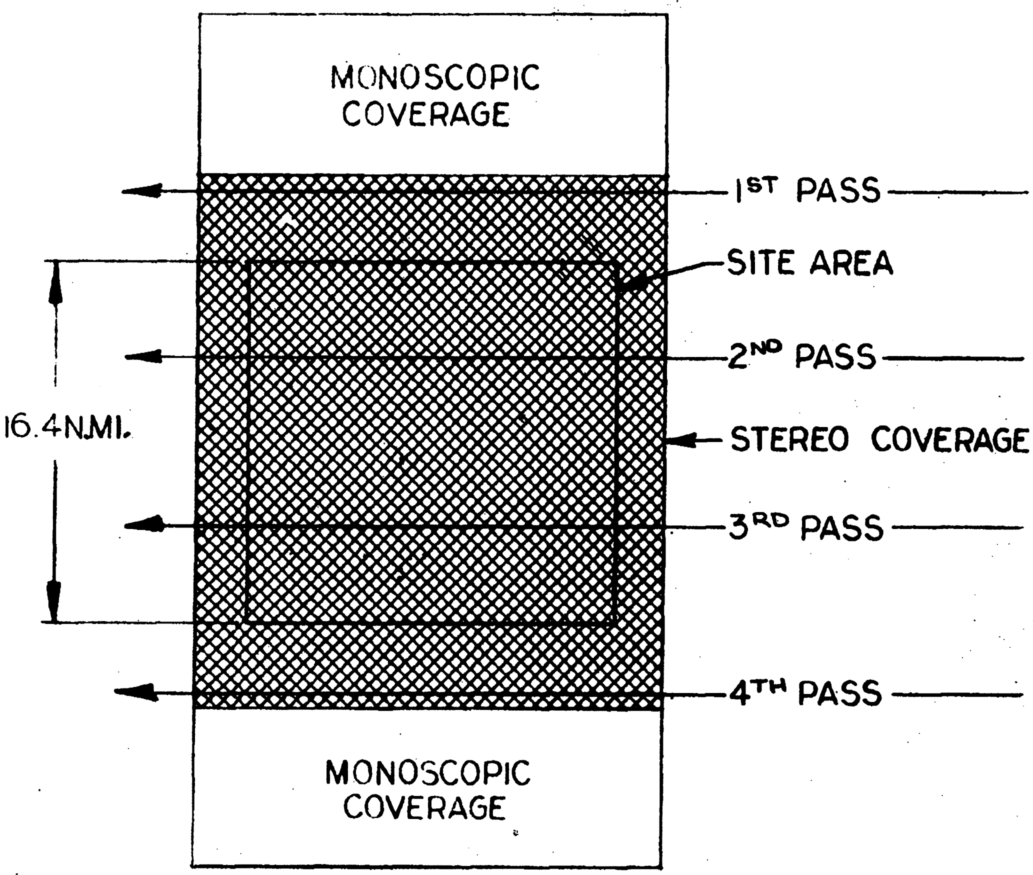


Figure 6-2. Panoramic Camera Coverage

the vector sum of the two orthogonal components at the image plane and then rotating this IMC velocity so its direction is equivalent to the resultant image velocity, perfect compensation is possible. The required IMC rotation or τ angle is obtained by crabbing the stereo mirror. Away from nadir the in-track component or image velocity decreases as outlined earlier. To compensate this variation, a cosine drive is employed which varies the velocity of the platen and panning mirror (these two units are physically tied together) as a function of the cosine of the pan angle. Since the platen and mirror are tied together cosine variation of their velocity has no effect on crosstrack IMC. Thus, all geometric components of IMC can be compensated at all pan angles. Altitude variations are compensated by adjustments in the nadir or base IMC speed which will be established by a nadir viewing V/h sensor backed up by command capability.

6.1.3 Stereo Acuity

Stereo acuity resulting from convergent stereo is basically a function of two factors; ground resolution and the base-to-height ratio. Assuming one has achieved the highest ground resolution pssible, achievable stereo acuity then depends on the base-to-height ratio only.

For the proposed system, crosstrack displacement of the vehicle for alternate overlapping photos (not in-track as was used with the strip configuration) produces a stereo acuity roughly equivalent to the ground resolution. Roll of the vehicle about its longitudinal axis to a fixed look angle up-track on one photo pass and down-track on the next pass would result in an in-track displacement of the vehicle between overlapping photos and an improvement in the stereo acuity by a factor of about 1.5 to 2. However, associated with this up-track and down-track look angle is a minor adjustment to the C/P IMC drive. This adjustment is in effect the addition of a slightly varying drive ratio between the film and the pan mirror. Normally this is accomplished by the addition of a cam between the two drives and presents no serious problem.

6.1.4 Numerical Summary

The basic numerical summary as outlined in Paragraph 3.12 will remain in effect with the following changes.

<u>Photographic Output</u>

Ground resolution at 30 n.mi.	[redacted] (nadir)
Lens film resolution (dynamic)	[redacted]
Ground swath	
30 n. mi.	3.3 by 16.1 n.mi.
80 n. mi.	8.9 by 42.9 n.mi.
Length of scene on film (approx.)	40 inches
Stereo acuity	Dependent upon geometry of orbit pattern, worst case equivalent to ground resolution
Area coverage per frame	
30 n. mi.	53 sq. n. mi.
80 n. mi.	382 sq. n. mi.
Swath direction	Perpendicular to nadir track

<u>Camera</u>

Type	Strip/panoramic
Slit widths	Not determined
γ angle	7.3 degrees
Pan angle	±15 degrees
Pan rate (line of sight)	13°/second at 30 n. mi. 4.5°/second at 80 n. mi.
Cycle time	
30 n. mi.	3.5 sec.
80 n. mi.	9.8 sec.
Active pan time (photo portion)	2.3 sec. at 30 n. mi. 6.6 sec. at 80 n. mi.

Mirror return time available	
30 n. mi.	1.2 sec.
80 n. mi.	3.4 sec.
IMC control (altitude)	V/h sensor
(Pan angle)	cosine drive
Film velocity (nominal)	17.7 inch/second at 30 n. mi. within 5-0.A
	6.1 inch/second at 80 n. mi.
IMC step size	0.5 percent

Hardware

Platen size	11 inch
Supply/Take-up film velocity	1% faster than IMC speed

6.2 DESIGN CONCEPTS

In a panning mode of operation the vehicle is yawed by 90 degrees to place its Y axis parallel to the ground-track direction and the "stereo" mirror is used as a "panning" mirror.

The exposure unit platen shaft drives the panning mirror directly in order to synchronize film velocity to mirror pan rate which provides proper image motion compensation. Emphasis is placed on the rigidity and smoothness of the pan mirror-platen shaft coupling in order to achieve optimum photographic quality.

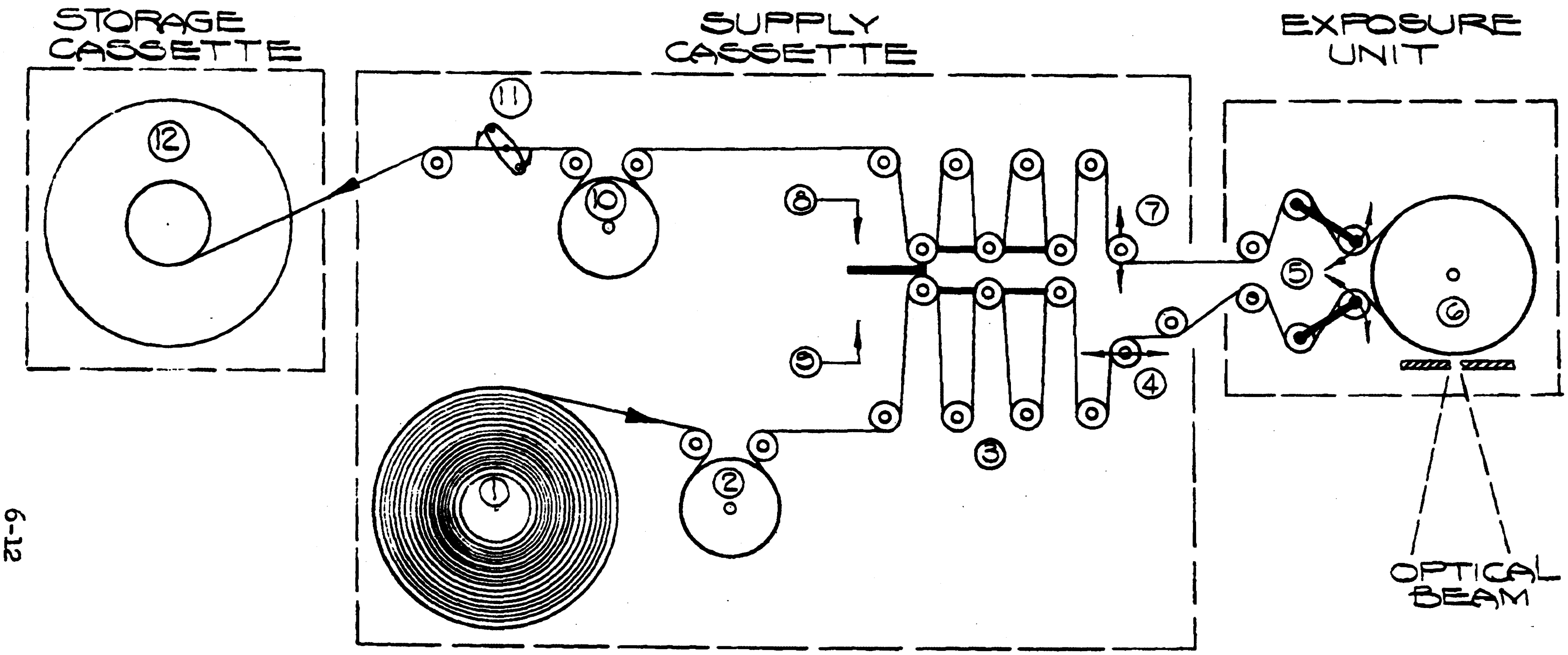
The following paragraphs describe the two principal components of the system the film handling and the mirror - platen shaft coupling.

6.2.1 Mechanical-Optical Coupling

A brief description of this coupling, the drive and the resultant action is described in the following paragraphs. The return or re-positioning of the mirror for the next photographic cycle is described. Changes to the existing hardware are given. Figure 6-4 is a schematic diagram of the system. The system is maintained inside the space envelope defined on EKC dwg. No. 1600-100.

The basic drive is provided by the platen drive motor. This motor drives the film platen through the platen drive clutch-brake assembly and a large ratio precision helical gear pair. The precision helical form and the large gear ratio provides a smooth and quiet running drive for the film platen. Next to this drive gear are two preloaded bearings that support the platen and absorb the end thrust of the drive gear. Outboard of the bearings is the mirror drive clutch and the mirror drive capstan. The capstan is carried on free wheeling idlers and when the mirror drive clutch is engaged, the platen, platen drive gear, and capstan are carried on the two sets of platen bearings. The platen bearing on the other end of the platen, is pilot bearing and is pre-loaded for radial loads only. The bearing shafts are the smallest permissible size to insure minimum bearing noise.

Rigidly mounted on the back of the mirror is the mirror drive sector. The actual mirror drive and synchronization is accomplished by a tape-bar drive consisting of a tape-and-bar, the mirror drive sector and the capstan. The drive sector and capstan are sized and positioned to give the correct synchronization between the film platen and the mirror. The tape and bar provides an extremely smooth drive connection. In order to drive the mirror shaft which is tilted with respect to the film platen axis, the drive bar bearing surfaces are parallel to the mirror axis and also to the platen axis each in the respective areas of contact. The drive bar is hollow and



CODE

① FILM SUPPLY SPOOL
② FILM SUPPLY DRIVE
③ INTEGRATED LOOPER
④ PIVOT ROLLER
⑤ FILTER ROLLERS
⑥ EXPOSURE UNIT DRIVE & PLATEN
⑦ PIVOT ROLLER
⑧ SUPPLY/TAKE-UP "STOP" SWITCH
⑨ SUPPLY/TAKE-UP "RUN" SWITCH
⑩ TAKE-UP DRIVE
⑪ HOT WIRE FILM CUTTER
⑫ TAKE-UP SPOOL

Figure 6-3. Panning Mode Film Path Schematic of large size for maximum rigidity and minimum weight. The drive capstan is mounted close to the platen drive gear for torsional stiffness.

During the actual panning or photographic cycle the mirror and platen drive clutches are engaged. The drive is from the platen drive motor through the helical gears to the platen, then from the platen to the mirror through the capstan, drive-bar and drive sector. At the end of the photographic cycle, the platen drive clutch-brake assembly is disengaged and the braking action stops the forward motion of the mirror and platen. The mirror drive clutch is then disengaged, isolating the mirror from the platen. This enables the mirror to be returned or repositioned for the next photographic cycle, independent of the film platen. The film platen is advanced only during the photographic cycle.

The mirror is repositioned by engaging the mirror return drive unit. The re-positioning is through the belt drive, with driven pulley fastened to, and concentric with the mirror trunion. The drive is by a motor driven geneva mechanism with clutches on the geneva input and output shafts. Both clutches are engaged during the repositioning cycle; both clutches are disengaged during the photographic cycle. The geneva mechanism stops the mirror in the correct location for the next photographic cycle without requiring additional braking action. The geneva can be used to lock the mirror in position during launch by removing power from the motor and engaging the clutches with the geneva in the locked position. A belt return drive is used because it gives the smoothest load transferral to the mirror when the return drive unit is idling during the photographic cycle.

?. of the desirability unless some means of isolation

The changes to existing hardware required by the pan-mode of photography are itemized below:

(1) Redesign the exposure unit to accommodate the larger platen, the platen drive, mirror drive capstan and associated bearings, clutches and mounts.

(2) Redesign the mirror pivot blocks to accommodate the new position of the mirror pivot blocks.

(3) Modify the component support tube, lens barrel and the mount to accommodate the larger exposure unit, and to increase the structural strength of the connection between the film platen and the panning mirror.

(4) Modify the stereo mirror outer cell to accommodate the mirror drive sector.

(5) Modify the stereo mirror support truss to clear the modified mirror outer cell and to accommodate the new locations of the mirror pivot blocks.

(6) Modify the mirror trunion for the re-positioning drive pulley.

(7) Modify the mirror bridge to accept the mirror return drive unit.

6.2.2 Film Handling System

The panoramic camera film handling system, for the most part, resembles the strip film handling system discussed in Section 7.0.

Figure 6-4 is a schematic diagram of the panoramic system. Some features shown in the schematic are not required for stereo/monoscopic photography; these are: an independently driven exposure unit platen and an integrated film looper between the platen and the supply/take-up drive. Assuming a 3 second panning cycle of which 2 seconds are used for active photography and 1 second for mirror return, the system can be said to operate as follows:

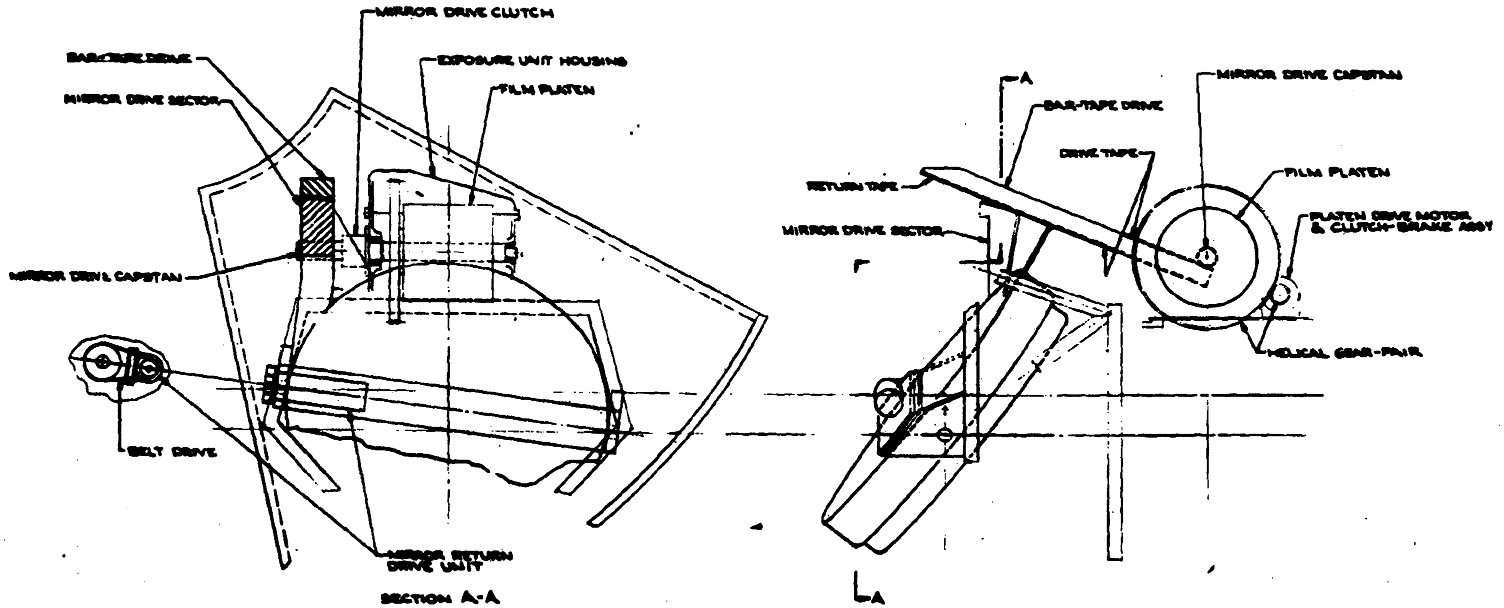


Figure 6-4. Panning Drive

During the entire panning operation, film is drawn continuously from the supply spool by the supply drive which is powered by a synchronous motor. Assuming the (arbitrary) time base mentioned above and imposing the conditions that the supply side of the integrated looper contains a minimum of 1/3 of a pan frame as the exposure unit platen commences to move the film and the panning mirror for an initial exposure, it is evident that if the supply is moving film at the rate of 1/3 frame per second and the exposure unit platen is moving film at the rate of 1/2 film per second, the looper will be empty at exactly the same time one photographic frame has been exposed. The exposure unit stops moving film at this point and waits 1 second for the panning mirror to return to its original position as required for initiating exposure of a subsequent photographic frame. During this 1 second's photographic hiatus, the supply drive continues to put film into the looper such that the looper once more contains a head start of 1/3 frame in advance of the beginning of another exposure.

The opposite side of the integrated looper is being emptied of film by the take-up drive at the same rate film is delivered by the supply drive. This is accomplished by coupling the take-up drive to the supply drive or by providing the take-up drive with its own synchronous motor. Differentially coupled at the take-up drive is a small vernier motor which incrementally adjusts the film length (and tension) as might be periodically required. The vernier motor is controlled by a sensor on the exposure unit platen filter rollers.

Cycles of photography might continue smoothly and indefinitely if the supply/take-up drives could exactly fulfill the demands of the exposure unit platen drive. In order to accomplish this goal exact speed ratios must be maintained on the drives and parts must be manufactured with zero tolerances. In the face of this impractically, the system is made to periodically rectify accumulated error in relative drive velocities.

The supply and take-up drives are deliberately designed to function at rates a trifle (perhaps 1%) faster than the exposure platen's demands. The supply side of the looper gradually fills up (and take-up side gradually empties). When full capacity is nearly reached, a logic switch stops the supply/take-up drives until the exposure unit uses enough film to bring the looper back to its original state. An integrated looper with a capacity of 2/3 pan frame and a 1% supply/take-up overdrive requires the drives to stop for a period of one second every 33-1/3 pan exposure frames. Choice of other values of looper capacity and overdrive percentage would vary this correction cycle.

Except for the cyclic stopping and re-starting of the supply/take-up drives at infrequent intervals, the system is smoothly operating and will yield high quality panoramic photography.